Role of the superior shoulder capsule in passive stability of the glenohumeral joint

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**Background:** The shoulder capsule is the main static stabilizer of the glenohumeral joint. However, few studies specifically address the function of the superior shoulder capsule, which is usually damaged in patients with complete rotator cuff tears. Therefore, the purpose of this study was to determine the biomechanical contribution of the superior shoulder capsule to passive stability of the glenohumeral joint.

**Methods:** Seven cadaveric shoulders were tested with a custom testing system. Glenohumeral translations, subacromial contact pressure, and glenohumeral external and internal rotations were quantified at $5^\circ$, $30^\circ$, and $60^\circ$ of glenohumeral abduction. Data were compared among 3 conditions: (1) intact superior capsule, (2) after detaching the superior capsule from the greater tuberosity (tear model), and (3) after complete removal of the superior capsule from the greater tuberosity to the superior glenoid (defect model).

**Results:** A tear of the superior capsule significantly ($P < .05$) increased anterior and inferior translations compared with those in the intact capsule. Creation of a superior capsular defect significantly ($P < .05$) increased glenohumeral translation in all directions, subacromial contact pressure at $30^\circ$ of glenohumeral abduction, and external and internal rotations compared with those of the intact capsule.

**Conclusion:** The superior shoulder capsule plays an important role in passive stability of the glenohumeral joint. A tear in the superior capsule at the greater tuberosity, which may be seen with partial rotator cuff tears, increased anterior and inferior translations. A defect in the superior capsule, seen in massive cuff tears, increased glenohumeral translations in all directions.

**Level of evidence:** Basic Science Study, Biomechanics.

**Keywords:** Capsule; defect; shoulder; stability; superior; tear
shown that the superior shoulder capsule is attached to a substantial area (30% to 61%) of the greater tuberosity, suggesting that the superior shoulder capsule is an important component of the glenohumeral joint.

Articular-sided partial-thickness tears of the supraspinatus and infraspinatus tendons include detachment of the superior shoulder capsule from the greater tuberosity. Because shoulder capsule tears can lead to increases in glenohumeral translation, articular-sided partial-thickness supraspinatus and infraspinatus tendon tears may be associated with increased glenohumeral joint laxity.

In a cadaveric model of irreparable rotator cuff tear, reconstruction of the superior shoulder capsule restored superior stability of the glenohumeral joint. Furthermore, in 24 consecutive patients with irreparable rotator cuff tears who underwent arthroscopic superior capsule reconstruction, acromiohumeral distance increased from 4.6 ± 2.2 mm preoperatively to 8.7 ± 2.6 mm postoperatively, mean active elevation increased significantly from 84° to 148°, and the American Shoulder and Elbow Surgeons score improved from 23.5 to 92.9. These results suggest that the superior shoulder capsule is important for shoulder stability and function.

The shoulder capsule is well understood as the main static stabilizer of the glenohumeral joint. Previous biomechanical studies have shown that the anterior capsule (including the superior, middle, and anteroinferior glenohumeral ligaments) provides glenohumeral stability anteriorly and that the posterior capsule (including the posteroinferior glenohumeral ligament) stabilizes the glenohumeral joint posteriorly. However, the function of the superior shoulder capsule has not been directly addressed in previous studies. Therefore, the purpose of this study was to determine the biomechanical contribution of the superior shoulder capsule to passive stability of the glenohumeral joint for a superior capsule tear, commonly seen with partial supraspinatus tears, and a capsule defect, seen in massive rotator cuff tears. Specifically, glenohumeral translation, glenohumeral range of motion, and subacromial contact pressure will be quantified. We hypothesized that the superior shoulder capsule tear and the large defect will increase glenohumeral joint translation, rotational range of motion, and subacromial contact pressure.

**Materials and methods**

**Specimen preparation**

The study used 7 fresh frozen cadaveric shoulders (2 female and 5 male) from donors who were an average age of 79.7 years (range, 70-91 years) at the time of death. The specimens were thawed overnight at room temperature before testing. The shoulders were screened by means of visual inspection for signs of abnormality and pathologic changes. Each specimen was dissected free of skin, subcutaneous tissue, and all muscles; the glenohumeral joint capsule was preserved. The supraspinatus, infraspinatus, subscapularis, and teres minor were peeled away from their origins on the scapula toward their insertions on the greater or lesser tuberosity of the humerus. The superior capsule was isolated by the careful removal of the supraspinatus with a scalpel.

The separation between the supraspinatus tendon and superior capsule was clearly found with careful observation in all specimens, as described in a previous anatomic study. The width of the supraspinatus at the greater tuberosity was marked on each specimen before removal. The coracohumeral ligament, superior glenohumeral ligament, and biceps tendon were also preserved because they may be confluent with the superior capsule. After dissection, the rotator interval was opened in all specimens to ensure all specimens were vented to atmospheric pressure.

The humeral shaft was potted in polyvinyl chloride pipe (diameter, 1.5 inches) with plaster of Paris, aligning the humeral intramedullary axis with the long axis of the pipe. One screw was placed through the polyvinyl chloride pipe and humeral shaft to provide additional rigidity to the humeral fixation. The scapula was potted in plaster of Paris with the glenoid oriented parallel to the top edge of an aluminum box used for mounting the shoulder on the testing system. The shoulder then was mounted on the shoulder-testing system (Fig. 1). All specimens were kept moist with 0.9% saline throughout the experiment. Compressive force (22 N) was applied to the glenohumeral joint throughout the entire test. This was determined to be the minimum glenohumeral joint compressive force required to prevent dislocation on application of 20 N of translation loads.

**Shoulder-testing system**

A shoulder-testing system was used to measure glenohumeral translation and humeral rotation. This system allowed 6° of freedom for positioning the glenohumeral joint. Anterior–posterior and superior–inferior translations were provided by manipulating 2 translation plates. Compression–distraction was applied by using a lever arm and bearing system attached to the top translation plate, where the scapula box was mounted. The humeral cylinder was attached along the top arc of the shoulder-testing system. The angle of the arc could be adjusted to generate various degrees of shoulder abduction. The humerus could be positioned along any point of the arc, simulating horizontal...
abduction or adduction. The shoulder testing system allowed humeral rotation, which was measured with a goniometer placed at the distal end of the humerus.

Measurements

Glenohumeral rotational range of motion (ROM) was measured at 5°, 30°, and 60° of glenohumeral abduction in the scapular plane; 90° of external rotation was defined by aligning the posterior edge of the bicipital groove with the anterior edge of the acromion. The glenohumeral joint capsule was preconditioned with 10 cycles of 1.1 Nm of torque applied for 5 seconds in external and internal rotation. Maximal internal and external rotations then were measured at 2.2 Nm of torque. These torque values were determined from preliminary studies to measure humeral rotation without capsular stretching or tearing.

Glenohumeral translations were measured in 3 positions: neutral rotation at 5° and 30° of glenohumeral abduction, and at 90° external rotation at 60° of glenohumeral abduction. Translation was measured at 90° external rotation in 60° of glenohumeral abduction to simulate the late cocking phase of throwing motion. Neutral rotation of the humerus was defined as the middle position along the total rotational ROM. The reference plane and coordinate system (x, anterior–posterior; y, superior–inferior; z, medial–lateral) were defined before testing. To establish a reproducible starting point, the initial position was determined by centering the humeral head by using 22 N of joint compressive force. The amount and direction of translation relative to the initial position were quantified using the Microscribe 3DLX 3-dimensional digitizer (Revware Inc, Raleigh, NC, USA); the accuracy of this device was 0.30 mm, as determined by the manufacturer.

Before measurement of the anterior and posterior translations, the capsule was preconditioned with 10 cycles of 10 N in the anterior and posterior directions. The glenohumeral translations in the anterior and posterior directions then were measured as 20 N was applied in each direction. Preconditioning and translation measurements were repeated in the superior and inferior directions in the same manner.

Contact pressure between the coracoacromial arch (coracoacromial ligament and acromion) and humerus was recorded with an applied superior translation force of 40 N using a pressure-measuring system (model 4000, saturation pressure, 10.3 MPa; Tekscan, South Boston, MA, USA). Both of the sensor pads were used to cover the entire coracoacromial arch.

Superior capsular tear and defect models

To create the superior capsular tear model, which simulates an articular-sided partial-thickness supraspinatus tendon tear, a scalpel was used to detach the superior capsule from the greater tuberosity along the previously marked width of the supraspinatus tendon. After all measurements were obtained from the superior capsular tear model, a superior capsular defect model was created by removing the entire superior capsule to simulate an irreparable rotator cuff tear. The width of the superior capsule defect was determined as the distance between the anterior and posterior edges of the supraspinatus tendon at the greater tuberosity (Fig. 2). The anterior and posterior margins of the superior capsule defect were defined perpendicular to the articular margin of the superior capsule footprint on the greater tuberosity from the anterior and posterior torn edges in the superior capsule tear model toward the superior capsule insertion on the scapula. After an incision was made along the anterior and posterior margins of the superior capsule, the superior capsule was detached from the superior glenoid. Two observers used a digital caliper to measure the dimensions of the superior shoulder capsule; the average of the 2 values was used for analysis.

Figure 2  Testing conditions. (Left) Intact superior capsule. The superior capsule was isolated by careful removal of the supraspinatus tendon with a scalpel. The coracohumeral ligament, superior glenohumeral ligament, and biceps tendon were also preserved because they may be confluent with the superior capsule. (Middle) Superior capsule tear model. (Right) Superior capsule defect model. A, acromion; C, coracoid; GT, greater tuberosity; H, humeral head; S, superior capsule.
Data analysis

All measurements were performed twice, and the average value was used for data analyses. Statistical analyses were performed with STATISTICA 6.0 software (StatSoft, Tulsa, OK, USA). Repeated-measures analysis of variance was performed for each independent variable, including glenohumeral translation, subacromial contact pressure, and ROM. Post hoc analysis using the Fisher least significant difference test was performed to identify differences between conditions or positions when a significant main effect was found. The significance level was set at $P < .05$.

Data are presented as mean ± the standard error of the mean.

Results

A tear in the superior capsule significantly increased anterior translation at 30° glenohumeral abduction (2.5% increase, $P < .01$) and inferior translation at 60° glenohumeral abduction (4.1% increase, $P < .05$) compared with those with the intact capsule (Table I). Compared with the intact capsule, creation of a superior capsular defect significantly ($P < .05$) increased glenohumeral translation in all directions; in particular, superior translation increased at 5° (70% increase, $P < .001$) and 30° (171% increase, $P < .01$) of glenohumeral abduction.

Tearing the superior capsule led to subtle but significant ($P < .05$) increases in external rotation at 5° and 60° of glenohumeral abduction (Table II). In comparison, the superior capsule defect model showed significant ($P < .05$) increases in external and internal rotations at 5°, 30°, and 60° of glenohumeral abduction.

A tear created in the superior capsule at the greater tuberosity had no significant effect on mean subacromial contact pressure (Fig. 3). In the superior capsular defect model, mean contact pressure between the humerus and coracoacromial arch was increased significantly ($P < .05$) at 30° of glenohumeral abduction.

The average dimensions of the superior capsule defect were 24.5 ± 1.2 mm on the lateral side, 16.5 ± 3.4 mm on the medial side, 30.7 ± 3.0 mm on the anterior side, and 35.2 ± 4.7 mm on the posterior side. The average thickness of the superior capsule was 2.9 ± 0.4 mm laterally and 1.5 ± 0.2 mm medially.

Discussion

Here, we investigated the biomechanical contribution of the superior shoulder capsule to glenohumeral translation, glenohumeral ROM, and subacromial contact pressure. Articular-sided partial-thickness tears of the rotator cuff typically include detachment of the superior shoulder capsule from the greater tuberosity. In the current study, anterior and inferior glenohumeral translations increased significantly after the superior capsule was detached from the greater tuberosity. Therefore, articular-sided
partial-thickness tears of the rotator cuff may increase anterior and inferior laxity in the glenohumeral joint. Even though the changes in translation seen with the capsular tear were relatively small, any change in laxity from normal may contribute to pathologic conditions; however, the clinical implications of these increases are unknown. Previous clinical studies have shown that glenohumeral motion is increased in overhead-throwing athletes with articular-sided partial-thickness rotator cuff tears.7 This increased anterior translation is believed to be due to anterior capsular laxity,8,9 but the results of the current study suggest that laxity of the superior capsule may also cause increased laxity.

In a clinical study by Mihata et al,20 24 irreparable rotator cuff tear patients with a supraspinatus tendon tear all underwent arthroscopic superior capsule reconstruction. In this novel surgical treatment for irreparable rotator cuff tear, the defective superior shoulder capsule that results from an irreparable tear in the supraspinatus tendon is reconstructed using a fascia lata graft, without repair of the supraspinatus tendon. A biomechanical study using cadaveric shoulders showed that this reconstruction of the superior capsule normalized the stability of the glenohumeral joint in this direction.18 In the 24 consecutive patients with irreparable rotator cuff tears who underwent arthroscopic superior capsule reconstruction, acromiohumeral distance increased from 4.6 ± 2.2 mm preoperatively to 8.7 ± 2.6 mm postoperatively, mean active elevation increased from 84° to 148°, and the American Shoulder and Elbow Surgeons score improved from 23.5 to 92.9.20

Therefore, in our study, we used the width of the supraspinatus tendon for the capsule tear and defect models to enable us to assess the biomechanical role of the superior shoulder capsule beneath the supraspinatus tendon. In the superior capsular defect model, glenohumeral translation increased in all directions, particularly superiorly, compared with those in the intact capsule. Subacromial contact pressure at 30° of glenohumeral abduction also increased. These results suggest that a superior capsular defect that spans from the greater tuberosity laterally to the superior glenoid medially increases glenohumeral laxity, potentially leading to secondary cuff tear arthropathy, as has been previously postulated.22

With the supraspinatus tendon, the superior capsule is thought to have a spacer effect under the acromion.27 In support of this hypothesis, we found that the increase in superior translation after complete removal of the superior capsule was similar to the thickness of the superior capsule. However, the superior capsular defect significantly increased glenohumeral translations anteriorly, posteriorly, and inferiorly, as well as superiorly, and also increased glenohumeral external and internal rotations and increased subacromial contact pressure. These findings together suggest that the superior capsule works not only as a spacer but also as a stabilizer in the glenohumeral joint.

The current study had several limitations. First, we used a static testing model that enabled us to evaluate only the effect of the osseous, labral, and capsular tissues on
biomechanical and kinematic parameters. No loads were applied to any of the muscle–tendon units. However, we believe that we were able to investigate the role of the superior capsule in the passive stability of the glenohumeral joint because the shoulder capsular ligaments are the main static stabilizers of this joint.2,4,24-26,30,32

Second, we investigated only the effect of the superior capsule under the supraspinatus tendon because most irreparable rotator cuff tears include tears of this tendon. Larger tears or defects may have greater effects on glenohumeral stability, and additional studies are necessary to better understand the pathomechanics of irreparable rotator cuff tears.

Third, we studied only at 5°, 30°, and 60° of glenohumeral abduction positions. The superior shoulder capsule loosens at higher abduction angles; therefore, we believe that our tested positions were reasonable to investigate the effect of superior capsule on shoulder biomechanics.

The fourth limitation is that the cadaveric specimens in this study were an average age of 79.7 years (range 70-91 years), which is older than some patients with rotator cuff tears. Lee et al10 reported that older specimens are appropriate for nondestructive biomechanical studies because the stiffness in the functional range of the shoulder capsular ligament was similar between the younger and older groups.

Fifth, the acromion and coracoacromial ligament were preserved in this study. However, some surgeons perform acromioplasty and release of the coracoacromial ligament with rotator cuff surgery. Further studies are needed to evaluate the effect of acromioplasty.

Conclusions

The superior shoulder capsule may play an important role in passive stability of the glenohumeral joint. A tear of the superior capsule from the greater tuberosity, which may be seen with partial rotator cuff tears, significantly increased anterior and inferior translations. A superior capsular defect that spanned from the greater tuberosity laterally to the superior glenoid medially, as in massive cuff tears, significantly increased glenohumeral translations in all directions.

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