

ORIGINAL RESEARCH

THE ACUTE EFFECTS OF TWO PASSIVE STRETCH MANEUVERS ON PECTORALIS MINOR LENGTH AND SCAPULAR KINEMATICS AMONG COLLEGIATE SWIMMERS

Jeffrey G. Williams, MS, ATC¹Kevin G. Laudner, PhD, ATC¹Todd McLoda, PhD, ATC¹

ABSTRACT

Purpose/Background: To compare the acute effects of two passive stretches on pectoralis minor length and scapular kinematics among a group of collegiate swimmers.

Methods: The study was a descriptive design with repeated measures. All procedures were conducted in a biomechanics laboratory and collegiate swimming facility. Fifty asymptomatic shoulders from 29 NCAA swimmers were used (15 control shoulders, 17 focused stretch shoulders, 18 gross stretch shoulders). Pre- and post-test linear pectoralis minor length, as well as scapular kinematics (upward/downward rotation, external/internal rotation, anterior/posterior tilt) were measured as dependent variables. Pectoralis minor length was measured using a standard tape measure and three-dimensional scapular kinematics were measured using an electromagnetic capture system.

Results: The gross stretch shoulders had a significant increase in pectoralis minor length compared to the control shoulders ($P = .007$). There were no other significant changes in length for either the focused stretch or control shoulders ($P > .07$). No statistically significant ($P > .08$) differences for all three scapular kinematic variables were found among any of the three groups ($P > .08$).

Conclusions: Our results revealed no acute improvements of scapular upward rotation, external rotation, or posterior tilt after the application of either passive stretch maneuver to the pectoralis minor muscle.

Level of Evidence: 2b

Key Words: Scapular dyskinesis, overhead athlete, muscle, tightness

CORRESPONDING AUTHOR

Jeffrey G. Williams, MS, ATC
Instructional Assistant Professor, School of
Kinesiology and Recreation
Illinois State University
Campus Box 5120
Normal, IL 61790
United States
E-mail: jgwilli@ilstu.edu

¹ Illinois State University, Normal, IL, USA
All subjects provided informed consent prior to participating in the study and the study was approved by the university's institutional review board – IRB# 2009-0078.

INTRODUCTION

Competitive swimmers routinely swim six to seven days per week during the competitive season, reaching distances of six to eight miles per practice, which equates to approximately 2500 sequential shoulder revolutions per day.¹ As such, the scapular orientations and kinematics during humeral elevation tasks of swimmers can be altered due to changes of surrounding musculature including weakness, fatigue, and inflexibility.² Optimal shoulder function is closely associated with proper scapular orientation and motion.²⁻⁵ Therefore, it is vital that any alterations to the periscapular musculature are addressed through preventative and rehabilitative interventions among such athletes.

Scapular dyskinesis has been associated with several shoulder pathologies, such as subacromial impingement syndrome,⁶⁻⁹ rotator cuff pathology,¹⁰⁻¹² internal impingement,¹³ glenohumeral instability,^{14,15} and adhesive capsulitis.¹⁶⁻¹⁸ One specific cause of scapular dyskinesis may be an abnormally shortened pectoralis minor muscle.^{8,19} Diminished pectoralis minor flexibility prohibits optimal scapular kinematics, specifically in upward rotation, external rotation, and posterior tilting.^{20,21} Therefore, tightness of the pectoralis minor may be a contributing factor to various shoulder injuries, most frequently, subacromial impingement syndrome.^{6,8,22} Furthermore, tightness of the pectoralis minor may be more prevalent among swimmers due to the repetitive overhead nature of their sport.²³

Due to the potential for development of scapular dyskinesis and upper extremity injury when pectoralis minor tightness is present, stretching of the pectoralis minor muscle is believed to be critical in the prevention and treatment of shoulder dysfunction. Various stretching techniques to lengthen the pectoralis minor are currently used in clinical practice.^{19,21} However, results of studies that have investigated optimal stretching techniques for the pectoralis minor are conflicting, which has caused increased confusion among researchers and clinicians.^{20,21,24-26} Further investigations are necessary to determine how stretching exercises alone might acutely affect the length of the pectoralis minor, as well as the dynamic orientation of the scapula. Therefore, the purpose of this study is to compare the acute effects

of two passive stretch maneuvers aimed at lengthening the pectoralis minor and the subsequent effects on scapular kinematics among a group of collegiate swimmers. The authors hypothesized that the passive stretching maneuvers utilized in this study would acutely change the length of the pectoralis minor muscle and affect scapular kinematics among a sample of collegiate swimmers.

METHODS

Subjects

Twelve healthy NCAA Division I competitive swimming athletes and 17 Division III competitive swimming athletes (4 male, 25 female, age = 19.5 ± 1.2 years, height = 171.7 ± 5.7 cm, weight = 68.5 ± 6.9 kg) participated in the study. All participants were in season at the time of data collection. Both left and right shoulders of each subject were used for data collection. Shoulders of swimmers that had a recent history (past 2 months) of upper extremity injury or any history of upper extremity surgery were excluded from the study. Of the 29 subjects, 8 shoulders were excluded from analysis due to previous injury leaving 50 shoulders for final data analysis; control shoulders ($n = 15$), focused stretch shoulders ($n = 17$), gross stretch shoulders ($n = 18$).

Instrumentation

A standard tape measure was used to measure pectoralis minor length. A Polhemus Liberty electromagnetic tracking system (Polhemus, Colchester, VT) with Motion Monitor software (Innovative Sports Training, Chicago, IL) was used to measure scapular kinematics. The Motion Monitor software uses data conveyed by electromagnetic receivers for the calculation of receiver position and orientation relative to an electromagnetic transmitter. The specific hardware used in this investigation consisted of an extended range direct current transmitter and four receivers. The instrumentation sampling frequency used for all kinematic assessments in the current study was 100 Hz.

Procedures

Testing occurred during a single session at the participating team's swimming facilities or within a biomechanics laboratory using a pre-test post-test design. Each shoulder was randomly assigned as

either focused stretch shoulder, gross stretch shoulder, or control shoulder. All subjects read and signed an informed consent form approved by the institutional review board prior to participation. The study was conducted in accordance with the Helsinki declaration. Scapular kinematic data for the experimental shoulders (focused stretch, gross stretch) were measured immediately before and after an application of one of the two passive stretch treatments. Control shoulders received initial scapular kinematic measurements and post-intervention measurements after an approximate 1.5 minute rest period without receiving any form of treatment. This rest period was approximately the same amount of time necessary to apply the assigned stretch to the experimental shoulders.

Pectoralis Minor Length Measurement

To measure the length of the pectoralis minor participants were standing erect with their test arm resting at their side. A tape measure was used to measure the linear distance between the origin and insertion of the muscle. The primary investigator of the study performed all measurements. The origin was defined as the inferior aspect of the 4th rib, which was one finger width lateral to the sternum, just lateral to the sternocostal junction. The insertion was defined as the medial-inferior aspect of the coracoid process. This method of measuring pectoralis minor length has previously been proven to be valid (intraclass correlation coefficients between 0.82 to 0.87) when compared with measurements made using an electromagnetic tracking system.²⁷

Scapular Kinematic Measurement

Three electromagnetic tracking receivers were secured to each subject's C7 spinous process, the distal, flat, broad surface of the acromion, and the mid portion of the humerus using adhesive spray, pre-wrap, and athletic tape to minimize skin movement. A fourth receiver was attached to an 11 cm long stylus and was used to digitize various anatomical landmarks on each subject's thorax, scapula, and humerus. The protocol adopted by the International Shoulder Group of the International Society of Biomechanics was used for all scapular kinematic measurements.²⁸ This protocol uses a global coordinate system, which is represented by an x-axis (directed horizontally to

the right), a y-axis (directed vertically upwards), and a z-axis (directed posteriorly). Local coordinate systems of each of the three segments (thorax, scapula, and humerus) were matched to the global coordinate axis system. Decomposition of the Euler angle sequences were used to determine orientations between the three segments (thorax, scapula, and humerus). Scapular orientations were determined as rotations about its axes (Figure 3); rotation around the x-axis (anterior/posterior tilt), rotation around the y-axis (external/internal rotation), and rotation around the z-axis (upward/downward rotation). Humeral elevation was determined as rotation of the humerus about the z-axis (elevation). Scapular orientations were analyzed at 30°, 60°, 90°, and 120° of humeral elevation. Utilizing electromagnetic tracking devices has been demonstrated to be a reliable and valid method of measuring three-dimensional motion.^{29,30} However, data above 120° was not collected because of the increased incidence of error at these levels of humeral elevation.³¹

In a standing position, with the thumb pointed superiorly, each subject performed ten successful humeral elevation and depression tasks in the scapular plane in sequence with a metronome paced at 60 beats per minute. Successful tasks were defined as humeral elevations performed using one second to elevate and one second to lower the arm beginning with the arm rested at his/her side and up to his/her limit of active elevation.

Pectoralis Minor Stretches

It is accepted that a passive stretch duration of 15 to 30 seconds and a frequency of 2 to 4 repetitions is appropriate for acutely improving flexibility.^{32,33} Thus, the focused and gross passive stretching interventions in this study were performed for two sequential repetitions, holding the stretches for 30 seconds, with a 30 second break between each stretch. The primary investigator applied all stretches at the end range of motion.

For the focused stretch shoulders, the authors placed each subject in a supine position with the test arm at their side while the primary investigator palpated medially into the proximal axilla, followed by proceeding superiorly towards the coracoid process. This maneuver allowed the investigator's fingers to

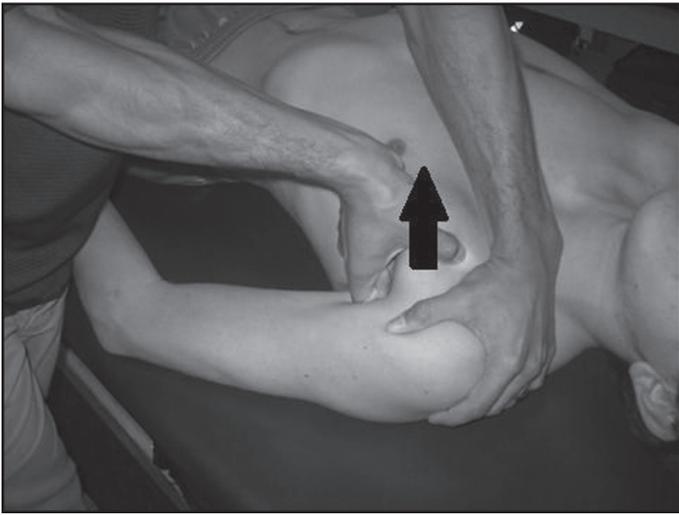


Figure 1. Focused stretch procedure. Arrow indicates an anteriorly directed line of pull applied by the clinician, as if to lift the pectoralis minor muscle away from the thorax.

be fixed posterior to the proximal end of the pectoralis minor muscle. The investigator then applied pressure in the anterior direction, similar to attempting to lift the muscle, thereby applying tensile force directly to the pectoralis minor. The opposite hand of the investigator was used to stabilize the scapula and humeral head (Figure 1).

For the gross-stretch, subjects were positioned in the supine position with the test arm abducted and externally rotated to 90° and the elbow flexed to 90°. The investigator stabilized each subject's body by placing a hand on the contralateral coracoid. The investigator then passively, horizontally abducted the subject's shoulder (Figure 2).

Statistical Analyses

A repeated measures analysis of variance (ANOVA) with repeated measures on time was utilized for com-



Figure 2. Gross stretch procedure. Arrow indicates an over-pressure force applied by the clinician in a direction of horizontal abduction.

parison. Time (pre-, post-test) and shoulder assignment (control, focused stretch, gross stretch) were the independent variables. The dependent variables included a linear measurement of pectoralis minor length, as well as angular measurements of scapular upward/downward rotation, external/internal rotation, and anterior/posterior tilting. If a significant group-by-time interaction was found, a one-way ANOVA using pre-post difference values and a Tukey post hoc analysis was utilized to compare shoulders. Within-group effect size was calculated as (post-intervention mean – pre-intervention mean)/pre-interven-

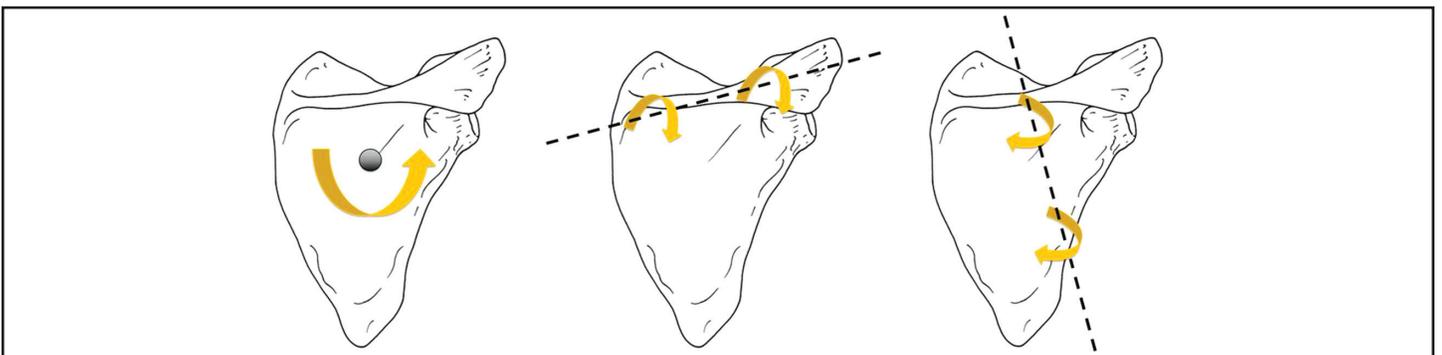


Figure 3. Illustration of three-dimensional scapular kinematics: upward/downward rotation (left), anterior/posterior tilt (middle), external/internal rotation (right).

Table 1. Pre and Post-Test Pectoralis Minor Length (mean ± SD in cm)				
Shoulder Group	Pre-Test	Post-Test	Difference	Effect Size
Control	13.0 ± 1.1	13.0 ± 1.0	0	0
Focused Stretch	12.8 ± 1.0	13.2 ± 0.8	0.4	0.4
Gross Stretch	12.8 ± 1.7	13.4 ± 1.5	0.6	0.4

Table 2. Pre and Post-Test Scapular Upward/Downward Rotation (mean ± SD in degrees)				
Shoulder Group	Pre-Test	Post-Test	Difference	Effect Size
<u>30° of Humeral Elevation</u>				
Control	1.9 ± 15 *	1.39 ± 15.9 *	-0.51	0.03
Focused Stretch	1.43 ± 17.1	1.39 ± 17.1	-0.04	0.00
Gross Stretch	1.59 ± 18.8	1.31 ± 18.5	-0.28	0.01
<u>60° of Humeral Elevation</u>				
Control	9.67 ± 14.9	10.9 ± 16.2	1.23	0.08
Focused Stretch	12.4 ± 17.5	13.6 ± 17.5	1.20	0.07
Gross Stretch	12.3 ± 17.7	11.9 ± 17.8	-0.40	0.02
<u>90° of Humeral Elevation</u>				
Control	23 ± 15.4	24.4 ± 16.9	1.40	0.08
Focused Stretch	25.2 ± 17.8	26.8 ± 17.9	1.60	0.09
Gross Stretch	24.3 ± 17.3	24 ± 16.9	-0.31	0.02
<u>120° of Humeral Elevation</u>				
Control	32.8 ± 15.5	34 ± 16.5	1.20	0.07
Focused Stretch	33.9 ± 19.7	35.3 ± 19.9	1.40	0.07
Gross Stretch	32.6 ± 16.1	31 ± 15.2	-1.6	0.10
* Values indicate downward rotation				

tion standard deviation. The effect size calculations provide an indication of clinical meaningfulness of changes among the dependent variables. Alpha level was set a priori at .05. All data were analyzed using PASW software (Version 18.0, IBM Corp, Somers, NY).

RESULTS

Descriptive data for pre- and post-test pectoralis minor length and scapular kinematics of the three groups are summarized in Tables 1-4. Pectoralis minor length showed a significant interaction effect ($p = .009$, $\eta^2 = .18$). Post hoc analysis showed that the gross stretch produced significantly more lengthening of the pectoralis minor compared to the control shoulders ($p = .007$, $\eta^2 = .40$). The effect size suggests that a small to moderate amount (40%) of the change in pectoralis minor length may be attributed to the treatment. There were no significant differences in pectoralis minor length change between the focused stretch and the control shoulders

($p = .07$) or the focused stretch and the gross stretch shoulders ($p = .64$). The main effect for time was also significant ($p = .001$, $\eta^2 = .30$).

No significant group-by-time interactions were found for scapular upward/downward rotation at any angle of humeral elevation ($p > .08$, $\eta^2 < .10$). Similarly, no significant group-by-time interactions were found for scapular anterior/posterior tilt at any angle of humeral elevation ($p > .33$, $\eta^2 < .05$). Significant group-by-time interactions were found for scapular external/internal rotation at humeral elevation angles of 30°, 60°, and 90° ($p < .04$, $\eta^2 < .16$), but not for 120° ($p = .76$, $\eta^2 = .01$). However, post hoc analysis showed no significant differences between shoulders for scapular external/internal rotation ($p > .33$).

DISCUSSION

Previous authors have indicated that pectoralis minor tightness can lead to scapular dyskinesis^{8,22}

Table 3. Pre and Post-Test Scapular External/Internal Rotation (mean ± SD in degrees)				
Shoulder Group	Pre-Test	Post-Test	Difference	Effect Size
<u>30° of Humeral Elevation</u>				
Control	4.72 ± 30.9	5.54 ± 30.0	0.82	0.03
Focused Stretch	7.2 ± 23.9 *	7.69 ± 24.4 *	0.49	0.02
Gross Stretch	1.04 ± 26.3 *	2.81 ± 26.9 *	1.77	0.07
<u>60° of Humeral Elevation</u>				
Control	9.29 ± 30.5	10.3 ± 29.5	1.01	0.03
Focused Stretch	3.94 ± 24 *	3.78 ± 24.8 *	-0.16	0.01
Gross Stretch	1.68 ± 27.5	0.63 ± 28.3 *	-1.05	0.04
<u>90° of Humeral Elevation</u>				
Control	9.37 ± 32.4	10.1 ± 31.6	0.73	0.02
Focused Stretch	5.09 ± 25.2 *	5.32 ± 26 *	0.23	0.01
Gross Stretch	0.44 ± 30.9 *	3.05 ± 31.7 *	2.61	0.08
<u>120° of Humeral Elevation</u>				
Control	4.88 ± 35.6	3.5 ± 35.9	-1.38	0.04
Focused Stretch	13.7 ± 28.3 *	16.8 ± 27.1 *	3.10	0.11
Gross Stretch	8.73 ± 35.8 *	11.1 ± 36.5 *	2.37	0.06
* Values indicate internal rotation				

Table 4. Pre and Post-Test Scapular Anterior/Posterior Tilt (mean ± SD in degrees)				
Shoulder Group	Pre-Test	Post-Test	Difference	Effect Size
<u>30° of Humeral Elevation</u>				
Control	9.38 ± 20.1 *	9.18 ± 20.4 *	-0.2	0.01
Focused Stretch	9.34 ± 15 *	9.48 ± 15.3 *	0.14	0.01
Gross Stretch	10 ± 13.8 *	9.71 ± 14.2 *	-0.29	0.02
<u>60° of Humeral Elevation</u>				
Control	4.66 ± 20.3 *	4.82 ± 20.6 *	0.16	0.01
Focused Stretch	1.9 ± 17 *	1.77 ± 17.4 *	-0.13	0.01
Gross Stretch	4.24 ± 17 *	3.32 ± 18.4 *	-0.93	0.05
<u>90° of Humeral Elevation</u>				
Control	3.12 ± 23.3	2.8 ± 23.9	-0.32	0.01
Focused Stretch	9.48 ± 20.9	9.95 ± 21.5	0.47	0.02
Gross Stretch	4.58 ± 24.4	5.82 ± 26.7	1.24	0.05
<u>120° of Humeral Elevation</u>				
Control	17 ± 29.9	17.3 ± 32.7	0.30	0.01
Focused Stretch	27.1 ± 26.3	30 ± 26.3	2.90	0.11
Gross Stretch	20.9 ± 34.9	21.4 ± 37.9	0.50	0.01
* Values indicate anterior tilt				

and is associated with several shoulder pathologies.^{9,11,13,14,16} Therefore, stretching techniques for lengthening the pectoralis minor may be important to ensure proper scapular kinematics and to rehabilitate athletes with disorders associated with this tightness. The authors hypothesized that both passive stretch maneuvers would acutely increase pectoralis minor muscle length and scapular upward rotation, external rotation, and posterior tilt. However, the results of the current investigation indicate that although the gross stretch produced a significant increase in pectoralis minor length compared to the control shoulders; there were no acute changes in scapular kinematics in the shoulders that had either the gross or focused stretch interventions.

Borstad and Ludewig²⁴ compared three pectoralis minor stretches. Although, all three stretches were reported to increase the length of the pectoralis minor during the stretch period, the “unilateral self stretch” was found to create the most tissue lengthening. This stretch was performed in a standing position with the target shoulder abducted to 90° and the elbow flexed to 90°. With the hand’s volar surface of the target arm placed against a vertical door frame or other flat rigid structure the subject then rotated their trunk away from the target shoulder. The gross stretch performed in our investigation was similar to Borstad and Ludewig’s²⁴ self-stretch as both stretching maneuvers place the humerus in an abducted and externally rotated position while stretching the shoulder further into horizontal abduction and sequentially retracting the scapula. Similar to Borstad and Ludewig’s²⁴ findings, the gross stretch procedure in the current study showed an increase in the length of the pectoralis minor compared to control shoulders. This shoulder position is in accordance with other investigators who suggest that applying a stretch to the pectoralis minor would require movement of the muscle’s insertion in a posterior direction in conjunction with scapular retraction that is performed at or above 30° of flexion or elevation in the scapular plane (scaption), thereby lengthening the muscle.²¹ The authors specifically chose to perform the gross stretch with the subjects lying supine as it allowed the investigator to better control the amount of overpressure applied during the stretches. Subjects performing the stretch independently in a standing position may demonstrate

varying amounts of applied overpressure to the shoulder during the stretch.

In addition to lengthening of the pectoralis minor, the authors hypothesized that an acute stretch conducted above 30° of humeral elevation with the shoulder in abduction and scapular retraction would alter scapular kinematics. This hypothesis was based on the theory that because of the anatomical location of the pectoralis minor and its change in length during scapular movement, greater arm elevation angles would aid in the necessary scapular motions.²¹ Arm elevation angles that are 30° or greater would require the scapula to upwardly rotate and further posteriorly tilt to provide additional lengthening of the otherwise shortened muscle.²¹ However, the current results did not support this theory as greater upward rotation and posterior tilting of the scapula following passive stretching of the pectoralis minor muscle was not observed. Wang et al²⁶ provided subjects with a home exercise program that incorporated gross strengthening of the shoulder complex as well as a stretching procedure for the pectoralis minor over a six week period. A corner stretching exercise, similar to the gross stretch used in the current research, was performed with the subjects’ hands above his or her head on adjoining corner walls. The subjects leaned into the wall in order to feel an anterior chest and shoulder stretch and hold for duration of ten seconds and ten repetitions. The researchers’ results revealed significantly less scapular upward rotation and greater internal rotation and inferior translation of the scapula at a horizontal arm position following the exercise program.²⁶ However, McClure et al³⁸ prescribed a six-week home exercise program to subjects diagnosed with subacromial impingement syndrome using a similar self stretch and reported no significant kinematic changes. Although the current results parallel those of McClure et al,³⁸ demonstrating that a gross stretch of the pectoralis minor has no effect on scapular kinematics, it is difficult to generalize the results because of dissimilar subject populations.

The focused stretch maneuver was not shown to increase the length of the pectoralis minor compared to either the control or gross stretch shoulders. As a result, this stretch produced no significant change in scapular kinematics. It is possible that with the humerus in greater elevation angles and with repeated applications

of the stretch, the focused stretch might increase the amount of lengthening undergone by the pectoralis minor, subsequently improving scapular motion. However, future research is needed in this area.

There are several limitations of the current study worth noting. Subjects were not stratified into groups based on having short or long pectoralis minor muscle lengths before testing. There is a potential that changes in pectoralis minor length and subsequent scapular kinematics were not observed because the subjects did not have tightness prior to testing. This limitation reveals a gap in current research where there are no accepted, clinically meaningful standards of short- versus long- pectoralis minor lengths. However, when clinically stretching a muscle that is short, it is expected that that short muscle becomes longer. Similarly, when stretching a muscle that is lengthened, it is expected that it too becomes longer. This clinical ideology is what led us to believe it was appropriate to measure changes in muscle length, regardless of initial length, and utilize the difference values as data for analysis.

As previously mentioned, it is also possible that the single application of the focused and gross stretches was not enough to cause alterations in scapular motion. Based on clinical observations, the authors believe that repeated applications of the stretch procedures over time might produce improvements in scapular upward rotation, external rotation, and posterior tilt, but further research is needed. Additionally, numerous other periscapular muscles may have inhibited changes in scapular kinematics. Such muscles may include weakness and/or tightness of the upper, middle, and lower trapezius, rhomboids, levator scapulae, and serratus anterior. Furthermore, the lack of significant changes in scapular kinematics among the gross stretch and focused stretch shoulders may have been due to applying these stretches to subjects in a supine position. This position may have allowed the surface of the treatment table to act as a physical barrier to scapular motion and may partially explain the lack of change in scapular orientations post stretch. Additionally, the subjects in the current study were asymptomatic at the time of testing. Therefore, it is possible that subjects with different shoulder pathologies associated with pectoralis minor tightness and scapular dyskinesis may present with different results.

There remain few studies investigating the effects of stretching alone on scapular kinematics. Future research should seek to investigate the effects that passive stretching might have on scapular kinematics. Future investigations may benefit from utilizing subjects that have been clinically diagnosed with shortened pectoralis minor muscles. Investigations might also employ repeated applications of passive stretch maneuvers over time in order to observe resultant changes in scapular kinematics.

CONCLUSIONS

The results of this study demonstrated that no immediate changes occurred in scapular upward rotation, external rotation, or posterior tilt after the application of either the gross or focused passive stretch maneuvers of the pectoralis minor on a sample of asymptomatic competitive swimming athletes. However, the gross stretch did produce a significant increase in pectoralis minor length as compared to the control group. Practicing clinicians should continue to use evidence-based decisions when treating pectoralis minor tightness. Future prospective investigations are necessary to determine the relationship between stretching of the pectoralis minor and scapular kinematics.

REFERENCES

1. Pink MM, Tibone JE. The painful shoulder in the swimming athlete. *Orthop Clin North Am.* 2000; 31(2):247-261.
2. Kibler WB. Scapular involvement in impingement: Signs and symptoms. *Instr Course Lect.* 2006; 55:35-43.
3. Kibler WB, McMullen J. Scapular dyskinesis and its relation to shoulder pain. *J Am Acad Orthop Surg.* 2003; 11(2):142-151.
4. McClure PW, Michener LA, Sennett BJ, et al. Direct 3-dimensional measurement of scapular kinematics during dynamic movements in vivo. *J Shoulder Elbow Surg.* 2001; 10(3):269-277.
5. Meyer KE, Saether EE, Soiney EK, et al. Three-dimensional scapular kinematics during the throwing motion. *J Appl Biomech.* 2008; 24(1):24-34.
6. Lukasiewicz AC, McClure P, Michener L, et al. Comparison of 3-dimensional scapular position and orientation between subjects with and without shoulder impingement. *J Orthop Sports Phys Ther.* 1999; 29(10):574-83; discussion 584-6.
7. Su KP, Johnson MP, Gracely EJ, et al. Scapular rotation in swimmers with and without impingement syndrome: Practice effects. *Med Sci Sports Exerc.* 2004; 36(7):1117-1123.

8. Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated muscle activity in people with symptoms of shoulder impingement. *Phys Ther.* 2000; 80(3):276-291.
9. Atalar H. Restricted scapular mobility during arm abduction: Implications for impingement syndrome. *Acta Orthop Belg.* 2009; 75(1):19.
10. Graichen H, Stammberger T, Bonel H, et al. Three-dimensional analysis of shoulder girdle and supraspinatus motion patterns in patients with impingement syndrome. *J Orthop Res.* 2001; 19(6):1192-1198.
11. Mell AG, LaScalza S, Guffey P, et al. Effect of rotator cuff pathology on shoulder rhythm. *J Shoulder Elbow Surg.* 2005; 14(1 Suppl S):58S-64S.
12. Yamaguchi K, Sher JS, Andersen WK, et al. Glenohumeral motion in patients with rotator cuff tears: A comparison of asymptomatic and symptomatic shoulders. *J Shoulder Elbow Surg.* 2000; 9(1):6-11.
13. Laudner KG, Myers JB, Pasquale MR, et al. Scapular dysfunction in throwers with pathologic internal impingement. *J Orthop Sports Phys Ther.* 2006; 36(7):485-494.
14. Ogston JB, Ludewig PM. Differences in 3-dimensional shoulder kinematics between persons with multidirectional instability and asymptomatic controls. *Am J Sports Med.* 2007; 35(8):1361-1370.
15. Illyes A, Kiss RM. Kinematic and muscle activity characteristics of multidirectional shoulder joint instability during elevation. *Knee Surg Sports Traumatol Arthrosc.* 2006; 14(7):673-685.
16. Fayad F, Roby-Brami A, Yazbeck C, et al. Three-dimensional scapular kinematics and scapulohumeral rhythm in patients with glenohumeral osteoarthritis or frozen shoulder. *J Biomech.* 2008; 41(2):326-332.
17. Rundquist PJ. Alterations in scapular kinematics in subjects with idiopathic loss of shoulder range of motion. *J Orthop Sports Phys Ther.* 2007; 37(1):19-25.
18. Vermeulen HM, Stokdijk M, Eilers PH, et al. Measurement of three dimensional shoulder movement patterns with an electromagnetic tracking device in patients with a frozen shoulder. *Ann Rheum Dis.* 2002; 61(2):115-120.
19. McClure P, Greenberg E, Kareha S. Evaluation and management of scapular dysfunction. *Sports Medicine and Arthroscopy Review.* 2012; 20(1):39.
20. Borstad JD, Ludewig PM. The effect of long versus short pectoralis minor resting length on scapular kinematics in healthy individuals. *J Orthop Sports Phys Ther.* 2005; 35(4):227-238.
21. Muraki T, Aoki M, Izumi T, et al. Lengthening of the pectoralis minor muscle during passive shoulder motions and stretching techniques: A cadaveric biomechanical study. *Phys Ther.* 2009; 89(4):333-341.
22. Hebert LJ, Moffet H, McFadyen BJ, et al. Scapular behavior in shoulder impingement syndrome. *Arch Phys Med Rehabil.* 2002; 83(1):60-69.
23. Rupp S, Berninger K, Hopf T. Shoulder problems in high level swimmers--impingement, anterior instability, muscular imbalance? *Int J Sports Med.* 1995; 16(8):557-562.
24. Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. *J Shoulder Elbow Surg.* 2006; 15(3):324-330.
25. Roddey TS, Olson SL, Grant SE. The effect of pectoralis muscle stretching on the resting position of the scapula in persons with varying degrees of forward head/rounded shoulder posture. *Journal of Manual & Manipulative Therapy.* 2002; 10(3):124.
26. Wang CH, McClure P, Pratt NE, et al. Stretching and strengthening exercises: Their effect on three-dimensional scapular kinematics. *Arch Phys Med Rehabil.* 1999; 80(8):923-929.
27. Borstad JD. Measurement of pectoralis minor muscle length: Validation and clinical application. *J Orthop Sports Phys Ther.* 2008; 38(4):169-174.
28. Van der Helm FC. A standardized protocol for the description of shoulder motions. *International Shoulder Group of the International Society of Biomechanics.* 2002.
29. An KN, Browne AO, Korinek S, et al. Three-dimensional kinematics of glenohumeral elevation. *J Orthop Res.* 1991; 9(1):143-149.
30. Barnett ND, Duncan RD, Johnson GR. The measurement of three dimensional scapulohumeral kinematics--a study of reliability. *Clin Biomech (Bristol, Avon).* 1999; 14(4):287-290.
31. Karduna AR, McClure PW, Michener LA, et al. Dynamic measurements of three-dimensional scapular kinematics: A validation study. *J Biomech Eng.* 2001; 123(2):184-190.
32. Bandy WD, Irion JM. The effect of time on static stretch on the flexibility of the hamstring muscles. *Phys Ther.* 1994; 74(9):845-50; discussion 850-2.
33. Taylor DC. Viscoelastic properties of muscle-tendon units the biomechanical effects of stretching. *Am J Sports Med.* 1990; 18(3):300.
34. McClure PW, Bialker J, Neff N, et al. Shoulder function and 3-dimensional kinematics in people with shoulder impingement syndrome before and after a 6-week exercise program. *Phys Ther.* 2004; 84(9):832-848.