Glenohumeral articular contact areas and pressures following labral and osseous injury to the anteroinferior quadrant of the glenoid

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The objective of this study was to determine the effect of progressive labral and bone loss on the articular contact area and pressures across the glenohumeral joint under compressive loads of 220 and 440 N. Eight fresh-frozen cadaver shoulders were used, and contact pressures in 4 quadrants of the glenoid were determined with a Tekscan flexible tactile force sensor. Testing conditions included intact glenoids, glenoids with the anteroinferior labrum removed, and glenoids with 3 sizes of bone defects in the anteroinferior quadrant. By means of Tekscan sensing equipment, the measured contact area over the glenolabral complex was between 49.0% and 61.5% of the calculated surface area for the intact specimens. Loss of the anteroinferior labrum decreased contact area by 7% to 15% compared with the intact specimens, and the mean contact pressure increased by 8% to 20%. With bone loss corresponding to a defect measuring 30% of the diameter in the anteroinferior quadrant, contact area across the entire glenoid decreased a mean of 41% compared with the intact specimens, whereas the mean contact pressure increased nearly 100%. When the anteroinferior quadrant of the glenoid was analyzed separately, loss of the anteroinferior labrum alone resulted in an increase in the mean contact pressure in this quadrant compared with the intact specimens (mean, 53%). Bone loss of 30% of the diameter resulted in mean contact pressures in this quadrant increasing by 300% to 400% compared with the intact specimens, with 2 of 8 specimens becoming grossly unstable. In addition, with 30% diameter bone loss, the mean contact pressure decreased by 26% in the posterosuperior quadrant, indicating a shift in loading of the cadaveric glenoid. Peak pressures followed similar trends, with labral loss alone increasing peak pressures in the anteroinferior quadrant by a mean of 28% of that seen for the intact specimens. (J Shoulder Elbow Surg 2002;11:442-51.)

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INTRODUCTION

Stability of the glenohumeral joint relies upon a variety of factors including dynamic muscle control, restraint from ligamentous structures, and the intrinsic stability of the joint due to bone and labral constraints on the glenoid.[5,13,17,18] Injury to the anteroinferior labrum is often associated with anterior dislocation of the shoulder.[30] Less commonly, fracture of the anteroinferior glenoid may occur, or erosion of the anterior bony glenoid may occur as a result of recurrent subluxation/dislocation events. The effect of labral loss on stability of the glenohumeral joint has been studied by numerous authors and has been shown to play a role in maintaining normal joint stability.[5,12,14,16,20,28,29,33] The effect of bone loss in the anteroinferior glenoid region has also been shown to decrease intrinsic stability of the glenohumeral joint under compressive loads.[14] Large defects may result in gross instability. These studies, however, do not delineate how articular contact pressures are affected by labral and bone injury.

Other authors have investigated the patterns of contact area and pressure across the intact glenohumeral joint.[7,10,26,27,32] These studies have quantified normal articular cartilage contact patterns throughout a range of motion of the shoulder and have indicated that contact area may change with arm position.[7,27,32] Variation in contact area has been seen between specimens, and both concentric and biconcentric loading patterns have been described.[7] Maximal contact pressures across the articular cartilage during loading have also been shown to vary depending on arm position. These authors, however, have investigated only the intact situation. Although investigators have evaluated how articular injury and incongruity affect contact pressures in other joints,[1,2,6,9,15,19,22] to date, no studies have investigated how labral and bone loss affects articular cartilage contact patterns and pressures across the glenohumeral joint through a range of motion.

It was the purpose of this study to evaluate how labral and bone loss in the anteroinferior quadrant of the glenoid affects contact area, mean articular cartilage contact pressure, and peak pressures across the glenohumeral joint under compressive loads. The hypothesis of this study was that injury to both the labral and bony portions of the anteroinferior glenoid would result in increased articular cartilage contact pressures in the anteroinferior quadrant of the glenoid and that large bone defects would cause a change in loading patterns.

MATERIALS AND METHODS

Specimen preparation

Eight fresh-frozen adult cadaver shoulders that had no evidence of glenohumeral pathology were used. The sample size (n = 8) provided 95% power to detect a 5% difference in contact pressure with repeated-measures analysis of variance. The mean age of the specimens was 56 years (range, 43-67 years). They were kept moist with normal saline solution throughout testing. On the scapular side, the glenoid and the entire labral complex were left in situ with the remaining soft tissues removed. The humerus was stripped of soft tissue.

Before the scapula was potted, calipers were used to measure 4 diameters for each glenoid with its labrum. The diameter measurements were based on viewing the glenoid as a clock face (direct superior equaling 12 o'clock). The measured diameters included 12:00 to 6:00, 9:00 to 3:00, 10:30 to 4:30, and 7:30 to 1:30. These measurements were used to determine the appropriate bone resections during testing and to calculate surface area of the intact specimens.

To determine the total surface area of the glenoid-labral complex, a flat paper cutout was made replicating the dimensions of the each specimen face. These cutouts were then scanned with a computerized digital scanner to determine their area. Because paper cutouts would not conform to the concavity of the glenoid, these face cutouts represented only the surface area of the glenoid-labral opening. Because of the concavity of the glenoid, it was necessary to multiply these scanned data by a correction factor to account for the increase in surface area due to glenoid depth. To determine this correction factor, we assumed the glenoid-labral area to be represented roughly as a segment of an ellipsoid and the face cutouts to be approximated by an ellipse of known radii.[4,12] Through use of standard mathematical formulas[4] to calculate these areas based on the measured radii of the glenoids, as well as the estimated curvature based on known relationships of glenoid size and curvature as described by Iannotti et al,[12] the ratio of these 2 areas (area of a segment of an ellipsoid—area of a flat ellipse) was used as the correction factor and applied to each scanned area.

Testing Apparatus

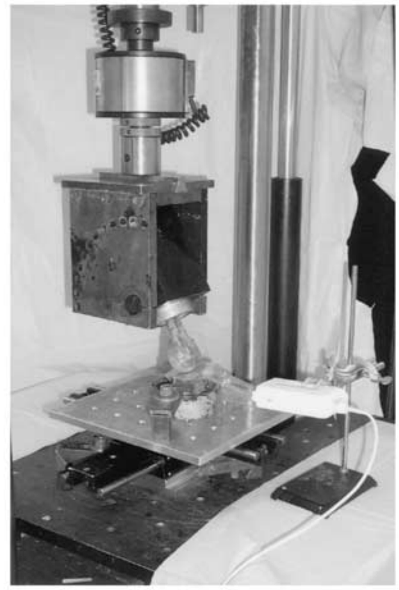

Figure 1 The mounted specimen with a Tekscan sensor in place.

Each scapula was potted in a low-melting metal alloy (Cerro Bond Alloy 158F; Cerro Alloy Co, Pittsburgh, Pa) with the glenoid positioned parallel to the floor so that loads across the joint would be purely compressive. A level was used across the glenoid in the superoinferior and anteroposterior directions to confirm the position. Two perpendicular 0.45-inch K-wires were placed in the glenoid neck, parallel to the articular surface of the glenoid. These were placed through the bone from the 6 to 12 o'clock positions and from the 3 to 9 o'clock positions and acted as reference points, dividing the glenoid into 4 quadrants.

The humeral shaft was also potted in low-melting metal alloy in an aluminum cylinder. The longitudinal axis of the humeral diaphysis was positioned parallel to the length of the cylinder. The exposed length of the proximal shaft was consistently 5 cm in order to permit glenohumeral abduction without testing apparatus interference, yet to minimize diaphyseal bending moments when loading the shoulder.

Biomechanical testing

The humerus was mounted on a multipositional cannon mount receiver, allowing the humerus to be moved throughout positions of 30°, 60°, and 90° of scapular abduction in a position of neutral rotation (Figure 1). The humerus was fixed in position during each of the tests. The neutral position was defined by placing the bicipital groove directly anteriorly, then externally rotating the humerus 10° with a goniometer, as described by Matsen et al.[18] This rotation was maintained throughout all degrees of abduction. The cannon mount was attached to a servohydraulic material testing machine (Model 8500; Instron Corp, Canton, Mass). The potted glenoid was attached to a 2-*df* table that allowed for both anteroposterior and mediolateral translation. This allowed the humeral head to center within the glenoid during testing.

A flexible tactile force sensor (model 5051; Tekscan, Inc, South Boston, Mass) was placed between the humerus and the glenoid. These are matrix-based sensors that operate via conductive and semiconductive inks.[31] Each sensor is made up of electrically conductive rows and columns separated by a material that varies its electrical resistance with applied force. This device measured pressures across the glenohumeral joint and gave detailed information on the articular contact pressures over the entire joint surface. These sensors are approximately 0.1-mm thick and have a matrix width and height of 56×56 mm, with a sensel density of 62/cm^2. The sensitivity range for this device was 0 to 3.45 MPa and was calibrated before testing. The manufacturer's guidelines and recommendations were followed.[31] Specially designed software (I-Scan, Tekscan, Inc) was used to analyze pressure sensing data. Before testing, sensors were conditioned and equilibrated with a pneumatic pressure bladder. Calibration was performed with loads of 20% and 80% of the maximum (440 N) applied across the glenohumeral joint. The calibration software in the Tekscan system creates a power function calibration curve using these 2 points and the (0, 0) reference point.

Through use of the Instron machine, compressive loads of 220 and 440 N were applied across the glenohumeral joint and contact pressure data for the entire surface of the glenoid-labral complex were recorded. The testing sequence with regard to the status of the glenoid for each specimen was as follows:

1. Intact specimen with normal labrum and no bony abnormalities.
2. Removal of the anteroinferior labrum from 2 o'clock to 6 o'clock on the glenoid face.
3. Loss of 10% of the glenoid diameter from the anteroinferior quadrant of the glenoid.
4. Loss of 20% of the glenoid diameter from the anteroinferior quadrant.
5. Loss of 30% of the glenoid diameter from the anteroinferior quadrant.

The amount of bone resection was calculated from the measured 10:30 to 4:30 glenoid diameter, which bisected the anteroinferior quadrant. This diameter was then used as a reference to determine the size of each cut. Bony cuts of 10% of this length were sequentially made to the glenoid. Bone was removed with a sharp 2-inch osteotome.

For each test condition, 6 measurements were made, 3 at 220 N and 3 at 440 N. Between each measurement, the pressure sensor was removed and then repositioned. Marks were placed with an indelible pen at the 12, 3, 6, and 9 o'clock positions on each sensor, and the Tekscan sensor was carefully positioned to ensure that each mark was appropriately positioned according to the K-wires previously placed within the glenoid. Pressure data for each test condition were saved to a personal computer and later analyzed.

Data analysis

The calculated surface areas of the intact glenoid and labrum were compared with the measured contact surface areas recorded by the Tekscan sensors to determine the percentage contact area for the intact condition. Pressure and contact area data were recorded for the glenoid as a whole and with the glenoid divided into 4 quadrants (anterosuperior, anteroinferior, posterosuperior, and posteroinferior) to determine the effect of progressive soft-tissue and bone loss on articular contact pressures. Through use of I-Scan software, the contact area, mean contact pressure, and peak contact pressure were determined for each test condition. Data were analyzed by comparison of each test condition with the measured intact condition for that specimen. This had the effect of normalizing data between specimens with respect to glenoid size.

Statistical analysis

Repeated-measures analysis of variance was used to evaluate the 6 sets of data to determine whether significant changes in contact pressures and areas occurred with progressive bone loss. For pairwise comparisons between the 6 sets of data, paired *t* tests were used with *P* values adjusted for multiple comparisons by means of the Tukey-Ciminera-Heyse multiple comparison procedure for paired sample data.[23]

RESULTS

Contact area at 30°, 60°, and 90° of scapular abduction in intact specimens

The calculated surface areas of the glenoid-labral complex ranged from 10.5 to 17.7 cm^2 (mean, 14.76 cm^2). These measurements include the entire labrum and take into account the increased surface area due to the concavity of the glenoid.

The contact areas recorded by the Tekscan sensors as a percentage of the calculated surface areas of the glenoid-labral complex under 220 and 440 N of load are summarized in Figure 2. Although there was a trend toward increasing contact area with increased abduction, these differences were not statistically significant. Figure 3 demonstrates the variation in contact area seen with increasing degrees of abduction when the glenohumeral joint was loaded to 440 N. By use of the Tekscan sensors, even areas with very low pressures (<0.05 MPa) were counted toward total contact area.

Effects of progressive labral and bone loss

Changes in the total contact area, mean contact pressure, and peak pressure for the glenoid surface as a whole were determined to evaluate the effect of progressive anteroinferior labral and bone loss on these variables. The data were further examined to determine the effect of labral and bone loss on the contact area, mean contact pressure, and peak pressure for each quadrant of the glenoid surface. Changes in each of these values were similar during loading at both 220 and 440 N. In addition, changes in values at each degree of abduction tested were

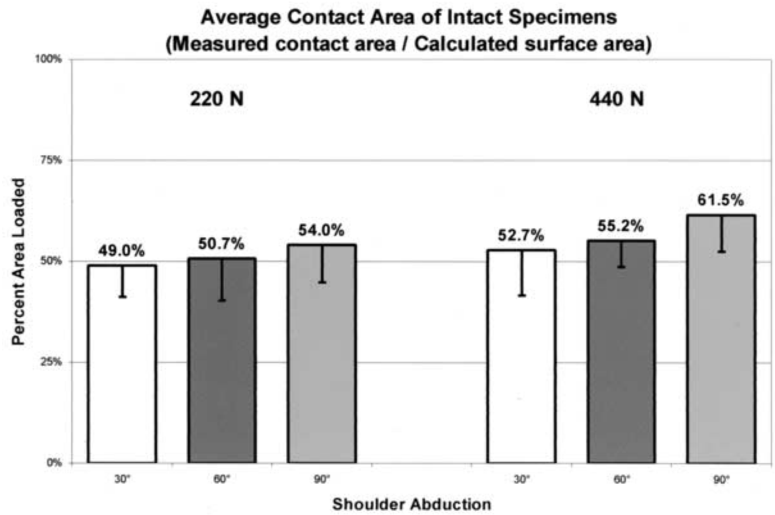

Figure 2 Mean contact area of the specimens as a percentage of the measured surface of the glenolabral complex. The 6 testing conditions are displayed.

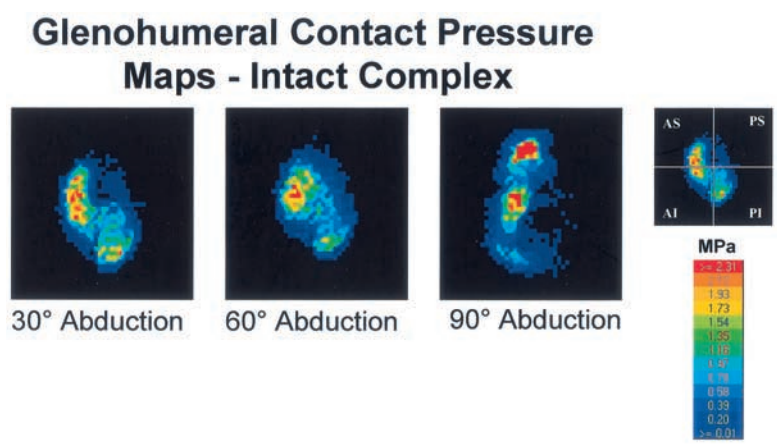

Figure 3 Contact pressure maps at the 3 positions of abduction. *Red areas* indicate higher pressures. Note the bicentric loading at 90° of abduction.

relatively consistent during all test conditions. For this reason, data presented in graphical form will be for the 440-N load, 90° abduction test condition to eliminate redundancy in presentation.

Whole glenoid surface

Contact area. At both 220 and 440 N of load and at all 3 degrees of abduction, the mean contact area for the glenoid-labral surface as a whole progressively decreased with increasing labral and bone loss. Differences between the intact and labral loss conditions were statistically significant in 5 of 6 test conditions. Labral loss alone decreased contact area by 7% to 15% in the 6 test conditions (mean, 9.8%; $P < .05$ in all 6 test conditions) with the greatest change (15%) seen at 440 N of load and 90° of abduction (Figure 4). An increase of 10% diameter bone loss resulted in only small additional decreases in contact area (1%-5%), whereas 20% diameter bone loss had a more substantial effect (mean decrease, 23%). A 30% diameter bone loss from the anteroinferior quadrant of the glenoid resulted in contact areas for the glenoid-labral surface as a whole being a mean of 41% less than the intact condition ($P < .05$ in all 6 test conditions). In addition, 2 of 8 specimens became grossly unstable with a 30% diameter bone loss and could not be loaded. During the attempted loading of these specimens, the glenohumeral joint dislocated in an anteroinferior direction. This occurred because of the 2-*df* table, which allowed posterior and superior movement of the glenoid, resulting in it slipping out from under the humeral head as it axially loaded the

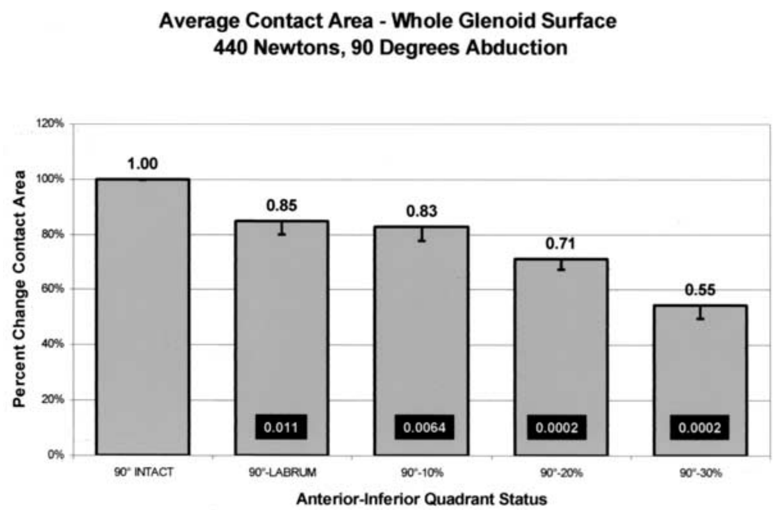

Figure 4 Mean contact area data for the entire glenoid at 90° of abduction under 440 N of load. Results are presented in relation to the intact condition for the entire glenoid surface. *P* values are shown within each bar.

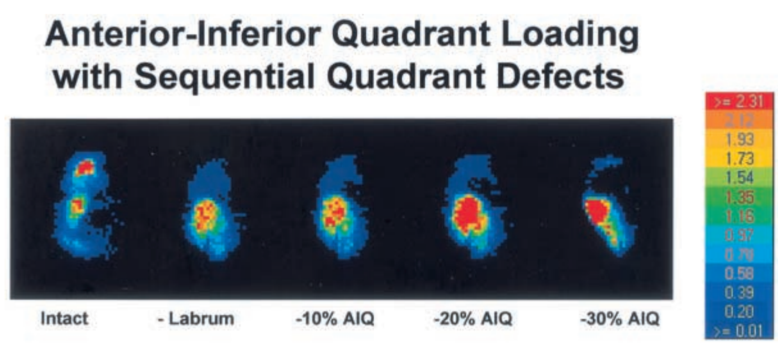

Figure 5 Change in the contact pressure maps with labral and bone loss. *AIQ,* Anteroinferior quadrant.

glenoid.

The decrease in contact area appeared to result from two factors: (1) the decrease in available glenoid surface due to bone loss and (2) an anteroinferior shift of contact area on the glenoid as the anteroinferior labrum and bone rim were removed. This shift resulted in a change in the load pattern, with a concentration of pressure and contact along the anteroinferior glenoid being seen with progressive bone loss (Figure 5).

Mean contact pressure. As the mean contact area decreased with labral and bone loss, the mean contact pressures increased as a result of the inverse relationship of contact pressure and contact area. Labral loss alone increased mean contact pressure on the glenoid by 8% to 20% (mean, 12.3%; $P < .05$ in 5/6 test conditions) compared with intact specimens. The 10% diameter bone loss condition had small additional effects (increase of 1%-7%) on mean contact pressure ($P < .05$ in all 6 test conditions) compared with the labral loss condition. However, a 20% diameter bone loss resulted in more substantial increases, and a loss of 30% diameter of the glenoid increased mean contact pressure by nearly 100%. The effects of labral and bone loss tended toward being more pronounced at 90° of abduction (Figure 6) compared with 30° and 60°; however, statistically significant differences between these conditions were not observed.

Peak pressures. In the evaluation of peak pressures seen over the glenoid surface, values trended toward a slight increase with progressive labral and bone loss up to a 30% diameter bone loss. The mean peak pressures measured in this study for intact specimens were 1.31 MPa, 1.39 MPa, and 1.67 MPa at 30°, 60°, and 90° of abduction under 220 N of load. Increasing the load to 440 N increased the mean peak pressures to 2.10 MPa, 2.35 MPa, and 2.58 MPa at 30°, 60°, and 90° of abduction. This doubling of load had the effect of increasing peak pressures by a mean of 61%, indicating a change in distribution of force over the glenoid.

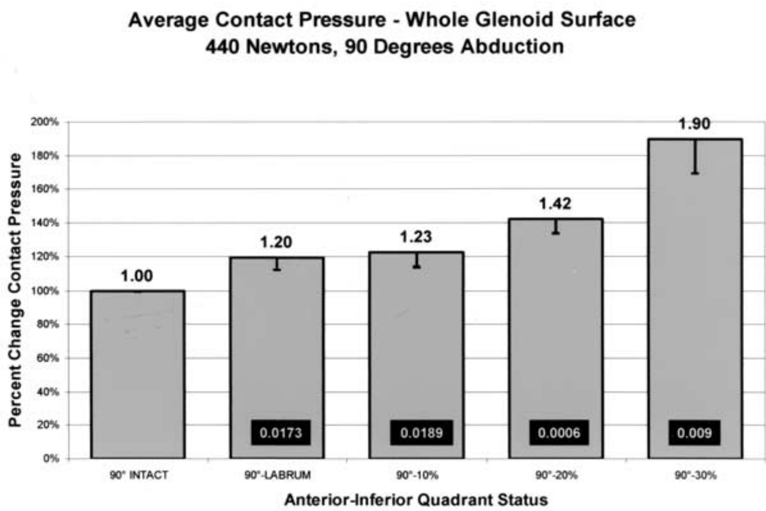

Figure 6 Mean contact pressures across the entire glenoid at 90° of abduction under 440 N of load. Results are presented in relation to the intact condition for the entire glenoid surface. *P* values are shown within each bar.

Peak pressures at 30% diameter bone loss were a mean of 46% higher than the peak pressures seen with the intact specimens. At 220 N of load and 30% diameter bone loss, the peak pressures ranged from 2.30 to 2.41 MPa, and at 440 N of load and 30% diameter bone loss, they ranged from 2.95 to 3.11 MPa. Contact shift into the anteroinferior quadrant at the 30% diameter bone loss condition appeared to focus pressure, resulting in a concentration of force on the anteroinferior rim of the glenoid (Figure 5).

Glenoid surface by quadrant

Mean contact area. In addition to evaluating the effect of labral and bone loss on contact area, contact pressure, and peak pressure for the glenoid surface as a whole, the data were evaluated by glenoid quadrant to determine whether differential changes across the glenoid surface occurred. The mean contact area in each of the 4 quadrants was evaluated for each test condition. The largest changes were seen to occur in the anteroinferior quadrant. Contact area in this quadrant decreased as labrum and bone were resected from the anteroinferior portion of the glenoid. Labral removal decreased the measured contact area by a mean of 10% in this quadrant ($P < .05$ in 5/6 test conditions). Progressive bone loss resulted in a continued decrease in measured contact areas in the anteroinferior quadrant for all of the test conditions and followed a pattern similar to that demonstrated for 90° of abduction at 440-N load (Figure 7). By the time 30% of the diameter of the glenoid was resected, measured contact areas in the anteroinferior quadrant for the 6 test conditions were a mean of 39% of the intact condition as a result of the loss of available surface area for contact ($P < .05$ in all 6 test conditions). Nearly all available surface area in this quadrant measured contact. In addition, with progressive labral and bone loss, there was also a decrease in contact area in the posterosuperior quadrant, indicating a shift in contact pattern away from this quadrant and toward the anteroinferior glenoid rim.

Mean contact pressure. Data followed a consistent pattern for the mean contact pressure and the peak pressures in each of the quadrants. There was an increase in the mean contact pressure with progressive labral and bone loss in 3 of the 4 quadrants (anteroinferior, anterosuperior, and posteroinferior), as well as a decrease in mean contact pressure in the posterosuperior quadrant. The increase in mean contact pressure was most dramatic in the anteroinferior quadrant, in which labral loss alone resulted in an increase in the mean contact pressure of 53% for the 6 test conditions ($P < .05$ in 6/6 test conditions), with a trend toward greater changes at 90° of abduction (Figure 8). Bone loss resulted in a progressive increase in the mean contact pressure, with the 20% diameter defect increasing mean contact pressure to over 200% of normal. Further increase in bone loss to 30% diameter of the glenoid resulted in further increase in the mean contact pressure on the remaining cartilage in the anteroinferior quadrant of the glenoid, with pressures being 300% to 400% of the intact specimens ($P < .05$ in all 6 test conditions).

Changes in the anterosuperior quadrant followed trends similar to those seen in the anteroinferior quadrant but with changes being of a smaller magnitude. Isolated labral loss increased mean contact pressure in the anterosuperior quadrant by a mean of 10% for

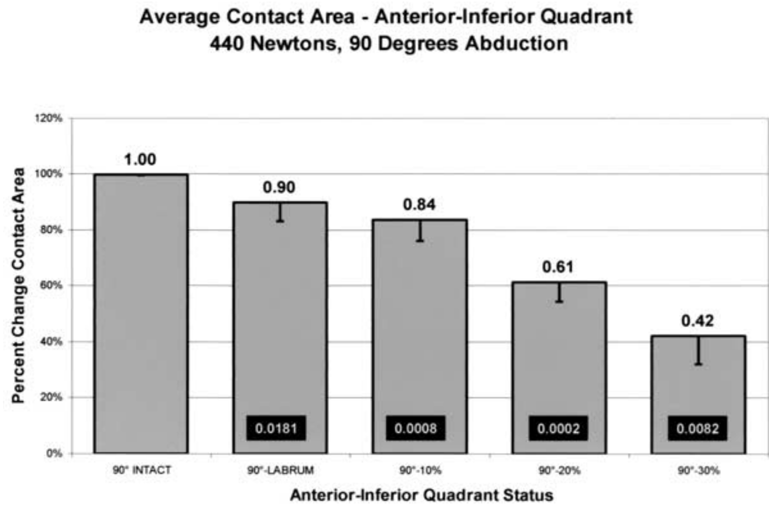

Figure 7 Mean contact area data for the anteroinferior quadrant at 90° of abduction under 440 N of load. The mean contact areas are presented in relation to the intact condition. *P* values are shown within each bar.

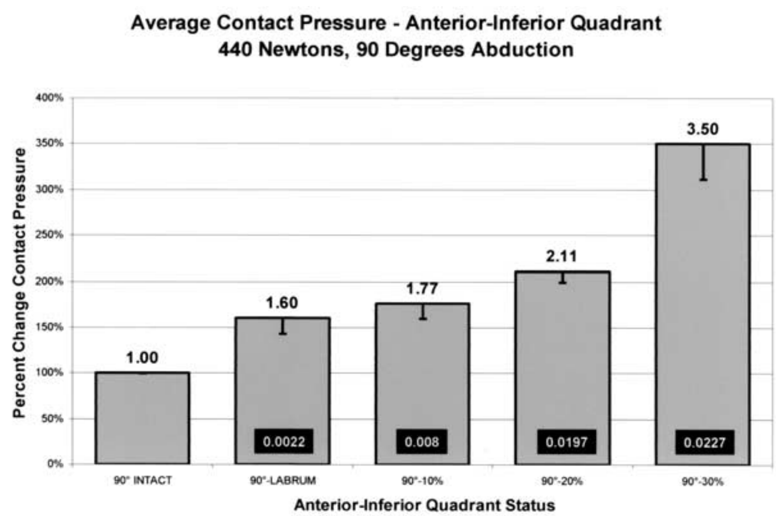

Figure 8 Mean contact pressure data for the anteroinferior quadrant at 90° of abduction under 440 N of load. Data are presented in relation to the intact condition. *P* values shown within each bar.

the 6 test conditions. Thirty percent diameter defects increased contact pressures by a mean of 63% when compared with the intact condition.

In the posteroinferior quadrant, mean contact pressures also increased by a mean of 19% following labral loss when compared with the intact test condition. There was a mean 78% increase in contact pressures with a 30% diameter anteroinferior glenoid-labral loss. In each of these 3 quadrants (anteroinferior, posteroinferior, and anterosuperior), increased contact pressure was seen during progressive labral and bone loss. This appeared to be due to a shift in the center of force within the glenohumeral joint as anteroinferior labral and bone loss occurred.

The posterosuperior quadrant became unloaded with progressive anteroinferior labral and bone loss, with a decrease in the mean contact pressure of 26% at the 30% diameter glenoid bone loss condition. There appeared to be a shift in loading away from the posterosuperior quadrant toward the anteroinferior quadrant.

Peak pressures. Peak pressures followed patterns similar to those seen for mean contact pressures, although the magnitude of the changes was smaller. The peak pressure increased in the anteroinferior quadrant by a mean of 28% with the loss of the anteroinferior labrum. Progressive bone loss resulted in increases in peak pressures in the anteroinferior quadrant, indicating a concentration of force into the anteroinferior quadrant.

At both 220 and 440 N of load, peak pressures in the anterosuperior and posteroinferior quadrants increased with progressive labral and bone loss in the anteroinferior quadrant, but changes were of lower magnitude when compared with those seen in the anteroinferior quadrant. Peak pressures in the posterosuperior quadrant remained relatively unchanged, with only a small decrease with progressive labral and bone loss.

DISCUSSION

Changes in glenohumeral contact pressures following labral and bone injury to the glenoid rim may have a significant impact on joint loading characteristics. Although other studies have documented the effect of these defects on joint stability, none has looked closely at the changes in articular contact pressures that occur with labral and bone loss. This study has been able to evaluate pressure changes that occur under compressive loads across the glenohumeral joint following progressive labral and bone loss. Using Tekscan pressure sensing technology, we have been able to evaluate accurately contact area, mean contact pressure, and peak pressure across the glenoid-labral surface during compressive loading of the joint. DeMarco et al[8] have documented the accuracy and reproducibility of this technology. Although Fuji film has been used in the past for similar studies,[7,24,25,33,34] it is our belief that Tekscan sensing technology allowed us to evaluate the data more fully in an accurate and reproducible fashion.

In evaluating the data presented in this study, a comparison to work by others reveals several differences as well as similarities. Soslowsky and colleagues,[3,26-28] Warner et al,[32,33] and others[12] have published data on the size of the glenoid surface. Soslowsky and colleagues[3,27] used stereophotogrammetry to determine the articular geometry of the glenohumeral joint. The cartilage surface area of the glenoid in their study was 5.79 ± 1.69 cm^2 for male patients and 4.68 ± 0.93 cm^2 for female patients. Warner et al[32] published work on contact areas of the intact glenoid during loading. From their data, one can calculate that the intact glenoid surface area in their study averaged approximately 8.25 cm^2 (65% contact equaled 5.37 cm^2; 100% contact, therefore, equaled 8.24 cm^2). In the present study, both the glenoid and the entire labrum were evaluated. The mean surface area of the glenoid-labral complex in this study was 14.76 cm^2. Although much larger than the values reported by others, this finding is not unexpected, given that the labrum was included in our calculation of available surface area. Because the surface area of an ellipse-like structure such as the glenoid is related to its 2 radii multiplied by each other, small increases in the radii due to the labrum result in large increases in surface area.

In this study, we observed a relatively high percentage of contact between the humeral head and glenoid-labral complex during compressive loading at 30°, 60°, and 90° of abduction compared with other studies. On average, contact areas of 49.0% at 30° of abduction and 50.7% at 60° of abduction of the measured glenolabral complex were recorded during loading to 220 N. These values are higher than those reported by Warner et al[32]: 13.3% and 17.2% of the glenoid surface at 30° and 60° of scapular abduction under 222 N of load. However, the 54.0% contact area at 90° of scapular abduction in our study is close in value to the 65.2% glenoid contact area that Warner et al reported at 90° of abduction under a load of 222 N. The results at 440 N in both our study and that of Warner et al demonstrated this same pattern. It is important to emphasize that the present study includes labral contact in the calculations, whereas the study by Warner et al evaluated only the glenoid articular surface.

Conzen and Eckstein[7] reported results that differed from those in both the present study and that by Warner et al.[32] The loads used in their study were determined by calculating what the forces across the joint would be during abduction of single arm weight (SAW) or double arm weight (DAW).[21] These calculated forces resulted in the greatest loads being applied at 58° of scapular abduction and no rotation (595 N SAW and 1785 N DAW assuming mean body weight of 70 kg), with lesser loads applied at 24° and 91° of scapular abduction and no rotation (266 N SAW and 798 N DAW). The SAW loads were most similar to those used in this work and that by Warner et al. Conzen and Eckstein noted the greatest degree of contact at 58° of scapular abduction and 5° of retroversion. Contact areas in their study equaled approximately 35% of the measured glenoid surface area in this position. Contact areas at 91° of abduction decreased to 15% to 30% of the measured surface area. In performing their studies, they used two types of Fuji film with differing sensitivities (SL: 0.25-3.5 MPa sensitivity, and L: 2-11 MPa sensitivity). SAW tests used SL film, which has a minimum sensitivity of 0.25 MPa. Loads lower than this would not register and would not be counted toward contact area. Warner et al used similar film. In doing so, both studies may underestimate contact because of insensitivity of the film at low pressures. In this study, pressure sensors were calibrated to detect pressures from 0.01 to 3.45 MPa, and areas that experience even low loads ($<$0.25 MPa) were detected and counted toward total contact area. This increased sensitivity may account for the higher percentages reported in this study compared with other investigations.

Previous investigations examining the effect of labral and bone loss have generally focused on how these factors affect joint stability. Lazarus et al[16] demonstrated that chondral-labral defects that decreased the height of the glenoid rim had the effect of decreasing stability. They proposed reconstruction of the rim in order to restore stability. Others have evaluated capsular and labral contributions to joint stability.[5,28,29,33] Itoi et al[14] looked at how the labrum and anteroinferior glenoid rim affect stability of the glenohumeral joint, as well as how a Bankart repair affects stability and motion. However, none of these studies evaluated how these factors affect contact pressures.

This study demonstrated the effect that the anteroinferior labrum has on glenoid-labral contact areas and pressures as loads are applied across the glenohumeral joint. When compared with the intact situation, isolated labral loss decreased contact area by a mean of 9.8% for the glenoid as a whole, and the mean contact pressure rose by a mean of 12.3% across the glenoid as a whole and by a mean of 53% for the anteroinferior quadrant of the glenoid. Changes in mean contact pressure following labral loss trended toward being greater at 90° of abduction. The loss of the anteroinferior labrum also resulted in a shift in contact pattern in the direction of the anteroinferior quadrant and away from the posterosuperior quadrant. This had the effect of concentrating force into an area that was compromised by the loss of surface area when the labrum was removed. The net effect was an increase in the mean and peak contact pressures in this quadrant following labral excision. Peak pressures were greater in the anteroinferior quadrant following labral excision. The altered loading patterns are most evident in the anteroinferior quadrant of the glenoid.

Natural history studies with long-term follow-up of patients who have had an anterior shoulder dislocation (with a presumed Bankart injury) have demonstrated that some of these patients will have degenerative changes.[11] The cause of this is unknown and may be related to the initial trauma that occurs at the time of dislocation. Hovelius et al[11] demonstrated that at 10-year follow-up, patients with a previous dislocation but no recurrent episodes had a 6% incidence of moderate to severe arthropathy of the glenohumeral joint. An additional 10% had mild arthropathy. Although many factors may be responsible for this finding, alterations in joint loading due to labral detachment could possibly play a role.

Progressive bone loss in the anteroinferior quadrant, in addition to the loss of the labrum, was found to have the effect of causing further increases in mean contact pressures and peak pressures and a decrease in contact area. These findings became most dramatic at 20% to 30% diameter bone loss. At 20% diameter bone loss, mean contact pressure approximately doubled in the anteroinferior quadrant and peak pressure increased 50% to 100%.

Although this study has been able to examine the effects of labral and bone loss on loading mechanics, we recognize several limitations. As in the case in the studies by Warner et al[32] and Conzen and Eckstein,[7] this is a static model. Because of the limitations of the setup, it was not possible to gather data reliably in a dynamic fashion where muscle and ligaments are modeled for. Although the pressures across the glenohumeral joint during active motion may be different than observed in the present study, we believe that the information provided in this study is useful. Under compressive loading conditions as performed in this experiment, the natural concavity of the glenoid-labral complex permitted centralization of the humerus within the glenoid, minimizing pressures. This may represent the best case scenario for disbursing load across the joint. As the labrum and bone are removed, this self-centering ability is progressively lost and changes in joint loading mechanics are observed. This study, therefore, examines the inherent loading characteristics of the joint due to bone, cartilage, and labral restraints. Another limitation involves our limited testing of positions of abduction and rotation of the humerus relative to the glenoid. Although 3 positions of abduction were tested, the rotational position of the humerus was not changed during testing. Positions of maximal abduction and external rotation, which may result in subluxation and/or dislocation, were not studied. Because the humerus is stabilized in this position in large part by the effects of the inferoglenohumeral ligament[33] and affected by muscular forces,[17,28] a more dynamic model would be necessary to examine the full effect of arm position on contact pressures.

Despite these limitations, we believe that this new information is helpful in delineating the role that the anteroinferior labrum of glenoid and the bone in the anteroinferior quadrant play in distributing forces across the glenoid-labral complex during compressive loads.

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