Effect of Bankart repair on the loss of range of motion and the instability of the shoulder joint for recurrent anterior shoulder dislocation

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Background: Bankart repair postoperative complications include loss of shoulder motion and shoulder instability. The primary reason that postoperative complications develop may be excessive imbrication of the anterior band of the inferior glenohumeral ligament (AIGHL) or inadequate repair position. The purpose of this study was to quantitatively evaluate the influence of inadequate repair by computer simulation for a normal shoulder joint.

Methods: Magnetic resonance images of 10 normal shoulder joints were acquired for 7 positions every 30° from the maximum internal rotation to the maximum external rotation with the arm abducted at 90°. The shortest 3-dimensional path of the AIGHL in each rotational orientation was calculated. We used computer simulations to anticipate the loss of motion and instability by changing the AIGHL length and insertion sites on the glenoid.

Results: The AIGHL length measured 50 ± 5 mm at the maximum external shoulder rotation. AIGHL shortening by 3, 6, and 9 mm made the angle of maximum external rotation 80°, 68°, and 54°, respectively. A superior deviation of 3, 6, and 9 mm on the glenoid insertion resulted in a maximum external rotation angle of 85°, 79°, and 77°. An inferior deviation of 3, 6, and 9 mm produced humeral head translation of 1.7, 2.9, and 3.6 mm.

Conclusion: Simulation of both excessive imbrication and deviation of the insertion position led to quantitative prediction of the resulting loss of motion and instability. These findings will be useful for anticipating complications after Bankart repair.


Keywords: Shoulder; in vivo; 3-dimensional kinematics; Bankart repair; anterior band of the inferior glenohumeral ligament; simulation

Traumatic recurrent anterior shoulder dislocation is thought to be due to the Bankart lesion, in which the anterior and anteroinferior glenoid labrum is detached from the glenoid. Speer et al. reported that the simulated Bankart lesion resulted in selected increases in humeral
head anterior translation from the glenoid at 0°, 45°, and 90° of shoulder elevation. Turkel et al.23 described the dislocation of all shoulders at 45° and 90° of elevation when the anterior band of the inferior glenohumeral liga-
ment (AIGHL) was cut. They concluded that glenoid labrum detachment from the glenoid resulted in subsequent anterior humerus dislocation. Mizuno et al.19 reported that an isolated Bankart lesion was present in 84.5% of 303 recurrent shoulder dislocations and that the labral detach-
ment from the glenoid was also present in a majority of recurrent shoulder dislocations.

Bankart repair is often performed to repair labral injury after shoulder dislocation. It is important that the Bankart lesion be repaired adequately. Excessive surgical imbrication of the anteroinferior capsule including the AIGHL results in loss of shoulder motion.20 Instability and loss of motion may also occur when the repair is performed in an inadequate position.2 Little has been reported on objective evaluation of motion loss due to excessive imbrication as well as instability due to a Bankart repair glenoid insertion site deviation.6,10-12,18,21,24 We are able to evaluate 3-dimensional joint kinematics with magnetic resonance imaging (MRI) in multiple positions. The advantage to this approach is the analysis of joint kinematics in the living under physiologic conditions, unlike cadaver studies. We studied the effects of the amount of imbrication and the deviation of the Bankart repair position. The purpose of this study was to investigate shoulder joint loss of motion and instability by changing the amount of AIGHL imbrication or insertion position with computer simulation for a normal shoulder joint.

Materials and methods

This is a study designed to quantify Bankart repair postoperative complications. We evaluated the loss of external rotation and shoulder translation by changing the ligament length and the ligament insertion site with computer simulation.

Subjects

The right shoulders of 10 healthy volunteers (1 man and 9 women; age range, 22-32 years; mean age, 27.8 years) were examined. All shoulders were asymptomatic and had no history of injury and no clinical sign of disease, such as laxity or impingement sign.

Image acquisition for 3-dimensional MRI

Three-dimensional magnetic resonance images were acquired by use of a wide-gantry open MRI scanner (1.5 T MAGNETOM Espree, Siemens, Erlangen, Germany) with an open-bore system (internal bore, 70 cm; length, 125 cm). MRI scanning was performed with the 3-dimensional FLASH method (repetition time, 12 ms; echo time, 5.8 ms; flip angle, 20°; thickness, 0.8 mm; field of view, 240 × 240 mm²; 452 × 512 matrix; scan time of 5 m 25 s). Each subject was examined in the supine position with the arm abducted at 90°.

Figure 1 Images were acquired by 3-dimensional magnetic resonance imaging. We created a special device designed to allow free movement of the scapula while maintaining a comfortable posture. We scanned at 30° external rotation with the arm abducted to 90°.

Figure 1

All images were digitized by a computer with 3-dimensional images of the shoulder reconstructed with use of the Virtual Place M software (AZE, Tokyo, Japan), developed at our institution. Contours of the humerus and scapula were automatically segmented from the magnetic resonance volume images in the neutral rotational position, and the contours were then manually modified, including the cortical bones. An individual 3-dimensional surface bone model was reconstructed from the magnetic resonance image segmented area by use of the marching cubes algorithm for each subject.13 The surface bone model was visualized with original software based on the Visualization Toolkit (Kitware, Clifton Park, NY, USA). There were variations in bone size among individuals. We scaled the bone models up or down with a computer to normalize all subjects to the same bone size. The accuracy of this method has been determined to be 0.04 mm in translation and 0.82° in rotation.5

Image matching (voxel-based registration)

The voxel-based registration technique is a method for superimposing images by minimizing the sum of squared intensity differences for segmented voxels.8 Segmented humerus and scapula at the neutral rotational position were superimposed on the same bones in images of other positions by this method. Transformation matrices from the neutral rotational position to other positions were calculated for each bone in the global coordinate system of the MRI scanner. Six degrees of freedom of in vivo bone kinematics at the shoulder joint could be respectively analyzed by this method. In our previous validation study, mean
absolute rotational error of this voxel-based registration technique ranged from 0.24° to 0.43°, and mean absolute translational error ranged from 0.41 to 0.52 mm. The error was calculated by comparing the movements between the occipital bone and markers attached to the humeral head. The shoulder kinematics could also be visualized as a motion picture by interfacing the kinematics of each of the 7 positions. Thus, we acquired in vivo shoulder kinematics during maximum internal and external rotation with the arm abducted at 90°.

Calculating AIGHL functional length

The AIGHL insertion sites were identified on the humerus and glenoid on the basis of the 3-dimensional bone model. Yang et al. investigated the centroids of AIGHL insertion area from cadavers and defined the humerus and scapula model along with the mean ligamentous insertion areas as the template for calculating virtual measurements of the ligaments. Three-dimensional lengths between the humeral and scapular ligament insertions were calculated as the shortest path in 3-dimensional space along the 3-dimensional bone model surface. The changes in length and path were represented by curved lines in the 3-dimensional bone models to express the ligament paths between the humeral and scapular insertions, as shown in Figure 2. Because these ligament paths were not actual lengths, we defined this distance as the functional length. In the present study, we calculated the change in AIGHL functional length during maximum internal and external rotation with the arm abducted at 90° and used it to calculate the approximated curve of the change in AIGHL functional length.

Calculation of loss of shoulder motion and shoulder instability with computer simulations

Effect of excessive imbrication or excessive capsular tightening on loss of motion

Excessive AIGHL imbrication suggested that the 3-dimensional AIGHL length between humeral and scapular insertions was shortened. We then calculated the angle of maximum external rotation when the amount of AIGHL imbrication was increased by 3, 6, and 9 mm from the maximum AIGHL length using the computer-simulated approximate curve of AIGHL functional length.

Effect of glenoid Bankart repair site superior or inferior plane deviation on loss of shoulder motion and shoulder instability

We calculated the angle of maximum external rotation when the glenoid insertion site was deviated 3, 6, and 9 mm superior to the anatomical site (Fig. 3). We also calculated the approximated curve of AIGHL functional length under each condition. Then we calculated the external rotation angle for the maximum AIGHL functional length of the original glenoid sites on the approximated curve.

We calculated the amount of humeral translation when the insertion site on the glenoid was deviated 3, 6, and 9 mm inferior to the anatomical site and calculated the AIGHL functional length under each condition. Three-dimensional distance of the AIGHL was relatively shortened when the insertion site was deviated inferiorly; however, the AIGHL functional length could increase until the maximum length was reached. This increase enabled the humeral head to translate anteroinferiorly. Then, we simulated the 1-mm each anteroinferior humeral head translation toward 4:30 (right shoulder) and calculated the AIGHL functional length and the approximated curve under each translation under each condition. We calculated the amount of humeral translation when the calculated AIGHL functional length under each condition became the maximum length on the original insertion onto the glenoid.

Statistical analysis

All data were expressed as a mean and standard deviation. Statistical analysis was performed with a one-way analysis of variance with Tukey post hoc test. The significance level was established as \( P < .05 \).
Results

Change in AIGHL functional length

The change in AIGHL functional length in different shoulder rotations is shown in Figure 4. The AIGHL functional length was constant from maximum internal rotation to neutral rotation and then was elongated gradually with increasing external rotation. The functional length was the greatest at maximum external rotation, and the mean maximum length was $50 \pm 5$ mm.

Effect of excessive surgical imbrication on loss of motion

The angle of maximum external rotation was $80^\circ$, $68^\circ$, and $54^\circ$, respectively, when the amount of AIGHL imbrication was increased by 3, 6, and 9 mm. These values indicate the angle of maximum shoulder external rotation under each computer-simulated condition.

Effect of superior glenoid insertion site deviation relative to the anatomical site on loss of shoulder motion

The AIGHL length was never elongated more than 50 mm. We calculated the angle of maximum external rotation when the glenoid insertion site deviated superiorly from the anatomical site by 3, 6, and 9 mm. The angle of maximum shoulder external rotation was $85^\circ$, $79^\circ$, and $77^\circ$, respectively (Fig. 5). These values signify the angle of maximum external rotation of the shoulder under each condition with computer simulations.

Effect of inferior glenoid insertion site deviation relative to the anatomical site on loss of shoulder instability

The humeral translation when the AIGHL length approached 50 mm was 1.7, 2.9, and 3.6 mm as calculated with the approximated curves (Fig. 6). These values signify the amount of shoulder instability under each condition with computer simulations.

Discussion

Invasive treatment of the recurrent anterior shoulder dislocation is intended to repair the Bankart lesion (Bankart repair) with open and arthroscopic surgery. A variety of clinical results after Bankart repair are reported with both open and arthroscopic procedures. Hawkins et al reported that 31 of 46 patients with continuing difficulties after anterior reconstruction for shoulder instability still had shoulder instability and that a loss of mobility was seen in 10 patients. Magnusson et al reported that a 20° loss of shoulder external rotation was present even 90 months after open Bankart repair. Gill et al reported a 12° loss of external rotation persisting more than 8 years after open Bankart repair. Meyer et al reported that loss of shoulder external rotation with the elbow at the side of the body was $14.1^\circ$ and loss of shoulder external rotation in 90° of shoulder abduction was $12.8^\circ$ 2 years after arthroscopic Bankart repair. Hubbell et al compared the clinical results between open and arthroscopic Bankart repair more than 5 years after surgery. The open repair group had no instability, but 45% had some loss of external rotation with a
mean loss of 18°. The arthroscopic group had a 60% rate of instability, but there were no limitations of motion. The major complications after Bankart repair are a loss of motion and instability of the shoulder. Little objective and specific information has been reported relative to surgical complications after Bankart repair.

In cadaveric studies, McMahon et al\(^{16}\) reported that AIGHL elongation from plastic deformation to ultimate deformation was 4% or 1.4 mm of the entire ligament length. They insisted that the elongation was a factor in determining shoulder external rotation range of motion and the entire AIGHL length was 37.3 ± 0.9 mm, which was elongated by 12 to 14 mm because of tensioning. Some plastic deformation may occur in the Bankart lesion, but we think that plastic deformity will have little effect on Bankart repair because Mizuno et al\(^{19}\) reported that an isolated Bankart lesion was present in a majority of recurrent shoulder dislocations.

Novotny et al\(^{20}\) reported that a 5-mm capsule imbrication in the Bankart repair resulted in a loss of 14° of motion in the cocked phase of throwing. Black et al\(^{21}\) compared humeral head translation between the 2-site and 3-site glenoid insertion Bankart repair techniques; 3-site labral repair resulted in statistically significantly less anterior and inferior translation than 2-site repair.

We performed computer simulations based on the results of in vivo 3-dimensional shoulder kinematics to investigate how excessive imbrication affected loss of shoulder motion. When the AIGHL imbrication was increased by 3, 6, and 9 mm, the loss of external rotation was 14°, 22°, and 36°, respectively. We found that loss of motion increased by about 4° when the amount of imbrication was increased by 1 mm. When the insertion deviated 3, 6, and 9 mm superiorly from anatomical position, the loss of external rotation was 10°, 22°, and 36°, respectively. We found that loss of external rotation increased by about 2° as the insertion was deviated 1 mm. When the insertion was deviated 3, 6, and 9 mm inferiorly from the anatomical position, the degree of instability increased by about 0.5 mm as the insertion was deviated 1 mm.

The present study has some limitations. First, this kinematic analysis was combined with static MRI in multiple positions, not analysis of continuous movement. Second, the rate of AIGHL yield deformation may change because of remodeling occurring at the repair site. Third, the
AIGHL functional length measured in this study was not the actual ligament length. The AIGHL functional length was defined as the 3-dimensional distance between the humeral and scapular AIGHL insertion sites. Finally, this study was performed with use of a computer simulation, so the actual instability was not measured. Also, this study was a theoretical result by computer simulation with consideration that the main cause of traumatic recurrent shoulder dislocation was Bankart lesion. Because shoulder instability occurs clinically by multifactorial causes, this result had not adapted to all shoulder dislocation. However, the AIGHL is considered to act as the shoulder joint stabilizer when the functional length reaches the maximum. Simulation of the amount of imbrication and deviation of insertion position led to quantitative speculation about shoulder joint loss of motion and instability. We objectively and specifically examined the influence of motion loss and instability with computer simulation in this study. Surgeons should pay special attention to the amount of imbrication to reduce the risk of postoperative Bankart repair complications.

Conclusion

We evaluated the effect of increased imbrication on the loss of motion and shoulder instability quantitatively with computer simulation. Specifically, we analyzed the changes in AIGHL functional length and simulated an inadequate Bankart repair. We showed that AIGHL length was greatest at maximum external rotation and that excessive imbrication had a greater effect on loss of shoulder motion than did the superior repair site deviation. Clinically, surgeons should focus on maintaining no more than 6 mm excessive imbrication because the loss of external rotation was 22° when the amount of AIGHL imbrication was 6 mm.

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