Original Article

Anterior Bankart Repair With Superior Capsular Plication Causes Increased Mean Tension in Posterior Glenohumeral Capsule

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Purpose: The purpose of this study is to investigate if a biomechanical difference exists in the prerepair and postrepair states of the posterior inferior glenohumeral ligament (PIGHL) following anterior Bankart repair with respect to capsular tension, labral height, and capsular shift. **Methods:** In this study, 12 cadaveric shoulders were dissected to the glenohumeral capsule and disarticulated. The specimens were loaded to 5-mm displacement using a custom shoulder simulator, and measurements were taken for posterior capsular tension, labral height, and capsular shift. We measured the capsular tension, labral height, and capsular shift of the PIGHL in its native state and following repair of a simulated anterior Bankart lesion. **Results:** We found that there was a significant increase in the mean capsular tension of the posterior inferior glenohumeral ligament ($\Delta = 2.12 \pm 2.10$ N; $P = .005$), as well as posterior capsular shift ($\Delta = .362 \pm 0.365$ mm; $P = .018$). There was no significant change in posterior labral height ($\Delta = 0.297 \pm 0.667$ mm; $P = .193$). These results demonstrate the sling effect of the inferior glenohumeral ligament. **Conclusion:** Although the posterior inferior glenohumeral ligament is not directly manipulated during an anterior Bankart repair, when the anterior inferior glenohumeral ligament is plicated superiorly, some of the tension is transmitted to the posterior glenohumeral ligament as a result of the sling effect. **Clinical Relevance:** Anterior Bankart repair with superior capsular plication results in an increased mean tension of the PIGHL. Clinically, this may contribute to shoulder stability.

Introduction

The inferior glenohumeral ligament (IGHL) consists of an anterior and posterior band, joined by the axillary pouch between them. The anterior band attaches proximally between 2 and 4 o'clock on the glenoid rim, while the posterior band attaches between 7 and 9 o'clock.[1] The anterior inferior glenohumeral ligament (AIGHL) is the most important anterior stabilizer when the arm is in abduction and external rotation. It has been shown to have the highest tensile strength of all the fibers in the inferior glenohumeral ligament.[1] Conversely, the posterior inferior glenohumeral ligament (PIGHL) functions as a posterior stabilizer with the arm in flexion and internal rotation.[2]

Previously, it had been thought that the attachment of the IGHL to the humerus has two distinct morphologies: a C-shaped "collar" attachment or a V-shaped attachment pointing inferiorly.[3,4] More recently, however, it has been discovered that the IGHL attaches to the humerus with a V-shape when viewed from the outside, but it consistently attaches with a C-shape close to the border of the articular cartilage when viewed intra-articularly.[5,6] Studies have also shown that there are variations in the thickness of the glenohumeral ligament. The inferior part of the capsule is consistently thicker than the superior part. Additionally, the thickened part of the inferior capsule extends superiorly along the borders of the glenoid and humeral neck.[6] The IGHL is thicker at the glenoid origin compared to

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The authors report the following potential conflicts of interest or sources of funding: R.A.A. reports speaking fees from Arthrex and consulting fees from Smith & Nephew, outside the submitted work. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received October 8, 2022; accepted January 27, 2023.

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2666-061X/221265

https://doi.org/10.1016/j.asmr.2023.01.017

its humeral attachment (mean thickness 2.3 mm vs. 1.6 mm, respectively).[7]

This configuration of the inferior glenohumeral ligament is responsible for providing the sling effect, in which forces can be redistributed bidirectionally from anterior to posterior or vice versa to prevent any one location of the inferior glenohumeral ligament from experiencing excess strain during dynamic motion. Overall shoulder stability is determined by a complex interaction between active stabilizers, such as the rotator cuff muscles and the long head of the biceps and passive stabilizers, such as the bony, cartilaginous, capsular, and ligamentous structures of the shoulder. As such, it is difficult to quantify the contribution from any one stabilizing structure in isolation.

Studies have been performed to evaluate the biomechanical changes in the AIGHL before and after a Bankart repair; however, little is known about any biomechanical changes that may be present in the PIGHL. The purpose of this study is to investigate whether a biomechanical difference exists in the prerepair and postrepair states of the PIGHL following anterior Bankart repair with respect to capsular tension, labral height, and capsular shift. We hypothesize that the tension in the PIGHL will increase without a resultant change in labral height or capsular shift.

Methods

This study was exempt from Institutional Review Board approval at our institution. Twelve frozen human cadaveric shoulders were obtained (MedCure Inc., and Science Care). Each specimen served as its own control for comparing prerepair and postrepair states. The bone mineral density of each specimen at the anterior inferior glenoid rim was measured using a DEXA scan (Lunar DPI XQ Dexascan, GE Healthcare).

Prior to dissection, specimens were allowed to thaw for 24 hours. The skin and soft tissues were removed carefully to preserve the glenohumeral capsule. To disarticulate the glenohumeral joint, we removed the glenohumeral ligament from its insertion around the humeral neck. Any specimen that was identified as having a preexisting injury to the labrum or glenohumeral ligament was excluded from the study. Following dissection, specimens were potted in a 3 × 2 × 3 in rectangular mold using bone cement. The scapular body was placed in the mold, ensuring that the horizontal axis of the glenoid face was parallel with the edge of the mold, and the vertical axis of the glenoid face was perpendicular to the ground.

Next, the locations of the AIGHL and PIGHL were identified, and high tensile sutures (no. 2 FiberWires, Arthrex, Naples, FL) were placed in the center of these structures at a distance of 2 cm from the edge of the glenoid using a figure-of-8 technique. Additional tensile sutures were placed 2 cm from the glenoid in locations 1 hour superior and inferior to the central ones, using the anatomic clock face described by Dekker et al.[8] In total, 6 sutures were placed to allow for uniform loading of the entire inferior glenohumeral ligament. Next, additional nonabsorbable sutures (4-0 FiberWire, Arthrex) were placed at the 6:30, 7:30, and 8:30 positions at the capsulolabral junction. A similar arrangement was placed on the anterior side at 3:30, 4:30, and 5:30 to serve as a control. The purpose of these sutures was to provide reference points to allow for consistent, reproducible measurements of the labral height by placing the tip of the MicroScribe at the locations where the sutures pierce the tissue to perform each measurement. The placement of the loading and marking sutures is shown in Fig 1.

Once the preparation was complete, the potted scapula was mounted securely to the custom shoulder simulator[9] using a level to ensure that the vertical axis of the glenoid was perpendicular to the ground. The loading sutures were attached to adjustable tension screws in series with linear screw-driven actuators (Bimba, Monee, IL), which were connected to 444 N load cells (Futek, Irvine, CA). Data from the load cells were monitored with Sens it V2.5.10 software (Futek). The load cells have a reported accuracy of ± 0.1 N, and laboratory accuracy was confirmed to be ±0.08 N using precision weights and comparing the load cell measurement to the value of the known weight attached to

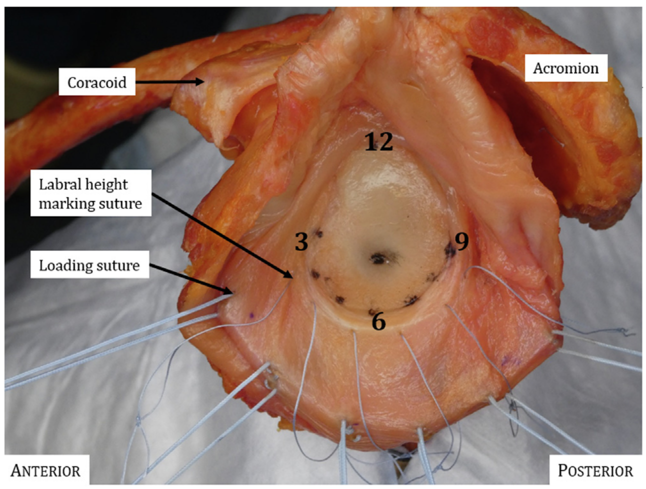

Fig 1. Location of loading and marking sutures. Glenoid clock face descriptions are shown for a left shoulder. The standard clock face is used to describe a right shoulder, with 3 o'clock always referring to the anterior direction and 9 o'clock always referring to the posterior direction. Loading sutures were placed 2 cm from the glenoid in the center of the anterior inferior glenohumeral ligament and posterior inferior glenohumeral ligament and then 1 hour superior and inferior to each, for a total of 6. Labral height marking sutures were placed at the capsulolabral junction at the 3:30, 4:30, 5:30, 6:30, 7:30, and 8:30 positions.

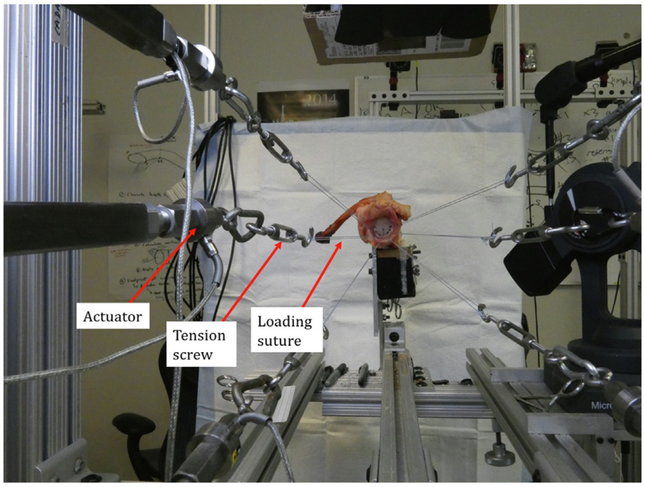

Fig 2. Custom shoulder simulator. Loading sutures were connected in line with tensionable screws to each actuator. Load cells are not pictured. Each actuator was positioned to pull in the direction of the native fibers of the anterior inferior glenohumeral ligament and posterior inferior glenohumeral ligament.

it. The actuators were positioned to allow for tensioning of the AIGHL and PIGHL in the same direction as their fibers. The setup of the custom shoulder simulator can be seen in Fig 2.

The tension of each actuator was adjusted to 2 N in order to remove slack from the glenohumeral ligament without overstretching it. Each specimen was preconditioned by pulling the loading sutures to 5 mm of displacement in the same direction as the vector of each ligament for 25 cycles at 0.1 Hz. Following preconditioning, the loading sutures were held at 5 mm displacement to measure the capsular tension, labral height, and capsular shift in its native state. After the measurements were obtained, a simulated anterior Bankart lesion was made using a scalpel to detach the labrum from the glenoid rim between the 3:00 and 6:00 positions. Following creation of the Bankart lesion, the tension in each actuator was reset to 2 N, and the specimen was loaded to 5-mm displacement for 10 cycles at 2 Hz. Although holding 5 mm of displacement, measurements of the capsular tension, labral height, and capsular shift were recorded for the PIGHL. Next, the lesion was repaired following accepted surgical procedures.[9] Three suture anchors were placed according to the manufacturer's guidelines from inferiorly to superiorly at the 5 o'clock, 4 o'clock, and 3 o'clock positions. The glenohumeral ligament was plicated by grabbing tissue one half hour inferiorly from the placement of the suture anchor (i.e., 5:30 for the 5 o'clock anchor) to incorporate a superior capsular shift. All repairs were performed by the same orthopedic surgeon. Following the repair, another round of measurements were collected, as described above. Capsular tension was calculated by taking the mean tension in each of the three posterior loading sutures.

Data for the labral height and capsular shift were collected using a MicroScribe G2X 3D digitizer device (Revware, Raleigh, NC) and Rhino 5 software (Robert McNeel & Associates, Seattle, WA). The MicroScribe digitizer has a reported accuracy of ± 0.229 mm with a laboratory confirmed accuracy of ±0.3 mm, determined by measuring known distances on a ruler and comparing to the MicroScribe's output. A localized coordinate system was set up with the *x*-axis in the anterior-posterior direction, the *y*-axis in the superior-inferior direction, and the *z*-axis in the medial-lateral direction. The labral height was calculated as the difference in the *z*-coordinate from the center of the glenoid to each of the three marking sutures in the posterior capsulolabral junction in its native state, following creation of the Bankart lesion, and after completion of the repair. Capsular shift was calculated by taking the difference of the *y*-coordinate of the loading suture placed centrally in the PIGHL in its native state and after completion of the repair.

We calculated the means and standard deviations for posterior capsular tension, labral height, and capsular shift. Comparisons of the native and postrepair states were performed using each specimen as its own control. Results are reported as mean differences with corresponding 95% confidence intervals. A *P* value of <0.05 was considered significant. Analysis was performed with Stata 15 Software (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC).

Results

A total of 12 specimens were included in this study (age: 55.5 ± 6.8 years; bone mineral density: 0.589 ± 0.124 g/cm^2). A summary of the results is shown in Table 1.

There was a significant increase in the posterior capsular tension at 5-mm displacement between the native and postrepair states (Δ = 2.12 N; 95% CI: 0.937 to 3.31 N; *P* = .005). The average tension of the PIGHL in its native state was 18.61 ± 4.51 N. Following simulation of an anterior Bankart lesion, the average tension of the PIGHL was 17.69 ± 4.18 N. After completion of the anterior Bankart repair, the average tension of the PIGHL was 20.74 ± 4.46 N. Figure 3 shows the change in tension for each specimen between its native and postrepair state. One of the specimens saw an increase of 7.11 N between the native and postrepair states while the next biggest difference was 3.85 N. Even if this outlier is ignored, there is still a significant difference present between the two groups (Δ = 1.67 N; 95% CI: 0.845 to 2.50 N; *P* = .004).

There was no significant difference in the posterior labral height between the native and postrepair states

Table 1. Summary of Results

	Capsular Tension (N)	Labral Height (mm)	Capsular Shift (mm)
Native	18.61 ± 4.51	5.49 ± 1.45	0 (reference)
Defect	17.69 ± 4.18	5.90 ± 1.28	0.0867 ± 0.868
Repair	20.74 ± 4.46	5.78 ± 1.34	0.362 ± 0.365
Difference between native and repair	2.12 ± 2.10	0.297 ± 0.667	0.362 ± 0.365
P value	.005	.193	.018

Data are presented as means ± SD.

(Δ = 0.297 mm; 95% CI: −0.080 to 0.674 mm; *P* = .193). The average posterior labral height in its native state was 5.49 ± 1.45 mm. Following simulation of a Bankart lesion, the average posterior labral height was 5.90 ± 1.28 mm. After completion of the repair, the average posterior labral height was 5.78 ± 1.34 mm.

There was a significant difference in the superior capsular shift of the PIGHL between the native and postrepair states (Δ = 0.362 mm; 95% CI: 0.155 to 0.569 mm; *P* = .018). The initial location of the *y*-coordinate (vertical axis) of the PIGHL was considered as the reference point and set to a value of zero. A positive change in this value represents superior translation, while a negative change represents inferior translation. Generally, after creation of the Bankart lesion, we observed superior translation of the PIGHL, and after completion of the repair, the PIGHL continued to translate superiorly.

Discussion

The results from this study supported our hypothesis that Bankart repair incorporating a superior capsular shift would cause an increase in the tension of the PIGHL due to the sling effect of the inferior glenohumeral ligament. Following repair of a Bankart lesion, the tension in the PIGHL increased by an average of 2.12 N. The PIGHL is not directly manipulated during a Bankart repair, but it is continuous with the AIGHL, which is plicated superiorly to remove excess laxity and improve anterior instability. This is an important step of the procedure because undertensioning of the AIGHL may lead to recurrent anterior glenohumeral instability, while overtensioning of the AIGHL may lead to decreased range of motion of the glenohumeral joint.

Previously, studies have demonstrated that anterior capsular plication results in increased stability compared to labral repair alone.[10,11] Further studies have demonstrated that there is no advantage in incorporating a posterior plication in addition to an anterior plication for addressing anterior instability.[12] Penna et al.[13] demonstrated that the forces experienced at the glenoid-labrum interface are greater when a capsular shift is included in the repair compared to labral repair alone. They found that with passive abduction and external rotation, the average tension at the antero-inferior capsulolabral junction was 4.59 N for labral repair alone versus 17.67 N for labral repair with capsular shift. For comparison, previous cadaveric studies have demonstrated that the load to failure of the inferior glenohumeral ligament is 712.9 ± 238.2 N.[14] Diop et al.[15] found that in a simulated 270° labral tear from 12 to 9 o'clock, there was no significant difference in the anterior glenohumeral ligament tension with repair from 12 to 6 o'clock versus repair from 12 to 9 o'clock. However, they did find that there was a significant increase in the posterior glenohumeral ligament tension in the posterior and inferior directions for the combined anterior and posterior repair compared to anterior repair only.

Most studies that have evaluated outcomes of Bankart repairs have a younger patient population than the specimens used for this study. A meta-analysis of 29 studies by Verweji et al.[16] found that the mean age at the time of shoulder stabilization surgery was between 18.3 and 35.5 years. The mean age of the specimens included in this study was 55.5 years. Therefore, results should be extrapolated to patients carefully.

There is an increase in the tension of the PIGHL as a result of anterior Bankart repair. The magnitude of this difference (2.12 N) is small compared to the overall strength of the inferior glenohumeral ligament. Presently, it is unclear what clinical significance this has on long-term clinical outcomes. It is accepted that overtightening of the AIGHL during Bankart repair leads to

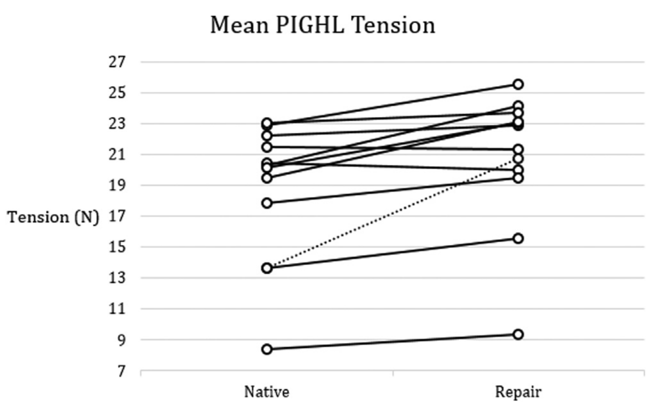

Fig 3. Mean posterior inferior glenohumeral ligament (PIGHL) tension for each specimen before creation of Bankart defect and after repair. The dashed line represents the outlier which increased in tension almost twice as much as any other specimen.

decreased range of motion of the glenohumeral joint. The presence of the sling effect may potentially amplify or mitigate this risk, as some of the increased tension is transmitted to the PIGHL.

We were expecting to see either no change or an inferior translation of the PIGHL, but we hypothesize that the reason we observed superior translation of the PIGHL following superior plication of the AIGHL may be due to stretching of the capsule during the period of time between the creation of a labral defect and its repair. After creating the defect, the capsule was uniformly loaded according to protocol to collect data regarding its tension. It is possible that the tissue in the PIGHL experienced plastic deformation as a result of the stress concentration in this area due to the presence of a simulated Bankart lesion anteriorly. It is important to note that the dynamic stabilizers of the glenohumeral joint were removed, which may have contributed to these observations as well. The overall magnitude of the change that we observed (0.362 mm) is small when compared to the reported accuracy (± 0.229 mm), and laboratory confirmed accuracy (±0.3 mm) of the MicroScribe digitizer that we used to record these measurements. Further testing is needed to investigate whether this superior translation of the PIGHL can be reproduced under conditions that more closely match the natural physiology of the glenohumeral joint.

Limitations

This study is not without limitations. The rotator cuff muscles and their tendinous insertions were dissected off of the specimens in order to expose the glenohumeral ligament and to allow for integration with our loading simulator. These muscles are important dynamic stabilizers of the glenohumeral joint, and their presence in vivo may account for differences in the glenohumeral ligament tension. Additionally, this study was unable to evaluate any changes that may result from the healing process that would take place in vivo.

Conclusion

Although the posterior inferior glenohumeral ligament is not directly manipulated during an anterior Bankart repair, when the anterior inferior glenohumeral ligament is plicated superiorly some of the tension is transmitted to the posterior glenohumeral ligament as a result of the sling effect.

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