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Posterior Shoulder Capsules Are Thicker and Stiffer in the Throwing Shoulders of Healthy College Baseball Players

A Quantitative Assessment Using Shear-Wave Ultrasound Elastography

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Background: Posterior and posteroinferior capsules in the shoulder joints of throwing athletes have been reported to be thicker in throwing than nonthrowing shoulders, and this has a relationship to glenohumeral internal rotation deficit (GIRD). However, the stiffness of these thickened capsules has not been reported. Shear-wave ultrasound elastography is a new technology that can measure tissue elasticity quantitatively.

Hypothesis: The posterior and posteroinferior capsules are stiffer as well as thicker in the throwing shoulders of baseball players than in their nonthrowing shoulders. The thickness and elasticity of these capsules are inversely correlated with glenohumeral internal rotation.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Forty-five male college baseball players were examined. The thickness and elasticity of the posterior capsule beneath the infraspinatus and the posteroinferior capsule beneath the teres minor were measured using an ultrasonic device equipped with shear-wave elastographic technology. Glenohumeral internal rotation at 90° of shoulder abduction and humeral retrotorsion were also measured.

Results: The mean thickness and elasticity of the posterior capsule were significantly greater for the throwing compared with the nonthrowing shoulder (thickness: 1.34 vs 1.04 mm, respectively; elasticity: 40.0 vs 32.2 kPa, respectively; $P < .001$ for both). The mean thickness and elasticity of the posteroinferior capsule were also significantly greater in the throwing compared with the nonthrowing shoulder (thickness: 1.40 vs 1.04 mm, respectively; elasticity: 39.4 vs 31.6 kPa, respectively; $P < .001$ for both). After correcting the range of motion for bilateral differences in retrotorsion, correlation coefficients showed that posterior capsule thickness and elasticity (Pearson $r = -0.43$ and -0.56, respectively; $P < .001$ for both) and posteroinferior capsule thickness and elasticity (Pearson $r = -0.51$ and -0.52, respectively; $P < .001$ for both) were negatively correlated with the corrected glenohumeral internal rotation. Bilateral differences in posterior and posteroinferior capsule elasticity correlated with bilateral differences in the corrected glenohumeral internal rotation (Pearson $r = 0.46$ [$P = .0015$] and 0.48 [$P < .001$], respectively), whereas bilateral differences in posterior and posteroinferior capsule thickness did not (Pearson $r = -0.13$ [$P = .38$] and 0.17 [$P = .28$], respectively).

Conclusion: The posterior and posteroinferior capsules were stiffer as well as thicker in the throwing shoulder of college baseball players compared with the nonthrowing shoulder. Posterior capsule elasticity appeared to have a greater effect on GIRD than did posterior capsule thickness. This technology could be used as a noninvasive screening method for throwing athletes to identify players at potential risk of shoulder injuries.

Keywords: shoulder; baseball; glenohumeral internal rotation deficit (GIRD); posterior capsule of the shoulder; ultrasound elastography

During the follow-through phase of pitching a baseball, the posterior part of the deltoid, the posterior rotator cuff, and the posteroinferior capsule endure significant distraction forces.[5,8] These forces have been reported to be approximately 90% to 150% of the pitcher's body weight.[9,30,31]

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Repetitive microtraumas due to overhead throwing and subsequent tissue healing are thought to thicken the posterior aspect of the shoulder capsule.[24] Some researchers performing ultrasonography have reported thicker posterior capsules in throwing shoulders compared with nonthrowing shoulders.[24,25] Thomas et al[24] reported that a negative correlation existed between hypertrophy of posterior capsules and loss of glenohumeral internal rotation (IR).

Burkhart et al[5] described an acquired loss of IR caused by posteroinferior capsular contracture as the essential lesion causing throwing injuries. Tuite et al[27] reported that overhead-throwing athletes who have internal impingements and IR deficits tend to have thicker posteroinferior capsules compared with athletes who do not throw overhead. However, the stiffness of the thickened posterior capsule and its relationship to glenohumeral IR are unknown.

Shear-wave ultrasound elastography is a relatively new, real-time diagnostic imaging technique that uses the following principles: the acoustic radiation force generated by a transducer creates shear waves; the velocity of the shear waves is measured as they travel through tissue; and from this velocity, the tissue's elasticity (Young modulus) is calculated.[2] This imaging method provides a quantitative assessment and is quite different from conventional axial-strain sonoelastography, which requires manual cyclic compression forces and evaluates tissue strain. The ability of shear-wave ultrasound elastography to measure quantitative values of elasticity has been evaluated using phantoms, calibrated for different elasticities, and showed reliable results.[12]

The purpose of this study was to investigate (1) the thickness and elasticity of the posterior and posteroinferior capsules of the shoulder joint and (2) the relationship of these capsules to glenohumeral IR in college baseball players using shear-wave ultrasound elastography.

METHODS

This study was performed as a part of medical checkups and was approved by our institutional review board. Before starting the study, written informed consent to participate in the study was obtained from all participants.

Forty-five male college baseball players with a mean (±SD) age of 19.7 ± 0.96 years, a mean height of 172.2 ± 4.1 cm, and a mean weight of 70.8 ± 6.8 kg were examined during the off-season. Thirteen players were pitchers, and 32 were fielders. Thirty-six players were right-handed, and 9 were left-handed. The mean career length of the baseball players was 10.4 years (range, 6-14 years). Participants were excluded if they had a history of significant shoulder injuries or surgeries, such as fractures or dislocations, or presented with significant injuries at the time of examination. Of 46 players recruited for medical checkups, only 1 player was excluded from the data analysis because he had a history of shoulder dislocations.

Figure 1. Position of participants during ultrasound examination of the posterior capsule.

Ultrasound Measurements of the Posterior Capsule Beneath the Infraspinatus

Measurements were made with participants seated upright in a chair with their shoulders in the same neutral position used by other ultrasound researchers, that is, with arms at their side, with 0° of abduction and adduction, and with forearms resting on the thighs.[24] In addition, we asked participants to rotate their shoulders 30° internally and relax so that all participants were measured in the same posture and without their muscles causing tension in the capsules. A single orthopaedic surgeon carried out all sonography using an Aixplorer ultrasound diagnostic device and a SuperLinear SL10-2 linear-array transducer (SuperSonic Imagine), which obtains measurements with an accuracy of less than 0.2 mm. This device was equipped with shear-wave elastographic technology and enabled the operator to measure tissue elasticity quantitatively without probe compression.

The linear-array transducer was placed on the posterior aspect of the shoulder, and a long-axis scan of the infraspinatus was obtained (Figure 1). The location of the transducer was then adjusted to clearly visualize the humeral head, glenoid rim, labrum, and infraspinatus, and the thickness and elasticity of the posterior capsule (PCT and PCE, respectively) beneath the infraspinatus were measured 5 mm lateral to the edge of the labrum (Figure 2).

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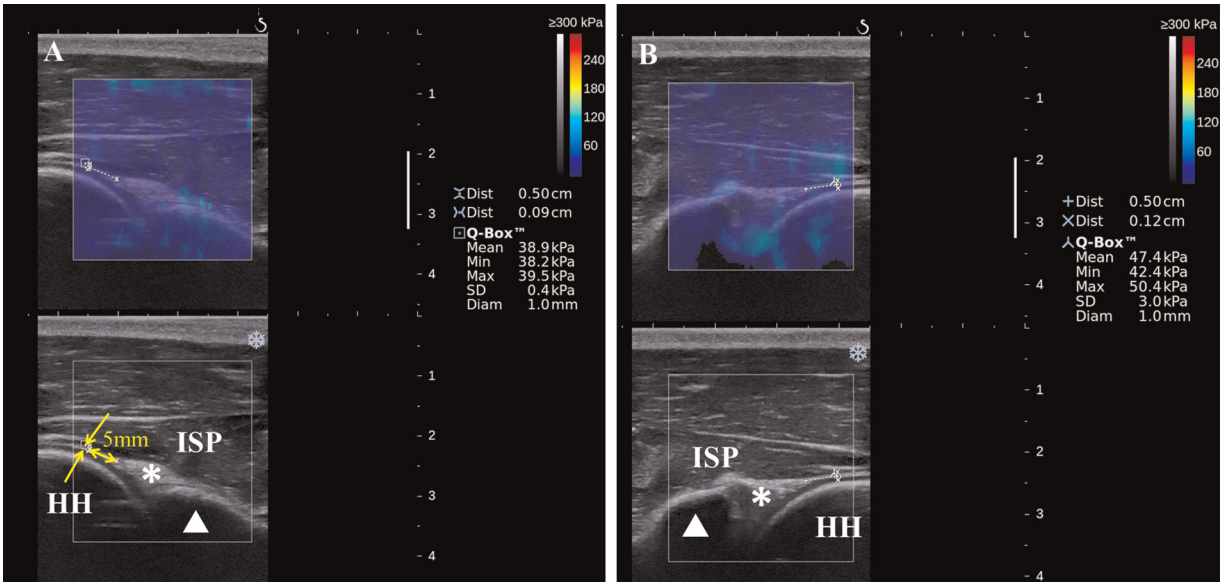

Figure 2. Ultrasound images of the posterior aspect of the shoulder joint for (A) a nonthrowing shoulder and (B) a throwing shoulder. In each figure, the upper panel shows the ultrasound elastogram, and the lower panel shows the same field in B-mode. The colored region in A represents the shear elasticity map, with the scale to the right of the figure. The thickness and elasticity of the posterior capsule were measured 5 mm lateral to the edge of the labrum (between yellow arrows in B). The thickness was measured vertically to the posterior capsule. The elasticity was automatically calculated by software when the circle (Q-Box, set at a 1-mm diameter in this study) was placed on the capsule. The mean, minimum, and maximum tissue elasticity (Young modulus) in the Q-Box are displayed in the right-hand column. The mean value was recorded. HH, humeral head; ISP, infraspinatus; Δ = glenoid rim; * = labrum.

Ultrasound Measurements of the Posteroinferior Capsule Beneath the Teres Minor

The participants remained seated and were asked to flex their shoulder by 90° while maintaining the same IR angle. They were asked to place their arms on a table and relax. The same operator placed the transducer on the posteroinferior aspect of the participants' shoulder to visualize the posteroinferior capsule beneath the teres minor (Figure 3). First, the teres minor overlying the lateral border of the scapula was identified using a short-axis scan (Figure 4A). Second, the transducer was turned through 90° to visualize the long axis of the teres minor (Figure 4B; Supplementary Video). Third, the location of the transducer was adjusted to clearly visualize the humeral head, glenoid rim, labrum, and teres minor, and the thickness and elasticity of the posteroinferior capsule (PICT and PICE, respectively) were measured in the same manner as measurements of the posterior capsule, that is, at a location 5 mm lateral to the edge of the labrum.

Figure 3. Position of participants during ultrasound examination of the posteroinferior capsule.

Measurements of Glenohumeral Range of Motion

Passive glenohumeral range of motion (ROM) for both IR and external rotation at 90° of shoulder abduction was measured using a goniometer with participants in a supine position. Glenohumeral IR at 90° of shoulder abduction has frequently been measured to evaluate posterior shoulder tightness.[4,5,13,28] While the measurement was obtained, the operator restrained the participants' scapula with his hand so that the scapulothoracic joint was immobilized and the extent of the isolated motion of the glenohumeral joint was maximized.

Measurements of Humeral Retrotorsion

Many authors have reported differences in the humeral retrotorsion angle between throwing and nonthrowing shoulders

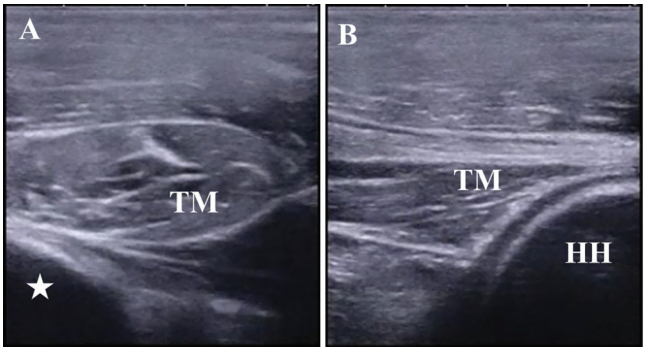

Figure 4. Ultrasound images of the posteroinferior aspect of the shoulder joint. (A) Short-axis scan of the teres minor. The transducer was adjusted to centralize the intramuscular tendon of the teres minor. (B) Long-axis scan of the teres minor. The transducer was turned 90°, including the intramuscular tendon of the teres minor in the scan. ★ = lateral border of the scapula. HH, humeral head; TM, teres minor.

in baseball players, which affect the bilateral difference in glenohumeral ROM.[7,18,19] Therefore, measuring humeral retrotorsion was essential to the investigation of the relationship between capsular elasticities and glenohumeral ROM.

Ultrasound scans for humeral retroversion were obtained using an 18-MHz linear transducer and a compact ultrasound system (MyLab25; Esaote). The humeral retrotorsion measurements were performed as described by Myers et al.[14] Although this ultrasonic technique was an indirect measure of humeral retrotorsion, a strong relationship was reported between the humeral torsion data obtained using ultrasound measurements with computed tomography–obtained humeral torsion data.[14] Each operator measuring capsular thickness and elasticity, glenohumeral ROM, or humeral retrotorsion was unaware of the other parameters measured.

Statistical Analysis

The assessment of intrarater and interrater reliabilities for the ultrasound measurements of the capsules used 30 healthy shoulders. Intrarater reliability was assessed for a single rater (rater 1) measuring the thickness and elasticity of the posterior and posteroinferior capsules on 2 separate occasions. Because at least 2 weeks separated the 2 measurement sessions, we made the assumption that rater 1 was effectively blinded to the original values during the second grading session. Interrater reliability was assessed using measurements by a second rater (rater 2), who was blinded to the thickness and elasticity values obtained by rater 1. The intrarater and interrater reliabilities were evaluated using intraclass correlation coefficients (ICCs) with 95% CIs in a 2-way random model with absolute agreement using single measurements. Intrarater and interrater reliabilities were also investigated for measurements of humeral retrotorsion and glenohumeral ROM in the same way as ultrasonic capsular measurements. Minimum detectable changes were calculated to evaluate the accuracy for all measurements.

Paired *t* tests were used to evaluate the differences between the throwing and nonthrowing shoulder for each measurement of the thickness and elasticity of the capsules, ROM, and humeral retrotorsion. The Cohen *d* was also calculated to evaluate the results. The Pearson correlation coefficient was used to analyze the relationship between the thickness and elasticity of the posterior and posteroinferior capsules and ROM. When calculating the Pearson correlation coefficient, we corrected the ROM in throwing shoulders for differences in the bilateral humeral retrotorsion angle. The corrected IR for the throwing shoulder was calculated by adding the difference in the humeral retrotorsion angle to the original IR angle. The corrected external rotation for the throwing shoulder was calculated by subtracting the difference in the humeral retrotorsion angle from the original external rotation angle. The total rotational arc was the same for the original and corrected ROMs in the throwing shoulder. Each value of ROM in the nonthrowing shoulder remained as original values.

To confirm the capsular contributions to glenohumeral internal rotation deficit (GIRD), bilateral differences were calculated for each capsular parameter and glenohumeral IR, and correlation analyses were performed using the Pearson correlation coefficient. Bilateral differences in IR (ΔIR) were calculated by subtracting the corrected IR of the throwing shoulder from the IR of the nonthrowing shoulder. Bilateral differences in the PCT (ΔPCT), PCE (ΔPCE), PICT (ΔPICT), and PICE (ΔPICE) were calculated by subtracting each value for the nonthrowing shoulder from that of the throwing shoulder.

The statistical program R (R package; http://www.r-project.org/) was used for data analysis. $P < .05$ was considered to be statistically significant.

RESULTS

ICC values with 95% CIs for intrarater and interrater reliabilities and the minimum detectable change for ultrasound measurements of the capsules are shown in Table 1. They showed that the measurements were obtained with a high level of reliability. ICC values with 95% CIs for intrarater and interrater reliabilities and the minimum detectable change for glenohumeral ROM and humeral retrotorsion are shown in Table 2. They showed almost perfect reliability. Table 3 shows the means ± SDs for all the measurements collected. Paired *t* tests showed that the posterior capsule, which lies beneath the infraspinatus, had significantly greater thickness and elasticity in the throwing shoulder than in the nonthrowing shoulder ($P < .001$) (Table 3). The posteroinferior capsule, which lies beneath the teres minor, was also significantly thicker and stiffer in the throwing shoulder than in the nonthrowing shoulder ($P < .001$) (Table 3).

Glenohumeral ROM at 90° of shoulder abduction was significantly greater in terms of external rotation and significantly smaller in terms of IR and the total rotational arc for the throwing shoulder than for the nonthrowing shoulder (Table 3). There was also a significant difference

TABLE 1
Reliability and Precision of Ultrasonic Measurements of the Shoulder Capsules[a]

	Posterior Capsule		Posteroinferior Capsule	
	Thickness	Elasticity	Thickness	Elasticity
Interrater reliability				
ICC (2,1)	0.783	0.788	0.813	0.761
95% CI	0.519-0.900	0.605-0.893	0.532-0.919	0.556-0.879
MDC[b]	0.19	7.4	0.24	8.7
Intrarater reliability				
ICC (1,1)	0.901	0.936	0.928	0.934
95% CI	0.799-0.952	0.869-0.969	0.855-0.965	0.866-0.968
MDC[b]	0.13	4.1	0.11	5.2

[a]ICC, intraclass correlation coefficient; MDC, minimum detectable change.
[b]Values in millimeters (mm) for thickness and kilopascals (kPa) for elasticity.

TABLE 2
Reliability and Precision of Range of Motion and Humeral Retrotorsion Measurements[a]

	Range of Motion		
	Internal Rotation	External Rotation	Humeral Retrotorsion
Interrater reliability			
ICC (2,1)	0.968	0.920	0.974
95% CI	0.935-0.985	0.840-0.961	0.894-0.990
MDC[b]	5.53	5.00	3.40
Intrarater reliability			
ICC (1,1)	0.990	0.988	0.996
95% CI	0.954-0.997	0.885-0.996	0.966-0.999
MDC[b]	3.16	2.47	2.50

[a]ICC, intraclass correlation coefficient; MDC, minimum detectable change.
[b]Values in degrees.

in humeral retrotorsion between the throwing and nonthrowing shoulder (Table 3). Shoulder ROMs corrected for humeral retrotorsion differences are shown in Table 4. When we compared ROM again, after applying the correction for bilateral differences in humeral torsion, there were significant differences in IR and the total rotational arc between bilateral shoulders. However, no significant difference was found in external rotation between throwing and nonthrowing shoulders. Pearson correlation coefficients showed significant correlations between the PCT and PCE and the corrected glenohumeral IR (Table 5). The PICT and PICE were also significantly correlated with the corrected glenohumeral IR (Table 5).

With regard to bilateral differences, the mean ΔIR was 16.3° ± 14.6°, the mean ΔPCT was 0.29 ± 0.16 mm, the mean ΔPCE was 7.8 ± 6.8 kPa, the mean ΔPICT was 0.36 ± 0.23 mm, and the mean ΔPICE was 7.8 ± 9.6 kPa. The Pearson correlation coefficients between ΔIR and each capsular parameter are shown in Table 6. Both ΔPCE and ΔPICE were correlated with ΔIR, but neither ΔPCT nor ΔPICT showed any correlation.

DISCUSSION

Differences in elasticity are very important to distinguish pathological changes from normal conditions. Shear-wave ultrasound elastography has been reported to be a better technology than axial-strain sonoelastography in terms of reproducibility and quantification.[17] This technology has been applied to musculoskeletal tissues[2,6,11,15,29,33] as well as other parts of the body such as the thyroid, breast, and abdominal organs.[3,21,23] Therefore, we applied shear-wave ultrasound elastography to the measurement of elasticity in the posterior shoulder capsules of college baseball players as a novel approach to analyzing GIRD, one of the leading causes of throwing-related shoulder injuries. The intrarater and interrater reliabilities of our measurements of capsular elasticity were high and in common with a previous shear-wave ultrasound elastography study.[33] The minimum detectable change for intrarater reliability was smaller than the bilateral differences in the PCE and PICE, which were measured by a single examiner. Therefore, there were significant differences in the PCE and PICE, although these differences were subtle. This is the first study demonstrating that posterior and posteroinferior capsules were stiffer in throwing shoulders than nonthrowing shoulders and that the PCE and PICE negatively correlated with glenohumeral IR angles, which was an intuitively sensible observation. Of course, the PCT and PICT also negatively correlated with glenohumeral IR angles as previously reported.[24] However, the capsular elasticity was thought to more strongly affect GIRD than the capsular thickness because bilateral differences in capsular elasticity correlated with bilateral differences in glenohumeral IR and bilateral differences in capsular thickness did not correlate with bilateral differences in glenohumeral IR (Table 6). This technology could be used as a noninvasive screening method for throwing athletes to identify the players at potential risk of shoulder injuries.

Another novel finding of this study was demonstrating the ultrasonic diagnostic technique to visualize the posteroinferior capsule of the shoulder joint. Tuite et al[27] measured the PICT using magnetic resonance arthrography. However, this approach is too expensive and time-

TABLE 3
Comparison of Parameters for Throwing and Nonthrowing Shoulders[a]

	Throwing Shoulder	Nonthrowing Shoulder	*P* Value	Cohen *d*
Posterior capsule				
Thickness, mm	1.34 ± 0.20	1.04 ± 0.09	<.001	1.934
Elasticity, kPa	40.0 ± 5.5	32.2 ± 5.7	<.001	1.393
Posteroinferior capsule				
Thickness, mm	1.40 ± 0.20	1.04 ± 0.13	<.001	2.134
Elasticity, kPa	39.4 ± 7.4	31.6 ± 5.4	<.001	1.204
Internal rotation, deg	41.7 ± 11.7	67.6 ± 9.0	<.001	2.481
External rotation, deg	105.6 ± 8.1	95.0 ± 7.7	<.001	1.341
Total rotational arc, deg	147.2 ± 14.3	162.6 ± 10.9	<.001	1.211
Humeral retrotorsion, deg	78.8 ± 5.6	69.2 ± 5.9	<.001	1.669

[a]Results are reported as mean ± SD.

TABLE 4
Range of Motion of Throwing and Nonthrowing Shoulders Corrected for Differences in Humeral Retrotorsion[a]

	Throwing Shoulder	Nonthrowing Shoulder	*P* Value	Cohen *d*
Internal rotation, deg	51.2 ± 12.0[b]	67.6 ± 9.0	<.001	1.546
External rotation, deg	96.0 ± 8.5[b]	95.0 ± 7.7	.416	0.123
Total rotational arc, deg	147.2 ± 14.3	162.6 ± 10.9	<.001	1.211

[a]Results are reported as mean ± SD.
[b]Range of motion corrected for bilateral humeral retrotorsion differences.

TABLE 5
Pearson Correlation Coefficients for Each Capsule Parameter and Corrected Internal Rotation Angles

	Posterior Capsule		Posteroinferior Capsule	
	Thickness	Elasticity	Thickness	Elasticity
Pearson correlation coefficient	–0.43	–0.56	–0.51	–0.52
P value	<.001	<.001	<.001	<.001

TABLE 6
Pearson Correlation Coefficients for Bilateral Differences in Internal Rotation (ΔIR) and Each Capsule Parameter[a]

	Posterior Capsule		Posteroinferior Capsule	
	ΔPCT	ΔPCE	ΔPICT	ΔPICE
Pearson correlation coefficient	–0.13	0.46	0.17	0.48
P value	.38	.0015	.28	.00077

[a]PCE, posterior capsule elasticity; PCT, posterior capsule thickness; PICE, posteroinferior capsule elasticity; PICT, posteroinferior capsule thickness.

consuming to be utilized as a screening method or at medical checkups. Thomas et al[24] measured the PCT with the participant's arm at the side and shoulders at 0° of abduction and adduction. However, the posteroinferior capsule around the posteroinferior glenohumeral ligament, which is the more important area of interest in throwing injuries,[5] could not be visualized with participants in that position, as the ultrasound beam could not reach the posteroinferior area vertically. Therefore, we asked participants to flex their shoulders to 90° for scans of the posteroinferior capsule so that the region of interest could be more clearly visualized. Arai et al[1] described the location of the rotator cuff using clockface positions in the right shoulder as 7:43 to 10:27 for the infraspinatus and as 6:21 to 7:43 for the teres minor. Therefore, we measured the posteroinferior capsule, which lies beneath the teres minor. The posteroinferior capsule lay beneath the teres minor regardless of the shoulder position, as the teres minor tendon and muscle fibers have been reported to attach directly to the posteroinferior capsule.[10,20,32] It was difficult initially to identify the teres minor using a long-axis scan. However, in short-axis scans, it was easy to identify the teres minor, as it has a characteristic appearance in echograms, as shown in Figure 4A. The ICCs for interobserver and intraobserver reliabilities for our measurements of the PICT were also high, as has been the case in other ultrasound studies.[24,25] The minimum detectable change for intrarater reliability was also smaller than the bilateral differences in the PCT and PICT, which were measured by a single examiner, although these differences were subtle.

We decided to measure the thickness and elasticity of the capsules at a site 5 mm lateral to the edge of the labrum because judgments about the location of the borderline between the labrum and capsule can vary between operators. At this location, isolated posterior and posteroinferior capsules, which were medial to the confluence of the capsule and intramuscular tendon, were identified in all participants.

The mean PCT and PICT ranged from 1.04 to 1.40 mm in our study, which were somewhat thinner than the average PCT reported by Thomas et al[24] of 2.03 mm in the dominant arm and 1.65 mm in the nondominant arm. Although the participants were college baseball players in both studies, their weights and heights were much greater in the Thomas et al cohort than in ours. Other differences, such as the ultrasonographic devices used or the location at which the thickness measurements were obtained, might also have affected the results. On the other hand, Burkhart et al[5] reported that the posteroinferior capsule was $\geq$6 mm thick in patients who underwent arthroscopic selective posteroinferior capsulotomy, which was much thicker than has been reported in ultrasound studies,[24,25] including ours. Most of the patients in the Burkhart et al[5] study were older elite pitchers who had been throwing for many years, and this report also noted that most college pitchers responded to stretching and rarely required selective posteroinferior capsulotomy. In our study, most of the players were asymptomatic because our data were collected as part of a medical checkup. Such subtle side-to-side differences of capsular thickness and elasticity shown in this study might be adaptive changes found in skeletally mature baseball players with over 10 years' experience. Therefore, further research is needed to investigate patients who have had longer careers as baseball players and are suffering from throwing disorders. Such research may be able to distinguish pathological conditions that require treatment from predominantly adaptive changes.

This study has some limitations that should be acknowledged. First, the thickness and elasticity of the posterior and posteroinferior capsules were only measured in one plane. However, target organs should be evaluated in echograms in which they are most clearly visualized. When we tried to measure the posterior capsules at several different locations, some of the echograms were too poor to evaluate.

Second, although we examined all participants in approximately the same shoulder position, actual tension on the capsule will vary with the amount of humeral torsion. This is a potential confounder as the association between capsular thickness/stiffness and rotational range could be potentially affected by torsion, with which they are also correlated.[25]

Third, we did not investigate muscular elasticity in this study. GIRD has been thought to be affected by many factors, including soft tissues and humeral retrotorsion.[16,22,26] We do, of course, expect muscular structures to affect posterior tightness and doubt that all shoulder movement can be fully explained by the capsules alone. However, as a report on the relationship between hypertrophied posterior capsules and GIRD had already been published,[24] we started by measuring the elasticity of these thickened posterior capsules in this study. Investigating the elasticity of the musculature will be the subject of a future study. Finally, this study lacked a control group, and comparison with a nonthrowing cohort is another future direction for this research.

CONCLUSION

The posterior and posteroinferior capsules were stiffer as well as thicker in the throwing shoulder than in the nonthrowing shoulder in college baseball players with a mean career length of 10 years. Both the elasticity and thickness of the posterior and posteroinferior capsules were negatively correlated with the corrected glenohumeral IR, adjusted for bilateral differences in humeral retrotorsion, which indicated posterior tightness. Correlation analysis of bilateral differences showed that capsular elasticity could more strongly affect GIRD than capsular thickness.

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A Video Supplement for this article is available in the online version or at http://ajsm.sagepub.com/supplemental.

REFERENCES

1. Arai R, Harada H, Tsukiyama H, Saji T, Kobayashi M. Anatomy of structures around the glenoid for improving the learning curve of shoulder arthroscopy. *Shoulder Joint*. 2013;37:915-918.
2. Arda K, Ciledag N, Aktas E, Aribas BK, Köse K. Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. *AJR Am J Roentgenol*. 2011;23:532-536.
3. Athanasiou A, Tardivon A, Tanter M, et al. Breast lesions: quantitative elastography with supersonic shear imaging. Preliminary results. *Radiology*. 2010;256:297-303.
4. Bigliani LU, Codd TP, Connor PM, Levine WN, Littlefield MA, Hershon SJ. Shoulder motion and laxity in the professional baseball player. *Am J Sports Med*. 1997;25:609-613.
5. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology. Part I: pathoanatomy and biomechanics. *Arthroscopy*. 2003;19:404-420.
6. Chen XM, Cui LG, He P, Shen WW, Qian YJ, Wang JR. Shear wave elastographic characterization of normal and torn Achilles tendons: a pilot study. *J Ultrasound Med*. 2013;32:449-455.
7. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med*. 2002;30:20-26.
8. DiGiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the upper extremity in pitching. *J Shoulder Elbow Surg*. 1992;1:15-25.

9. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J Orthop Sports Phys Ther*. 1993;18:402-408.
10. Hayashi N, Tuiki T. Connection form of posterior rotator cuff (infraspinatus and teres minor) and articular capsule of the shoulder. *Rigakuryouhougaku*. 1996;23:522-527.
11. Kot BC, Zhang ZJ, Lee AW, Leung VY, Fu SN. Elastic modulus of muscle and tendon with shear wave ultrasound elastography: variations with different technical settings. *PLoS One*. 2012;7:e44348.
12. Madsen EL, Hobson MA, Frank GR, et al. Anthropomorphic breast phantoms for testing elastography systems. *Ultrasound Med Biol*. 2006;32:857-874.
13. Myers JB, Laudner KG, Pasquale MR, Bradley JP, Lephart SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 2006;34:385-391.
14. Myers JB, Oyama S, Clarke JP. Ultrasonographic assessment of humeral retrotorsion in baseball players: a validation study. *Am J Sports Med*. 2012;40:1154-1160.
15. Nakamura M, Ikezoe T, Kobayashi T, et al. Acute effects of static stretching on muscle hardness of the medial gastrocnemius muscle belly in humans: an ultrasonic shear-wave elastography study. *Ultrasound Med Biol*. 2014;40:1991-1997.
16. Noonan TJ, Shanley E, Bailey LB, et al. Professional pitchers with glenohumeral internal rotation deficit (GIRD) display greater humeral retrotorsion than pitchers without GIRD. *Am J Sports Med*. 2015;43:1448-1454.
17. Ooi CC, Malliaras P, Schneider ME, Connell DA. ''Soft, hard, or just right?'' Applications and limitations of axial-strain sonoelastography and shear-wave elastography in the assessment of tendon injuries. *Skeletal Radiol*. 2014;43:1-12.
18. Osbahr DC, Cannon DL, Speer KP. Retroversion of the humerus in the throwing shoulder of college baseball pitchers. *Am J Sports Med*. 2002;30:347-353.
19. Reagan KM, Meister K, Horodyski MB, Werner DW, Carruthers C, Wilk K. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *Am J Sports Med*. 2002;30:354-360.
20. Romanes GJ. *Cunningham's Textbook of Anatomy*. 12th ed. London: Oxford University Press; 1981:318-320.
21. Sebag F, Vaillant-Lombard J, Berbis J, et al. Shear wave elastography: a new ultrasound imaging mode for the differential diagnosis of benign and malignant thyroid nodules. *J Clin Endocrinol Metab*. 2010;95:5281-5288.
22. Shanley E, Thigpen CA, Clark JC, et al. Changes in passive range of motion and development of glenohumeral internal rotation deficit (GIRD) in the professional pitching shoulder between spring training in two consecutive years. *J Shoulder Elbow Surg*. 2012;21:1605-1612.
23. Sporea I, Bota S, Jurchis A, et al. Acoustic radiation force impulse and supersonic shear imaging versus transient elastography for liver fibrosis assessment. *Ultrasound Med Biol*. 2013;39:1933-1941.
24. Thomas SJ, Swanik CB, Higginson JS, et al. A bilateral comparison of posterior capsule thickness and its correlation with glenohumeral range of motion and scapular upward rotation in collegiate baseball players. *J Shoulder Elbow Surg*. 2011;20:708-716.
25. Thomas SJ, Swanik CB, Kaminski TW, et al. Humeral retroversion and its association with posterior capsule thickness in collegiate baseball players. *J Shoulder Elbow Surg*. 2012;21:910-916.
26. Tokish JM. Acquired and adaptive changes in the throwing athlete: implications on the disabled throwing shoulder. *Sports Med Arthrosc Rev*. 2014;22:88-93.
27. Tuite MJ, Petersen BD, Wise SM, Fine JP, Kaplan LD, Orwin JF. Shoulder MR arthrography of the posterior labrocapsular complex in overhead throwers with pathologic internal impingement and internal rotation deficit. *Skeletal Radiol*. 2007;36:495-502.
28. Tyler TF, Nicholas SJ, Roy T, Gleim GW. Quantification of posterior capsule tightness and motion loss in patients with shoulder impingement. *Am J Sports Med*. 2000;28:668-673.
29. Vergari C, Rouch P, Dubois G, et al. Non-invasive biomechanical characterization of intervertebral discs by shear wave ultrasound elastography: a feasibility study. *Eur Radiol*. 2014;24:3210-3216.
30. Werner SL, Gill TJ, Murray TA, Cook TD, Hawkins RJ. Relationship between throwing mechanics and shoulder distraction in professional baseball pitchers. *Am J Sports Med*. 2001;29:354-358.
31. Wilk EK, Andrews JR, Arrigo CA, Keirns MA, Erber DJ. The strength characteristics of internal and external rotator muscles in professional baseball pitchers. *Am J Sports Med*. 1993;21:61-66.
32. Williams PL, Warwick R, Dyson M. *Gray's Anatomy*. 36th ed. New York: Churchill Livingstone; 1980:570-571.
33. Yoshitake Y, Takai Y, Kanehisa H, Shinohara M. Muscle shear modulus measured with ultrasound shear-wave elastography across a wide range of contraction intensity. *Muscle Nerve*. 2014;50:103-113.

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