A CADAVERIC MODEL OF THE THROWING SHOULDER: A POSSIBLE ETIOLOGY OF SUPERIOR LABRUM ANTERIOR-TO-POSTERIOR LESIONS

BY MARK G. GROSSMAN, MD, JAMES E. TIBONE, MD, MICHELLE H. MCGARRY, MS,
DAVID J. SCHNEIDER, MD, SERGIO VENEZIANI, MD, AND THAY Q. LEE, PhD

Investigation performed at Orthopaedic Biomechanics Laboratory,
VA Long Beach Healthcare System and University of California Irvine, Long Beach, California

Background: It has been speculated that a shift of the throwing arc commonly develops in athletes who perform overhead activities, resulting in greater external rotation and decreased internal rotation caused by anterior capsular laxity and posterior capsular contracture, respectively. Osseous adaptation in the form of increased humeral and glenoid retroversion may provide a protective function in the asymptomatic athlete but cannot explain the pathological changes seen in the shoulder of the throwing athlete. Therefore, the objective of the present study was to examine the biomechanical effects of capsular changes in a cadaveric model.

Methods: Ten cadaveric shoulders were tested with a custom shoulder-testing device. Humeral rotational range of motion, the position of the humerus in maximum external rotation, and glenohumeral translations in the anterior, posterior, superior, and inferior directions were measured with the shoulder in 90° of abduction. Translations were measured with the humerus secured in 90° of external rotation. To simulate anterior laxity due to posterior capsular contracture, the capsule was nondestructively stretched 30% beyond maximum external rotation with the shoulder in 90° of abduction. This was followed by the creation of a 10-mm posterior capsular contracture. Rotational, humeral shift, and translational tests were performed for the intact normal shoulder, after anterior capsular stretching, and after simulated posterior capsular contracture.

Results: Nondestructive capsular stretching resulted in a significant increase in external rotation (average increase, 18.2° ± 2.1°; p < 0.001), and subsequent simulated posterior capsular contracture resulted in a significant decrease in internal rotation (average decrease, 8.8° ± 2.3°; p = 0.02). There also was a significant increase in anterior translation with the application of a 20-N anterior translational force after nondestructive capsular stretching (average increase, 1.7 ± 0.3 mm, p = 0.0006). The humeral head translated posteroinferiorly when the humerus was rotated from neutral to maximum external rotation. This did not change significantly in association with anterior capsular stretching. Following simulated posterior capsular contracture, there was a trend toward a more posterosuperior position of the humeral head with the humerus in maximum external rotation in comparison with the position in the stretched conditions, although these differences were not significant.

Conclusions: A posterior capsular contracture with decreased internal rotation does not allow the humerus to externally rotate into its normal posteroinferior position in the cocking phase of throwing. Instead, the humeral head is forced posterosuperiorly, which may explain the etiology of Type-II superior labrum anterior-to-posterior lesions in overhead athletes.

Clinical Relevance: Understanding the biomechanical effects of capsular changes in a cadaveric model of the throwing shoulder may confirm clinical observations and provide insight into the pathological changes often seen in the shoulder of throwing athletes.

Athletes who participate in overhead activities commonly develop a shift of humeral rotational range of motion toward greater external rotation to accommodate their throwing demands. This shift is accompanied by a decrease in internal rotation. Although we are not aware of any studies that have examined throwers during development,

many studies have demonstrated the differences between the dominant (throwing) and nondominant (nonthrowing) arms, specifically with respect to motion of the shoulder[1-4]. There is speculation that the etiology for the shift of humeral rotational range of motion toward greater external rotation is a capsular or an osseous phenomenon, or both. The capsular theory suggests that the increase in external rotational range of motion of the humerus is the result of anterior glenohumeral joint laxity and/or instability and that the decrease in internal humeral rotational range of motion is the result of a posteroinferior capsular contracture[5-9]. The osseous theory implies that increased glenoid and humeral retroversion, compared with the contralateral shoulder, provides a protective shift during growth and may place less stress on the anterior capsuloligamentous structures[3,4]. The osseous theory does not delve into the pathological production of the painful shoulder but does call attention to the possible protective role of osseous adaptation in the asymptomatic thrower. Excessive retroversion may place less stress on the anterior capsuloligamentous structures. Therefore, it has been hypothesized that the capsular changes described above may lead to pathological changes within the glenohumeral joint, such as superior labrum anterior-to-posterior lesions and rotator cuff tears.

F.W. Jobe et al.[8] noted gradual stretching of the anterior capsuloligamentous structures in association with overhead motion and postulated that anterior instability allows anterosuperior migration of the humeral head. C.M. Jobe[7] further advanced the principle when he described posterosuperior glenohumeral impingement. Specifically, Jobe expanded the concept of internal impingement, originally described by Walch et al.[10], and applied it to throwers. In the position of 90° of abduction and ≥90° of external rotation, the posterosuperior aspect of the glenoid and the intra-articular portion of the humeral neck may contact. This position of contact may cause injury to the interposed rotator cuff and posterosuperior labrum. It is theorized that anterior capsular stretching, leading to anterior instability, aggravates this effect. Burkhart and Morgan[5,6,9] proposed the so-called peel-back mechanism. The key pathologic element in the peel-back mechanism is a posteroinferior capsular contracture. In the position of 90° of abduction and ≥90° of external rotation, the posterior capsular contracture may cause a posterosuperior shift of the humeral head. This theory then relies on increased forces at the posterosuperior biceps-labrum-rotator cuff complex. A Type-II superior labrum anterior-to-posterior lesion, in which the labrum is not only fraying and undergoing degenerative changes (as seen with a Type-I lesion) but also has become unattached from the underlying glenoid, is possibly created as the labrum peels back over the posterosuperior aspect of the glenoid[11]. The so-called break in the labral circle may lead to anterior pseudolaxity. Both internal impingement and the peel-back mechanism describe biomechanical alterations in the late cocking phase of throwing.

The purpose of the present study was to examine the biomechanical effects of capsular changes in a cadaveric model. A model of the shoulder of the overhead athlete was developed by creating anterior laxity and by simulating a posterior capsular contracture, thus increasing external rotation and decreasing internal rotation, respectively. The rotational range of motion, the humeral head shift during the late cocking phase of throwing, and the translational effects of these capsular changes were quantified.

Materials and Methods

Specimens

On the basis of the results of a power analysis performed on data from previous studies and pilot studies, ten cadaveric shoulders were used in this study[12,13]. The donors had been an average of 75.1 ± 3.4 years old (range, sixty-one to ninety-two years old) at the time of death. All specimens were normal macroscopically and radiographically, without any evidence of degenerative joint disease. Each specimen was dissected free of all soft tissues, with the glenohumeral capsule being left intact. The humerus was cut 2 cm distal to the deltoid tuberosity, centered in a polyvinylchloride pipe, and potted with use of plaster of Paris. The scapula was potted with use of plaster of Paris, with the glenoid surface positioned parallel to the floor in an aluminum box. The shoulder was then mounted in the shoulder-testing system.

Shoulder-Testing System

A custom shoulder-testing system was developed to measure humeral rotational range of motion, the position of the humerus with rotational range of motion, and glenohumeral translation (Fig. 1)[12]. The testing apparatus allowed six degrees of freedom for glenohumeral positioning. Two translation plates, anteroposterior and superoinferior, were fixed to the base of the jig. Each plate could be independently locked to capture direct anteroposterior or superoinferior motion. If unlocked, translation in both anteroposterior and superoinferior directions could occur simultaneously, thus allowing secondary translation. This latter setting was utilized throughout the experiment. The scapular box was mounted onto a linear bearing and a lever-arm system that was attached to the top translation plate, which allowed for the application of a joint compressive force and anterior-posterior and medial-lateral translation. The humeral polyvinylchloride pipe was centered and secured in a cylinder that was attached along the top arc of the jig. The angle of the arc could be varied to simulate different degrees of glenohumeral abduction. The jig allowed 360° of humeral rotation, which could be measured with use of a goniometer placed at the distal end of the humerus. Translational forces were applied in the anterior, posterior, superior, and inferior directions by hanging weights from a cable-and-pulley system that was attached to the top translation plate. The humeral shift and translation data were recorded with use of a Microscribe 3DLX (Immersion, San Jose, California). This device has an accuracy and resolution of 0.30 mm and 0.13 mm, respectively. These values were verified in the laboratory.

Once the intact specimen had been mounted in the testing apparatus, the glenohumeral joint was abducted 60°. This
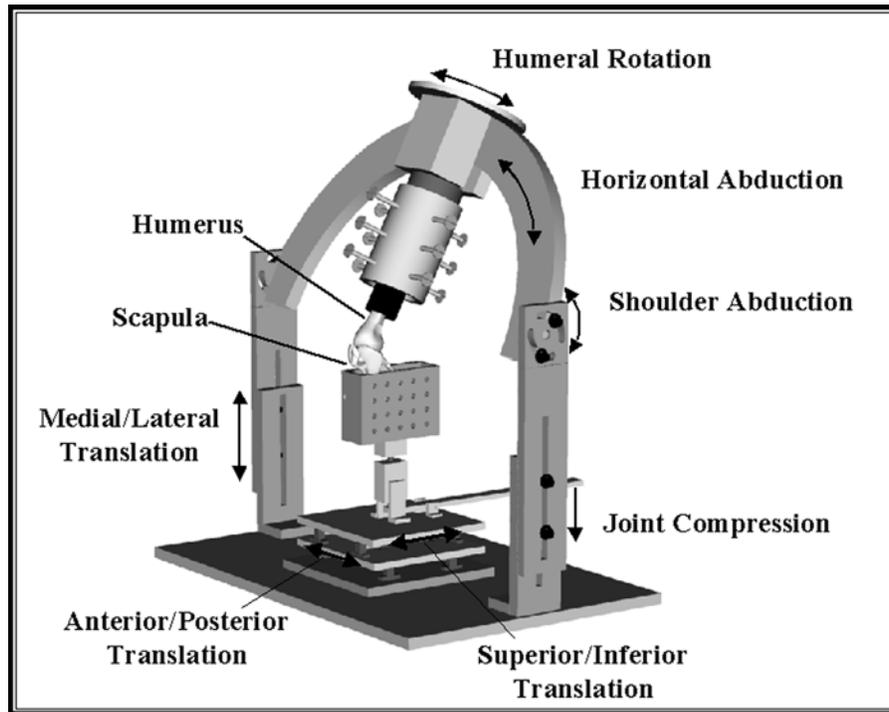
Fig. 1

Schematic of the custom testing system, showing the six degrees of freedom for anatomical positioning of the shoulder joint.

position simulated 90° of humerothoracic abduction. The biceps tendon was aligned with the tip of the acromion to represent 90° of external rotation. Ninety degrees of internal rotation from that point was defined as neutral humeral rotation. A joint compressive force of 22 N was applied to center the humeral head in the glenoid, thus defining the starting point[12,13]. The specimen was vented and lubricated with 2 mL of normal saline solution and was kept moist throughout testing with normal saline solution.

Humeral rotational range of motion, humeral position at maximum external rotation, and glenohumeral translation in all four directions were measured for each experimental condition: for the intact normal shoulder, after anterior capsular stretching, and after simulation of a posterior capsular contracture. Three trials were performed for each condition and position, and the average of the three trials was used for comparison. Measurements were recorded after preconditioning in each direction to ensure repeatability. Previous studies in this laboratory with use of this technique have demonstrated the repeatability to be within 0.2 mm[12,13].

Humeral Rotational Range of Motion

The specimen was rotationally preconditioned manually with ten cycles of 1.1 Nm of torque, administered with use of a torque wrench, in external and internal rotation; each cycle lasted five seconds. The rotational range of motion was then measured with 2.2 Nm of torque being applied in each direction. Pilot studies were performed using different specimens,

with two surgeons determining the amount of torque that was needed to reach the end point of the range of motion. These studies demonstrated that an average torque of 2.2 Nm was needed to reach the end point of the range of motion without damaging the capsular tissue. The total range of motion, external rotation, and internal rotation were recorded with a 360° goniometer. The internal and external ranges of motion were measured with respect to the predefined neutral rotation position (90° of internal rotation from the point where the biceps tendon aligns with the anterior edge of the acromion). A 22-N joint compressive force was utilized throughout this portion of the experiment.

Humeral Head Position

The humeral head position was calculated as the movement of the humeral head with respect to the glenoid when the humerus was externally rotated from neutral rotation to maximum external rotation. All measurements were made with a 44-N compressive force applied to the glenoid. Twice the usual compressive force was used for this portion of the experiment in order to achieve a higher degree of concavity compression. Humeral shift measurements were obtained for three successive trials, compared, and averaged to ensure repeatability.

Glenohumeral Translation

Glenohumeral translation was measured with a compressive force of 22 N and translational forces of 15 and 20 N being applied to the shoulder in the anterior, posterior, superior, and

inferior directions. These forces produced normal ranges of shoulder translation as reported in previous studies[12-14]. With both plates unlocked, translational preconditioning in the anteroposterior direction was performed by applying a 10-N force for five seconds in both directions for ten cycles. Anterior and posterior glenohumeral translation was then recorded during the application of a 15-N force in both directions. Translational preconditioning in the superoinferior direction also was performed by applying 10 N of force for five seconds in both directions for ten cycles. Superior and inferior glenohumeral translation was then recorded with the application of the 15-N force in both directions. The entire process, including the 10-N preconditioning force, was repeated for the 20-N translational force in each direction as previously described.

Anterior Laxity

Nondestructive stretching of the anterior capsule in external rotation was performed to increase external rotation. A 30% increase beyond maximum humeral external rotation was achieved by gradually increasing the torque applied to the glenohumeral capsule. An increase of >30% would have risked capsular rupture. A 3.3-Nm torque was applied for one minute, and then the capsule was relaxed for thirty seconds. The torque was then increased in 1.1-Nm increments for one minute until the rotational goal was reached. The shoulder was maintained at this rotation for thirty minutes. Following stretching, the shoulder was released and the capsule was vented and lubricated with another 2 mL of normal saline solution. Rotational range of motion, humeral shift, and glenohumeral translation measurements were repeated as previously described. All speci-

mens were visually inspected for capsular failure after stretching. If the capsule was torn, the test was stopped.

Simulated Posterior Capsular Contracture

A glenoid-based posterior capsular shift was performed to simulate a posterior capsular contracture. Care was taken to leave the superior leaflet in its anatomic position. The inferior leaflet was shifted 10 mm superiorly. The repair was sutured with a number-1 Ethibond suture (Ethicon, Somerville, New Jersey). The capsule was vented a third time, and the joint was lubricated with a final 2 mL of normal saline solution. Rotational range of motion, humeral shift, and glenohumeral translation measurements were repeated as previously described.

Statistical Methods

Each measurement was repeated three times to ensure repeatability, and the average was used for analysis. A repeated-measures analysis of variance was used to analyze the data for each set of measurements performed within the experiment, with the level of significance set at $p < 0.05$. A Tukey post hoc test was used to determine significance between the three conditions: the intact normal shoulder, after anterior capsular stretching, and after simulated posterior capsular contracture.

Results

Humeral Rotational Range of Motion

The range of external rotation increased in association with rotational stretching of the glenohumeral joint capsule, and the range of internal rotation decreased in association with simulated posterior capsular contracture (Fig. 2). Intact specimens had an average total humeral rotational range of
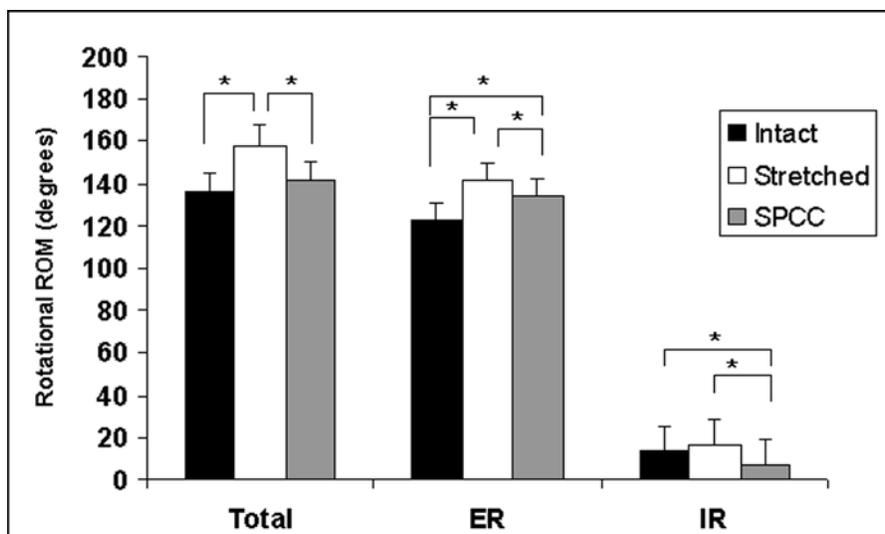
Fig. 2

Humeral rotational range-of-motion graphs showing total range of motion, external rotation (ER), and internal rotation (IR) for each condition (intact, stretched, and simulated posterior capsular contracture [SPCC]). External and internal rotation measurements were recorded from neutral or 0° of humeral rotation (90° of internal rotation from the position where the biceps tendon aligns with the anterior edge of the acromion).
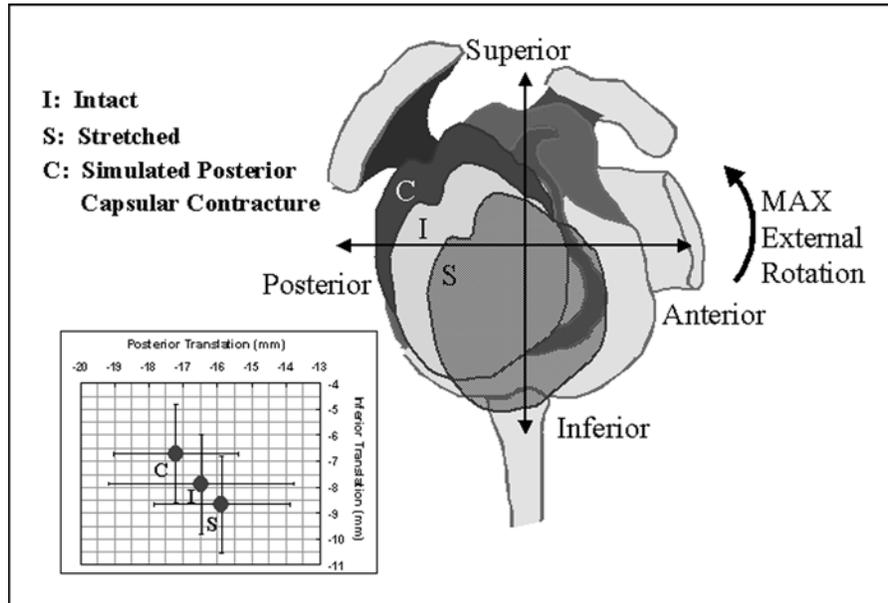
Fig. 3

Schematic and graphical representations of the humeral shift from neutral to maximum external rotation, showing the superior shift of the humeral head following the simulated posterior capsular contracture.

motion (and standard deviation) of 136.3° ± 8.6°, with an average external rotation of 122.9° ± 7.9° and an average internal rotation of 13.4° ± 12.2° from neutral humeral rotation. Anterior capsular stretching resulted in a significant increase in total rotational range of motion (average, 157.3° ± 10.2°; $p < 0.001$) and external rotation (average, 141.1° ± 8.7°; $p < 0.001$) but not internal rotation (average, 16.2° ± 13.0°; $p = 0.36$). Following the simulated posterior capsular contracture, there was a significant decrease in total rotational range of motion (average, 141.3° ± 9.1°; $p < 0.001$), external rotation (average, 133.9° ± 8.2°; $p = 0.001$), and internal rotation (average, 7.4° ± 11.2°; $p = 0.001$) when compared with the stretched condition. Following both anterior capsular stretching and simulated posterior capsular contracture, there was a significant increase in external rotation ($p < 0.001$) and a significant decrease in internal rotation ($p = 0.02$) compared with the intact condition.

Humeral Head Position

For the intact specimens, the humeral head moved 16.5 ± 2.7 mm posteriorly and 7.9 ± 1.9 mm inferiorly when the humerus was rotated from 0° of humeral rotation to maximum external rotation. After stretching of the anterior capsule, the humerus could externally rotate more and thus could settle in a more inferior position; specifically, the humeral head moved 15.9 ± 2.0 mm posteriorly and 8.7 ± 1.9 mm inferiorly. These positions were not significantly different from the intact condition ($p = 0.85$ for the change in the posterior direction and $p = 0.6$ for the change in the inferior direction). Following the simulated posterior capsular contracture, the humeral head translated 17.2 ± 1.8 mm posteriorly and 6.7 ± 1.9 mm inferi-

orly when rotated from 0° to maximum external rotation (Fig. 3). Although there was a trend toward a more posterosuperior position when these values were compared with those for the stretched anterior capsule condition, the differences were not significant; specifically, the head was located 1.3 ± 0.9 mm more posteriorly ($p = 0.47$) and 2.0 ± 0.6 mm more superiorly ($p = 0.07$) when the position following simulated posterior capsular contracture was compared with the position following anterior capsular stretching.

Glenohumeral Translation

There was a consistent, although not significant, trend indicating an increase in translation in all directions following stretching of the anterior capsule (Fig. 4). The only significant increase was associated with the application of a 20-N force in the anterior direction, with an average increase of 1.7 ± 0.3 mm being recorded following anterior capsular stretching ($p = 0.0006$). Following creation of the simulated posterior capsular contracture, there was a trend toward decreasing translation in each direction compared with the stretched condition; however, none of the differences reached significance ($p = 0.15$ to 0.5). During the application of the 20-N force, the anterior translation following posterior contracture was still significantly higher than that in the intact condition ($p = 0.01$).

Discussion

Overhead throwing athletes commonly develop a shift in the rotational range-of-motion arc whereby external rotation is increased and internal rotation is decreased at 90° of abduction when the involved extremity is compared with the
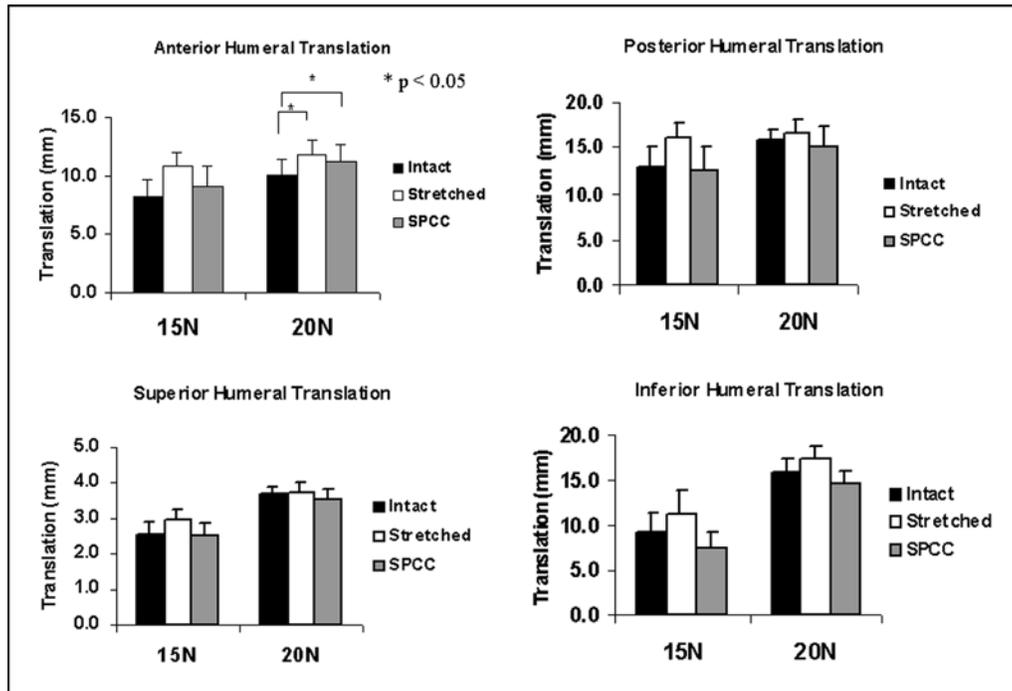
Fig. 4

Histograms illustrating the glenohumeral translations associated with the application of 15 and 20-N translational forces under each condition (intact, stretched, and simulated posterior capsular contracture [SPCC]).

contralateral extremity[1-4]. Bigliani et al.[1] evaluated seventy-two professional pitchers and reported an average external rotation of 118° (range, 95° to 145°) at 90° of abduction. Brown et al.[2] reported that pitchers had an average external rotation of 141° at 90° of abduction. Wilk et al.[4], in an ongoing study of 372 professional baseball players, reported an average external rotation of 130° and an average internal rotation of 63°. The adaptation of the throwing shoulder allows overhead athletes to develop this advantageous arc of motion; however, it may lead to damage of the biceps-labral complex and the rotator cuff.

The cadaveric model developed in the present study demonstrated a significant increase in external rotation (average increase, 18.2°) in association with anterior capsular stretching. The model also showed a significant decrease in internal rotation (average decrease, 8.8°) in association with a simulated posterior capsular contracture. The results regarding external rotation are comparable with those of the above-cited clinical studies; however, the internal rotation that was achieved in this cadaveric model is lower than that found clinically. This finding may be due to the inability of this model to incorporate scapulothoracic motion, which is a large component of internal rotation when it is measured clinically.

Most overhead athletes develop laxity of the glenohumeral joint. Bigliani et al.[1] examined laxity in 148 professional baseball players (seventy-two pitchers and seventy-six position players). The authors noted a high degree of laxity, with 61% of pitchers and 47% of position players having a positive sulcus sign. Our cadaveric model simulated clinical laxity, as we reported previously[12,13]. Stretching the anterior capsule in

external rotation resulted in a significant increase in anterior translation in association with the application of a 20-N force (Fig. 4). These data are consistent with those of O'Brien et al.[15], who found that the anterior structures, including the inferior glenohumeral ligament, are the primary restraint to anterior translation at 90° of abduction. Therefore, our model achieved its goal of creating anterior laxity.

Shoulder laxity and rotation are related. Overhead athletes may have increased external rotation in association with a lax anterior capsule. Capsular volume must have a limit as increased external rotation is accompanied by a loss of internal rotation. Our cadaveric model incorporated a simulated posterior capsular contracture to address internal rotation loss. Overall, posterior capsular contracture did demonstrate a trend toward reducing translation in all directions. However, it did not have a significant global effect on glenohumeral translation.

According to our data for the intact normal shoulder condition and our observations of the humerus during rotational range of motion, the humerus follows the coracoacromial arch and rotates into a posterior and inferior position when it is rotated from neutral to maximum external rotation as seen in the late cocking phase of throwing (Fig. 3). With anterior laxity, the humeral position associated with maximum external rotation is more inferior but less posterior than that associated with the intact normal condition (Fig. 3). Although these differences were not significant, it may be that the increased external rotation allows the humerus to travel farther down the coracoacromial arch to a more inferior and

less posterior position. With the addition of a simulated posterior capsular contracture, the humeral head translated more posteriorly and less inferiorly with external rotation than was the case in the stretched condition; however, these differences were not significant. The posteroinferior capsular contracture may act as a barrier in maximum external rotation and may force the humerus posterosuperiorly.

Other cadaveric studies have examined the effects of posterior capsular contracture of the shoulder. Harryman et al.[14] noted a superior and anterior translation during passive forward flexion in the presence of a simulated posterior capsular contracture in a cadaveric model, but they did not test abduction and external rotation. Anderson et al.[16], in a cadaveric model involving a simulated posterior capsular contracture, found that many of the changes in the overhead athlete can be attributed to the posterior capsule. Koffer et al.[17] incorporated a posterior capsular contracture into their model and found a posterosuperior shift of the humerus. Although those studies suggested the so-called peel-back mechanism, anterior laxity was not incorporated into the models. In the current study, we simulated in a human cadaveric model a thrower's shoulder in which both anterior laxity and a posterior contracture were imposed. This model also demonstrated increased humeral external rotation and decreased internal rotation as observed in throwers. We also simulated the late cocking phase of the throwing motion, during which pathological changes of the shoulder are likely to occur as a result of tightening of the capsule.

Our findings are consistent with the clinical observation that a posterior capsular contraction may be pathological in the thrower's shoulder[5,6,9]. Pure anterior laxity may be protective as the humerus rotates to a greater inferior position away from the rotator cuff and posterosuperior labrum. In our study, an added posterior capsular contracture caused posterosuperior migration of the humeral head. The posterosuperior shift may increase contact between the humeral head, labrum, and rotator cuff in the late cocking phase. This may lead to labral peel-back and cause a Type-II superior labrum anterior-to-posterior lesion. Burkhart and Morgan[5] speculated that a Type-II superior labrum anterior-to-posterior lesion may then lead to a break in the labral ring and cause anterior pseudolaxity. Our model suggests that the anterior laxity is probably real as increased laxity may be the cause of increased external rotation. However, our experiment suggests that internal impingement at the posterosuperior aspect of the glenoid may be the result of posterior capsular tightness rather than increased anterior laxity due to the trend toward a less inferior position of the humeral head in

maximum external rotation following simulated posterior capsular contracture ($p = 0.07$) (Fig. 3). Additional studies are being performed at our laboratory to measure contact pressures in order to quantify the humeral head-labrum-cuff internal impingement that occurs with this model.

The present study has several limitations. It was not known how much laxity or tightness to create in our model of a thrower's shoulder. In addition, the kinematic measurements reflected only the relative movement between the glenoid and the humeral head in the late cocking phase of throwing. Additional studies are necessary to assess true glenohumeral kinematics by mapping out the glenoid and tracking the humeral head center as well as by quantifying glenohumeral articulation patterns. In addition, this was a cadaveric study, without the influence of the shoulder muscles. Despite these limitations, this model represents what we believe to be the first attempt to simulate both anterior laxity and posterior capsular contracture together. Understanding the biomechanical effects of capsular changes in a cadaveric model of the throwing shoulder may confirm clinical observations and may give insight into the pathological changes often seen in throwers' shoulders. ■

Mark G. Grossman, MD
Department of Orthopaedic Surgery, Winthrop University Hospital, 120 Mineola Boulevard, Suite 600, Mineola, NY 11501. E-mail address: mgrossman@winthrop.org

Michelle H. McGarry, MS
David J. Schneider, MD
Sergio Veneziani, MD
Thay Q. Lee, PhD
Orthopaedic Biomechanics Laboratory, VA Long Beach Healthcare System (09/151), University of California Irvine, 5901 East 7th Street, Long Beach, CA 90822. E-mail address for T.Q. Lee: tqlee@med.va.gov

James E. Tibone, MD
Orthopaedic Surgery Associates, University of Southern California, 1510 San Pablo Street, Suite 322, Los Angeles, CA 90033

References

1. 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; 25:609-13.

2. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. Am J Sports Med. 1988;16:577-85.

3. Crockett HC, Gross LB, Wilk KE, Schwartz ML, Reed J, O'Mara J, Reilly MT,

Dugas JR, Meister K, Lyman S, Andrews JR. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. Am J Sports Med. 2002;30:20-6.

4. Wilk KE, Meister K, Andrews JR. Current concepts in the rehabilitation of the overhead throwing athlete. Am J Sports Med. 2002;30:136-51.

5. Burkhart SS, Morgan CD. The peel-back mechanism: its role in producing and extending posterior type II SLAP lesions and its effect on SLAP repair reha-

bilitation. Arthroscopy. 1998;14:637-40.

6. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology Part I: pathoanatomy and biomechanics. Arthroscopy. 2003; 19:404-20.

7. Jobe CM. Posterior superior glenoid impingement: expanded spectrum. Arthroscopy. 1995;11:530-6.

8. Jobe FW, Giangarra CE, Kvitne RS, Glousman RE. Anterior capsulolabral reconstruction of the shoulder in athletes in overhand sports. Am J Sports Med. 1991;19:428-34.

9. Morgan CD, Burkhart SS, Palmeri M, Gillespie M. Type II SLAP lesions: three subtypes and their relationships to superior instability and rotator cuff tears. Arthroscopy. 1998;14:553-65.

10. Walch G, Boileau J, Noel E. Impingement of the deep surface of the supraspinatus tendon on the posterior superior glenoid rim. An anatomic study. J Shoulder Elbow Surg. 1992;1:238-43.

11. Snyder SJ, Karzel RP, Del Pizzo W, Ferkel RD, Friedman MJ. SLAP lesions of the shoulder. Arthroscopy. 1990;6:274-9.

12. Remia LF, Ravalin RV, Lemly KS, McGarry MH, Kvitne RS, Lee TQ. Biome-

chanical evaluation of multidirectional glenohumeral instability and repair. Clin Orthop. 2003;416:225-36.

13. Selecky MT, Tibone JE, Yang BY, McMahon PJ, Lee TQ. Glenohumeral joint translation after arthroscopic thermal capsuloplasty of the posterior capsule. J Shoulder Elbow Surg. 2003;12:242-6.

14. Harryman DT 2nd, Sidles JA, Clark JM, McQuade KJ, Gibb TD, Matsen FA 3rd. Translation of the humeral head on the glenoid with passive glenohumeral motion. J Bone Joint Surg Am. 1990;72:1334-43.

15. O'Brien SJ, Schwartz RS, Warren RF, Torzilli PA. Capsular restraints to anterior-posterior motion of the abducted shoulder: a biomechanical study. J Shoulder Elbow Surg. 1995;4:298-308.

16. Anderson K, Deng X-H, Johnson T, Altchek DW. Biomechanical analysis of posterior capsular contracture of the shoulder. American Orthopaedic Society for Sports Medicine; 2001 Keystone, CO.

17. Koffer KM, Bader D, Eager M. The effect of posterior capsule tightness on glenohumeral translation in the late cocking phase of pitching: a cadaveric study. Read at the Annual Meeting of the Arthroscopy Association of North America; 2002 Apr 25-28; Washington, DC.