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Original Research

Bilateral Comparison of Anterior Shoulder Position in Elite Tennis Players

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Background

In elite tennis players, musculoskeletal adaptations in the dominant upper extremity have been reported for range of motion, strength, and scapular biomechanics. In addition to scapular dysfunction, tightness and inflexibility of the pectoral musculature have been identified as risk factors for the development of overuse shoulder injury in overhead athletes.

Hypothesis

Differences in anterior shoulder position will be identified between the dominant and non-dominant extremity in elite tennis players. The purpose of this study was to examine bilateral differences in anterior shoulder posture measured using a double square in elite tennis players without shoulder injury.

Study Design

Descriptive Laboratory Study

Methods

Three hundred and six uninjured elite tennis players were measured in the supine position using a double square method to measure anterior shoulder position. The distance from the surface of the table to the anterior most position of the shoulder (in millimeters) was measured bilaterally and compared. A dependent t-test was used to test for significant differences in anterior shoulder position between the dominant and non-dominant extremity.

Results

One hundred thirty-three males and 173 females were included in this study with a mean age of 16.58 years. The mean difference between extremities indicates increased anterior shoulder positioning on the dominant shoulder of 7.65 mm in females, and 8.72 in males. Significantly greater ($p<.001$) anterior shoulder position measures were documented on the dominant shoulder as compared to the non-dominant shoulder.

Conclusions

The results of this study showed significantly ($p<.001$) greater anterior shoulder position on the dominant extremity of elite male and female tennis players. The differences of

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7-8mm between extremities has clinical application for interpreting anterior shoulder position test results in this population.

Level of Evidence

3

INTRODUCTION

The unilaterally dominant muscular activation inherent in tennis groundstrokes and in the serve specifically target the internal rotators during the acceleration phase and may lead to asymmetrical scapular postures.[1,2] Prior authors have shown bilateral asymmetries in glenohumeral joint rotational range of motion and shoulder postures, respectively in elite level tennis players.[3,4] Clinical assessment of the shoulder and scapular positioning for unilateral overhead athletes often reveals asymmetry between the dominant and non-dominant sides.[5–12] It has been well established that overhead athletes regularly have increased external rotation and corresponding decreases in internal rotation range of motion of the dominant shoulder compared to their non-dominant shoulder.[9,13] In addition, when both internal rotation and the total arc of rotation between shoulders is asymmetrical, it has been associated with an increased risk of injuries in overhead athletes.[7,14]

Injuries to the shoulder in elite level tennis players can occur from repetitive overuse required for elite skill development and competition. The repetitive demands of the game of tennis inherently produce selective strength development of the internal rotators on the dominant shoulder without concomitant increases in posterior strength development of the rotator cuff and scapular stabilizers.[15–18] Pectoralis minor length and associated tightness have been measured using differing techniques in several studies.[6,19–24] These descriptive studies[15–18] aid clinicians in the design of preventative treatment as well as in the rehabilitation of sports-specific injuries.

Various methods to quantify scapular position asymmetries in athletes have been published,[5–13,19,20,25–29] Kibler has highlighted the association between scapular dyskinesis and overuse injury in tennis players and in overhead athletes in general.[21,27,30–32] Kibler has developed a method for evaluating and classifying scapular pathology using visual observation during movement and static positioning.[21,28] One of the challenges encountered by clinicians is the accurate identification of scapular dysfunction and general scapulo-thoracic positioning in the clinical environment. Kibler developed and reported on the "Lateral Scapular Slide Test" using a tape measure to measure bilateral scapular positioning and established a criterion by which patients and athletes could be classified "at risk" by using a bilateral difference of 1 to 1.5 cm as a baseline criterion measure.[33] Further studies assessing the reliability of these measurement techniques have been conducted and report acceptable reliability metrics for clinical usage.[22,34] The double square method has been used to measure the distance (in millimeters) between the most anterior aspect of the acromion and a supportive surface.[27] This measurement provides a clinically applicable measure of the anterior positioning of the shoulder and can be performed in either supine or standing position.

Shoulder posture has been objectively studied in athletes who participate in several overhead sports in order to help describe and understand posture among these athletes. Kleumper et al.[27] analyzed whether a stretching program would effectively reduce the forward shoulder posture in competitive swimmers. The study utilized the double square method in a standing position in a population of competitive swimmers. The authors' postulated that the repetitive propulsive training inherent in the concentric internal rotation dominant phases of the primary swimming mechanics used in training and competition led to adaptive changes producing an anterior shoulder posture in these elite athletes. A pilot study concluded that the double square method was highly reliable with an intraclass correlation coefficient (ICC) of 0.99 and SEM of 0.1 mm. Following a six-week anterior shoulder stretching program, there was a 9mm decrease bilaterally in forward shoulder posture.

A clinical study by Borstad[23] validated methods of measuring pectoralis minor length using Vernier calipers as well as a tape measure. These two measurement techniques have been shown to have good intratester reliability with ICCs of 0.85 and 0.84, respectively. Lewis et al.[20] utilized a rigid transparent right angle to measure the distance in millimeters between the table and the posterior aspect of the acromion to assess pectoralis minor length in subjects with and without shoulder symptoms. This method demonstrated excellent intra-rater reliability with ICC ranging from 0.92 to 0.97.

Despite the evidence presented on the asymmetries of the resting scapular posture for overhead athletes, little has been reported in regards to normative values for the asymmetric anterior shoulder position, and no prior information reported in tennis players. The purpose of this study was to examine bilateral differences in anterior shoulder posture measured using a double square method in elite tennis players without shoulder injury. It was hypothesized that increased anterior shoulder positioning would be present on the dominant extremity in elite level tennis players due to the unilateral upper extremity demands inherent in the sport. This information will allow clinicians and sport scientists to use this measure to identify abnormal scapular and shoulder positioning from potential normal sport specific adaptations using a readily available device and methodology.

METHODS

Three-hundred and six uninjured elite level tennis players (133 Males, 173 Females) between the ages of 10 and 24 were recruited to participate in this study. The definition of elite for this study is: competitive junior players involved in year-round training and participating in regional and/or national level tournaments as well as NCAA collegiate tennis players. Subjects signed an informed consent prior to measurement and participation in this research. The IRB of

Physiotherapy Associates reviewed and approved this study. All subjects were free from shoulder injury in the year prior to testing and had no prior surgical procedures performed to either shoulder in their medical history. Subjects with significant observable scoliotic curves were excluded from the study due to the unknown association of significant spinal scoliosis on scapular positioning using visual examination by the primary author, a physical therapist with 37 years of clinical experience.

PROCEDURES

Subjects were positioned in a supine position on a plinth with a firm supportive surface. They were positioned with their knees bent 90 degrees and hips flexed 45 degrees. This position was meant to promote relaxation in the supine position. The upper extremities were positioned at the side of the subject with the forearms pronated such that the hands were resting comfortably on the supportive surface. Males were tested with their shirts removed, and females wore either a sports bra or tank top such that the entire anterior surface of the shoulder was exposed.

A double square (Model #420EM, Johnson Level and Tool Manufacturing, Inc, Mequon, Wisconsin) was used to measure the distance from the supportive surface to the anterior most aspect of the skin overlying the humeral head of the shoulder. No overpressure was used and the force of gravity was used to consistently rest the upper arm of the double square against the anterior shoulder. The double square has levels on each end to ensure that the perpendicular distance from the supportive surface to the anterior most aspect of the shoulder is measured bilaterally. The examiner slid one double square up or down to accurately position the square against the anterior most aspect of the shoulder and recorded the distance on the 30 cm ruler to the nearest millimeter. This number was entered on the data collection sheet along with tennis specific demographic data on each subject (including years of competitive tennis play, use of a one-handed or two-handed backhand). One trial was used bilaterally with a random determination of first measured extremity. The dominant shoulder was operationally defined as the shoulder the player served with and used during their forehand groundstroke. Figure 1 shows the experimental set-up with subject positioning and use of the double square for measurement of anterior shoulder position.

DATA ANALYSIS

SPSS (version 23.0) was used to generate descriptive data as well as compare means from the dominant and non-dominant extremity of the elite tennis players measured in this study. A dependent t-test was used to test for differences between the dominant and non-dominant extremity. Significance was set at the $p < 0.05$ level.

RESULTS

Three hundred and six elite junior tennis players (mean age 16.58 years) were measured in this study. Subject demographics are presented in Table 1. Players had 6.99 to 7.82 mean years of competitive tennis experience and nearly

Figure 1. Supine Anterior Shoulder Position Measurement Technique

all (88-99%) used a two-handed backhand groundstroke. For males, the mean anterior most aspect of the dominant shoulder was positioned 125.1 ± 17.87 mm from the table with the non-dominant arm positioned 116.38 ± 17.11mm. For females the mean positioning was 121.95 ± 12.42mm for the dominant arm and 114.30 ± 12.34 for the non-dominant arm. The mean difference in anterior shoulder positioning between extremities was 7.65 mm for females, and 8.72 for males, indicating greater anterior shoulder positioning on the dominant shoulder. Significantly greater ($p < 0.001$) anterior shoulder position measures were documented on the dominant shoulder as compared to the non-dominant shoulder (Table 2).

DISCUSSION

In the modern game of tennis, a great majority of tennis strokes include the serve and forehand.[35] Both of these strokes are characterized by strong concentric muscular contractions during the acceleration phase by the pectoralis major during internal rotation of the shoulder. Musculoskeletal profiling studies of elite tennis players have identified significantly greater internal rotation strength development on the dominant arm likely as a result of this repetitive concentric internal rotation.[15–18]

The results of the present study show significantly greater anterior shoulder position on the dominant arm compared to the non-dominant arm using this simple, clinically applicable technique with a double square. Reeser et al.[36] used a standard carpenter's level placed across the shoulders in the supine position in elite level volleyball players and reported that 63% of the players in their sample had anterior shoulder positioning which they attributed to pectoral tightness/shortening. Additionally, in a previous investigation, players with pectoral tightness identified using this supine carpenter level technique had a significant association with shoulder pain.[36] In the current sample of athletes, 64% of males and females had greater than 5 mm of increased anterior shoulder position with a mean dominant / non-dominant difference of 7-8 mm.

Table 1. Participant demographics [a]

	Female	Male
Age (years)	17.08 ± 3.45	15.83 ± 3.77
Height (in)	66.22 ± 3.86	67.99 ± 5.51
Weight (kg)	60.09 ± 10.53	61.61 ± 16.81
Years of Competitive Tennis Play	7.92 ± 3.89	6.99 ± 4.23
# of Tournaments/Year	14.78 ± 8.14	17.05 ± 6.50
2-handed Backhand (%)	99.4	88.5

[a] Data presented as mean ± SD unless otherwise indicated

Table 2. Anterior shoulder measurement [a]

	Female				Male			
	Dominant	Non-Dominant	t	p-value	Dominant	Non-Dominant	t	p-value
Anterior Shoulder Position	121.95 ± 12.42	114.30 ± 12.34	15.47[b]	.001	125.1 ± 17.87	116.38 ± 17.11	13.94[b]	.001

[a]Data presented as mean ± SD (mm) unless otherwise indicated
[b]Indicates significant association, $p \leq 0.05$

Kluemper et al.[27] did not report bilateral difference data in their study using the double square method in elite level swimmers, but used this technique to show improvements (decreases) in anterior shoulder position with the use of two stretches and multiple elastic resistance exercises for the posterior rotator cuff and scapular musculature. Peterson et al.[37] tested the reliability of the double square technique alongside three other measurement techniques to quantify shoulder and scapular positioning. Similar to Kluemper et al.,[27] Peterson et al.[37] found this technique had high levels of intratester reliability (ICC=0.89).

The use of the double square technique in this investigation to measure anterior shoulder position has significant clinical application. Due to the role scapular dysfunction plays in the overhead athlete, this test can accompany other scapular evaluation techniques to objectively identify the anterior shoulder position caused by tightness of the pectoralis musculature or other factors.[5] The descriptive data presented in this study may help to identify thresholds for intervention whereby anterior shoulder position differences between dominant and non-dominant side may be greater than the apparent musculoskeletal side to side adaptations reported in this descriptive investigation. The results of this study indicate that increases in dominant arm anterior shoulder positioning by more than 7-8 mm compared to the contralateral side in elite tennis players could indicate a need for the utilization of interventions to address pectoralis muscle tightness/shortening specifically. This test can provide objective measurements whereby prescription of specific stretches to address pectoral muscle tightness may be considered and changes in side-to-side anterior shoulder positioning could be monitored.

To address pectoralis tightness in the shoulder with an increase in anterior shoulder position several studies provide objective guidance.[38–40] Borstad et al.[38] compared the efficacy of a unilateral self-stretch, a manual sitting stretch and a manual supine stretch of pectoralis minor. They found that the most effective stretch of the three to be the self-stretch. The unilateral self-stretch was described as stabilizing the subject's forearm in a vertical plane and then rotating the trunk in an opposite position. However, when performed as part of a six-week home stretching program, there was no increase in pectoralis minor length in both healthy and symptomatic subjects.[1] Conversely, pectoralis minor stretching done in conjunction with a shoulder strengthening routine have led to improvements in posterior scapular tilting and forward shoulder position.[21,41]

Care must be taken when selecting stretches for the pectoralis musculature to protect the anterior capsule in the overhead athlete.[28] The supine foam roll stretch used by Kluemper et al.[27] places the shoulders in a neutral rotated position with low levels of abduction while a partner or clinician presses the shoulder girdle posteriorly. This technique does not compromise the anterior capsule through the excessive use of horizontal abduction and external rotation positions inherent in other pectoralis muscle stretches.[38] Research studies demonstrating the efficacy of pectoralis stretches as well as anatomic and biomechanical analysis of the glenohumeral joint position used during stretching of the pectoralis musculature ultimately should guide the clinician in the optimal selection to address anterior shoulder tightness in the overhead athlete.

Limitations in the present study include the use of only uninjured elite level tennis players in the current sample. This does not allow the present study to identify a critical dominant / nondominant side to side difference where symptoms or pathology may be present. Additional studies including population specific injured athletes could provide insight into identifying this critical level. The physical therapist performing all measurements was not blinded to arm dominance of the subjects being tested in this study. Further study comparing pre-post stretching regimens in players with symptoms and excessive anterior shoulder position profiles should be conducted to provide additional insight into the optimal evaluation and subsequent management of anterior shoulder position.

CONCLUSION

The results of this study showed significantly ($p < 0.001$) greater anterior shoulder position on the dominant extremity of elite male and female tennis players. The use of elite level uninjured tennis players and the identification of mean differences of 7-8mm between extremities has clinical application for the interpretation of anterior shoulder position test results in this population. The characteristic anterior shoulder muscle activation required in high level tennis play may produce anatomic musculoskeletal adaptations such as an increase in anterior shoulder position which can be measured and monitored using the double square technique in a supine position.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

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REFERENCES

1. Rosa DP, Borstad JD, Pogetti LS, Camargo PR. Effects of a stretching protocol for the pectoralis minor on muscle length, function, and scapular kinematics in individuals with and without shoulder pain. *J Hand Ther*. 2017;30(1):20-29. doi:10.1016/j.jht.2016.06.006

2. Elliott BC, Marshall RN, Noffal GJ. Contributions of upper limb segment rotations during the power serve in tennis. *J Appl Biomech*. 1995;11(4):433-442. doi:10.1123/jab.11.4.433

3. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Med Sci Sports Exerc*. 2002;34(12):2052-2056. doi:10.1097/00005768-200212000-00028

4. Priest JD, Nagel DA. Tennis shoulder. *Am J Sports Med*. 1976;4(1):28-42.

5. Cools AM, Palmans T, Johansson FR. Age-related, sport-specific adaptions of the shoulder girdle in elite adolescent tennis players. *J Athl Train*. 2014;49(5):647-653. doi:10.4085/1062-6050-49.3.02

6. Hodgins JL, Rubenstein W, Kovacevic D, Padaki A, Jobin CM, Ahmad CS. Pectoralis Minor Contracture in Throwing Shoulders of Asymptomatic Adolescent Baseball Players. *Orthop J Sport Med*. 2017;5(9):1-10. doi:10.1177/2325967117728041

7. Laudner KG, Moline MT, Meister K. The relationship between forward scapular posture and posterior shoulder tightness among baseball players. *Am J Sports Med*. 2010;38(10):2106-2112. doi:10.1177/0363546510370291

8. Oyama S, Myers JB, Wassinger CA, Daniel Ricci R, Lephart SM. Asymmetric Resting Scapular Posture in Healthy Overhead Athletes. *J Athl Train*. 2008;43(6):565-570. doi:10.4085/1062-6050-43.6.565

9. Shadmehr A, Bagheri H, Ansari NN, Sarafraz H. The reliability measurements of lateral scapular slide test at three different degrees of shoulder joint abduction. *Br J Sports Med*. 2010;44(4):289-293. doi:10.1136/bjsm.2008.050872

10. Turgut E, Colakoglu FF, Baltaci G. Scapular motion adaptations in junior overhead athletes: a three-dimensional kinematic analysis in tennis players and non-overhead athletes. *Sport Biomech*. 2018;3141:1-9.

11. Ribeiro A, Pascoal AG. Resting scapular posture in healthy overhead throwing athletes. *Man Ther*. 2013;18(6):547-550. doi:10.1016/j.math.2013.05.010

12. Shimpi AP, Bhakti S, Roshni K, et al. Scapular Resting Position and Gleno-Humeral Movement Dysfunction in Asymptomatic Racquet Players: A Case-Control Study. *Asian J Sports Med*. 2015;6(4).

13. Moreno-Pérez V, Moreside J, Barbado D, Vera-Garcia FJ. Comparison of shoulder rotation range of motion in professional tennis players with and without history of shoulder pain. *Man Ther*. 2015;20(2):313-318. doi:10.1016/j.math.2014.10.008

14. Ellenbecker TS, Roetert EP. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J Sci Med Sport*. 2003;6(1):63-70. doi:10.1016/s1440-2440(03)80009-9

15. Chandler TJ, Kibler WB, Uhl TL, Wooten B, Kiser A, Stone E. Flexibility comparisons of junior elite tennis players to other athletes. *Am J Sports Med*. 1990;18(2):134-136. doi:10.1177/036354659001800204

16. Ellenbecker TS. A total arm strength isokinetic profile of highly skilled tennis players. *Isokinet Exerc Sci*. 1991;1(1):9-21. doi:10.3233/ies-1991-1103

17. Ellenbecker TS. Shoulder internal and external rotation strength and range of motion in highly skilled tennis players. *Isokinet Exerc Sci*. 1992;2:1-8.

18. Ellenbecker TS, Roetert EP. Age specific isokinetic glenohumeral internal and external rotation strength in elite junior tennis players. *J Sci Med Sport*. 2003;6(1):63-70. doi:10.1016/s1440-2440(03)80009-9

19. Hibberd EE, Laudner KG, Kucera KL, Berkoff DJ, Yu B, Myers JB. Effect of Swim Training on the Physical Characteristics of Competitive Adolescent Swimmers. *Am J Sports Med*. 2016;44(11):2813-2819. doi:10.1177/0363546516669506

20. Lewis JS, Valentine RE. The pectoralis minor length test: A study of the intra-rater reliability and diagnostic accuracy in subjects with and without shoulder symptoms. *BMC Musculoskelet Disord*. 2007;8:1-10.

21. Kibler WB, Chandler TJ, Livingston BP, Roetert EP. Shoulder range of motion in elite tennis players. *Am J Sports Med*. 1996;24(3):279-285. doi:10.1177/036354659602400306

22. Finley M, Goodstadt N, Soler D, Somerville K, Friedman Z, Ebaugh D. Reliability and validity of active and passive pectoralis minor muscle length measures. *Brazilian J Phys Ther*. 2017;21(3):212-218. doi:10.1016/j.bjpt.2017.04.004

23. Borstad JD. Measurement of pectoralis minor muscle length: Validation and clinical application. *J Orthop Sports Phys Ther*. 2008;38(4):169-174. doi:10.2519/jospt.2008.2723

24. Umehara J, Nakamura M, Nishishita S, Tanaka H, Kusano K, Ichihashi N. Scapular kinematic alterations during arm elevation with decrease in pectoralis minor stiffness after stretching in healthy individuals. *J Shoulder Elb Surg*. 2018;27(7):1214-1220. doi:10.1016/j.jse.2018.02.037

25. Cools AM, Johansson FR, Cambier DC, Velde AV, Palmans T, Witvrouw EE. Descriptive profile of scapulothoracic position, strength and flexibility variables in adolescent elite tennis players. *Br J Sports Med*. 2010;44(9):678-684. doi:10.1136/bjsm.2009.070128

26. Gibson MH, Goebel GV, Jordan TM, Kegerreis S, Worrell TW. A reliability study of measurement techniques to determine static scapular position. *J Orthop Sports Phys Ther*. 1995;21(2):100-106. doi:10.2519/jospt.1995.21.2.100

27. Kluemper M, Uhl T, Hazelrigg H. Effect of stretching and strengthening shoulder muscles on forward shoulder posture in competitive swimmers. *J Sport Rehabil*. 2006;15(1):58-70. doi:10.1123/jsr.15.1.58

28. Lai CC, Chen SY, Yang JL, Lin JJ. Effectiveness of stretching exercise versus kinesiotaping in improving length of the pectoralis minor: A systematic review and network meta-analysis. *Phys Ther Sport*. 2019;40(19):19-26. doi:10.1016/j.ptsp.2019.08.003

29. Lin JJ, Lim HK, Yang JL. Effect of shoulder tightness on glenohumeral translation, scapular kinematics, and scapulohumeral rhythm in subjects with stiff shoulders. *J Orthop Res*. 2006;24(5):1044-1051. doi:10.1002/jor.20126

30. Struyf F, Nijs J, Mottram S, Roussel NA, Cools AMJ, Meeusen R. Clinical assessment of the scapula: A review of the literature. *Br J Sports Med*. 2014;48(11):883-890. doi:10.1136/bjsports-2012-091059

31. Kibler WB. Role of the scapula in the overhead throwing motion. *Contemp Orthop*. 1991;22:525.

32. Kibler WB. The role of the scapula in athletic shoulder function. *Am J Sports Med*. 1998;26(2):325-337. doi:10.1177/03635465980260022801

33. Kibler WB, Uhl TL, Maddux JWQ, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study. *J Shoulder Elbow Surg*. 2002;11(6):550-556. doi:10.1067/mse.2002.126766

34. da Costa BR, Armijo-Olivo S, Gadotti I, Warren S, Reid DC, Magee DJ. Reliability of scapular positioning measurement procedure using the Palpation Meter (PALM). *Physiotherapy*. 2010;96(1):59-67. doi:10.1016/j.physio.2009.06.007

35. Johnson CD, McHugh MP. Performance demands of professional male tennis players. *Br J Sports Med*. 2006;40(8):696-699. doi:10.1136/bjsm.2005.021253

36. Reeser JC, Joy EA, Porucznik CA, Berg RL, Colliver EB, Willick SE. Risk factors for volleyball-related shoulder pain and dysfunction. *PM & R*. 2010;2(1):27-36. doi:10.1016/j.pmrj.2009.11.010

37. Peterson DE, Blankenship KR, Robb JB, Walker MJ, et al. Investigation of the validity and reliability of four objective techniques for measuring forward shoulder posture. *J Orthp Sports Phys Ther*. 1997;25(1):34-42.

38. Borstad JD, Ludewig PM. Comparison of three stretches for the pectoralis minor muscle. *J Shoulder Elb Surg*. 2006;15(3):324-330. doi:10.1016/j.jse.2005.08.011

39. Williams JG, Laudner KG, McLoda T. The acute effects of two passive stretch maneuvers on pectoralis minor length and scapular kinematics among collegiate swimmers. *Int J Sports Phys Ther*. 2013;8(1):25-33.

40. Muraki T, Aoki M, Izumi T, Fujii M, Hidaka E, Miyamoto S. Lengthening of the Pectoralis Minor Muscle During Passive Shoulder Motions and Stretching Techniques: A Cadaveric Biomechanical Study. *Phys Ther*. 2009;89(4):333-341. doi:10.2522/ptj.20080248

41. Camargo PR, Alburquerque-Sendín F, Avila MA, Haik MN, Vieira A, Salvini TF. Effects of stretching and strengthening exercises, with and without manual therapy, on scapular kinematics, function, and pain in individuals with shoulder impingement: A randomized controlled trial. *J Orthop Sports Phys Ther*. 2015;45(12):984-997. doi:10.2519/jospt.2015.5939