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original research

Shoulder-Rotator Strength, Range of Motion, and Acromiohumeral Distance in Asymptomatic Adolescent Volleyball Attackers

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Context: Sport-specific adaptations at the glenohumeral joint could occur in adolescent athletes because they start participating in high-performance sports in early childhood.

Objective: To investigate shoulder-rotator strength, internal-rotation (IR) and external-rotation (ER) range of motion (ROM), and acromiohumeral distance (AHD) in asymptomatic adolescent volleyball attackers to determine if they have risk factors for injury.

Design: Cross-sectional study.

Setting: University laboratory.

Participants: Thirty-nine adolescent high school-aged volleyball attackers (22 boys, 17 girls; age = 16.0 ± 1.4 years, height = 179.2 ± 9.0 cm, mass = 67.1 ± 10.9 kg, body mass index = 20.7 ± 2.6 kg/m^2).

Main Outcome Measure(s): Shoulder IR and ER ROM, total-rotation ROM, glenohumeral IR deficit, AHD, and concentric and eccentric strength of the shoulder internal and external rotators were tested bilaterally.

Results: External-rotation ROM was greater ($t_{38} = 4.92$, $P < .001$), but IR ROM ($t_{38} = -8.61$, $P < .001$) and total ROM ($t_{38} = -3.55$, $P = .01$) were less in the dominant shoulder, and 15 athletes had a glenohumeral IR deficit (IR ROM loss > 18°). We observed greater concentric internal-rotator ($t_{38} = 2.89$, $P = .006$) and eccentric external-rotator ($t_{38} = 2.65$, $P = .01$) strength in the dominant than in the nondominant shoulder. The AHD was less in the dominant shoulder ($t_{38} = -3.60$, $P < .001$).

Conclusions: Adolescent volleyball attackers demonstrated decreased IR ROM, total ROM, and AHD and increased ER ROM in their dominant shoulder. Therefore, routine screening of adolescent athletes and designing training programs for hazardous adaptive changes could be important in preventing shoulder injuries.

Key Words: ultrasonography, sports, glenohumeral joint, muscle strength

Key Points

- Asymptomatic adolescent volleyball attackers demonstrated less internal-rotation range of motion (ROM), total ROM, and acromiohumeral distance and more external-rotation ROM in the dominant than in the nondominant shoulder, which might put them at risk for shoulder injuries.
- Routinely screening adolescent athletes and designing training programs to address hazardous adaptive changes could help prevent shoulder injuries.

Shoulder problems are estimated to account for 8% to 20% of all volleyball-related injuries.[1] These problems occur during repetitive high-demand throwing activities, such as spikes and serves.[2,3] During spikes, hand speed can reach up to 120 km/h, and dynamic shoulder stabilization has a critical role in maintaining glenohumeral joint integrity.[4] Researchers have demonstrated that repetitive overhead activities might alter shoulder-rotation motion, rotator strength, and acromiohumeral distance (AHD), which may cause shoulder pain and dysfunction.[5–8]

Side-to-side differences in shoulder range of motion (ROM) have been documented in overhead athletes.[9–11] These differences are characterized by increased external-rotation (ER) and decreased internal-rotation (IR) and total-rotation ROM in the dominant shoulder.[9,11] Reduced shoulder IR is defined as a *glenohumeral IR deficit* (GIRD).[12] Individuals with more than 18° of IR ROM loss and 5° difference in total-rotation ROM between the dominant and nondominant shoulders are at risk for shoulder injury.[12,13] Posterior shoulder stiffness is thought to be related to GIRD.[14] Borsa et al[14] hypothesized that the repetitive loads on the posterior shoulder during the deceleration phase of overhead activity cause microtrauma and scarring of the posterior soft tissue. This selective posterior shoulder stiffness causes an abnormal humeral head transition, which alters glenohumeral motion and may decrease the AHD.[8] The AHD varies from 10 to 15 mm in asymptomatic individuals[15–17] and, when less than 7 mm, may reflect the risk for subacromial impingement syndrome.[18]

Weakness or imbalance in rotator cuff muscle strength causes excessive stress on the passive stabilizers of the shoulder joint and may lead to changes in shoulder motion.[6] The strength balance between the external- and internal-rotator muscles (ER : IR ratio) typically ranges from 66% to 75% in asymptomatic individuals.[5,19,20] However, abnormal ER : IR strength ratios can be observed in overhead athletes, as external-rotator strength tends to decrease and IR strength tends to increase in the dominant shoulder with repetitive overhead activities.[21]

Given the incomplete development of their musculoskeletal systems, adolescents may be more susceptible to sports injuries than adult athletes. Cools et al[5] reported that sport-specific adaptations at the glenohumeral joint could occur during adolescence because athletes begin participating in high-performance sports in early childhood. Strength and ROM adaptations in the shoulders of adolescent tennis, baseball, and softball players have been documented.[5,10,22] However, limited information is available about whether adolescent volleyball players have sport-specific adaptations in their dominant shoulders, as have been demonstrated in adult volleyball players.[7,23] Therefore, the purpose of our study was to investigate shoulder-rotator muscle strength, glenohumeral IR and ER motion, and AHD in asymptomatic adolescent volleyball attackers to document whether they had strength and ROM adaptations in their dominant shoulder that were related to their sport. We hypothesized that ER ROM would be greater and IR ROM, AHD, and ER : IR would be less in the dominant than in the nondominant shoulder.

METHODS

Participants

Thirty-nine adolescent asymptomatic volleyball attackers (22 boys, 17 girls; age = 16.0 ± 1.4 years, height = 179.2 ± 9.0 cm, mass = 67.1 ± 10.9 kg, body mass index = 20.7 ± 2.6 kg/m^2, time participating in overhead sports activity = 5.6 ± 1.5 h/wk, experience in sport = 4.6 ± 2.3 years) were recruited from 3 volleyball teams. Athletes with a positive Hawkins, Neer, Jobe, or apprehension test or a shoulder or upper extremity injury in the 12 months before the study were excluded. We examined demographic characteristics (age, dominant shoulder, experience in sport, training hours, and hand dominance) using a questionnaire and assessed body composition (TBF-300 GS Pro Body Composition Analyzer; Tanita Corporation, Tokyo, Japan). The *dominant shoulder* was defined as the hand used for serving or spiking.[24] All participants and their parents or guardians provided written informed assent or consent, respectively, and the study was approved by the Hacettepe University Clinical Research Ethics Board.

Data Collection

We assessed the concentric and eccentric strength of the external and internal rotators of the dominant and nondominant shoulders using an isokinetic dynamometer (IsoMed 2000; DR Performance GmbH, Düsseldorf, Germany) while each participant sat with the upper extremity abducted to 90° and the elbow flexed to 90°. For the measurements, ROM was set to 90° (beginning to end ROM = 90° to 0°) of ER. Stabilization straps were placed across the participant's shoulder and hips to minimize compensatory movements of the body during the tests. We selected 90°/s for measurement velocity because this angular velocity has been shown to be more sensitive in evaluating ER : IR ratio.[25]

The test was started at 90° of ER, and IR was the first movement assessed. Participants performed 3 submaximal familiarization trials. Next, they performed 10 maximal concentric internal- and external-rotator strength tests followed by 10 maximal eccentric internal- and external-rotator strength tests. They rested for 2 minutes between concentric and eccentric measurements. We gave standardized, consistent oral encouragements: "push as hard as possible" and "as fast as possible." After a 5-minute break, the testing was repeated on the other shoulder using the same protocol. The shoulders were randomized for testing to minimize the effect of fatigue on muscle strength. The peak torques generated from the isokinetic dynamometer were normalized to each participant's mass, and the ER : IR ratio in both the dominant and nondominant extremities was calculated for analysis. We calculated the ER : IR ratio 2 ways: concentric ER : IR ratio and eccentric external rotator to concentric internal rotator ratio (functional ER : IR ratio).

We measured passive IR and ER ROM using a digital inclinometer (model ACU360; Lafayette Instrument Co, Lafayette, IN). Participants were positioned supine with their knees flexed, shoulder in 90° of abduction, elbow in 90° of flexion, and forearm in neutral.[13] For all measurements, the inclinometer was mounted on a bar that was aligned from the olecranon to the ulnar styloid process. The inclinometer was aligned with the ventral midline of the humerus. The final ROMs for IR and ER were determined when a firm capsular end-feel was felt or scapular motion was detected. The same physical therapist (H.G.) measured each ROM 3 times, and we calculated the average of the measurements. All ROM measurements were performed before isokinetic strength testing.

Total-rotation ROM was calculated by summing the IR and ER ROMs of each limb. We calculated the GIRD measurements from the difference in IR ROM between the dominant and nondominant shoulders. Pathologic GIRD was identified in athletes presenting an IR deficit greater than 18° and total-rotation motion difference of more than 5° between the shoulders.[13]

A radiologist with 10 years of experience (U.T.) performed the ultrasonographic (US) measurement for AHD using a US scanner with a 7 to 12 MHz linear transducer (model Aplio 500; Toshiba Corporation, Otawara, Japan). We defined the *AHD* as the distance between the head of the humerus and the inferior edge of the acromion. Participants were seated upright, and the upper limb was positioned on a pillow placed on their lap, the shoulder in 60° of abduction; the elbow in 90° of flexion by using a goniometer, and the hand in neutral with the thumb pointing upward. We measured AHD at 60° of shoulder abduction, as acoustic shadows might occur in higher ranges of shoulder abduction,[26,27] and US measurement of AHD at 60° of shoulder abduction has shown excellent reliability in asymptomatic individuals[27] and patients with subacromial impingement syndrome.[28]

The transducer was placed on the lateral surface of the acromion in the coronal plane and was parallel with the long axis of the humerus, where the shortest distance between the humerus and acromion was observed. During

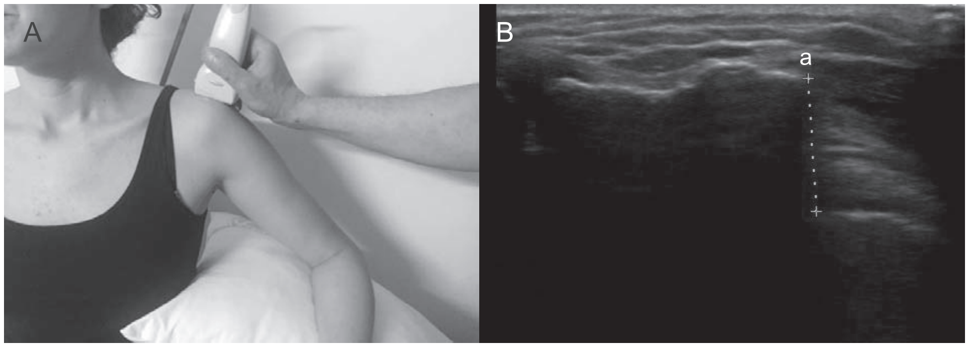

Figure. **A, Participant position and probe placement during ultrasound imaging of acromiohumeral distance (AHD). B, Measurement of the AHD on ultrasound image. ᵃ Line indicates the AHD.**

the US measurements, we instructed participants to rest their upper extremity on the pillow and visually inspected to ensure that they elevated or abducted their shoulder (Figure). The measurements were repeated 3 times, and the mean value was calculated. Researchers[26,27,29,30] have shown good interrater and intrarater reliability in the US measurement of AHD in healthy individuals.

Data Analysis

The Kolmogorov-Smirnov test was used to determine the normal distribution of the data. We used *t* tests to compare shoulder strength, ROM, and AHD between the dominant and nondominant shoulders. The α level was set at .05. All analyses were conducted in SPSS (version 15.0; SPSS Inc, Chicago, IL) for statistical analysis.

RESULTS

The ER and IR ROMs were different between the dominant and nondominant shoulders. We observed that ER ROM was greater ($t_{38} = 4.92$, $P < .001$) but IR ROM was less ($t_{38} = -8.61$, $P < .001$) in the dominant shoulder, and 15 athletes had GIRD. Total ROM was less for the dominant than the nondominant shoulder ($t_{38} = -3.55$, $P = .01$; Table 1).

The AHD was smaller on the dominant side than the nondominant side ($t_{38} = -3.60$, $P < .001$; Table 1).

Concentric internal-rotator ($t_{38} = 2.89$, $P = .006$) and eccentric external-rotator strength ($t_{38} = 2.65$, $P = .01$) was greater for the dominant than the nondominant shoulder. We noted no difference between shoulders in concentric ($t_{38} = -1.52$, $P = .14$) or functional ER : IR ratios ($t_{38} = -0.24$, $P = .81$; Table 2).

DISCUSSION

The main outcomes indicated that adolescent volleyball attackers had altered shoulder-rotation motion and shoulder-rotator strength and decreased AHD in the dominant shoulder compared with the nondominant shoulder. We could not completely support our hypothesis that IR ROM and AHD would decrease and ER ROM would increase in the dominant shoulder, but the ER : IR ratio was not different between shoulders.

Glenohumeral-Rotation Motion

Researchers[5,9–11,13,14] have reported that GIRD occurs in overhead athletes and is the most common adaptation seen in the glenohumeral joint, with excessive ER ROM and decreased total ROM. Several reasons explain how these motion adaptations occur in overhead athletes.[11,14,31] Repetitive and cumulative loads during the deceleration phase of overhead activity cause microtrauma and posterior capsule scarring.[14] The stiff posterior capsule decreases glenohumeral IR and horizontal-adduction mobility, which have been shown to be related to shoulder injuries.[12,32] Clarsen et al[9] reported that decreased total ROM was related to increased shoulder pain in handball players.

Our participants exhibited less IR ROM, more ER ROM, and less total ROM for the dominant than the nondominant shoulder, which is consistent with the literature. The ROM difference between shoulders was more obvious in IR ROM (dominant shoulder = 46.3°, nondominant shoulder = 60.4°). The mean difference between shoulders was 14.1°, but 15 participants had GIRD (IR ROM difference > 18°). We observed that the ER and total ROM differences between shoulders were quite small but were significant. Therefore, one could interpret that, whereas their average sport experience was about 5 years, adolescent volleyball players demonstrated motion adaptations.

Shoulder-Rotator Strength

Researchers[7,21,33] have documented that collegiate and adult overhead athletes may have adaptive strength changes, such as decreased eccentric external-rotator

Table 1. Internal- and External-Rotation Range of Motion and Acromiohumeral Distance of the Dominant and Nondominant Shoulders

Variable	Shoulder, Mean ± SD		95% Confidence Interval
	Dominant	Nondominant	
Internal rotation, °	46.30 ± 10.98	60.40 ± 8.88	−17.40, −10.75
External rotation, °	110.92 ± 7.99	104.59 ± 6.11	3.73, 8.94
Total rotation, °	157.21 ± 13.27	164.93 ± 11.27	−12.13, −3.32
Acromiohumeral distance, mm	10.26 ± 0.98	10.97 ± 0.77	−1.11, −0.31

Table 2. External- and Internal-Rotator Strength and Strength Ratios of the Dominant and Nondominant Shoulders

Variable	Shoulder, Mean ± SD (Nm/kg)		95% Confidence Interval	Limb Symmetry Index, %
	Dominant	Nondominant		
Strength				
Internal rotator				
Concentric	0.80 ± 0.19	0.74 ± 0.19	0.02, 0.10	93.41 ± 15.24
Eccentric	1.05 ± 0.29	1.03 ± 0.31	−0.01, 0.06	103.07 ± 12.34
External rotator				
Concentric	0.36 ± 0.22	0.36 ± 0.18	−0.02, 0.03	94.14 ± 21.01
Eccentric	0.52 ± 0.26	0.47 ± 0.24	0.01, 0.08	112.39 ± 29.58
External rotator : internal rotator ratio				
Concentric	0.44 ± 0.18	0.48 ± 0.20	−0.09, 0.01	Not applicable
Functional[a]	0.63 ± 0.22	0.64 ± 0.27	−0.06, 0.05	Not applicable

[a] *Functional* indicates eccentric external-rotator to concentric internal-rotator strength ratio.

strength and increased concentric internal-rotator strength in the dominant shoulder due to the repetitive overhead activities. This adaptation leads to a lower ER : IR ratio in the dominant shoulder and is an accepted risk factor for shoulder injuries.[4,7] We found greater concentric internal-rotator strength but also greater eccentric external-rotator strength in the dominant shoulder. Therefore, the ER : IR ratio was similar between the dominant and nondominant shoulders. Cools et al[5] reported that the ER : IR ratio decreased with increasing athlete age. Therefore, adaptive changes in external-rotator strength might not be seen in the dominant shoulders of adolescent volleyball players. However, Stickley et al[4] suggested that rotator cuff strengthening is crucial in adolescent overhead athletes, who might demonstrate an imbalance between the internal- and external-rotator muscles due to incomplete musculoskeletal development.

Investigators[4,25,33,34] have demonstrated a wide range of ER : IR ratios, depending on the testing position and velocity, study population, and muscle-contraction type. They proposed that eccentric external-rotator strength should be similar to concentric internal-rotator strength to control the dynamic stability of the glenohumeral joint during the deceleration phase of throwing. Yet the ER : IR ratios in our study were less than 1.0 in both shoulders. The concentric ER : IR ratios were 0.44 and 0.48 and functional ER : IR ratios were 0.63 and 0.64 in the dominant and nondominant shoulders, respectively. The large ROM (90° of ER and 90° of IR) with isokinetic testing might lead to less muscle strength, as it might be difficult to exert maximal effort during this range. However, smaller ER : IR ratios should be considered a risk factor for shoulder injuries in adolescent overhead athletes, and external-rotator strengthening and strength balance between rotator muscles should be emphasized in training programs.

Acromiohumeral Distance

The GIRD and ER : IR ratio have been associated with a narrowing AHD in overhead athletes.[17,30,35] Muraki et al[35] reported that tightening the posterior shoulder capsule of cadaveric shoulders increased subacromial contact pressure during shoulder flexion and the follow-through phase of throwing. In addition, Leong et al[30] measured AHD in 0° of shoulder abduction and found positive correlations among external-rotator strength, ER : IR ratio, and AHD in volleyball players. They concluded that rotator cuff muscles were important to limit the superior migration of the humeral head during activities and that weakness of the rotator cuff muscles could decrease the AHD and lead to subacromial impingement syndrome.[30]

The literature is conflicting regarding differences in AHD that may exist between the dominant and nondominant shoulders in asymptomatic overhead athletes. Researchers[36,37] have reported that AHD was similar at 90° of shoulder abduction in baseball players. In contrast, Leong et al[30] showed that AHD was greater in the dominant than the nondominant shoulder of volleyball players. Measuring posture, scapular muscle activities, shoulder-abduction and adduction forces, and shoulder-abduction angle during US measurement might lead to different findings among studies. We located only 1 study in which the relationship between GIRD and AHD was investigated. Maenhout et al[17] demonstrated that overhead athletes with a GIRD greater than 15° had smaller AHDs at 0°, 45°, and 60° of abduction in their dominant shoulder, which was consistent with our results. Therefore, in our study, smaller AHD in the dominant shoulder might have been due to GIRD.

Our study had limitations. First, the results were limited to adolescent volleyball attackers. We chose only attackers because we thought adaptive changes would be more obvious in this group than in other playing positions. Second, we measured muscle strength at only 90°/s angular velocity, as Yildiz et al[25] suggested that slower angular speeds were more sensitive for evaluating the functional ER : IR ratio. However, this speed might not be functional because the spike and serve motions are performed at higher velocities. Third, the AHD difference between shoulders was quite small and was not clinically meaningful.[38] Yet the average AHD was close to the lower end of the normal AHD range.[18]

CONCLUSIONS

Asymptomatic adolescent volleyball attackers demonstrated decreased IR ROM, increased ER ROM, and decreased AHD in the dominant shoulder compared with the nondominant shoulder, which might put them at risk for shoulder injuries. Therefore, routinely screening adolescent athletes and designing training programs to address hazardous adaptive changes could be important for preventing potential shoulder injuries.

REFERENCES

1. Briner WW Jr, Kacmar L. Common injuries in volleyball: mechanisms of injury, prevention and rehabilitation. *Sports Med*. 1997;24(1):65–71.
2. Coleman SG, Benham AS, Northcott SR. A three-dimensional cinematographical analysis of the volleyball spike. *J Sports Sci*. 1993;11(4):295–302.
3. Aagaard H, Jrgensen U. Injuries in elite volleyball. *Scand J Med Sci Sports*. 1996;6(4):228–232.
4. Stickley CD, Hetzler RK, Freemyer BG, Kimura IF. Isokinetic peak torque ratios and shoulder injury history in adolescent female volleyball athletes. *J Athl Train*. 2008;43(6):571–577.
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.
6. Kugler A, Krüger-Franke M, Reininger S, Trouillier HH, Rosemeyer B. Muscular imbalance and shoulder pain in volleyball attackers. *Br J Sports Med*. 1996;30(3):256–259.
7. Wang HK, Cochrane T. Mobility impairment, muscle imbalance, muscle weakness, scapular asymmetry and shoulder injury in elite volleyball athletes. *J Sports Med Phys Fitness*. 2001;41(3):403–410.
8. Huffman GR, Tibone JE, McGarry MH, Phipps BM, Lee YS, Lee TQ. Path of glenohumeral articulation throughout the rotational range of motion in a thrower's shoulder model. *Am J Sports Med*. 2006;34(10):1662–1669.
9. Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med*. 2014; 48(17):1327–1333.
10. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS, Garrison JC, Thigpen CA. Shoulder range of motion measures as risk factors for shoulder and elbow injuries in high school softball and baseball players. *Am J Sports Med*. 2011;39(9):1997–2006.
11. Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *Am J Sports Med*. 2011; 39(2):329–335.
12. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology part I. Pathoanatomy and biomechanics. *Arthroscopy*. 2003;19(4):404–420.
13. Manske R, Wilk KE, Davies G, Ellenbecker T, Reinold M. Glenohumeral motion deficits: friend or foe? *Int J Sports Phys Ther*. 2013;8(5):537–553.
14. Borsa PA, Laudner KG, Sauers EL. Mobility and stability adaptations in the shoulder of the overhead athlete: a theoretical and evidence-based perspective. *Sports Med*. 2008;38(1):17–36.
15. Azzoni R, Cabitza P. Sonographic versus radiographic measurement of the subacromial space width. *Chir Organi Mov*. 2004;89(2):143–150.
16. Maenhout A, van Cingel R, De Mey K, Van Herzeele M, Dhooge F, Cools A. Sonographic evaluation of the acromiohumeral distance in elite and recreational female overhead athletes. *Clin J Sport Med*. 2013;23(3):178–183.
17. Maenhout A, Van Eessel V, Van Dyck L, Vanraes A, Cools A. Quantifying acromiohumeral distance in overhead athletes with glenohumeral internal rotation loss and the influence of a stretching program. *Am J Sports Med*. 2012;40(9):2105–2112.
18. Mayerhoefer ME, Breitenseher MJ, Wurnig C, Roposch A. Shoulder impingement: relationship of clinical symptoms and imaging criteria. *Clin J Sport Med*. 2009;19(2):83–89.
19. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE Jr, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *Am J Sports Med*. 2010;38(7):1375–1382.
20. Ellenbecker T, 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.
21. Chandler TJ, Kibler WB, Stracener EC, Ziegler AK, Pace B. Shoulder strength, power, and endurance in college tennis players. *Am J Sports Med*. 1992;20(4):455–458.
22. Mulligan IJ, Biddington WB, Barnhart BD, Ellenbecker TS. Isokinetic profile of shoulder internal and external rotators of high school aged baseball pitchers. *J Strength Cond Res*. 2004;18(4):861–866.
23. Hadzic V, Sattler T, Veselko M, Markovic G, Dervisevic E. Strength asymmetry of the shoulders in elite volleyball players. *J Athl Train*. 2014;49(3):338–344.
24. Wang HK, Macfarlane A, Cochrane T. Isokinetic performance and shoulder mobility in elite volleyball athletes from the United Kingdom. *Br J Sports Med*. 2000;34(1):39–43.
25. Yildiz Y, Aydin T, Sekir U, Kiralp MZ, Hazneci B, Kalyon TA. Shoulder terminal range eccentric antagonist/concentric agonist strength ratios in overhead athletes. *Scand J Med Sci Sports*. 2006; 16(3):174–180.
26. Mackenzie TA, Bdaiwi AH, Herrington L, Cools A. Inter-rater reliability of real-time ultrasound to measure acromiohumeral distance. *PM R*. 2016;8(7):629–634.
27. Duerr M. *Reliability and Accuracy of Distance Measurements Between Shoulder Bony Landmarks Evaluated by Ultrasound in Asymptomatic Subjects* [master's thesis]. New Zealand: Auckland University of Technology; 2010.
28. Pijls BG, Kok FP, Penning LI, Guldemond NA, Arens HJ. Reliability study of the sonographic measurement of the acromiohumeral distance in symptomatic patients. *J Clin Ultrasound*. 2010;38(3): 128–134.
29. Kumar P, Chetwynd J, Evans A, Wardle G, Crick C, Richardson B. Interrater and intrarater reliability of ultrasonographic measurements of acromion-greater tuberosity distance in healthy people. *Physiother Theory Pract*. 2011;27(2):172–175.
30. Leong HT, Tsui S, Ying M, Leung VY, Fu SN. Ultrasound measurements on acromio-humeral distance and supraspinatus tendon thickness: test-retest reliability and correlations with shoulder rotational strengths. *J Sci Med Sport*. 2012;15(4):284–291.
31. Gagey OJ, Boisrenoult P. Shoulder capsule shrinkage and consequences on shoulder movements. *Clin Orthop Relat Res*. 2004;419: 218–222.
32. Cools AM, Declercq G, Cagnie B, Cambier D, Witvrouw E. Internal impingement in the tennis player: rehabilitation guidelines. *Br J Sports Med*. 2008;42(3):165–171.
33. van Cingel R, Kleinrensink G, Stoeckart R, Aufdemkampe G, de Bie R, Kuipers H. Strength values of shoulder internal and external rotators in elite volleyball players. *J Sport Rehabil*. 2006;15(3):236–245.
34. Ellenbecker TS, Davies GJ. The application of isokinetics in testing and rehabilitation of the shoulder complex. *J Athl Train*. 2000;35(3): 338–350.
35. Muraki T, Yamamoto N, Zhao KD, et al. Effect of posteroinferior capsule tightness on contact pressure and area beneath the coracoacromial arch during pitching motion. *Am J Sports Med*. 2010;38(3):600–607.
36. Wang HK, Lin JJ, Pan SL, Wang TG. Sonographic evaluations in elite college baseball athletes. *Scand J Med Sci Sports*. 2005;15(1): 29–35.

37. Thomas SJ, Swanik CB, Kaminski TW, Higginson JS, Swanik KA, Nazarian LN. Assessment of subacromial space and its relationship with scapular upward rotation in college baseball players. *J Sport Rehabil*. 2013;22(3):216–223.

38. Cholewinski JJ, Kusz DJ, Wojciechowski P, Cielinski LS, Zoladz MP. Ultrasound measurement of rotator cuff thickness and acromio-humeral distance in the diagnosis of subacromial impingement syndrome of the shoulder. *Knee Surg Sports Traumatol Arthrosc*. 2008;16(4):408–414

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