THE EFFECT OF PILATES EXERCISE ON TRUNK AND POSTURAL STABILITY AND THROWING VELOCITY IN COLLEGE BASEBALL PITCHERS: SINGLE SUBJECT DESIGN

Tony English, PT, MSEd
Katherine Howe, MSPT

ABSTRACT

Background. Baseball pitchers need trunk strength to maximize performance. The Pilates method of exercise is gaining popularity throughout the country as a fitness and rehabilitation method of exercise. However, very few studies exist that examine the effects of the Pilates method of exercise on trunk strength or performance.

Objectives. Using a single subject, multiple baseline across subjects design, this study examines the effects of the Pilates method of exercise on performance of double leg lowering, star excursion balance test, and throwing velocity in college-aged baseball pitchers.

Methods. A convenience sample of three college baseball pitchers served as the subjects for this single subject design study. For each subject, double leg lowering, star excursion balance test, and throwing speed were measured prior to the introduction of the intervention. When baseline test values showed consistent performance, the intervention was introduced to one subject at a time. Intervention was introduced to the other subjects over a period of 4 weeks as they also demonstrated consistent performance on the baseline tests. Intervention was continued with periodic tests for the remainder of the 10 week trial.

Results. Each subject improved in performance on double leg lowering (increased 24.43-32.7%) and star excursion balance test (increased 4.63-17.84%) after introduction of the intervention. Throwing speed improved in two of the three subjects (up to 5.61%).

Discussion and Conclusions. The Pilates method of exercise may contribute to improved performance in double leg lowering, star excursion balance tests, and throwing speed in college baseball pitchers.

Key Words: trunk strength, throwing speed, core stability

CORRESPONDENCE:
Tony English, PT, MSEd
Division of Physical Therapy
CHS Building Room 204
900 S. Limestone Avenue
Lexington, KY 40536-0200
Phone: (859) 323-1100 x 8083
Fax: (859) 323-6003
eMail: tenglish@uky.edu

ACKNOWLEDGEMENTS:
The authors would like to acknowledge and thank Susan Effgen, PT, PhD and Tim Uhl, PT, PhD for their support and editorial help.

a University of Kentucky
Lexington, KY, USA
INTRODUCTION

Previous studies have demonstrated that proximal stability and strength of the abdominal and spinal muscles of the trunk are important in performance of many functions.\(^2,3,6,8-10\) Rehabilitation and fitness specialists use a variety of combinations of exercises to address these muscles. A combination of mobility and stability is required by active people for optimal functional performance and for correction of poor posture, muscle imbalances, and poor biomechanics.\(^2\)

This concept of trunk mobility and stability contributing to improved performance is being used in training and rehabilitating athletes today. In baseball, proximal strength through the scapular and pelvic girdles and the trunk coupled with appropriate mobility is important in reaching optimum performance levels in pitching and throwing.\(^4\) Pitching a baseball is a total body activity that requires a coordinated sequence of movements involving upper and lower extremities and the trunk. This coordinated sequence involves dynamic balance as the pitcher alternately shifts weight from both feet to one foot, then sets the trunk, rotates and extends the arm, as he uses his strength, stability, and mobility to result in a highly skilled activity.\(^5\) Tests of trunk strength and dynamic stability in this population may provide evidence for the contributions these characteristics may have on throwing velocity.

Several methods have been developed to address trunk stability and mobility issues in various populations. Among these methods is a static to dynamic muscular re-education approach founded in the Pilates tradition.\(^2,6,11\) Joseph Pilates described his method of exercise as a “set of healthful lifestyle changes and corrective exercises.” This method has become popular with a wide variety of athletes and people seeking fitness and rehabilitation.\(^7\) A key to successful use of the Pilates method of exercise lies in learning the proper way to activate abdominal and spinal muscles to maintain correct positioning while moving other segments of the body. Activation of trunk stabilizers in a variety of positions is believed to be a key in promoting more efficient performance of recreational and sport activities and activities of daily living. This trunk stabilization is the basis for many trunk stability programs because both upper and lower extremity muscles have proximal anchors at the shoulder and pelvic girdles, respectively.\(^2,3,6,10\)

According to advocates, the Pilates method of exercise uses the concept of maintenance of the normal lumbar lordotic curve, called the neutral spine, coupled with movement of the lower and upper extremities to simultaneously enhance mobility through improved flexibility and proximal stability. However, only a few studies with dancers have been performed that demonstrate a positive impact of Pilates style exercises on function and posture.\(^6,11\) Although the concepts and techniques utilized in this exercise approach appear to have application to other activities such as baseball, no studies exist to validate its use in this population. Based on the knowledge of the complex process used in pitching a baseball, it may be expected that a Pilates method exercise program will improve performance in baseball pitchers. For this reason, a need exist for controlled experimental trials to verify the effectiveness of this method in this population.

Studies have demonstrated that improved trunk stability may have a significant, positive impact on function and performance of activities.\(^12,14\) Improved trunk muscle activity also has also been shown to have a positive effect on people with chronic back pain.\(^14,15\) Since Pilates style exercises have been shown to result in increased activity and performance of the deep abdominal and spinal muscles,\(^2,6,14\) a pilot study utilizing a single subject design with a population of baseball pitchers was developed to study the effects of a Pilates exercise intervention on three outcomes related to pitching a baseball: abdominal muscle strength, dynamic stability in single leg stance, and baseball throwing velocity.

As early as 1976, researchers have reported the procedures for single subject design studies and analysis of data in rehabilitation research.\(^6,17\) Later, Zahn and Ottenbacher\(^10\) and Fetko et al\(^19\) further described how the single subject design can be effectively used in disability and rehabilitation research. The basic methodology sequence in single subject design allows each subject to be his own control. Baseline data is collected prior to introduction of the intervention to establish a stable performance level. This stable level helps account for a learning effect common with the introduction of a set of tests to a group of subjects. In a repeated measures design, the intervention is introduced to only one subject at a time. The other subjects continue testing to demonstrate maintenance of their baseline performance. The results of the study are strengthened by observing improvement in the subjects’ performance only after introduction of the intervention.\(^2,10,19\)

The purpose of this study was to examine the effects of the Pilates method of exercise targeting the deep abdominal and spinal muscles on a trunk strength test (double
leg lowering), a single leg dynamic stability test (star excursion balance test), and throwing velocity in collegiate baseball pitchers.

METHODS

Subjects

Three subjects (ages 18-20 years) were recruited from a convenience sample of fit, healthy college baseball pitchers. Two subjects were second year players and one was a first year player. Two were right handed and one left handed. Subjects were excluded if there was a history of injury to the throwing arm, back, or lower extremities in the past year.

Each subject was given a written description of the study and signed an informed consent form in compliance with the Institutional Review Board (IRB) of the University of Kentucky. The rights of all human subjects were protected via the IRB oversight. Subjects were tested and the Pilates exercise program was completed in the Musculoskeletal Research Laboratory of the College of Health Sciences at the University of Kentucky.

Materials/Equipment

The Pilates method exercises were taught and performed on exercise mats and tables in the research area. No other equipment was required for this intervention.

A Chattanooga (Hixson, TN) High Low Therapy table was used for the double leg-lowering (DLL) test. A Stabilizer Unit (Chattanooga Group, Hixson, TN) was used to determine the ability of the subjects to hold the proper pelvic position. A large wall-mounted goniometer was used to measure the angle of hip flexion that corresponded to the loss of pelvic stability. A Bushnell Speedster Radar Gun (Bushnell Performance Optics, Overland Park, KS) was used to assess throwing speed and the throwing target was a large, strike zone sized piece of vinyl hanging within a portable throwing net. The radar gun measures the speed of a moving baseball at a distance up to 75 feet with an accuracy of +/- 1 mph.

Procedures

To avoid threats to internal validity inherent in testing during baseball season, subjects were recruited during the off-season (fall semester) and were allowed to continue off-season conditioning. The off-season conditioning program consisted of running, weight lifting, and a long toss throwing program. These activities were performed by the subjects on an informal schedule and were not under the supervision of a coach or athletic trainer. Subjects, coaches, and athletic trainers were asked to avoid introducing new exercises during the study. Subjects reported compliance with this request throughout the course of the study.

The principal investigator collected baseline data prior to the introduction of the intervention. The double limb lowering (DLL), star excursion balance test (SEBT), and throwing speed data were collected three times per week until a subject reached a stable baseline in one of the dependent variable tests. The testing order was constant for each subject. Warm-up was done outside the building and throwing velocity was tested within 5 minutes of warm-up (subjects went directly from the warm-up to the throwing speed test to avoid cooling off). The DLL was tested followed by SEBT, as neither was expected to influence the other.

The DLL test was performed following the procedure outlined by Kendall et al. The use of the Stabilizer was modeled after the procedure described by Hagins et al. Subjects lay supine on the therapy table in a hooklying position with the greater trochanter aligned with the central axis of the wall-mounted goniometer (Figure 1). Each subject was instructed to perform the abdominal hollowing maneuver used to stabilize the pelvis with the back in a neutral position. After each subject exhibited proficiency in the stabilization maneuver, the Stabilizer was placed between the subject’s lumbar spine and the table while maintaining a neutral spine position. This neutral spine position was operationally defined as the position in which the subject felt a slight space between the table and the most lordotic point in the lumbar spine. The tester
visually observed the subject’s anterior superior iliac spines to be in the same plane as the pubic symphysis. The pressure gauge of the Stabilizer was increased to 40 mm Hg in this position. The examiner lifted the subject’s legs to a position of 90 degrees of hip flexion with the knees fully extended. Each subject was able to maintain this test position of hips at 90 degrees with the knees extended so specific unilateral hamstring flexibility was not measured. The subject was asked to hold this position by performing the abdominal hollowing maneuver and to lower the legs toward the table. At the point when the stabilizer pressure dropped below 40 mm Hg, it was determined the subject was no longer able to maintain the neutral spine position and the examiner recorded the hip flexion angle in degrees. Subjects were given three trials with the average of the trials recorded.

The SEBT has been described and demonstrated to be of moderate to high reliability based on Intraclass Correlation Coefficient (ICC) ranging from .67-.87.22 The test was performed as described by Kinzey and Armstrong.22 A box, 2 feet square, was outlined with the center line marked by perpendicular lines that formed 45 degree angles from the horizontal in each of four directions (right-anterior, left-anterior, right-posterior, left-posterior). Each subject stood in the center on one leg and reached forward and back along the marked lines with the other leg as far as possible while maintaining balance. Subjects were allowed to lightly tap the floor to establish the point of the reach (Figure 2). This distance was marked by the examiner and later measured with a tape measure in centimeters. Each subject was allowed six practice motions in each direction to control for a learning effect, and three trials in each direction were recorded and averaged.22,23 This procedure was repeated with both legs.

Throwing velocity was measured after each subject had warmed-up in his usual manner. After warm-up, the subject was positioned 30 feet from a net and instructed to throw as hard as possible into the net at the strike zone target. Accuracy was not assessed in this study. The target was used as a focus point for the subjects. Three trials were recorded and averaged and speed was documented in miles per hour.24

The baseline data were collected by the principal author based on the subject availability. Data were graphed and a 2 standard deviation line was established after the first three testing periods by using the Microsoft Excel graphing function. The principal author also used visual inspection of the data points on the graphs of performance to determine baseline performance. If the data points showed a level or decreasing performance and were within the 2 standard deviation line, baseline performance was determined to be stable. Subject 1 exhibited a decrease in performance during baseline within the 2 standard deviation line in throwing speed first and was introduced to the intervention on day seven at the start of week three. After the intervention was started on Subject 1, weekly testing began for all subjects. Subject 2 demonstrated maintenance of a stable baseline through three weeks of testing and was scheduled to start on the intervention in week four. A scheduling conflict pushed his intervention start back to day 13 at the beginning of week five. Beginning the following week, subject 3 had established a stable baseline and began the intervention period on day 20 during week seven. Once the intervention was started, weekly, random day testing of all subjects continued throughout the 10 week study. All three subjects had one week in which testing could not be performed due to school schedule conflicts or illness.

A Pilates method of exercise mat program was taught to the subjects and supervised by a physical therapist who
was also a Pilates Certified Instructor (second author). Subjects were scheduled to attend sessions supervised by the physical therapist 2-3 times per week dependent on their availability. Each activity was performed for 5-10 repetitions each and each session lasted 30-40 minutes. Repetitions were based on the quality of performance as observed by the instructor. As quality of performance decreased, the activity was changed to facilitate the concept of high quality over quantity. The exercise instructor advanced each subject weekly according to the program outlined in Table 1. See Appendix A for the descriptions of each exercise.

Data Analysis

Data were analyzed in a variety of ways. Reliability of the measurements of throwing speed and double leg lowering was assessed by correlating the second and third baseline testing data. Test-retest reliability of the throwing speed data points was reliable with an Intraclass Correlation Coefficient (ICC) of 0.90 and a standard error of measure (SEM) of 1.48. Likewise, test-retest reliability of the double leg lowering procedure in the sample population was reliable with an ICC of .95 and a SEM of 2.52.

Table 1. Outline of Pilates exercise program intervention

<table>
<thead>
<tr>
<th>Week One</th>
<th>Week Four</th>
<th>Week Five</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. warm-ups</td>
<td>1. warm-ups</td>
<td>1. warm-ups</td>
</tr>
<tr>
<td>2. single leg stretch</td>
<td>2. single leg stretch</td>
<td>2. single leg stretch</td>
</tr>
<tr>
<td>3. double leg stretch</td>
<td>3. double leg stretch</td>
<td>3. double leg stretch</td>
</tr>
<tr>
<td>4. roll</td>
<td>4. single straight leg</td>
<td>4. roll</td>
</tr>
<tr>
<td>5. hundred</td>
<td>5. criss cross</td>
<td>5. hundred</td>
</tr>
<tr>
<td>6. rolling</td>
<td>6. roll</td>
<td>6. roll</td>
</tr>
<tr>
<td>8. side kick: hot potato</td>
<td>8. side kick: small circles</td>
<td>8. side kick: hot potato</td>
</tr>
<tr>
<td>9. spine twist</td>
<td>9. spine twist</td>
<td>9. spine twist</td>
</tr>
<tr>
<td>10. spine stretch forward</td>
<td>10. rowing 3</td>
<td>10. saw</td>
</tr>
<tr>
<td>11. rowing 3</td>
<td>11. rowing 3</td>
<td>11. rowing 4</td>
</tr>
<tr>
<td>12. rowing 4</td>
<td>12. rowing 4</td>
<td>13. pull straps 1</td>
</tr>
<tr>
<td>13. single leg kick</td>
<td>14. pull straps 1</td>
<td>14. pull straps 2</td>
</tr>
<tr>
<td>14. pull straps 2</td>
<td>15. pull straps 2</td>
<td>15. swan</td>
</tr>
<tr>
<td>15. pull straps 2</td>
<td>16. rolling down</td>
<td>16. teaser</td>
</tr>
<tr>
<td>16. rolling down</td>
<td>17. twist</td>
<td>18. leg pull front</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19. rolling down</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week Two</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. warm-ups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. single leg stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. double leg stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. roll</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. hundred</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. rolling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. side kick: front/back</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. side kick: small circles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. spine twist</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. spine stretch forward</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. pull straps 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. pull straps 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. rolling down</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Week Three</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. warm-ups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. single leg stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. double leg stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. criss cross</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. roll</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. hundred</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. side kick: small circles</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The principal author collected independent variable reliability data during 11 of the 32 training sessions to assure the physical therapist followed the procedure outlined. Of the 183 planned exercises, 94% were observed. The Pilates instructor observed and recorded measurements during seven of the 26 data collection periods to determine if the data were collected accurately. The two investigators agreed on the subjects' observed performance 100% of the time.

All data were ultimately analyzed by the principal author. Table 2 outlines the numerical changes in performance throughout the study. Baseline means and standard deviations were calculated for each dependent variable and post-intervention data is bold. Figures 3-5 graphically

Independent Variable reliability = (# of procedures observed / # of procedures planned) X 100.
Dependent Variable reliability = (# of agreements / # of agreements + # of disagreements) X 100.

Table 2. Data collected on each subject at each individual test session. Double leg lowering (DLL) is measured in degrees. Star Excursion Balance Test (SEBT) is measured in centimeters. Throwing (speed) is measured in miles per hour. Each reported test score is an average of three trials in a test session. Bold figures represent data collected after intervention had been introduced. In DLL, lower scores represent improved performance.
illustrate the subjects’ performance on each dependent variable. Baseline data is separated from the data collected during the intervention in the graphs by a vertical line. Visual inspection of the graphs was used in conjunction with the two standard deviation band method of analysis described by Ottenbacher. A two standard deviation line above and below the calculated means were marked on each graph. According to this method, if over half of the data points in the intervention period fall above or below these lines, the difference during the intervention phase is significant at the p<0.05 level.

Upon initially graphing the SEBT data, it was noted that the graphs in each of four directions made the graphs unusually complex. Pearson product moment correlation analysis of the SEBT data between the right and left legs demonstrated high correlations for the majority of the trials (r = 0.77-0.88). Since the correlations were high, the data for left and right reach in the SEBT for each subject were collapsed into one graph for clarity of graphic display.

RESULTS
The three subjects recruited completed each phase of the study from baseline through the complete 10-week period, but were unable to attend every exercise session planned. Subject 1 was originally scheduled to attend 16-24 sessions and attended 12. Subject 2 was scheduled to attend 14-21 sessions and attended 14. Subject 3 was scheduled to attend 9-12 sessions and attended 6. All data were analyzed by the principal author. Table 2 outlines the numerical changes in performance throughout the study and Figures 3-5 graphically illustrate the subjects' performance on each dependent variable.
Improvement in performance during intervention is noted for each subject in each outcome variable. Subject 1 demonstrated improvement in the SEBT posterior reach in four of seven data points during the intervention. However, only three of these points fell above the 2 standard deviation band so the improvement was not considered significant at the level of $p < 0.05$. Subject 3’s performances in the SEBT posterior reach showed improvement in all data points collected, but the changes were also below the 2 standard deviation band. Throwing speed data for subject 3 during the intervention phase fell between the 2 standard deviation band lines and were considered insignificant. All other changes observed were significant at the $p < 0.05$ level.

Table 2 displays the numerical values of the data collected during each test session. Table 3 displays pre-intervention and post-intervention change data. The average of all data collected during baseline testing was compared to the average of the data collected after introduction of the intervention. The percent change is noted. The largest percent change is noted in the DLL test with a range from 24.43-32.6%. Improvement in the SEBT ranged from 4.63-17.84%. Throwing speed improvements ranged from -2.29-5.3%.

**DISCUSSION**

The dependent variables in this study were chosen to address outcomes related to the specific foundation strength of the targeted muscles (DLL), a single leg dynamic stability activity related to function in this population (SEBT), and the specific outcome of throwing speed that is important to performance in baseball. Each dependent variable shows significant improvement in the subjects’ performances after the intervention was introduced with the exception of subject 3’s throwing...
speed and SEBT posterior reach and subject 1’s SEBT posterior reach. Positive changes occurred in the DLL test very early in the intervention in each subject. For all subjects this trend toward improvement stabilized or continued throughout the course of the study. The immediate improvement noted in this dependent variable may correspond to motor learning and improved motor control, as previously reported. 13

All subjects improved in the distance reached with the SEBT with the exception of posterior reach. It is interesting to note that subject 2 showed much greater improvement in all four directions than subject 1 or subject 3, but that all subjects demonstrated a gradual improvement in each direction over the course of the intervention. This finding may support the importance of proximal stability in functional lower extremity activities involving balancing on a single leg. In pitching, dynamic balancing on a single leg is a key component of the total body motion used.

Figure 3 depicts the differences measured in throwing velocity before and after the intervention. Possible reasons for these small differences include the many factors that contribute to increased throwing velocity and the fact that near maximal values such as throwing velocity in mature pitchers will demonstrate very small changes with interventions. However, a small change can be very significant at this level of competition.

Subjects 1 and 2 showed small, but statistically significant increases in their average throwing speed. Subject 3 showed a slight decrease in performance that was statistically insignificant. In all cases, the fall practice season had ended just prior to the start of the study. The first test of throwing speed was performed when the subjects had been throwing regularly in practice for 5-6 weeks and they considered themselves to be in good condition and form. When formal practice stopped, the subjects reduced their throwing practice to 1-2 times per week.

Even though their workouts did not consistently include throwing, when the Pilates intervention began, all subjects exhibited a gradual improvement in throwing speed. Subject 1 showed an initial spiked improvement and then returned to the baseline level. After this return to baseline, he gradually increased his throwing speed on
each subsequent test day. Subject 2 showed more marked improvement in the first 1-2 weeks after intervention, and was able to maintain this throughout the study. After an initial drop in performance that was a continuation of baseline testing, subject 3 began improvement after week 2 of his intervention period and gradually increased performance back near the average baseline level noted prior to the intervention. With the improvements noted after introducing the intervention, evidence appears to exist of a positive result regarding the outcomes measured.

Limitations do exist to this study. A small sample size, although adequate for a single subject design, limits the external validity of the study. Findings related to the study sample may confidently be applied only to this group. It is also unclear whether the positive results observed in the outcomes may have been even better had the subjects been able to attend all planned sessions.

Tester bias is a possibility, but unavoidable issue as well in this study. In future studies, this bias can be limited by having the tester be blinded to when or if subjects are receiving the intervention. A primary purpose of this single subject design study was to gather data that may illuminate the value of a Pilates method exercise program on outcomes relevant to baseball players and coaches. The principal author identified when subjects demonstrated stable baselines so they could begin the intervention. As each subject was his own control and the principal author knew when the intervention was started, blinding was not possible. Future studies should include control groups and more personnel to allow for blinding of the testers to the status of the subjects regarding the group to which they are assigned.
Some inconsistencies were also noted with the measurement of throwing speed. With a distance of only 30 feet, difficulty existed in focusing completely on ball speed without including arm movement. To control for this difficulty, additional repetitions of throwing were allowed until the investigator was able to obtain accurate ball speed readings.

Finally, although the exercise program was complete and addressed trunk mobility and stability as planned, a Pilates trained practitioner was required to implement the program. The need for a Pilates trainer practitioner could limit implementation of this type of exercise program in a typical baseball team setting. In addition, subjects may not comply with the program since it is a nontraditional exercise method for this population. However, each of the players reported compliance with the program and asked for a follow-up program to continue after the study was completed.

CONCLUSION

Visual and statistical analysis of the graphs and data demonstrates that the introduction of the Pilates method of exercise into an off-season baseball conditioning program had a positive and desired effect on performance in a trunk strength and stability test and a single leg balance test in all three subjects studied. Throwing velocity was also positively affected in two of the three subjects. The trunk stability and balance tests were chosen for their ease of performance in any clinical setting and because of their potential importance to throwing performance.

REFERENCES


### Appendix A. Exercises used with position and description.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Position</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ribcage breathing</td>
<td>Hooklying</td>
<td>Inhale letting ribs rise and expand, exhale encouraging ribs to descend and come together.</td>
</tr>
<tr>
<td>pelvic rocking</td>
<td>Hooklying</td>
<td>Inhale tilting pelvis into an anterior position, exhale tilting pelvis posteriorly.</td>
</tr>
<tr>
<td>knee folds</td>
<td>Hooklying</td>
<td>Inhale and exhale engaging the deep abdominals by connecting your navel to your spine. Raise one knee up toward the chest and back down to the floor while the deep abdominals are engaged.</td>
</tr>
<tr>
<td>knee sways</td>
<td>Hooklying</td>
<td>Feet off the floor, legs/knees hugging together. Inhale and let knees drop to one side, exhale return knees to center position.</td>
</tr>
<tr>
<td>upper body curl</td>
<td>Hooklying</td>
<td>Inhale and exhale lifting head, neck, and shoulders off floor, reaching toward feet with hands.</td>
</tr>
<tr>
<td>hundred</td>
<td>Lie on back, arms along sides, hips and knees flexed to 90º</td>
<td>Inhale for 5 counts, and exhale for 5 counts contracting the deep abdominals and encouraging the abdominals to hollow out during the exhales.</td>
</tr>
<tr>
<td>roll-up</td>
<td>Lie supine on mat, arms overhead, lower extremities extended</td>
<td>Inhale to prepare, exhale as you slowly roll up through spine to long sitting. Inhale and exhale as you roll down slowly articulating through the spine.</td>
</tr>
<tr>
<td>rolling</td>
<td>Seated, hip/knees flexed, hands “holding on” posterior knees, feet on mat</td>
<td>Back gently flexed to promote “c-shape” of spine. Inhale to prepare and exhale contacting the deep abdominals and rolling backward and returning to starting position.</td>
</tr>
<tr>
<td>single-leg stretch</td>
<td>One knee flexed with hands holding knee toward chest, other leg extended with 45º hip flexion</td>
<td>Inhale as you exchange legs and exhale as you arrive other side with opposite knee to chest and opposite leg extended. Optional head, neck, and shoulders off mat (“upper body curl”).</td>
</tr>
<tr>
<td>double-leg stretch</td>
<td>Lower extremities flexed (knees to chest), hugging. One hand on each knee.</td>
<td>Inhale extending to 45º hip flexion; arms overhead. Exhale circling arms down close to mat, finishing with hands on flexed knees (original position).</td>
</tr>
<tr>
<td>single straight leg</td>
<td>Both legs extended; one leg close to floor, other leg extended hip flexion 90º or greater while holding on to leg with hands, arms extended.</td>
<td>Upper body curl. Inhale as you exchange legs and exhale as you arrive with opposite leg in hands emphasizing a navel to spine connection by drawing the lower abdominals inward.</td>
</tr>
<tr>
<td>side kick hot potato</td>
<td>Performed on mat on side</td>
<td>Legs in front of torso at approximately 45º angle. Top/working leg raised 6 inches. Inhale: Foot dorsiflexed as leg is kicked forward. Exhale: Foot plantarflexed as leg is kicked back beyond base leg on mat. Kick forward and back equals “one set.”</td>
</tr>
<tr>
<td>side kick front/back</td>
<td>Performed on mat; patient lying on side</td>
<td>Working leg extended, foot dorsiflexed entire exercise. Keeping leg extended pulse leg and touch heel softly to mat five times behind base leg and five times in front of base leg. Inhale as you switch from back to front and exhale as you gently tap heel on floor.</td>
</tr>
<tr>
<td>side kick small circles</td>
<td>Performed on mat; patient lying on side</td>
<td>Working leg extended, foot dorsiflexed. Make small circles (size of soccer ball) counterclockwise and then clockwise. Alternate inhaling for two circles and exhaling for two circles.</td>
</tr>
<tr>
<td>spine stretch forward</td>
<td>Seated in “v-position” (legs extended, feet dorsiflexed, legs in approximately 30º abduction.)</td>
<td>Inhale to prepare, exhale as arms reach forward, spine flexes above waist and deep abdominals hollow out. Return to original position.</td>
</tr>
<tr>
<td>Exercise</td>
<td>Position</td>
<td>Description</td>
</tr>
<tr>
<td>-------------</td>
<td>--------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>spine twist</td>
<td>Seated in v-position. Arms extended, abducted 90°</td>
<td>Inhale as arms and torso are rotated to one side. Exhale return to center.</td>
</tr>
<tr>
<td>saw</td>
<td>Seated in v-position. Arms extended, abducted 90°</td>
<td>Inhale as you rotate arms and torso to one side. Exhale as you reach toward lateral side of foot with opposite hand. Inhale as you recover from position and rotate to other side.</td>
</tr>
<tr>
<td>swan</td>
<td>Lying prone, legs extended, arms flexed</td>
<td>Inhale for preparation, exhale extending arms and back keeping pelvis on floor.</td>
</tr>
<tr>
<td>neck roll</td>
<td>Lying prone, legs extended, arms flexed, hands adjacent to shoulders, back extended</td>
<td>Rotate head to the right. Flex cervical spine as you rotate to the left. Remain back extension for entire exercise keeping lower abdominals engaged toward spine.</td>
</tr>
<tr>
<td>pull straps 1</td>
<td>Prone</td>
<td>Arms extended, shoulders flexed forward off mat. Inhale and extend shoulders as hands reaching toward toes.</td>
</tr>
<tr>
<td>pull straps 2</td>
<td>Prone</td>
<td>Arms extended, shoulders abducted out to sides off mat. Inhale extending shoulders, reaching toward toes.</td>
</tr>
<tr>
<td>single-leg kick</td>
<td>Prone, propped in extension on forearms, hands clasped.</td>
<td>Legs extended. Inhale and kick one foot twice toward buttocks. Exhale, kick other leg towards buttocks. Opposite leg extended while working leg kicks.</td>
</tr>
<tr>
<td>swimming</td>
<td>Prone</td>
<td>Lift opposite arm and leg off floor. Head and chest come off floor too. Alternate “kicking” legs and arms continuously as if swimming. Inhale for 5 counts and exhale for 5 counts.</td>
</tr>
<tr>
<td>teaser</td>
<td>Supine</td>
<td>Legs extended, arms along sides. Inhale for preparation, exhale as you lift legs off mat to 45° of hip flexion while torso lifts off floor and arms reach forward toward legs. Body is in a v-position; balancing.</td>
</tr>
<tr>
<td>rowing 3</td>
<td>Seated. Legs extended in front, hugging. Arms along sides, elbows flexed, palms facing downward</td>
<td>Inhale as you extend arms forward at 45° angle, exhale lower arms in front of body until tips of fingers touch mat, inhale raising arms overhead, exhale arms open up and out to sides - 90° abduction.</td>
</tr>
<tr>
<td>rowing 4</td>
<td>Seated. Legs extended in front, hugging. Arms by sides</td>
<td>Inhale and exhale as you engage lower abdominals; roll through spine as you flex torso and reach arms toward toes. Inhale rolling back up through spine and reach arms high to ceiling, finishing with arms opening out to sides and 90° abduction.</td>
</tr>
<tr>
<td>criss-cross</td>
<td>Supine</td>
<td>One knee flexed to chest, other leg extended with 45° hip flexion. Upper body curled to lift shoulders off floor. Hands behind head. Inhale as you rotate to one side and exhale as opposite elbow and knee touch.</td>
</tr>
<tr>
<td>leg pull back</td>
<td>Push-up position, hand and wrists under shoulders</td>
<td>Inhale lifting and extending right leg, allowing weight to shift backward and stretching the supporting heel cord.</td>
</tr>
<tr>
<td>leg pull front</td>
<td>Sitting position, legs extended in front, hands by hips. Lift pelvis in a front “plank” position</td>
<td>Keep chin tucked to chest gently. Inhale and kick one leg up to ceiling, foot plantar flexed. Exhale, dorsiflex foot and return to mat with foot.</td>
</tr>
<tr>
<td>mermaid</td>
<td>Seated position, legs flexed and tucked into right side. Right hand holds onto ankles. Extend left arm to ceiling</td>
<td>Inhale stretching up high and laterally flex to the right as you exhale engaging the deep abdominals. Inhale as you recover and bring left forearm down to mat. Right arms extends and reaches overhead as you laterally flex to the left.</td>
</tr>
<tr>
<td>rolling down</td>
<td>Standing, feet shoulder-width apart</td>
<td>Inhale and exhale as you sequentially roll down through the spine. Let upper body and arms hang down as you keep the lower abdominals engaged. Inhale and exhale again as you sequentially roll up through the vertebrae back to the original standing position.</td>
</tr>
</tbody>
</table>
ABSTRACT

Pectoralis major tendon rupture is a rare shoulder injury, most commonly seen in weight lifters. This injury is being seen more regularly due to the increased emphasis on healthy lifestyles. Surgical repair of the pectoralis major tendon rupture has been shown to provide superior outcomes regarding strength return. Thus it appears that surgical repair is the treatment of choice for those wishing to return to competitive or recreational athletic activity. This article describes the history and physical examination process for the athlete with pectoralis tendon major rupture. Surgical vs conservative treatment will be discussed. This manuscript provides post surgical treatment guidelines that can be followed after surgical repair of the pectoralis tendon rupture.

Key Words: weightlifting, pectoralis major, rupture

CORRESPONDENCE:
Robert C. Manske, PT, DPT, SCS, ATC
Wichita State University
Department of Physical Therapy
1845 North Fairmount
Wichita, KS 67260-0043
Office: 316-978-3702
Fax: 316-978-3025
eMail: Robert.manske@wichita.edu
INTRODUCTION
Patissier initially described rupture of the pectoralis major muscle in 1822. Although, initially described as a rare injury, the numbers of athletic patients requiring surgical repair of the ruptured pectoralis tendon is increasing. This injury can be devastating to the active athletic patient if treatment does not return full functional strength and range of motion of the injured upper extremity. The objectives of this article are to describe the relevant anatomy of the pectoralis region and discuss evaluation, operative, and rehabilitative approaches to treatment of this potentially disabling upper extremity injury.

Anatomy/Kinesiology
The pectoralis major muscle is a very powerful shoulder muscle during its function – that of shoulder adductor, internal rotator, and flexor of the humerus. Origins of the pectoralis major include the clavicle, sternum, ribs, and external oblique fascia as well as cartilage of the first six ribs. This large muscle, located on the anterior chest wall overlying the pectoralis minor, has both a sternal and a clavicular head. The clavicular portion of the pectoralis major originates on the lateral clavicle and upper sternum and inserts onto the inferior surface of the humerus at the crest of the greater tuberosity. The sternal head of the pectoralis major originates on the manubrial end of the sternum and inserts onto the lower humerus with the clavicular portion. The insertion of the pectoralis tendon onto the humerus occurs with the muscle twisting on itself so that the lowest fibers of the tendon insert at the highest location on the humerus. Wolfe et al. have previously demonstrated that this attachment results in significant tension in the inferior portion of the pectoralis muscle and predisposes this portion to rupture when stretched and loaded. Wolfe and colleagues measured excursion of individual pectoralis muscle fibers at seven different points along the origin by the use of fine wires connected to humeral insertion and to dial gauges. Inferior fibers of the pectoralis major muscle lengthened disproportionately during the final 30 degrees of humeral extension. This attachment arrangement may result in partial tears being much more common than that of complete ruptures.

Mechanism of Injury
Although pectoralis tendon ruptures are most commonly seen in weight lifting, ruptures have also been reported in many other sporting activities such as boxing, football, rodeo, water skiing, and wrestling. These injuries tend to occur more commonly in patients during their second to fourth decade of life. To date, this rupture is a totally male dominated athletic injury with not even a single case study report of injury to the female athletic population. The diagnosis of pectoralis tears is generally not elusive. Patients often give a history of doing a maximal lift or effort and feeling something in the shoulder giving or ripping; while the injury is often accompanied by an audible “snap” or “pop.” Mild swelling and often ecchymosis follows. Bruising can be seen over the anterior lateral chest wall or in the proximal arm. Pain generally is not intense.

Physical exam reveals a loss of the anterior axillary fold and normal pectoralis contour (Figure 1). Asking patients to press the hands together in a “prayer position” eliciting an isometric contraction will reveal asymmetry to the chest wall. This asymmetry can be easily confirmed by looking for medial movement of the nipple on the chest wall. Often a distinct deformity or hollow exists where the pectoralis muscle will move medial. Loss of strength is particularly notable to internal rotation of the arm when tested at neutral.

Diagnostic testing may include plain radiographs which are usually not diagnostic, although reports of bony abnormalities have been noted. Magnetic resonance imaging (MRI) can be helpful and is becoming the imaging method of choice and can be helpful where a partial tear is suspected. The partial tear may be difficult to evaluate. An MRI can be helpful in assessing location and severity of the tear. The tendon fibers from the clav-
icular head may be intact and be interpreted as an intact tendon. This finding must be interpreted carefully as partial tears which do not include the clavicular head have significant morbidity and should be given consideration for operative treatment. If edema is present, careful scrutiny should be given to the tendon to assess for pathology.

CONSERVATIVE VS. SURGICAL TREATMENT
Historically, non-operative treatment has been advocated for older or sedentary individuals or for those with incomplete tears. Unfortunately, rarely does non-operative treatment result in return of normal strength. Wolf et al has reported up to a 26% loss of peak torque and a 39.9% work deficit in shoulder adduction in unrepaired ruptures. Furthermore, numerous studies have demonstrated that surgical treatment of complete pectoralis tendon ruptures has a defined advantage in regards to increased strength over that of non-operative treatment, especially in athletes.

SURGICAL TREATMENT
The authors preferred method of repair of the pectoralis major tendon is with the patient on the operative table in a beach chair position with the arm draped free. The incision is placed in the anterior axillary fold. A short incision of 5-8 cm is usually used in acute cases, or longer if the tendon tear is more chronic. This incision is very cosmetic and can be placed posterior enough in the axillary fold to allow the incision to be hidden when the arm is at the side. When done at this position, the resultant fine scar will often blend in and appear as a stretch mark which is met with favorable acceptance by the typical patient with this injury.

The surgical approach is begun by developing soft tissue planes and identifying the torn tendon end (Figure 4). If the tendon is identified after finding the deltopectoral interval and appears intact, the arm should be abducted and externally rotated. This maneuver will often identify a partial tear of the sternal head, which should be repaired. More chronic cases will require mobilization of the tendon. This mobilization of the tendon can be performed with careful dissection recognizing potential hazards posterior and medial to the pectoralis tendon.

The tendon can rupture from the attachment to bone or as a musculotendinous junction tear. If the tendon has ruptured proximal to the bony insertion, the tendon is repaired with permanent sutures, preferably a polyblend for strength to allow for mobilization.

If the tendon ruptures from the bony attachment, then the repair can be performed with bone tunnels and sutures, or by the authors’ preference of using suture anchors. This technique will require pre-drilling bone tunnels for suture anchor placement (Figure 5). The suture anchor technique has some pitfalls as this bone is very hard and care has to be taken not to fracture a bioabsorbable anchor on insertion or twist off a metal anchor if this is how it is inserted. Preparation of the insertion site can be performed with a rongeur (a spring-loaded forceps with a sharp blade), or if concerned about the healing potential, the cortex can be further abraded with a burr. Three to four anchors are placed in a typical complete tear. Sutures are then passed using a grasping suture technique with one strand, such as the Modified Mason-Allen. The second strand is brought into the end of the tendon and...
then out the anterior aspect 5-10 mm from the lateral edge. This technique allows for the suture to slide through the anchor and the tendon to pull the grasping arm down and allows the tendon to have full interface with the bone. This technique also places the suture knot on the anterior aspect of the tendon where the knot will not cause any irritation.

Before and after the tendon is repaired the range of motion of the shoulder is assessed while observing the repair site. Early repairs, less than three weeks, are often very mobile. This mobility allows for a more rapid return of shoulder motion post-operatively.

Once the repair is finished, (Figure 6) the wound is closed in layers with a dermal subcuticular closure for cosmesis. Subcuticular injection of local anesthetic is used. The arm is placed in a sling immobilizer, unless concern exists about abduction and then consideration is given to a simple sling.

**POST-OPERATIVE REHABILITATION**

Because no studies have been published that discuss pectoralis major tendon repair strain properties, the amount of stress this tissue can tolerate prior to rupture or compromise in the post surgical patient is not fully understood. Therefore, post surgical rehabilitation soft tissue healing time frames following pectoralis tendon repair are based on clinical impression and empirical evidence in treating these athletes. Additionally, some general assumptions can be made based on previous literature related to soft tissue healing of other common tendon rupture repairs including the rotator cuff and Achilles tendons.

Post-operative rehabilitation following pectoralis major tendon repair is dependent on several surgical considerations. Direct repairs of pectoralis major muscle to tendon is difficult because the ability to obtain a firm anchorage for suture in soft muscle tissue is limited. For this reason, speculation is that direct repairs of muscle to tendon or those from tendon to tendon may require greater soft tissue time constraints. This repair may be so tenuous that some authors even suggest conservative treatment following a tear in the musculotendinous region. Post surgical rehabilitation requires a balancing act of maintaining enough restriction of range of motion to allow adequate soft tissue healing, yet still allowing enough activity and motion to restore shoulder mobility, all the while gradually returning functional strength to allow a return of full unrestricted functional activities. In numerous instances these functional activities are to return the athlete to very high levels of strength since a large majority of these injuries occur in competitive or recreational weightlifters. Because damaging the healing tendon immediately following surgery is contraindicated, the patient’s shoulder is generally placed in an immobilizer or a sling for the first 3-4 weeks, depending on the type of surgery required (Table 1).

As with most post-operative rehabilitation, the ultimate goals following pectoralis major repair include 1) maintaining structural integrity of the repaired soft tissues, 2) gradually restoring full functional range of motion, 3) restoring or enhancing full dynamic muscle control and stability, and 4) return of full unrestricted upper extremity activities including activities of daily living and recreation and sporting athletic endeavors. The ultimate goal is to return
the patient to their preferred level of activity as quickly and safely as possible. The ability to achieve this goal must rely on utilizing progressive treatment phases that are delineated with specific goals and achievements.

**Immediate Post-operative Phase (0-2 weeks)**

Goals for the immediate post-operative phase are 1) protect the healing tissue, 2) diminish post-operative pain and swelling, and 3) limit the effects of prolonged immobilization. Direct soft tissue repairs (tendon to tendon or muscle-tendon unit to tendon) require a slight rehabilitation delay to allow for adequate soft tissue healing before placing considerable stress to the repaired tissue. The immediate post-operative phase lasts for up to 3 weeks. In this time frame a gradual progression of passive range of motion (PROM) is began at 2 weeks. The patient is maintained in sling immobilization for 3 weeks. Passive ROM is taken to neutral external rotation and allowed to be increased by 5 degrees per week. Forward flexion is passively taken to 45 degrees increasing 5-10 degrees per week (Table 2). Passive ROM is performed to help soft tissue healing by increasing collagen synthesis and promoting correct alignment of fibers that are oriented parallel to the movement that is required to return full functional use of the upper extremity. No active range of motion (AROM) is allowed in the shoulder, but AROM is promoted for the rest of the upper extremity including elbow, forearm, and wrist/hand.

As with any surgical procedure, controlled trauma is part of the surgical process. Therefore, recognizing pain and localized edema is common. Since this surgical procedure is extracapsular, an actual joint effusion should not occur. To help decrease these physical symptoms, electrical stimulation and cryotherapy are recommended. Spear et al\(^5\) has demonstrated that cryotherapy appears to be an effective adjunct following shoulder surgical procedures. Interferential electrical stimulation or high volt galvanic stimulation can be used to assist in decreasing post-operative pain, soreness, and swelling.\(^5\,6\)

In this phase, PROM is performed by the clinician to decrease the risk or unwanted adhesion formation in and around the post-operative surgical site. Because this surgical procedure does not require entrance into the joint cavity, intra-articular adhesions are generally not one of post surgical sequelae. Of more concern with these procedures are extra-articular adhesion formation around the surgical incisions, which will create mobility problems. Additionally, an unsightly and unfavorable scar can be emotionally and socially devastating, especially to body-builders whose main desire is anatomical symmetry and cosmetic perfection. Once the incisions are healed and closed, gentle superficial scar tissue mobilization can be initiated. Scar mobilization should occur parallel to the superficial incision, progressing to running across the actual scar. Scar massage should be with enough pressure to blanch the scar. Scar massage will be helpful to break up collagen fibers, resulting in a softer, flatter, paler scar with better cosmesis,\(^7\) in addition to promoting soft tissue mobility.\(^8\)

Passive pendulum exercises are also encouraged as part of the home exercise program to increase mobility of the shoulder joint. Active assistive range of motion (AAROM) and gentle submaximal isometrics are began at 2-4 weeks post-operatively to begin stressing the contractile

<table>
<thead>
<tr>
<th>Type of Repair</th>
<th>Guidelines</th>
<th>Full AROM/PROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tendon – tendon</td>
<td>Sling 4 weeks</td>
<td>14-16 weeks</td>
</tr>
<tr>
<td>Bone – tendon</td>
<td>Sling 3 weeks</td>
<td>12-14 weeks</td>
</tr>
</tbody>
</table>

Table 1. Pectoralis tendon repair guidelines

<table>
<thead>
<tr>
<th>Week</th>
<th>ER @ 0° Shoulder Adduction</th>
<th>Forward Flexion</th>
<th>Abduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
<td>45</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>50-55</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>55-65</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>60-75</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>65-85</td>
<td>50</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>70-95</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>30</td>
<td>75-105</td>
<td>60</td>
</tr>
<tr>
<td>9</td>
<td>35</td>
<td>80-115</td>
<td>65</td>
</tr>
<tr>
<td>10</td>
<td>40</td>
<td>85-125</td>
<td>70</td>
</tr>
<tr>
<td>11</td>
<td>45</td>
<td>90-135</td>
<td>75</td>
</tr>
<tr>
<td>12</td>
<td>50</td>
<td>95-145</td>
<td>80</td>
</tr>
</tbody>
</table>

Table 2. Range of Motion Guidelines

ER = External rotation
POST-OPERATIVE REHABILITATION FOLLOWING PECTORALIS TENDON REPAIR

PHASE I – IMMEDIATE POST-OPERATIVE PHASE (WEEKS 0-2)

Goals
- Protect healing repaired tissue
- Decrease pain and inflammation
- Establish limited range of motion (ROM)

Exercises
- No exercise until end of 2nd week

Sling
- Sling immobilization for 2 weeks
- Passive rest for full 2 weeks
- Allow soft tissue healing to begin uninterrupted
- Allow acute inflammatory response to run normal course

PHASE II – INTERMEDIATE POST-OPERATIVE PHASE (WEEKS 3-6)

Goals
- Gradually increase ROM
- Promote healing of repaired tissue
- Retard muscular atrophy

Week 2
- Sling immobilization until 3rd week
- Begin passive ROM per guidelines (Table 2)
  - External rotation to 0 beginning 2nd week
  - Increasing 5 degrees per week
  - Forward flexion to 45 degrees
  - Increasing 5-10 degrees per week

Week 3
- Wean out of sling immobilizer – week 3
- Continue passive ROM per guidelines (Table 2)
  - Begin abduction to 30 degrees
  - Increasing 5 degrees per week
- Begin gentle isometrics to shoulder/arm EXCEPT pectoralis major
- Scapular isometric exercises

End of Week 5
- Gentle submaximal isometrics to shoulder, elbow, hand, and wrist
- Active scapular isotonic exercises
- Passive ROM per guidelines (Table 2)
  - Flexion to 75 degrees
  - Abduction to 35 degrees
  - External rotation at 0 degrees of abduction to 15 degrees

PHASE III – LATE POST-OPERATIVE PHASE (WEEKS 6-12)

Goals
- Maintain full ROM
- Promote soft tissue healing
- Gradually increase muscle strength and endurance
Week 6 Continue passive ROM to full
Continue gentle sub maximal isometrics progressing to isotonics
Begin sub maximal isometrics to pectoralis major in a shortened position progressing to neutral muscle tendon length.
Avoid isometrics in full elongated position

Week 8 Gradually increase muscle strength and endurance
Upper body ergometer
Progressive resistive exercises (isotonic machines)
Theraband exercises
PNF diagonal patterns with manual resistance
May use techniques to alter incision thickening
Scar mobilization techniques
Ultrasound to soften scar tissue

Week 12 Full shoulder ROM
Shoulder flexion to 180 degrees
Shoulder abuction to 180 degrees
Shoulder external rotation to 105 degrees
Shoulder internal rotation to 65 degrees
Progress strengthening exercises
Isotonic exercises with dumbbells
Gentle 2-handed sub maximal plyometric drills
  Chest pass
  Side-to-side throws
  BodyBlade
  Flexbar
  Total arm strengthening

PHASE IV – ADVANCED STRENGTHENING PHASE (WEEKS 12-16+)

Goals Full ROM and flexibility
Increase muscle strength and power and endurance
Gradually introduce sporting activities

Exercise Continue to progress functional activities of the entire upper extremity
Avoid bench press motion with greater than 50% of prior 1 repetition max (RM)
Gradually work up to 50% of 1 RM over next month.
Stay at 50% prior 1 RM until 6 months post-operative, then progress to full slowly after 6 month time frame

KEYS Don't rush ROM
Don't rush strengthening
Normalize arthrokinematics
Utilize total arm strengthening
properties of the repaired tissue and surrounding musculature which helps retard muscle atrophy and loss of muscle control. To maintain cardiovascular condition the athlete should continue with prior aerobic training on recumbent or standard exercise cycle, but is asked not to perform aerobic exercises such as elliptical runners, cross-country machines, or running/jogging on treadmills to decrease risk of injury in case of accidental loss of balance (Table 3).

Intermediate Post-operative Phase (3-6 weeks)

This phase is a short 3 week phase in which PROM is slowly advanced. Goals in the Intermediate Post-operative Phase include 1) Continued progression of ROM, 2) enhance neuromuscular control, and 3) increase muscular strength. Prior ROM is advanced per earlier discussion, while shoulder abduction is begun at 30 degrees increasing 5 degrees per week, with abduction and external rotation performed last. Toward the end of this phase AAROM is begun and patient’s performance of PROM is allowed. Because in this phase soft tissue healing should already be initiated, patient AAROM is started. Range of motion of the shoulder can be performed with a cane or L-bar into gentle flexion, scaption, and external rotation. Patient education regarding ROM limitations that still exist are imperative for safe return of full mobility without re-rupture, stretching, or loosening of repaired soft tissue. No AROM is allowed early in this phase, while gentle limited AROM is allowed toward the end of this phase. Painful elevation or active mobility of the shoulder is detrimental to the healing soft tissue and, therefore, should not be allowed.

Gentle sub-maximal isometrics are performed for the rotator cuff muscles at this time to enhance dynamic shoulder stability. Known as “rhythmic stabilization” exercises, these isometric exercises are performed with the patient lying supine with the arm in the balance position of 90 degrees of flexion. The athlete is asked to maintain a position of full elbow extension while the arm is in 90 degrees of flexion while the clinician applies small joint perturbations in various directions. These exercises are performed in a manner initially in which the athlete can view and prepare for the contraction needed to keep the arm stable in a proactive manner, known as proactive training. This stabilization can be progressed to performing these perturbations in randomized patterns followed by increasing speed in which perturbations are made. These exercises can further be progressed from eyes open to eyes closed pattern, which is known as reactive training.60 Performance of these stabilization exercises with eyes closed is done to enhance reactive muscle performance. These exercises are generally performed in multiple angles at approximately 20 degree intervals through a safe range of motion. The isometrics are performed in this fashion because of a 20 degree range of motion physiological overflow found with isometric exercises.59

In this phase, exercises for the scapula can be initiated. Scapular “setting” exercises are performed with the scapula in a retracted position to enhance postural control. Early in the intermediate phase, internal shoulder rotation and shoulder flexion isometrics are not performed to decrease risk of excessive activation of the pectoralis major muscle contractions during those movements. Toward the end of this phase (5-6 weeks), gentle sub-maximal isometrics with the pectoralis major in a shortened position can begin and carried into the next phase. Judicious use of extension, abduction, and external rotation isometrics are performed. It should be cautioned that during this early time frame that exercises such as “rhythmic stabilization” are performed initially at very low levels, reaching forces of 2-4 pounds at most.

Additionally scapulothoracic isometrics and AROM exercises are used during this time frame. Davies and Ellenbecker60 have described total arm strengthening that can have a positive effect on the entire upper extremity. These exercises should be initiated early to ensure adequate strength of other remaining upper extremity musculature.

Late Strengthening Phase (6-12 weeks)

The advanced strengthening phase begins at around 6 weeks and extends to around 16 weeks. Goals to be obtained at this time include achieving and maintaining full shoulder mobility both actively and passively, and gradually increasing muscular strength and endurance. Davies60 has described an exercise progression continuum as a means of integrating a safe and systematic process of progressing patients through an exercise program. Therapeutic exercises in this phase should begin with gentle submaximal isometrics for the pectoralis. These exercises should initially be performed with the shoulder adducted to place the pectoralis in a relatively shortened position. This activity should not be performed in full horizontal adduction as the pectoralis would be placed in a position nearing active insufficiency. Isometric exercises should be progressed to neutral shoulder or the
“balance position” (Figure 7) and toward the end of this phase performed in a more lengthened position. Rarely should these isometric exercises be performed in full horizontal abduction with the pectoralis muscle in a fully lengthened position, which may place excessive strain on the repaired tissue.

Usually by the 12 week period gentle isotonic tubing exercises can be started in a safe ROM that does not place excessive stretch on the repair site. At the end of this phase proprioceptive neuromuscular facilitation (PNF) techniques can be helpful by simultaneously recruiting all the muscles in the upper extremity by incorporating both spiral and diagonal patterns of motion. In the overhead athletes, the PNF patterns of diagonal 2 (D2) flexion and extension movements are performed because these patterns are very similar to overhead throwing patterns. Initially, the PNF patterns should be concentric against gentle manual resistance. Following tolerance of manual techniques, PNF can be performed using exercise tubing. Progressive resistance can be increased by using tubing for eccentric control.

Full AROM exercises can be performed at this time. Careful emphasis should be placed on normalizing glenohumeral arthrokinematics to allow unrestricted mobility. Due to prolonged immobilization with this surgical procedure some arthrokinematic limitations are common that need to be addressed. Arthrokinematic issues that commonly remain include a decrease in anterior, inferior, and posterior glide passive motions of the glenohumeral joint. Joint mobilizations for these restrictions should be initiated (Figure 8). Additionally, arthrokinematic limitations of the sternoclavicular and acromioclavicular should be assessed with appropriate interventions, as needed.

Because the scapulothoracic joint is not a true synovial joint, rarely does this pseudo-joint incur motion problems. Motion restrictions of the scapulothoracic joint can result from excessive use and compensation of the posterior scapular muscles. Commonly during this time the patient may exhibit a compensatory “shrug sign,” also known as scapular “hiking” or a reverse scapulohumeral rhythm in which the scapula moves more than the humerus. When initiating shoulder elevation movements, if the entire shoulder girdle or scapula elevates, a faulty neuromuscular pattern is occurring. In this form of compensation the weaker rotator cuff muscles are being overpowered by the stronger deltoid muscles. If this pattern of movement occurs, it should be stopped and addressed immediately. Continuation of this faulty pattern will only prolong its use and potentially set the patient up for rotator cuff impingement problems and possible rotator cuff tear. If these compensations are occurring, the patient should limit AROM in shoulder elevation to below 90 degrees and begin dynamic stabilization drills for the scapular and rotator cuff muscles.

Advanced Strengthening Phase (12-16+ weeks)
The final phase of the post-operative program following pectoralis tendon repair is the Return to Activity Phase and occurs after 12-16+ weeks. The goals for this period include full AROM/PROM of the shoulder and a gradual return of full strength for resumption of all prior activities of vocation or daily living. Treatment at this stage can begin to be more aggressive, simply meaning, weight can be increased and multi planar exercises can be begun. If shoulder ROM is full, light overhead activities can be progressed. These activities can include gentle advanced activities that employ concentric/eccentric contractions such as plyometric activities with plyoball catches or use of the BodyBlade (Figure 9). For the weightlifter or bodybuilder a slow progression of light shoulder press and bench press can now be performed. No lifting greater than 50% of the athlete’s previous 1 repetition maximum should be performed.
pectoralis rupture and noted that the muscle belly injuries do well when treated non-operatively, as long as there is not a large hematoma or infection. Finally, Wolfe and colleagues reported superior results with surgical repair vs conservative treated patients. Their surgically treated group had peak torque and low-speed work values of 105.8% and 109.0% that of the uninvolved side, respectively, compared with 74.0% and 60.1% which was that of the conservatively treated group. Bak and colleagues performed a meta-analysis of 112 cases of pectoralis major rupture and found that excellent or good results were reported for 88% of surgically treated cases versus 27% of those treated conservatively. These authors concluded that with rare exceptions, no indication for nonsurgical treatment of pectoralis tendon ruptures was indicated.

In a more recent meta-analysis, Aarimaa and colleagues analyzed final outcomes following surgical repair of the pectoralis major using 33 patients with operative treated pectoralis major rupture patients of their own and combined these with a meta-analysis of previously reported cases in the literature. The authors found that both their cases and those from the literature demonstrated that early operative treatment is associated with better outcome than delayed treatment, while delayed treatment had better outcomes than non-surgical treatment.

**Surgical Outcomes**

Reviewing 16 repairs, Kretzler and Richardson reported full strength return in 13 cases. Two of the three who did not have full strength presented for testing more than 5 years after the repair. Despite this delay, and the fact that full strength was not attained, all three experienced significant improvements in their pre-surgery strength. All 16 had a return of normal pectoralis contour and relief of pain.

Schepsis et al assessed surgical outcomes following 13 patients undergoing pectoralis major repair. Surgical patients were broken into acute and chronic repairs, both of which fared significantly better with subjective reports of function rated at 96% and 93%, respectively, compared to 51% in a group of non-operative treated patients. Isokinetic strength was greatest in the acute group (102%) of the opposite side, compared to 94% with the chronic group, while non-operative patients only achieved 71% of the contralateral upper extremities strength.

Zeman and colleagues reported on nine athletes that sustained pectoralis major tears. Five of their patients were treated conservatively and obtained good results in that they were able to achieve normal ROM, with only mild pain and weakness. Four of the patients were treated surgically and obtained excellent results which were described as normal ROM and excellent strength.

McEntire and colleagues reported on 11 cases of pectoralis rupture and noted that the muscle belly injuries do well when treated non-operatively, as long as there is not a large hematoma or infection. Finally, Wolfe and colleagues reported superior results with surgical repair vs conservative treated patients. Their surgically treated group had peak torque and low-speed work values of 105.8% and 109.0% that of the uninvolved side, respectively, compared with 74.0% and 60.1% which was that of the conservatively treated group.

Bak and colleagues performed a meta-analysis of 112 cases of pectoralis major rupture and found that excellent or good results were reported for 88% of surgically treated cases versus 27% of those treated conservatively. These authors concluded that with rare exceptions, no indication for nonsurgical treatment of pectoralis tendon ruptures was indicated.

In a more recent meta-analysis, Aarimaa and colleagues analyzed final outcomes following surgical repair of the pectoralis major using 33 patients with operative treated pectoralis major rupture patients of their own and combined these with a meta-analysis of previously reported cases in the literature. The authors found that both their cases and those from the literature demonstrated that early operative treatment is associated with better outcome than delayed treatment, while delayed treatment had better outcomes than non-surgical treatment.

**Return to Play Guidelines**

The return to play criteria presented in this manuscript is somewhat dependent upon the activity that the athlete plans to continue. Although a cookbook approach should not be used for return to play criteria, several commonalities do exist. To begin with, the athlete's willingness to return to play both physically and mentally is very important. Because a gradual progressive rehabilitation program has been utilized, a general idea of the athlete's physical capabilities is well known. In general, to be released from the physician the athlete must have a satisfactory clinical exam which consists of pain-free full, or adequate ROM, and normal strength. When available, isokinetic testing can be utilized to gain a more objective measure of muscle strength. As mentioned previously, for the weightlifter or bodybuilder a slow progression of weight training should be followed. A strong recommen-
dation is that no lifting greater than 50% of the athlete's previous 1 repetition maximum be performed until 6 months post-operative. Additionally, the use of heavy weighted pec dec and flys should be avoided for up to 6 months due to abnormally large amounts of stress to the pectoralis major.

**SUMMARY**

Early recognition and surgical treatment of a ruptured pectoralis major tendon followed by a graded post surgical rehabilitation program that incrementally increases ROM and stress to the repaired tendon allows a full return of functional strength and mobility. This manuscript outlines a graduated post-operative protocol for return following pectoralis major tendon repair.

**REFERENCES**


SURFACE ELECTROMYOGRAPHIC ANALYSIS OF THE LOWER TRAPEZIUS MUSCLE DURING EXERCISES PERFORMED BELOW NINETY DEGREES OF SHOULDER ELEVATION IN HEALTHY SUBJECTS

Robert A. McCabe, MS, PT, OCSa
Karl F. Orishimo, MSc
Malachy P. McHugh, PhD
Stephen J. Nicholas, MD

ABSTRACT

Background. The lower trapezius is an important muscle for normal arthrokinematics of the scapula. In the early stages of rehabilitation, it is generally accepted to perform exercises with the shoulder kept below 90° of elevation in order to minimize risk for shoulder impingement. Few exercises for the lower trapezius have been studied which maintain the shoulder below 90° of humeral elevation.

Objective. To identify therapeutic exercises performed below 90° of humeral elevation that activate marked levels of lower trapezius electromyographic (EMG) activity.

Methods. Surface EMG activity of the lower, middle, upper trapezius, and serratus anterior was collected bilaterally on fifteen healthy subjects during four exercises: the press-up, unilateral scapular retraction with the shoulder positioned at 80° of shoulder flexion, bilateral shoulder external rotation, and unilateral scapular depression.

Results. The press-up exercise elicited marked lower trapezius EMG activity, moderate upper trapezius EMG activity, and a high ratio of lower trapezius to upper trapezius EMG activity. Scapular retraction produced marked EMG activity of both the lower and upper trapezius and moderate activity of the middle trapezius. Bilateral shoulder external rotation generated moderate lower trapezius EMG activity, minimal upper trapezius activity, and the highest ratio of lower trapezius to upper trapezius EMG activity. Scapular depression produced moderate lower trapezius EMG activity, minimal upper trapezius EMG activity, and a moderately high ratio of lower trapezius to upper trapezius EMG activity.

Discussion and Conclusions. This study identified two exercises performed below 90° of humeral elevation that markedly activated the lower trapezius: the press-up and scapular retraction.

Key Words: lower trapezius, electromyography, scapula

CORRESPONDENCE
Robert A. McCabe
165 Annuskemunnica Rd.
Babylon, NY 11702
Fax (212) 422-2158
eMail: ram294@nyu.edu

ACKNOWLEDGEMENTS
The authors wish to acknowledge Rudi Hiebert, ScM for his assistance with data analysis.
INTRODUCTION

Lower trapezius muscle performance is an essential component to normal scapulohumeral rhythm. Normal scapulohumeral rhythm requires upward scapular rotation, provided by the force couple of the trapezius and serratus anterior muscles, in order to prevent the rotator cuff tendon from impinging against the anterolateral acromion. During active humeral elevation, upward scapular rotation of the scapula is initiated by the serratus anterior. One function of the lower trapezius muscle is to stabilize the scapula against lateral displacement produced by the serratus anterior. The serratus anterior and upper trapezius can then exert an upward rotation moment about the scapula. A second function of the lower trapezius is to stabilize the scapula against scapular elevation produced by the levator scapulae. Therefore, the lower trapezius muscle is an essential component of the trapezius-serratus anterior force couple by maintaining vertical and horizontal equilibrium of the scapula during humeral elevation.

Research has shown an association between shoulder pathology and abnormal scapular motion or muscle firing patterns of the lower trapezius. Increased scapular elevation has been found in subjects with subacromial impingement compared to subjects without shoulder pathology. Cools et al found a decrease in lower trapezius activity during isokinetic scapular protraction-retraction in 19 overhead athletes with subacromial impingement. A delayed onset of lower trapezius muscle activity and over-activity of the upper trapezius was found in a study comparing 30 normal athletes and 39 athletes with subacromial impingement in response to external forces imposed on the arm.

Although it is not known whether abnormal scapular arthokinematics precedes or is a consequence of abnormal motor recruitment patterns of the scapular muscles, normal movement and function of the shoulder is dependent upon normal function of the scapular upward rotator muscles. Subsequently, it is important to strengthen the lower trapezius muscle during rehabilitation of patients with shoulder pathology. These exercises should be performed below 90° of humeral elevation during the initial stages of shoulder rehabilitation in order to prevent impingement or strain on the rotator cuff tendons and shoulder ligaments. Despite these recommendations, to our knowledge, no exercises performed with the shoulder below 90° of elevation have been identified which markedly recruit the lower trapezius using the standard established by McCann et al.

Several studies have reported that maximum lower trapezius muscle electromyographic (EMG) activity occurs between 90° and end range of humeral elevation during active motion or therapeutic exercises. Ekstrom et al assessed the EMG activity of the trapezius and serratus anterior muscles in 30 healthy subjects with the use of surface EMG during 10 exercises. The authors found that shoulder elevation while lying prone with the externally rotated shoulder positioned in line with the lower trapezius was the best exercise for the lower trapezius, eliciting 97% of maximum voluntary isometric contraction (MVIC). Prone lying shoulder external rotation and horizontal extension with the arm positioned at 90° of abduction was found to activate 79% MVIC and 74% MVIC respectively. Utilizing indwelling electrodes on 20 healthy subjects, Ballantyne et al determined that shoulder external rotation while lying prone with the arm positioned at 90° produced 40% MVIC of the lower trapezius. Mosely et al analyzed 16 exercises in nine subjects with the use of indwelling electrodes and concluded that five exercises qualified as optimal for recruiting the lower trapezius: shoulder abduction, rowing, shoulder flexion, shoulder horizontal abduction with external rotation, and shoulder horizontal abduction in neutral rotation. Peak muscle activity for these exercises occurred between 90° and 150° of shoulder elevation and ranged from 56%-68% of MVIC.

All of the exercises cited in the aforementioned studies require the shoulder to be positioned at or greater than 90° of elevation. Subsequently, these exercises may not be appropriate for patients in the initial stage of shoulder rehabilitation with subacromial impingement. Only two previous studies were identified that examined lower trapezius muscle activity during exercises performed while maintaining the shoulder below 90° of humeral elevation. Ekstrom et al found that shoulder abduction performed below 80° in the plane of the scapula activated 50±21% MVIC of the lower trapezius while prone unilateral rowing produced 45±17% MVIC. Lear and Gross utilized surface EMG on 16 healthy subjects performing three variations of a push-up: push-up with a plus, push-up with a plus and the feet elevated, and push-up with a plus with the feet elevated and hands placed on a trampoline. All three conditions elicited lower trapezius muscle activity of less than 40% MVIC. The purpose of this study was to identify exercises performed with the
shoulder below 90° that elicited marked levels of lower trapezius muscle activity using the standard established by McCann et al ( >50% MVIC).

METHODS
Subjects
Subjects for this study consisted of fifteen healthy volunteers (age = 31.7 ± 9.5; height = 1.8 ± .09 meters; 8 females and 7 males; weight = 76.2 ± 14.2 kg.). The ages of the subjects ranged from 18 to 38 years. The inclusion criteria were being at least 18 years of age and being able to communicate in English. Potential subjects were excluded from this study if they reported a recent history (less than one year) of a musculoskeletal injury, condition, or surgery involving either upper extremity or the cervical spine. Subjects were also excluded if they reported a prior history of a neuromuscular condition, pathology, or the presence of numbness or tingling in either upper extremity. The senior author performed the assessment for the inclusion and exclusion criteria through the use of a verbal questionnaire. This study was approved by the Lenox Hill Hospital Institutional Review Board and informed consent was obtained from all subjects prior to participation.

Testing Procedures
Silver/silver-chloride (Ag/AgCl) surface electrodes were placed bilaterally over the serratus anterior and the upper, middle, and lower trapezius muscles of each subject according to the method described by Basmajian and DeLuca and as outlined in Table 1. The skin was prepared prior to electrode placement by shaving hair (if necessary), abrasing the skin with fine sandpaper, and cleaning the site with isopropyl alcohol. A reference electrode was placed on the olecranon process of each subject.

An 8-channel Telemyo EMG system (Noraxon USA, Inc., Scottsdale, AZ) was used to acquire surface EMG data. The center to center interelectrode distance was 25 mm. The Telemyo system has a gain of 2000, a common mode rejection ratio (CMRR) of greater than 100 dB at 60 Hz, a bandwidth of 10 to 500 Hz, and a differential input impedance of >10 M. The Telemyo was interfaced with a personal computer via a 16 channel, 12 bit A/D card. Each subject performed one manually resisted sub-maximal voluntary isometric contraction of each muscle according to the methods outlined by Daniels and Worthingham in order to verify the quality of the tele-

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Electrode position</th>
<th>MVIC position</th>
<th>MVIC Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper trapezius</td>
<td>At the angle of the neck and shoulder, over the belly of the muscle in line with the muscle fibers.</td>
<td>Sitting with arms relaxed at sides</td>
<td>Resisted maximum shoulder elevation</td>
</tr>
<tr>
<td>Middle trapezius</td>
<td>Centered vertically between the medial border of the scapula and the spines of the thoracic vertebrae at the same level (T-1 to T-6)</td>
<td>Prone, shoulder abducted to 90° and lateral rotation, elbow flexed 90°</td>
<td>Resisted horizontal arm abduction</td>
</tr>
<tr>
<td>Lower trapezius</td>
<td>Placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process.</td>
<td>Prone, shoulder in 130° of abduction.</td>
<td>Resisted arm elevation</td>
</tr>
<tr>
<td>Serratus anterior</td>
<td>Placed vertically below the axilla, anterior to the latissimus, over the 4th-6th ribs</td>
<td>Supine, shoulder in 90° of flexion and elbow in extension</td>
<td>Resisted end range protraction</td>
</tr>
</tbody>
</table>

Table 1. Muscles tested, electrode position, and maximal voluntary contraction (MVIC) Protocol
metric signal and to ensure that each subject became familiar with the muscle testing procedures. Three manually resisted maximum voluntary isometric contractions (MVICs), each for duration of 3 seconds, were then performed for each muscle. Table 1 displays the electrode placement location, MVIC position, and MVIC action for each of the five muscles during the testing protocol.

Each subject then performed five repetitions of four selected isotonic therapeutic exercises as illustrated in Figures 1 to 4. The four exercises were as follows: 1) the press-up (Figure 1), 2) unilateral scapular retraction with the shoulder positioned at 80° of shoulder flexion (Figure 2), 3) bilateral shoulder external rotation (Figure 3), and 4) unilateral scapular depression (Figure 4). Exercises two through four were performed with the use of Theraband® (The Hygenic Corporation, Akron, Ohio) to provide resistance. The subjects began the exercises from a position in which the elastic resistance was just taut and permitted them to complete five repetitions with correct form. The level of resistance was adjusted based on the subject reporting a moderate level of effort to complete the five repetitions. All exercises were performed with a 4-second cadence as determined by the senior author (2 seconds for each concentric and eccentric phase). Each testing repetition was separated by a 5 second rest period.

All subjects became familiar with the exercises during a pretest session that took place just prior to the testing session. During this pretest session, each subject received instructions regarding proper execution of exercises. Each subject performed 3 to 5 practice repetitions of each exercise to ensure that they executed the exercises with correct biomechanics and rate of movement as determined by the senior author. The exercises were performed in random order to avoid bias from order effects.

Data Processing
The raw EMG data for all MVIC trials and exercise repetitions were full-wave rectified and processed using a root-mean-square algorithm with a 20-ms moving window. All data were low-pass filtered with a fourth order Butterworth filter with a 10Hz cut-off frequency. After processing, the maximum EMG activity recorded for each muscle during the MVICs was determined and used to normalize the trial data. The sampling rate was set at a 1000 Hz per channel. An average of the peak maximum activation values (% MVIC) for the middle three repetitions of each exercise was then calculated for each muscle. Muscle activity during each exercise was categorized according to the criteria proposed by McCann (2002): minimal (0% to 20% MVIC), moderate (21 to 50% MVIC), or marked (>50% MVIC).

Data Analysis
One-way repeated measures analysis of variance (ANOVA) was applied to the data to determine if significant differences existed in EMG activity between muscles for each
Bonferonni corrections were used for pair-wise comparisons between muscles.

**RESULTS**

**Electromyography Exercise Data**

The normalized EMG data, including mean and standard deviation, for each muscle during each exercise is displayed in Table 2. The distribution of the EMG activity for each exercise is shown by box-and-whisker plots in Figures 5 to 8. The EMG data for each muscle during each exercise was found to be normally distributed.

**DISCUSSION**

**Press-Up**

This exercise elicited marked EMG activity of the lower trapezius (56 ± 23% MVIC). Only one other study was identified which found exercises performed below 90° of humeral elevation that produced comparable levels of lower trapezius EMG activity. Ekstrom et al determined that shoulder abduction performed below 80° in the plane of the scapula elicited 50 ± 21% MVIC of the lower trapezius while prone unilateral rowing produced 45 ± 17% MVIC. Only moderate upper trapezius muscle activity (27 ± 32% MVIC) was found during the press-up exercise whereas Ekstrom et al reported marked upper trapezius activity during shoulder abduction below 80° (72 ± 19% MVIC) and during unilateral rowing (63 ± 17% MVIC). During the press-up, the muscle activity level of lower trapezius (56 ± 23% MVIC) was more than twice (2.07) the level of upper trapezius activity (27 ± 32% MVIC). In cases where excessive scapular elevation is observed, the press-up exercise may be beneficial in promoting scapular depression.

To date, only one prior study reported lower trapezius...
ius muscle activity during closed chain exercises performed with the shoulders below 90°. Lear and Gross reported that three variations of a push-up activated the lower trapezius to levels of less than 40% MVIC. Since standard deviations of EMG activity were not reported by Lear and Gross in this study, no comparisons can be made on the variability of muscle activity levels between the press-up exercise and the push-up exercises. A biomechanical explanation of the muscle activity recorded during the press-up exercise is that an inferior directed moment is imposed on the scapula from the body-weight of the subjects. The lower trapezius would, theoretically, function to prevent the scapula from being displaced superiorly. Since several authors have advocated the use of closed chain exercises for shoulder rehabilitation, the press-up exercise is an exercise that clinicians may use as a component of a scapular stabilization program.

**Scapular Retraction**
Scapular retraction produced marked activity of both the lower trapezius (51 ± 29% MVIC) and upper trapezius (62 ± 44% MVIC) while eliciting moderate activity of the middle trapezius (50 ± 36% MVIC). This exercise elicited lower trapezius %MVIC that was very similar to the exercise in the study by Ekstrom et al in which shoulder abduction in the plane of the scapula below 80° was performed (50 ± 21% MVIC). An important function of the scapula is retraction and protraction along the thoracic wall. The primary function of the upper and middle trapezius muscles are to pull the scapula posterior and medially during retraction. The lower trapezius has an important stabilizing and eccentric role against the laterally directed moment on the scapula created by the serratus anterior. Throwing athletes with posterior glenohumeral tightness may demonstrate excessive scapular protraction at follow-through, which is thought to decrease the subacromial space and increase risk for impingement. Therefore, the scapular retraction exercise may be more beneficial in cases where such excessive scapular protraction is evident as this exercise involves training the lower trapezius more specifically to promote mediolateral stabilization of the scapula.

**Bilateral Shoulder External Rotation**
This exercise elicited moderate levels (40 ±12% MVIC) and minimal levels of upper trapezius activity (17 ±18% MVIC). This exercise was expected to elicit greater lower trapezius activity in order to stabilize the scapula against the supero-lateral moments imposed on the
scapula by the external rotators. However, this exercise was the most effective in isolating the lower trapezius from the upper trapezius. The ratio of lower trapezius to upper trapezius muscle activity was the highest (2.35) of the four exercises studied. Subsequently, although this bilateral external rotation only elicited moderate lower trapezius activity, this exercise may be particularly useful in isolating the lower trapezius in cases where excessive scapular elevation is noted. A possible reason for the relatively low levels of upper trapezius muscle activity is that this bilateral external rotation was the only exercise that did not require humeral elevation and subsequent upward scapular rotation. A possible benefit is that exercise simultaneously trains the shoulder external rotators, which is a common aim in the rehabilitation of patients with shoulder pathology.

**Scapular Depression**

This exercise generated moderate muscle activity of the lower trapezius (21 ±16% MVIC) and a low ratio of lower trapezius to upper trapezius muscle activity (1.05). Subsequently, this exercise was determined to be the least successful of the four exercises in training the lower trapezius.

**Limitations**

Direct comparisons between previous studies and the present one is limited by methodological differences, including the types of electrodes utilized, the levels and types of resistance used, and the velocity of muscle contraction during exercises. The use of surface electrodes, as used in this study, are more susceptible to cross talk than fine wire electrodes, yet are more reliable and less invasive.

Because this protocol was chosen to represent low load exercises, such as used in postoperative or post-injury patients, moderate resistance levels were utilized. Conversely, in the study by Ekstrom et al exercises were performed at a high level of intensity (85%-90% of maximum lifting capacity). The study involved a mixture of three open chain and one closed chain exercise. For the open chain exercises, a subjectively defined level of moderate resistance was used. The closed chain exercise (press-up) involved the subject raising the body against gravity and subsequently the level of resistance could not be adjusted. The resistance level of this exercise was relatively moderate as subjects felt they could perform several more repetitions of this exercise. However, the lack of standardized resistance levels used in our study limits direct comparison between exercises within this study and to exercises in previous studies. In addition, the mode of resistance differed in our study as compared to previous studies. Three of the four exercises in this study were performed with the use of elastic resistance. Previous studies primarily utilized free weights as the mode of resistance.

Another limiting factor that was not totally controlled for was the rate at which each exercise was performed. Although exercises were performed deliberately at a slow cadence of approximately four seconds, a purely objective method to control for the rate at which exercises were performed was not used. Previous research indicates that the relationship between EMG activity and muscle force can be affected by velocity of muscle contraction. Sugamoto et al determined that scapulohumeral rhythm during shoulder motion is constant at slow speeds and variable at high speeds. Despite the limitations with respect to the level and rate of resistance, the variability of our data is consistent with previous EMG studies.

Future studies are recommended which analyze lower trapezius muscle exercises while objectively controlling for resistance level and rate of movement. In addition, further research on lower trapezius muscle activity dur-
ing exercises in patients with shoulder pathology is encouraged. The majority of the subjects in this study were young, active individuals who exercised on a regular basis. Since these exercises may be more challenging to perform for older, less active or fit individuals, or patients with shoulder pathologies, generalizing the results of this study to those populations should be taken with caution.

CONCLUSIONS
The results of this study suggest that the lower trapezius muscle is markedly activated by the press-up and scapular retraction exercises. The press-up exercise preferentially recruited the lower trapezius muscle over the middle and upper trapezius muscles, but not the serratus anterior muscle. Scapular retraction elicited marked activity of the lower and upper trapezius, however, this was not significantly greater than middle trapezius activity. Serratus anterior muscle activity was significantly less than the upper, middle, and lower trapezius muscles during scapular retraction. Bilateral shoulder external rotation and scapular depression failed to produce marked muscle activity of the lower trapezius muscle.

REFERENCES


ABSTRACT

Background. The increasingly popular sport of rock climbing is an activity which predisposes participants to overuse injuries. The unique physical demands associated with climbing, as well as a reported 33%-51% incidence of shoulder injuries in these athletes is suggestive of abnormalities in scapulohumeral biomechanics.

Objective. To examine the glenohumeral to scapulothoracic (GH:ST) ratio, as represented by end range static positions (ERSP) of the scapula and humerus, in a group of rock climbers and compare it to a group of non-climbers.

Methods. The GH:ST ratio of twenty-one experienced rock climbers was compared with 40 non-climbers using a bubble inclinometer to measure scapular upward rotation at the subjects' maximum glenohumeral elevation.

Results. As represented by ERSP, rock climbers had a significantly greater GH:ST ratio than non-climbers. The mean ratio of climbers was 3.7:1 compared with non-climbers at 2.8:1. Scapulothoracic motion appeared to be the source of this difference.

Discussion and Conclusion. A possible explanation for this difference could be related to the extreme and prolonged positioning associated with rock climbing maneuvers that result in shoulder musculature imbalances in strength and flexibility.

Key Words: rock climbing, shoulder injuries, scapulohumeral dyskinesis

CORRESPONDENCE:
Aimee Roseborrough
780 Hattie Greene
Flagstaff, AZ 86001
eMail: aimeel_3@hotmail.com

ACKNOWLEDGEMENTS:
Kyle Roseborrough and Chris Bickford for statistical help.
INTRODUCTION
Due to a lack of stability with respect to bony articulations, the shoulder complex is highly dependent upon soft tissue relationships to maintain joint congruency. The interactions of these muscular, ligamentous, and capsular structures lead to coordinated movements between the glenohumeral (GH) and scapulothoracic (ST) articulations, known as scapulohumeral rhythm. While, this value varies greatly throughout the literature, normal scapulohumeral rhythm is approximately 2:1 overall, with the scapula elevating 1 degree for every 2 degrees of corresponding humeral movement. Significant deviations from standard ratios, often referred to as abnormal scapulohumeral rhythm, are frequently cited as a predisposition to shoulder impingement and injuries. A possible etiology of abnormal scapulohumeral rhythm is the presence of imbalances in shoulder girdle musculature strength and length. For efficient upward rotation of the scapula, the serratus anterior and lower trapezius must be strong and at their optimum length-tension relationship. Also, the pectoralis minor must be sufficiently flexible otherwise passive insufficiency may occur, restricting full upward rotation of the scapula. When considering how these biomechanical interactions allow normal movement of the shoulder complex, it is possible to envision how impairments affecting any part of this system may result in pathology.

Sports involving sustained overhead and end range movements and extreme positioning, such as rock climbing, place intense demands on the soft tissues surrounding the glenohumeral joint. These circumstances have the potential to result in imbalances in muscle performance and soft tissue length and is a primary reason shoulder injuries are common among rock climbers. Rooks reported a 33% incidence of rotator cuff tendonitis or impingement in a group of recreational rock climbers. This high incidence of reported shoulder injuries among rock climbers, the relationship between participation in this sport and scapular mechanics has not been investigated. It is the opinion of the investigators that rock climbers possess a significantly different glenohumeral:scapulothoracic (GH:ST) ratio in comparison to those not participating in the sport.

Despite the high incidence of reported shoulder injuries among rock climbers, the relationship between participation in this sport and scapular mechanics has not been investigated. It is the opinion of the investigators that rock climbers possess a significantly different glenohumeral:scapulothoracic (GH:ST) ratio in comparison to those not participating in the sport.

Since this GH:ST ratio is a function of the available glenohumeral and scapular motion during upper extremity elevation, the ranges through which these segments move to achieve their end range positions may be compared to produce a representation of the GH:ST ratio. For the purpose of this investigation, the term ERSP (End Range Static Position) is used to represent the degrees of active movement in the scapulothoracic or glenohumeral joints at maximum shoulder elevation. The ERSP measures of the humerus and scapula are then used to calculate an “end range” representation of the GH:ST ratio. Considering these principles, it was the purpose of this study to analyze and compare GH:ST ratios, as represented by ERSP’s of the scapula and humerus, in climbing and non-climbing individuals.

METHODS
Subjects
A convenience sample of 21 rock climbers volunteered for the study at a rock climbing trade show and competition near Phoenix, Arizona. The group included 17 males and 4 females, with a mean age of 25.8 years (SD = 6.8) and a mean of 8.4 (SD = 7.2) years of rock-climbing experience. Forty non-climbing (11 male, 29 female, mean age = 25.7 years old, SD = 4.7 years) physical therapy students at Northern Arizona University served as the
comparison group. Exclusion criteria for the non-climbers included a history of shoulder macro-trauma and rock climbing experience of greater than 1 year. Approval for the study was obtained from the Institutional Review Board at Northern Arizona University. All subjects were informed of the nature and details of the study and signed an informed consent form before participation. A power analysis confirmed that the sample was appropriate for detecting differences and minimizing statistical error.

Equipment

A Baseline® bubble inclinometer was used to assess ERSP associated with scapular upward rotation and glenohumeral elevation. This fluid filled instrument was calibrated on the basis of its position in space against gravity. This approach allows for fixation of the starting position of the inclinometer and minimizes the placement error. The use of such measurement devices is well described in the literature. Similar fluid filled inclinometers have been shown to have “acceptable” intra-rater reliability in measuring glenohumeral joint motion. Johnson et al. established “good to excellent” intra-rater reliability (ICC = 0.89 – 0.96; 95% CI) using an inclinometer with a digital readout to measure scapular upward rotation.

The measurement protocol utilized in this study was based on the method of assessing scapular upward rotation described by Johnson et al. To measure glenohumeral elevation, a vertical guide pole was secured to a plinth. Standing position for subjects was standardized by lines marked on the floor. This position was established so that when the subject elevated his or her arm, their arm would be raised in the scapular plane (40 degrees anterior to the frontal plane) while maintaining contact with the guide pole. Subjects were instructed to keep their elbow straight and thumb pointing upward during elevation. The bubble inclinometer was aligned over the mid-shaft of the humerus while the subject elevated their arm as far as possible. At end range, maximum glenohumeral motion was recorded. Motion in the right upper extremity of all subjects was measured regardless of hand dominance.

Subjects then rested while the root of the right scapular spine was identified and marked in preparation for measuring upward rotation of the scapula. The left edge of the bubble inclinometer was placed on this mark and another mark was placed where the right edge of the inclinometer rested on the scapula (Figure 1). These marks ensured that the bubble inclinometer rested on the same location on the scapula in repeated measures. The subject then returned to their maximum GH elevation and the angle of upward rotation of the scapula, as measured by the inclinometer, was recorded. The investigator recorded both measures three times for each subject. These measurements were performed in both the climber group and the comparison group of non-climbers.

Prior to data collection, the investigators assessed measurement consistency of the bubble inclinometer using the procedures just described. Intratester reliability for the measurement of glenohumeral elevation and scapular upward rotation was examined using a test-retest design on 40 subjects. The intraclass correlation coefficient (ICC-2,1) was 0.88 for glenohumeral elevation and 0.89 for scapular upward rotation.

Data Analysis

Mean scores derived from the three range of motion measurements at maximum glenohumeral elevation and scapular upward rotation were used for calculation of the end range GH:ST ratio. An independent, two-tailed t-test was used to compare the ratios, maximum glenohumeral range of motion, and maximum scapular upward rotation of the rock climbers and the non-climbing population. Using a Bonferroni correction due to the use of three separate tests, significance was set at p < .017.

RESULTS

As presented in Table 1, the end range GH:ST ratio of the rock climber group
was greater than that of the non-climber comparison group (2.8:1; SD = 0.62). Also, rock climbers demonstrated greater glenohumeral range of motion (160.0 degrees; SD = 8.7) in comparison to non-rock climbers (154.4 degrees; SD = 9.2), while demonstrating less scapular upward rotation (35.3 degrees; SD = 7.5) than non-climbers (41.1 degrees; SD = 6.7). The end range GH:ST ratio (t = 4.7, p < 0.017) and scapular upward rotation values (t = 3.8, p < 0.017) were found to be significantly different via a two-tailed, independent t-test. The maximum glenohumeral range of motion was not found to be significantly different between rock climbers and the non-climbing population (t = 2.2, p > 0.017).

The means for glenohumeral range appear to be lower than expected norms, due to the manner in which the inclinometer records motion. Prior to measurement, the instrument is set at zero with the subject’s arm at his or her side. In this position, the humerus is situated approximately 10–20 degrees away from the vertical axis. Therefore, the end range measures in these subjects are reflective of movement of the humerus through the available range rather than its resulting angle from the vertical as is the case in traditional goniometry. Considering this measurement technique, it is concluded that these subjects were within normative values for humeral elevation.

**DISCUSSION**

The group of rock climbers participating in this study were found to have a higher end range GH:ST ratio than the studied control population. A higher end range ratio may result from decreased upward rotation of the scapula, excess humeral elevation, or a combination of both events during overhead movements. In this group of climbers, the data demonstrate the greatest differences with respect to scapular upward rotation, with the climbers having significantly less mobility in this plane. One etiology of decreased upward scapular rotation is the presence of imbalances in shoulder girdle musculature strength and length. For efficient upward rotation of the scapula, the serratus anterior and lower trapezius must be strong and at their optimum length-tension relationship. Also, pectoralis minor must be sufficiently flexible otherwise passive insufficiency may occur, restricting full upward scapular movement.

The authors offer the following hypotheses for altered scapular mechanics in the climber group. Decreased upward rotation of the scapula in rock climbers may occur due to muscle imbalances in strength and flexibility secondary to the intense tissue stresses associated with frequent participation in this sport. As stated by Rooks, rock climbers are “chronically gripping and pulling without stretching the tight muscles or exercising the antagonist muscles” which often leads to overdevelopment and contractures of the pectoral muscles. Tightness in these muscles may inhibit the scapular upward rotators from fully rotating the scapula. Furthermore, strength is developed in a position of scapular protraction (Figure 2), where the pectoral muscles are in a shortened position. This scenario enhances the potential for adaptive shortening of the pectoralis minor, which as previously discussed may result in abnormal scapulothoracic rhythm by not allowing full upward rotation of the scapula. Borstad and Ludewig confirmed this idea by demonstrating that shortening of the pectoralis minor leads to increased downward rotation of the scapula and, therefore, impingement.

The roles of the lower trapezius and serratus anterior muscles during rock climbing are also worthy of discussion. While these muscles may be active during rock climbing maneuvers, the extent to which the muscles are trained is likely within limited ranges and static positions. Bourdin et al demonstrated that under highly challenging circumstances, climbers tended to increase the velocity of upper extremity movements and decrease the “free motion” portion of reaching maneuvers. Therefore, movements through a range were minimized in an attempt to re-establish stability, supporting the idea that
the majority of upper limb muscle activity during climbing occurs in static fashion.

Because impairment of the lower trapezius is common in many overhead athletes,\textsuperscript{19,20} it is logical to suspect that rock climbers may have a similar problem. Intuitively, it might seem that having one's arms positioned overhead for prolonged periods of time would increase strength in the lower trapezius. However, climbers typically support their body weight through the limbs, using the bony articulations and ligaments of the upper extremity in order to rest the muscles (Figure 3).

In this resting position, the passive restraints of the upper extremity are supporting the rock climber, rather than the contractile tissues. Thus when active, the lower trapezius functions primarily in an isometric fashion, rather than as contractile tissue which facilitates coordinated scapular movement. This concept is supported by Watts\textsuperscript{21} stating that "rock climbing is characterized by repeated bouts of isometric contractions."

The constant need for postural stability and associated isometric muscle demands also suggest that the serratus anterior is not trained in a manner which facilitates upward rotation. During climbing maneuvers, the emphasis appears to be on shoulder protraction rather than elevation. Therefore, the degree to which the serratus anterior actively functions as a scapular upward rotator during this activity is questionable. It may be argued that the recruitment of serratus motor units and, thus, the training effect in climbers may occur in a manner which overemphasizes protraction and minimizes facilitation of upward scapular rotation. Therefore, with respect to both of the lower trapezius and serratus anterior muscles, the lack of dynamic contractions elicited may lead one to conclude that when strengthening and motor learning do occur, it is specific to static and isometric positions rather than throughout the available range of motion.\textsuperscript{21}

If valid, these hypotheses support the argument for relative weakness and inefficient function of scapular rotators in these individuals. This occurrence, combined with overtraining of anterior groups may result in inefficient force coupling during humeral elevation.\textsuperscript{22} The resulting imbalances and decrease in upward scapular rotation have the potential to further increase the risk for impingement syndrome in frequent rock climbers who, as a group, already demonstrate a high incidence of shoulder injuries.\textsuperscript{6} Additional research is necessary, however, to substantiate these conclusions and identify actual mechanisms of altered scapular mechanics in rock climbers.

The potential for altered scapular mechanics and shoulder injury in rock climbers is relevant to clinicians due to the nature and increasing popularity of the sport.\textsuperscript{6,8} Over the past two decades, indoor rock climbing gyms have proliferated and equipment technology has advanced, allowing the activity to be accessible to almost anyone. Sheel\textsuperscript{7} estimated there to be approximately 300,000 rock climbers in the U.S. Furthermore, many of these individuals increase their risk for injury by overtraining. While strenuous workouts require as much as 48 hours of recovery,\textsuperscript{6} rock climbers frequently travel for the sole purpose of climbing during which they engage in high intensity activity for multiple days to weeks at a time. Indoor climbing gyms also promote overtraining by allowing climbers to conveniently participate in their sport and permitting multiple bouts of climbing in short periods of time. These types of extended activities may overfatigue rotator cuff and scapular
musculature, inhibit their actions during sustained, overhead maneuvers and be further reason these athletes are susceptible to impingement syndromes.

Limitations
The homogeneity and size of the samples is a limitation to the study. The non-climbing group consisted of healthy, young adults of mixed sex, while the majority of the rock climbing population were male, young adults. The non-climbing group also demonstrated a higher ratio (2.8:1) than what is considered “normal” (2:1).

Other limitations concern the measurement approach and consideration that the study only addressed the upward rotation aspect of scapular motion. Since scapular motion occurs in three planes, it would be useful to examine motion within the two planes not addressed in this study.

CONCLUSIONS
This investigation suggests that the sample of rock climbers had a significantly higher GH:ST ratio as represented by ERSP than the studied non-climbing population. The stresses associated with rock climbing may have the potential to create such a change. While future research is necessary to substantiate these ideas, knowledge of such potential differences may be of value to clinicians who are likely to be involved with the evaluation and treatment of individuals participating in this sport due to its recent rise in popularity.

REFERENCES


ABSTRACT

Ankle sprains are among the most common injuries incurred by participants in athletics. Conservative management of the patient after an ankle sprain includes a comprehensive rehabilitation program of which the resistance exercises are a part and are frequently advised by the clinician, many times as part of a home exercise program. The purpose of this Clinical Suggestion is to present a unique method of using elastic resistance band to provide strengthening activities to the inverters, evertors, plantarflexors, and dorsiflexors of the ankle. The method is unique, as well as convenient and efficient, as it allows the subject to perform all four exercises with a minimum of change in position, while staying seated in a chair.

Key Words: ankle, sprain, resistance training

CORRESPONDENCE:
James P. Fletcher PT, MS, ATC
Department of Physical Therapy
University of Central Arkansas
201 Donaghey Ave
Conway, AR 72035
eMail: fletcher@uca.edu

CLINICAL SUGGESTION

UNIQUE POSITIONING FOR USING ELASTIC RESISTANCE BAND IN PROVIDING STRENGTHENING EXERCISE TO THE MUSCLES SURROUNDING THE ANKLE

James P. Fletcher, PT, MS, ATC
William D. Bandy, PT, PhD, SCS, ATC

* University of Central Arkansas
Department of Physical Therapy
PROBLEM
Ankle sprains are among the most common injuries among athletes, frequently leading to impairment in joint stability, proprioception, and muscle strength. \cite{1,2} Conservative management of ankle sprains includes cryotherapy, \cite{3} bracing, \cite{4} taping, \cite{5} elastic bandaging, \cite{6} mobilization, \cite{7,8} balance/proprioception training, \cite{9,10} and resistance exercises. \cite{2,4,13} As part of different case studies, Kern-Steiner et al \cite{11} and Glasoe et al \cite{2} reported the use resistance exercises as part of their treatment regime in the successful treatment of two patients with ankle sprains. Although stating that ankle resistance training was incorporated, the authors did not provide specifics as to the techniques used for these strengthening activities.

Docherty et al \cite{13} examined the effects of six weeks of ankle resistance exercises on strength and joint position sense in 20 subjects with “functionally unstable ankles” using elastic bands “attached to a table.” The authors concluded that training using elastic bands increased isometric strength of the muscles around the ankle, as well as increasing joint position sense in the ankle.

Given that evidence exists that resistance training is an important component to a comprehensive rehabilitation program for the individual following an ankle sprain, it is incumbent upon the physical therapist to introduce this activity to his/her patient in the clinic, as well as in a home exercise program. To that end, a unique method of using elastic resistance band to provide resistance training to the inverters, evertors, plantarflexors, and dorsiflexors of the ankle is proposed.

SOLUTION
In undertaking the strengthening portion of the rehabilitation program for a patient following an ankle sprain, it is imperative for the therapist to implement a home exercise program using resistance activities that are not only kinesiologically sound, but are also convenient for the patient to perform in terms of the type of resistance and positioning of the patient. A simple strengthening program using an elastic resistance band, with all exercises performed while sitting in a chair, has been found to meet such demands. Additionally, these techniques are potentially an improvement upon other common methods of using elastic band for strengthening the low leg muscles in that they establish an appropriate angle of resistance without the patient having to tie the band to an immovable object or hold the elastic band with his/her hand(s); the exception being the plantarflexion exercise. These exercise techniques are best suited for a population of individuals who have at least functional levels of strength and joint range of motion in both upper and lower extremities for positioning/holding the involved extremity or the elastic band. The intent is that these exercises are for the early stages of rehabilitation and that more functional strength and neuromuscular training is required in the later stages of the rehabilitation program after an ankle injury.

The challenges presented by the use of elastic band as a form of resistance for strengthening activities have been expounded upon in the literature.\cite{4} Using his/her knowledge, clinical expertise, and the available research evidence, the physical therapist should first determine the level of elastic band resistance, meaning color and length, appropriate for the patient's needs and goals. For each exercise technique, the band should be tied in a loop and the patient should sit on a stationary chair, specifically on the front half of the seat. The patient should be wearing sneakers (if possible) and the band should be placed around each foot in the midfoot-forefoot region and both feet placed on the floor.

The technique to strengthen the muscles of eversion is performed with the uninvolved foot firmly and flatly on the floor to stabilize the band on one end. On the involved side, the patient extends the knee enough to rest that foot on the floor only by contact of the heel. The band should be wrapped around the lateral portion of the forefoot, specifically in the region of the fifth metatarsal, on the involved ankle-foot. Given that the distance between the feet will impact the amount of tension/resistance generated by the elastic band, the band should be stretched enough initially so that the ankle-foot, at rest, is pulled into a starting position of full inversion. The patient then forcefully (concentrically) everts the ankle-foot through full range of motion (pivoting on the heel) against the resistance of the band, with the other foot continuing to anchor the other end of the band. No femoral or tibial rotation or abduction-adduction movement of the hip should be allowed during the eversion; the thigh and low leg should remain stable. The patient then slowly returns (eccentrically) to the starting position; this completes one repetition. (Figure 1)

The technique to strengthen the muscles of dorsiflexion is performed with the uninvolved foot still firmly and flatly on the floor to stabilize the band on one end. To position the involved side, the patient flexes, adducts, and externally rotates the hip so that the leg is snugly crossed over the uninvolved leg; a so called “crossing the legs at the
knees’ positioning that is commonly observed in a person’s sitting posture. The elastic band is wrapped over the entire dorsal aspect of the forefoot on the involved side. The band should be stretched enough initially so that the ankle-foot, at rest, is pulled into a starting position of full plantarflexion. This position is achieved by the patient grasping the involved leg at the knee with two hands and reclining back onto the chairback, thus pulling the involved hip into flexion and positioning the involved ankle-foot further from the floor. At this point, subtle adjustments in the positioning/alignment of the feet can be made so that the line of resistance is optimal, such as to resist a pure dorsiflexion movement. The patient can now forcefully (concentrically) dorsiflex the ankle-foot through full range of motion against the resistance of the band, with the uninvolved foot on the floor anchoring the other end of the band. The thigh and low leg should remain stable during the dorsiflexion. The patient then slowly returns (eccentrically) to the starting position; this completes one repetition. (Figure 2)

The technique to strengthen the muscles of inversion is performed with the uninvolved foot still firmly and flatly on the floor to stabilize the band on one end. To position the involved side, the patient flexes, abducts, and externally rotates the hip so that the distal low leg of the involved side is crossed over and resting on the distal thigh of the uninvolved leg; yet another positioning of the lower extremities that is commonly observed in a person’s sitting posture. The elastic band is wrapped over the medial side of the forefoot, specifically in the region from the navicular to the head of the 1st metatarsal, on the involved ankle-foot. The band should be stretched enough initially so that the ankle-foot, at rest, is pulled into a starting position of full eversion. This position is achieved by the patient pressing on the involved leg at the knee to place and maintain the hip in full external rotation, thus positioning the involved ankle-foot further from the floor. At this point, subtle adjustments in the positioning/alignment of the feet can be made so that the line of resistance is optimal, such as to resist a pure inversion movement or perhaps to even incorporate resistance against an inversion and dorsiflexion combined motion. Once positioning is complete, the patient can now forcefully (concentrically) invert the ankle-foot through full range of motion against the resistance of the band, with the other foot continuing to anchor the other end of the band. The thigh and low leg should remain stable during the inversion. The patient then slowly returns (eccentrically) to the starting position; this completes one repetition. (Figure 3)

The technique to strengthen the muscles of plantarflexion is not unlike traditional methods already in use clinically. The patient holds the elastic band on one end with his/her hands and places the other end around the plantar surface of the forefoot on the involved side. The band should be stretched enough initially so that the ankle-foot, at rest, is pulled into a starting position of full dorsiflexion. The patient forcefully (concentrically) plantarflexes the ankle-foot through full range of motion against the resistance of the band. The thigh and low leg should remain stable during the plantarflexion. The patient then slowly returns (eccentrically) to the starting position; this completes one repetition. For this exercise, the knee of the involved side can be placed in a fully extended position to exercise the gastrocnemius and soleus muscles together (Figure 4) or flexed to exercise just the soleus muscle. (Figure 5)

**DISCUSSION**

As indicated, this exercise program for strengthening the muscles of the ankle can easily be independently performed by the patient, with minimal changes in position while sitting in a chair.
should be emphasized that strengthening the muscles around the ankle is but one component of the rehabilitation of a patient after an ankle injury. In addition, all four of the exercises listed in this Clinical Suggestion do not have to be used. The clinician may choose to have the patient only use a subset of the exercises dependent on the needs of the patient.
ORIGINAL RESEARCH

THE EFFECTS OF REPETITIVE OVERHEAD THROWING ON SHOULDER ROTATOR ISOKINETIC WORK-FATIGUE.

Dale RB\textsuperscript{a}
Kovaleski JE\textsuperscript{a}
Ogletree T\textsuperscript{b}
Heitman RJ\textsuperscript{a}
Norrell PM\textsuperscript{a}

ABSTRACT

\textit{Background.} Muscle strength and endurance of the shoulder rotators is important for overhead throwing performance and dynamic glenohumeral stability. Baseball pitching is distinguished as an intermittent activity with explosive, high intensity muscle contractions separated by periods of rest. Rotator cuff muscle performance could acutely decrease due to fatigue associated with bouts of throwing.

\textit{Objective.} This study examined the effects of repeated overhead throwing upon isokinetic muscle performance of the shoulder rotators.

\textit{Methods.} Repeated-measures analyses of variance were used to compare peak torque, total work, and work-fatigue by muscle group, time, and contraction type. Ten collegiate baseball pitchers underwent isokinetic testing of the internal (IR) and external shoulder (ER) rotators one week before and immediately after a throwing protocol of 60 maximal-effort pitches arranged into four innings of 15 pitches per inning. Isokinetic testing consisted of 12 concentric and eccentric repetitions at 300 deg/sec for internal and external rotation of the throwing extremity.

\textit{Results.} The main effect of time and the interaction of muscle group and contraction type were significant for work-fatigue. Post-hoc analysis revealed that subjects had significantly greater eccentric IR work-fatigue (13.3 ± 1%) compared to the pre-test (7.3 ± 2%).

\textit{Discussion and Conclusion.} Throwing-related fatigue affected both muscle groups, especially the IR, which has implications for dynamic glenohumeral stability. Rehabilitation and conditioning programs for competitive baseball pitchers should emphasize eccentric muscle endurance training of the shoulder rotators.

\textit{Key Terms:} shoulder, baseball pitching, rotator cuff

CORRESPONDENCE:
R. Barry Dale, PT, PhD, SCS, ATC
Assistant Professor
Department of Physical Therapy
University of South Alabama
1504 Springhill Avenue, Room 1214
Mobile, AL 36604
bdale@usouthal.edu

\textsuperscript{a} University of South Alabama, Mobile, AL
\textsuperscript{b} Thomas Hospital, Fairhope, AL
INTRODUCTION

Overhead throwing performance requires an intricate balance between the static and dynamic structures of the shoulder in order to maintain functional stability. Such integration requires muscular strength and endurance, flexibility, and neuromuscular control. If any one of these factors is compromised, functional instability results, performance diminishes, and shoulder injuries are more likely to occur.

Previous studies have investigated the influence of extended pitching primarily on kinetic and kinematic parameters of the pitching motion. Limited information exists on the effects of throwing on shoulder muscle strength and fatigue. Mullaney et al. examined the isometric muscle strength of various shoulder muscle groups after pitching multiple innings and indicated that upper extremity isometric muscle fatigue occurs in some shoulder and scapular muscles but not in the supraspinatus and external rotators. Since the supraspinatus and external rotators predominantly function dynamically during throwing, isometric assessment may not have been the appropriate testing mode for evaluating supraspinatus and external rotation muscle function following a pitching performance.

Results from a study by Nocera et al. assessing shoulder strength of the external and internal rotators following throwing showed no significant decline when measured as a one repetition maximum (1RM) or as isokinetic peak torque. In addition, Mullaney and McHugh assessed isokinetic strength and reported that the shoulder rotators fatigue similarly during concentric and eccentric muscle actions. Despite these recent findings, no published information exists on the occurrence of shoulder rotator fatigue that is based on isokinetic work and described as a work-fatigue index. No documentation exists of muscle-specific fatigue within the shoulder internal and external rotators before or after repetitive overhead throwing. The hypothesis to be tested is that shoulder internal and external rotation musculature could experience work-fatigue as a result of throwing which might have implications for controlling dynamic glenohumeral stability, especially if muscle-specific fatigue exists. Therefore, the purpose of this study was to determine the effects of repeated overhead throwing on shoulder internal and external rotator isokinetic muscle fatigue following a pitching performance.

METHODS

Subjects
Ten male collegiate baseball pitchers (20.3 + 0.5 yr; 1.85 + 0.2 m; 88.1 + 2.8 kg) without injury to either shoulder volunteered to participate. Nine pitchers were right-hand dominant and one was left-hand dominant. Subjects averaged 10.1 + 0.9 years of pitching experience, dating back to youth league baseball. The Institutional Review Board of the University of South Alabama approved the study and all subjects gave informed consent to participate.

Instrumentation

Isokinetic testing of the shoulder rotator muscles was conducted using a Biodex System 3 (Biodex Corporation, Shirley, NY). Subjects were seated during the test with appropriate stabilization provided by a lap belt, crisscrossed chest straps, and footrest in accordance with the Biodex Isokinetic Dynamometer manual. The chair of the Biodex and the dynamometer attachment were individually adjusted to each subject to ensure proper fit and alignment and these settings were recorded from the numerical scale on the machine and attachment. A Velcro® strap was used to secure the forearm in the dynamometer attachment cradle. The upper extremity was positioned in shoulder abduction at 90° of elbow flexion and shoulder rotation was performed from 90° external rotation to 60° internal rotation, for a total range of motion of 150°. Gravity compensation was performed prior to each test.

Procedures

Subjects participated in two isokinetic tests (pre and post-throwing) and one pitching session. All testing was preceded by an orientation session in which the isokinetic testing and throwing protocols were explained and each subject performed isokinetic exercise to become familiar with the testing protocol.

Seven days before performing the throwing protocol, subjects participated in isokinetic testing of the shoulder internal rotators (IR) and external rotators (ER) by performing 12 concentric and eccentric contractions at 300 deg/sec. Subjects were given detailed verbal instruction of procedures and performed five warm-up
repetitions prior to each test. For the IR and ER muscle groups, concentric contractions were tested initially, a 3-minute rest provided, and then the eccentric testing was performed. Each muscle group worked for approximately six seconds during the 12 repetition set. With 180 seconds to recover, this provided a work:rest ratio of 1:30. Since each muscle group only worked for approximately six seconds, intramuscular ATP should have been adequately regenerated. Stone and Connelly showed that complete ATP-phosphocreatine resynthesis occurs with a work:rest ratio of at least 1:12. Subjects were verbally encouraged to maximally move the extremity “as hard and as fast as possible” during concentric testing and to “resist or fight” the movement of the dynamometer attachment with eccentric testing. Subjects were not allowed visual feedback during testing.

Subjects returned one week after performing the pre-throwing isokinetic test and participated in the throwing session. All subjects stretched and warmed-up prior to pitching. Subjects threw from a standard pitching mound located in an outdoor bullpen, which was elevated 0.254 meters above the level of home plate. Throws were made to a catcher located behind home plate at a distance of 18.4 meters from the pitching mound and threw a baseball that weighed 0.14 kilograms. Maximum throwing speed was measured using a Jugs Radar Model 620-c Gun (Decatur Electronics; Decatur, IL) and calibrated with a tuning fork prior to all throwing sessions.

Each subject threw 60 maximal-effort pitches (all fastballs) arranged into four innings of 15 pitches per inning. Five pitches were thrown as a warm-up at the beginning of each inning at a self-selected intensity (straight fastballs only). The pitch rate was standardized by throwing every 15 seconds, which yielded a total of five minutes of throwing per half inning. Following the completion of 20 pitches (5 warm-up and 15 maximal throws), the subject rested in a seated position for five minutes before throwing another inning. Thus, the throwing protocol consisted of 20 minutes of pitching and 20 minutes of seated rest. One author monitored the pitches thrown, rest between innings, and recorded pitch velocities.

Subjects performed the second isokinetic test immediately following the completion of the throwing session. The procedures used were identical to those of the pre-throwing test.

**Data Analysis**

The work-fatigue index (means + SEM) was recorded for concentric and eccentric IR and ER. Work-fatigue is the difference between the first one-third (first four repetitions of the 12) and last one-third (last four repetitions) of the work (Nm/kg) performed in a given set, which is then divided by the work in the first one-third of the set and multiplied by 100. This index measures the amount of fatigue from the beginning to the end of an endurance test bout, with a larger work-fatigue index value indicating greater fatigue.

Reliability of the work-fatigue index was previously determined using ten additional healthy male subjects. Each subject performed 12 repetitions for concentric and eccentric ER and IR at 300 deg/sec, which was repeated one week later. Intra-class coefficients (ICC) ranged from 0.66 to 0.81. The ICC data were as follows: concentric ER = 0.69 (95% CI = 0.60-0.74); concentric IR = 0.81 (95% CI = 0.73-0.89); eccentric ER = 0.66 (95% CI = 0.59-0.72); and eccentric IR = 0.79 (95% CI = 0.73-0.84). These ICCs are considered to be “moderate” in strength, as ICC values of 0.75 or greater generally indicate high reliability.

Concentric and eccentric peak torques and total work were normalized to body mass (Nm/kg). These data were analyzed for descriptive purposes and to document shoulder rotator strength across the pre- and post-test trials.

Data were analyzed with repeated measures analysis of variance (ANOVA) using within-subjects factors of muscle group (ER and IR), muscle action (concentric and eccentric), and time (pre-throwing and post-throwing). Post hoc analyses consisted of paired t-tests corrected for alpha inflation by the Bonferroni procedure. Additionally, to provide an indication of whether work-fatigue was indeed a meaningful measure of fatigue, a one-sample t-test was used to compare the work-fatigue index to a baseline value of zero that represented zero percent fatigue.

All statistical analyses set the alpha level at 0.05. Power was set to be 80% Apriori. Using ten subjects it was determined that a 12% difference in percent fatigue could be detected from pre-test to post-test assuming that the within subject variability was similar to values previously reported.
RESULTS
The average pitched ball velocity was $36.7 \pm 1.2 \text{ m/s} \ (82.1 \pm 2.7 \text{ mph})$. The average ball velocity in the first inning was $36.87 \pm 0.6 \text{ m/s} \ (82.5 \pm 1.3 \text{ mph})$, which was not statistically different ($p = 0.12$) from the ball velocity in the final inning ($36.43 \pm 0.4 \text{ m/s} \ or \ 81.5 \pm 0.9 \text{ mph}$). The mean time from the last ball thrown to commencement of the isokinetic post-test was $12.0 \pm 0.8$ minutes.

Isokinetic Work-Fatigue Index
The main effect of time was significant ($p < 0.01$) for work-fatigue across muscle groups and muscle actions, with greater work-fatigue observed in the post-test ($15.5 \pm 1\%$) when compared to the pre-test ($7.6 \pm 2\%$). Post-hoc analysis ($p < 0.01$) showed greater eccentric IR work-fatigue following the throwing bout ($13.3 \pm 1\%$) when compared to the pretest ($7.3 \pm 2\%$). No significant main effects for work-fatigue were found for muscle group ($p = 0.07$) or muscle action ($p = 0.14$) (Table 1).

The work-fatigue interaction for muscle group and muscle action was significant ($p < 0.02$). Post-hoc tests ($p < 0.01$) indicated greater eccentric work-fatigue ($13.8 \pm 2\%$) of the ER compared to the IR ($7.3 \pm 2\%$) for the pretest only.

For the pretest trial, only the eccentric ER work-fatigue index was significantly greater ($p < 0.001$) from the zero-fatigue baseline condition. Whereas, for the post-test trial, both the concentric and eccentric ER and IR work-fatigue values were found to be significantly different ($p < 0.05$) from the zero-fatigue baseline condition (Table 1). This finding shows that work-fatigue values are indicative of fatigue occurring.

| Table 1. Normalized total work (Ng/kg) and work-fatigue (Means ± SEM) |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | Total Work      | Work Fatigue    |                |                |
|                | Concentric      | Eccentric      | Concentric     | Eccentric      |
| ER**           | pre-test        | 6.74 ± 0.44    | 9.44 ± 0.89*   | 8.41 ± 3.41    | 13.78 ± 1.9 §¶  |
|                | post-test       | 6.81 ± 0.44    | 9.13 ± 1.11*   | 13.40 ± 4.2¶   | 16.42 ± 3.0¶    |
| IR**           | pre-test        | 10.23 ± 0.97†  | 19.35 ± 0.98*† | 7.40 ± 4.00    | 7.3 ± 2.0       |
|                | post-test       | 10.59 ± 0.68†  | 17.92 ± 1.23*† | 18.35 ± 3.9¶   | 13.30 ± 1.3¶    |
| IR              | Internal Rotators |
| ER              | External Rotators |

* Eccentric total work (TW) > concentric TW ($p<0.05$)
† IR TW > ER TW ($p<0.05$)
‡ Post-test IR work-fatigue > pretest IR work-fatigue ($p<0.05$)
§ Eccentric ER work-fatigue > eccentric IR work-fatigue at pre-test ($p<0.01$)
¶ Work-fatigue values were significantly different from 0.0 ($p<0.05$)

DISCUSSION
A paucity of research exists examining the impact of muscle fatigue on upper extremity muscle function in the throwing athlete. Increasing our understanding of these effects may be imperative in preventing injury.5,10,20 The practical significance of this study was that shoulder rotator work-fatigue was observed in both muscle groups and in both muscle actions after a bout of repetitive throwing. Specifically, a significant difference pre to post-test for work-fatigue was found. Post-hoc analysis revealed greater eccentric IR work-fatigue ($13.3 \pm 1\%$) compared to the pre-test ($7.3 \pm 2\%$).

The importance of these findings appears clinically relevant to the biomechanics of pitching. The rotator cuff muscles are active throughout the entire throwing motion, with activity levels peaking during the cocking phase, as the infraspinatus and teres minor provide external rotation and the subscapularis and supraspinatus assist in providing stability to the glenohumeral joint.31 The findings support the hypothesis that repetitive eccentric IR activity during the cocking phase of throwing diminished the thrower’s capacity to maintain work output over the 12 repetitions of the isokinetic post-test. Increased fatigue could lead to a lack of coordination and control by the...
rotator cuff during this phase of throwing and result in excessive movement of the humeral head with added stress on the anterior stabilizing structures of the shoulder.3 To date, no other study has analyzed shoulder isokinetic eccentric work-fatigue immediately following a pitching performance.

Although a number of studies examining baseball pitching performance in relation to shoulder strength and throwing velocity exist, there is a lack of information regarding the direct effects of throwing on shoulder muscle work-fatigue.4-10 Decreased performance in baseball pitching depends upon many factors including pitching pace, pitching style, and the athlete’s physical conditioning.22 To control for these variables among the pitchers, throwing rate and rest between innings were standardized. The athletes were instructed to give their best effort and were allowed to throw only fastballs as an approach to standardize pitch type and relative exertion levels relating to ball velocity. It is important to note that the throwing bout likely contributed to the increased isokinetic work-fatigue values observed after throwing even though ball velocity did not significantly change over the 60 pitches. The absence of change in throwing velocity after the 60 pitches demonstrates that the athletes were physically capable of both performing and completing the throwing protocol. Since the isokinetic pre- and post-tests consisted of the same number of repetitions performed and since greater work-fatigue was observed in the post-throwing isokinetic test, it seems appropriate to conclude that repetitive throwing contributed to greater eccentric muscle fatigue.

When compared to the pre-test isokinetic total work and peak torque values, the post-test values were not significantly changed. These findings are supported in part by Nocera et al11 who reported peak torque was unchanged after a throwing bout. It may be important to emphasize that a peak torque value represents only one repetition within a given set and may not be a sensitive indicator of the ability of a muscle to sustain work over time. Furthermore, comparing peak torque values across time is difficult when metabolic recovery is likely to occur. In this study, the elapsed time of approximately 12 minutes from the completion of the throwing bout to the isokinetic post-test could have been sufficient to allow metabolic recovery and, thus, no differences in peak torque would be expected.

### Work-Fatigue

High-intensity muscle contractions often lead to a significant decline in contractile function, which is the basic definition of skeletal muscle fatigue.12 Isokinetic muscle endurance is the capacity of a muscle to perform work, and fatigue is measured as a decline in work production over a series of consecutive contractions.13 Total work performed over several isokinetic contractions has been reported as a valid indicator of the endurance capacity of a single muscle group. Kannus et al27 showed that the total work performed during a 25 repetition isokinetic test and the total work performed for the final five of the 25 repetitions were both as significant and consistent as peak torque in measuring muscle endurance capacity.

Mullaney and McHugh12 examined 32 maximal effort isokinetic contractions of the shoulder rotators at 120 deg/sec and calculated muscle fatigue using average torque decrements from the first and last five repetitions of each set. They reported isokinetic testing at 120 deg/sec based on preliminary data that showed subjects had difficulty consistently maintaining peak torque at higher testing speeds. In contrast, the isokinetic protocol used in this study incorporated a faster isokinetic speed (300 deg/sec), but included only one set of 12-maximal effort ER/IR repetitions. From pilot work, one set of 12 repetitions was chosen based on a high degree of delayed-onset-muscle-soreness that occurred following performance of multiple sets which included a greater number of eccentric muscle actions. More importantly, the pilot work showed that subjects were unable to maintain isokinetic speed at 300 deg/sec for 20 repetitions after a throwing bout.

### Table 2. Normalized peak torque (Nm/kg)

<table>
<thead>
<tr>
<th></th>
<th>Concentric</th>
<th>Eccentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER</td>
<td>pre-test</td>
<td>0.38 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>post-test</td>
<td>0.39 ± 0.02</td>
</tr>
<tr>
<td>IR</td>
<td>pre-test</td>
<td>0.60 ± 0.04†</td>
</tr>
<tr>
<td></td>
<td>post-test</td>
<td>0.63 ± 0.03†</td>
</tr>
</tbody>
</table>

IR: Internal Rotators
ER: External Rotators
* Eccentric > concentric (p<0.05)
† IR > ER (p<0.05)
Post-hoc analysis showed greater post-test work fatigue (13.3%) when compared to the pre-test (7.3%) for only the shoulder IR muscles. This finding is similar to those of Mullaney et al. who reported that repetitive overhead throwing caused an 18% decrease in post-game IR isometric muscle strength. In addition, Mullaney et al. observed no significant decrease in the isometric muscle force of the ER following throwing. The findings in this study and those previously reported by Mullaney et al. demonstrate the high performance demands placed on the IR during repetitive overhead throwing. The absence of measurable isometric fatigue assessed by isometric testing could be explained by the dynamic nature by which the ER muscles function during throwing. This finding further illustrates the importance of muscle testing specificity and the significance of assessing a performance-related activity such as throwing.

**Clinical Implications**

Shoulder rotator cuff muscle strength and endurance is important to act against potentially injurious forces produced during the throwing motion. Distraction forces commonly reach or surpass equivalency to body mass and the failure to counteract these forces is often cited as a potential injury mechanism for repetitive microtrauma. Repetitive microtrauma related to multiple bouts of overhead throwing is thought to contribute to injury of the rotator cuff musculature, which is one of the most common injuries in baseball pitchers. Andrews and Wilk proposed that the repetitive microtrauma associated with throwing leads to tissue fatigue, inflammation, decreased muscle performance with resulting instability, and ultimately tissue damage.

Insidious rotator cuff injury could be associated with impaired dynamic stability related to muscle fatigue. The finding that the eccentric fatigue occurred in both muscle groups after throwing is an important consideration about dynamic stability during prolonged bouts of overhead throwing. For pitchers lacking ER eccentric fatigue resistance, dynamic stability may be compromised during arm deceleration in latter innings compared to early innings. This reduction in eccentric work coupled with a fatigue-induced decline of joint position sense could allow superior migration of the humeral head on the face of the glenoid fossa that is associated with impingement and other glenohumeral injuries. It is well documented that the IR muscles are stronger than ER, but we found that throwing induced similar percentages of fatigue in both muscle groups in both concentric and eccentric muscle actions.

**CONCLUSION**

The results of this study demonstrated greater IR and ER work-fatigue after a pitching performance with the IR eccentric work-fatigue showing the greatest fatigue. These findings have implications for pre-season conditioning and post-injury rehabilitation of overhead throwing athletes and underscore the importance of eccentric endurance training exercise for the rotator cuff musculature. Future studies are necessary to validate these findings and to further determine the clinical usefulness of the work-fatigue index.

**REFERENCES**

ABSTRACT

Background. Knee pain can cause a deconditioned knee. Deconditioned is defined as causing one to lose physical fitness. Therefore, a deconditioned knee is defined as a painful syndrome caused by anatomical or functional abnormalities that result in a knee flexion contracture (functional loss of knee extension), decreased strength, and decreased function. To date, no published studies exist examining treatment for a deconditioned knee.

Objective. To determine the effectiveness of a rehabilitation program focused on increasing range of motion for patients with a deconditioned knee.

Methods. Fifty patients (mean age 53.2 years) enrolled in the study. Objective evaluation included radiographs, knee range of motion, and isokinetic strength testing. The International Knee Documentation Committee (IKDC) subjective questionnaire was used to measure symptoms and function. Patients were given a rehabilitation program to increase knee extension (including hyperextension) and flexion equal to the normal knee, after which patients were instructed in leg strengthening exercises.

Results. Knee extension significantly improved from a mean deficit of 10° to 3° and knee flexion significantly improved from a mean deficit of 19° to 9°. The IKDC survey scores significantly improved from a mean of 34.5 points to 70.5 points 1 year after beginning treatment. The IKDC subjective pain frequency and severity scores were significantly improved.

Conclusions. A rehabilitation program that improves knee range of motion can relieve pain and improve function for patients with a deconditioned knee.

Key Words. knee pain, flexion contracture, range of motion

Correspondence: K. Donald Shelbourne, MD
1815 N. Capitol Ave., Suite 600
Indianapolis, IN 46202
Telephone: 317-924-8662
Fax: 317-624-8414
e-mail: tgray@aclmd.com

Acknowledgment: The authors would like to thank The Methodist Health Foundation, Indianapolis, Indiana for their generous and continued contribution to their research.

Financial Disclosure: K. Donald Shelbourne, MD is a consultant to Kneebourne Therapeutics, Inc.
INTRODUCTION

Knee pain is a common complaint and reason for people to seek medical care by a primary care physician or an orthopaedic surgeon. Each year over 1 million emergency room visits and 1.9 million visits to primary care physicians are for complaints of knee pain. Knee pain can be caused by an acute knee injury, or many times, the pain is chronic and can progressively get worse with time. Approximately 30% of adults 65 years of age and older report knee pain or stiffness in the past 30 days. Sixty percent of adults 65 years and older and 37% of young adults age 20 to 44 report pain lasting 1 year or more, with the knee joint being the most common area of pain cited. People who have persistent knee pain often favor the painful knee. As a result, he or she may lose knee range of motion, develop a knee flexion contracture, and lose strength, which alters the normal function of the knee. Deconditioned means causing one to lose physical fitness. Therefore, a deconditioned knee is described as a painful syndrome caused by anatomical or functional abnormalities that result in a knee flexion contracture (functional loss of knee extension), decreased strength, and decreased function.

A deconditioned knee may occur from osteoarthritis or a knee that has not been completely rehabilitated after a surgery or injury. This condition may also result from extreme overuse, failed previous knee surgery, or from favoring one knee over the other for an extended period of time. Patients who develop a knee flexion contracture experience rehabilitation difficulty because a knee with a flexion contracture is difficult to strengthen. Patients are often treated with medication, braces, foot orthotics, or knee surgery. However, these treatment options do not specifically address the loss of knee range of motion.

Studies of patients with knee pain and osteoarthritis have shown that rehabilitation programs that include manual therapy, strengthening exercises, hydrotherapy, or general exercise can reduce pain and improve function. Other similar studies have found no benefit from exercise programs or that exercises are most helpful when conducted in a supervised setting. According to the Philadelphia Panel systematic review on rehabilitation interventions for knee pain, transcutaneous electrical nerve stimulation (TENS) and therapeutic exercise were beneficial for knee osteoarthritis. However, a void remains in the literature demonstrating the effectiveness of specific therapeutic exercises correlated with a valid and reliable outcome measurement tool. In addition, no published literature exists that describes the effectiveness of increasing range of motion in the treatment of a deconditioned knee.

Range of motion is a critical factor in determining the clinical outcome following total knee arthroplasty. It is also an important factor following anterior cruciate ligament reconstruction. Research has shown that obtaining full knee hyperextension equal to the opposite normal knee is one of the most important factors in contributing to a successful outcome after anterior cruciate ligament reconstruction. Even 3º to 5º of extension loss resulted in a poorer outcome.

In many text books, knee range of motion is described as 0º of extension and 135º of flexion. According to a study by De Carlo and Sell, however, 96% of the population has some degree of hyperextension. They found normal knee extension to be a mean of 5º of hyperextension in males and 6º of hyperextension in females. Given that knee extension is an important factor in the success of surgical treatment, this study was performed to determine the relevance of full knee extension in the treatment of chronic knee conditions described as a deconditioned knee. No studies exist that have examined whether an improvement of knee range of motion to normal (equal to the opposite normal knee) can reduce subjective complaints of patients with chronic knee pain. Therefore, the purpose of this study was to determine the effectiveness of a rehabilitation program that focused on improving knee range of motion to treat patients with a deconditioned knee. The hypothesis to be tested was that patients who underwent rehabilitation to improve knee range of motion would have a statistically significant improvement in subjective knee pain scores.

METHODS

A power analysis was performed before the study began. An improvement of 10 points on the subjective knee questionnaire would be considered a clinical improvement. A sample size of 41 patients was required for \( a = 0.05 \) and power = 0.80.
Patients who complained of knee pain and had a lack of knee range of motion were prospectively asked to enroll in the study. To be included in the study, the patient had to have a knee flexion contracture of at least 5º, could not be taking any narcotic pain medication, and had to have an intact anterior cruciate ligament. Exclusion criteria included patients with bilateral knee pain or who had an injury or condition that would obviously explain pain or lack of knee range of motion (i.e. meniscus tear) and required surgical intervention. Patients signed a voluntary consent approved by the Institutional Review Board at Methodist Hospital in Indianapolis.

Radiographs were obtained at the initial visit and the posterior 45º flexed weightbearing view was used to evaluate for osteoarthritis.34 Patients attended physical therapy and were given a rehabilitation program that included exercises to restore full knee extension equal to the opposite normal knee first, followed by exercises to restore normal knee flexion. Light strengthening exercises were prescribed as needed when knee range of motion was restored, and the exercises included the stationary bike, single leg press, and single leg extension.

The IKDC (International Knee Documentation Committee) subjective survey was used to evaluate pain, activity, and knee function. The IKDC is a reliable, responsive, and validated instrument used to assess symptoms, function, and sports activity in patients with a variety of knee disorders.35 In addition, normative data is available to assist in the interpretation of the subjective results.36 Patients were asked to complete the questionnaire independently in a private treatment room at the initial visit and at 1 and 3 months after initial treatment. The same questionnaire was sent in the mail to patients at 6 and 12 months after the initial visit.

Range of motion measurements were taken using a goniometer as described by Norkin and White.37 Range of motion measurements were recorded as A-B-C, with A being the degrees of hyperextension, B indicating lack of extension from zero, and C documenting the degrees of flexion. Measurements were taken by the treating physical therapist. Intra-tester and inter-tester reliability measurements of the treating therapists were high (kappa > 0.8) for both flexion and extension.38 Range of motion was recorded at the initial visit and at 1 and 3 months after the initial visit. The IKDC objective form grades range of motion as normal, nearly normal, abnormal, or severely abnormal. Range of motion was graded according to IKDC criteria (Table 1).

Quadriceps muscle strength was evaluated by the treating physical therapist with isokinetic strength testing performed at 180º/sec at the 1 month and 3 month visit. The strength test was not performed at the initial visit because most patients’ knees were too painful for them to tolerate the evaluation.

Patients who required surgical intervention for symptoms were considered a failure of rehabilitation treatment.

Rehabilitation Program

Patients were instructed and issued a home exercise program that focused on improving knee extension first. Patients were instructed in prone hang exercises, heel prop exercises, and towel extension stretches (Figure 1) to increase knee extension equal to the opposite normal knee. The

<table>
<thead>
<tr>
<th>IKDC rating</th>
<th>Extension difference in degrees</th>
<th>Flexion difference in degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt; 2</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>Nearly Normal</td>
<td>3-5</td>
<td>6-15</td>
</tr>
<tr>
<td>Abnormal</td>
<td>6-10</td>
<td>16-25</td>
</tr>
<tr>
<td>Severely Abnormal</td>
<td>&gt;10</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

*The difference in range of motion is compared with the opposite normal knee to include hyperextension.

Figure 1. Towel stretch exercises. The patient holds on to the ends of a towel that is wrapped around the ball of the foot. While using one hand to hold the top part of the leg down on the table, the other hand pulls the ends of the towel so that the knee is hyperextended and the heel of the foot comes up off the table.
patients were instructed to perform 10 repetitions of each exercise 3x/day. If patients were unable to achieve normal knee extension through the previous exercises, a hyperextension device (Elite Seat, Kneebourne Therapeutic, Noblesville, IN) (Figure 2) was utilized in addition to the other extension exercises. Patients were instructed to use the extension device for 10 minutes 3x/day.

In addition to exercises, patients were educated in daily habits to be performed throughout the day to help maintain knee extension gained by the exercises. These extension habits included performing heel prop exercises while sitting or standing on the involved extremity with the knee locked out forcing the knee into full hyperextension via an active quadriceps contraction (Figure 3). Improving knee extension remained the focus of the treatment until full hyperextension equal to the opposite knee was achieved. Patients were also encouraged to ice their knee for swelling and soreness as needed.

As knee extension improved towards normal, the exercise program was progressed to include flexion exercises if a deficit was present. The knee flexion exercises included heel slides while sitting and wall slides while lying supine; again, all exercises were performed at 10 repetitions 3x/day

Upon near full range of motion, patients were instructed to begin a low impact aerobic exercise such as the bike, elliptical, or stair-stepping machine. They were also instructed in light strengthening exercises including single leg press, leg extensions, quarter squats, and step down exercises. Patients were continually encouraged to maintain full range of motion while advancing their exercise program of low impact activity and leg strengthening exercises.

Data Analysis

Descriptive statistics were used to determine the mean knee range of motion at each visit and the mean IKDC subjective scores at each observation. Data analysis comparing pre-treatment and post-treatment subjective scores was performed on patients who completed the study. Two-tailed t-test was used to determine whether a statistically significant difference existed between initial and final values for parametric data of IKDC total scores and isokinetic quadriceps muscle strength scores. Wilcoxon signed-rank test was used to determine whether there was a statistically significant difference between initial and final values for nonparametric data of knee extension, knee flexion, and IKDC pain frequency and severity scores. Repeated measures analysis of variance was used to determine if the IKDC total subjective scores improved through time after the initial visit. For all statistical analysis, the 0.5 level of probability was used. Due to the fact that six t tests were performed on this part of the study, a Bonferroni adjustment was performed, (0.05/6) thereby, setting the alpha level at p<0.008.

The IKDC subjective score of patients in this study was compared with normative IKDC data obtained by the IKDC committee. Anderson et al compiled normative data for 5,246 knees of men and women in four age groups (18-24 years, 25 to 34 years, 35 to 50 years, 51 to 65 years) and means for the groups were established. The investigators offered a formula for converting raw IKDC subjective scores to a standardized score that would give the standard deviation units above or
below the population average, which was then applied to
the present study group. A one sample t-test was per-
formed to determine if the standardized IKDC score was
significantly different than zero for each sex and age
group. Again, the level of probability was set at p<0.05
and following a Bonferroni correction due to four t tests
(0.05/4), the alpha level was adjusted to p<0.013.

RESULTS
Fifty patients enrolled into the study; 42 patients
completed the study and 8 patients were considered a fail-
ure of treatment because they underwent a surgical pro-
cedure by other physicians for their symptoms. The
mean age of patients (25 men; 25 women) at the time of
enrollment into the study was 53.2 ± 9.9 years (range
25.0 to 72.4) and no significant difference in age existed
between men and women. The underlying pathology in
the knee was osteoarthritis in 41 patients (Table 2), previ-
ous arthroscopy without rehabilitation in seven patients,
and disuse osteoporosis in two patients.

A statistically signifi-
cant improvement
was found in knee
extension, knee flex-
ion, and quadriceps
muscle strength from
initial evaluation to
final follow-up (Table
3). At the initial evalu-
ation, the mean range
of motion in the non-
involved knee was
from 4° of hyperexten-
sion to 135° of flexion, and 44 of 50 patients had some
degree of hyperextension in their normal knee (range 1º
to 15º). The mean deficit in knee range of motion com-
pared with the opposite normal knee was 10° of extension
and 19° of flexion. The mean deficit in knee range of
motion at final follow-up was 3° of extension and 9° of
flexion, which was a statistically significant improvement
for both extension and flexion (p<0.008). Twenty
patients achieved what is considered normal knee exten-
sion (within 2° of the uninvolved knee). Sixteen patients
achieved knee extension that is considered nearly normal
(within 5° of the uninvolved knee), and six patients had
abnormal extension (lacking 6° to 10° of extension
compared to the uninvolved knee). All patients had
improvement in knee extension and all but four patients
had improvement in knee flexion. The mean improve-
ment in extension was 6° (range 1° to 11°) and the mean
improvement in flexion being 10° (range 0°-40°; Table 3).

Eight patients were considered a failure of rehabilitation
treatment because they had subsequently undergone sur-
gical intervention for their symptoms. Three patients had
a total knee arthroplasty, four patients had a knee
arthroscopy, and one patient had a meniscal transplant.
All eight patients, however, had improvement in knee
extension (mean 5°, range 1° to 10°) and five of eight
patients had improvement in flexion (mean 5°, range -5
to 15). Furthermore, the IKDC subjective scores improved
from a mean of 30.8 ± 9.5 points to 45.7 ± 18.7 points,
although this improvement is not statistically significant
(p=0.0675).

International Knee Documentation Committee survey
scores significantly improved with treat-
ment from a mean of
34.5 ± 14.0 points to
70.5 ± 20.6 points
(p<0.008). Repeated
measures analysis of
variance showed that
the mean IKDC
subjective scores sig-
nificantly improved
(p<0.008) through
time with the greatest increase in scores being from the
initial evaluation to the one month evaluation (Figure 4).

The IKDC subjective survey evaluates both severity and
frequency of pain on a scale of 0 to 10, with 0 being “no
pain” and frequency as “never” and 10 being “worst pain
imaginable” and “constant” frequency. The mean score of
pain frequency significantly improved from 8.7 ± 3.3
points to 3.3 ± 2.8 points (p<0.008). Similarly, the mean
score for pain severity significantly improved from 6.0 ±
2.0 points to 2.5 ± 2.3 points (p<0.008).

<table>
<thead>
<tr>
<th>Compartments Involved</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial only</td>
<td>7</td>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>Lateral only</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Patellofemoral only</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Medial and lateral</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Medial, lateral, and patellofemoral</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Medial and patellofemoral</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Lateral and patellofemoral</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 2. Grade and compartment of osteoarthritis at time of initial evaluation
The final total IKDC subjective scores for the study group compared with normative data is shown in Table 4, which include the mean IKDC standardized score showing the standard deviation above or below the population average. The one sample t-test comparing the IKDC scores between the study group and normative data showed that no statistically significant difference existed for men or women in the different age groups (Table 4).

**DISCUSSION**

The results of this study show the effectiveness of a rehabilitation program that focused on increasing range of motion equal to the opposite normal knee to improve subjective symptoms in patients with deconditioned knees. The results demonstrate the effectiveness of non-operative rehabilitation in treating a deconditioned knee. This particular study shows that knee pain and function can significantly improve by increasing knee range of motion and, in particular, knee extension.

The underlying knee pathology causing pain in many of the patients in this study was osteoarthritis. Most of these patients had been told by other physicians that they needed a total knee arthroplasty or arthroscopic procedure to alleviate their pain. However, 84% of the patients in this study improved with non-operative treatment. These results demonstrate that physical therapy can improve
knee pain and function with non-operative treatment, which is an important factor considering rising health care costs. Non-operative treatment can be more effective and cost efficient to the patient and insurance companies.

Forty-two of 50 patients completed the study and 38 of 42 patients had improvement in knee extension, knee flexion, and subjective outcome measures. Only eight of the 50 patients (16%) dropped out of the study to undergo a surgical procedure. These eight patients all had some degree of improvement in knee extension, which is an important factor in determining the success after surgery. So, although eight patients underwent surgery, the improvement in range of motion obtained pre-operatively may help minimize post-operative range of motion complications.

When comparing the mean IKDC score from the study group to the normative data, there was no statistical difference for patients of the same sex and age group. This fact indicates that the rehabilitation program was effective for returning patients back to a normal level of function for their age group.

The loss of knee extension is common after knee surgery, knee injury, or knee pain. While recovering, it is a person’s natural tendency to favor the involved extremity and stand with the involved knee bent, unless otherwise instructed to do so. Within a short period of time, even days, a person can develop a flexion contracture resulting in a loss of motion and subsequent loss of leg strength. Many times, the patient is unaware that a loss of knee extension has occurred because the deficit has come on gradually. A typical scenario is one where the patient has seen a physician for knee pain and has been told to reduce activities to accommodate the pain. While this habit can temporarily make the knee feel better, it does nothing to assist the patient with functioning normally with everyday activities.

A thorough and accurate knee evaluation is critical to recognizing knee asymmetry. During evaluation, a flexion contracture can often be observed when the patient is lying supine on the table. When the patient is unable to fully extend the knee, he or she must externally rotate the hip (Figure 5). Another way to observe the patient is during standing. Patients with a flexion contracture will typically stand with the involved knee bent and most of their weight is placed on the non-involved leg. These observation techniques alert the clinician to the possible presence of a flexion contracture. In addition to taking goniometric measurements, it is important to assess the passive end feel of knee extension (Figure 6). Examining the normal knee first will help identify what is normal for that individual.

**Table 4.** Final IKDC total scores compared with normative data.

<table>
<thead>
<tr>
<th>Sex/Age Group (n)*</th>
<th>Study Group (mean ± SD)</th>
<th>Normative data (mean ± SD)</th>
<th>Mean difference from 0b</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female 35 – 50 years (5)</td>
<td>75.2 ± 22.3</td>
<td>79.9 ± 22.6</td>
<td>-0.208</td>
<td>0.6614</td>
</tr>
<tr>
<td>Female 51 – 65 years (15)</td>
<td>62.0 ± 21.8</td>
<td>70.9 ± 26.0</td>
<td>-0.310</td>
<td>0.1740</td>
</tr>
<tr>
<td>Male 35 – 50 years (9)</td>
<td>77.9 ± 23.4</td>
<td>84.9 ± 19.3</td>
<td>-0.364</td>
<td>0.3949</td>
</tr>
<tr>
<td>Male 51 – 65 years (9)</td>
<td>77.3 ± 13.8</td>
<td>77.4 ± 23.3</td>
<td>-0.004</td>
<td>0.9826</td>
</tr>
</tbody>
</table>

*a Four patients were older than 65 and could not be included in the analysis

*b Formula was used to convert each patient’s IKDC subjective score to a standardized score showing the standard deviation difference above or below the population average.

\[ z = \frac{\text{Patient’s IKDC subjective score} - \text{mean score for age/gender group}}{\text{Standard deviation for age/gender group}} \]

**Figure 5.** Flexion contracture sign. Observe the position of the leg when you ask patients to lie supine and relax their legs. A person who has a flexion contracture in one knee compared with an opposite normal knee will lie with the hip externally rotated because the knee cannot go into full extension.
Regaining full knee hyperextension can provide long lasting relief. The mean IKDC subjective score improved significantly between the initial and the 1 month follow-up evaluation, and patients continued to have subjective improvement through the latest evaluation at 1 year after receiving treatment. While rehabilitation sessions can be successful for improving knee extension, the patient must change daily habits to be able to maintain the gains achieved. Educating the patient regarding normal gait and how to stand and properly use the involved extremity is an important factor in maintaining the improvements gained.

CONCLUSION
A rehabilitation program that focuses on increasing range of motion, in particular knee extension, can relieve symptoms and improve function for patients diagnosed with a deconditioned knee. Physical therapy and non-operative treatment should be considered as a primary treatment objective in the treatment of a deconditioned knee regardless of the underlying pathology. As shown in this study, most patients with a deconditioned knee can be treated effectively through non-operative management.

REFERENCES:


ABSTRACT

**Background.** Upper extremity weight-bearing exercises are routinely used in physical therapy for patients with shoulder pathology. However, little evidence exists regarding the demand on the shoulder musculature.

**Objective.** To examine changes in shoulder muscle activity and center of pressure during upper extremity weight-bearing exercises of increasing difficulty.

**Methods.** Electromyographic (EMG) and kinetic data were recorded from both shoulders of 15 healthy subjects (10 male and 5 female). Participants were tested in a modified tripod position under three conditions of increasing difficulty: (1) hand directly on the force plate, (2) on a green Stability Trainer™ and (3) on a blue Stability Trainer™. Ground reaction forces were recorded for each trial. Surface EMG was recorded from the serratus anterior, pectoralis major, upper trapezius, lower trapezius, infraspinatus, anterior deltoid, posterior deltoid, and the lateral head of the triceps muscles.

**Results.** Mean deviation from center of pressure significantly increased when using the Stability Trainer™ pads. The activities of the triceps, serratus anterior, and anterior deltoid muscles significantly increased as each trial progressed, irrespective of stability condition. Additionally, activity in the anterior deltoid, lower trapezius, and serratus anterior muscles significantly decreased with increasing difficulty, whereas activity in the triceps muscles significantly increased.

**Discussion and Conclusion.** Balancing on a foam pad made it more difficult to maintain the upper extremity in a stable position. However, this activity did not alter the proprioceptive stimulus enough to elicit an increase in shoulder muscle activation. While the results of this study support the use of different level Stability Trainers™ to facilitate neuromuscular re-education, a less compliant unstable surface may produce larger training effects.

**Key Words:** closed chain, shoulder, muscle activity.

**CORRESPONDENCE**
Karl F. Orishimo, MS
130 E77th Street
Nicholas Institute of Sports Medicine & Athletic Trauma
Lenox Hill Hospital, NY, NY 10021
Karl@nismat.org
212-434-4587
INTRODUCTION
During activities of daily living and sports, the upper extremity is used in both open kinetic chain and closed kinetic chain positions. Examples of closed kinetic chain activities of the shoulder include pushing oneself up from a chair or pass blocking a rushing defender during a football game. Therefore, both open and closed chain exercises should be integrated into a comprehensive rehabilitation program. Examples of upper extremity weight bearing exercises include push-ups with or without modifications and quadruped, prayer, and tripod positions. The rationale for these exercises is to improve proprioception, joint stability, and strength. In addition, a progression from a stable surface to an unstable surface is a standard method of increasing the difficulty of the exercise. Despite the large use of upper extremity weight bearing exercises in the clinical setting little is known about the demand on the shoulder musculature.

The purpose of this study was to examine changes in the deviation of the hand center of pressure and activity of shoulder musculature during three different upper extremity weight-bearing positions of increasing difficulty. The hypothesis to be tested is that with an increasingly compliant surface (less stability), both the mean deviation of the center of pressure and shoulder muscle activity will increase. These findings would support the use of such exercises for the purpose of increasing demand on the shoulder by using increasingly compliant surfaces.

METHODS
Subjects
Electromyographic and kinetic data were recorded from both shoulders of 15 healthy subjects (10 male and 5 female) (age: 30 ± 6 years; height: 171 ± 8 cm; weight: 76 ± 19 kg). Prior to participation, subjects provided informed consent and the study was approved by the Lenox Hill Hospital Institutional Review Board. Subjects were included if they were without a history of upper extremity pathology, had bilateral shoulder strength of 4/5 or greater in all shoulder girdle manual muscle testing positions, and were able to maintain the modified tripod test position for > 20 seconds.

Instrumentation
The subject's skin was prepared in a standard fashion prior to electrode application to minimize electrical impedance. After cleaning and abrading the skin, bipolar surface electrodes (Ag/AgCl) were placed over the serratus anterior, pectoralis major, upper trapezius, lower trapezius, infraspinatus, anterior deltoid, posterior deltoid, and the lateral head of the triceps muscles using a standardized methodology. Serratus anterior electrodes were placed below the axilla, anterior to the latissimus, and placed vertically over the ribs. The pectoralis major electrodes were positioned one-third of the distance from the greater tuberosity to the xiphoid process with the arm abducted to 90°. Upper trapezius electrodes were located one-third of the distance between the spinous process of the C7 vertebra and the distal clavicle. For the lower trapezius, subjects were lying prone with the arm extended overhead. Electrodes were placed at the level of the inferior angle of the scapula, 2 cm from the vertebral column. Infraspinatus electrodes were placed one-half the distance from the inferior angle to the scapular spine root, 2 cm lateral from the scapula's medial border. Anterior deltoid electrode placement was two to three finger-breadths below the acromion process, over the muscle belly, in line with the fibers. Posterior deltoid electrode placement was three finger-widths behind the angle of the acromion, over the muscle belly, in line with the fibers. The location of the triceps electrodes was 4 cm distal to the axillary fold. Subjects performed maximal volitional contractions (MVC) against manual resistance to determine the maximum activation for each muscle in a standard manual muscle test position. Muscle activity was recorded at 1000 Hz with an eight-channel telemetry system (Noraxon Telemyo). To compute the linear envelope of the electromyography (EMG), data from each muscle was full-wave rectified and low-pass filtered using a fourth-order Butterworth filter with a 10 Hz cutoff frequency (the same processing was applied to the EMG from each trial described later in the methods). The maximal value for EMG from each muscle (during the appropriate test) was used to normalize the EMG data for analysis.
Test Protocol
The subjects performed three trials for each of the three conditions, for a total of nine trials for both arms. The testing position was a modified tripod position. Subjects were on both knees with one hand on the force plate (Multicomponent Force Plate for Biomechanics, Model #9286, Kistler, Amherst, NY) and the opposite hand on the lower back. To standardize the position, the subjects were instructed to maintain 70° of shoulder flexion, neutral shoulder horizontal abduction/adduction, and 50° of hip flexion throughout data collection. The tester documented this position with goniometric measurements at the start of each trial. Force plate and EMG data were recorded as subjects held the test position under three different conditions: the subject’s hand resting directly on the force plate (floor) (Figure 1), on a green Thera-Band® (The Hygenic Corp., Akron, OH) Stability Trainer™ (75% deformable under 1000 lb. load) over the force plate, (Figure 2) and on a blue Stability Trainer™ (61% deformable under 1000 lb. load) over the force plate. The order of these positions was randomized for each subject to reduce fatigue or learning effects. Each trial lasted twenty seconds and a one-minute rest was given between trials. Both the dominant and non-dominant arms of each subject were tested. The dominant arm was defined as the arm with which the subjects would throw a ball.

Data Analysis
The average location of the center of pressure for each trial was calculated from the ground reaction forces. The mean deviation from the center of pressure was defined as the average distance of the instantaneous center of pressure from the mean location for the entire trial (Figure 3). This distance gives a region where the center of pressure can be expected to be located. To assess the main effects and any interactions, a 2 (hand dominance) x 3 (test condition) repeated-measures analysis of variance (ANOVA) was performed on this measurement.

The linear envelope (rectified, smoothed) EMG activity was normalized to the maximal activation level determined for each muscle, as described above. Each 20-second trial was divided into three equal parts to examine potential changes in muscle activity over time. The average value over each third of each trial was used for analysis. Repeated-measures ANOVA (2 (hand dominance) x 3 (test condition) x 3 (time)) was then performed to assess the main effects and any interactions of hand dominance, test condition, and test duration on the EMG data from each muscle. Pairwise post-hoc t-tests with Bonferroni corrections were applied where significant main effects were found. Any p values less than 0.05 were considered significant.
RESULTS

Mean Deviation of the Center of Pressure
Statistical analysis revealed a significant main effect of the stability condition on the mean deviation of the center of pressure (p= 0.015). The mean deviation of the center of pressure was lower for the floor condition compared to either of the Stability Trainers (p = 0.04). No difference in the mean deviation existed between the blue and green Stability Trainers (p = 0.977). Additionally, no effect of hand-dominance was found for this measurement (p=0.99).

EMG Data
Statistical analysis revealed a significant main effect of time (p=0.005) on overall muscle activity. Further analysis revealed that the activity of the triceps, serratus anterior, and anterior deltoid muscles increased as each trial progressed (p=0.001, p = 0.025, p = 0.002, respectively) (Table 1), irrespective of the stability condition utilized. A significant condition by muscle interaction (p=0.015) on overall muscle activity also occurred. Activity in the anterior deltoid, lower trapezius, and serratus anterior muscles significantly decreased with decreasing stability, whereas, activity in the triceps significantly increased (p = 0.002) (Table 2).

DISCUSSION
When complementing common open chain therapeutic exercise with closed chain therapeutic exercise during shoulder rehabilitation, the demand placed on the surrounding shoulder musculature during these exercises should be understood. The hypothesis to be tested was that with an increasingly compliant surface, stability would decrease (as evidenced by the increased deviation of the center of pressure) and muscle activity would increase (as evidenced by increased EMG activity). The increase in the mean deviation of the center of pressure indicates that balancing on a foam pad made it more difficult for the subject to maintain the upper extremity in a stable position. The EMG data, however, was less conclusive. Anterior deltoid, upper trapezius, lower trapezius, and serratus anterior muscles demonstrated small decreases in muscle activity with decreasing stability, while the triceps showed a small increase. These findings seem to indicate that the increase in center of

<table>
<thead>
<tr>
<th>Muscle</th>
<th>% Change (SD)</th>
<th>Time Main Effect (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Deltoid</td>
<td>13.5 (20.6)</td>
<td>0.002*</td>
</tr>
<tr>
<td>Posterior Deltoid</td>
<td>-0.7 (15.0)</td>
<td>0.652</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>2.5 (19.9)</td>
<td>0.941</td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>11.9 (21.4)</td>
<td>0.457</td>
</tr>
<tr>
<td>Upper Trapezius</td>
<td>4.5 (20.0)</td>
<td>0.383</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>9.1 (17.3)</td>
<td>0.025*</td>
</tr>
<tr>
<td>Pectoralis</td>
<td>10.8 (30.4)</td>
<td>0.115</td>
</tr>
<tr>
<td>Triceps</td>
<td>11.3 (13.5)</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

(*) Significant

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Floor %MVC (SD)</th>
<th>Green %MVC (SD)</th>
<th>Blue %MVC (SD)</th>
<th>Condition Main Effect (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Deltoid</td>
<td>11.0 (7.2)</td>
<td>9.9 (7.0)</td>
<td>9.7 (7.0)</td>
<td>0.023*</td>
</tr>
<tr>
<td>Posterior Deltoid</td>
<td>12.5 (8.5)</td>
<td>12.1 (9.1)</td>
<td>12.0 (8.3)</td>
<td>0.506</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>26.3 (10.0)</td>
<td>26.0 (9.9)</td>
<td>25.4 (10.5)</td>
<td>0.656</td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>16.2 (8.9)</td>
<td>15.4 (9.4)</td>
<td>14.5 (8.2)</td>
<td>0.029*</td>
</tr>
<tr>
<td>Upper Trapezius</td>
<td>4.6 (4.6)</td>
<td>4.3 (4.1)</td>
<td>4.3 (4.1)</td>
<td>0.103</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>15.0 (9.3)</td>
<td>13.5 (9.2)</td>
<td>13.0 (9.6)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Pectoralis</td>
<td>8.7 (7.2)</td>
<td>9.6 (8.6)</td>
<td>9.6 (8.1)</td>
<td>0.135</td>
</tr>
<tr>
<td>Triceps</td>
<td>23.1 (11.6)</td>
<td>25.1 (12.8)</td>
<td>25.1 (12.5)</td>
<td>0.002#</td>
</tr>
</tbody>
</table>

(*) EMG activity decreased as task stability decreased.
(#) EMG activity increased as task stability decreased.
pressure deviation produced by balancing on the Stability Trainers was not large enough to require an increase in shoulder muscle activation. Compared to balancing on the floor, balancing on the Stability Trainers most likely changed the position of the hand and the force distribution under it. These changes may have produced the need for more stability at the elbow, hence the increase in triceps activity.

Muscle activity increased throughout each trial, which may indicate muscle fatigue. While muscle fatigue was not explicitly measured, it seems to be a logical conclusion based on the increase in EMG activity over the length of the trial. Physiologically, as a muscle fatigues, more motor units are recruited in order to maintain the specific force output. This results in an increase in action potentials along the muscle (i.e. increased EMG activity).

In order to support the weight of the body and maintain stability, more motor units were recruited as the prime support muscles fatigued. Considering that the activity is essentially an isometric exercise, the increase in EMG activity could not have been due to muscle length changes or a change in contraction velocity.

Few studies have examined upper extremity weight bearing exercises. Lear et al. supported incorporating push-up progressions into upper extremity rehabilitation for advanced training of the scapular stabilizers (serratus anterior, upper and lower trapezius muscles) using the push-up “plus” (“plus” indicating active scapular protraction at the end of the up phase). Lear et al. chose to vary the exercise by elevating the subject's feet and having the subjects place their hands on a mini trampoline. The authors found that elevating the subject's feet had a significant effect on serratus anterior and upper trapezius muscle activity but no significant effect on lower trapezius activity. Placing the hands on an unstable surface also increased activity of the serratus anterior and upper trapezius but did not increase lower trapezius activity. In contrast, the present study demonstrated an increase in triceps activity while anterior deltoid, upper and lower trapezius, and serratus anterior muscle activity decreased with decreasing stability.

The use of the “plus” phase of the push-up in the Lear et al. study is likely to explain the increase in muscle activity of the serratus anterior. In the current study, subjects were not instructed to hold a protracted position of the scapula during the trials. The low activation levels of the serratus anterior may be explained by the difficulty of protracting the scapula in a unilateral, close kinetic chain position. Additionally, changes in surface compliance may not have provided a strong enough stimulus to require an increase in serratus anterior muscle activity.

While the push-up plus position in rehabilitation is one of the greatest activators of the serratus anterior muscle, the purpose for this study was not to determine what muscles would activate the most, but to see what muscles are activated and to what degree during a standard rehabilitation progression of a stable surface to an unstable surface. Clinically, a patient is not typically placed in a closed chain “plus” position when the program is initiated. This position would be more advanced and would be added at a later time with this current progression. In terms of maintaining “neutral” position, human positioning is always a difficult thing to standardize, especially in the shoulder. While the subject maintained the tripod position, verbal feedback was provided from the investigators when the subject began to shift into a retracted or protracted position (retracted was more common). At this point, the subject was cued to maintain their shoulders parallel to the floor.

Uhl et al. also sought to determine the demand on shoulder muscles with weight-bearing exercises, and the relationship between increased weight-bearing posture and shoulder muscle activation of the anterior and posterior deltoid, infraspinatus, pectoralis major, and supraspinatus muscles in a progression of seven static upper extremity weight-bearing exercises. The authors found that force, measured through household bathroom scales, significantly increased with an increase in weight-bearing position ($r = 0.97, p < 0.01$). They also found that muscle activity changed with position and increased with the progression of exercises. Similar to the present findings, the infraspinatus had the highest EMG activity in all conditions. Additionally, the standard push-up had the highest levels of muscle activation, with values significantly higher than the majority of other exercises. Uhl et al. concluded that alterations of weight-bearing exercises, by varying the amount of arm support and force, resulted in very different demands on the shoulder musculature.

A properly designed shoulder rehabilitation program needs to encompass both open and closed chain thera-
peutic exercises. Previous studies have provided insight into the muscle activity generated by various open chain exercises. Complementing these exercises with closed chain training, will offer a well-balanced rehabilitation program. However, only a few studies have offered insight into the muscle activity generated by upper extremity closed chain exercises. Understanding a progression of when and how to incorporate these closed chain exercises into a rehabilitation program is very important. This study has demonstrated that by increasing the compliance of the surface during a tripod closed chain exercise, the ability to maintain stability is challenged. Interestingly, no significant difference was noted between maintaining stability with the green or the blue Thera-Band® Stability Trainer. As noted earlier, balancing on the Stability Trainers may have altered hand position and distribution of forces acting on the hand. While this altered hand position changes the deviation of the center of pressure, an increase in shoulder muscle activity was not necessary to maintain stability at the level of the shoulder. Also, because the Stability Trainers were compliant, subjects tended to "sink" into the surface. Therefore, stability may have been added to the system due to the fact that the foam conformed around the hand as subjects held the tripod position. While the foam Stability Trainers have been shown to increase the deviation of the center of pressure, using a less compliant but unstable surface, such as a balance board, may be more successful in eliciting an increase in shoulder muscle activity.

This study utilized healthy subjects with no history of upper extremity involvement; future work should investigate the utilization of upper extremity closed chain exercises for subjects with shoulder pathology. In choosing appropriate interventions for individuals with impairment, it will be necessary to consider the different forces being transmitted through the shoulder with these exercises in addition to desired muscle activity, selective muscle activation, and patient tolerance to positions.

CONCLUSION

The use of unstable surfaces was shown to progressively challenge proprioception and joint stability in the upper extremity. However, providing progressively more unstable surfaces did not lead to a progressive and selective increase in muscle activity. Although activity increased in most muscles throughout the exercise duration, irrespective of the stability condition, increasing the difficulty of the task did not have a similar effect. The compliance of the foam Stability Trainer pads may not have provided enough proprioceptive stimulus to elicit an increase in shoulder muscle activation. Using a less compliant unstable surface may produce the desired increases in shoulder muscle activation; however, further investigation needs to determine a safe and selective progression of treatment.

REFERENCES


ABSTRACT

In this clinical commentary, the use of reactive neuromuscular training (RNT) will be discussed as part of an overall functional rehabilitation program in the treatment of the unstable glenohumeral joint. The RNT program is designed to restore the synchrony and synergy of muscle firing patterns about the shoulder, which are required for dynamic joint stability and fine motor control. Reactive neuromuscular training allows the clinician to bridge the gap between the achievement of clinical based goals and a return to athletic competition. The possible effects of RNT on central nervous system (CNS) programming to establish appropriate reflex responses and functional stability at the glenohumeral joint will be explored. The issues reviewed in this article will highlight the need for future research in this area.

Key Words: reactive neuromuscular training, shoulder instability, central nervous system

CORRESPONDENCE

John Stemm, MED, PT, ATC
Rehabilitation Coordinator
Oklahoma State University
Department of Intercollegiate Athletics
Stillwater, OK 74078
Phone: 405-744-3294
Fax: 405-744-0358
john.stemm@okstate.edu

ACKNOWLEDGEMENTS

The authors would like to acknowledge Mike Voight for his contribution to this clinical commentary.
INTRODUCTION
Overhand (baseball, softball) and overhead (swimming, tennis) athletes rely on proper function of the shoulder girdle to allow them to complete the tasks necessary to compete in their respective sports. The shoulder has been measured to move at over 7000 deg/sec and can attain in excess of 16,000 different positions. Due to the inherent instability of the glenohumeral joint and the repetitive nature of many sports, several of these individuals may suffer a shoulder injury at some time in their athletic careers. This clinical commentary attempts to provide a theoretical framework describing the use of reactive neuromuscular training (RNT) as part of a functional exercise progression in the treatment of the overhead and overhand athlete with an unstable shoulder.

The concept of RNT was originally proposed by Voight in 1990. The RNT program is the umbrella heading for a variety of rehabilitation techniques designed to restore dynamic stability and fine motor control at an injured joint. The RNT techniques are intended to augment traditional rehabilitation in a complementary fashion via proprioceptive and balance training in order to promote a more functional return to activity. The main objective of the RNT program is to facilitate the unconscious process of interpreting and integrating the peripheral sensations received by the central nervous system (CNS) into appropriate motor responses. The purpose of this article is to describe the possible effects of RNT on CNS programming and the use of various RNT techniques in the rehabilitation of the unstable shoulder. The unstable shoulder refers to a pathologic condition in which unwanted translation of the humeral head on the glenoid causes pain and dysfunction of the shoulder.

PHYSIOLOGY OF PROPRIOCEPTION
Proprioception is a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesesthesia) and joint position (joint position sense). Knowing exactly where the shoulder girdle is in space and how much muscular effort is required to perform a particular action is critical for the successful performance of overhand activities.

Information about the position and movement of the shoulder is available from the peripheral receptors located in and around the articular structures of the shoulder. These specialized receptors provide information to the CNS regarding joint position sense and movement. The mechanoreceptors do this by converting mechanical deformation into electrical impulses that are sent into the CNS. This proprioceptive information, in turn, via descending efferent pathways, influences joint stiffness, coordinated motor patterns, and reflex activity to provide enhanced joint stability.

Both static and dynamic stabilizers serve to provide support to the normal healthy joint. The role of the capsuloligamentous tissues in the dynamic restraint of the joint has been well established in the literature. While the primary role of these structures is mechanical in nature, by providing structural support and stabilization to the joint, the capsuloligamentous tissues also play an important sensory role by detecting joint position and motion. Vangsness et al described the neural anatomy of the glenohumeral ligaments and labrum in the shoulder. They found Ruffini end organs and Pacinian corpuscles in the superior, middle, and inferior glenohumeral ligaments. However, the glenoid labrum contained only free nerve endings relating to the perception of pain. These authors concluded that any disruption of the ligaments by trauma or surgery can deprive the shoulder of mechanical stability, and may cause a decrease in proprioception because of injury to these afferent neural receptors. Sensory afferent feedback from the receptors in the capsuloligamentous structures projects directly to the reflex and cortical pathways, thereby, mediating reactive muscle activity for dynamic restraint. Sensory information is sent to the CNS to be processed and appropriate motor responses are executed. The efferent motor response that ensues from the sensory information, whether volitional or reflex, simple or complex, is called neuromuscular control.

A role for the muscle spindle has also been elucidated. Diederichsen et al found mechanoreceptors in the coracoacromial ligament, the rotator cuff tendons, the musculotendinous junctions of the rotator cuff, and the joint capsule. Joint rotation will stretch one set of muscles and relax another set of muscles. Since the response of the muscle spindle afferents is known to be a function of muscle length, muscle afferents are able to provide an unconfounded, unidirectional signal of movement.
When an athlete moves the glenohumeral joint into external rotation at 90 degrees of abduction, the stretch of the subscapularis causes firing of the muscle spindles. This information is relayed to the CNS regarding position sense and movement. The exact contribution of each of these tissues has yet to be resolved, but information from all locations provides some position and movement sense throughout the total available range of motion.

**PATHOPHYSIOLOGY**

Following a traumatic subluxation or dislocation, or an atraumatic instability of the glenohumeral joint, disruption to the articular mechanoreceptors inhibits normal neuromuscular reflex joint stabilization. Proprioceptive deficits have been uncovered in unstable shoulders in male subjects with unilateral, traumatic, recurrent anterior shoulder instability. This partial deafferentation results in a proprioceptive deficit, which contributes to repetitive injuries and the progressive decline of the joint. Injuries to the rotator cuff may also lead to a compromise of the afferent feedback from the muscle spindles. Motor programs are adapted to receive specific sensory feedback for the accurate execution of various motor tasks. Injury causes sensory feedback which does not “fit” the existing motor program, causing errors in the normal and coordinated patterns of the muscles and functional joint stability. Ultimately, the individual will be unable to resume high level overhead and overhead activities despite achieving clinical-based goals.

Recognizing the deafferentation of the injured and unstable joint is only half the battle. The rehabilitation specialist must design a program that re-establishes the dynamic functional stability of a joint in hopes of returning the athlete back to competition. Reactive neuromuscular training is employed as part of a functional exercise progression and can be instituted during and following the achievement of clinical-based goals. Before the clinician can utilize these activities, he or she must understand the possible effects RNT has on the CNS.

**SPINAL LEVEL**

Coordinated movement is made possible by the interaction between multiple subsystems located at all levels of the CNS. Three main levels exist in the CNS—the spinal cord, brainstem, and cortical motor areas. The muscle spindle is the key mechanoreceptor at the spinal level. Afferent fibers from the muscle spindles synapse with spinal interneurons, resulting in an efferent response which causes either facilitation or inhibition of the motor neuron—in other words, a stretch reflex. If an external disturbance, such as an increase in load, lengthens the muscle, the discharge rate of the spindle afferents increases. The stretch produced by the load is counteracted by a reflex contraction maintaining the muscle length close to a set value. The stretch reflex allows muscle tone to be regulated quickly and efficiently without direct interaction by higher neural centers. The perception of joint position and joint movement sense in the shoulder is essential for the placement of the hand in upper limb function. This perception cannot be accomplished without feedback from the mechanoreceptors and central programming from the motor cortex. The
objective of the RNT program is to stimulate the joint and muscle mechanoreceptors to encourage maximal afferent discharge to the appropriate CNS levels. Afferent discharge, will then create an appropriate efferent response at the joint in terms of reflex stabilization and somatosensory perception. Arm movement, reflex stabilization, postural control, and somatosensory perception are not separate events but rather different parts of an integrated action that raises the arm while maintaining balance. A rehabilitation program designed to encourage this feedback will increase the chances of returning an overhand and overhead athlete to their pre-injury level of function.

REHABILITATION

At the present time, no randomized controlled clinical trials exist examining the effects of RNT in the treatment of the unstable glenohumeral joint in the overhead and overhead athlete. However, some guiding principles must be kept in mind when designing the RNT program. The natural progression of these exercises should focus on the continuum of difficulty with respect to the sport or desired activity. These exercises should initially focus on static stabilization of the shoulder joint and progression would then focus on stimulating multiple systems, including vision. Exercises designed to develop dynamic stabilization should progress from bilateral to unilateral, supported to unsupported, and minimal capsular stress to maximal capsular stress. These activities can be performed early in the rehabilitation program, first in protected positions such as 90 degrees of elevation, again at 45 degrees of abduction, and eventually at the ends of the available range of motion when the glenohumeral joint is more likely to be unstable. Rhythmic stabilization in the plane of the scapula provides joint congruency and appropriate muscle length tension relationships to protect healing structures immediately post-injury or post-operatively (Figure 1). As the athlete progresses, more challenging positions include 90 degrees of abduction (Figure 2) combined with 90 or more

![Figure 1: Rhythmic Stabilization- Patient is sidelying, scapula retracted, upper extremity at side. Therapist moves forearm into ER/IR and pushes scapula toward protrusion as patient resists both.](image-url)
degrees of external rotation, and a similar position in standing (Figure 3-5). Raising the arm above shoulder level can induce increased muscle output and places the compromised glenohumeral joint in a sport-specific position. This position replicates the activities performed by overhand and overhead athletes and will undoubtedly create increased mechanoreceptor output and facilitate dynamic neuromuscular stabilization at the spinal level. Load the system with body weight first and then progress to external resistance. In turn, develop the core of the body before the extremity. The onset of transverse abdominus muscle activity has been documented to occur prior to, or in preparation for, upper extremity tasks.

Simple active and passive joint repositioning, or performing a scapula clock exercise (patient in sidelying, moves the shoulder toward the numbers of a clock, counterclockwise and then clockwise) can enhance somatosensory perception at the motor cortex. The position of the scapula and the scapulothoracic musculature plays a significant role in shoulder stability by providing a stable base of support from which the glenohumeral mus-
icles can fixate and function.\textsuperscript{46} The motor cortex also regulates many sports movements that entail controlled acceleration and deceleration.\textsuperscript{4} This control makes a case for performing sport-specific plyometric activities near the end of the rehabilitation process when dynamic stability and postural control have been established. Plyometric activities using a weighted ball stimulate unconscious programming as the focus is shifted from holding the arm stable to catching a ball. Movements can be progressed from a supine ball toss and catch in the 90-90 position to kneeling and standing. Eccentric throwing and catching activities enhance joint stabilization while working on deceleration of the upper extremity. These RNT activities are an integral part of the functional exercise progression and will help the athlete return to their pre-injury level of function.

**FUTURE RESEARCH**

Several areas surrounding RNT need to be addressed to further define the usefulness of this rehabilitation approach. Although this paper describes the use of RNT for an unstable shoulder, these techniques may be useful for any shoulder injury or someone with generalized ligamentous laxity. Secondly, randomized controlled clinical trials investigating RNT are needed to validate this approach. Lastly, objective milestones or outcome measures to better progress patients through the RNT program and determine when it is safe to return to athletic competition are recommended.

**CONCLUSION**

In this clinical commentary, the use of reactive neuromuscular training (RNT) is discussed as part of an overall functional rehabilitation program in the treatment of the unstable glenohumeral joint. Normal function of the musculoskeletal system requires a complex coordination of functional joint stability and motor control skills. Following injury to the glenohumeral joint, inappropriate or absent mechanoreceptor discharge can alter neuromuscular control resulting in increased risk for re-injury. An RNT program as part of a sport-specific functional exercise progression can re-establish dynamic stability and neuromuscular control. Clinicians can employ these techniques to target specific levels of the CNS to establish appropriate reflex responses and functional stability at the shoulder. Incorporating the principles of an RNT program in the treatment of an unstable shoulder can bridge the gap between traditional rehabilitation and competition, increasing the chances of an athlete returning to their pre-injury level of function.

**REFERENCES**

ABSTRACT

Background. Jumping and landing tasks are commonly used functional measurement tools to assess lower extremity performance in female athletes. However, few studies have established the number of trials needed to achieve reliability of measurement for evaluating landing mechanics.

Objective. To determine the reliability of peak hip and knee joint angles and peak ground reaction forces during two anterior-posterior unilateral functional tasks performed by young women.

Methods. Sixteen young women (28.5 ± 4.2 years; 162.2 ± 4.8 cm; 59.5 ± 8.1 kg) participated in this investigation. Each participant performed five trials of a 40-cm single leg drop jump and two trials of a ten-repetition, 20-cm, single leg up-down hop task during the same session. Peak hip and knee joint angles, peak vertical ground reaction forces, and ground contact time were measured. Intraclass correlation coefficients (ICC), standard errors of measurement, and 95% confidence intervals were calculated for all variables measured during multiple trials for both tasks.

Results. The five-trial mean ICC values of the drop jump were ≥0.75 for all variables. The single and two to four-trial average ICC values yielded good reliability for only some variables. Single-trial and two-trial mean ICC values for the up down test were ≥.77.

Discussion and Conclusion. The use of five-trial averages for the 40-cm drop jump and a single trial for the 20-cm, up-down hop task showed that for these functional tasks performed by young adult women, reliable measurement of lower extremity landing mechanics can be achieved.

Key Words: reliability, kinematics, landing, kinetics, hop test
INTRODUCTION
Women athletes experience higher knee joint injury rates compared to men in all sports.1-3 Study of lower extremity movement using three-dimensional motion analysis can contribute to the understanding of their knee injuries. Various functional tasks have been described by several investigators for analyzing lower extremity performance, especially when studying landing mechanics in young women. Functional tasks are ideal assessment tools since these tasks integrate several performance components such as joint mobility, muscle strength, power, proprioception, neuromuscular control, balance, and agility.4-6 However, most of the lower extremity tasks assessed with motion analysis in previous investigations have been bilateral landing tasks in men, or a combination of men and women.7,8 While bilateral tasks provide good information regarding lower extremity performance, these tasks could be missing critical unilateral events that are commonly experienced during sports.9,10 In most sports maneuvers, one limb encounters greater loads than the contralateral limb, even during bilateral activities such as cutting and pivoting.9,10 Investigators who conduct motion analysis research rarely report reliability estimates for analyzed tasks. Reliability refers to the reproducibility of the measurement and the ability to minimize measurement error, guaranteeing more accurate data.4,6,12,15 Investigators who have addressed reproducibility for kinematic variables have primarily assessed bilateral landing tasks in men and women participants combined.7,8 Researchers who have assessed reliability of both kinetic and kinematic variables during bilateral jump tasks performed by both sexes combined have calculated intraclass correlation coefficients (ICC’s) of 0.89 and above.7,8 Reliability values for single-leg tasks can be found in the literature but are limited because the focus has been only for jumping distance and time measures.6,15-17 No reliability values, measurement error estimation, or number of trials needed have been previously assessed for kinematic and kinetic variables during single-leg tasks. Furthermore, performance during single-leg tasks is influenced by external factors such as practice, confidence, fatigue, and number of trials.11,13,18 Greater reliability values have been reported when the average of selected trials was representative of 100% performance effort, which was not achieved until several practice trials had been taken.18 Several practice trials improve confidence and learning of the task.4,12,18 However, large numbers of trials may also increase the time during data collection and the risk of injuries during task performance.16,18 The researchers attest that during development and assessment of research protocols involving human participants, efforts should be made to maximize performance during testing procedures by allowing sufficient warm-up and an adequate number of trials.5

The purpose of this investigation was to determine reliability of peak hip and knee joint angles and peak ground reaction forces during two single-leg jumping and landing tasks in healthy young women in order to determine the number of trials needed to achieve acceptable reliability. Data was collected for hip flexion, hip adduction, hip internal rotation, knee flexion, knee valgus, knee external rotation, and vertical ground reaction force measures during a single-leg, 40-cm drop jump and a single-leg, 20-cm up-down hop task. A secondary purpose was to examine potential differences in these measures between the dominant and non-dominant legs.

METHODS
Participants
Sixteen physically active young adult women (age: 28.5 ± 4.2; height: 162.2 ± 4.8 cm; weight: 59.5 ± 8.1 kg) engaged in fitness activities such as jogging and weightlifting participated in this study. Participants were physical therapy students. Exclusion criteria were any history of back or lower extremity surgery and recent injury in the lower back or lower extremities over the past six months. Each participant read and signed an informed consent approved by Texas Woman’s University Institutional Review Board prior to participation. All participants were asked to perform a single hop for distance and a cross-over hop for distance as a screening procedure to obtain clearance for participation. Ability to stick the landing with no report of giving away of the knee during both functional screening tasks were used as criteria for participation and inclusion in the study.

Instrumentation
Participants had 12 retro-reflective markers attached to the skin. These markers were placed over the following
landmarks: bilateral anterior superior iliac spines; the second sacral vertebra; bilateral greater trochanters; bilateral lateral femoral epicondyles; bilaterally, mid-distance between the greater trochanters and lateral femoral epicondyles; bilateral medial femoral epicondyles; bilateral lateral malleoli; bilaterally, mid-distance between the lateral femoral epicondyles and lateral malleoli; bilateral medial malleoli; bilateral calcaneal tuberosities; and bilateral second metatarsophalangeal joints.

The motion analysis system consisted of four digital cameras (60-Hz sampling rate) time-synchronized to one force plate (AMTI, Watertown, MA) (1000 Hz sampling rate). Video data was captured with APAS CapDV software (Ariel Dynamics, Inc. San Diego, CA). Force plate data was recorded with APAS Analog software (Ariel Dynamics, Inc. San Diego, CA). Prior to data collection, space was calibrated according to the manufacturer's recommendation using a Direct Linear Transformation algorithm with an 8-point, 81.5-cm3 cube. A static trial was captured with each participant standing still, with arms across the chest, to align the joint coordinates to the laboratory recording instruments. After the static trial, the medial femoral epicondyle and medial malleolus markers were removed, to prevent interference between markers and the lower extremities during the performance trials.

**Procedures**

Weight, height, and the distance between anterior superior iliac spines were measured in each participant. The hip joint center was calculated using the distance between the anterior superior spines and Kwon 3D software (VISOL Inc., Seoul, Korea). Leg dominance was determined by the leg preferred to perform a single hop for distance.

The warm-up protocol consisted of five minutes of cycling at 40 to 60 rpm on a cycle ergometer, 10 half squats, and five continuous vertical jumps. In addition, each participant performed two practice trials with the dominant and non-dominant limbs for both jump tasks. Before participants performed these practice trials, a member of the research team demonstrated both tasks. Two practice trials following demonstration of functional tasks have shown to be sufficient for reliable results during performance of functional tasks.

The jump tasks utilized in this investigation consisted of a 40-cm single-leg drop jump (Figure 1) and a ten-repetition, single-leg, 20-cm up-down hop task (Figure 2). These tasks were randomly ordered. A total of five trials for the drop jump and two trials of the up-down task were performed during the same session. The drop jump was selected for its ability to create large eccentric loading on the lower extremities. The up-down task was selected because of its sensitivity, specificity, and accuracy (58%, 97%, and 80%, respectively) in diagnosing dynamic knee instability.

The drop jump (Figure 1) consisted of initially standing with both feet on the 40-cm platform

![Figure 1: 40-cm single-leg drop jump. Each participant dropped from a 40-cm box onto the force plate. Each participant performed a maximal vertical jump upon landing.](image1)

![Figure 2: 20-cm up-down hop task. Each participant jumped up-to and down-from a 20-cm box ten consecutive times. The middle six jumps were averaged and used for analysis.](image2)
and standing on the jumping leg when the command "on your mark" was given. After the command "set", the participant was instructed to drop down when she felt ready to do so. No additional instructions on how to stand on the drop jump box were given. Each participant was told not to jump vertically, but drop from the box. If the participant performed a vertical jump that was visible to the researchers, the trial was repeated. Each participant was instructed to perform a maximal effort vertical jump upon landing, single-leg, on the center of the force plate. Participants were allowed to use arms freely during all moments of the drop jump. Each participant was allowed to rest as long as she wanted between trials and tasks. Researchers did not allow participants to take less than one minute of rest between trials and tasks.

For the up-down hop task (Figure 2), the participant performed ten repetitive single-leg hops, up to and down from a 20-cm step. As developed by Itoh et al, this task began with each participant standing in front of the 20-cm step. As soon as she felt ready to do so, she jumped single-leg up to and down from the 20-cm step ten consecutive times. The ten consecutive up and down hops comprised one trial. Participants were allowed to use arms freely during all moments of the up-down hop task. Due to the high demands imposed on the lower extremities during this task, participants were required to perform this task only twice. Resting time between trials was similar to the drop jump.

Data Reduction

Joint angles were synchronized and analyzed with Kwon3D 3.1 software (VISOL Inc., Seoul, Korea). Synchronizing events were detected by the moments of initial contact and push-off from the force plate. Joint angles were derived and calculated from the three-dimensional trajectory of the retro-reflective markers. Frequency contents were initially screened using residual analysis and then filtered through a second order, low-pass Butterworth filter (6 Hz). Hip and knee joint angles were defined in the sagittal, frontal, and transverse planes as the first, second, and third rotations, respectively. Local reference frames fixed to the body were defined based on the markers and joint centers for the pelvis, thigh, shank, and the foot. Rotational transformation matrices between linked segments were computed based on the unit vectors of the local frames: pelvis to thigh (hip joint), thigh to shank (knee joint), and shank to foot (ankle joint). Euler angles (orientation angles) were computed from the rotational transformation matrices using the ML-AP-longitudinal axis (XYZ) rotation sequence.

Peak hip flexion, adduction, and internal rotation, and peak knee flexion, valgus, and external rotation were measured. In addition, peak vertical ground reaction forces and ground contact time were assessed. Joint angles and ground reaction force data were exported to Microsoft Excel™ for analysis. Peak values were identified as the greatest value for all variables from the moment each participant landed on the force plate through the moment she left the force plate into the vertical jump. Peak hip and knee joint angles and peak ground reaction forces were chosen as key variables of interest given these measurements are related to the main injury-causing factors to the knee joint.

From the total of ten continuous hops for the up-down hop task, the first two and last two jumps were excluded to account for acceleration and deceleration during the performance task, averaging the middle six jumps for analysis. This method of exclusion has been shown to help control for performance variability during physical performance tasks including multiple repetitions. The up-down data included the same peak joint angles and kinetic variables as the drop jump. The mean peak values of the middle six hops were considered for analysis.

Data Analysis

All kinematic and kinetic data were screened for normality assumptions and outliers using the Kolmogorov-Smirnov test and histograms. Means, standard deviations, intraclass correlation coefficients (ICC), standard errors of measurement (SEM), and 95% confidence intervals (CI) around the mean and ICC values among the trials in both tasks were calculated for the following measures: hip flexion, hip adduction, hip internal rotation, knee flexion, knee valgus, knee external rotation, vertical ground reaction forces, and contact time during landing. Mean values for peak joint angles and vertical ground reaction forces during the landing phase were used for analysis.

Repeated measures multivariate analyses of variance for mean peak values for five trials of the drop jump and mean peak values for two trials of the up-down task were conducted to determine any significant differences in
peak hip and knee joint angles, ground reaction forces, and contact time between the dominant and non-dominant limbs. Given that no significant differences between dominant and non-dominant legs were found, only the dominant leg was considered for the reliability analysis.

Repeated measures analyses of variance for the dominant limb were performed to develop within-session intraclass correlation coefficients for the averages of two to five trials of the drop jump (ICC [3, k]) and for the two-trial average of the up-down hop task (ICC [3, 2]). Intraclass correlation coefficients for a single trial (ICC [3, 1]) were calculated based on the number of multiple trials by using the following formula: between subjects mean square – error mean square / between subjects mean square + (k-1) error mean square.14

RESULTS

Means, standard deviations, ICC values, SEMs, and 95% CIs for the drop jump and up-down hop task are presented in Tables 1 and 2, respectively. The five-trial averages of the drop jump (Table 1) showed good reliability for all joint angles (ICC ≥ .75) and kinetic (ICC ≥ .86) measures. The single trial and 2, 3, and 4-trial averages yielded good reliability for some of the kinematic and kinetic variables for the drop jump, but not all. The single trial and 2-trial averages for the up-down task (Table 2) showed good reliability for all joint angles (ICC ≥ .77) and kinetic (ICC ≥ .86) measures.

DISCUSSION

The purpose of this investigation was to evaluate the number of trials needed to achieve acceptable reliability when assessing kinematic and kinetic variables during two single-leg tasks in young women. In sports physical therapy, single-leg testing using functional tasks such as the ones used in this investigation help detect muscle weaknesses and knee instabilities to a much greater extent than bilateral functional testing.23 Several components such as practice, familiarization, and confidence of the participant are necessary to perform functional tasks in an optimal manner.16,18 The researcher and sports physical therapist need to be aware how testing procedures could be performed in a more reliable manner and how reliability could be affected by several extraneous variables. Using the average score of multiple trials may improve reliability but may likely also increase the possibility of fatigue and increase the time for data collection and analysis.26 Therefore, a balance between the number of trials to obtain reliable results and feasibility in terms of fatigue and time management is needed during the measurement process.

The results of this investigation suggest that several trials are needed but the number of trials differs according to the specific movement and task analyzed. If tri-planar movements of the hip are considered during the drop jump, four trials are sufficient for reliable results, with hip internal rotation showing the lowest ICC value (0.81). When peak knee joint angles are assessed during the drop jump, five trials are recommended for reliable results in all three planes of motion, with knee flexion exhibiting the lowest ICC value (0.75). During the up-down hop task, a single trial exhibited good reliability for all hip and knee peak joint angles (>0.77). Therefore, these two tasks can be used as functional research tools in this population in a reliable manner for tri-planar hip and knee motion if five trials of the drop jump and a single trial of the ten-repetition up-down task are used to achieve ICC values greater than 0.75.11

Multiple factors could have affected each participant’s performance across trials. One of the most common factors thought to affect reliability of measurements is fatigue during testing procedures.5,13 Fatigue has shown to impair physical performance27 and affect reliability of hop testing.11 Augustsson et al11 assessed test-retest reliability of 11 male participants during a single-hop for distance during non-fatigued and fatigued sessions performed on separate days. The non-fatigue session comprised of performing the single-leg hop task after a warm-up protocol. During the fatigue session, each participant performed the single-leg hop task after a knee extensor fatigue protocol in a dynamometer. Participants performed three trials of a single-leg hop for distance on each of the sessions. The researchers found that within-trials reliability for the non-fatigue session was higher (ICC = 0.98) than the reliability values for the fatigue session (ICC = 0.75). However, when participants were retested three minutes after finishing the fatigue session hop tasks values were similar to the non-fatigue state exhibiting almost full recovery.8 In this investigation, to prevent the possible effects of fatigue on each participant’s performance, each woman was allowed to rest as long as she needed before performing
Table 1. Kinematic and kinetic reliability values for the drop jump

<table>
<thead>
<tr>
<th>Kinematics</th>
<th>Trials</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ICC (SEMº)</td>
<td>ICC (SEMº)</td>
<td>ICC (SEMº)</td>
<td>ICC (SEMº)</td>
<td>ICC (SEMº)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>95% CI</td>
<td>95% CI</td>
<td>95% CI</td>
<td>95% CI</td>
<td>95% CI</td>
</tr>
<tr>
<td>Kinematics</td>
<td>Single Trial</td>
<td>55.13 ± 12.06</td>
<td>54.66 ± 12.23</td>
<td>54.41 ± 11.85</td>
<td>54.12 ± 11.80</td>
<td>53.76 ± 12.04</td>
</tr>
<tr>
<td></td>
<td>2-Trial Avg</td>
<td>45.38-64.88</td>
<td>47.47-61.85</td>
<td>49.22-59.60</td>
<td>50.11-58.13</td>
<td>50.42-57.10</td>
</tr>
<tr>
<td></td>
<td>3-Trial Avg</td>
<td>.83a (4.97)</td>
<td>.91 (3.67)</td>
<td>.95 (2.65)</td>
<td>.97 (2.04)</td>
<td>.98 (1.70)</td>
</tr>
<tr>
<td></td>
<td>4-Trial Avg</td>
<td>.55-.94</td>
<td>.71-.97</td>
<td>.88-.98</td>
<td>.93-.99</td>
<td>.95-.99</td>
</tr>
<tr>
<td></td>
<td>5-Trial Avg</td>
<td>13.47 ± 5.19</td>
<td>11.74 ± 4.87</td>
<td>10.95 ± 5.04</td>
<td>10.61 ± 5.20</td>
<td>10.43 ± 5.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45.38-64.88</td>
<td>47.47-61.85</td>
<td>49.22-59.60</td>
<td>50.11-58.13</td>
<td>50.42-57.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.75a (2.60)</td>
<td>.86 (1.82)</td>
<td>.93 (1.33)</td>
<td>.93 (1.38)</td>
<td>.95 (1.19)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.39-.91</td>
<td>.56-.95</td>
<td>.84-.98</td>
<td>.85-.98</td>
<td>.88-.98</td>
</tr>
<tr>
<td>Hip flexion</td>
<td></td>
<td>11.27 ± 9.24</td>
<td>12.01 ± 9.66</td>
<td>11.37 ± 8.24</td>
<td>10.81 ± 7.68</td>
<td>10.54 ± 7.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45.38-64.88</td>
<td>47.47-61.85</td>
<td>49.22-59.60</td>
<td>50.11-58.13</td>
<td>50.42-57.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0-24.33</td>
<td>0.81-23.31</td>
<td>2.98-19.76</td>
<td>4.25-17.37</td>
<td>5.39-15.69</td>
</tr>
<tr>
<td>Hip adduction</td>
<td></td>
<td>.48 (6.66)</td>
<td>.65 (5.71)</td>
<td>.73 (4.28)</td>
<td>.81 (3.35)</td>
<td>.88 (2.63)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-.05-.80</td>
<td>-.10-.89</td>
<td>.33-.91</td>
<td>.59-.93</td>
<td>.73-.95</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td></td>
<td>63.46 ± 10.78</td>
<td>60.11 ± 6.82</td>
<td>59.60 ± 5.73</td>
<td>59.82 ± 6.05</td>
<td>60.04 ± 6.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>43.30-83.62</td>
<td>47.86-72.36</td>
<td>50.14-69.06</td>
<td>52.41-67.23</td>
<td>53.74-66.34</td>
</tr>
<tr>
<td>Knee flexion</td>
<td></td>
<td>.09 (10.28)</td>
<td>.16 (6.25)</td>
<td>.29 (4.83)</td>
<td>.61 (3.78)</td>
<td>.75 (3.22)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-.44-.58</td>
<td>-1.61-.73</td>
<td>-.73-.75</td>
<td>.12-.86</td>
<td>.46-.91</td>
</tr>
<tr>
<td>Knee valgus</td>
<td></td>
<td>3.40-17.48</td>
<td>4.90-14.76</td>
<td>6.08-13</td>
<td>6.87-12.29</td>
<td>7.14-12.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.34 (3.59)</td>
<td>.51 (2.51)</td>
<td>.73 (1.77)</td>
<td>.84 (1.38)</td>
<td>.86 (1.26)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-.20-.73</td>
<td>-.52-.84</td>
<td>.34-.91</td>
<td>.63-.94</td>
<td>.70-.95</td>
</tr>
<tr>
<td>Knee external rotation</td>
<td></td>
<td>11 ± 7.79</td>
<td>10.65 ± 6.71</td>
<td>10.76 ± 7.06</td>
<td>10.79 ± 7.46</td>
<td>10.78 ± 7.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.74 (3.97)</td>
<td>.85 (2.60)</td>
<td>.93 (1.87)</td>
<td>.96 (1.49)</td>
<td>.97 (1.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.36-.91</td>
<td>.53-.95</td>
<td>.82-.97</td>
<td>.90-.98</td>
<td>.94-.99</td>
</tr>
<tr>
<td>GRF (BW)</td>
<td></td>
<td>3.40-17.48</td>
<td>4.90-14.76</td>
<td>6.08-13</td>
<td>6.87-12.29</td>
<td>7.14-12.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.34 (3.59)</td>
<td>.51 (2.51)</td>
<td>.73 (1.77)</td>
<td>.84 (1.38)</td>
<td>.86 (1.26)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-.20-.73</td>
<td>-.52-.84</td>
<td>.34-.91</td>
<td>.63-.94</td>
<td>.70-.95</td>
</tr>
<tr>
<td>Contact time (seconds)</td>
<td></td>
<td>11 ± 7.79</td>
<td>10.65 ± 6.71</td>
<td>10.76 ± 7.06</td>
<td>10.79 ± 7.46</td>
<td>10.78 ± 7.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.74 (3.97)</td>
<td>.85 (2.60)</td>
<td>.93 (1.87)</td>
<td>.96 (1.49)</td>
<td>.97 (1.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.36-.91</td>
<td>.53-.95</td>
<td>.82-.97</td>
<td>.90-.98</td>
<td>.94-.99</td>
</tr>
</tbody>
</table>

SD: standard deviation; ICC: Intraclass Correlation Coefficient; SEM: standard error of measurement estimated using SD of the score; 95% CI: confidence interval based on SEM; GRF: ground reaction forces/times body weight. a Intraclass correlation coefficients for a single trial (ICC [3, 1]) were calculated based on the number of multiple trials used by the following formula: between subjects mean square – error mean square / between subjects mean square + (k-1) error mean square (Figure 3).
Table 2. Kinematic and kinetic reliability values for the up-down hop test

<table>
<thead>
<tr>
<th>Trials</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
</tr>
<tr>
<td></td>
<td>ICC (SEMº)</td>
<td>ICC (SEMº)</td>
</tr>
<tr>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
<td></td>
</tr>
<tr>
<td><strong>Kinematics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Trial</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kinematics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hip flexion</strong></td>
<td>36.95 ± 7.56</td>
<td>38.69 ± 7.37</td>
</tr>
<tr>
<td></td>
<td>36.34-42.96</td>
<td>36.19-41.19</td>
</tr>
<tr>
<td></td>
<td>.95° (1.69)</td>
<td>.97 (1.28)</td>
</tr>
<tr>
<td></td>
<td>.82-.99</td>
<td>.90-.99</td>
</tr>
<tr>
<td><strong>Hip adduction</strong></td>
<td>9.72 ± 7.42</td>
<td>9.14 ± 7.17</td>
</tr>
<tr>
<td></td>
<td>5.87-13.57</td>
<td>6.71-11.58</td>
</tr>
<tr>
<td></td>
<td>.93° (1.96)</td>
<td>.97 (1.24)</td>
</tr>
<tr>
<td></td>
<td>.76-.98</td>
<td>.87-.99</td>
</tr>
<tr>
<td><strong>Hip internal rotation</strong></td>
<td>7.59 ± 7.53</td>
<td>7.78 ± 7.42</td>
</tr>
<tr>
<td></td>
<td>5.04-10.15</td>
<td>5.72-9.84</td>
</tr>
<tr>
<td></td>
<td>.97° (1.30)</td>
<td>.98 (1.05)</td>
</tr>
<tr>
<td></td>
<td>.89-.99</td>
<td>.94-1.0</td>
</tr>
<tr>
<td><strong>Knee flexion</strong></td>
<td>51 ± 4.25</td>
<td>49.55 ± 5.39</td>
</tr>
<tr>
<td></td>
<td>47.01-54.99</td>
<td>45.74-53.36</td>
</tr>
<tr>
<td></td>
<td>.77° (2.04)</td>
<td>.87 (1.94)</td>
</tr>
<tr>
<td></td>
<td>.36-.94</td>
<td>.53-.97</td>
</tr>
<tr>
<td><strong>Knee valgus</strong></td>
<td>7.49 ± 5.97</td>
<td>6.25 ± 4.88</td>
</tr>
<tr>
<td></td>
<td>4.63-10.36</td>
<td>4.59-7.90</td>
</tr>
<tr>
<td></td>
<td>.94° (1.46)</td>
<td>.97 (0.85)</td>
</tr>
<tr>
<td></td>
<td>.79-.99</td>
<td>.88-.99</td>
</tr>
<tr>
<td><strong>Knee external rotation</strong></td>
<td>10.12 ± 8.09</td>
<td>8.96 ± 7.93</td>
</tr>
<tr>
<td></td>
<td>5.92-14.32</td>
<td>6.27-11.65</td>
</tr>
<tr>
<td></td>
<td>.93° (2.14)</td>
<td>.97 (1.37)</td>
</tr>
<tr>
<td></td>
<td>.76-.98</td>
<td>.86-.99</td>
</tr>
<tr>
<td><strong>Kinetics</strong></td>
<td>2.67 ± .57</td>
<td>2.80 ± .39</td>
</tr>
<tr>
<td></td>
<td>2.29-3.06</td>
<td>2.61-2.99</td>
</tr>
<tr>
<td><strong>GRF (BW)</strong></td>
<td>.88° (.20)</td>
<td>.94 (.10)</td>
</tr>
<tr>
<td></td>
<td>.65-.96</td>
<td>.79-.98</td>
</tr>
<tr>
<td><strong>Contact time</strong></td>
<td>.04 ± .03</td>
<td>.07 ± .02</td>
</tr>
<tr>
<td>(seconds)</td>
<td>.03-.05</td>
<td>.07-.08</td>
</tr>
<tr>
<td></td>
<td>.97° (.01)</td>
<td>.99 (0.0)</td>
</tr>
<tr>
<td></td>
<td>.91-.99</td>
<td>.95-1.0</td>
</tr>
</tbody>
</table>

SD: standard deviation; ICC: Intraclass Correlation Coefficient; SEM: standard error of measurement estimated using SD of the score; 95% CI: confidence interval based on SEM; GRF: ground reaction forces/times body weight. * Intraclass correlation coefficients for a single trial (ICC [3, 1]) were calculated based on the number of multiple trials used by the following formula: between subjects mean square – error mean square / between subjects mean square + (k-1) error mean square (Figure 3).
the next trial. Although sufficient rest was allowed between trials, the possibility of cumulative fatigue throughout the testing session could not be dismissed.

The 60 Hz sampling rate could have introduced variability into the measurement of such fast movements. However, the high frequency components for the drop jump and up-down jump tasks, especially during impact with the force plate capable of introducing such variability, were filtered through the 6 Hz low-pass filter. Therefore, the 60 Hz sampling rate with a 6 Hz Butterworth filter seems reasonable given the data of interest were peak hip and knee joint moments during the ground contact phase.

Perry et al18 assessed the number of trials during hop tests needed for reliable distance and height measures in individuals with anterior cruciate ligament deficiency and ACL reconstruction. The researchers reported that for the single-hop for distance and triple crossover tasks, a minimum of 10 trials ensured 99% of maximum performance effort values in both tasks. Similarly, a minimum of 15 trials were needed to ensure 97.6% of maximum performance effort during the vertical single-leg jump. The number of trials needed in a research protocol are important if accurate results are expected and if the trials are indeed representative of maximum performance.18 The results of the current investigation showed results similar to Perry et al18 in terms of total number of jumps needed for acceptable reliability.

Previous investigations evaluating landing performance in young women during bilateral landing tasks used three to five trials and reported good ICC values for knee joint kinematics and kinetics without a comprehensive warm-up.7,8 No investigations of reliability for kinematic and kinetic variables have reported SEM or 95% CI values.7,8 These statistics indicate the trial-to-trial error expected in the functional tasks and determine the range for a population’s true score.12 Known error scores help the researcher assess whether changes in participants’ performance are really true changes or are within the range of error for the specific measurement.112 In addition, these statistics allow observation of the improvements in reliability values with greater number of trials (Tables 1-2).

Typically, only the dominant leg is used as reference for biomechanical analysis and to make group comparisons when evaluating lower extremity landing mechanics. The findings of this investigation suggest that in non-injured young women, either the dominant or non-dominant leg may be considered as reference for analysis. These findings are consistent with other investigations in which no statistically significant differences between the dominant and non-dominant legs were found for lower extremity joint angles,25 muscle strength,21 and endurance28 during physical performance tasks.

Several practical applications exist that could be derived from this investigation. First, the process of familiarization and warm-up should be included in testing protocols to ensure near maximum performance. In addition, the use of multiple trial or multiple repetition averages enhances the reliability of the measurements and reduces the absolute measurement error. The protocol used in this investigation was acceptable for reliably testing single-leg landing mechanics in young women. Because ligamentous injuries have been shown to occur mainly during unilateral tasks, single-leg functional tasks should be incorporated into biomechanical assessments of performance.

CONCLUSIONS
The results of this investigation revealed that the average of five trials of the drop jump and one trial of the 10-repetition up-down task are recommended to obtain good trial-to-trial reliability for hip and knee peak joint angles and ground reaction forces. Additionally, in healthy non-injured individuals either dominant or non-dominant legs could be used to assess landing mechanics.

REFERENCES


ABSTRACT

Methicillin resistant Staphylococcus aureus (MRSA), is a problematic infection which is becoming more common in a variety of athletic related environments. Early recognition, diagnosis, and timely management of infection can help minimize the severity of infection and decrease the rate of transmission. Since most sports physical therapists typically lack adequate knowledge and ability to identify cases of MRSA infection, the purpose of this review is to provide a background for associated risk factors, recognition, treatment, and prevention of community associated-MRSA in athletic environments.

CORRESPONDENCE:
Terry L. Grindstaff
University of Virginia
290 Massie Road
McCue Center
PO BOX 400834
Charlottesville, VA 22903
434-243-2419 (work)
434-243-2430 (fax)
tlg6q@virginia.edu

1 Department of Athletics
University of Virginia
Charlottesville, VA

2 Curry School of Education
University of Virginia
Charlottesville, VA

3 Department of Physical Medicine and Rehabilitation
Department of Internal Medicine
Curry School of Education
University of Virginia
Charlottesville, VA

4 Clinical Internal Medicine & Orthopaedic Surgery
University of Virginia
Charlottesville, VA
Introduction

The role of the sports physical therapist as a member of the sports medicine team continues to expand, making it critical to increase the knowledge related to non-musculoskeletal issues. Recognition and management of skin infections becomes increasingly necessary in the comprehensive medical care of the athlete. One infection of concern is *Staphylococcus aureus*, a commonly occurring bacterial species which is moving from nosocomial (hospital-based) to community-acquired infections found in a variety of athletic-related environments.\(^1\)\(^2\) *Staphylococcus aureus* is a naturally occurring bacteria found on skin and can be divided into two categories based on its susceptibility or resistance to beta-lactam antibiotics; methicillin susceptible (MSSA) or methicillin resistant (MRSA).\(^3\)

Methicillin resistant *Staphylococcus aureus* has been typically associated with healthcare acquired (HA-MRSA) risk factors including recent surgery and hospitalization, indwelling catheter, kidney dialysis, and prolonged stay in long-term care facility (nursing home, hospice).\(^4\)\(^5\) In the late 1990’s, cases of MRSA began to appear in the community (CA-MRSA)\(^6\) and athletic-related environments.\(^7\)\(^8\) These athletic-related cases had risk factors for acquisition and clinical characteristics distinct from HA-MRSA.\(^5\)\(^6\)\(^12\) Risk factors included participation in contact sports with repeated close physical contact with other competitors, open abrasions, increased use of antibiotics, and sharing of personal equipment.\(^7\)\(^8\)\(^12\)\(^13\)\(^14\)

The medical management of MRSA can be problematic due to low incidence rates, rapid transmission, and limited pharmacological interventions that effectively manage the infection. Low incidence rates of CA-MRSA in athletic environments can delay accurate recognition, diagnosis, and timely management which can increase the risk of infection in other individuals and cause subsequent increase in morbidity. Unrecognized or untreated cases of MRSA can quickly progress to a severe infection requiring hospitalization,\(^16\)\(^17\) surgery,\(^17\) and may lead to death. Selection of appropriate treatment strategies can also be further complicated by the characteristic antibiotic resistance patterns associated with CA-MRSA.\(^5\)\(^10\) Most sports physical therapists typically lack adequate knowledge and ability to identify cases for physician referral and an understanding of the severity and complications of untreated cases. Since the prevalence of CA-MRSA cases has increased in athletic environments,\(^12\)\(^13\)\(^15\)\(^20\) individuals who provide medical care for athletes should have a basic understanding of CA-MRSA infections. Therefore, the purpose of this review is to provide the sports physical therapist with a background for associated risk factors, recognition, treatment, and prevention of CA-MRSA in athletic environments.

Literature Search

A search of PubMed (1966-2006) and Web of Science (1981-2006) was conducted in December 2006, using combinations of the terms, Staphylococcus aureus, methicillin resistant, MRSA, athletic, and sport. The search was limited to articles written in English using human subjects. Fifty articles were obtained in the original search and titles and abstracts were screened for relevance. References were also cross-referenced and other relevant literature was reviewed for identification of studies not found using the original search terms. A total of 13 manuscripts ranging from case reports to retrospective cohort studies related to CA-MRSA in athletics were retained.\(^7\)\(^8\)\(^12\)\(^14\)\(^16\)\(^21\)

Risk Factors

*Staphylococcus aureus* is a ubiquitous bacteria which can cause infections in patients of any age, race, gender, or economic background and has been found in a variety of settings, regions, and countries.\(^24\) Community-associated MRSA has been diagnosed in individuals who participate in contact and non-contact sports from high school to professional levels (*Table 1*). Reported cases have ranged from 1-13 athletes per team and involved up to 25% of the team.\(^7\)\(^8\)\(^12\)\(^14\)\(^16\)\(^21\) Three common factors implicated in the development of CA-MRSA include exposure to infection, compromised skin integrity, and transmission via direct (person-to-person) or indirect contact (person-to-object).

Exposure to Infection

Swabs from the anterior nares indicate approximately 35% of healthy individuals are colonized with MSSA\(^12\)\(^25\) and less than 10% are colonized with MRSA.\(^12\)\(^14\)\(^25\) Teens, younger adults, males, and individuals with asthma tend to be the most likely carriers.\(^3\)\(^5\)\(^25\) The high use of antibi-
otics throughout the year is an additional risk factor for CA-MRSA. Increased antibiotic use alters nasal bacterial flora and thus provides a more conducive environment for MRSA colonization.

Compromised Skin Integrity

Areas of compromised skin integrity serve as an entry portal for a variety of infectious agents. The most common method of transmission is thought to occur when sites of skin injury or abrasion are in direct contact with sites of bacterial colonization. Burns associated with athletic surfaces such as turf or wrestling mats are associated with CA-MRSA infections, both near and distant to the site of injury. Infection tends to occur most often on extremities which are not covered by athletic apparel (elbow, forearm, knee, lower leg). Unfortunately, areas covered by clothing or protective equipment are also at risk following recent skin trauma due to shaving or abrasions. Shaving body areas other than the face (cosmetic shaving) has been shown to increase the risk of infection of areas covered by athletic equipment and clothing.

Transmission via Person-to-Person

The most common method of transmission is direct contact with contaminated individuals. A definitive relationship has been demonstrated between CA-MRSA cases and direct contact with infected individuals. Risk of infection is thought to be proportional to the frequency and duration of exposure to infected individuals. Prolonged contact usually occurs between athletes on the same team, as well as competitors from other teams who participate in sports with a greater duration of competition (football). This risk is less for athletic events with shorter durations (wrestling).

American football, wrestling, and rugby have been commonly implicated in increased infection rates due to frequent close contact between athletes. Retrospective analysis of cases indicate the highest infection rates tend to occur with positions such as rugby forwards; American football linemen, cornerbacks, and wide receivers; and wrestlers where repeated direct contact occurs throughout competition and practices. It should be noted since CA-MRSA has a low incidence rate,
analysis of infection rates by position or sport should be interpreted with caution. Community associated-MRSA has been proposed to be more common in individuals with a higher body mass index (BMI). \textsuperscript{12} Wrestlers tend to be affected equally across all weight classes\textsuperscript{7} which contrasts findings that CA-MRSA has been associated with higher BMI. \textsuperscript{12} Findings related to higher BMI in American football may have been due to the association between position (i.e. linemen) and weight. Additionally, wrestlers may be at decreased risk due to strict guidelines involving participation in competition and management of skin infections and open wounds.\textsuperscript{27}

**Transmission via Person-to-Object**

Identification of the source of infection plays a critical role in limiting the spread and thorough management of CA-MRSA. As CA-MRSA infections become more common in athletics, it is possible that individuals who compete against each other could become independently infected with the same strains,\textsuperscript{12} thus increasing the difficulty to identify the source of infections.

Cases reported in non-contact sports have been associated with shared equipment in facilities such as the locker room or athletic training room.\textsuperscript{16,20} Even roommates of infected individuals have been shown to be at risk of infection.\textsuperscript{14,23,28} Cases of MRSA have also been reported in athletes who shared fencing equipment,\textsuperscript{20} razors,\textsuperscript{11} towels,\textsuperscript{11,20} and bar soap.\textsuperscript{14} Staphylococcus aureus has also been shown to be present in whirlpools and taping gel applicators.\textsuperscript{12} Common areas in athletic environments which may aid in the transmission of infections include treatment tables, benches, training equipment, and flooring (especially carpeted) in locker rooms, weight rooms, and athletic training rooms. However, other studies have failed to demonstrate a definitive link between MRSA cases and playing surfaces\textsuperscript{12} or sharing of equipment or facilities.\textsuperscript{1,12,13,19}

**SOLUTION**

**Case Identification/Differential Diagnosis**

The most common presentation of CA-MRSA is in the form of soft tissue lesions such as an abscess or cellulitis.\textsuperscript{5,6,12,14,15,20,20} Visual inspection offers several clues for identification of CA-MRSA (Figure 1 and 2). Clinically, the lesion and erythema are associated with pain that is out of proportion for the severity of the lesion. Other characteristic signs and symptoms include redness, swelling, warmth, and possible purulent discharge from the lesion site. Lesions are commonly mistaken for a spider bite,\textsuperscript{15,20} pimple, or boil.\textsuperscript{12,14} Occasionally, the diameter of the affected area can be as large as 5-7 cm.\textsuperscript{12}

**Management**

The increased prevalence of MRSA soft tissue infections found in the general population necessitates a low threshold for timely physician referral following the appearance of a lesion that presents with the aforementioned characteristics. The sports physical therapist should contact the physician to facilitate and ensure expedited care. Since recurrent infections are common\textsuperscript{12,13} the sports physical therapist should have an even lower threshold for physician referral for individuals with a history of CA-MRSA. In the event that the team physician or patient's primary care physician is unavailable for immediate consult, the patient should be directed to an urgent care facility. Until the wound has been formally diagnosed, MRSA should be suspected.

A small, uncomplicated area can be managed using over the counter topical antibacterial ointment (Neosporin), with close monitoring of the concerning lesion for up to 48 hours. The sports physical therapist should be able to gain a sense over 24-48 hours as to whether an area is pro-
Topical antibiotics are useful for less severe infections. However, strains of CA-MRSA are resistant to numerous antibiotics, including commonly used beta-lactams, cephalosporins, macrolides, penicillins, and quinolones. Therefore, if the initial treatment with oral antibiotics is unsuccessful in eradicating pain, swelling, or erythema, the lesion should be excised, drained, and the fluid cultured to direct treatment based on antibiotic sensitivity.

Systemic antibiotic use should be reserved for severe infections or mild to moderate infections that cover a large surface area. Large wounds may require hospitalization, surgical debridement, and intravenous antibiotics. It is recommended to use an antimicrobial agent that successfully treats a variety of gram positive bacterial infections. Antibiotics such as clindamycin, sulfamethoxazole/trimethoprim (SMX-TMP), ciprofloxacin, rifampin, vancomycin, or linezolid are appropriate treatment options. However, treatment with SMX-TMP and fluoroquinolones have been shown to be associated with higher recurrence rates and are not recommended as first line therapy. Most infections resolve in 10 days with appropriate treatment. Infections that do not respond to initial treatment regimens or recur should be treated with another group of antibiotics based on antibiotic sensitivity.

Obtaining nasal cultures from individuals who may have been exposed to CA-MRSA to determine the presence of infection is questionable. Approximately 35% of asymptomatic individuals carry MSSA and less than 10% of asymptomatic individuals carry MRSA. A positive nasal culture may warrant the use of topical mupirocin if deemed necessary by the treating physician. Topical mupirocin is applied to the nares prophylactically for 5 days to 4 weeks to prevent or limit the spread of skin flora.
infection, but may not entirely reduce the risk of infection since infection can occur regardless of a positive nasal culture.19

APPLICATION IN PHYSICAL THERAPY

Prevention

The management of CA-MRSA begins with prevention. Reports of CA-MRSA cases tend to be relatively isolated, yet individuals have been diagnosed in numerous athletic settings.7,8,12-14,18-20 Although CA-MRSA cannot be entirely prevented, best practice measures can be employed to reduce the risk among athletes. The National Athletic Trainers’ Association (NATA) and the Centers for Disease Control (CDC) have outlined recommendations (Tables 2 and 3, respectively) for the prevention and management of CA-MRSA.20,33 One retrospective study was able to demonstrate a decreased rate of infection after implementing a variety of prevention strategies.17 Future research should determine the effectiveness of these recommendations.

Athletes should be encouraged to use liquid antibacterial soap (3% hexachlorophene or 4% chlorhexidine) for showers immediately after practice and frequently wash hands. Clinicians should also be encouraged to wash hands thoroughly with soap or utilize an alcohol-based hand sanitizer, both before and after treatment sessions. Attention to meticulous wound cleanliness and care should be rigorously emphasized. Universal precautions should be employed when treating open skin wounds, which may serve as a reservoir of infection. All wounds should be appropriately covered during and following competition at all athletic events.

Techniques to reduce the frequency of abrasions should be employed, although the use of elbow and knee pads may facilitate infection due to moisture retention conducive to bacterial growth.13 It is recommended that disposable, adhesive mesh strips (Figure 3) be firmly secured to the skin in order to prevent wounds that occur via contact from either playing surfaces or other competitors. Skin irritation may develop in a subset of athletes with sensitive skin secondary to removal of the mesh on a daily basis. Therefore, the decision to use an adhesive mesh should be made on an individual basis.

The practice of sharing personal hygiene products (soap, razors) and sports equipment should also be discouraged. Individual or dis-
Disposable towels should replace community towels commonly used at practices and games. Towels used in the clinic should be washed in hot water (> 71 °C) using detergent and chlorine bleach after each use.32

Athletes should be required to shower immediately following practice before entering the sports medicine clinic or athletic training room. Equipment such as treatment tables and weight room benches should be cleaned and disinfected appropriately after use with a commercial product that contains anti-viral and anti-microbial substances, such as CaviCide® (Unimed-Midwest, Inc., Burnsville, MN).37 Pillow cases and other treatment table linens should be changed following individual treatment sessions and washed in a similar manner as towels. Proper disinfection techniques should also be employed for hydrotherapy (whirlpool) areas. Circulating tubs should be cleaned with an Environmental Protection Agency (EPA) registered disinfectant. The cleaning solution is circulated in the spa for 10 minutes, followed by a rinse with water, and finally air-dried.37 Non-circulating tubs should be scrubbed, rinsed and drained, sprayed with an EPA registered disinfectant, allow to sit for 10 minutes, rinsed with water, and air-dried.37 Traditional pools, Jacuzzi spas, and exercise pools (Hydroworx or Swimex) use chlorine or ultrasonics to filter and disinfect the pools. Sports physical therapists should be cautious of an athlete with open skin wounds who uses pools. Turbulence can cause skin debridement and subsequent use of towels can produce a source of cross-contamination.

Secondary to the potent virulence and potential adverse sequelae, CA-MRSA is reportable in many states. Outbreaks in confined environments should be closely monitored, but ethical concerns and issues exist when reporting communicable diseases. Individuals and teams may fear the negative stigma associated with a communicable disease.14 Also, the consequences resulting from restricted participation may have implications on win/loss records, and current and future financial incentives (scholarships and contracts) for participation in athletic events. Ultimately, the sports medicine team should determine the time for return to participation that ensures safety of the athlete with CA-MRSA, teammates, and other competitors.

CONCLUSIONS
Research regarding CA-MRSA in athletic environments is relatively limited and retrospective designs are typically used to describe prevalence rates and treatment strategies. Due to low incidence rates, systematic tracking using large database programs such as the NCAA Injury Surveillance System (ISS) may help determine treatment and prevention effectiveness. Community associated-MRSA is increasingly prevalent in athletic settings. The sports physical therapists must be aware of risk factors, differential diagnosis, optimal timing for referral, and treatment strategies, while working closely with certified athletic trainers and team physicians. Due to rapid transmission and adverse sequelae of infection (hospitalization, surgery, death), cases of CA-MRSA should not be minimized. Ultimately, prevention is the greatest defense and all members of the sports medicine staff should utilize universal precautions when treating athletes, maintain clean environments within commonly shared areas, encourage proper hygiene practices, and discourage sharing of personal items such as razors, soap, and towels.
REFERENCES


ABSTRACT

Background. Little data exists regarding injury risk factors for professional football players. Athletes with poor dynamic balance or asymmetrical strength and flexibility (i.e. poor fundamental movement patterns) are more likely to be injured. The patterns of the Functional Movement Screen™ (FMS) place the athlete in positions where range of motion, stabilization, and balance deficits may be exposed.

Objectives. To determine the relationship between professional football players’ score on the FMS™ and the likelihood of serious injury.

Methods. FMS™ scores obtained prior to the start of the season and serious injury (membership on the injured reserve for at least 3 weeks) data were compiled for one team (n = 46). Utilizing a receiver-operator characteristic curve the FMS™ score was used to predict injury.

Results. A score of 14 or less on the FMS™ was positive to predict serious injury with specificity of 0.91 and sensitivity of 0.54. The odds ratio was 11.67, positive likelihood ratio was 5.92, and negative likelihood ratio was 0.51.

Discussion and Conclusion. The results of this study suggest fundamental movement (as measured by the FMS™) is an identifiable risk factor for injury in professional football players. The findings of this study suggest professional football players with dysfunctional fundamental movement patterns as measured by the FMS™ are more likely to suffer an injury than those scoring higher on the FMS™.

Key words: Functional Movement Screen, injury prediction

CORRESPONDENCE:
Kyle Kiesel
Wallace Graves Hall 206
University of Evansville
Evansville, IN 47722
Kk70@evansville.edu
Phone: (812) 479-2646
Fax: (812) 479-2717

Kyle Kiesel, PT, PhD, ATC, CSCSa
Phillip J. Plisky, PT, DSc, OCS, ATCa
Michael L. Voight, PT, DHSc, OCS, SCS, ATCb

* ProRehab PC
Evansville, IN

* Belmont University
Nashville, TN
INTRODUCTION

Participation in football is one of the leading causes of sport related injury with over 500,000 injuries occurring per year in high school and collegiate football. To date, the injury rate for professional football has not been reported in the literature; but, the injury rate for high school and collegiate football ranges from 1.3 to 26.4 per 1000 athletic exposures (18.4-51.7 injuries per 100 players). Although limited published reports exist on injury risk factors for professional football players, researchers have prospectively identified risk factors for injury in high school and collegiate levels of competitive football. These risk factors include previous injury, body mass index, body composition (percent body fat), playing experience, femoral intercondylar notch width, cleat design, playing surface, muscle flexibility, ligamentous laxity, and foot biomechanics. Although these risk factors have been examined individually, injury risk is likely multifactorial. The dynamic interplay of risk factors during sport and their relationship to injury, needs additional investigation. Furthermore, evaluation of isolated risk factors does not take into consideration how the athlete performs the functional movement patterns required for sport.

Recently, researchers have utilized movement examinations that involve comprehensive movement patterns to predict injury. Pilsky et al hypothesized that tests assessing multiple domains of function (balance, strength, range of motion) simultaneously may improve the accuracy of identifying athletes at risk for injury through pre-participation assessment. The Functional Movement Screen (FMS™) is a comprehensive exam that assesses quality of fundamental movement patterns to identify an individual’s limitations or asymmetries. A fundamental movement pattern is a basic movement utilized to simultaneously test range of motion, stability, and balance. The exam requires muscle strength, flexibility, range of motion, coordination, balance, and proprioception in order to successfully complete seven fundamental movement patterns. The athlete is scored from zero to 3 on each of the seven movement patterns with a score of 3 considered normal. The scores from the seven movement patterns are summed and a composite score is obtained. The intra-rater reliability of the composite score (which was used in the analysis for this study) for the FMS™ is reported to have an ICC value of 0.98. Additional information regarding the development and uses of the FMS™ was documented by Foran, Cook, and recently published journal articles. Mobility and stability extremes are explored in order to uncover asymmetries and limitations. The scoring system was designed to capture major limitations and right-left asymmetries related to functional movement. Additionally, clearing tests were added to assess if pain is present when the athlete completes full spinal flexion and extension and shoulder internal rotation/extension.

The seven tests utilize a variety of basic positions and movements which are thought to provide the foundation for more complex athletic movements to be performed efficiently. The Appendix includes pictures of and detailed scoring criteria for each of the seven tests which compose the FMS™. The seven tests are: 1) the deep squat which assesses bilateral, symmetrical, and functional mobility of the hips, knees and ankles, 2) the hurdle step which examines the body's stride mechanics during the asymmetrical pattern of a stepping motion, 3) the in-line lunge which assesses hip and trunk mobility and stability, quadriceps flexibility, and ankle and knee stability, 4) shoulder mobility which assesses bilateral shoulder range of motion, scapular mobility, and thoracic spine extension, 5) the active straight leg raise which determines active hamstring and gastroc-soleus flexibility while maintaining a stable pelvis, 6) the trunk stability push-up which examines trunk stability while a symmetrical upper-extremity motion is performed, and 7) the rotary stability test which assesses multi-plane trunk stability while the upper and lower extremities are in combined motion.

The relationship between the FMS™ score and injury risk has not been previously reported. Therefore, the purpose of this study was to examine the relationship between professional football players' score on the FMS™ and the likelihood of a player suffering a serious injury over the course of one competitive season.

METHODS

The strength and conditioning specialist associated with the team studied had extensive experience (11 years) as a professional football strength and conditioning specialist and utilized the FMS™ as part of pre-season physical per-
formance testing prior to the 2005 season. All players who attended training camp were tested on each of the seven tests of the FMS (as described in the Appendix) each year. The composite score for each player was then variable analyzed in this retrospective study.

In order to protect the identity of the subjects, only limited injury information and FMS™ data were available to the authors for analysis, which is why common demographic data routinely reported in most studies are not included. In addition, the authors agreed with the professional football team not to state the name of the team in any subsequent publications.

The sample included only those players who were on the active roster at the start of the competitive season (n = 46) and the surveillance time for the study was one full season (approximately 4.5 months). Membership on the injured reserve and time loss of 3 weeks was utilized as the injury definition. This operational definition of injury ensured the player was placed on the injured reserve due to a serious injury. The study was approved by the University of Evansville Institutional Review Board.

Data Analysis
To determine if a significant difference existed in composite FMS scores between those injured and those who were not injured, a dependent t-test was performed with significance set at the p< 0.05 level. To determine the cut-off score on the FMS™ that maximized specificity and sensitivity a receiver-operator characteristic (ROC) curve was created. In this context, the FMS™ can be thought of as a special test used to determine if a player is at risk for a serious injury. An ROC curve is a plot of the sensitivity (True +’s) versus 1-specificity (False +’s) of a screening test. Different points on the curve correspond to different cut-off points used to determine at what value a test is considered positive. The test value (FMS™ score) which maximizes both True +’s and controls for False +’s is identified on the ROC curve as the point at the upper left portion of the curve. Once the cut-off score was identified, a 2 x2 contingency table was created dichotomizing those who suffered an injury and those who did not, and those above and below the cut-off score on the FMS™.

Simple odds ratios, likelihood ratios, sensitivity and specificity were then calculated. Post-test odds and post-test probability were calculated according to the formula provided, which allowed for the estimation of how much an individual’s FMS™ score influenced the probability of suffering a serious injury.

At the start of the season, a probability (pretest probability) existed for suffering a serious injury. To determine how much the probability of serious injury increased when a player’s score is below the cut-off score (magnitude of the shift from pre-test to post-test probability), the post-test probability was calculated utilizing a 3-step calculation process as described by Sackett et al. The positive likelihood ratio (+LR) value is the value associated with the special test utilized. In this case, the special test is the FMS™ and is considered negative for a given subject when their score is above the cut-off score determined by the ROC curve. The FMS™ scale is considered positive if a given subject’s score is equal to or below the cut-off score determined by the ROC curve. The calculation is as follows:

1. Convert the pre-test probability to odds:

\[ \text{Pre-test odds} = \frac{\text{pre-test probability}}{1 - \text{pre-test probability}} \]

2. Multiply the odds by the appropriate +LR value:

\[ \text{Pre-test odds} \times \text{+LR} = \text{post-test odds} \]

3. Convert the post-test odds back to probability:

\[ \frac{\text{post-test odds}}{\text{post-test odds} + 1} = \text{post-test probability} \]

Pre-test probability is synonymous with the prevalence of the disorder. In this case it would be the probability (at the start of the season) of a player suffering a serious injury as defined. In the absence of published data, an estimation of prevalence was made. Since no injury rate data was available for professional football, a conservative prevalence of 15% was used based on previous high school and collegiate injury surveillance studies and expert opinion.

RESULTS
The subjects were professional football players who made the final team roster before the start of a competitive sea-
son. The mean (SD) FMS™ score (highest possible score is 21) for all subjects was 16.9 (3.0). The mean score for those who suffered an injury was 14.3 (2.3) and 17.4 (3.1) for those who were not injured. A t-test revealed a significant difference between the mean scores of those injured and those who were not injured (df = 44; t = 5.62; p<0.05).

Upon analysis of the ROC curve (Figure) and corresponding table of sensitivity and specificity values, it was determined that an FMS™ score of 14 maximized specificity and sensitivity of the test. Specifically, the point is chosen so that the test correctly identifies the greatest number of subjects at risk (true positives) while minimizing incorrectly identifying subjects not at risk (false positives). On a ROC curve, this point is usually at the left uppermost point of the graph27 (the point where the curve turns). Using this value, subjects were dichotomized into groups with a score of 14 as well as by injury status (Table). This cut-off score represents a sensitivity of 0.54 (CI95= 0.34-0.68) and specificity of 0.91 (CI95 = 0.83-0.96). The odds ratio was 11.67 (CI95 = 2.47-54.52), positive likelihood ratio 5.92 (CI95 = 1.97-18.37), and negative likelihood ratio 0.51 (CI95 = 0.34-0.79).

The odds ratio of 11.67 can be interpreted as a player having an eleven-fold increased chance of injury when their FMS™ score is 14 or less when compared to a player whose score was greater than 14 at the start of the season. The post-test probability was calculated to be = 0.51. That is to say, if an athlete's score on the FMS™ was 14 or less, their probability of suffering a serious injury increased from 15% (pre-test probability of 0.15) to 51% (post-test probability of 0.51; CI95=0.25-0.76).

### Table

<table>
<thead>
<tr>
<th>FMS score ≤ 14?</th>
<th>Serious Injury?</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES</td>
<td>7</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>6</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

**DISCUSSION**

Sports physical therapists, athletic trainers, and
strength and conditioning specialists using the FMS™ in professional football have casually observed that players with lower scores were more likely to be injured. Basic statistical procedures were used to test this observation. Those players with a score of less than 14 were found to have a substantially greater chance of membership on injured reserve over the course of one competitive season than those scoring greater than 14.

To estimate the value of the FMS™ as a diagnostic test to predict the likelihood of injury, the purpose of the tests such as the FMS™ was considered. It was important to maximize the test's ability to rule in the potential disorder (injury), or in other words, to maximize the test's specificity. Higher specificity increases the ability to use the test to recognize when the disorder is present. That is, a highly specific test has relatively few false positive results and speaks to the value of a positive test. The reverse is true when a given diagnostic test has high sensitivity. Because the FMS™ in this study was shown to be highly specific (0.91) for suffering a serious injury, the test can be used to rule in the condition studied. The sensitivity was 0.54, so the test offers limited capability to rule out the condition.

To consider how this information can be applied to an individual athlete, the shift from pre to post-test probability was calculated. Accurate estimation of the prevalence (pre-test probability) of a given disorder when attempting to determine the magnitude of the shift from pre to post-test probability when using the positive likelihood ratio of a special test is critical. If too high of a value is used, it will artificially inflate the magnitude of the shift and imply the special test (in this case the composite FMS™ score) is more powerful than it really is. A conservative prevalence rate (15%) was used to control for this potential error. In the absence of published data, professional football injury rates were discussed with professional football sports medicine personnel, who indicated that 15% was on the low end of what they would expect over the course of one competitive season.

The findings of this report suggest that athletes with dysfunctional fundamental movement patterns (as measured by lower scores on the FMS™) are more likely to suffer a time-loss injury, but can not be used to establish a cause-effect relationship. Some additional limitations of this study should be noted. Because this review only considered data from one team, selection bias is a limitation. Furthermore, the same data set that was used to determine the ROC curve cut-off score was used to test the cut-off score in the prediction model. Using the same data to determine cut-off score and evaluate those cut-off scores as predictive is more likely to demonstrate meaningful findings than when using cut-off scores determined with different data. Ideally, a cut-off score should be established from a separate prospective study, and then that value is applied to the prediction model to prevent inflation of the post-test probability and odds ratio.

Another limitation of the study was that only those on injured reserve for at least 3 weeks were used as the definition of an injury. These criteria may not have captured injuries that were meaningful, but were not of long enough duration to place the athlete on the injured reserve.

Future research should be conducted in a prospective manner that includes detailed injury surveillance and a more robust injury definition. Having access to data on multiple variables (such as previous injury) not available for this study would allow researchers to build a regression equation that predicts those who will suffer a time loss injury. Based on this retrospective analysis, the authors suggest including the FMS™ score in the model by using the individual test scores in addition to the composite score. With this detailed information, it may be possible to specifically identify factors (previous injury, deep squat score, lunge score) that contribute most to injury risk and then focus injury prevention efforts on modifiable factors such as dysfunctional movement.

CONCLUSION
Fundamental movement patterns such as those assessed by the FMS™ can be easily tested clinically. This retrospective descriptive study demonstrated that professional football players with a lower composite score (<14) on the FMS™ had a greater chance of suffering a serious injury over the course of one season.
REFERENCES

Appendix. The scoring criteria and descriptions of the 7 tests of the FMS™.

1. Deep Squat
The subject will assume the starting position by placing his/her feet shoulder width apart with the feet in line with the sagittal plane. The dowel will be held overhead with the shoulders flexed and abducted and the elbows extended. The subject will squat down with the heels on the floor and head and chest facing forward. If a score of III is not accomplished, the subject will be asked to perform the test with a 2x6 board under their heels. If this allows for a completed squat a II is given. If the subject still cannot complete the movement a I is scored.
2. Hurdle Step
For the hurdle step the subject will align their feet together with the toes touching the base of the hurdle, which is then adjusted to the height of the subject’s tibial tuberosity. The dowel will be positioned across the shoulders, just below the neck. The subject will be instructed to slowly step over the hurdle and touch their heel to the floor while the stance leg remains in extension. The moving leg is then returned to the starting position. A III is scored if one repetition is completed bilaterally, a II if the subject compensated in some way by twisting, leaning or moving the spine, and a I if loss of balance occurs or contact is made with the hurdle.

III

II

I
3. **In-line lunge.**
The length of the subject's tibia will be measured from the floor to the tibial tuberosity. The subject will then be instructed to place the end of his/her heel on the end of the 2x6 board. Using the tibia length a mark is made on the board from the end of the subject's toes. The dowel is held behind the back in contact with the head, thoracic spine, and sacrum. The hand that is opposite the front foot should grasp the dowel at the cervical spine and the other hand at the lumbar spine. The subject will then place the heel of the opposite foot at the measured mark on the board, and the back knee will be lowered enough to touch the board behind the heel of the front foot. A III is given for a successfully completed repetition, a II for compensation and a I for incompletion or loss of balance.
4. Shoulder Mobility
The subject’s hand will first be measured from the distal wrist crease to the tip of the third digit. The subject will then be asked to make a fist with each hand. The subject will be instructed to assume a maximally adducted, extended and internally rotated position with one shoulder and a maximally abducted, flexed and externally rotated position with the other so that the fists are located on the back. The distance between the two fists on the back at the closest point will be measured. A III is given if the fists are within one hand length, a II if the fists are within 1 1/2 hand lengths, and a I if the fists fall outside this length. At the end of this test a clearing exam is administered. The subject will place his/her hand on their opposite shoulder and attempt to point the elbow upward. If pain results from this movement using either shoulder a score of zero is given for the entire shoulder mobility test.
5. **Active Straight Leg Raise**

The starting position for the active straight-leg raise requires the subject to lie supine with the arms in an anatomical position and head flat on the floor. The 2x6 board is placed under the knees, and the anterior superior iliac spine (ASIS) and mid-point of the patella are identified. Using those two landmarks a mid point on the thigh is found. The dowel is placed on the ground perpendicular to this position. The subject will be instructed to lift the test leg with a dorsiflexed ankle and extended knee while keeping the opposite knee in contact with the board. If the malleolus of the raised leg is located past the dowel than a score of III is given. If the malleolus does not pass the dowel then the dowel is aligned along the medial malleolus of the test leg, perpendicular to the floor. If this point is between the thigh mid point and patella, a II is scored. If it is below the knee a I is received. The test should be performed bilaterally.
6. **Trunk stability push-up**
The subject will begin in a prone position with both feet together. The hands will be placed shoulder width apart with the thumbs at forehead height for males and chin height for females. With the knees fully extended and the feet dorsiflexed the subject should perform one push-up in this position with no lag in the lumbar spine. By completing the push-up a score of III is given. If the subject cannot perform the push-up the hands are lowered, with the thumbs aligning with the chin for males and the clavicles for females. If a push-up is successful in this position a score of II is given; if not, a I is scored. At the end of this test a clearing exam is given. The subject should perform a press-up in the push-up position. If there is pain associated with this motion a score of zero is given for the entire test.

![III](image1)

![II](image2)

![I](image3)

![Clearing Exam](image4)
ABSTRACT

**Background.** The Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) is a tool developed and used in the clinic to evaluate progress during upper extremity rehabilitation. A need exists for reference values of CKCUEST for use in a clinical setting.

**Objectives.** To calculate reference values for the CKCUEST that may assist clinicians in developing goals and objectives for male collegiate baseball players who are recovering from injuries to the upper extremity. To determine if differences exist in scores according to playing position.

**Methods.** The sample consisted of 77 collegiate, male baseball players between the ages of 18 and 22 who reported no recent history of injuries to the shoulder, elbow, or the hand-wrist complex. The CKCUEST was administered three times to the athletes and the number of touches when performing the CKCUEST during the 15-second test was measured and recorded. An average of the three tests was used for data analysis.

**Results.** No significant differences existed according to playing position. The data did not differ from the normal distribution; therefore, reference values were calculated and reported for use by clinicians in development of goals and objectives for this population.

**Discussion and Conclusion.** The CKCUEST appears to be a clinically useful test for upper extremity function.

**Key Words:** upper extremity, functional testing, closed-kinetic chain
INTRODUCTION

In the college baseball population, injuries to the upper extremities are very common, as throwing and batting activities place an enormous amount of stress on the joints of the upper extremity.\(^1\) Fifty-eight percent of all injuries in collegiate baseball involved the upper extremity and accounted for seventy-five percent of the total time lost from sport, longer than injuries to other parts of the body.\(^1\) Pitchers sustain the majority of upper extremity injuries, as the intense, repetitive throwing that pitching requires places a greater amount of stress on the upper extremity compared to other positions.\(^1\) Throwing a baseball produces rotational velocities greater than 6000 degrees per second; and, at the point of release, distraction forces at the glenohumeral joint can be one to one and a half times the athlete's body weight.\(^2\) Because throwing places so much stress on the upper extremity, the athlete must have adequate strength, stability, and mobility in order to return to activity after injury. If the athlete returns to activity too soon, re-injury may occur rather easily.

A closed-kinetic chain activity is defined as an activity in which the terminal joint meets considerable external resistance which prohibits or restrains free motion; whereas, an open-kinetic chain activity is defined as an activity in which the terminal joint is free.\(^3\) Most of the activities in baseball are open-kinetic chain movements. However, an increase in the use of closed-kinetic chain activities in clinical rehabilitation has occurred to help return the athlete to their sport. Closed-kinetic chain activities may help improve dynamic stability through joint approximation and co-contraction.\(^4\) Compression from closed-kinetic chain activity also stimulates mechanoreceptors and helps improve proprioception.\(^4\) These improvements may be important when determining if the patient is ready to return to activity.

A need exists to develop tests that provide objective data to help clinicians determine a patient's readiness to return to activity. These tests should be easy for clinicians to use and for patients to understand. The tests should also be cost efficient and require minimal space in the clinic.\(^4,5\) The closed-kinetic chain upper extremity stability test (CKCUEST) is intended for these purposes. The starting position for performing the CKCUEST is a traditional push-up position. The subject maintains this position while touching with one hand the ground on their opposite side. The score on the test is the number of touches completed in 15 seconds.\(^4,5\)

To be useful in the clinical setting, reference values for the CKCUEST are needed to assist the clinician in developing goals and objectives for their clients. The purpose of this study is to establish a set of reference values for the CKCUEST in the collegiate baseball population at a community college or NCAA Division III college level. A secondary purpose was to determine if there were differences in CKCUEST scores based on playing position. Once reference data is developed, clinicians may have a quick and easy method to objectively determine if their patient is progressing in their rehabilitation.

METHODS

Subjects

This study was determined to be safe for human subjects by the Institutional Review Board of Arizona School of Health Sciences, A. T. Still University – Mesa Campus. Informed consent was obtained from each subject prior to data collection. The initial sample consisted of 78 collegiate, male baseball players between the ages of 18 and 22 who reported no recent history of injuries to the shoulder, elbow, or the hand-wrist complex. Subjects were recruited from two community colleges in Arizona and one NCAA Division III college in California. Subjects were excluded if they did not meet the age range, they had surgery on either upper extremity within the last year, were not fully cleared by their team physician to participate in practice or competition, or were experiencing pain or fatigue in either upper extremity from recent activity.

Data Collection Procedures

Subjects completed a screening questionnaire to ensure that no recent surgery or injury existed to the shoulder, elbow, and hand-wrist complex. Each subject was then assigned a number for identification. The weight of each subject was measured (in pounds), converted to metric units, and recorded. The height was measured using a standard 10-foot tape measure (in inches), converted to metric units, and recorded. Each player’s position was also recorded. Each subject was then given a brief explanation on how to perform the test.
Two strips of athletic tape with a width of 1.5 inches were placed parallel to each other 36 inches apart on a tile floor as measured with a standard tape measure. The starting position for the test is one hand on each piece of tape while assuming a pushup position (Figure). The subjects were instructed that from the starting position they were to use one hand to reach across their body and touch the piece of tape lying under the opposing hand. After touching the tape line the hand would be returned to the original starting position. The subject would perform the same movement with the other hand. Touches were counted as every time the hand reached across the subject's body and touched the tape. The total time for the trial was 15 seconds. Each subject performed a warm up trial and then three real trials of the test with a rest period of 45 seconds between trials. An average of the three trials was used for data analysis.

Table 1: Descriptive statistics for all players (n = 7)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>19.03</td>
<td>1.22</td>
<td>0.27</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.83</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.5</td>
<td>12.23</td>
<td>2.73</td>
</tr>
<tr>
<td>BMI*</td>
<td>24.92</td>
<td>2.91</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 2: Scores on CKCUEST according to playing position

<table>
<thead>
<tr>
<th>Position</th>
<th>n</th>
<th>Mean *</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitcher</td>
<td>30</td>
<td>30.30</td>
<td>4.82</td>
</tr>
<tr>
<td>Catcher</td>
<td>9</td>
<td>30.41</td>
<td>3.52</td>
</tr>
<tr>
<td>Infielder</td>
<td>26</td>
<td>30.78</td>
<td>4.02</td>
</tr>
<tr>
<td>Outfielder</td>
<td>12</td>
<td>30.30</td>
<td>4.00</td>
</tr>
<tr>
<td>All Players</td>
<td>77</td>
<td>30.41</td>
<td>3.87</td>
</tr>
</tbody>
</table>

*The number of touches performed on the CKCUEST

Data Analysis
Descriptive statistics including mean, standard deviation, 95% confidence interval (CI), kurtosis (with 95% CI) and skewness (with 95% CI) were calculated for the number of touches performed for the CKCUEST. In addition, a Kolmogorov-Smirnov Goodness-of-Fit Test was also performed to determine that the data fit the normal distribution. To ensure no differences in scores on the CKCUEST according to player position, a one way analysis of variance was performed to determine differences in the scores among four difference groups: pitchers, catchers, infielders, and outfielders. An alpha level of 0.05 was chosen as the level of significance.

RESULTS
Initially, 79 subjects participated in this study. Two subjects were excluded due to upper extremity pain or discomfort while participating in the actual test. The descriptive statistics for the sample can be found in Table 1.

Scores on the CKCUEST can be found in Table 2. As a result of the analysis of variance, no significant difference was found between the scores on the CKCUEST across position (F = 0.045; df = 3,73; p = 0.99). Therefore, the scores on the CKCUEST are not dependent on the position of the baseball player.

A 95% CI was used to test the null hypothesis that the data fit a normal distribution. If zero is included in the range of the confidence interval, the null hypothesis cannot be rejected. Zero was included in the ranges for both skewness and kurtosis, and it can be concluded the data did not differ from a normal distribution. A Kolmogorov-Smirnov Goodness-of-Fit Test was also performed to insure that the data fit the normal distribution, which revealed the data fit a normal distribution (p = 0.22).
DISCUSSION

A proliferation of rehabilitation techniques has occurred for the upper extremity using closed-kinetic chain activities. The use of closed-kinetic chain exercises are beneficial for the lower extremity; therefore, it is reasoned closed-kinetic chain exercise is probably beneficial for the upper extremity. Closed-kinetic chain exercises may increase electromyographic activity, improved joint stability and proprioception, and utilize multiple joint involvement. Closed-kinetic chain exercises may provide large resistance with low acceleration, greater compression forces, increased joint congruency, low shear forces, and enhanced dynamic stabilization. Wilk et al proposed closed-kinetic chain exercise for the upper extremity such as isometric press-ups and isometric weight bearing with weight shift for functional tests. Closed-kinetic chain exercise involving weight bearing and shifting during rehabilitation may enhance muscular co-contraction of the glenohumeral joint through joint compression and approximation. These exercises parallel the demands when performing the CKCUEST.

Most common assessments of the upper extremity are performed in an open-kinetic chain fashion, which measure the patient's pathology and levels of strength, stability, proprioception, and range of motion. Yet, assessment of these variables only test part of the role of the upper extremity in its main function; to place the hand/wrist complex in a position to manipulate the environment. When comparing open- and closed-kinetic chain assessments, no relationships exist between the outcomes, suggesting that a complete and thorough assessment of the shoulder must include more simple open-kinetic chain assessments and more complex closed-kinetic chain assessments. Ellenbecker reported reference values for the CKCUEST of 18.5 touches for males and 20.5 touches for females (females used a modified starting position). These numbers are drastically different from the results obtained in this study (30.41 touches for males; SD = 3.87). The number of touches recorded for males in Goldbeck and Davies study was 27.8 (SD = 1.77). Using 95% confidence intervals to determine differences, a difference does exist in the data collected by Goldbeck and Davies (27.09 – 28.51 touches) and the data from this study (29.55 – 34.28 touches).

A major issue with the CKCUEST is the validity of the test. The authors were unable to assess any studies which evaluated the sensitivity and specificity of the test with any pathological conditions at this time. Nor were the authors able to assess the agreement or relationship with any other test used to evaluate function of the upper extremity. Still, the CKCUEST is a published test in the literature and is probably being used in a multitude of settings. Therefore, more descriptive data is needed for clinicians who use the test, which was a major objective in conducting this study.

The current authors had several concerns with the CKCUEST. One possible problem with the CKCUEST is the test places high loads of force on the wrist, elbow, and shoulder. The starting push-up position is not a position that the general population performs regularly. Patients presenting with co-morbidities of the upper extremities may have difficulties performing the task. The body position when performing the test requires a substantial amount of trunk strength or stability and patients who have compromised trunk strength or impairments may not be good candidates for the CKCUEST. The older geriatric population may not be able to perform the test and patients who are susceptible to fracture may be at increased risk because of the force of impact. For an athletic population or a population of conditioned individuals, the test might be perceived as a good functional assessment.
CONCLUSION
Closed-kinetic chain exercise and testing have become popular as it assesses the upper extremity as a unit. The CKCUEST appears to be a clinically useful test for upper extremity function. Reference values have been developed for the CKCUEST for collegiate-level baseball players. No differences existed in scores by position, and the values found in this sample fit a normal distribution.

REFERENCES
ABSTRACT

Background. Poor alignment between the patella, tibia, and femur has been identified as a primary cause of anterior knee pain. More recently, impaired hip strength has been discussed as a possible reason for the onset of knee pain.

Objectives. The purpose of this study was to determine if individuals with knee pain had weakness in the hip muscles.

Methods. Nineteen females between the ages of 18 and 40, experiencing unilateral knee pain for no greater than four weeks, were examined. Bilateral gluteus maximus and medius strength were measured with a MicroFET hand-held dynamometer.

Results. Strength of the gluteus medius and maximus muscles were significantly less in the extremities of patients experiencing knee pain than the extremity without knee pain.

Discussion and Conclusion. Given biomechanical relationships between the hip and knee, examining the entire lower kinetic chain should occur when evaluating patients with knee pain. Using impairment-based interventions, such as addressing hip strength in addition to knee pain, may enhance intervention effectiveness. Results of this study provide data that suggest that individuals with knee pain had weak hip muscles.

Key Words: knee pain, hip strength

CORRESPONDENCE:
Douglas J. Mattson, PT, EdD, SCS
MGH Institute of Health Professions
36 First Avenue
Charlestown Navy Yard
Boston, MA 02129
dmattson@mghihp.edu

ACKNOWLEDGEMENTS:
The authors wish to thank St. Luke’s Memorial Hospital Center in Utica, New York for the kind use of the MicroFET dynamometer and Deborah Marr OTR, ScD and Peter Pawson PT, PhD for the advisement provided during the initial phases of this project. This work contains data and text originally written as a Master’s thesis presented to the faculty of Utica College, December 2003.
INTRODUCTION
According to the American Academy of Orthopaedic Surgeons,1 knee pain is a common condition resulting in 19.4 million pain-related visits to a physician's office each year. This number is significantly higher than low back pain (5.9 million visits), hip pain (3.2 million visits), and ankle pain (1.9 million visits). Knee pain impairs function, which can lead to disability.2

Historically, causes of knee pain have been related to a structural deformity or malalignment of the patella and its relationship to surrounding structures. Patella and distal femur malalignment have been linked to anterior knee pain.3 Interventions for such impairments have been to use either surgical or non-surgical strategies to correct the deformity or re-align the patella.4 More recent information has indicated that improper alignment at the knee may originate proximally and that poor force production at the hip, secondary to muscle weakness, could be a factor that ultimately causes stress to the knee.5 6 Juhn7 and Powers8 hypothesized that knee pain could be caused by a maltracking of the patella on the femur. They proposed that instability of the patella can result from unequal activity in the components of the quadriceps femoris muscle8 or diminished hip extensor, rotator, or abduction strength.5 Repetitive contact between the patella and femur, along with maltracking due to muscular imbalance in the hip, can result in anterior knee pain.7

It is important to understand the relationship between the different forces acting on the femur when considering the biomechanics of the lower extremity. A number of forces are exerted on the femur during ambulation, and the muscles acting on the femur play an important role in balancing these forces.9 Duda et al9 suggest an important relationship between the gluteal muscles and femoral neck loading. Femoral neck loading occurs when the muscle contraction exerts a force on the femur. When femoral loading occurs during weight bearing, the proximal and distal ends of the femur are subject to considerable shear forces. Previous research has suggested that hip strength may be a factor in anterior knee pain, therefore, the purpose of this study was to determine if individuals with knee pain had weakness in the hip muscles.

METHODS
Subjects
A sample of convenience of 24 females between 18 and 40 years of age were recruited for this study. Fulkerson10 stated that females are more likely to be affected by anterior knee pain and Lephart et al11 demonstrated that biomechanical differences exist between men and women. Given the effects of gender on biomechanics, females were chosen for this study to decrease the impact of a potentially confounding variable.

According to Berk,12 bone growth is complete in most girls by age 16, when the epiphyses close completely. Torry and McCaw13 reported "approximately ninety percent of all persons over the age of 40 will show pathological evidence of osteoarthritis in weight bearing joints." Based on these findings, females within the range of 18 to 40 years of age were recruited in order to minimize the chance of results being skewed by pubertal changes before the age of 18 or the onset of osteoarthritis after the age of 40.

The inclusion criteria were females with unilateral anterior knee pain (intermittent or constant) for no greater than four weeks. Exclusion criteria included (1) back, hip, or foot pain, (2) bilateral knee pain, (3) prior surgery or trauma to the back, hip, knee, or foot, and (4) medical conditions such as pregnancy, cancer, neurological impairment, bone disease, or stomach ulcer. These exclusion criteria were chosen to ensure subject safety and enable proper positioning.

The Utica College Institutional Review Board approved this research proposal. Upon approval, subjects were recruited using general announcements. All subjects signed an informed consent form prior to participation in this study.

Instrumentation
The International Knee Documentation Committee (IKDC) Subjective Knee Form was used to measure participants' knee pain and function in order to further define the sample. This form is knee specific, rather than disease specific, and provides data relative to knee symptoms and function during activities of daily living, sports, and work activities.14 Irrgang et al14 studied a group of 533
patients with a variety of knee pathologies to determine the reliability and validity of the IKDC Subjective Knee Form. The results of the study revealed a test-retest reliability coefficient of 0.94 and an internal consistency coefficient alpha of 0.92.

The MicroFET hand-held dynamometer (Noggan Health Industry; South Draper, UT) was used to measure muscle strength on all subjects. A reliability study was performed to determine the testers with the highest intrarater reliability for the hand-held dynamometer in order to maximize reliability. The reliability study took place on a sample of female subjects in the Utica College Clark Athletic Center, Physical Therapy Clinical Laboratory. Intrarater reliability was determined by testing gluteus medius and gluteus maximus muscles bilaterally on five female subjects without knee pain, each measured three times. Data were analyzed using Pearson product-moment coefficient of correlation in order to decipher the two researchers with the greatest interrater reliability. Intrarater reliability for the tester chosen to perform all measurements was \( r = 0.87 \) and 0.93 for the gluteus medius and gluteus maximus, respectively, which is consistent with high reliability reported previously by Click et al (0.95).\(^\text{15}\)

**Procedures**

Once recruited, and after the consent form was signed, participants completed an intake form for demographic and subjective information about their knee pain. After reviewing the intake forms, subjects that met inclusion criteria completed the IKDC Subjective Knee Form, answering questions regarding performance during activity. Participants did not need to carry out physical activity while completing this form.

Participants underwent bilateral gluteus medius and maximus muscle strength testing using the MicroFET hand-held dynamometer. Each researcher tested bilateral gluteus medius and maximus muscles using the positions outlined by Bohannon\(^\text{16}\) for the gluteus medius and Kendall et al\(^\text{17}\) for the gluteus maximus. Hip extension force (Figure 1) was measured in prone on the posterior aspect of the thigh, just proximal to the lateral condyle of the femur. Hip abduction force (Figure 2) was measured in supine with the knee extended and the hip in neutral relative to extension, abduction, and rotation. Force was measured at the lateral surface of the thigh, just proximal to the lateral condyle of the femur.\(^\text{16}\)

The unaffected extremity was measured first. For hip extension, stabilization was given at the lumbar spine and for hip abduction it occurred at the lateral aspect of the contralateral extremity. Subjects performed three trials of one repetition each, with five to seven second holds, for both the gluteus maximus (Figure 1) and medius (Figure 2). Twenty to thirty seconds of rest were provided between each trial as recommended by Bohannon.\(^\text{18}\) Time for muscle contraction and rest periods was measured with a stopwatch.

![Figure 1. Gluteus maximus muscle strength testing position](image)

**Data Analysis**

Descriptive data for the average of the three measurements of the gluteus maximus and medius muscles included means and standard deviations. One dependent t-test was used to compare the strength differences in the extremity with pain and the extremity with no pain for the gluteus maximus and one t-test for the gluteus medius muscle. In order to adjust for possible inflation of the 0.05 alpha level due to multiple t-tests, the signifi-
The gluteus maximus is one of the muscles thought to play a role in controlling alignment of the lower extremity and is identified as an important muscle to consider when treating anterior knee pain. The gluteus maximus posteriorly rotates the pelvis and controls limb activities during rotational movements. Weakness of the gluteus maximus could, therefore, alter the rotational forces on the femur during activities and possibly affect the knee joint.

Powers et al provided evidence for a biomechanical theory that the entire lower extremity chain should be considered during patient management. Using kinematic magnetic resonance imaging these authors observed that, during weight bearing conditions, femoral internal rotation was associated with lateral patellar displacement. The authors found that during knee extension in the closed-kinetic chain a measurable femoral internal rotation occurred. These findings are consistent with the idea that forces in an area other than the site of pain may be associated with the problem.

Previous authors have supported the relationship between gluteal weakness and knee pain. Ireland et al tested abduction and external rotation strength of 15 females, between the ages of 12 and 21, who had patellofemoral pain and 15 non-symptomatic subjects matched for age, gender, and body weight. Subjects with knee pain demonstrated less strength in hip abduction and external rotation. Although the research of these authors is valuable, limitations existed that should be identified. All subjects experienced pain for longer than three months, which presents a potential significant confounding variable because it is possible that gluteal weakness, from disuse or guarding, was a result of knee pain. The present study differed in that subject recruitment was limited to subjects who had an onset of pain for less than 28 days; therefore, reducing the potential confounding nature of this variable.

Tyler et al suggested that subjects with anterior knee pain responded favorably to interventions that included hip abduction, adduction, flexion, and extension progressive resistive strengthening strategies. Similar to Ireland et al, Tyler et al included only subjects that had experienced anterior knee pain for four weeks or more.

As the evidence mounts for a relationship between hip weakness and knee pain; causality has not been estab-
lished. The methodology of Ireland et al., Tyler et al. and the present study do not allow for causality to be inferred. Implications for patient/client management, however, should be considered. Patients may benefit from these findings by receiving a comprehensive examination, as well as interventions for deficits along the entire lower extremity kinetic chain during treatment.

**Limitations**

A small age range hindered the study. Given that females with knee pain were obtained through a sample of convenience from the college community and the surrounding area, this study's age distribution was skewed. The majority of subjects were students in the age range of 18 to 24. For these reasons, study results cannot be considered to represent the general population.

A control group was not considered at the time of data collection. It was not within the scope of the study given limitations on study time and resources. The study could be enhanced by including a control group in future investigations.

**Future Studies**

Future study on this topic should involve a broader age range in order to illustrate a better representation of the general population with knee pain. A study comparing males and females could also be conducted to compare differences in gluteal strength and knee pain between the genders.

Results of our study suggested that perhaps intervention for weak hip musculature could be useful when treating patients with knee pain. These results, therefore, provide a seed of evidence that could lead to further study. Studying the effectiveness of hip strengthening to address deficits in a randomized controlled manner is a possible outgrowth of this work. Considering the relationship that hip strength has on the entire biomechanical chain, it may also prove beneficial to examine the most reliable means of strengthening the abductors and adductors of the hip.

**CONCLUSION**

The results of this study suggested that individuals with knee pain had weak hip muscles. Results may have significant clinical implications consistent with the foundational components of physical therapy practice. Physical therapist examination and intervention strategies that consider the entire lower extremity kinetic chain were supported by the study results.

**REFERENCES**


ABSTRACT
Exercise related leg pain (ERLP) is a regional pain syndrome described as pain between the knee and ankle which occurs with exercise. Indiscriminant use of terminology such as “shin splints” has resulted in ongoing confusion regarding the pathoanatomic entities associated with this pain syndrome. Each of the pathoanatomic entities – medial tibial stress syndrome, chronic exertional compartment syndrome, tibial and fibular stress fractures, tendinopathy, nerve entrapment, and vascular pathology – which manifest as ERLP are each described in terms of relevant anatomy, epidemiology, clinical presentation, associated pathomechanics, and intervention strategies. Evidence regarding risk factors for ERLP general and specific pathoanatomic entities are presented in the context of models of sports injury prevention.

CORRESPONDENCE:
Mark F. Reinking, PT, PhD, SCS, ATC
Associate Professor
Saint Louis University
Doisy College of Health Sciences
Department of Physical Therapy
3437 Caroline Mall
St. Louis, MO 63104

* Saint Louis University
Doisy College of Health Sciences
Department of Physical Therapy
INTRODUCTION
Leg pain associated with exercise is a common experience among athletes. One of the earliest published descriptions of leg pain was by Hutchins in 1913. He described “spike soreness” as soreness in the medial leg in runners. He stated, “Specifically, the area begins four and a quarter inches above the internal malleolus and extends about an inch along the tibial border.” Over time, the term “shin splints” came to be associated with leg pain. Some used the term with regard to medial leg pain, while others have used the term more generically. Slocum reported that shin splints “designates a symptom complex characterized by pain and discomfort in the lower part of the leg after repetitive overuse in walking and running.”

In 1966, the American Medical Association (AMA) Committee of the Medical Aspect of Sports, Subcommittee on Classification of Sports Injuries published the Standard Nomenclature of Athletic Injuries. This book defined shin splints as “pain and discomfort in the leg from repetitive running on hard surface or forcible excessive use of the foot flexors; diagnosis should be limited to musculotendinous inflammations, excluding fatigue fracture or ischemic disorder.” Detmer opined that the AMA definition of shin splints was too restrictive, and suggested that the term include “injuries which are not obvious muscle strains, tendinitis, stress fracture, or compartment problems.”

Recognizing the confusion in terminology regarding “shin splints,” Batt wrote a review of terminology associated with leg pain. He concluded that the term “shin splints” is a generic term which does not refer to any specific pathology, but rather, to the location of pain.

Other generic descriptions of pain syndromes exist based on the location of pain, including anterior knee pain, metatarsalgia, and low back pain. As the term “shin splints” is accompanied by a great deal of confusion as to the type and location of pain, it is reasonable to use a term that more accurately describes the location and association of the pain. Brukner recommended avoiding use of the term “shin splints” and proposed the term “exercise related lower leg pain” to describe shin, calf, ankle, or foot pain associated with or aggravated by exercise. Reinking and Hayes suggested the use of the term “exercise related leg pain” (ERLP) to describe pain between the knee and ankle which is associated with exercise. These authors recommended elimination of foot pain from this syndrome as the foot is anatomically distinct from the leg, and also suggested elimination of the term “lower” from the syndrome name as ERLP can and does occur along the length of the leg. This nomenclature confusion has delayed development of a good understanding of leg pain. The objective of this paper is to provide a literature review of ERLP including epidemiology, pathoanatomic entities, risk factors, and preventative strategies.

METHOD OF REVIEW
Searches of two electronic databases were conducted: the National Library of Medicine (MedLine) and the Cumulative Index for Nursing and Allied Health Literature (CINAHL) over the past 10 years during this ongoing research on exercise related leg pain. Searches have included terms such as shin splints, exercise related lower leg pain, exercise related leg pain, leg pain, lower leg pain, chronic leg pain, medial tibial stress syndrome, stress fracture, tibial stress fracture, fibular stress fracture, chronic exertional compartment syndrome, exertional compartment syndrome, exertional leg pain, tendinopathy, tendinitis, tendinosis, nerve entrapment, arterial occlusive disease, popliteal artery, tibial artery, injury prevention, and sports injury prevention. Searches have been limited to articles written in English using human subjects. Over 350 articles appeared relevant based on titles or abstracts and were screened for inclusion in this review. A total of 111 articles were selected for use in this paper including epidemiological studies, observational studies, randomized controlled trials, literature reviews, systematic reviews, meta-analyses, and case reports. As this is not a systematic review, the intent was not to critically evaluate the evidence but rather to provide a summary of the literature on ERLP to assist the sports physical therapists in better understanding the conditions that present as ERLP.

EPIDEMIOLOGY OF ERLP
While only a few studies have investigated ERLP epidemiology in athletes, the data consistently show it to be a commonly experienced pain syndrome. Running (cross-country and distance track events) has the most common occurrence of ERLP; other sports with reported occurrence of ERLP include soccer, volleyball, field hockey, basketball, gymnastics, and dance. Orava and Puranen reported an 18% incidence of ERLP over a five year period in a group of 2750 athletes presenting to a
Finnish sports clinic with overuse injuries. Researchers at a sports medicine clinic in British Columbia have published three epidemiological reports of overuse running injuries from 1981 to 2002. In those studies, the percentage of total running injuries attributed to ERLP were 13.2% of 1819 injuries, 20.4% of 4173 injuries, and, most recently, 12.8% of 2002 injuries. In a study of 63 collegiate cross-country athletes, 52% reported a history of ERLP which interfered with running. Sallis et al reported the most common site of injury in collegiate cross-country runners was the leg. In 2005, the National Collegiate Athletic Association (NCAA) began to collect overuse injury data for men's and women's cross-country as a part of the NCAA Injury Surveillance System. The data indicated that in men's cross country, ankle sprains and ERLP were the most common practice and race injuries that kept participants out seven days or more. Exercise related leg pain was also one of the most common injuries for women's cross country that kept participants out seven days or more. In a 15-year longitudinal study of high school cross country running injuries, Rauh et al reported that the leg was the most common site of injury and re-injury.

PATHOANATOMIC ENTITIES
Exercise related leg pain includes the pathoanatomic entities of medial tibial stress syndrome (MTSS), chronic exertional compartment syndrome (CECS), tibial or fibular stress fractures, tendinopathies (posterior tibialis, anterior tibialis, peroneals, and Achilles), nerve entrapment syndromes, and vascular syndromes. Of these conditions, MTSS, stress fractures, CECS, and tendinopathies are the most common causes of ERLP. Nerve entrapments and vascular syndromes are very rare entities in athletes. A review of the pathoanatomy, clinical signs and symptoms and, as available, specific epidemiological data for six pathoanatomic entities follows.

Medial Tibial Stress Syndrome
Medial tibial stress syndrome presents as pain along the posteromedial border of the distal two-thirds of the tibia, usually most localized at the intersection of the distal and middle thirds. The pain typically intensifies at the initiation of the exercise session, may subside during exercise, and resolves with rest. No neurological symptoms are associated with MTSS. Mubarak et al published the first descriptive paper on MTSS in 1982. These authors reported that Dr. Drez was the individual who coined the term “medial tibial stress syndrome” based on his clinical experience with the presentation of the condition. The investigators studied a group of 12 patients with posterior-medial leg pain and using compartmental pressure studies, ruled out chronic compartment syndrome. They identified the condition as most likely a periostitis along the posterior medial border of the tibia.

Traditionally, the tibialis posterior muscle was considered the anatomic source of medial leg pain associated with MTSS. However, anatomic studies have challenged this hypothesis as the tibialis posterior tibial origin is lateral to the area of symptom identification. These studies suggested the soleus muscle and its investing fascia, along with the flexor digitorum longus and the deep crural fascia, are responsible for traction-induced posterior-medial periosteal pain. Bouche and Johnson used fresh frozen cadaver limbs to examine the pathomechanics of MTSS. They concluded that distal tibia fascial traction is generated by contraction of the superficial and deep posterior compartment muscles and this tension contributes to the development of MTSS.

Detmer developed a classification system for MTSS with three types of lesions. Type I involves tibial stress fractures or stress reactions, Type II involves the fascial attachment of soleus to the tibia, and Type III is a chronic deep posterior compartment syndrome. However, this classification system is not recommended as the system combines multiple diagnostic entities, perpetuating confusion regarding the tissue origin of the athlete’s pain. In this paper, MTSS will be used to describe pain along the fascial insertion of the soleus muscle on the tibia.

Regarding the epidemiology of MTSS, the terminology confusion in the literature confounds precise identification of the incidence of this condition. An early study of MTSS in runners showed 239 runners of a group of 1650 (14.5%) developed medial tibial pain, but this work was done before clarity existed in the diagnostic parameters of MTSS. James et al reported 13% of 232 injuries to runners was “posterior tibial syndrome,” a condition described similar to MTSS. Two studies of high school cross-country runners have shown an overall MTSS incidence of 12% and 15%, with higher incidence in females than males.
Although MTSS is a condition involving the interface of soft tissue and bone, evidence exists that MTSS is associated with decreased tibial bone density. In a study of leg pain in male soccer players, tibial bone density in the MTSS group was 15% lower than a group of non-athletic control subjects, and 23% lower than a group of athletic control subjects. These data should not be misinterpreted that the decreased bone density caused MTSS; in fact, lower bone density may have been a result of chronic MTSS. However, this research is the first to raise the question of the relationship between bone health and MTSS. In a follow-up study, Magnusson et al found that the low regional density of the distal tibial returned to normal following recovery from pain symptoms. The authors concluded that the decreased bone density develops in conjunction with MTSS, but whether a causal relationship exists is unknown.

Treatment for MTSS is largely based on anecdotal reports rather than evidence-based practice. Early management of MTSS pain often includes relative rest from the offending activity, cross-training, and the use of modalities such as icing and ultrasound. Other recommendations include ankle muscle strengthening, stretching, and a progressive return to running. Little, if any, evidence exists to support such recommendations. A survey study of the effect of custom foot orthotics on MTSS suggested that most athletes who were prescribed foot orthotics reported that the orthotics helped their condition. In recalcitrant cases, fasciotomy of the superficial and deep fascia of the posteromedial leg may be recommended, but the outcome of this surgery is not always successful in returning the athlete to sport.

**Chronic Exertional Compartment Syndrome**

The second condition in the ERLP complex is CECS. This condition was first described in 1956 by Mavor in a professional soccer player. The leg has five osseofascial compartments, each bounded by an inelastic layer of fascia. These compartments – anterior, lateral, superficial posterior, deep posterior, and posterior tibialis – enclose the ankle and foot musculature. When the volume of these compartments increases, the compartmental pressure increases, potentially affecting the movement of blood, lymph, and nerve impulses through the compartment and inducing tissue ischemia. This increase in compartmental pressure is referred to as compartment syndrome, and can be caused by either macrotraumatic or microtraumatic events. In the case of a macrotraumatic injury to a limb, acute compartment syndrome may occur as bleeding into the compartment increases the compartmental volume and pressure. This condition is a medical emergency and must be dealt with promptly. Chronic exertional compartment syndrome, on the other hand, is a microtraumatic condition associated with overuse and results from increased muscle volume within a compartment during exercise.

The onset of CECS is usually distinct from MTSS as the athlete describes pain that does not begin at the initiation of exercise but rather begins at a predictable point after exercise initiation. The pain is characterized as “cramping” or “burning” and may or may not subside immediately after exercise. In addition, complaints of numbness and weakness in the lower leg and foot are frequent. The classic diagnostic sign of CECS is elevated intra-compartmental pressure with exercise. The anterior compartment is the most common site of symptoms. In their retrospective review of 2002 running injuries, Taunton et al reported 28 cases (1.4%) of anterior compartment syndrome. The anterior compartment is described as the most commonly affected, followed by the lateral compartment. In a review article, Blackman reported that the preponderance of the literature indicates CECS commonly presents bilaterally with no difference in incidence of CECS between males and females. Styf investigated the cause of ERLP in 98 athletes with purported CECS. He found that 27% of the patients had elevated compartmental pressures with exercise; the other patients had diagnoses including MTSS and peroneal nerve compression.

Little evidence exists to support conservative treatment for CECS. Blackman et al reported that in a pilot study, a combination of massage and stretching intervention increased the amount of work performed prior to onset of symptoms, but no change in the intra-compartmental pressures occurred. Recalcitrant cases may require compartmental fasciotomy for symptom reduction.
Stress Fracture
Bony overuse injury is a third category of ERLP. Bone is a dynamic tissue with a mineral component that is constantly being remodeled based on the imposed stresses. In normal bone, a balance exists between mineral deposition and mineral resorption and no net loss of bone mineral content. However, with excessive repetitive stress over time, bone mineral resorption can exceed deposition. This condition causes a net loss of bone mineral content resulting in a fatigue fracture.43 Unlike the macrotraumatic acute bone fracture injury caused by a large imposed force in a short period of time, the fatigue fracture is a microtraumatic injury representing a maladaptation to smaller repetitive forces. This condition was first described as leg or foot pain in soldiers after marching, and hence, was initially named “march fractures.”44

The onset of pain is usually gradual, and pain decreases with rest in early stages. As the stress fracture develops, the pain may persist after exercise and occur during daily activities.45 Tibial stress fractures are more common than fibular, consistent with the fact that the tibia bears greater load in ambulation.46 As the tibia is the more medial bone of the leg, the symptoms of stress fracture may present indistinguishable from MTSS; the athlete will typically complain of pain along medial leg. In order to make a definitive diagnosis, the gold standard imaging technique is the triple-phase bone scan.45 On a bone scan, a stress fracture will present as intense uptake in one focal site of the bone, whereas MTSS presents as diffuse uptake along the medial tibial border.

Few studies have been done examining the incidence rates of stress fractures in athletes. Bennell and Brukner47 stated, “Incidence rates, expressed in terms of exposure, have rarely been reported for stress fractures in athletes. Nevertheless, available data suggest that runners and ballet dancers are at relatively high risk for stress fractures.” Johnson et al48 tracked injuries for all athletes at a Division II institution over a two-year period. During this time, 34 stress fractures in 24 athletes were diagnosed in the 914 athletes. Of the 34 stress fractures, 13 were tibial, more than any other anatomic site. Of those 13 fractures, nine occurred in females and four in males. Goldberg and Pecora49 studied three years of data on stress fracture occurrence in collegiate athletes at a large private university. They found an annual incidence of 1.9%, but 67% of the injuries were in freshmen. The authors suggested the injuries were a result of the significant increase in training volume between high school and college. The tibia was the second most common region of stress fracture in the study, following the metatarsals of the foot.

Female athletes are at greater risk for stress fractures than male athletes.43,46,47,50-52 Several hypotheses have been forwarded to explain this increased risk. In a review article, Bennell et al53 stated, “menstrual disturbances, caloric restriction, lower bone density, muscle weakness, and leg length differences are risk factors for stress fracture.” However, these authors note that no evidence exists to support lower extremity alignment issues such as pelvic width and knee valgus as risk factors for stress fracture.

Shaffer and Uhl54 recently completed a systematic review of the prevention and treatment of stress fractures in athletes. They reported that while no high level evidence supports any prevention strategies, limited evidence exists to support the use of shock absorbing insoles for stress fracture prevention. Likewise, another systematic review of the interventions for prevention and treatment of stress fractures found evidence that the use of shock absorbing inserts in footwear reduced the incidence of stress fractures in military personnel.55 These authors also found limited evidence to support the use of a pneumatic brace during the rehabilitation period after a stress fracture.

Tendinopathy
The fourth diagnostic entity within ERLP is tendinopathies, or pathologic conditions affecting tendon tissue. Tendons are collagenous structures which link muscle to bone. In a normal tendon, the collagen fibrils are arranged in a parallel fashion. In a pathologic tendon, the collagen alignment is disorganized with abnormal intratendinous material. Khan et al56 described the two primary tendinopathies as tendinitis and tendinosis. A key finding in much of the research on tendon pathology is the conspicuous absence of inflammatory cells in involved tendon tissue. In an essay on the use of language in medicine, Bernstein57 pointed out that the words we use influence how we think. The pervasive and indiscriminant use of the term “tendinitis” to describe any tendon pathology
causes health care practitioners and patients to continue to view tendon pathology as inflammatory, which is, in fact, rarely the case.

The pain pattern of an athlete with tendon pain depends on the chronicity of the condition. In an early stage, the athlete may have tendon pain only after exercise. As the condition progresses, the pain may become constant with all daily activities. The pain is typically located along the course of the tendon, in some cases at the enthesis site and in other cases as the tendon passes around a bony prominence. Tendon pain is typically intensified with resisted testing of the involved muscle group.

As with the other ERLP conditions, little accurate epidemiological information is available regarding the tendon conditions. Several authors report tendon pathology is a “common” overuse injury, but give no specific incidence of injury. In their study of injuries in runners, James et al reported Achilles tendinitis was the third most common problem behind knee pain and posterior tibial pain, with 11% of the running injuries in this category. Using a population of 2002 injured runners, Taunton et al identified Achilles tendinitis in 96 runners (4.8%), peroneal tendinitis in 13 runners (0.65%), and posterior tibialis tendinitis in 11 runners (0.55%). All tendon pathologies in this study were referred to as “tendinitis.”

Interventions for tendon pain also are largely based on anecdotal reports and clinical lore. Such interventions include relative rest, cross-training, stretching, strengthening, ultrasound, iontophoresis, cryotherapy, counterforce bracing, foot orthotics, non-steroidal anti-inflammatory medications, extracorporeal shock wave therapy, and surgery. At present, the only conservative intervention that is supported by evidence is the use of eccentric training.

Nerve Entrapment
Nerve entrapment is a rare clinical condition in athletes, but one that the clinician must recognize from a thorough examination. The peripheral nerves involved in entrapment syndromes of the leg include the saphenous, common peroneal, superficial or deep peroneal, sural, and tibial nerves. The symptoms of these syndromes may include pain, paresthesia, motor weakness, and decreased coordination, depending on the specific nerve. For example, the saphenous nerve is a sensory nerve only, and entrapment may result in sensory loss or medial leg pain that may mimic vascular claudication type pain. Hirose and McGarvey describe three stages of nerve entrapment: Stage 1 in which patients feel pain and occasional paresthesia, especially at night; Stage 2 in which the paresthesia is more constant throughout the day and muscle weakness may develop; and Stage 3 in which patients experience constant pain, and sensory and motor loss.

Nerve symptoms may occur secondary to CECS and compartmental pressure assessments are necessary to distinguish CECS from nerve entrapment. The etiology of nerve entrapment is not well understood, but is hypothesized to be a result of either blunt trauma or repetitive motion leading to scarring of the nerve sheath. No epidemiological data pertaining to nerve entrapment in the leg were found in the literature. Detail regarding specific nerve entrapments is outside the scope of this paper; the reader is referred to excellent review papers on this topic for more information.

Treatment of nerve entrapment includes such conservative measures as nerve flossing, padding, orthotic prescription, and corticosteroid injections. Recalcitrant cases may require a surgical decompression of the nerve entrapment.

Vascular Pathology
The last of the clinical entities within the umbrella of ERLP is vascular pathology. Entrapments of the popliteal artery or the anterior tibial artery have been reported in the literature but are extremely rare. This condition presents with symptoms very similar to CECS, and diagnostic differentiation requires compartmental pressure testing. Distal pulses are diminished in this condition, and the athlete will describe a deep ache or “cramping” sensation. If identified, this condition requires surgical intervention.

EXERCISE RELATED LEG PAIN RISK FACTORS
Van Mechelen et al proposed a “sequence of prevention” model for sport injury which involved four steps: identifying the extent of the injury problem, understanding the etiology and mechanism of injury, introducing appropriate preventative measures, and assessing the effectiveness of those measures. In a systematic review on the prevention of exercise-related leg pain (ERLP) in athletes, the authors concluded there is “little objective evidence to support the widespread use of any existing
interventions to prevent shin splints.\textsuperscript{a} A primary reason for this paucity of evidence regarding interventions is that the risk factors for ERLP are not well understood. Multiple factors are hypothesized to contribute to the development of ERLP including intrinsic and extrinsic factors. Intrinsic factors are those contained within a person, including sex, race, bone structure, bone density, muscle length, muscle strength, joint range of motion, diet, and body composition. Extrinsic factors are those outside of a person, including training volume (frequency, duration, and intensity), types of conditioning activities, specific sport activities, training surface, shoes, and environmental conditions.

Extrinsic Risk Factors
Extrinsic factors, including training volume, training surfaces, shoes, and sport activities, are often cited as causes of lower extremity overuse injury. However, consensus evidence is generally lacking to support most of these factors. A preponderance of evidence suggests that excessive training mileage in runners is a risk factor for lower extremity overuse injury.\textsuperscript{13,25,75-77} Macera et al\textsuperscript{76} reported that the most important predictor of lower extremity overuse injury was running 40 or more miles per week. A study of overuse injuries in 1300 United States Marine Corps recruits indicated that a higher weekly training volume was associated with an increase in lower extremity overuse injuries.\textsuperscript{78} However, although excessive training is commonly mentioned as a risk factor for ERLP, no supporting evidence exists specific to ERLP.

Sport type is another purported risk factor for ERLP. Ugalde and Batt\textsuperscript{11} stated, “A high incidence of shin pain is associated with running and jumping sports,” but offered no specific epidemiological information. In their prospective study of athletes with acute shin splints, Batt et al\textsuperscript{79} found that most of the athletes (83%) were cross-country runners or track athletes. In a study of ERLP in collegiate female athletes, Reinking\textsuperscript{80} found the highest incidence in cross-country and field hockey athletes.

Intrinsic Risk Factors
More research has focused on intrinsic risk factors associated with lower extremity overuse injuries. Several studies have reported a greater risk of lower extremity overuse injury in athletes with a pronatory foot type.\textsuperscript{25,59,81-84} However, conflicting data exist suggesting excessive foot pronation is not an intrinsic risk factor for lower extremity overuse injury.\textsuperscript{25,49} Three recent studies have not supported this relationship.\textsuperscript{10,30,85} Potential confounding issues in the conflicting results regarding foot pronation and ERLP include the variation in the static and dynamic foot pronation measures, sample populations, and pathoanatomic entity included in the study.

Poor musculotendinous flexibility is another commonly cited intrinsic factor for generic lower extremity overuse injury.\textsuperscript{61,96-98} Kaufman et al\textsuperscript{59} reported that tight posterior calf muscles as measured by limited ankle dorsiflexion with the knee extended was a risk factor for lower extremity overuse injury, but close examination of his data show that this was only true for the development of Achilles tendon pain. In a review of the relationship between flexibility and sport injury, Gleim and McHugh\textsuperscript{99} concluded “There is no scientifically based prescription for flexibility training and no conclusive statements can be made about the relationship of flexibility to athletic injury.” This conclusion was supported by a second systematic review on the effect of stretching on sport injury.\textsuperscript{100}

Neely\textsuperscript{101} conducted a comprehensive review of the literature on intrinsic risk factors for ERLP using studies of both military and civilian populations. The review focused on intrinsic factors including age, somatotype, sex, past history of injury, and physical fitness. From the review, the author concluded that “overwhelming evidence” supports several intrinsic factors as increasing the risk of ERLP. Those factors are female sex, including age > 24 years, a high body mass index (BMI), low BMI in females, poor physical fitness as measured by a 1- or 2-mile timed run, and past history of injury. The BMI data indicated that for both men and women, a higher percentage of body fat resulted in a greater risk of injury. The authors suggested that higher body fat may be a consequence of excessive forces placed on tissues because of additional weight. However, women showed a bimodal relationship between BMI and injury; not only was more body fat a risk for injury but also less body fat than normal.

Intrinsic factors associated with bone-related ERLP (stress fractures) include sex, menstrual function, bone density, and foot type. It is well documented that stress fractures are more common in females than in males.\textsuperscript{37,46,49,52,102,103} Barrow and Saha\textsuperscript{104} found stress fractures to be more common in collegiate female runners with menstrual
irregularity. These authors also found a much higher incidence of disordered eating in the women with menstrual abnormalities. These results were corroborated in a study of 113 track and field athletes, where the authors found not only menstrual dysfunction to be a risk factor for stress fractures in female athletes but also low bone density.105 Based on anecdotal evidence, foot pronation is considered a risk factor for tibial stress fractures, while others have reported that excessive supination is a causal factor.106,107 In a literature review on risk factors for stress fractures, Bennell et al108 stated, “time-honoured risk factors such as lower extremity alignment have not been shown to be causative even though anecdotal evidence indicates they are likely to play an important role in stress fracture pathogenesis.”

PREVENTION OF ERLP

As described earlier in this paper, van Mechelen73 proposed a sport injury prevention model involving four steps: (1) identifying the extent of the injury problem, (2) understanding the etiology and mechanism of injury, (3) introducing appropriate preventative measures, and (4) assessing the effectiveness of those measures. The second step of his model, injury etiology and mechanism, was further developed by Meeuwisse109 in which he described a multifactorial causation model involving intrinsic and extrinsic factors. In this model, intrinsic factors predisposed an athlete to injury, and subsequent exposure to extrinsic factors resulted in injury to susceptible athletes. Bahr and Krosshaug109 focused on the complex interaction of intrinsic and extrinsic factors as an inciting event in sports injury etiology. Based on these previous models,73,108,109 Meeuwisse et al110 has proposed a new expanded model of sport injury etiology which takes “the cyclic nature of changing risk factors into account to create a dynamic, recursive picture of etiology.” This model attempts to take into account both intrinsic and extrinsic risk factors as well as repeated exposures and changing circumstances that combine to cause injury. The current problem with ERLP is that very little is understood about the specific intrinsic and extrinsic factors which may predispose an athlete to injury with repeated exposures.

In a recent systematic review on the prevention of ERLP in athletes, Thacker et al74 concluded there is “little objective evidence to support the widespread use of any existing interventions to prevent shin splints.” In another systematic review focused on the prevention of stress fractures in athletes and soldiers, the authors reported that their comprehensive review of the literature “highlights how little we know about what works to prevent one of the most common and potentially serious sports- and exercise-related overuse injuries.” These two systematic reviews on the status of ERLP prevention strategies exemplify the lack of understanding of the etiology of ERLP and highlights the need for future research in this area.

CONCLUSION

In summary, it is evident from this review that in spite of the common occurrence of ERLP in athletes, the lack of success in the prevention and treatment of ERLP is a reflection of the limited understanding of the risk factors which lead to the development of ERLP. In Van Mechelen’s sequence of prevention model,73 development of successful prevention strategies requires development of knowledge of the mechanisms and factors associated with the development of the condition. In addition to a lack of consensus knowledge, another barrier to the development of successful approaches to address this problem is the indiscriminate use of terms such as “shin splints,” which can unintentionally lead one to not consider the complexity of the different pathoanatomic entities that manifest as ERLP. Careful and thorough examination identifying the location, nature, and chronology of symptoms as well as static and dynamic neuromusculoskeletal impairments is essential in the development of an appropriate intervention plan. A great need exists for ongoing high quality research both in the identification of extrinsic and intrinsic risk factors and the development of successful intervention programs.

REFERENCES


CLINICAL SUGGESTION
USE OF POOL NOODLES FOR THE SHOULDER AND ANKLE
Russell Nelson PT, PhD, SCS, ATC

ABSTRACT
The purpose of this manuscript is to provide two clinical suggestions that are inexpensive, easy to fabricate, and very user-friendly activities that can be used for most patients and athletes. The first clinical suggestion is a method of restoring stability of the scapular muscles around the shoulder complex. Following a period of disuse, whether from a surgery or an injury, weakness may be present in the shoulder. This suggestion is an easy and inexpensive tool which can be used in restoring stability of the scapula in all planes of movement as well as combinations of these planes. The method can also be used as a progression from gravity assisted to gravity resisted active range of motion. The purpose of the second clinical suggestion is to provide an inexpensive and easy to use method of improving proprioception in the ankle. Ankle sprains are among the most common injuries seen in sports. Proprioceptive activities are used not only in the rehabilitation process following an injury but as a training tool to help prevent ankle injuries. This method can be used in the clinic, in a training facility, or as part of a home exercise program.

CORRESPONDENCE
Russell Nelson PT, PhD, SCS, ATC
Christus St. Michael
Outpatient Rehabilitation
2223 Morris Lane
Texarkana, TX 75503
Phone: 903-614-4422
Fax: 903-614-4444
runnelson@cableone.net

* Christus St. Michael Outpatient Rehabilitation
Texarkana, TX
PROBLEM #1-SHOULDER

The most frequent cause of shoulder pain is subacromial impingement syndrome accounting for 44 – 60% of all complaints of shoulder pain during a physician visit.1 Although the cause of shoulder impingement is often multifactorial, scapular stabilizer weakness is often associated with the impingement. Cools et al2 found that overhead athletes with impingement syndrome demonstrated strength deficits and muscular imbalances in scapular muscles compared with non-injured athletes. Weakness in scapular stabilizers will create poor length tension relationship between the scapula and the humerus. The length between the scapula and humerus will put the rotator cuff in a more lengthened position. If the scapular stabilizers are weak or fatigued, the result will be a destabilized scapula which will contribute to impingement. Muscular weakness and fatigue in the scapular stabilizers will also lead to a loss of upward scapular rotation during overhead activities referred to as scapular dyskinesis.3 Scapular squeezes and shoulder shrugs are excellent ways of strengthening the musculature surrounding the scapula. Both of the exercises work in one plane of motion and, therefore, do not prepare the shoulder for many of the functional activities of life or sport. Because the glenohumeral joint is the most mobile joint in the body, the scapula must be able to stabilize that joint in multiple positions.

SOLUTION TO PROBLEM #1

A nice way to train the scapular stabilizers in multiple positions and planes of movement is to perform extreme shoulder ABC’s. The only piece of equipment needed for extreme ABC’s is a giant marker.

To fabricate a giant marker for the extreme shoulder ABC’s take a 1 foot piece of ½ inch piece of PVC pipe and slip the pipe approximately 6 inches into the hole at one end of a pool noodle. The PVC pipe will serve as the handle for the marker. Cut the pool noodle in half making it 3 feet in length. Have the patient hold the PVC pipe handle to draw the alphabet (Figure 1). Very weak or deconditioned patients can start by drawing the alphabet on the floor in an effort to stay below 90° of shoulder flexion (Figure 2). As the patient gets stronger, progress to where they are drawing the alphabet on the wall. Writing larger letters seems to challenge the scapular stabilizers.
more than smaller letters (Figure 3). Repeating the alphabet two times is quite challenging to the patient.

**PROBLEM #2-ANKLE**

Another use for a swimming pool noodle is as a device to help a patient to regain kinesthetic awareness after an ankle injury or surgery. As many as 70% of athletes in some sports suffer from recurrent ankle sprains. Following an ankle sprain, many patients will complain of residual symptoms 6 to 18 months after the injury. Research has found that there is a loss of kinesthetic awareness following trauma to the ankle. This deficit in kinesthetic awareness or proprioception can lead to a re-injury of the same area, injury to another area, or at the very least a decrease in performance in athletic activities.

The core of ankle training research over the past decade has been directed toward the development of exercise programs aimed at preventing the occurrence and recurrence of ankle sprains. These programs have focused on proprioception, strengthening, balance, and coordination exercises. Often patients will perform activities on an uneven or unstable surface in hopes of regaining the kinesthetic awareness. Therapists will have patients walk in sand or over rolled towels to challenge the balance of the patient. Sand is often not readily available in a clinical setting. Towels, while readily available, will be compressed after the patient has walked across them several times.

**SOLUTION TO PROBLEM #2**

A foam pool noodle can be cut in half long ways and laid on the floor with the cut side down. To begin, the patient can simply balance on the foam noodle on one leg (Figure 4). Laying two halves of the noodle end to end will provide a 12 foot length to walk or run depending on where the patient is in the recovery process (Figure 5). Have the patient walk or run across the noodle as if they were walking along a balance beam. The foam will challenge the ankle in a safe manner.

**REFERENCES**


ABSTRACT

Examination of a painful hip is fairly concise and reliable at detecting the presence of a hip joint problem. Hip joint disorders often go undetected, leading to the development of secondary disorders. Using a thoughtful approach and methodical examination techniques, most hip joint problems can be detected and a proper treatment strategy can then be implemented based on an accurate diagnosis. The purpose of this clinical commentary is to present a systematic examination process that outlines important components in each of the evaluation areas of history and physical examination (including inspection, measurements, symptom localization, muscle strength, and special tests).

CORRESPONDENCE:
J. W. Thomas Byrd, M.D.
Nashville Sports Medicine and Orthopaedic Center
2011 Church Street, Suite 100
Nashville, TN 37203
615-284-5800
Fax: 615-284-5819
info@nsmoc.com
Consultant: Smith & Nephew Endoscopy

*Department of Orthopaedics and Rehabilitation
Vanderbilt University School of Medicine
Nashville, TN
Examination of a painful hip is fairly succinct. One study demonstrated that the clinical assessment can be 98% reliable at detecting the presence of a hip joint problem; although the exam may be poor at defining the exact nature of the intra-articular disorder. However, examination of the hip region can be quite complex due to co-existent pathology, secondary dysfunction, or coincidental findings.

For example, hip joint disease may co-exist with lumbar spine disease. Considerable attention may be necessary in order to distinguish which is the major factor. Among athletes, a significant incidence of hip pathology and concomitant athletic pubalgia can occur. The symptoms can be difficult to distinguish, especially when they co-exist.

Hip joint disorders often remain undetected for protracted periods of time. In the course of compensating for their symptoms, patients often develop secondary dysfunction. This dysfunction may lead to symptoms of trochanteric bursitis or chronic gluteal discomfort. The examination findings for the secondary disorders may be more evident and mask the underlying problem with the hip.

Coincidental findings unrelated to disorders of the hip may exist. Snapping of the iliopsoas tendon and iliotibial band are usually incidental findings without clinical significance. However, this snapping can become a source of symptoms or may exist coincidentally with hip joint pathology. Once again the clinical assessment can become challenging to distinguish the features of each.

A myriad of structures may create similar or overlapping symptoms. In addition to the joint, the clinician must be cognizant of bone problems, surrounding musculotendinous and bursal structures, neurological disorders including numerous small sensory nerves, and even visceral disorders that can refer symptoms to the hip area.

HISTORY
As there are various disorders that can result in a painful hip, the history may be equally varied as far as onset, duration, and severity of symptoms. For example, acute labral tears associated with an injury have gone undiagnosed for decades, presenting as a chronic disorder. Conversely, patients with a degenerative labral tear may describe the acute onset of symptoms associated with a relatively innocuous episode and gradual progression of symptoms.

In general, a history of a significant traumatic event is a good prognostic indicator of a potentially correctable problem. Insidious onset of symptoms is a poor prognostic indicator and suggests either underlying degenerative disease or some predisposition to injury. Patients may recount a minor precipitating episode such as a twisting injury; however, even under these circumstances, be wary that underlying susceptibility of the joint to damage may exist and, again, a less certain prognosis. With any hip joint problem, the clinician must look closely for predisposing factors. For example, femoro-acetabular impingement is a recognized cause of joint breakdown in young adults. Often, the cause may be multi-factorial including age, rigors of sport, and joint morphology. The management strategy may have to be multi-faceted, as well. Perhaps not all factors can be identified or corrected, but the evaluation must be thorough.

Mechanical symptoms such as locking, catching, popping, or sharp stabbing in nature are better prognostic indicators of a correctable problem. Simply pain in absence of mechanical symptoms is a poorer predictor. However, the presence of a “pop” or “click” is an often over-rated feature of the hip examination. This finding may indicate an unstable lesion inside the joint, but many painful intra-articular problems never demonstrate this finding, and popping and clicking can occur due to many extra-articular causes, most of which are normal.

There are characteristic features of the history that often indicate a mechanical hip problem (Table 1). These characteristics are helpful in localizing the hip as the source of trouble, but are not specific for the type of pathology. As expected, the pain is worse with activities, although the degree is variable. Straight plane activities such as straight ahead walking or even running are often well tolerated, while twisting maneuvers such as simply turning to change direction may produce sharp pain, especially turning towards the symptomatic side which places the hip in internal rotation. Sitting may be uncomfortable, especially if the hip is placed in excessive flexion. Rising from the seated position is especially painful and the
patient may experience an accompanying catch or sharp stabbing sensation. Symptoms are worse with ascending or descending stairs or other inclines. Entering and exiting an automobile is often difficult with accompanying pain, because the hip is in a flexed position along with twisting maneuvers. Dyspareunia is often an issue due to hip joint pain, commonly a problem among females, but may be a difficulty for males as well. Difficulty with shoes, socks, or hose may simply be due to pain or may reflect restricted rotational motion and more advanced hip joint involvement.

Based on the information obtained in the history, a preliminary differential diagnosis should be formulated. The history assists the examiner in performing an appropriately directed physical examination.

**PHYSICAL EXAMINATION**

The information obtained in the history is just a screening tool. The history helps direct the examination, but should not unduly prejudice the approach. The examiner must be systematic and thorough to avoid potential pitfalls and missed diagnoses. In reference to examination of the hip, Otto Aufranc noted that “more is missed by not looking than by not knowing.”

**Inspection**

The most important aspect of inspection is stance and gait. The patient’s posture is observed in both the standing and seated position. Any splinting or protective maneuvers used to alleviate stresses on the hip joint are noted. While standing, a slightly flexed position of the involved hip and concomitantly the ipsilateral knee is common (Figure 1). In the seated position, slouching or listing to the uninvolved side avoids extremes of flexion. (Figure 2).

An antalgic gait is often present, but dependent on the severity of symptoms. Typically, the stance phase is shortened and hip flexion appears accentuated as extension is avoided during this phase. Varying degrees of abductor lurch may be present as the patient attempts to place the center of gravity over the hip, reducing the forces on the joint. In addition, observation is made for any asymmetry, gross atrophy, spinal alignment, or pelvic obliquity that may be fixed or associated with a gross limb length discrepancy.

---

**TABLE 1: Characteristic Hip Symptoms (reprinted with permission5)**

- Symptoms worse with activities
- Twisting, such as turning or changing directions
- Seated position may be uncomfortable, especially with hip flexion
- Rising from seated position often painful (catching)
- Difficulty ascending and descending stairs
- Symptoms with entering/exiting an automobile
- Dyspareunia
- Difficulty with shoes, socks, hose, etc.

---

**Figure 1.** During stance, the patient with an irritated hip will tend to stand with the joint slightly flexed. Consequently, the knee will be slightly flexed as well. This combined position of slight flexion creates an effective leg length discrepancy. To avoid dropping the pelvis on the affected side, the patient will tend to rise slightly on his or her toes. (Reprinted with permission.)

**Figure 2.** In the seated position, slouching and listing to the uninvolved side allows the hip to seek a slightly less flexed position. This position is usually combined with slight abduction and external rotation, which relaxes the capsule. (Reprinted with permission.)
Measurements

Certain measurements should be recorded as a routine part of the assessment. Limb lengths should be measured from the anterior superior iliac spine to the medial malleolus (Figure 3). Significant limb length discrepancies (greater than 1.5 cm) may be associated with a variety of chronic conditions. Typically, if limb length difference appears to be a contributing factor, half of the recorded discrepancy should be corrected in the course of conservative treatment. Treatment with an insert is cosmetically more acceptable than a built-up shoe. Thigh circumference, while a crude measurement, may reflect chronic conditions and muscle atrophy (Figure 4). It is important to measure the involved compared with the uninvolved side. Sequential measurement on subsequent examination may be helpful as an indicator of response to therapy. Again, circumference is a crude measure that only indirectly reflects hip function, but hip disease conversely usually affects the entire lower extremity.

Range of motion of the hip should be accurately recorded in a consistent and reproducible fashion. While reduced range of motion itself is rarely an indication for arthroscopic intervention, decreased range is often a good indicator of the extent of disease and response to treatment.

The degree of flexion and the presence of a flexion contracture are determined by using the Thomas test. Maximal extension of the uninvolved hip stabilizes the pelvis, eliminating the contribution of pelvic tilt in recording flexion of the involved hip. Conversely, maximal flexion of the uninvolved hip locks the pelvis and allows assessment for a flexion contracture of the involved hip. Extension is recorded with the patient in the prone position, raising the leg.

Several effective mechanisms exist for recording rotational motion of the hip. It is important to select one and be consistent. Flexing the hip 90° and then internally...
and externally rotating the joint is an easy, reproducible method for recording rotational motion (Figure 5). Abduction and adduction are recorded as well.

**Symptom Localization**

**The One Finger Rule**

Although this rule is not as accurate when applied to the hip than to other joints, such as the knee, it is still important to ask the patient to use one finger and point to the spot that hurts the worst. This pointing provides much useful information before beginning palpation by allowing the examiner to discern the point of maximal tenderness. Consequently, this area is reserved until last when performing the examination. This information forces the examiner to be more systematic, exploring uninvolved areas first, and enhances the patient's trust by not stimulating pain at the beginning of the examination.

Hilton’s law states that “the same trunks of nerves whose branches supply the groups of muscles moving a joint furnish also a distribution of nerves to the skin over the insertion of the same muscles, and the interior of the joint receives its nerves from the same source.” While this quote may ensure physiological harmony among the various structures, it also explains why muscle spasms and cutaneous sensations may accompany joint irritation.

Classic mechanical hip pain is described as being anterior, typically emanating from the groin area. The hip joint receives innervation from branches of L2 to S1 of the lumbosacral plexus, predominantly L3. Consequently, hip symptoms may be referred to the L3 dermatome, explaining the presence of symptoms referred to the anterior and medial thigh, radiating distally to the level of the knee.

Intra-capsular hip pathology almost always has a component of anterior hip pain. A sensation of deep, lateral discomfort or posterior pain may be present, but usually only in conjunction with a predominant anterior component.

**The C Sign**

The classic complaint of patients with hip pathology is “groin pain.” However, the author has identified a common characteristic sign of patients presenting with hip disorders. The patient will cup their hand above the greater trochanter when describing deep interior hip pain. The hand forms a C and thus this has been termed the “C-sign” (Figure 6).

---

**Figure 5. A, B.** Supine, with the hip flexed 90°, the hip is maximally rotated internally and externally with motions recorded. This method is simple, quick, and reproducible. (Reprinted with permission J. W. Thomas Byrd, M.D.)

**Figure 6. A, B.** The C sign. This term reflects the shape of the hand when a patient describes deep interior hip pain. The hand is cupped above the greater trochanter with the thumb posterior and the fingers gripping deep into the anterior groin. (Reprinted with permission J. W. Thomas Byrd, M.D.)
Patrick or Faber test (flexion, abduction, external rotation) has been described both for stressing the SI joint, looking for symptoms localized to this area, and for isolating symptoms to the hip (Figure 8). Differentiation between 6). Because of the position of the hand, this sign can be misinterpreted as indicating lateral pathology such as the iliotibial band or trochanteric bursitis, but quite characteristically, the patient is describing deep interior hip pain.

**Palpation**

Palpation is usually unrevealing as far as any specific areas of discomfort related to an intra-articular source of hip symptoms. Obviously, one must be familiar with the topographical and deep anatomy in order to correlate the structures being palpated. Aufranc6 noted that “a continuing study of anatomy marks the difference between good and expert ability.”

Palpation is used more to assess potential sources of hip-type pain, other that the joint itself. It is important to be systematic, palpating the lumbar spine, sacroiliac (SI) joints, ischium, iliac crest, lateral aspect of the greater trochanter and trochanteric bursa, muscle bellies, and even the pubic symphysis, each of which may elicit information regarding a potential source of hip symptoms.

**Muscle Strength**

Manual muscle testing is a crude measure of hip function but may elicit useful information. If injury to a specific muscle group is suspected, resisted contraction should reproduce localized symptoms.

Active range of motion and resisted active range of motion may also reproduce joint symptoms. However, when carefully interpreted, a distinction can be made between symptoms of a muscle strain and hip pain. This differentiation may be least clear with a strain of the hip flexors. In this situation, active hip flexion reproduces pain while passive flexion should not.

**Special Tests**

Special tests include those maneuvers used to define other sources of symptoms as well as those used to define symptoms localized to the hip. The examiner should also be aware of how tests for other sources might affect a painful hip.

The passive straight leg raise is important for assessing signs related to lumbar nerve root irritation (Figure 7). The test may also provoke local joint symptoms. The
pain localized to the SI joint and the hip is usually easy. The single most specific test for hip pain is log rolling of the hip back and forth (Figure 9). Log rolling moves only the femoral head in relation to the acetabulum and the surrounding capsule. No significant excursion or stress occurs on myotendinous structures or nerves. Absence of a positive log roll test does not preclude the hip as a source of symptoms, but its presence greatly raises the suspicion.

Forced flexion combined with internal rotation is a more sensitive maneuver which may elicit symptoms associated with even subtle hip pathology (Figure 10). This test is often referred to as an “impingement test” eliciting symptoms associated with femoro-acetabular impingement. However, this maneuver is usually uncomfortable with any irritable hip and is not specific for the nature of the pathology. An accompanying pop or click may be present, but it is more important to determine if this maneuver reproduces the type of hip pain that the patient experiences with activities. This maneuver may normally be uncomfortable, so it is important to compare the response on the symptomatic and asymptomatic sides. Alternatively, forced abduction with external rotation will sometimes produce symptoms (Figure 11).

An active straight leg raise or straight leg raise against resistance often elicits hip symptoms (Figure 12). This maneuver generates a force of several times the body weight across the articular surfaces and actually can generate more force than walking.
The Trendelenburg test is used to assess for gross abductor weakness. This weakness may develop as a chronic condition secondary to joint disease or may represent a neuromuscular disorder. The patient stands on the affected leg and lifts the contralateral leg off of the ground. With adequate abductor strength the pelvis should remain level. With gross abductor weakness the pelvis drops towards the contralateral side (Figure 13).

Various maneuvers may create a click or popping sensation. This popping may reflect an unstable labral tear or chondral fragment. However, the origin of these clicks or pops is often unclear and do not uniformly reflect an intra-articular lesion.

Snapping of the iliopsoas tendon is a common incidental finding without clinical significance. However, the snapping can become painful and can be difficult to distinguish from an intra-articular problem. The snapping is sometimes subtle, better experienced by the patient than detected by the examiner; but is often quite prominent with a distinct audible component. The characteristic examination maneuver for creating the snap is bringing the hip from a flexed, abducted, externally rotated position into extension with internal rotation (Figure 14). The snapping occurs as the iliopsoas tendon transiently lodges on the anterior aspect of the hip capsule or pectineal eminence. Often this snapping is a dynamic process better demonstrated by the patient than can be elicited by the examiner. The maneuver performed by the patient can be variable in sitting, standing, or lying down; but the snapping invariably occurs when going from flexion to extension. It is important not to misinterpret snapping of the iliopsoas tendon as an intra-articular problem, but it is also likely that numerous intra-articular disorders get misdiagnosed as a “snapping hip syndrome.” For recalcitrant symptomatic snapping of the iliopsoas tendon, fluoroscopy with iliopsoas bursography and ultrasonography can often substantiate the source. However, these studies may not be conclusive, therefore, the history and examination findings remain the most reliable clinical assessment tool.

Figure 13. The patient stands on the affected right leg, lifting the left leg off of the ground. With normal abductor strength, the pelvis should remain level. However, as illustrated here, with abductor weakness, the pelvis drops towards the contralateral side, reflecting a positive Trendelenburg test. (Reprinted with permission J. W. Thomas Byrd, M.D.)

Figure 14. A,B. Snapping of the iliopsoas tendon may be elicited as the hip is brought from a flexed, abducted, externally rotated position into extension with internal rotation. (Reprinted with permission J. W. Thomas Byrd, M.D.)
Snapping due to the iliotibial band is more easily distinguished from a hip joint disorder because of its lateral location. These patients frequently present with a sensation that their hip is subluxing or dislocating. The process is dynamic in that the patient can demonstrate much more vividly than can be detected by the examiner. The visual appearance is created by the tensor fascia lata flipping back and forth across the greater trochanter, and not instability of the hip. With the patient in the lateral position, the snapping may be created by flexing and extending the hip, moving the abductor mechanism across the greater trochanter (Figure 15). Ober testing to assess for tightness of the abductor mechanism can be performed by lowering the leg on the table.

Good generalizations exist regarding snapping hip syndromes. If you can hear it from across the room it is the iliopsoas tendon, and if you can see it from across the room it is the iliotibial band.

Athletic pubalgia occurs most often in male athletes. The symptoms emanate from the groin and the findings can be confused with a hip joint problem. This condition often co-exists with hip joint pathology in an athletic population. Diminished rotational motion of the hip is compensated by increased pelvic motion. This motion places more stress on the pelvic stabilizers and can result in soft tissue breakdown of the lower abdominal muscles, pelvic floor, and adductor origins. This condition is characterized by localized soft tissue tenderness to palpation on examination (Figure 16); and absence of discomfort with passive range of motion that would be observed in patients with hip joint pathology. Resisted sit ups, hip adduction, and sometimes hip flexion may also precipitate symptoms associated with this soft tissue disorder.

CONCLUSIONS

Historically, hip joint problems in athletes have been largely neglected. This neglect has been due to a combination of factors including poor assessment skills and, without interventional methods to address these problems, little incentive has existed to pursue an investigation. Arthroscopy has defined the existence of numerous intra-articular disorders that previously went undetected and untreated. This information has served to enhance clinical assessment skills and has stimulated advancements in investigative studies. Using a thoughtful approach and methodical examination techniques, most hip joint problems can be detected. A proper treatment strategy can then be implemented including the role of conservative measures and interventional methods based on an accurate diagnosis.

REFERENCES


ABSTRACT

Among people who participate in sports, extra-articular soft tissue injuries around the hip are common. The hamstring, quadriceps, adductor, and abductor muscle groups are often the site of soft tissue injury. Overlapping conditions make it difficult to identify the primary cause of hip pain and dysfunction. A proper evaluation and diagnosis of the impairment are crucial for the selection of interventions and quick return to play. The purpose of the clinical commentary is to present an evidence based stepwise progression in the evaluation and treatment of several common soft tissue injuries of the hip.
Soft tissue injuries around the hip are common, particularly among people who participate in sports. The hip has four sets of strong muscles surrounding the joint: the hamstring muscles posteriorly, quadriceps muscles anteriorly, adductor muscles medially, and abductors laterally. Each of these sets of muscles are often the site of soft tissue injury.1 The hamstring and quadriceps muscle groups are particularly at risk for muscle strains because they cross both the hip and knee joints. These muscles are also used for high-speed activities such as track and field events, football, basketball, ice hockey, and soccer.

MUSCLE STRAINS
The most common mechanism of injury for muscle strains in the hip area occur when a stretched muscle is forced to contract suddenly. A fall or direct blow to the muscle, overstretching, and overuse can tear muscle fibers, resulting in a strain. The risk of muscle strain increases if the patient has had a history of injury to the area, inadequate warm-up before exercising, or attempts to do too much too quickly. Strains may be mild, moderate, or severe depending on the extent of the injury. Pain over the injured muscle is the most common symptom of a hip strain. Contracting the muscle increases the pain level. Swelling may also be present, depending on the severity of the strain. A loss of strength in the muscle may also exist.

Evaluation of hip muscle strains can be challenging. A muscle that is painful during contraction and painful when stretched may be strained. Specific exercises or stretches which stress the involved muscle can help determine which muscle is injured. An X-ray may be used to rule out the possibility of a stress fracture of the hip, which has similar symptoms, including pain in the groin area with weight bearing. In most cases, no additional tests are needed to confirm the diagnosis.

In general, treatment and rehabilitation are designed to relieve pain, restore range of motion, and restore strength – in that order. The use of RICE (rest, ice, compression, elevation) is the standard protocol for mild to moderate muscle strains. Gentle massage of the area with ice may help to decrease swelling. Non-steroidal anti-inflammatory drugs (NSAIDs) can be taken to reduce swelling and ease pain. Compression shorts or a wrap bandage may also be helpful in decreasing swelling and providing support. If walking causes pain, weightbearing should be limited and crutches should be considered for the first day or two after the injury.

Adductor Muscle Strains
The group of muscles along the inner thigh is referred to as the adductor muscle group. This group of six muscles includes the pectineus, adductor longus, adductor brevis, adductor magnus, gracillis, and obturator externus. All of the adductor muscles are innervated by the obturator nerve except for the pectineus, which gets its motor intervention from the femoral nerve. These muscles originate in the inguinal region at various points on the pubis. The muscles travel inferior to insert along the medial femur. The main action of this muscle group is to adduct the thigh in the open kinetic chain and stabilize the lower extremity to perturbation in the closed kinetic chain. Each individual muscle can also provide assistance in femoral flexion and rotation.1,2 The adductor longus is thought to be the most frequently injured adductor muscle.3 The lack of mechanical advantage may make the adductor muscles more susceptible to strain.

Adductor muscle strains can result in missed playing time for athletes in many sports. Adductor muscle strains are encountered more frequently in ice hockey and soccer.4,6 These sports require a strong eccentric contraction of the adductor musculature during competition.7,8 Adductor muscle strength has been linked to the incidence of adductor muscle strains. Specifically, the strength ratio of the adduction to abduction muscles groups has been identified as a risk factor in professional ice hockey players.7 Intervention programs can lower the incidence of adductor muscle strains but not avoid injury altogether. Therefore, proper injury treatment and rehabilitation must be implemented to limit the amount of missed playing time and avoid surgical intervention.8

Symptoms of a groin strain include pain on palpation of the adductor tendons or the insertion on the pubic bone, or both, and groin pain during adduction against resistance.6,9 Groin strains, and muscle strains in general, are graded as a first degree strain if there is pain but minimal loss of strength and minimal restriction of motion. A second-degree strain is defined as tissue damage that compromises the strength of the muscle, but not including complete loss of strength and function. A third degree strain denotes complete disruption of the muscle tendon unit; including complete loss of function of the muscle.10 A thorough history and a physical examination is needed to differentiate groin strains from athletic pubalgia, osteitis pubis, hernia, hip-joint osteoarthritis, rectal or testicular referred pain, piriformis syndrome, or presence of a co-existing fracture of the pelvis or the lower extremi-
Imaging studies can sometimes be useful to rule out other possible causes of inguinal pain.

The exact incidence of adductor muscle strains in sport is unknown – due, in part, to athletes playing through minor groin pain and the injury going unreported. In addition, overlapping diagnosis can also skew the exact incidence. Groin strains are among the most common injuries seen in ice hockey players, accounting for 10% of all injuries in elite Swedish ice hockey players. Furthermore, Molsa reported that groin strains accounted for 43% of all muscles strains in elite Finnish ice hockey players. Tyler et al. published that the incidence of groin strains in a single National Hockey League team was 3.2 strains per 1000 player-game exposures. In a larger study of 26 National Hockey League teams, Emery et al. reported the incidence of adductor strains in the National Hockey League has increased over the last six years. The rate of injury was greatest during the preseason compared to regular and postseason play. Prospective soccer studies in Scandinavia have reported a groin strain incidence between 10 and 18 injuries per 100 soccer players. Ekstrand and Gillquist documented 32 groin strains in 180 male soccer players, representing 13% of all injuries over the course of one year. Adductor muscle strains, certainly, are not isolated to these two sports.

Risk Factors

Previous studies have shown an association between strength and flexibility and musculoskeletal strains in various athletic populations. Ekstrandt and Gillquist found that preseason hip abduction range of motion was decreased in soccer players who subsequently sustained groin strains compared with uninjured players. This study is in contrast to the data published on professional ice hockey players that found no relationship between passive or active abduction range of motion (adductor flexibility) and adductor muscle strains. Adductor muscle strength has been associated with a subsequent muscle strain. Tyler et al. found preseason hip adduction strength was 18% lower in NHL players who subsequently sustained groin strains compared with the uninjured players. The hip adduction to abduction strength ratio was also significantly different between the two groups. Adduction strength was 95% of abduction strength in the uninjured players but only 78% of abduction strength in the injured players. Additionally, in the players who sustained a groin strain, preseason adduction to abduction strength ratio was lower on the side which subsequently sustained a groin strain compared with the uninjured side. Adduction strength was 86% of abduction strength on the uninjured side but only 70% of abduction strength on the injured side. Conversely, another study on adductor strains on ice hockey players found no relationship between peak isometric adductor torque and the incidence of adductor strains. Unlike the previous study this study had multiple testers using a hand held dynamometer, which would increase the variability and decrease the likelihood of finding strength differences. However, results reported by Emery et al. demonstrated that players who practiced during the off season were less likely to sustain a groin injury as were rookies in the NHL. The final risk factor was the presence of a previous adductor strain. Tyler et al. also linked pre-existing injury as a risk factor, in their study four of the nine groin strains (44%) were recurrent injuries. This results is consistent with the results of Seward et al. who reported a 32% recurrence rate for groin strains in Australian rules football.

Table 1. Adductor Strain Injury Prevention Program

<table>
<thead>
<tr>
<th>Warm-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bike</td>
</tr>
<tr>
<td>• Adductor stretching</td>
</tr>
<tr>
<td>• Sumo squats</td>
</tr>
<tr>
<td>• Side lunges</td>
</tr>
<tr>
<td>• Kneeling pelvic tilts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strengthening program</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Ball squeezes (legs bent to legs straight) with different ball sizes</td>
</tr>
<tr>
<td>• Concentric adduction with weight against gravity</td>
</tr>
<tr>
<td>• Adduction in standing on cable column or elastic resistance</td>
</tr>
<tr>
<td>• Seated adduction machine</td>
</tr>
<tr>
<td>• Standing with involved foot on sliding board moving in sagittal plane</td>
</tr>
<tr>
<td>• Bilateral adduction on sliding board moving in frontal plane (i.e. bilateral adduction simultaneously)</td>
</tr>
<tr>
<td>• Unilateral lunges with reciprocal arm movements</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sports specific training</th>
</tr>
</thead>
<tbody>
<tr>
<td>• On ice kneeling adductor pull together</td>
</tr>
<tr>
<td>• Standing resisted stride lengths on cable column to simulate skating</td>
</tr>
<tr>
<td>• Slide skating</td>
</tr>
<tr>
<td>• Cable column crossover pulls</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clinical Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Adduction strength at least 80% of the abduction strength</td>
</tr>
</tbody>
</table>
Prevention
Now that researchers can identify players at risk for a future adductor strain, the next step is to design an intervention program to address all risk factors. Tyler et al. were able to demonstrate that a therapeutic intervention of strengthening the adductor muscle group could be an effective method for preventing adductor strains in professional ice hockey players. Prior to 2000 and 2001 seasons, professional ice hockey players were strength tested. Thirty-three of these 58 players were classified as “at risk” (which was defined as having an adduction to abduction strength ratio of less than 80%) and placed on an intervention program. The intervention program consisted of strengthening and functional exercises aimed at increasing adductor strength. (Table 1) The injuries were tracked over the course of the two seasons. Results indicated three adductor strains which all occurred in game situations. This gives an incidence of 0.71 adductor strains per 1,000 player game exposures. Adductor strains accounted for approximately 2% of all injuries. In contrast, 11 adductor strains and an incidence of 3.2 adductor strains per 1,000 player game exposures occurred in the previous two seasons prior to the intervention. In those two seasons, adductor strains accounted for approximately 8% of all injuries. Injury rate after intervention was also significantly lower than the incidence reported by Lorentzon et al. who found adductor strains to be 10% of all injuries. Of the three players who sustained adductor strains, none of the players had sustained a previous adductor strain on the same side. One player had bilateral adductor strains at different times during the first season. This data demonstrated that a therapeutic intervention of strengthening the adductor muscle group can be an effective method for preventing adductor strains in professional ice hockey players.

Rehabilitation
Despite the identification of risk factors and strengthening intervention for ice hockey players, adductor strains continue to occur in all sports. The high incidence of recurrent strains could be due to incomplete rehabilitation or inadequate time for complete tissue repair. Hömlich et al. demonstrated that a passive physical therapy program of massage, stretching, and modalities was ineffective in treating chronic groin strains. By contrast, an 8-12 week active strengthening program consisting of progressive resistive adduction and abduction exercises, balance training, abdominal strengthening, and skating movements on a slide board proved more effective in treating chronic groin strains. An increased emphasis on strengthening exercises may reduce the recurrence rate of groin strains. An adductor muscle strain injury program, progressing the athlete through the phases of healing has been developed by Tyler et al. and anecdotally seems to be effective. (Table 2) This type of treatment regime combines modalities and passive treatment immediately, followed by an active training program emphasizing eccentric resistive exercise. This method of rehabilitation program has been supported throughout the literature.

Sports Hernia
A sports hernia occurs when weakening of the muscles or tendons of the lower abdominal wall occur. This part of the abdomen is the same region where an inguinal hernia occurs, called the inguinal canal. When an inguinal hernia occurs, sufficient weakening of the abdominal wall exists to allow a pouch, the hernia, to be felt. In the case of a sports hernia, the problem is due to a weakening or tear in the abdominal wall muscles, but no palpable hernia exist.

The symptoms of a sports hernia are characterized by pain during sports movements, particularly twisting and turning during single limb stance. This pain usually radiates to the adductor muscle region and even the testicles, although it is often difficult for the patient to pinpoint. Following sporting activity, the person with a sports hernia will be stiff and sore. The day after competition, mobility and practice will be difficult. Any exertion that increases intra-abdominal pressure, such as coughing or sneezing can cause pain. In the early stages, the patient may be able to continue playing their sport, but the problem usually gets progressively worse.

The diagnosis of a sports hernia is based on the patient’s history and clinical signs when all other causes are ruled out. Currently, no clinical special tests exist with a high degree of specificity to diagnose this pathology. In addition, an MRI is usually not helpful in further differentiation. Therefore, this pathology is a diagnosis of exclusion. Non-operative treatment usually involves a short period of rest followed by physical therapy focusing on abdominal strengthening which may temporarily alleviate the pain, but definitive treatment remains surgical repair and rehabilitation.

Hamstring Muscle Strain
The hamstrings are actually comprised of three separate
Table 2. Adductor Strain Post Injury Program

<table>
<thead>
<tr>
<th>Phase I (Acute)</th>
</tr>
</thead>
<tbody>
<tr>
<td>• RICE (rest, ice, compression and elevation) for first ~48 hours after injury</td>
</tr>
<tr>
<td>• NSAIDs</td>
</tr>
<tr>
<td>• Massage</td>
</tr>
<tr>
<td>• TENS</td>
</tr>
<tr>
<td>• Ultrasound</td>
</tr>
<tr>
<td>• Submaximal isometric adduction with knees bent with knees straight progressing to maximal isometric adduction, pain free</td>
</tr>
<tr>
<td>• Hip passive range of motion (PROM) in pain-free range</td>
</tr>
<tr>
<td>• Nonweight-bearing hip progressive resistive exercises (PREs) without weight in anti-gravity position (all except abduction). Pain-free, low load, high repetition exercise</td>
</tr>
<tr>
<td>• Upper body and trunk strengthening</td>
</tr>
<tr>
<td>• Contralateral lower extremity strengthening</td>
</tr>
<tr>
<td>• Flexibility program for noninvolved muscles</td>
</tr>
<tr>
<td>• Bilateral balance board</td>
</tr>
</tbody>
</table>

Clinical Milestone
• Concentric adduction against gravity without pain

Phase II (Subacute)
• Bicycling/Swimming |
• Sumo squats |
• Single limb stance |
• Concentric adduction with weight against gravity |
• Standing with involved foot on sliding board moving in frontal plane |
• Adduction in standing on cable column or elastic tubing |
• Seated adduction machine |
• Bilateral adduction on sliding board moving in frontal plane (i.e. bilateral adduction simultaneously) |
• Unilateral lunges (sagittal) with reciprocal arm movements |
• Multiplane trunk tilting |
• Balance board squats with throwbacks |
• General flexibility program |

Clinical Milestone
• Involved lower extremity PROM equal to that of the uninjured side and involved adductor strength at least 75% that of the ipsilateral abductors

Phase III (Sports Specific Training)
• Phase II exercises with increase in load, intensity, speed, and volume |
• Standing resisted stride lengths on cable column to simulate skating |
• Slide board |
• On ice kneeling adductor pull togethers |
• Lunges (in all planes) |
• Correct or modify ice skating technique |

Clinical Milestone
• Adduction strength at least 90-100% of the abduction strength and involved muscle strength equal to that of the contralateral side
muscles: the biceps femoris, semitendinosus and semimembranosus. These muscles originate just underneath the gluteus maximus on the pelvic bone and attach on the tibia. The hamstrings are primarily fast-twitch muscles, responding to low repetitions and powerful movements. The primary functions of the hamstrings are knee flexion and hip extension.

Hamstring muscle strains commonly result from a wide variety of sporting activities, particularly those requiring rapid acceleration and deceleration. An eccentric load to the muscle causes the majority of these injuries. Garrett demonstrated that, in young athletes, hamstring muscle strains typically involve myotendinous disruption of the proximal biceps femoris muscle. Other authors have also shown experimentally that the weak link of the muscle complex is the myotendinous junction. Although apophyseal fractures of the ischial tuberosity have been reported in young athletes, the majority of hamstring muscle strains are first and second degree strains.

Hamstring muscle strains are among the most common injuries in sports involving high-speed movement and physical contact. Hamstring strains are by far the most commonly seen muscle strains in Australian rules football with an incidence of 8.05 injuries per 1000 player-game-hours. Soccer players are also susceptible to hamstring strains with an incidence of 3.0 per 1000 player-game-hours for hamstring strains. Overall, any athlete who sprints as part of their sport may contribute to the incidence of hamstring strains.

### Risk Factors
Factors causing hamstring muscle injury have been studied for many years. Age and previous injury were identified as the main risk factors for hamstring strains injury among elite football players from Iceland. It has been suggested that muscle weakness, strength imbalance, lack of flexibility, fatigue, inadequate warm-up, and dyssynergic contraction may predispose an athlete to a hamstring strain.

Fatigue has been implicated in the pathogenesis of muscle strain injury. Because muscle strains have been observed to occur either late in training or late in competitive matches, muscle fatigue has been indicated as a risk factor. Another study suggests that the injuries occur either early in games or training or late in games or training with inadequate warm-up and muscle fatigue, respectively, being the hypothesized reasons. However, little quantitative data exists to support these statements. Croisier suggests that the persistence of muscle weakness and imbalance may give rise to recurrent hamstring muscle injuries and pain. These authors feel that when there is insufficient eccentric braking capacity of the hamstring muscles compared with the concentric motor action of the quadriceps muscles, the muscle may be at risk for injury.

Ekstrand and Gillquist prospectively studied male Swedish soccer players and found hamstrings to be the muscle group most often injured. The authors noted that minor injuries increased the risk of having a more severe injury within two months. Others have noted a recurrence rate of 25% for hamstring injuries in intercollegiate football players.

### Prevention
Most clinicians prescribe warm-up and stretching to help reduce the incidence of muscle strains. The evidence supporting this idea is weak and largely based on retrospective studies. In fact, following hamstring injury, the affected extremity and muscle group are significantly less flexible than the uninjured side, but no differences in isokinetic strength exists. However, Jonhagen et al found decreased flexibility and lower eccentric hamstring torques in runners who sustained a hamstring strain when compared with uninjured subjects matched for age and speed. The role of stretching and warm-up in injury prevention needs to be better understood so that optimal strategies can be developed.

### Rehabilitation
No consensus exists for rehabilitation of the hamstring muscles after strain. However, a rehabilitation program consisting of progressive agility and trunk stabilization exercises has been shown to be more effective than a program emphasizing isolated hamstring stretching and strengthening in promoting return to sports and preventing injury recurrence in athletes suffering an acute hamstring strain. The aim of the physical therapy is to restore full pain free range of motion and strength throughout the range of motion. In addition, as a complement to the usual restoration of function, restoration of eccentric muscle strength and correction of agonist/antagonist imbalances in the rehabilitation process. We recommend the inclusion of eccentric exercises at an elongated position of the hamstring muscles,
sub-maximally, as soon as the patient can tolerate. The rationale is based on basic science animal research\(^7\) and imaging studies of human muscle tissue\(^12\) that have indicated incomplete healing following muscle strains. Fibrosis at the injury site is thought to be related to the risk of re-injury. Based on these observations, interventions aimed at remodeling the muscle tissue may be effective in reducing the risk associated with a history of a prior muscle strain. Eccentric muscle contractions have been shown to result in muscle-tendon junction remodeling in an animal model\(^18\) and more recently have been shown to cause intramuscular collagen remodeling in humans.\(^39\) Therefore, an eccentrically based training program for previously injured muscles could theoretically reduce recurrence rates and would be worth studying in future research.

Rehabilitation would start with relative rest and protection of the injured muscle phase lasting from 1 to 3 days. Returning to exercise in this stage can lead to re-injury and disruption of the healing tissue. Multigait isometrics should be initiated to properly align the regenerating muscle fibers and limit the extent of connective tissue fibrosis. Rest, ice, compression, and elevation, along with anti-inflammatory medication, is helpful during the immediate stages of treatment. Heat, electrical stimulation, and ultrasound modalities can also be used in conjunction with each other during the rehabilitation program to facilitate a return to competition.\(^40,41\) Heat is effective at increasing tissue temperature prior to stretching and exercise. Electric stimulation can be used to control edema and pain. Ultrasound is used as a deep-heating agent during the subacute phase to decrease spasm and prevent soft-tissue shortening.

An effective strengthening program should treat the hamstrings as a two-joint muscle and focus on concentric and eccentric contractions. Although lack of flexibility has been identified as a factor leading to hamstring injuries, the effectiveness of pre-exercise muscle stretching in reducing injuries has recently been questioned. In fact, Worrell\(^44\) et al cites decreased strength and power up to one hour following passive stretching. In theory, this decrease in force production is thought to result from the relaxation of the muscle tendon unit. Therefore, prior to athletic competition, a general warm-up (jogging, cycling) to increase tissue temperature, followed by dynamic stretching that includes sports-specific movements is recommended. Examples of dynamic stretches for the legs include forward or backward lunges, high-knee marching, and straight-leg kicks. Static stretching should be performed after the athletic activity.

**Quadriiceps Muscle Strain**

The quadriceps is a group of four muscles that sit on the anterior aspect of the thigh - the vastus medialis, intermedius and lateralis, and rectus femoris. The quadriceps attaches to the front of the tibia via the patella tendon and originate at the top of the femur. The exception is the rectus femoris which actually crosses the hip joint and originates on the pelvis. The function of the quadriceps, as a whole, is to extend the knee. The rectus femoris functions to extend the knee but also acts as a hip flexor because the muscle crosses the hip joint. Any of these muscles can strain (or tear), but probably the most common is the rectus femoris. The grading system is the same as the adductor strains. A grade III tear is felt as an abrupt, sudden, acute pain that occurs during activity (often while sprinting). The injury may be accompanied by swelling or bruises on the thigh. The rehabilitation of quadriceps strains follow the same principles as the rehabilitation process of adductors and hamstring muscle strains.

**Hip Bursitis**

Bursae are lined with synovium and are synovial fluid filled sacs that exist normally at sites of friction between tendons and bone as well as between these structures and the overlying skin.\(^1\) A bursae is analogous to filling a balloon with oil and rubbing it between your fingers. The purpose of the bursa is to dissipate friction caused by two or more structures moving against one another.\(^1\) The development of a bursitis is the product of one of two mechanisms. The most common mechanism is inflammation secondary to excessive friction or shear forces as a result of overuse. Post-traumatic bursitis is the other mechanism and stems from direct blows and contusions that cause bleeding in the bursa with resultant inflammation. The three major bursae around the hip joint that are susceptible to bursitis are the iliopsoas bursae, ischial bursae, and the greater trochanteric bursae.

**Trocanteric Bursitis**

The greater trochanteric bursae lies between the gluteus maximus, tensor fascia lata (TFL), and the surface of the greater trochanter. Its location on the lateral aspect of the hip exposes it to contact injuries in sports such as football, soccer, and ice hockey. More commonly, trochanteric bursitis is seen in the clinic as an overuse injury found in
runners, bike riders, and cross-country skiers. The problem may also be found in individuals with an increased Q-angle, prominent trochanters, or a leg-length discrepancy. Repetitive motion of hip flexion and extension on an excessively compressed bursae can give rise to irritation and inflammation. This problem can occur with tightness in tissues around the hip, for example the iliotibial band (ITB) pulling across the hip or hip adductors bringing the thigh into a more midline position. Poor running mechanics or continuous running on banked surfaces that brings the lower extremity into an increased adducted position can also cause undue pressure at the hip.

Signs and symptoms of trochanteric bursitis include warmth and reported pain at the greater trochanter region of the hip. Pain with hip abduction resistance, palpable tenderness at lateral hip, pain with gait, and possible swelling or ecchymosis at the surface of the greater trochanter, as well as pain with lying on affected side may be present.42-44

Intervention begins by taking a thorough history from the patient to determine activity level, length of onset, or mechanism of possible traumatic incident. Examination is then performed to check for range of motion (ROM), tenderness, tightness, and weakness in surrounding soft tissue structures. It is necessary to analyze gait and stair patterns as well as possibly analyzing running mechanics if subjective complaints warrant.

Initial home rehabilitation for the individual will consist of rest, ice, and NSAIDs. Clinical treatment will emphasize modalities for inflammation (i.e ultrasound), stretching of appropriate structures such as the IT band and adductors, as well as slow integration into progressive resistive exercises for encompassing hip musculature. If the underlying cause is due to a leg-length discrepancy, the problem should be corrected with the appropriate device. Upon normalization of ROM and flexibility, a gradual return to sport specific activities should be implemented. Full return to sports should emphasize prevention with a regular stretching program or appropriate padding for traumatic injuries.

Ishial Bursitis

While uncommon, ischial bursitis may occur as a complication of an injury to the hamstring insertion into the ischial tuberosity such as a direct trauma, fall, or hit. The symptoms include pain while sitting and localized tenderness. It is important to distinguish this bursitis from a hamstring tear at the origin. Initial treatment consists of rest, ice, and NSAIDs. A sitting cushion may be utilized as needed. General stretching of the hamstrings and progressive resistant exercises are implemented as pain subsides.

Iliopsoas (Iliopectineal) Bursitis

Iliopsoas (iliopectineal) bursitis is most often due to excessive activity, possibly due to irritation by the iliopsoas muscle passing over the iliopsoas eminence. This rubbing may also be associated with a “snapping” hip. Pain is reported in the inguinal area and can radiate into femoral triangle. Associated palpable tenderness can be present by placing the hip in flexion and external rotation. This position can also help relieve symptoms. Treatment includes the rest, NSAIDs, and stretching of the iliopsoas. Strengthening of any muscle imbalances can be initiated in pain-free arcs.

Snapping Hip Syndrome

Snapping hip syndrome (Coxa Saltans) can arise from two different sources: intra-articular and extra-articular. Intra-articular causes include loose bodies, osteocartilaginous exotosis, labral tears, synovial chondromatosis, and subluxation of the hip. More common though are the extra-articular causes of a “snapping” hip. This problem occurs primarily when, but not exclusively to, the IT band snapping over the greater trochanter during hip flexion and extension. Hip adduction and knee extension will tighten the IT band and accentuate the snapping sensation. This continuous pathomechanical movement can lead directly to trochanteric bursitis. A second extra-articular source comes from the iliopsoas tendon as it passes just in front of the hip joint. This tendon can catch on the pelvic brim (iliopectineal eminence) and cause a snap when the hip is flexed.45

This syndrome is common in ballet dancers where 44 percent of reported hip pain involved a snapping or clicking.46 Most complaints concerned the sensation with only one-third reporting pain. The condition can present itself with specific flexion movements of the thigh such as sit-ups. Both have signs and symptoms of an audible snap or click either laterally or anterior deep in the groin which may or may not be painful.

Treatment for a patient with snapping hip syndrome begins with a thorough examination. During the subjective evaluation, the clinician must question the patient to determine which actions exacerbate symptoms during daily activities and athletics. The objective examination is designed to determine the severity of pathology and to
perform a biomechanical assessment. The information gathered in this portion of the examination can be used to guide specific elements of the treatment program. Muscle-tendon length and strength, joint mobility testing, and palpation of the injured area are key to a proper examination. Biomechanical assessment of the patient includes both static (posture) and dynamic (gait/functional movement) elements. Particular areas of attention during the examination include observation of genu recurvatum, knee flexion contracture, overpronation of the foot, hip flexion contracture, and the amount of internal or external rotation present in the lower extremity during static stance. Also take note of leg length. Gait analysis allows the clinician to confirm the findings of static examination and to observe if a movement dysfunction is present. Functional movements (eg, squatting, stair ascent/descent) may further demonstrate to the clinician the severity of the movement dysfunction.45

Once identification of contributing factors has been completed, treatment can be directed toward those factors. Intervention during the acute phase consists of standard anti-inflammatory care and the elimination of activities that exacerbate symptoms. Physical therapy modalities (eg, ice, ultrasound, electrical stimulation, iontophoresis) may be used during this time.46 Activity modification depends on the severity of the pathology. Crutches may be used in severe cases, while simply decreasing the time and intensity of the aggravating activity is commonly used in less acute cases. Muscle weakness and tightness in the thigh or pelvis is addressed with a strengthening and stretching program. Overpronation may require a foot orthotic to assist with foot stabilization. Leg length deformities commonly require a lift in the shoe to assist with balancing the entire lower extremity. For those patients with a symptomatic snapping hip and trochanteric bursitis unresponsive to conservative therapy, a surgical procedure has been described as an effective method of treatment in this specific population.47

CONCLUSION
In conclusion, proper treatment of soft tissue injuries of the hip starts with a thorough evaluation of the entire kinetic chain. Often, overlapping conditions exist around the hip joint making it difficult to identify the primary cause of the hip pain and dysfunction. Once a diagnosis has been made, an evidence based stepwise progression as outlined in this paper is paramount for returning the athlete to the playing field quickly and safely.

REFERENCES


ABSTRACT

Sports related injuries to the hip have received relatively little attention, in the part because the clinical assessment, imaging studies, and surgical techniques are less sophisticated. The evolution of hip arthroscopy has offered a less invasive technique that allows for recognition and treatment of hip pathologies that previously went unrecognized. The success of hip arthroscopy is dependent on proper patient selection based on the patient's history and diagnosis. The purpose of this clinical commentary is to outline mechanisms of injury and specific lesions that can be addressed using hip arthroscopy.

CORRESPONDENCE:
J. W. Thomas Byrd, M.D.
Nashville Sports Medicine and Orthopaedic Center
2011 Church Street, Suite 100
Nashville, TN 37203
615-284-5800
Fax: 615-284-5819
info@nsmoc.com
Consultant: Smith & Nephew Endoscopy
INTRODUCTION
Sports related injuries to the hip joint have received relatively little attention. This trend is changing but, until recently, few publications exist in peer reviewed journals and the topic has rarely been presented at scientific meetings. This lack of attention is due to three reasons. First, perhaps hip injuries are less common than other joints. Secondly, investigative skills for the hip have been less sophisticated, including clinical assessment and imaging studies. Thirdly, fewer interventional methods are available to treat the hip including both surgical techniques and conservative modalities and, thus, little impetus exists to delve into this unrecognized area.

The evolution of arthroscopy has been intimately tied to sports medicine. The motivating principle has been a less invasive technique that facilitates quicker return to unrestricted athletics. It is now recognized that this basic sports medicine principle applies well to all individuals, whether the goal is to accomplish an earlier return to the workplace or simply a return to normal daily activities. However, hip arthroscopy has followed a distinctly different route. It began as a surgical alternative to only a few recognized forms of hip pathology. These pathologies included removal of loose bodies that could otherwise only be addressed by an extensive arthrotomy and arthroscopic debridement for degenerative arthritis in an effort to postpone the need for hip arthroplasty.1,2 Neither of these early indications found much application in an athletic population. However, as the basic methods of hip arthroscopy were developed, arthroscopy became an option for select cases of unexplained hip pain. Arthroscopy revealed numerous intra-articular sources of disabling hip symptoms that were previously unrecognized but are potentially amenable to arthroscopic intervention.3,4 These pathologies include tearing of the acetabular labrum, traumatic injury to the articular surface, and damage to the ligamentum teres, among others.

The indications for hip arthroscopy fall into two broad categories. In one category, arthroscopy offers an alternative to traditional open techniques previously employed for recognized forms of hip pathology such as loose bodies or impinging osteophytes. In the second category, arthroscopy offers a method of treatment for disorders that previously went unrecognized including labral tears, chondral injuries, and disruption of the ligamentum teres. Most athletic injuries fall into this latter category. In the past, athletes were simply resigned to living within the constraints of their symptoms, often ending their competitive careers, diagnosed as a chronic groin injury. Based on the results of arthroscopy among athletes, it is likely that many of these careers could have been resurrected with arthroscopic intervention.5

MECHANISM OF INJURY
The mechanism of injury can be as varied as the sports in which athletes participate. In general, hip disorders attributable to a significant episode of trauma tend to respond better to arthroscopy.6 This positive response is because, other than the damage due to trauma, the athlete usually has an otherwise healthy joint. Insidious onset of symptoms usually suggests either underlying disease or some predisposition to injury that cannot be fully reversed and may leave the joint vulnerable to further deterioration in the future. Therefore, individuals who simply develop progressive onset of symptoms in absence of injury tend to experience a less complete response. Even an acute injury such as a twisting episode, which is known to cause a tear of the acetabular labrum, may be more likely if the labrum is vulnerable to injury and may represent a less certain response to surgery. This vulnerability can be due to abnormal labral morphology or underlying degeneration.

However, these broad generalizations must be tempered in the competitive athlete. Individuals who participate in contact and collision sports simply may not be able to recount which traumatic episode led to the onset of symptoms. Remember that significant intra-articular damage can occur from an episode without the athlete developing incapacitating pain. The athlete may be able to continue to compete and subsequently undergo work-up only when symptoms fail to resolve. Injury can occur from any contact or collision sport or sports involving forceful or repetitive twisting of the hip. The aging joint may also be more vulnerable. These parameters do not exclude many sports.

A particular entity that has been identified associated with acute chondral damage7 is a lateral impact injury to the area of the trochanter (Figure 1). Because young adult males are more apt to be participating in contact and col-
collision activities where this mechanism is frequent, this injury is most commonly encountered in this population. With good body conditioning and little adipose tissue overlying the trochanter, much of the force of the blow is delivered directly to the bone. This force is then transferred, unchecked, into the hip joint, resulting in either shearing of the articular surface on the medial aspect of the femoral head at the tide mark, or compression of the articular surface on the superior medial acetabulum, exceeding its structural threshold. The result is a full thickness articular fragment from the femoral head or articular surface breakdown of the acetabulum, possibly with loose bodies, depending on the magnitude of acetabular chondral, or chondro-osseous cell death (Figures 2 and 3). This mechanism is dependent on peak bone density as otherwise the force would result in fracture rather than delivery of the energy to the surface of the joint. The injury usually results in immediate onset of symptoms but may not be disabling. The problem may be assessed as a groin pull, with work-up ensuing only when symptoms persist.

Figure 1. Fall results in direct blow to the greater trochanter and, in absence of fracture, the force generated is transferred unchecked to the hip joint. (Reprinted with permission J.W. Thomas Byrd, M.D.)

Ice hockey is a sport with a particularly high prevalence of hip pathology. Hip flexibility is a premium consideration in this sport. The joint is subjected to violent and repetitive torsional maneuvers and is also subjected to relatively high velocity impact loading. Thus, the labrum is susceptible to tearing from the twisting maneuvers while the articular surface is vulnerable to impact injury. Often, acute episodes are simply superimposed on the cumulative effect of years of exposure (Figure 4).

Golf is another illustrative sport that seems to have a predilection for precipitating hip symptoms. It is not a contact or collision sport, but the golf swing does incorporate a significant element of twisting of the hip joint. Additionally, golf is a sport where participants can compete with advancing age, even at the professional level. Thus, there is a greater susceptibility to injury of an aging hip as well as the cumulative effect of repetitive trauma over a prolonged career. Tennis shares many of these same attributes.

Figure 2. A 20-year-old male collegiate basketball player with painful catching of the left hip following a fall with lateral impaction of the joint. A. MRI revealed extensive signal changes in the medial aspect of the femoral head characterizing the subchondral injury associated with his fall. B. A full-thickness chondral flap lesion (*) associated with the injury is identified. C. The unstable portion has been excised. (Reprinted with permission.)
Figure 3.  

A. AP radiograph left hip unremarkable.  
B. Radionuclide scan reveals increased activity, left hip.  
C. MRI remarkable for pronounced asymmetric effusion, left hip.  
D. CT coronal reconstruction demonstrates loose bodies.  
E. Follow-up radiograph 13 months post-injury reveals secondary changes with superolateral osteophyte formation on the femoral head.  
F. Loose bodies are evident (*) originating from the acetabulum. Scoring of the femoral head is also evident (arrow) due to third body wear.  
(Reprinted with permission J.W. Thomas Byrd, M.D.)

Figure 4. Three NHL hockey players were referred, each with a two week history of hip pain following an injury on the ice. Each case demonstrated MRI evidence of labral pathology (arrows). These cases were treated with two weeks of rest followed by a two week period of gradually resuming activities. Each of these athletes was able to return to competition and have continued to play for several seasons without needing surgery.  
A. Coronal image of a left hip demonstrates a lateral labral tear (arrow).  
B. Coronal image of a right hip demonstrates a lateral labral tear (arrow).  
C. Sagittal image of a left hip demonstrates an anterior labral tear with associated paralabral cyst (arrow).  
(Reprinted with permission J.W. Thomas Byrd, M.D.)
Femoro-acetabular impingement (FAI) is a condition that warrants particular attention. Abnormal morphology of the joint can lead to labral and articular breakdown commonly encountered in active individuals (Figure 5). Two types of impingement exist. Pincer impingement occurs from a bony prominence of the anterior acetabulum that crushes the labrum when it is compressed against the proximal femur during hip flexion. Cam impingement is created by a non-spherical femoral head that engages against the articular cartilage of the acetabulum during flexion and results in shear failure of the surface.

Pincer impingement is most common in females, especially as they approach middle age. Cam impingement is seen more frequently in young adult males. Cam impingement is also a cause of early onset osteoarthritis of men in their fifth and sixth decades. However, joint destruction is being observed among males in their second and third decades, accelerated by the intensity of competitive sports and activities.

Athletic pubalgia is characterized by a constellation of tendonopathy surrounding the insertion of the lower abdominal muscles, the origin of the hip adductors, and the pelvic floor. A significant correlation of FAI and athletic pubalgia in high demand athletes, predominantly male. Diminished hip range of motion is compensated by increasing pelvic motion, which overworks the pelvic stabilizers and results in tissue breakdown of the pelvic structures, culminating in athletic pubalgia. Clinically, difficulty exists in distinguishing the two conditions. The two conditions commonly co-exist, but can also occur separately.

Historically, rupture of the ligamentum teres is associated with hip dislocation. Although this injury can occur without dislocation, occurrence has been described only as

Figure 5. A. Normal joint morphology. B. Pincer lesion created by prominence of anterior acetabulum. C. Joint damage and pain is created by crushing of the labrum underneath the pincer lesion with hip flexion. D. Cam lesion is characterized by bony prominence of anterolateral femoral head/neck junction. E. Pathology and pain develops due to shearing of the acetabular articular surface by a bump during hip flexion. F. Combined pincer and cam impingement can occur. (Reprinted with permission J.W. Thomas Byrd, M.D.)
Disruption appears to be attributable to a twisting injury and is increasingly recognized as a source of intractable hip pain. In a review of 23 cases of traumatic injury to the ligamentum teres, 17 (74%) occurred without accompanying dislocation of the hip.14

PATIENT SELECTION
Successful hip arthroscopy is most clearly dependent on proper patient selection. A well-executed procedure will fail when performed for the wrong reasons. Patient expectation is paramount. The athlete should have reasonable goals and knows what can be accomplished with arthroscopy, which is only partially dictated by the nature of the pathology. Remember that much is not fully understood regarding the pathomechanics, pathoanatomy, and natural history of many of these lesions that are now being surgically addressed. However, an increasing amount of clinical experience exists upon which patients can be offered reasonable statistical data on likely outcomes.

Athletes are often set apart by their drive, discipline, and motivation as they push their bodies to their physiologic limits. However, the most uniquely challenging aspect of deciding on surgical intervention in this population is time constraints: How quickly does the surgeon decide to operate and how quickly will the patient recover? This decision is a year-round issue, whether it is attempting to return for the current season, preparing for the upcoming season, or simply resuming the necessary off-season conditioning regimen. With the exception of loose bodies, no literature exists to suggest that harm is caused by not recommending early surgical intervention for most of the problems that are now being recognized.15 Most disorders will declare themselves over time through failure of response to conservative measures but unfortunately, for athletes, time is often not an ally.

Extra-articular injuries far outnumber intra-articular problems in the hip region. Thus, it is best to temper the interest to perform an extensive intra-articular work-up for every athlete with pain around the hip. However, in our study of athletes who underwent arthroscopy with documented pathology, the hip was not initially recognized as the source of symptoms in 60% of the cases. These athletes were managed for an average of seven months before the hip was considered as a potential contributing source.5 The most common preliminary diagnoses were various types of musculotendinous strains. Thus, it is prudent to at least consider possible intra-articular pathology in the differential diagnosis when managing a strain around the hip joint. Thoughtful follow-up and re-assessment is critical when these injuries do not respond as expected.

A careful history and examination will usually indicate whether the hip is the source of symptoms. Single plane activities such as straight ahead running are often well-tolerated while torsional and twisting maneuvers are more problematic in precipitating painful symptoms. Stairs and inclines may be more troublesome, and the same athlete who can run pain-free on level surfaces may have more difficulty running hills. Prolonged hip flexion such as sitting can be uncomfortable and catching symptoms are often experienced when rising from a seated or squatted position.

Hip symptoms are most commonly referred to the anterior groin and may radiate to the medial thigh. However, a very characteristic clinical feature which has been described is the “C-sign”16. A patient describing deep interior hip pain will grip their hand above the greater trochanter with their thumb lying posteriorly and the fingers cupped within the anterior groin. It may appear that they are describing lateral pain such as from the iliotibial band or trochanteric bursa, but characteristically, they are reflecting pain within the joint.

On examination, log rolling the leg back and forth is the most specific maneuver for hip pathology since this rotates only the femoral head in relation to the acetabulum and capsule and does not stress any of the surrounding neurovascular or musculotendinous structures. More sensitive examination maneuvers include forced flexion combined with internal rotation or abduction combined with external rotation. Sometimes these movements will produce an accompanying click, but it is more important to determine if these maneuvers reproduce the athlete’s pain.

For long-standing conditions, athletes may secondarily develop extra-articular symptoms of tendinitis or bursitis or may have a co-existent extra-articular pathology. A useful test for distinguishing the intra-articular origin of symptoms is a fluoroscopically guided intra-articular injection of anesthetic. The hallmark is temporary alleviation of symptoms during the anesthetic effect. With the more
recent technology of gadolinium arthrography (MRA) combined with magnetic resonance imaging (MRI), it is important that anesthetic be included with the injection to elicit this useful diagnostic response.17

SPECIFIC LESIONS
Loose bodies represent the clearest indication for hip arthroscopy but are not a common problem among athletes (Figure 6).1 The work of Epstein et al15 has demonstrated the importance of removing loose bodies to prevent the secondary damage they can cause. Loose bodies can occur from trauma, disease such as synovial chondromatosis, or other disorder such as osteochondritis dissecans.1, 18-19 Recovery can be complete within weeks but depends on the amount of associated damage. Loose bodies can secondarily develop as a consequence of degenerative arthritis. In this setting, the results of loose body removal are not favorable because the degenerative disease cannot be corrected.

Labral lesions are the most common hip pathology, present in 61% of athletes undergoing arthroscopy.5 Labral debridement has resulted in 82% successful outcomes at 10 year follow-up when arthritis is not present (Figure 7).20

Figure 6. A 20 year old male with a three month history of acute left hip pain. A. AP radiograph demonstrates findings consistent with old Legg-Calvé Perthes disease. B. Lateral view defines the presence of intraarticular loose bodies (arrows). C. CT scan substantiates the intraarticular location of the fragments (arrows). D. Arthroscopic view medially demonstrates the loose bodies. E. Viewing anteriorly, the anterior capsular incision is enlarged with an arthroscopic knife to facilitate removal of the fragments. F. One of the fragments is being retrieved. G. Loose bodies are able to be removed whole. (Reprinted with permission.)
However, not all labral tears are the same with regards to etiology, associated pathology, treatment, and outcomes. Arthritis is a poor prognostic indicator, and various studies have demonstrated that articular damage is present in association with more than half of all labral tears.\(^{21-24}\) Often it is the extent of articular pathology that is the limiting factor as far as the success of arthroscopic intervention (Figure 8). Use of MRIs and MRAs are best at identifying labral lesions, but poor at demonstrating accompanying articular pathology.\(^ {17}\) Thus, the uncertain presence of articular damage is often the “wild card” in predicting the outcome of arthroscopy and should temper the surgeon’s enthusiasm for predicting uniform success in the presence of imaging evidence of labral damage.

Imaging (MRI and MRA) evidence of labral pathology must be carefully interpreted. Studies have shown evidence of labral abnormality even among asymptomatic volunteers and labral degeneration occurs naturally as part of the aging process.\(^ {22, 25-27}\) It is uncertain whether labral tears will spontaneously heal, but observations have been made among athletes of tears that became clinically asymptomatic without surgery.\(^ {28}\)

A common etiologic factor in the association of co-existent labral and articular pathology, may be FAI.\(^ 8\) Pincer impingement caused by an overhanging lip of bone from the acetabulum can be corrected by reshaping the acetabular rim (Figure 9). Cam impingement, the most common type among athletes, is corrected by contouring the bony prominence at the junction of the femoral head and neck to recreate the spherical shape of the femoral head (Figure 10).

Recovery from simple labral debridement can be as little as one to two months. Correcting impingement results in a more protracted recovery, partly because of the more extensive nature of the procedure, but also the severity of the joint damage is usually more extensive. The bone must be allowed to remodel for three months and return to competitive activities is anticipated at four to six months.

The severity of associated articular damage also influences the recovery. Full thickness Grade IV articular loss with exposed subchondral bone is best treated with microfracture (Figure 8).\(^ {29}\) This surgery is used to stimulate a fibrocartilaginous healing response and requires protected weight bearing for the first two months post-op while the defect matures. This surgery is an imperfect solution, but offers 86% positive results and is presently the standard of the industry.\(^ {30}\) Microfracture is a harbinger of a more prolonged recovery, not because of the procedure but because of the severity of the problem for which it is implemented.

Related to labral repair (Figure 11), the technology developed in the shoulder has been readily applied to the hip.\(^ {31, 32}\) However, labral function and pathogenesis of labral lesions in the hip is different and the understanding of which are amenable to repair is less clear. As the selection process improves, the results of labral repair will become more favorable. Recovery requires more time to protect the repair site.
Figure 8. A 23 year old elite professional tennis player sustained an injury to his right hip.  
A. Coronal MRI demonstrates evidence of labral pathology (arrow).  
B. Arthroscopy reveals the labral tear (arrows), but also an area of adjoining Grade IV articular loss (*).  
C. Microfracture of the exposed subchondral bone is performed.  
D. Occluding the inflow of fluid confirms vascular access through the areas of perforation.  
The athlete was maintained on a protected weight-bearing status emphasizing range of motion for 10 weeks with return to competition at three and a half months. (Reprinted with permission J.W. Thomas Byrd, M.D.)

Figure 9. A 16 year old high school football player develops acute onset of right hip pain doing squats.  
A. Sagittal image MR arthrogram demonstrates a macerated anterior labrum (arrows).  
B. Viewing from the anterolateral portal, a macerated tear of the anterior labrum is probed along with articular delamination at its junction with the labrum.  
C. The damaged anterior labrum has been excised, revealing an overhanging lip of impinging bone from the anterior acetabulum.  
D. Excision of the impinging portion of the acetabulum (acetabuloplasty) is performed with a burr. (Reprinted with permission J.W. Thomas Byrd, M.D.)
Figure 10. A 20 year old hockey player with a four year history of right hip pain. A. AP radiograph is unremarkable. B. Frog lateral radiograph demonstrates a morphological variant with bony build up at the anterior femoral head/neck junction (arrow) characteristic of cam impingement. C. A 3D CT scan further defines the extent of the bony lesion (arrows). D. Viewing from the anterolateral portal, the probe introduced anteriorly displaces an area of articular delamination from the anterolateral acetabulum characteristic of the peel back phenomenon created by the bony lesion shearing the articular surface during hip flexion. E. Viewing from the peripheral compartment the bony lesion is identified (*) immediately below the free edge of the acetabular labrum (L). F. The lesion has been excised, recreating the normal concave relationship of the femoral head/neck junction immediately adjacent to the articular surface (arrows). Posteriorly, resection is limited to the mid portion of the lateral neck to avoid compromising blood supply to the femoral head from the lateral retinacular vessels. G. Post operative 3D CT scan illustrates the extent of bony resection. (Reprinted with permission J.W. Thomas Byrd, M.D.)
Injury to the ligamentum teres is the third most common problem encountered among athletes undergoing hip arthroscopy. The disrupted fibers catch within the joint and can be quite painful. Resection of these disrupted fibers has found remarkable success based on the magnitude of improvement with a 93% successful outcome (Figure 12).

Clinical and radiographic evidence of arthritis is a poor prognostic indicator of the results of arthroscopy. Advanced disease with complete joint space loss is a contraindication because of uniformly unsuccessful results. Lesser disease may serve only as a relative contraindication depending on the goals of the procedure and the expectations of the athlete. For example, labral debridement or loose body removal in the presence of arthritis will not result in the same successful outcomes that have been reported for athletes in absence of arthritic changes. The expectations of the athlete must be more modest and practical. Otherwise, the procedure will be a failure by not accomplishing the desired outcome.

Hip instability can occur, but is much less common than instability in the shoulder. The primary reason is due to the inherent stability provided by the constrained ball and socket bony architecture of the hip joint. Also, the labrum is not as critical to stability of the hip as it is in the shoulder as no true capsulolabral complex exists. On the acetabular side, the capsule attaches directly to the bone, separate from the acetabular labrum. An entrapped labrum has been reported as a cause of an irreducible posterior dislocation and a Bankart type detachment of the posterior labrum has been identified as a cause of recurrent posterior instability. These circumstances have only rarely been reported, but may be recognized with increasing frequency as the understanding and intervention of hip injuries evolves.
Instability may occur simply due to an incompetent capsule. This instability is seen in hyperlaxity states and less often encountered in athletics. The most common cause is a collagen vascular disorder such as Ehlers-Danlos syndrome. With normal joint geometry, thermal capsular shrinkage has been met with successful results (Figure 13). If subluxation or symptomatic instability is due to a dysplastic joint, it is likely that bony correction for containment is necessary to achieve stability.

Based on this author’s observations, posterior instability is associated with macrotrauma. Mechanisms of injury include dashboard injuries and axial loading of the flexed hip encountered in collision sports. Atraumatic instability, or instability due to repetitive microtrauma, is anterior and develops when the normally occurring anterior translation of the femoral head exceeds the physiologic threshold and becomes pathological. Symptoms may be due to primary instability, secondary intra-articular damage, or a combination of both.

Figure 12. A 16 year old cheerleader has a two year history of catching and locking of the left hip following a twisting injury. A. Arthroscopic view from the anterolateral portal reveals disruption of the ligamentum teres (*). B. Debridement is begun with a synovial resector introduced from the anterior portal. The acetabular attachment of the ligamentum teres in the posterior aspect of the fossa is addressed from the posterolateral portal. (A,B reprinted with permission J. W. Thomas Byrd, M.D. C reprinted with permission Byrd JWT, Jones KS14)

Figure 13. A 19 year old female had undergone two previous arthroscopic procedures on her right hip for reported lesions of the ligamentum teres. Following each procedure, she developed recurrent symptoms of “giving way.” A. Radiographs revealed normal joint geometry. B. She was noted to have severe diffuse physiologic laxity best characterized by a markedly positive sulcus sign. C. With objective evidence of laxity and subjective symptoms of instability, an arthroscopic thermal capsulorraphy was performed, accessing the redundant anterior capsule from the peripheral compartment. Modulation of the capsular response was controlled by a hip spica brace for eight weeks postoperatively with a successful outcome. (Reprinted with permission J.W. Thomas Byrd, M.D.)
In general, for properly selected cases, hip arthroscopy has a high rate of improvement, but does not always assure returning to the rigors of athletic activities. Among a heterogeneous group of athletes, 93% were improved, but only 76% returned to their sport symptom-free and unrestricted or at an increased level of performance. Eighteen percent either chose to not return or were unable to return to their primary sport. Among a group of elite athletes, 96% were improved, but only 85% were able to successfully return to their sport.

CONCLUSIONS
Hip joint problems in athletes may go unrecognized for a protracted period of time. With an increased awareness of intra-articular disorders, these problems are now being diagnosed earlier. However, understanding of the pathogenesis and natural history of many of these lesions is incomplete, and may influence the strategies of both surgical and conservative treatment. Nonetheless, arthroscopy has defined numerous sources of intra-articular hip pathology. In many cases, operative arthroscopy has been met with significant success. For some athletes, arthroscopy offers a distinct advantage over traditional methods of treatment where none existed before.

REFERENCES


ABSTRACT

Over the past few years, arthroscopy of the hip joint is becoming more common as a technique in both the diagnosis and treatment of hip pain. A frequent cause of hip and groin pain is a tear of the acetabular labrum. Patients with labral tears complain of pain in the groin region and pain with clicking in the hip without a history of pain prior to the original onset. Once a patient presents with signs and symptoms of hip pain that are greater than four weeks in conjunction with indicative findings of a labral tear by way of MRI, he or she may be considered a good candidate for arthroscopy of the hip joint. Little evidence exists in the current literature on rehabilitative procedures performed after arthroscopy of the acetabular labrum. The purpose of this clinical commentary is to suggest a rehabilitation protocol after acetabular labral debridement or repair.

CORRESPONDENCE

J. Craig Garrison, PT, PhD, SCS, ATC
University of South Florida
12901 Bruce B. Downs Blvd. MDC 77
Tampa, FL 33612
Email: jgarriso@health.usf.edu
INTRODUCTION

Arthroscopy of the hip joint has become a common technique used over the past few years in both the diagnosis and treatment of hip pain. One of the more frequent diagnoses of hip and groin pain is a tear of the acetabular labrum. The most common etiology in patients with mechanical hip symptoms is the existence of a labral tear and can be related to intra-articular snapping hip syndrome up to 80% of the time. In 59 patients undergoing hip arthroscopy, 59% had a tear of the acetabular labrum. Likewise, a significant correlation exists between the tear and complaints of clicking and giving-way. In an athletic population, among eighteen patients presenting with a complaint of pain in the groin region, four (22%) were found to have a tear in the acetabular labrum. All of the patients with a tear reported pain with clicking in the hip, but did not have a history of pain prior to the original onset. In addition, of 45 professional athletes who presented with femoroacetabular impingement, all had a tear in the labrum. The presence of hip labral tears is also high in the general population. Of 100 patients (39±13 years of age) who presented with mechanical symptoms of pain, clicking, and locking in the hip, 66% were found to have labral tears.

The mechanism of injury for an acetabular labral tear often involves repetitive twisting, cutting, and pivoting movements in addition to repetitive flexion at the hip. However, the history of the mechanism associated with injury is not always apparent to the patient. Instead, patients will present with insidious complaints of groin pain and mechanical symptoms of clicking, locking, and giving way. Additional causes of acetabular labral tears may include femoral acetabular impingement, capsular laxity/joint hypermobility, hip dysplasia, and joint degeneration. The mechanism of femoral acetabular impingement occurs when the anterior superior portion of the labrum is pinched or squeezed by the edge of the acetabulum and the anterior neck of the femur. This type of mechanism is described as either cam or pincer. In cam, an abnormal femoral head is wedged against the acetabulum in motions such as forced or excessive flexion. On the other hand, pincer femoral acetabular impingement is the result of an irregular projection of the acetabular rim that contacts the head of the femur during movement.

Upon examination, the clinical characteristics of a tear in the acetabular labrum can vary. In 66 patients with a labral tear (confirmed arthroscopically) who were retrospectively examined, 61% had an insidious onset of symptoms while, 86% reported the symptoms as moderate to severe. Similarly, the most common location was in the groin, with either sharp or dull pain which was activity-related and included painful mechanical locking.

DIAGNOSIS

Because pain in the hip can arise from a variety of different sources, identification of a labral tear can be challenging and is often misdiagnosed. Using plain radiography is not always sufficient for identifying a labral tear. However, structural abnormalities of the hip such as a retroverted acetabulum or coxa valga have been found in a high percentage (87%) of those patients with labral tears. As these abnormalities are more closely scrutinized, earlier detection of a tear may be possible.

Acetabular labral tears are most reliably diagnosed arthroscopically. However, with the development of musculoskeletal imaging, correctly diagnosing a tear has become more manageable. Magnetic resonance imaging (MRI) and arthrography (MRA) are regularly used to evaluate and diagnose hip labral pathology. The MRI has been shown to accurately assess the presence of both hip labral and articular cartilage damage. Using MRI, labral pathologies were identified correctly in 94% and 95% of the cases respectively by two radiologists. Likewise, a high agreement exists between MRI and arthroscopy in the identification of chondral pathology. The MRA can provide an extension of MRI by allowing an in vivo image of the hip joint that can often be difficult to see secondary to the depth of the articulation. In fact, a significant correlation between the grade of cartilage loss with the grade of labral tear has been shown, causing the authors to suggest an MRA may be indicated if the presence of bone marrow edema is discovered with a routine MRI.

SURGICAL INTERVENTION

Once a patient presents with signs and symptoms of hip pain that are greater than four weeks in conjunction with indicative findings of a labral tear by way of MRI or MRA, he or she may be considered a good candidate for arthroscopy of the hip joint. Arthroscopic techniques for treating hip labral pathologies are becoming more routine in both adults and adolescents, and children. In the case of an acetabular labral lesion, surgical intervention may involve debridement or repair. Be aware, however, conditions such as acetabular dysplasia, femoral acetabular-
lar impingement, degenerative conditions of the joint, fractures, arthofibrosis, or non-compliance with the rehabilitation program may preclude the surgical intervention.

Both debridement and repair of an acetabular labral lesion may be performed in either the supine or lateral position. In the supine position, a standard fracture table is used with an oversized perineal post to apply traction. The affected hip is placed into slight extension and adduction to allow approach to the joint. Care is taken to minimize pressure in the perineal area as well as to carefully monitor the amount and duration of traction to avoid neurologic complications. The procedure is performed under the guidance of fluoroscopy. After an adequate amount of distraction is obtained, a 14 or 16 gauge spinal needle is inserted into the joint to break the vacuum seal and allow further distraction. Three portals are generally used, the anterolateral (which is established first), the anterior, and the distal lateral accessory or paratrochanteric portal.

After complete evaluation of the joint, including the articular cartilage surfaces of the acetabulum and femoral head, ligament fraying or tearing, and assessment of the posterior recess, any labral abnormality may then be addressed. Most labral tears occur in the anterior superior or quadrant of the acetabulum. Acute, longitudinal, and peripheral tears are most amenable to repair. For repair of a detached labrum, the edges of the tear are delineated and suture anchors are placed on the top of the acetabular rim in the area of detachment. Conversely, if the tear in the labrum has a secure outer rim and is still attached to the acetabulum, a suture in the midsubstance of the tear can be used to secure the tissue. Radial splits, significantly macerated or degenerative labral tissue, or labral tissue that appears unviable should be debrided. Not uncommonly, chondral lesions may be noted adjacent to labral pathology that may require either debridement, common microfracture, or other cartilage resurfacing techniques.

The natural history of untreated labral tears is unknown. Recently, authors have attempted to correlate the presence of labral tears with the development of degenerative osteoarthritis of the hip joint. Although this correlation remains unclear, some observations suggest labral lesions may be a contributory factor to the evolution and progression of osteoarthritis. Although debridement may be successful from the standpoint of pain relief, the surgery could potentially lead to joint load alteration and the progression of articular cartilage changes. In addition, alterations to the structure of the labrum, or disruption in the acetabular labral junction, may lead to the loss of the pressurized fluid film layer within the joint and uneven force distribution across the articular cartilage surfaces of the acetabulum and femoral head.

REHABILITATION

Little evidence exists in the current literature to support rehabilitative procedures performed after arthroscopy of the acetabular labrum. Likewise, because new surgical procedures are constantly evolving, it is the responsibility of the physical therapist to stay up to date with the most current techniques as well as to establish and maintain good communication with the orthopaedic surgeon.

Surgical techniques and outcomes have been reported in the literature with little or no attention to post-operative rehabilitation. Currently, the best evidence for post-operative rehabilitation is based upon surgeon and physical therapist experience. With a labral repair, the location and size of the tear should be noted. Most of these tears are located in the anterior or anterosuperior portion of the labrum; movements that stress this area should be avoided. However, communication with the surgeon about the location of the tear and surgical technique used is vital to the treating physical therapist.

Rehabilitation protocols following acetabular labral debridement (Table 1) or repair (Table 2) can be divided into four phases. The progression with both procedures is similar with the exception of differences which are noted within the protocol. Exercise, and particularly strengthening, progression in a repair of the labrum may be delayed by a few weeks depending upon tissue healing. The timelines for each phase are based on clinical findings and presentations of active, healthy individuals. If clinical presentation meets objective criteria an athlete may move through the phases at a faster rate, always keeping basic tissue healing physiology in mind.

Phase I – Initial Exercises. Weeks 1 to 4.

The primary goals immediately following acetabular labral debridement or repair are to minimize pain and inflammation, protect the surgically repaired tissue, and initiate early motion exercises. Patients are typically 50% weight-bearing for 7 to 10 days progressing to weight-bearing as tolerated. For a labral repair, the weight-bearing restrictions include toe-touch weight bearing for 3 weeks,
Table 1:

**Labral Debridement**

**Phase I: Initial Exercise (weeks 1-4)**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle Pumps</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteal, quad, HS, T-ab isometrics</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary biking with low resistance</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive ROM (emphasize IR, circumduction, and prone lying)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heel slides</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piriformis stretch</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive supine hip roll (IR)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water walking with flotation device</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-R stretching for IR/ER</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gentle hip joint mobilizations</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual long axis traction</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip abd isometrics</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uninvolved knee to chest</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 way leg raises (abd, add, ext)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water jogging with flotation device</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg press or shuttle (limited weight)</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Phase II: Intermediate Exercise (weeks 5-7)**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double 1/3 knee bends</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall sits with abductor band</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary biking with resistance</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-competitive freestyle swimming</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual A/P mobilizations</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kneeling hip flexor stretch</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved knee to chest, adductor stretch</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seated resisted internal rotation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seated resisted external rotation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side stepping with abductor band</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two leg bridging</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-leg bridging</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliptical / Stairclimber</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Phase III: Advanced Exercise (weeks 8 to 12)**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing resisted hip ER</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunges and lunges with trunk rotations</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water bounding / plyometrics</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core ball stabilization progression</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fred/Bkwd/Sideways walking with cord</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golf progression</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running progression</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial agility drills – single plane</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Phase IV: Sports Specific Training (weeks 12+)**

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-Cuts / W-Cuts</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cariocas / Ghirardelli’s</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sports specific drills</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional testing – sportcord test</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Courtesy of Proaxis Therapy, Spartanburg/Greenville, SC; used with permission.*
Table 2:

### Labral Repair

**Phase I: Initial Exercise (weeks 1-4)**

<table>
<thead>
<tr>
<th>Exercise/Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankle Pumps</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluteal, quad., HS, T-ab isometrics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary biking with no to min. resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive ROM (emphasize IR, circumduction, and prone lying)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heel slides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periforms stretch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive supine hip roll (IR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water walking with flotation device</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-R stretching for IR/ER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gentle hip joint mobilizations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual long axis traction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip abd/abd isometrics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uninvolved knee to chest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 way leg raises (abd, add, ext)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water jogging with flotation device</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Phase II: Intermediate Exercise (weeks 5-7)**

<table>
<thead>
<tr>
<th>Exercise/Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double 1/3 knee bends</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wall sits with abductor band</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stationary biking with resistance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-competitive freestyle swimming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manual A/P mobilizations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kneeling hip flexor stretch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Involved knee to chest, adductor stretch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seated resisted internal/external rotation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leg press or shuttle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side stepping with abductor band</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two leg bridging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single-leg bridging</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elliptical / Stair climber</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Phase III: Advanced Exercise (weeks 8 to 12)**

<table>
<thead>
<tr>
<th>Exercise/Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing resisted hip ER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lunges and lunges with trunk rotations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water bounding / plyometrics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Core ball stabilization progression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fwd/Bkwd/Sideways walking with cord</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golf progression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running progression</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial agility drills – single plane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Phase IV: Sports Specific Training (weeks 12+)**

<table>
<thead>
<tr>
<th>Exercise/Activity</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>13</th>
<th>17</th>
<th>21</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-Cuts / W-Cuts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caricocas / Ghirardelli’s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sports specific drills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functional testing – sportcord test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

*Courtesy of Proaxis Therapy, Spartanburg/Greenville, SC; used with permission.*
but may last up to 6 weeks depending upon the progression of healing and pain level of the patient. If the surgery involved additional procedures to the hip such as a microfracture, the weight-bearing restrictions can increase to 6 more weeks. However, for purposes of this paper, labral debridement and repair will be the main focus.

It is important to maintain a symmetrical gait pattern to prevent concomitant stress throughout the lower extremity and spine. If this gait pattern is not established, a muscular imbalance of tight hip flexors and erector spinae with inhibition of the gluteals and abdominals (lower crossed syndrome) could develop.30 The potential ramifications include increased weight-bearing through the acetabulum with labral tissue stresses secondary to hip flexor tightness.31 Consequently, continued crutch use may be a necessary prophylactic. Similarly, the patient should be instructed to control the hip in all three planes of motion. Decreased core and hip strength have been implicated in alterations of lower extremity alignment during functional activities.32-34 Also, hip abductor strength has been shown to be a predictor of frontal plane motion in the knee while weak hip extensors can lead to quadriceps overuse and increased compression and shear force at the knee.32 A correlation between weakness in the hip and core and lower extremity injuries has been established.35 Thus, when these studies32,34-36 are considered together, the suggestion is that rehabilitation of the hip should include a component of hip and core strengthening in each phase.

Aquatic therapy is an excellent resource, if available, once surgical incisions are well-healed. Ambulation in the water allows for improvements in gait by allowing appropriate loads to the joint while minimizing unnecessary stresses to the healing tissue.19,28 Light jogging in the water using a flotation device may begin as early as 2-3 weeks if pain is not an issue. Range of motion (ROM) precautions may vary, but typically include limiting flexion beyond 90° for 10 days to avoid undue compression of the anterior labrum. If treating a labral repair, in addition to the 90° of flexion, the patient is limited to 25° of abduction and 10° of extension for 10 days to 2 weeks. An emphasis should be placed on manual therapy for pain reduction and improvements in joint mobility and proprioception.31 Considerations include gentle hip joint mobilizations, contract-relax stretching for internal and external rotation, long axis distraction, and assessment of lumbo-sacral mobility. Particular attention should be paid to the posterolateral soft tissue structures and the lumbo-sacral spine (as each can contribute to pain) and unnecessary hypomobility which will limit progress in future phases.

Modalities for pain control such as immediate postoperative transcutaneous electrical nerve stimulation (TENS) units {preferably applied in recovery room (based on clinical experiences of the authors)}, cryotherapy, and appropriate pain management through medication are important, as well. Cautious and gentle stretching of hip muscle groups including piriformis, psoas, quadriceps, and hamstring muscles should begin with hip passive range of motion exercises, respecting the patient’s pain threshold. The risk of tissue damage must be considered,37 and the patient should provide verbal feedback following mobilization and ROM exercises. Prone lying for 1 to 2 hours per day and passive ROM exercises emphasizing internal rotation are beneficial to prevent adhesions.19 Stationary bike begins with no resistance and gradually progresses in resistance over the first 4 weeks with a seat height that limits hip flexion to less than 90°.

Strengthening in Phase I initially consists of isometric contractions for the hip adductors, abductors, extensors, and transverse abdominals, but progresses to straight leg raises for abduction, adduction, and extension. To prevent irritation of the psoas muscle,19 hip flexion straight leg raise is not performed early on. Seated hip flexion using a short lever arm might be an alternative. For labral debridement, closed-chain activities of low-level leg press or shuttle can also begin with limited resistance. This type of exercise allows weight-bearing through the lower extremity joints with the application of appropriate stresses to the tissue.38

Criteria to progress from Phase I to Phase II require ROM of greater than or equal to 75% of the uninvolved side28 and the ability to demonstrate a sidelying straight leg raise (Figure 1) using the gluteus medius muscle. This straight

Figure 1: Sidelying straight leg raise.
let raise should be performed without compensation from the tensor fascia lata and quadratus lumborum.

**Phase II – Intermediate Exercises. Weeks 5-7.**
The primary focus of the second phase is to continue progressing ROM and soft tissue flexibility while beginning to transition the emphasis to strengthening. Manual therapy should continue with mobilization becoming more aggressive, as appropriate. If capsular laxity was thought to be a contributing factor to developing labral pathology, normal mobility (but not hypermobility) should be achieved. Flexibility exercises involving the piriformis, adductor group, and psoas/rectus femoris should continue. The kneeling hip flexor stretch (Figure 2) can be particularly beneficial for psoas and rectus femoris once tolerated in this phase of rehabilitation. Passive ROM exercises should become more aggressive, as needed, for internal and external rotation.

Figure 2: **Kneeling hip flexor stretch.**

Strengthening of the hip and core musculature progresses ensuring the patient can dissociate pelvic movements and avoid muscular compensations. The strength goal is to build an endurance base prior to progressing to more advanced exercises. Patients can begin to add gradual resistance to the bike and use the elliptical machine, as tolerated, for cardiovascular endurance. Other examples of Phase II exercises include seated resisted internal (Figure 3) and external rotation, 1/3 knee bends progressing to wall sits with an abductor band for resistance (Figure 4), sidestepping with an abductor band for resistance, and core strengthening such as bridging on two legs progressing to single-leg bridging (Figure 5). Patients can return to non-competitive free-style swimming at week 5, as symptoms allow. Criteria to progress to Phase III are a normal gait pattern with no Trendelenburg sign. In addition, the patient should have symmetrical and passive ROM measurements with minimal complaints of pain.

Figure 3: **Resisted internal rotation – sitting.**

Figure 4: **Wall squats with abductor band for resistance.**

Figure 5: **Single leg bridging.**
Phase III – Advanced Exercises. Weeks 8-12.
The primary objectives for Phase III are for the patient to have symmetrical ROM and begin integrated functional strengthening. Manual therapy should be performed as needed. Flexibility and passive ROM interventions should become slightly more aggressive if limitations persist. If full ROM or flexibility has not been attained at week 10, terminal stretches should be initiated, and moderate pain with stretching becomes acceptable.

Strengthening exercises should now incorporate multi-planar movements involving multiple muscles groups. Single leg activities challenging proprioception and strengthening of the hip muscles in a functional position should be performed. Examples of Phase III exercises include standing resisted hip external rotation (Figure 6), walking lunges, lunges with trunk rotation, plyometric bounding in the water, resisted sportcord walking forward/backward/sideways, and a progressive exercise ball program for advanced core strengthening. Core strengthening is an essential component to successful rehabilitation of athletes with hip pathology. As the progression to running and agility drills nears in the latter stages of the phase, athletes should be repetitively instructed on the importance of shock absorption and eccentric control during functional training. Criteria to progress to Phase IV are symmetrical ROM and symmetrical flexibility of the psoas and piriformis. No noted Trendelenburg sign should exist with these higher level functional strengthening activities.

The primary objective of this phase is a safe and effective return to competition or previous activity level. Manual therapy, flexibility, and ROM exercises can be continued as deemed appropriate by the treating physical therapist. Careful attention and frequent re-assessment of these areas should take place to prevent loss of mobility and flexibility as the activity level increases. Once patients can demonstrate good muscular endurance, good eccentric control, and the ability to generate power, running may be progressed. Straight-ahead activities can be gradually progressed to lateral agilities. The completion of a return-to-play assessment using a sportcord test (developed by Steadman Hawkins Clinic and Howard Head Sports Medicine) prior to granted clearance for athletic competition. The athlete must perform a series of dynamic functional activities with resistance from a sportcord such as single-leg squats for 3 minutes, lateral bounding for 80 seconds, and forward/backward jogging for 2 minutes each. He or she is graded on the ability to demonstrate good neuromuscular control of the lower extremity during multi-planar movements that simulate athletic activities.

Post-operative protocols following acetabular labral debridement and repair will continue to develop as these procedures become more common. Current protocols are based on basic science and clinical experience, while future studies should include objective outcome measures to determine the most appropriate post-operative progression.

REFERENCES


ABSTRACT

Background. Research indicates return to golf is a safe activity following total hip arthroplasty (THA). Frequently, individuals have shown both physical faults and swing faults after THA, which can persist even following rehabilitation. Physical limitations and pain often lead to faults in the golfers swing, most notably “hanging back.” These problems may not be improved after surgery unless the proper re-training takes place.

Objectives. Using pre-surgical as well as post-surgical information, physical faults and swing faults were identified. A corrective training protocol was developed to normalize physical and swing limitations.

Case description. The patient is a 52-year old male golfer who underwent left total hip arthroplasty secondary to left hip osteoarthritis. Video analysis both pre and post surgery indicated the patient was “hanging back.” This “hanging back” can lead to an inefficient golf swing and potential injury. Following a physical evaluation, a training protocol was designed to correct abnormal physical findings to assist the patient in creating an efficient golf swing.

Outcomes. The patient was able to swing the golf club with proper weighting of the lead lower extremity, significant improvement of swing efficiency, and return to play at a zero handicap following a corrective training protocol.

Discussion. A return to full weight bearing, functional strength, range of motion, stability, and balance are critical to regaining the physical skills necessary to properly swing the golf club. Further, mastery of these objective components lend themselves to the trust needed to load the lead leg with confidence during the golf swing.

Key Words: total hip arthroplasty, golf, conditioning

CORRESPONDENCE:
John D’Amico, MSPT ATC
Golf Fitness Links, Inc
430 Cypress Way East
Naples, FL 34110

ACKNOWLEDGEMENT:
The authors would like to acknowledge the help and support from Dr. Greg Rose and Dave Phillips, co-founders of the Titleist Performance Institute.
INTRODUCTION
Research indicates that a return to golf is a safe activity following total hip arthroplasty (THA). While golfers have reported hip pain following play, most are able to continue enjoying their sport.1-5 Unfortunately, protocols to effectively and efficiently return patients to this sport have not been found in the literature.

Osteoarthritis (OA) of the hip often leads to hip pain and loss of hip range of motion, as well as possible weakening of surrounding musculature.6 Kaltenborn7 reports loss of medial rotation, extension, abduction and lateral rotation as the capsular pattern loss of hip range of motion. This limited range of motion can lead to compensatory changes in the golf swing. Hanging back or poor weight transfer to the lead lower extremity during the downswing of the club is a commonly seen occurrence for golfers with lead hip OA. Hanging back is diagnosed with video analysis from the face-on camera position. The golfer’s lateral lead knee and hip do not match a vertical line drawn from the lateral aspect of the lead foot perpendicularly up to the height of the lead shoulder in the impact position. (Figures 1, 2) Perpetuation of this swing fault can lead to a lack of power and inconsistency of ball flight. Hanging back may lead the player to manipulate the club with a premature wrist release as a compensatory mechanism to getting the club to the ball. These faulty mechanics can lead to right side lumbar injury, as weight bearing remains primarily on the trail side of the body at impact. 6

While optimal post THA rehabilitation and training approaches remain undefined, all protocols will need to be modified for each individual. The purpose of this case report is to describe the evaluation and application of exercises designed to return a golfer following lead hip THA back to play, while at the same time eliminate the physical swing faults in order to improve swing efficiency.

CASE DESCRIPTION
The patient is a 52-year old male golfer who underwent left minimally invasive total hip arthroplasty secondary to OA of the left hip. A modified Harris Hip outcome score was calculated prior to surgery and found to be 72.6 out of a possible 100 points. (Table 1) Following surgery, the patient underwent 2 weeks of home health physical therapy. This was followed with an active rest period performing a home exercise program and walking. The patient was then released to swing the golf club at 7 weeks post-op. At 8 weeks a golf specific physical evaluation was performed. Physical, video, and kinematic data was collected 12 weeks status post surgery.

Figure 1: Model of golfer hanging back at impact. The golfer’s lead knee and hip do not match the vertical line drawn perpendicularly from the lateral aspect of the foot to the shoulder.

Figure 2: Model of golfer “matching the line” at impact. The golfer is not hanging back.
### TABLE 1: Modified Harris Hip Scoring System

<table>
<thead>
<tr>
<th>Pain (points)</th>
</tr>
</thead>
<tbody>
<tr>
<td>44 None ignores</td>
</tr>
<tr>
<td>40 Slight, occasional, no compromise in activity</td>
</tr>
<tr>
<td>30 Mild, no effect on ordinary activity, pain after activity, uses aspirin</td>
</tr>
<tr>
<td>20 Moderate, tolerable, makes concessions, occasional codeine</td>
</tr>
<tr>
<td>10 Marked, serious limitations</td>
</tr>
<tr>
<td>0 Totally disabled</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function: Gait</th>
<th>Functional Activities:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Limp</strong></td>
<td><strong>Stairs</strong></td>
</tr>
<tr>
<td>11 None</td>
<td>4 Normally</td>
</tr>
<tr>
<td>8 Slight</td>
<td>2 Normally with banister</td>
</tr>
<tr>
<td>5 Moderate</td>
<td>1 Any method</td>
</tr>
<tr>
<td>0 Severe</td>
<td>0 Not able</td>
</tr>
<tr>
<td>0 Unable to walk</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Support</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>11 None</td>
</tr>
<tr>
<td>7 Cane, long walks</td>
</tr>
<tr>
<td>5 Can, full time</td>
</tr>
<tr>
<td>4 Crutch</td>
</tr>
<tr>
<td>2 2 canes</td>
</tr>
<tr>
<td>0 2 crutches</td>
</tr>
<tr>
<td>0 Unable to walk</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Socks Shoes</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>4 With ease</td>
</tr>
<tr>
<td>2 With difficulty</td>
</tr>
<tr>
<td>0 Unable</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Sitting</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Any chair, 1 hour</td>
</tr>
<tr>
<td>3 High chair, 1/2 hour</td>
</tr>
<tr>
<td>0 Unable to sit, 1/2 hour, any chair</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Distance Walked</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>11 Unlimited</td>
</tr>
<tr>
<td>8 6 blocks</td>
</tr>
<tr>
<td>5 2-3 blocks</td>
</tr>
<tr>
<td>2 Indoors only</td>
</tr>
<tr>
<td>0 Bed and chair</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Public Transportation</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Able to enter public transportation</td>
</tr>
<tr>
<td>0 Unable to use public transportation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Total Points</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>x 1.1</td>
</tr>
</tbody>
</table>

| **Total Score**                                                     |

Note: The Harris hip score includes 91 points for pain and function and 9 points for range of motion and deformity. Arthroscopy is principally indicated for pain and function. Consequently, the section for range of motion and deformity has been deleted. The multiplier (1.1) is used to give a total possible score of 100.
PHYSICAL EVALUATION
A subjective history was taken including past medical, exercise, and golf history. The patient was evaluated using the Titleist Performance Institute (TPI) Medical Evaluation and standard physical therapy impairment testing.

Hip Passive Range of Motion (PROM)
Range of motion on the left was less than the right for flexion (85 degrees on left, 115 degrees on right) and adduction (50 degrees left, and 55 degrees right). Range of motion was found to be the same on the left and right for extension (-10°), external rotation (50°), and internal rotation (21°).

Pelvic Tilt Test
The pelvic tilt test was used to assess overall mobility of the hips and lumbar spine and the ability to control the position of pelvic posture in the sagittal plane. The ability to move and control the position of the pelvis is critical for optimal power transfer from the lower body to the upper body in the golf swing. The patient was able to achieve a pelvic neutral position in standing; however, limited anterior and posterior pelvic tilt was noted. This limitation of motion is indicative of weakness of the abdominal and gluteal muscles as well as tightness of the erector spinae and hip flexors. A lack of smoothness and the presence of jerky movement was also noted during alternating between the two tilt positions. In addition, bilateral hamstring cramping was noted during testing. Cramping of the hamstrings is commonly seen in subjects who are hamstring dominant. These subjects try to control pelvic tilt through the hips and knees.8

Pelvic Rotation Test
The pelvic rotation test checks the player’s ability to rotate their lower body independently from their upper body. This rotation is an important skill to properly sequence the downswing and requires good mobility of the spine, hips, and pelvis.

The patient displayed a choppy limited rotation to both the right and left with more lateral than rotatory movement occurring. This lack of rotatory motion is most likely due to the limitation with hip internal rotation. In addition, the lateral shifting is usually indicative of the lack of ability to activate the oblique abdominals and hip rotators to isolate pelvic rotation.8

Overhead Deep Squat Test
The overhead deep squat test is one of the more informative tests performed on the golfer. The deep squat portion of the test is used to assess bilateral, symmetrical mobility of the hips, knees, and ankles8 If the golfer is unable to complete the deep squat with the heels on the ground, then it is almost impossible to for them to maintain their posture during the golf swing. The golfer will have a tendency to thrust their lower body toward the golf ball and raise up on their torso during the downswing (early extension). This movement is usually due to either tightness in their calf muscles or lack of pelvic stability due to weakness of their core.

Due to THA precautions still being observed, this test was modified to a 1/3 depth squat. Poor stability of the left hip led to decreased femoral control as demonstrated by femoral adduction and internal rotation. This can be viewed best by observing the client face on.

Single Leg Balance Test
The single leg eyes closed balance test is used to assess the golfer’s overall balance. This test will highlight any proprioceptive imbalance from left to right as well as overall stability of the core. The client was scored in the 0-5 second range for both the left and right.

Wobble Board Test
Front to back balancing was more difficult than side to side.

Leg Lowering Test
This test is used to assess how the golfer uses their abdominals and overall stability of the core. The abdominal muscles are used to stabilize the spine and pelvis, rotate the torso, and maintain a neutral posture throughout the golf swing.8 With the patient lying supine in a hook lying position, a blood pressure cuff is placed under the lumbar spine and inflated to 40mmHg. The client is then instructed to contract their abdominals and slowly slide one leg to the ground. This is then repeated with the opposite leg.

During this test, three things were observed: First, how do they engage their abdominals? As the client initially...
engages the abdominals, the pressure within the cuff should elevate between 40-50 mmHg without modifying the lumbar lordosis. If the pressure in the cuff drops, it is usually indicative of an anterior pelvic tilt caused by the over-activation of the hip flexors or erector spinae rather than the abdominals. This anterior pelvic tilt causes an increase in the lumbar lordosis and, thus, a pressure drop. If the pressure increases above 50 mmHg, it is usually indicative of the client performing a posterior pelvic tilt with the pelvis when engaging the abdominals. This demonstrates an abnormal sequence of recruitment with the client also activating the hamstring muscles and quite possibly the psoas major muscle to produce a posterior pelvic tilt.

Second, can their abdominals work independent of hip extension? In other words, can the client maintain a good abdominal brace with movement of the lower extremity? When you ask the client to slide their leg all the way down, hip extension should occur. Normally, hip extension should not affect pelvic or lumbar spine motion, especially when the abdominals are actively bracing the spine and pelvis. If the musculature of the hip is shortened and pulls on the lumbar spine and pelvis, the abdominals must resist this tension. If the mmHg in the blood pressure cuff drops during hip extension, then either the lack of mobility in the hip musculature or lack of strength of the abdominals is evident. Weak abdominals can be the main reason for loss of stability during this test however, any restriction in hip mobility will make extension of the hip difficult to isolate without movement of the pelvis and lumbar spine.

Third, is there an asymmetry between the left and right hip? In other words, if the mmHg in the blood pressure cuff drops during left hip extension, but does not during right hip extension, then an asymmetry exists.

The client demonstrated a pressure increase above 50 mmHg with the initial engagement or bracing of the abdominal musculature. In addition, with hip extension pressure was lost for both the right and left sides: Pressure lost: Left 21-40 mmHg; Right 21-40 lbs mmHg

**Bridge with Leg Extension Test**

This test evaluates stability in the pelvis, lumbar spine, and core musculature. In addition, this test will highlight any inhibition or weakness of the gluteus maximus muscle due to over recruitment of the synergistic muscles, such as the hamstring and erector spinae muscles. As the client attempts to single leg bridge and hold the position with the contralateral leg extended for 10 seconds, observe for a drop of the pelvis on the leg extension side (contralateral to the stance leg) or ipsilateral pelvic shaking which is indicative of weakness of the gluteals muscle on the ipsilateral or stance side. Another key indicator is hamstring cramping in the down or stance leg, which also indicates inhibition of the gluteals and recruitment of the synergistic muscles. Weakness in the right gluteals can cause the player to lose lower body stability in their backswing and may limit their power on the downswing. Weakness in the left gluteals can cause instability in the left leg through impact or forward movement toward the golf ball during the downswing. The client demonstrated bilateral gluteal inhibition with hamstring cramping.

**VIDEO**

Video analysis of the patient prior to training was performed. The patient was found to demonstrate the swing fault of hanging back.

**KINEMATIC SEQUENCE**

In sports such as golf that need to create maximal speed of a distal segment or implement (club, bat, racquet, etc), it is generally found through motion analysis techniques, that a precisely timed sequence of body segment motions exists progressing from the proximal, large segments to the distal, smaller segments. In biomechanical literature this is often called "proximal-to-distal-sequencing," "kinetic linking," or the "kinematic sequence." The kinematic sequence (swing signature) is one of the most important pieces of information that used to assess the golf swing. Using data collected from 3-D motion analysis systems, the efficiency of a golfers swing can be determined how golfers generate speed and transfer this speed or energy throughout their bodies can be assessed.

In analyzing how speed is transferred to the club head, it was discovered that all great ball strikers have the exact same kinematic sequence or the same basic signature of generating speed and transferring this speed throughout their body. What style they use to complete this signature is completely unique to each player. During the downswing in golf, all body segments must accelerate and
decelerate in the correct sequence with precise and specific timing so that the club arrives at impact accurately and with maximal speed. This sequence (Figure 3) of speed generation is: lower body first (red line on graph), trunk or torso second (green line), arms third (blue line), and the club last (maroon line) (pelvis, torso, arms, club). This motion must occur sequentially with each peak speed being faster but later (shifted to the right slightly) than the previous one. Each segment of the body builds on the previous segment, increasing speed up the chain (red is less than green, which is less than blue, which is less than maroon). This sequence reflects as efficient transfer of energy across each joint and facilitates an increase in energy from the proximal segment to the distal one. Each segment of the chain slows down once the next segment begins to accelerate in order to facilitate acceleration of the next segment. All of the body segments peak and then decelerate before impact, with the club speed peaking at impact.

The kinematic sequence for this client was measured at the Titleist Performance Institute using a full-body 12-sensor analysis using the AIM-3D golf swing biomechanics system (Advanced Motion Measurement LLC; Phoenix, AZ) and the Liberty electromagnetic tracking hardware (Polhemus Inc; Phoenix, AZ). As shown in Figure 4, this golfer had an improper kinematic sequence. While the pelvis did peak first, the second segment to peak was the arms, followed by the torso, and lastly the club head (pelvis, arms, torso, club head). If the timing and energy transfer is wrong, energy can be dissipated instead of added, as a result speed will be lost. Also if one body part has to compensate because another is not doing its job, injury may result. As noted on the proper kinematic sequence (Figure 3), after the peak is reached, each segment should decelerate rapidly. The kinematic sequence of a golfer with lead hip OA may be illustrated by an initial normal pelvic acceleration followed by a flattened slope and an extended or flattened deceleration slope. This lack of rapid deceler-
3. The patient exhibited decreased lumbo-pelvic mobility and stability in non-weight bearing and weight bearing positions as demonstrated by the pelvic tilt, pelvic rotation, and bridging with leg extension tests. The client had difficulty with full sagittal plane pelvic excursion as well as poor neuromuscular control through his available range. Inability to achieve a posterior pelvic tilt at impact can have a negative influence on the right side of the lumbar spine; especially true when combined with hanging back.

4. The patient exhibited deficits with balance. Proper balance and proprioceptive ability is necessary during static positions at address, as well as dynamic positions of the golf swing.

5. Upon 2-D video analysis the patient displayed less than normal transfer of weight to his lead lower extremity. Hanging back produces loss of power/distance and ball flight inconsistencies. Further 3-D kinematic sequence analysis revealed an improper order of activation/sequencing: Pelvis-arms-torso-club head.

INTERPRETATION OF FINDINGS

Five significant findings exist including four physical faults and one swing fault.

1. The patient displayed a lack of full hip extension along with inhibition of the gluteal musculature. This is an aspect of “lower crossed syndrome” which increases the probability of developing low back pain. The lower crossed syndrome, first described by Czech physical therapist Vladamir Janda, can be defined as a pattern of muscle imbalances leading to increased lumbar lordosis due to over active lumbar musculature and subsequent reciprocal inhibition of the abdominal musculature. The hip flexors are tight and the gluteals are inhibited. In this case, the patient presented with normal anterior pelvic tilt in standing but decreased lumbar lordosis. He also demonstrated inhibited abdominals during pelvic tilt activity which may be indicative of overactive global lumbar musculature. The global lumbar muscles include the spinalis, longissimus, and iliocostal muscles. The hip flexors were shortened and overactive, the gluteus maximus muscle was inhibited secondary to a loss of hip extension, and the hamstring musculature was over-utilized.

2. The patient also displayed limited hip internal rotation. Loss of hip internal rotation can lead to undue stress on the lower back during the golf swing and swing faults such as lateral movement away, from, or toward the target, and loss of spine angle. This subject was able to avoid these faults; however, limited lead hip internal rotation can also lead to a hanging back swing fault. This fault is possibly due to the golfer's anticipation of discomfort that is associated with forced internal rotation.

257

INTERVENTION

At 8 weeks post-op, training was performed in nine sessions over a twenty-five day period. A training protocol was developed and modified to address the client's physical limitations.

1. Strategies to improve hip extension were employed as follows: side lying passive range of motion, proprioceptive neuromuscular facilitation (PNF) hold relax stretch and active assist during hip extension stretch emphasizing gluteus maximus activation (Figure 5). A neutral pelvis and abdominal bracing was held throughout the stretch. Pillows
were placed between legs and care taken not to allow internal rotation of hip or break THA posterior precautions.

2. Increasing hip internal rotation without breaking total hip precautions of posterior movement presented a challenge. This physical fault was not directly addressed in training, however it eliminated itself with the application of weight bearing rotational exercises and the patient's continued swinging of the golf club as approved by the physician. These exercises occurred within 2 weeks of initial testing which was a total of 9 weeks post op (Figures 6-11)

3. The patient's inability to assume and maintain a stable core was another concern addressed in training. This training was addressed through exercises in supine, quadruped, standing, and in golf stance positions. Neuromuscular re-education was performed for proper pelvic tilt in the sagittal plane. This exercise was executed both in-clinic training and in his home exercise program. Abdominal hollowing and bracing, bridges, single leg bridging, and front planks were employed as part of training and home exercise program (Figures 12-17)

4. Testing also revealed that balance was deficient. The patient was given several weight bearing exercises aimed at challenging tri-planar balance in single limb stance as well as weight shifting activities. Balance exercises also focused on maintenance of spine angle throughout performance. (Figures 6, 8-11)

5. Correction of the swing fault was addressed by the patient's PGA teaching professional as training progressed.

Reassessment
The client was reassessed following 9 training sessions over a period of 25 days. While this is perhaps not an optimal length of training period the reader will find that positive changes had occurred.

Review of Problem List
1 and 2. Overall hip function was improved. Not only was hip range of motion improved, but gluteal muscle activation was improved as well. Hip flexion was increased to equal the right side. Hip internal rotation as measured prone was increased bilaterally with the left side improving almost 10 degrees and the right 15 degrees. The patient was also able to perform the bridge with leg extension without hamstring cramping, indicating improved gluteal muscle activation.
3. The patient also displayed increased core stability. Neuromuscular control was enhanced as evidenced by improved control with weight bearing sagittal plane pelvic motion. The patient was also able to maintain pelvic stability when performing the leg lowering test. He demonstrated improved stability and control when performing a modified 1/3 squat test.

4. Significant improvements in balance were demonstrated as the patient was now able to maintain single limb
stance for 8 seconds. The patient subjectively scored each direction of the wobble board balance test as “easy.”

5. The patient was able to eliminate his swing fault. He no longer exhibited hanging back at impact. In addition, 3D kinematic sequence analysis revealed that the client’s sequence returned to the pre-injury normal pelvis-torso-arms-club head sequence.

6. Reassessment of function with the Modified Harris Hip score produced a score of 100 out of the possible 100 points available.

DISCUSSION
The THA procedure is becoming more prevalent and occurring in younger individuals. As these trends continue, therapists, golf professionals, and fitness professionals, will be presented with the challenge of designing treatment protocols to most effectively and efficiently return the patient to normal function, as well as leisure activities such as golf.

The goal of this article was to present a case study that exhibited many of the physical faults and swing faults that are typically encountered when treating a patient with a left lead leg THA who wishes to return to golf. Several physical faults were identified including decreased hip extension and internal rotation, inhibition of hip extensor musculature, decreased core stability, and diminished balance. One significant swing fault, hanging back, was also identified. By initially addressing the client’s specific physical faults the authors aimed to eliminate the injury potential that can be caused by training for strength, power, and speed on top of those faults.

SUMMARY
The author’s rationale for the treatment approach, as well as specific treatment modalities, were detailed. Post-treatment results were given showing improvements in all five of the faults detailed in the problem list. The client was able to eliminate the vast majority of his physical faults and was able to eliminate his swing fault. The key to this success was multifactorial. Improvement in hip mobility, proper activation of hip extensors, improved lumbopelvic stability and control, improved weight bearing balance and stability, and technical weight bearing exercises to improve weight shift and rotation onto the lead side were all important.
components in eliminating the most significant swing fault- handling back. Restoration of proper swing mechanics followed without incident.

REFERENCES