Biomechanical Properties of Labral Repair: Simple Versus Vertical Suture Pattern

JASON HANNA, MD; AMANDA O. ESQUIVEL, PhD; DAVID LEMOS, MD; NIKHIL G. PANDHI, DO; JEFFREY S. STARON, MD; STEPHEN E. LEMOS, MD, PhD

abstract

The goal of this study was to evaluate contact area and surface pressure as a result of different suture patterns in the treatment of anterior shoulder instability caused by a Bankart lesion. Loads were applied through the humeral head to the glenoid surface in the intact shoulder and after simple suture labral repair (n=10) and vertical mattress labral repair (n=9). Peak contact pressure, mean contact pressure, and contact area were recorded for 0°, 45°, and 90° shoulder abduction, and then the repair was loaded to failure. A significant increase (P<.05) in mean contact pressure and peak contact pressure occurred in both repair groups at 90° abduction. No difference was seen between the 2 repair groups. Total contact area significantly decreased after both repairs at 90° abduction at 220 N force (P<.05). No significant difference occurred in load to failure between the groups. Joint loading properties can be affected by alterations in contact pressure within the glenohumeral joint. In the current study, the authors found no significant difference in contact pressure between the 2 repair groups. However, they found a significant increase in mean contact pressure and peak pressure between the intact specimen and the 2 repair groups. Both simple repair and vertical mattress repair provided similar load to failure for labral repair. Current techniques used to perform Bankart repair may need to be altered to provide the stability of current techniques with more normal glenohumeral joint contact pressure. [Orthopedics. 2015; 38(2):81-86.]
Traumatic shoulder instability is a significant cause of morbidity after anterior shoulder dislocation. The “essential lesion” that results from anterior shoulder dislocation is a Bankart lesion. Bankart lesions occur when the anterior labrum detaches from the glenoid rim. They are often the result of a traumatic shoulder injury involving subluxation or dislocation of the glenohumeral joint. These lesions can increase translation of the humeral head and impair its self-centering ability on the glenoid. This may result in anterior shoulder instability. Further, changes in joint loading mechanics may occur and subsequently lead to degenerative changes at the articular surface.

Open treatment traditionally has been the standard of care for Bankart lesions. However, as discussed by Pope et al, an arthroscopic staple technique for repairing these lesions was performed by Johnson in 1982. Further arthroscopic techniques included a transosseous suture technique, rivet fixation, and use of the Suretac (Acufex Microsurgical, Mansfield, Massachusetts). Arthroscopic Bankart repair has continued to evolve with the advent of suture anchors and different suture patterns, such as simple, vertical mattress, and horizontal mattress repair. In addition, the location of fixation on the glenoid and various capsular plication techniques have been debated.

The biomechanical properties of various repair techniques have also been examined. Mohammed et al studied the biomechanical performance of 3 labral reconstruction techniques, and Nho et al considered the biomechanical properties of 4 suture techniques for labral repair. However, to the authors’ knowledge, no study has evaluated the changes in glenohumeral contact area and pressure after labral repair.

Multiple studies have examined articular pressure and contact area in the normal intact glenohumeral joint. Soslowsky et al used a stereophotogrammetry technique to evaluate contact area in a cadaver model with intact ligaments and capsule. They found great variability in contact area with differing amounts of shoulder elevation and internal and external rotation. Conzen and Eckstein found that maximum pressure in a shoulder joint occurs at 90° abduction and 90° external rotation and that joint pressure depends on subtle variations in joint incongruity. Greis et al quantified the decrease in contact area and the increase in contact pressure after glenoid labral loss and varying amounts of glenoid bone loss.

Although shoulder biomechanics before and after Bankart lesions have been evaluated, the pressure measured at the glenohumeral joint after repair has not been examined. It is possible that a knot secured on the inside of the glenohumeral joint, which can occur during simple repair, can cause point pressure. The goal of this study was to evaluate contact area and surface pressure caused by different suture patterns in the treatment of anterior shoulder instability as a result of a Bankart lesion. It was hypothesized that the simple suture pattern would have a significant increase in peak contact force compared with the intact joint. The authors also evaluated the force at failure and the stiffness of each repair. The authors’ secondary hypothesis was that vertical mattress suture repair of a Bankart lesion would result in load to failure and stiffness similar to those with simple suture repair.

MATERIALS AND METHODS

A total of 20 fresh-frozen human cadaveric shoulders were used to determine load to failure. Nineteen shoulders were used to analyze the change in contact pressure before and after repair; 1 shoulder in the vertical repair group could not be used because of failure of the pressure sensor. All soft tissues were dissected from the humerus and glenoid except for the glenoid labrum and capsule. The humerus was cut 5 cm distal to the greater tuberosity and potted in an aluminum cylindrical pot with a polyester resin material (Bondo; 3M, Minneapolis, Minnesota). The scapula was cut 3 cm medial and parallel to the glenoid articular surface and fixed in a custom-built aluminum fixture. The same template was used for all specimens. The glenoid was marked at 3, 4, 5, and 6 o’clock for the right shoulders and at 6, 7, 8, and 9 o’clock for the left shoulders. The area directly superior on the glenoid was chosen as 12 o’clock. Specimens were kept moist with normal saline-soaked gauze.

Before creation and subsequent repair of the Bankart lesion, baseline pressure measurements were taken for each specimen with a materials testing machine (Instron 1321; Instron Corporation, Canton, Massachusetts) and a Tekscan pressure mapping sensor (I-Scan; Tekscan, South Boston, Massachusetts). The Tekscan (Tekscan, South Boston, Massachusetts) is placed on the glenoid surface.
Both the humerus and the glenoid were secured to the Instron (Figure 1). With the use of a level, the glenoid articular surface was placed parallel to the ground. For each position of shoulder abduction, the glenoid was allowed to self-center on the humeral head. The I-Scan pressure mapping system was used, and an appropriate sensor (Pressure Sensor Model 5051; Tekscan) was calibrated and placed on the glenoid surface. Loads of 220 N and 440 N (3 times for each load) were then applied through the humeral head to the glenoid surface. Peak contact pressure, mean contact pressure, and contact area were recorded for 0°, 45°, and 90° shoulder abduction.

Specimens were randomly assigned to 1 of 2 repair groups, either simple suture labral repair or vertical mattress labral repair. A Bankart lesion was created in each specimen with the use of a No. 15 blade to raise a periosteal flap of labrum and capsule from the antero-inferior quadrant. Titanium corkscrew suture anchors (4.5 mm; Arthrex, Naples, Florida) loaded with No. 2 FiberWire (Arthrex) were placed 5 mm posterior to the glenoid rim at the 3, 4, and 5 o’clock positions on the right shoulders and at the 7, 8, and 9 o’clock positions on the left shoulders. For the simple suture repair group, 1 limb of suture was passed through the capsulolabral junction 5 mm inferior to each anchor position. Knots were then tied with 2 half-hitches in the same direction, switching the post and locking the knot, followed by 3 alternating half-hitches. All sutures were cut with the same arthroscopic knot cutter. For the vertical mattress suture repair group, the labrum was divided into thirds 5 mm inferior to each suture anchor position. One limb was passed through the labrum at the two-thirds position, and the other limb was passed through the labrum at the one-thirds position. Knots were then tied and cut as noted earlier (Figure 2).

The pressure testing protocol was repeated (Figure 3), and the repair was loaded to failure. The anterior inferior quadrant of the labrum was sewn to Dacron webbing (Xiamen Jude Belt Company, Ltd, Houxi Industrial District, Jimei Area, Xiamen, China) in Krackow fashion. The tissue-webbing complex was secured to the actuator of the materials testing machine with a clamp. The specimens were pretensioned to 5 N and then pulled to failure at 15 mm/min. This protocol was similar to the one used by Nho et al. Load at failure was determined for each specimen, and displacement at that load was recorded. Stiffness was calculated for each specimen after testing by calculating the slope of the line in the linear portion of the force-displacement curve.

Statistical Analysis

Peak contact pressure, mean contact pressure, and contact area before and after repair were recorded by the I-Scan. Intact values were compared with repaired values with 2-tailed paired Student’s t test. Repair groups were compared with 2-tailed Student’s t test. Average values and standard error for each group were determined. Data were compared with 2-tailed Student’s t test. All data were considered significant at P<.05.
**Feature Article**

**RESULTS**

At 90° abduction at 220 N force, mean contact pressure increased significantly ($P<.05$) from 0.4 MPa in the intact state to 0.45 MPa after simple repair and from 0.35 MPa in the intact state to 0.41 MPa after vertical repair. A significant increase ($P<.05$) also occurred in peak contact pressure for both groups at 90° abduction (from 1.85 MPa to 2.33 MPa in the simple repair group and from 1.74 MPa to 2.23 MPa in the vertical repair group). When 440 N force was applied, a significant increase ($P<.05$) in mean contact pressure and peak contact pressure was noted in both repair groups at 90° abduction (Figure 4). Mean contact pressure increased from 0.56 MPa to 0.64 MPa for simple repair and from 0.49 MPa to 0.54 MPa for vertical repair. Peak contact pressure increased from 1.74 MPa intact to 2.23 MPa after simple repair and from 2.25 MPa intact to 2.73 MPa after vertical repair (Figure 4).

A significant increase ($P<.05$) in peak contact pressure after repair was also noted for both groups when the specimen was placed in 45° abduction at 220 N force (Figure 5), but no significant increase occurred at 440 N. No significant increase was found in mean contact pressure and peak contact pressure for both repair groups with the specimen at 0° abduction at 220 N force or 440 N force. Total contact area (Figure 6) significantly decreased after both repairs at 90° abduction at 220 N force ($P<.05$). No significant difference in peak contact pressure or mean contact pressure was seen between the 2 repair groups ($P>.05$).

Specimens also underwent a single load to failure test. The average load was 356 N (SEM, 39 N) for the simple repair group and 396 N (SEM, 48.5 N) for the vertical repair group. This difference was not significant ($P=.79$). No significant difference ($P=.43$) was found in stiffness between the simple repair group (38 N/mm; SEM, 2.7 N/mm) and the vertical repair group (40 N/mm; SEM, 3.8 N/mm) (Table).

**DISCUSSION**

The findings showed no significant difference in contact pressure between the 2 repair groups. However, a significant increase was noted in mean contact pressure and peak pressure between the intact specimen and the 2 repair groups at 90° abduction. Total contact area significantly decreased after both repairs at 90° abduction at 220 N force. The authors also found a significant increase in peak pressure at 45° abduction at both the 220 N and 440 N loads. No significant increase was found in either loading condition at 0° abduction. Further, both repairs had similar values for load to failure. Therefore, the findings suggest that both simple re-
pair and vertical mattress repair provided equivalent strength for labral repair and that both increased contact pressure at the glenohumeral articular surface at 45° and 90° abduction.

Multiple studies examined articular pressure and contact area in the glenohumeral joint. In 1992, Soslowsky et al used a stereophotogrammetry technique to evaluate contact area in a cadaver model with intact ligaments and capsule. They found great variability in contact area with differing shoulder elevation and internal and external rotation. In 1998, using a cadaver model, Warner et al found that as the shoulder was abducted, the humeral head became more congruent with the glenoid, contact area increased, and contact pressure decreased. The current study showed that as abduction increased from 0° to 90°, contact area increased and contact pressure decreased. These changes occurred before and after repair. In another cadaver study, Conzen and Eckstein found that maximal pressure in a shoulder joint occurs at 90° abduction and 90° external rotation and that joint pressure depends on subtle variations in joint incongruity.

Injuries and surgical procedures have the potential to change contact pressure and peak force inside the glenohumeral joint. Greis et al investigated changes in articular contact area and pressure across the glenohumeral joint with progressive loss of the labrum and glenoid. They found an increase in mean contact pressure with loss of the anteroinferior labrum. In addition, loss of the anteroinferior labrum resulted in a mean increase of 53% in mean contact pressure when the anteroinferior quadrant of the glenoid was analyzed separately. These alterations result in changes in joint loading mechanics and may ultimately hasten the degenerative process at the articular surface.

Hovelius and Saeboe reported the radiographic findings of 223 shoulders at 25 years of follow-up. They found that the surgically stabilized shoulders had less arthropathy than those with recurring dislocations that became stable over time. Arthropathy in the operated shoulders was not different than that in shoulders with only a single dislocation event. Despite these findings, glenohumeral arthrosis has been reported after Bankart repair. Kavaja et al found radiographic evidence of arthrosis in 68% of shoulders at an average of 13 years of follow-up with repair using a bioabsorbable tack. Most (80%) of these cases were mild arthrosis. Privitera et al also found a 40% incidence of arthrosis at an average of 13.5 years of follow-up after Bankart surgery using tacks. One study examined arthrosis after suture anchor repair and found a 21.8% rate of postoperative arthritis at a minimum of 5 years of follow-up. The change in contact pressure and contact area after Bankart repair has not been examined as a possible contributing factor to shoulder joint degeneration.

Nho et al conducted a controlled laboratory study to investigate the biomechanical properties of 4 repair techniques: a simple stitch, a knotless suture anchor, a horizontal mattress suture pattern, and an additional simple suture pattern using a double-loaded anchor. The 3 configurations that used a suture anchor were significantly stronger than the knotless suture anchor, and a significant difference was not noted among the other 3 configurations. The authors also found no difference in load to failure between the simple repair group and the vertical repair group. In addition, most failures in both groups occurred as a result of tissue failure. This finding suggests that both repair...

### Table

Average Peak Load, Stiffness, and Displacement for the Repair Groups

<table>
<thead>
<tr>
<th>Repair</th>
<th>Peak Load, N (±SEM)</th>
<th>Stiffness, N/mm (±SEM)</th>
<th>Displacement, mm (±SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average simple repair</td>
<td>356.5 (39.3)</td>
<td>38 (2.7)</td>
<td>12.6 (1.4)</td>
</tr>
<tr>
<td>Average vertical repair</td>
<td>396.3 (48.5)</td>
<td>39.7 (3.8)</td>
<td>13.2 (1.2)</td>
</tr>
</tbody>
</table>

*No significant difference was found between simple and vertical repairs.*
patterns provide equivalent strength for labral repair. A clinical study examining the long-term results after arthroscopic shoulder surgery using suture anchors found a trend indicating that the number of suture anchors affected recurrent instability. It is possible that the number of suture anchors is more important than the suture pattern in providing adequate fixation strength. In the current study, the same number of suture anchors was used in each group.

This study had several strengths. All specimens were dissected and prepared in a similar fashion. The Bankart lesion and labral repair were performed by the same orthopedic surgeon (J.H.), using the same instruments, suture material, knot-tying techniques, and testing protocols. To the authors’ knowledge, this is the first study to examine contact pressure before and after Bankart repair. The finding that contact pressure increased in the articular surface of the glenohumeral joint is important. Increased peak contact pressure has been associated with damage to articular cartilage. Although operating on unstable shoulders reduces the risk of arthropathy, closely mimicking preinjury glenohumeral joint contact pressure and stability should be the goal after Bankart repair.

Capsular, ligamentous, and tendinous attachments dissected from the specimen have the potential to affect glenohumeral contact pressure. In addition, this was a static model. With the extent of soft tissue dissection and the mode of testing, data could not be gathered dynamically. Also, the Tekscan cannot measure shear force. Although all specimens were examined for glenohumeral disease, it is impossible to know the true status of the articular cartilage through gross inspection. Further, only 3 positions of shoulder abduction and 1 position of shoulder rotation were evaluated. That is only a small sampling of possible positions of the glenohumeral joint.

**CONCLUSION**

Joint loading properties can be affected by alterations in contact pressure within the glenohumeral joint. The current study found no significant difference in contact pressure between the 2 repair groups. However, the authors found a significant increase in mean contact pressure and peak pressure between the intact specimen and the 2 repair groups. Both simple repair and vertical mattress repair provided a similar load to failure for labral repair. Current techniques used to perform Bankart repair may need to be altered to provide the stability of current techniques but with more normal glenohumeral joint contact pressure.

**REFERENCES**