ORIGINAL RESEARCH

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

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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

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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.[1-3] 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] 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.[2,3,6,8-10]

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,[2,6,7,14] 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.[16,17] Later, Zahn and Ottenbacher[18] 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.[2,18,19]

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.[20]

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[21] and the use of the Stabilizer was modeled after the procedure described by Hagins et al.[12] 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

Figure 1. Performance of the double leg lowering test using the Stabilizer and wall goniometer. Subjects started with hips at 90° and knees fully extended and lowered the legs until pressure in the Stabilizer measured less than 40 mm Hg.

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

Figure 2. Photo of performance of the star excursion balance test reaching in the right anterior direction. Subjects placed the stance foot in the center of the star and reached in the diagonal directions to the right and left.

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

Week One

1. warm-ups (choose 2-3 from among the following each week: ribcage breathing, pelvic rocking, knee folds, knee sways, upper body curl)
2. single leg stretch
3. double leg stretch
4. rolling
5. side kick: front/back
6. side kick: small circles
7. neck roll
8. pull straps 1
9. rolling down

Week Two

1. warm-ups
2. single leg stretch
3. double leg stretch
4. roll up
5. hundred
6. rolling
7. side kick: front/back
8. side kick: small circles
9. spine twist
10. spine stretch forward
11. pull straps 1
12. pull straps 2
13. rolling down

Week Three

1. warm-ups
2. single leg stretch
3. double leg stretch
4. criss cross
5. roll up
6. hundred
7. side kick: small circles
8. side kick: hot potato
9. spine twist
10. spine stretch forward
11. rowing 3
12. rowing 4
13. single leg kick
14. pull straps1
15. pull straps 2
16. rolling down

Week Four

1. warm-ups
2. single leg stretch
3. double leg stretch
4. single straight leg
5. criss cross
6. roll up
7. hundred
8. side kick: small circles
9. side kick: hot potato
10. spine twist
11. rowing 3
12. rowing 4
13. swimming
14. leg pull back
15. leg pull front
16. mermaid (modification)
17. teaser 1
18. rolling down

Week Five

1. warm-ups
2. single leg stretch
3. double leg stretch
4. criss cross
5. roll up
6. rolling
7. side kick: front/back
8. side kick: small circles
9. spine twist
10. saw
11. rowing 3
12. rowing 4
13. pull straps 1
14. pull straps 2
15. swan
16. teaser
17. twist
18. leg pull front
19. rolling down

Week Six

1. warm-ups
2. single leg stretch
3. double leg stretch
4. criss cross
5. single straight leg
6. roll up
7. rolling
8. side kick: front/back
9. side kick: small circles
10. spine twist
11. rowing 3
12. rowing 4
13. pull straps 1
14. pull straps 2
15. swimming
16. teaser 1
17. leg pull back
18. leg pull front
19. mermaid
20. rolling down

In addition to reporting the reliability of the dependent variable tests noted above, the two-member study team collected procedural reliability data on the delivery of the exercise program and the dependent variable data collection. The independent and dependent variable reliability was analyzed using the point to point method described by Fetko et al[19] and illustrated by the following formulas ($\geq$90% agreement is considered acceptable reliability in single subject design studies).[25]

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

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.

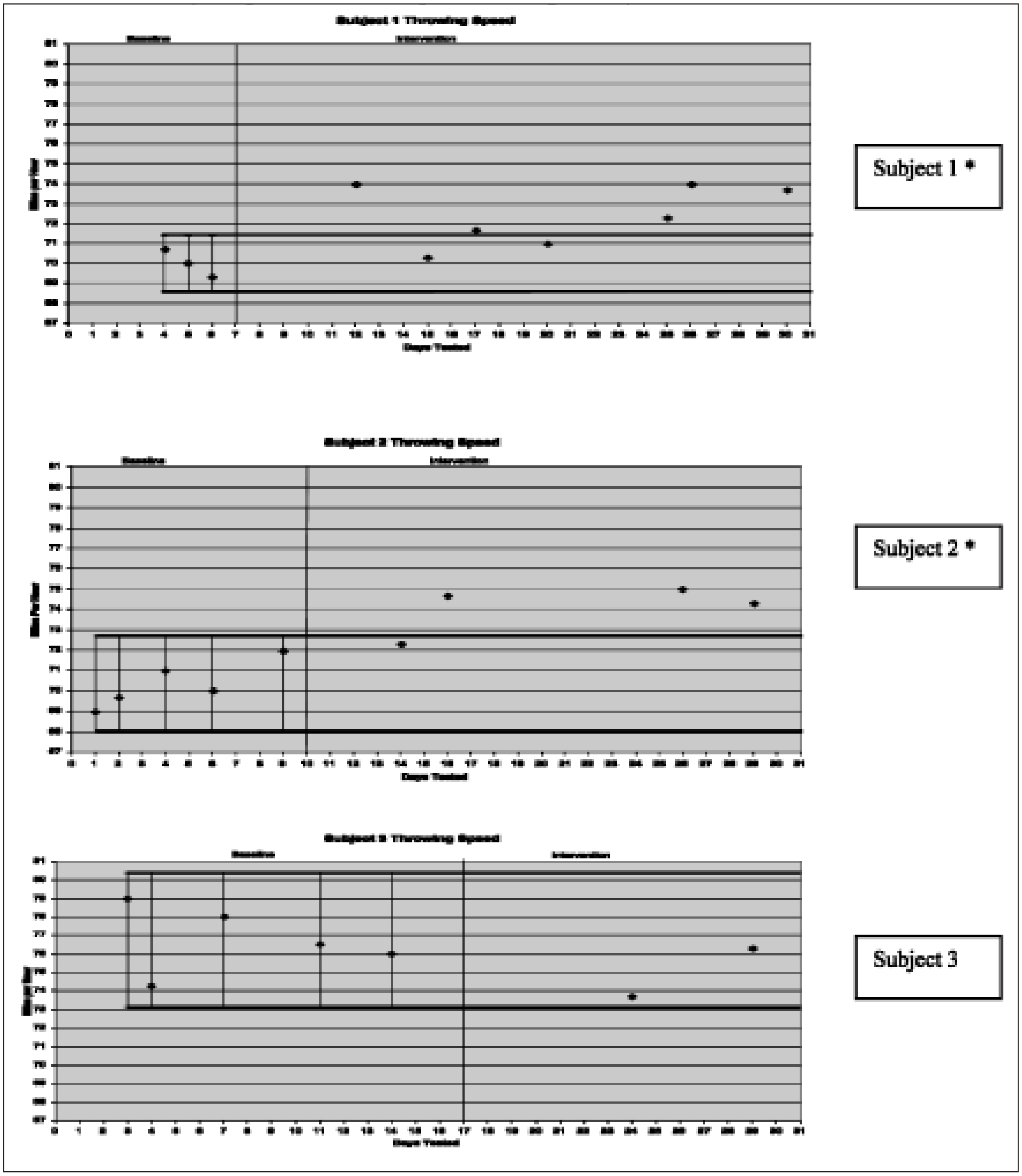
All data were ultimately analyzed by the principal author. Table 2 outlines the numerical changes in performance throughout the study. Baseline means and standard deviations were calculated for each dependent variable and post-intervention data is bold. Figures 3-5 graphically

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.

DLL(degrees)	**Test**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Subject									
1	65	68.3	63.3	**45**	**48.3**	**41.7**	**43.3**	**45**	**41.7**
2	71.67	73.3	81.7	71.7	75	**63.3**	**53.3**	**60**	**48.3**
3	55	53.3	56.7	65	56.7	**50**	**43.3**	**36.7**	
SEBT (cm)									
Subject 1									
RA	99.4	102.1	10.8	**99.5**	**100.1**	**103.5**	**109.1**	**111.7**	**111.5**
RP	112.3	112.9	108.3	**112**	**110**	**117.3**	**119**	**118.1**	**121.5**
LA	95.2	102.4	102.4	**104.9**	**104.3**	**107.3**	**107.5**	**111.3**	**109.9**
LP	110	115.2	106.9	**109.8**	**109.9**	**115.5**	**119.3**	**121.1**	**121.2**
Subject 2									
RA	81	86.7	91.57	89.1	87.8	**96.5**	**105.1**	**106.8**	**102.8**
RP	88	89.2	102.5	102.2	101.6	**104.6**	**113.3**	**115.7**	**113.6**
LA	85.4	95.9	95	93.4	93.1	**100.8**	**109.8**	**109.9**	**106.4**
LP	90	99.9	101	102.8	105.8	**107.3**	**116.9**	**115**	**121.1**
Subject 3									
RA	101.2	107.6	104.8	104.3	110.7	**118.7**	**119**	**117.5**	
RP	102.3	109.8	116.6	121.6	120	**121.7**	**125.5**	**123.2**	
LA	114	106.7	109.7	115.3	113.7	**118.5**	**121.2**	**117**	
LP	110.8	118.9	111.6	118.7	118.4	**123.8**	**122.5**	**129.4**	
Speed (mph)									
Subject									
1	70.7	70	69.3	**74**	**70.3**	**71**	**72.3**	**74**	**73.7**
2	69	69.7	71	70	72	**72.3**	**74.7**	**75**	**74.3**
3	79	74.3	78	76.5	76		**73.7**	**76.3**	

RA= Right Anterior
RP= Right Posterior
LA=Left Anterior
LP= Left Posteror

Figure 3. Graph of three subjects' performance on the throwing velocity test. Measured in mph. Black horizontal lines mark 2-standard deviatons from baseline mean. (* Improvement is significant at $p < 0.05$)



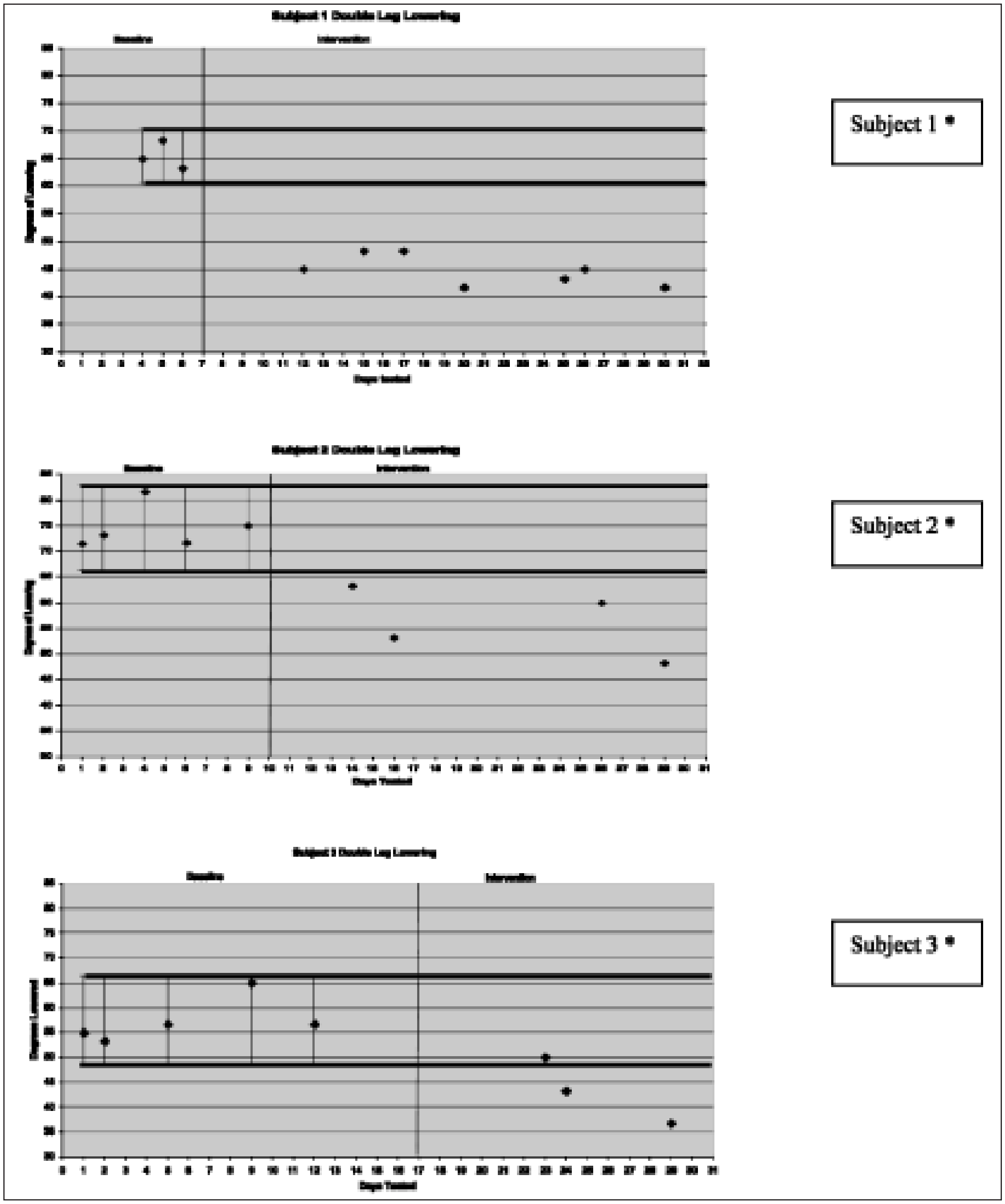
illustrate the subjects' performance on each dependent variable. Baseline data is separated from the data collected during the intervention in the graphs by a vertical line. Visual inspection of the graphs was used in conjunction with the two standard deviation band method of analysis described by Ottenbacher.[25] 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.

Figure 4. Graph of three subjects' performance on the double leg-lowering test, measured in degrees. Black horizontal lines mark 2-standard deviatons from baseline mean. (* Improvement is significant at $p < 0.05$) Improvement is notred by lower number of degrees.



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

Table 3. Table of percent change from baseline averages to average of performance after intervention was introduced.

	Subject 1	Subject 2	Subject 3
Double Leg Lowering avg pretest	65.53	74.67	57.304
Double Leg Lowering avg posttest	44.17	56.23	43.33
DLL % change	**32.60**	**24.71**	**24.43**
SEBT reach Left Anterior avg pretest	100.77	87.23	105.72
SEBT reach Left Anterior avg posttest	105.90	102.80	118.40
SEBT LA % change	**5.09**	**17.84**	**11.99**
SEBT reach Left Posterior avg pretest	111.17	96.70	114.06
SEBT reach Left Posterior avg posttest	116.32	111.80	123.48
SEBT LP % change	**4.63**	**15.65**	**8.25**
SEBT reach Right Anterior avg pretest	100.00	92.56	111.88
SEBT reach Right Anterior avg posttest	107.53	106.73	118.90
SEBT RA % change	**7.53**	**15.30**	**6.27**
SEBT reach Right Posterior avg pretest	110.70	99.90	115.68
SEBT reach Right Posterior avg posttest	116.13	115.08	125.23
SEBT RP % change	**4.91**	**16.39**	**8.26**
Throwing Speed avg pretest	70.00	70.34	76.76
Throwing Speed avg posttest	72.55	74.08	75.00
Throwing Speed % Change	**3.64**	**5.31**	**-2.29**

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]

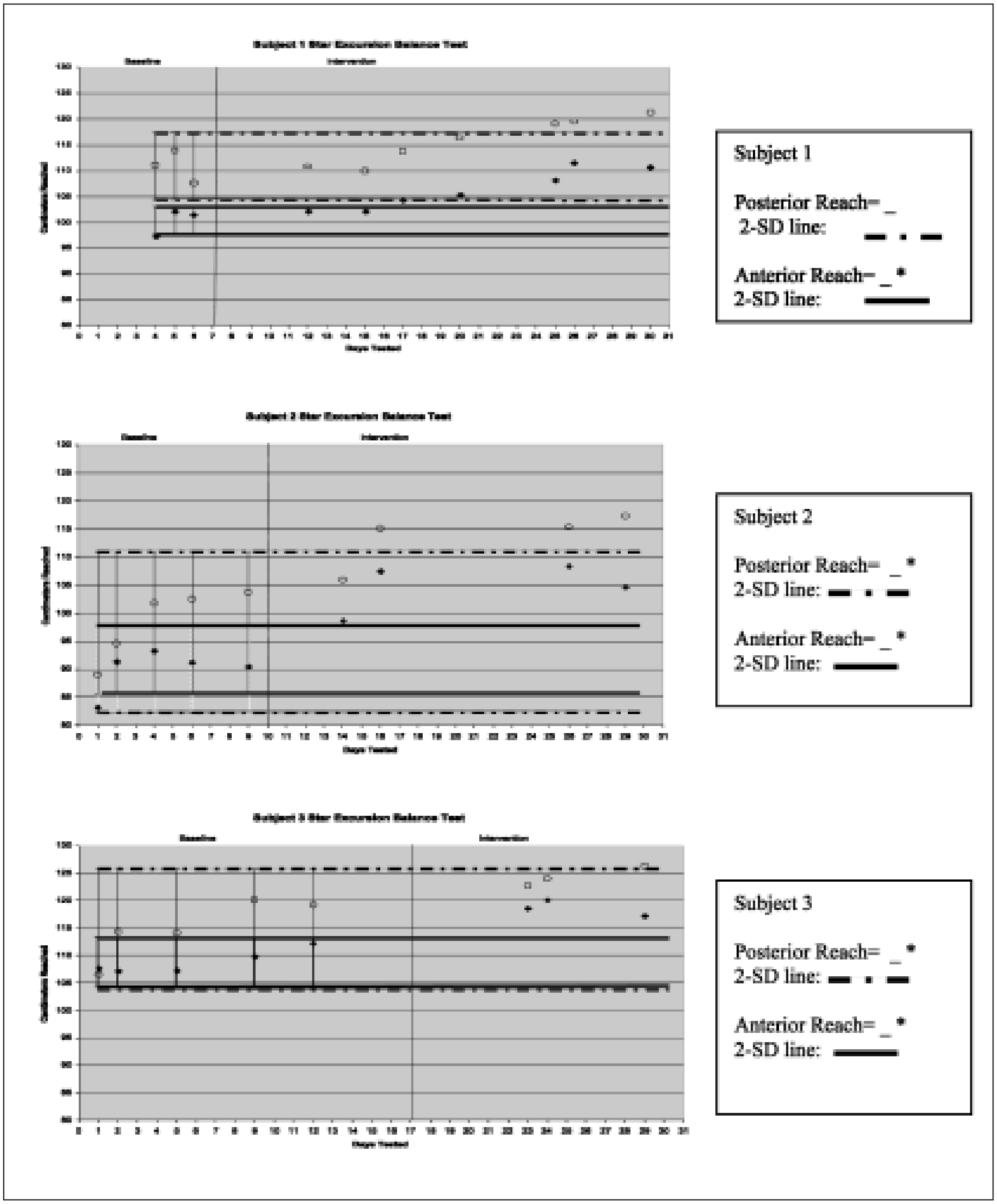
All subjects improved in the distance reached with the SEBT with the exception of posterior reach. It is interesting to note that subject 2 showed much greater improvement in all four directions than subject 1 or subject 3, but that all subjects demonstrated a gradual improvement in each direction over 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

Figure 5. Graph of three subjects' performance on the star excursion balance test, measured in centimeters. Black horizontal lines mark 2-standard deviatons from baseline mean. (* Improvement is significant at $p < 0.05$) Right and left leg performance was combined for graph.



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.

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Appendix A. Exercises used with position and description.

Exercise	Position	Description
ribcage breathing	Hooklying	Inhale letting ribs rise and expand, exhale encouraging ribs to descend and come together.
pelvic rocking	Hooklying	Inhale tilting pelvis into an anterior position, exhale tilting pelvis posteriorly.
knee folds	Hooklying	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.
knee sways	Hooklying	Feet off the floor, legs/knees hugging together. Inhale and let knees drop to one side, exhale return knees to center position.
upper body curl	Hooklying	Inhale and exhale lifting head, neck, and shoulders off floor, reaching toward feet with hands.
hundred	Lie on back, arms along sides, hips and knees flexed to 90º	Inhale for 5 counts, and exhale for 5 counts contracting the deep abdominals and encouraging the abdominals to hollow out during the exhales.
roll-up	Lie supine on mat, arms overhead, lower extremities extended	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.
rolling	Seated, hip/knees flexed, hands "holding on" posterior knees, feet on mat	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.
single-leg stretch	One knee flexed with hands holding knee toward chest, other leg extended with 45º hip flexion	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").
double-leg stretch	Lower extremities flexed (knees to chest), hugging. One hand on each knee.	Inhale extending to 45º hip flexion; arms overhead. Exhale circling arms down close to mat, finishing with hands on flexed knees (original position).
single straight leg	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.	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.
side kick hot potato	Performed on mat on side	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."
side kick front/back	Performed on mat; patient lying on side	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.
side kick small circles	Performed on mat; patient lying on side	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.
spine stretch forward	Seated in "v-position" (legs extended, feet dorsiflexed, legs in approximately 30º abduction.) Arms extended, abducted 90º	Inhale to prepare, exhale as arms reach forward, spine flexes above waist and deep abdominals hollow out. Return to original position.

Exercise	Position	Description
spine twist	Seated in v-position. Arms extended, abducted 90º	Inhale as arms and torso are rotated to one side. Exhale return to center.
saw	Seated in v-position. Arms extended, abducted 90º.	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.
swan	Lying prone, legs extended, arms flexed	Inhale for preparation, exhale extending arms and back keeping pelvis on floor.
neck roll	Lying prone, legs extended, arms flexed, hands adjacent to shoulders, back extended	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.
pull straps 1	Prone	Arms extended, shoulders flexed forward off mat. Inhale and extend shoulders as hands reaching toward toes.
pull straps 2	Prone	Arms extended, shoulders abducted out to sides off mat. Inhale extending shoulders, reaching toward toes.
single-leg kick	Prone, propped in extension on forearms, hands clasped.	Legs extended. Inhale and kick one foot twice toward buttocks. Exhale, kick other leg towards buttocks. Opposite leg extended while working leg kicks.
swimming	Prone	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.
teaser	Supine	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
rowing 3	Seated. Legs extended in front, hugging. Arms along sides, elbows flexed, palms facing downward	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.
rowing 4	Seated. Legs extended in front, hugging. Arms by sides	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.
criss-cross	Supine	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.
leg pull back	Push-up position, hand and wrists under shoulders	Inhale lifting and extending right leg, allowing weight to shift backward and stretching the supporting heel cord.
leg pull front	Sitting position, legs extended in front, hands by hips. Lift pelvis in a front "plank" position	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.
mermaid	Seated position, legs flexed and tucked into right side. Right hand holds onto ankles. Extend left arm to ceiling	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.
rolling down	Standing, feet shoulder-width apart	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.

CLINICAL COMMENTARY

PECTORALIS MAJOR TENDON REPAIR POST SURGICAL REHABILITATION

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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

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INTRODUCTION

Patissier[1] 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.[2] 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[3] as well as cartilage of the first six ribs.[4] 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 sterum 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.[5,6] Wolfe et al[7] 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 collegues[7] 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.

Figure 1. Loss of normal pectoralis contour.

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.[8-12] These injuries tend to occur more commonly in patients during their second to fourth decade of life.[2] 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".[11-18] Mild swelling and often ecchymosis[2,8,14,18,19-23] follows. Bruising can be seen over the anterior lateral chest wall or in the proximal arm.[24] Pain generally is not intense.[24]

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" *(Figure 2)* 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.[2,21,22,25,26] 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.[27-29] The partial tear may be difficult to evaluate. An MRI can be helpful in assessing location and severity of the tear.[30] The tendon fibers from the clavicular 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.

A) Anterior View

B) Lateral view

Figure 2. Asymmetry seen with isometric contraction of pectoralis major A) anterior view, B) lateral view.

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

CONSERVATIVE VS. SURGICAL TREATMENT

Historically, non-operative treatment has been advocated for older or sedentary individuals or for those with incomplete tears.[21] Unfortunately, rarely does non-operative treatment result in return of normal strength.[14,20,31] Wolf et al[7] has reported up to a 26% loss of peak torque and a 39.9% work deficit in shoulder adduction in un-repaired 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.[5,9,13,17-19,23,27,32-42]

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 *(Figure 3)*. 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.

Figure 3. Incision line.

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.[43-52]

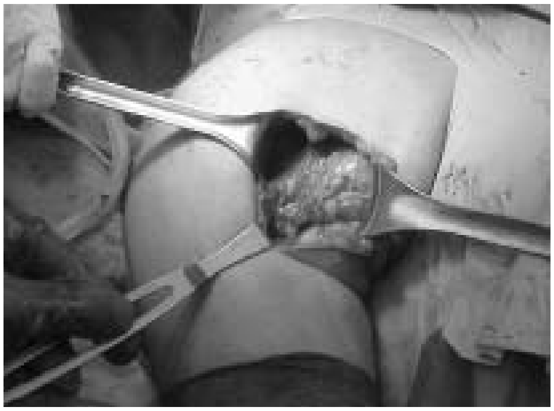

Figure 4. Identifying pectoralis major.

Figure 5. Drilling tunnel for suture anchor placement.

Figure 6. Completed pectoralis tendon repair.

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.[12] 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.[36,37] 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.

Table 1. Pectoralis tendon repair guidelines

Type of Repair	Guidelines	Full AROM/PROM
Tendon – tendon	Sling 4 weeks	14-16 weeks
Bone – tendon	Sling 3 weeks	12-14 weeks

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.

Table 2. Range of Motion Guidelines

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

ER = External rotation

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[53] 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.[54,55]

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 bodybuilders 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.[56] Scar massage will be helpful to break up collagen fibers, resulting in a softer, flatter, paler scar with better cosmesis,[57] in addition to promoting soft tissue mobility.[58]

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 3. Pectoralis Tendon Post-operative Protocol

POST-OPERATIVE REHABILITATION FOLLOWING PECTORALIS TENDON REPAIR

<u>PHASE I – IMMEDIATE POST-OPERATIVE PHASE (WEEKS 0-2)</u>

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

<u>PHASE II – INTERMEDIATE POST-OPERATIVE PHASE (WEEKS 3-6)</u>

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 <u>EXCEPT</u> 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
	    Abuction to 35 degrees
	    External rotation at 0 degrees of abduction to 15 degrees

<u>PHASE III – LATE POST-OPERATIVE PHASE (WEEKS 6-12)</u>

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 began at 30 degrees increasing 5 degrees per week, with abduction and external rotation performed last. Toward the end of this phase AAROM is began 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 Ellenbecker[60] 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. Davies[59] 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.

Figure 7. Isometrics for the shoulder in the "balance position."

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.[61] 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.

Figure 8. Joint mobilization to address inferior capsule contracture limiting normalization of glenohumeral joint arthrokinematics.

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.[62] 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 until 6 months after surgery. Additionally, the use of heavy weighted pec dec and flys should be avoided for up to 6 months after surgery due to abnormally large amounts of stress to the pectoralis major. A pec dec refers to the seated pectoralis exercise machine in which the arms/elbows of the participant are placed around pads bilaterally and the participant horizontally flexes or adducts the shoulders toward each other. The fly is a similar movement done with dumb bells in each hand on a flat or incline bench. When performing these exercises it may be wise to slightly alter the lift allowing maintenance of the humerus in a position anterior to the frontal plane, which drastically reduces the amount of strain on the pectoralis major muscle and tendon.

Figure 9. BodyBlade.

Surgical Outcomes

Reviewing 16 repairs, Kretzler and Richardson[24] 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[63] assessed surgical outcomes following 13 patients undergoing pectoralis major repair. Surgical patients were broken into acute and chronic repairs, both of which faired 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[19] 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[20] 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[7] 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[8] 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[3] 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 recommendation 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.

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ORIGINAL RESEARCH

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

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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 90º of elevation in order to minimize risk for shoulder impingement. Few exercises for the lower trapezius have been studied which maintain the shoulder below 90º 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 80º 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, mimimal 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

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INTRODUCTION

Lower trapezius muscle performance is an essential component to normal scapulohumeral rhythm.[1-7] 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.[6,8-12] During active humeral elevation, upward scapular rotation of the scapula is initiated by the serratus anterior.[10] One function of the lower trapezius muscle is to stabilize the scapula against lateral displacement produced by the serratus anterior.[10] The serratus anterior and upper trapezius can then exert an upward rotation moment about the scapula.[10] A second function of the lower trapezius is to stabilize the scapula against scapular elevation produced by the levator scapulae.[10] 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.[10]

Research has shown an association between shoulder pathology and abnormal scapular motion or muscle firing patterns of the lower trapezius.[3,6,13-27] Increased scapular elevation has been found in subjects with subacromial impingement compared to subjects without shoulder pathology.[19,27] Cools et al[13] 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.[14]

Although it is not known whether abnormal scapular arthrokinematics 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.[12] 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.[20,28-30] 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.[20]

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.[1,4,22,31-36] Ekstrom et al[32] 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[31] determined that shoulder external rotation while lying prone with the arm positioned at 90° produced 40% MVIC of the lower trapezius. Mosely et al[22] 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.[32,34] Ekstrom et al[32] found that shoulder abduction performed below 80° in the plane of the scapula activated 50 $\pm$ 21% MVIC of the lower trapezius while prone unilateral rowing produced 45 $\pm$ 17% MVIC. Lear and Gross[34] 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 90º that elicited marked levels of lower trapezius muscle activity using the standard established by McCann et al [20] (>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/AgC1) 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[37] and as outlined in Table 1. The skin was prepared prior to electrode placement by shaving hair (if necessary), abrading 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[38] in order to verify the quality of the tele-

Table 1. Muscles tested, electrode position, and maximal voluntary contraction (MVIC) Protocol

Muscle	Electrode position	MVIC position	MVIC Action
Upper trapezius	At the angle of the neck and shoulder, over the belly of the muscle in line with the muscle fibers.	Sitting with arms relaxed at sides	Resisted maximum shoulder elevation
Middle trapezius	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)	Prone, shoulder abducted to 90° and lateral rotation, elbow flexed 90°	Resisted horizontal arm abduction
Lower trapezius	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.	Prone, shoulder in 130° of abduction.	Resisted arm elevation
Serratus anterior	Placed vertically below the axilla, anterior to the latissimus, over the 4th-6th ribs	Supine, shoulder in 90° of flexion and elbow in extension	Resisted end range protraction

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.

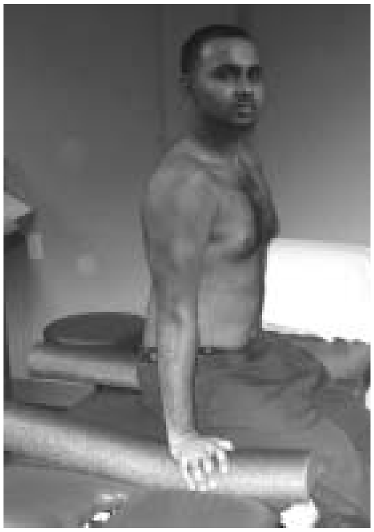

Figure 1. Seated press up

Figure 2. Unilateral scapular retraction

Figure 3. Bilateral shoulder external rotation

Figure 4. Unilateral shoulder depression

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[20]: 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

Table 2. Mean ($\pm$ SD) EMG activity of the lower trapezius (LT), middle trapezius (MT), upper trapezius (UT), and serratus anterior (SA) muscles expressed as a percentage of maximum voluntary isometric contraction (MVIC) for four selected exercises.

Exercise	UT %MVIC	MT %MVIC	LT %MVIC	SA %MVIC
1. Press Up	27 (32)	32 (16)	56 (23) ††	44 (35)
2. Scapular Retraction	62 (44)	50 (36)	51 (29)	26 (23) §
3. B/L Shld. ER	17 (18) **	37 (19) *	40 (12) *	29 (32)
4. Scapular Depression	20 (17)	19 (19)	21(16)	41 (38) †

* Significantly greater than UT activity. ($p< 0.05$)
** Significantly less than MT and LT activity, but not significantly different from SA activity. ($p< 0.05$)
† Significantly greater than UT and MT activity, but not significantly different than LT activity. ($p< 0.05$)
†† Significantly greater than UT and MT activity, but not significantly greater than SA activity. ($p< 0.05$)
§ Significantly less than UT, MT, and LT activity. ($p< 0.05$)

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

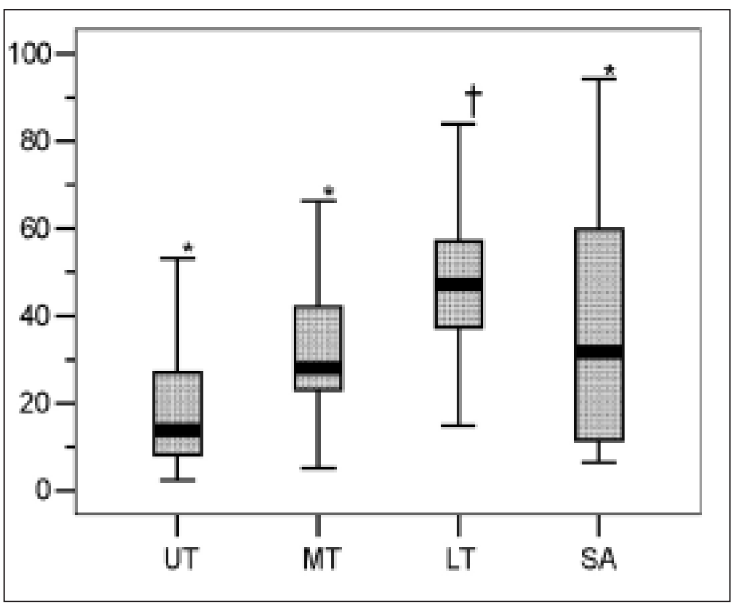

Figure 5. Box-and-whisker plot showing muscle activity, as expressed as % MVIC, of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA) during press-up exercise. The boxes in the plots represent the 25th and 75th percentiles. The line in the box represents the 50th percentile. The whiskers represent the highest and lowest values in the data.

To date, only one prior study reported lower trapezius muscle activity during closed chain exercises performed with the shoulders below 90°. Lear and Gross[34] 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[34] 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,[39-46] the press-up exercise is an exercise that clinicians may use as a component of a scapular stabilization program.

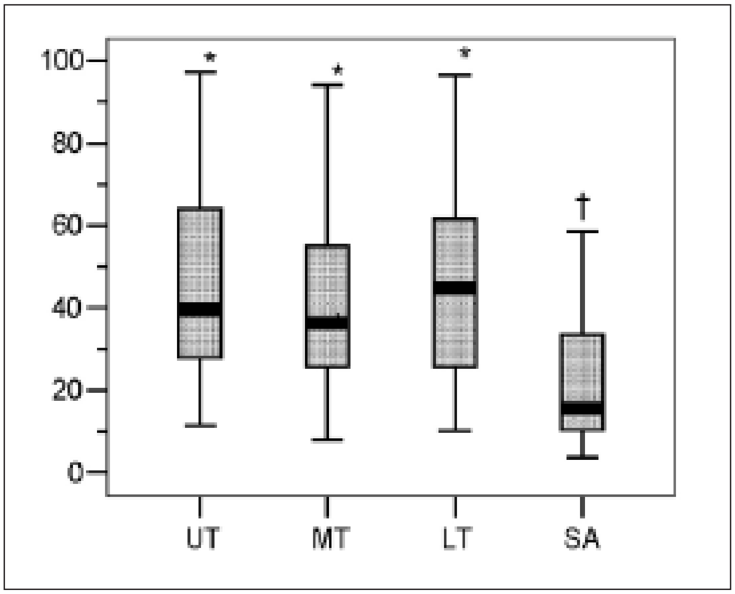

Figure 6. Box-and-whisker plot showing muscle activity, as expressed as % MVIC, of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA) during scapular retraction. The boxes in the plots represent the 25th and 75th percentiles. The line in the box represents the 50th percentile. The whiskers represent the highest and lowest values in the data.

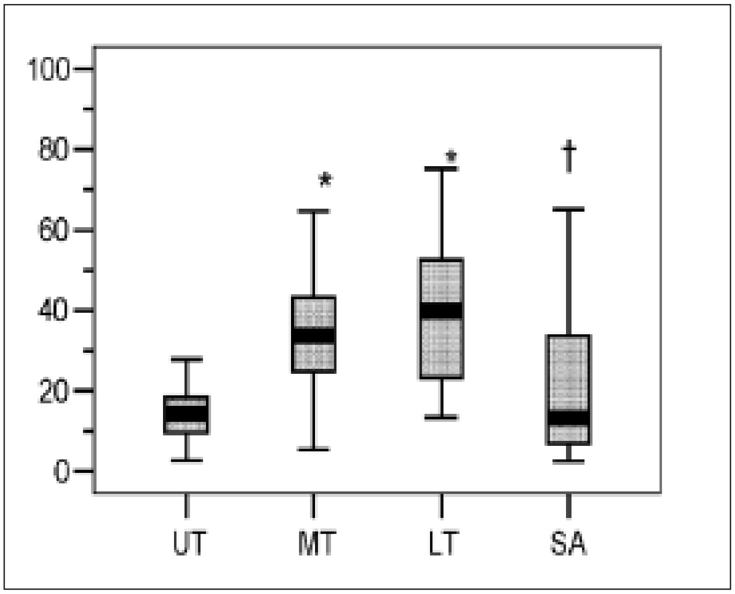

Figure 7. Box-and-whisker plot showing muscle activity, as expressed as % MVIC, of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA) during bilateral shoulder external rotation. The boxes in the plots represent the 25th and 75th percentiles. The line in the box represents the 50th percentile. The whiskers represent the highest and lowest values in the data.

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[32] 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.[5] The primary function of the upper and middle trapezius muscles are to pull the scapula posterior and medially during retraction.[10] The lower trapezius has an important stabilizing and eccentric role against the laterally directed moment on the scapula created by the serratus anterior.[10,47-48] Throwing athletes with posterior glenohumeral tightness may demonstrate excessive scapular protraction at follow-through,[49] which is thought to decrease the subacromial space and increase risk for impingement.[5] 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 medial-lateral 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.

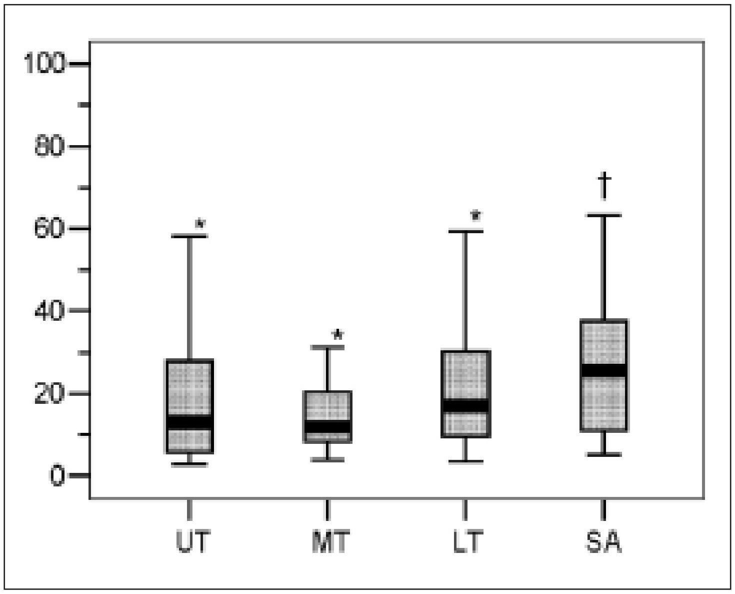

Figure 8. Box-and-whisker plot showing muscle activity, as expressed as % MVIC, of the upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA) during scapular depression. The boxes in the plots represent the 25th and 75th percentiles. The line in the box represents the 50th percentile. The whiskers represent the highest and lowest values in the data.

Scapular Depression

This exercise generated moderate muscle activity of the lower trapezius (21 $\pm$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.[50]

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[32] 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.[22,31-32]

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.[51] Sugamoto et al[52] 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.[14,22,50,53-55]

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 during 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.

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ORIGINAL RESEARCH

DIFFERENCES IN STATIC SCAPULAR POSITION BETWEEN ROCK CLIMBERS AND A NON-ROCK CLIMBER POPULATION

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Michael Lebec, PT, PhD[b]

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

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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.[1] 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.[2] While, this value varies greatly throughout the literature, normal scapulohumeral rhythm is approximately 2:1 overall,[3] 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.[3,4]

A possible etiology of abnormal scapulohumeral rhythm is the presence of imbalances in shoulder girdle musculature strength and length.[3] 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.[5] 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[6] reported a 33% incidence of rotator cuff tendonitis or impingement in a group of recreational rock climbers.

This high incidence of shoulder problems is important to clinicians because rock climbing is no longer a fringe sport. Over the past two decades its popularity has increased dramatically. During this time, the number of indoor rock climbing gyms has exploded and equipment technology has advanced, allowing the activity to be accessible to almost anyone. Rooks[6] proclaimed rock climbing to be "one of the most rapidly growing sports in the world." Sheel[7] estimated there to be approximately 300,000 rock climbers in the U.S. Additionally, the Outdoor Industry Association reports more than 3.4 million young people between the ages of 16-24 tried indoor rock climbing in 2004.[8]

With the continued increase in the number of rock climbers, physical therapists are more likely to provide treatment to these athletes, especially considering the frequency of overuse injuries. Wright et al[9] estimates that 75-90% of climbers can be expected to develop an upper extremity overuse injury, alluding to the fact that climbers may have an abnormal scapulohumeral ratio. The effect that the unique demands associated with this sport may have upon the soft tissues of the shoulder complex provide rationale for the hypothesis that frequent climbers may be predisposed to irregular scapulothoracic mechanics.

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,[3] 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.[10] 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.[11-15] Johnson et al[16] 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.[13] 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.

Figure 1. Measuring Scapular Upward Rotation with the Baseline® Bubble Inclinometer

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.[17]

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 Boneferroni 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

Table. Glenohumeral Motion, Scapulothoracic Motion, and GH:ST Ratio of Climbers and Non-Climbers

	Rock climbers (n = 21)	**Non-Rock climbers (n = 40)**
GH:ST ratio mean (SD)	3.7:1 (1.0)*	2.8:1 (0.62)*
GH max mean (SD)	160.0 (8.7)	154.4 (9.2)
Scapular upward rotation mean (SD)	35.3 (7.5)*	41.1 (6.7)*
*denotes significant differences		

(3.7:1; SD = 1.0) 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.[10] 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.[3] 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.[5]

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,[6] 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 scapulohumeral rhythm by not allowing full upward rotation of the scapula.[5] Borstad and Ludewig[5] 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[18] 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,[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[21] stating that "rock climbing is characterized by repeated bouts of isometric contractions."

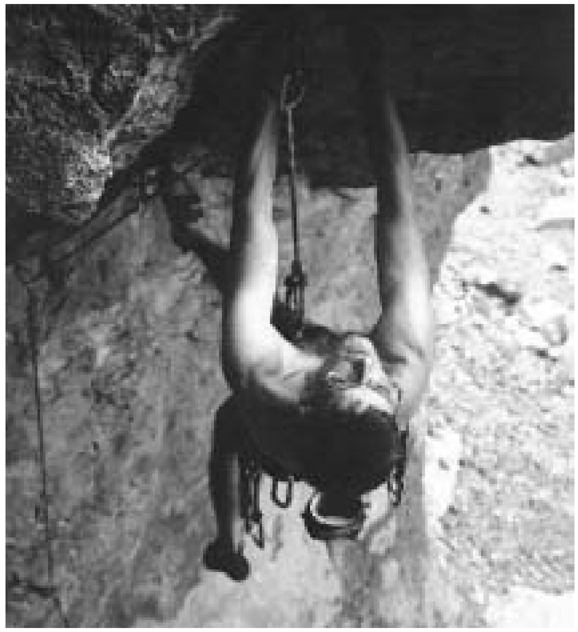

Figure 2. Rock Climber in Sustained Protraction

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.[21]

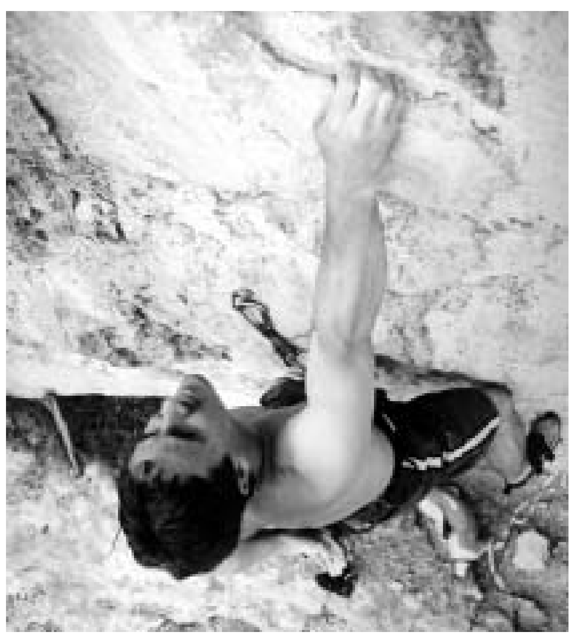

Figure 3. Rock Climber Using Passive Restraints of Upper Extremity to Support Body Weight

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.[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.[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.[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[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,[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.

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CLINICAL SUGGESTION

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

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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

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PROBLEM

Ankle sprains are among the most common injuries among athletes, frequently leading to impairment in joint stability, proprioception, and muscle strength.[1,2] Conservative management of ankle sprains includes cryotherapy,[3] bracing,[4] taping,[5] elastic bandaging,[6] mobilization,[7,8] balance/proprioception training,[9-12] and resistance exercises.[2,4,13]

As part of different case studies, Kern-Steiner et al[11] and Glasoe et al[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[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.[14] 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 dorsi- or plantarflexion 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)*

Figure 1. Technique to strengthen the muscles of eversion

Figure 2. Technique to strengthen the muscles of dorsiflexion

Figure 3. Technique to strengthen the muscles of inversion

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. It

Figure 4. Technique to strengthen the muscles of plantarflexion; knee extended

Figure 5. Technique to strengthen the muscles of plantarflexion; knee flexed

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.

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