The Effects of Latarjet Reconstruction on Glenohumeral Kinematics in the Presence of Combined Bony Defects

A Cadaveric Model

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Background: Recurrent glenohumeral instability is often a result of underlying bony defects in the glenoid and/or humeral head. Anterior glenoid augmentation with a coracoid bone block (ie, Latarjet procedure) has been recommended for glenoid bone loss in the face of recurrent instability. However, no study has investigated the effect of Latarjet augmentation in the setting of both glenoid and humeral head defects (Hill-Sachs defects).

Purpose: To evaluate the glenohumeral kinematics of the Latarjet procedure in the presence of combined bony defects.

Study Design: Controlled laboratory study.

Methods: Eighteen fresh-frozen cadaveric specimens void of all surrounding soft tissue were tested at all combinations of glenohumeral abduction (ABD) angles of 20°, 40°, and 60° and 3 external rotation (ER) levels of 0°, 40°, and 80°. Each experiment comprised anterior dislocation by translating the glenoid under a 50-N medial load applied on the humerus, simulating the static load of soft tissue. The primary outcome measurement was defined as the percentage of intact translation (normalized distance to dislocation). Specimens were tested in an intact condition (no defect), with different combinations of defects, and with Latarjet augmentation. The Latarjet procedure was performed for 20% and 30% glenoid defects by transferring the specimen's coracoid process anterior to the glenoid so that it was flush with the articulating surface.

Results: Results depended on the position of the arm. At 20° of ABD and 0° of ER, a 20% glenoid defect decreased the percentage of intact translation regardless of the humeral head defect size ($P \leq .0001$). In this same setting, Latarjet reconstruction restored translation to dislocation greater than the native intact joint for all sizes of humeral head defects. At 60° of ABD and 80° of ER, a 20% glenoid defect led to an overall decrease in translation to dislocation with increasing humeral head defects. While Latarjet augmentation resulted in increased translation to dislocation for all humeral head defect sizes, it was not able to restore translation greater than the native intact joint for large humeral head defects (31% and 44%); the normalized percentages of intact translation to dislocation were 65% and 30%, respectively.

Conclusion: These results demonstrate that some degree of translation can be regained for combined bony glenoid and humeral head defects with the Latarjet procedure. However, for humeral defects larger than 31%, the rotational effect of the humeral head defect led to persistent decreased translation and to dislocation despite glenoid augmentation. Thus, directly addressing the humeral defect to restore the articular surface should be considered in these cases.

Clinical Relevance: This study provides a critical value limit for combined anterior glenoid bone loss and humeral head defects. While this is a biomechanical study, the results indicate that in patients with humeral head defects greater than 31%, additional humeral-sided surgery may be needed.

Keywords: Latarjet; shoulder instability; glenoid bone loss; humeral head defect

The glenohumeral joint is the most commonly dislocated joint in the human body, with 98% of these dislocations occurring in the anterior direction.[5,21,27,31] Furthermore, 95% of patients with recurrent anterior shoulder instability have a humeral head defect, a glenoid defect, or both.[6] Humeral head defects were found in 74% of the patients examined by Hill and Sachs[11] in their original description of the injury. Other studies, subsequently, have found humeral head defects to be present in as much as 90% to 100% of patients with recurrent instability.[4,6,22,25,33] The incidence of anterior glenoid bone loss, traumatic or attritional, has been reported anywhere from 41% to 90% in shoulders with recurrent anterior instability.[10,17] The

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literature is relatively scarce regarding the presence of combined glenoid and humeral head bony defects. One study reported an incidence of 57% for combined defects in patients with recurrent instability.[32]

The presence of bony defects is associated with the failure of isolated capsulolabral repair.[28] Burkhart and De Beer[3] reported an overall 10.8% failure rate of arthroscopic anterior labrum repair. They found that almost 70% of patients with glenoid defects resulting in an "inverted pear" glenoid and an engaging humeral head bony defect had recurrence, whereas only 4% had recurrence if there were no significant bony defects. Furthermore, in this 4% subgroup, the bony defects that were found were characterized as nonengaging lesions, but descriptions on size, location, and combined bony defects were not provided. Boileau et al[1] found a 15% recurrence rate in patients who underwent arthroscopic anterior labrum repair and a significant association with the presence of a glenoid (P = .01) or humeral (P = .05) bony defect. Increased awareness of the significance of bony defects led to the investigation of threshold or "critical" sizes to improve the treatment of anterior instability.

Itoi et al[12] performed a cadaveric biomechanical study investigating the effect of an anteroinferior glenoid defect on shoulder stability. The authors found that defects involving greater than 21% of the glenoid length (25% of the glenoid width) resulted in decrease in stability. However, they oriented the defects at 135° from the long axis of the glenoid, which Saito and colleagues[23] suggested was incorrect. Yamamoto et al[35] re-evaluated the critical defect size with proper orientation of the glenoid defect at 90° and found that lesions greater than 20% of the glenoid length (26% of the glenoid width) resulted in a significant increase in shoulder instability.

Kaar and colleagues[13] investigated the critical defect size for humeral head defects and found that defects greater than 31% of the humeral head diameter caused a significant decrease in stability. The glenoid track, described by Yamamoto et al,[34] is the first model to incorporate the dynamic interaction of the glenoid and bony defects. Recently, Trivedi et al[26] suggested glenoid rim bone grafting in the setting of combined bony defects to increase the width of the glenoid track and create a nonengaging humeral head defect. Furthermore, a recent finite element analysis showed that arm position and combined defects affect shoulder stability.[29,30] However, no biomechanical evaluation exists on the effects of an anterior bone block procedure (ie, Latarjet) for combined bony defects and glenohumeral instability.

The purpose of this study was to investigate the effects of bone-only Latarjet augmentation for an anterior glenoid rim defect in the presence of varying humeral head defects. Our hypothesis was that the Latarjet procedure would increase intact translation distance in many, but not all, cases of combined bony defects. In turn, persistent decreased translational distance to dislocation may be a clinical indicator for glenohumeral instability.

METHODS

Specimen Preparation

Eighteen fresh-frozen human cadaveric shoulders were obtained from Anatomy Gifts and Science Care. There were 9 male shoulders and 9 female shoulders, as well as 9 left and 9 right shoulders. The mean age of the specimens was 57.4 years (range, 43-69 years). Each specimen was grossly inspected for any anatomic deformities, osteoarthritis, and prior surgical intervention. The specimens were stored at –20°C and thawed overnight before testing. Surgical dissections and osteotomies have been previously described but will be mentioned here briefly.[12,13,35] All soft tissue was carefully resected from the glenohumeral joint including the rotator cuff, capsule, and labrum. Dissection was performed sharply to ensure no damage to the articular surfaces. The humerus was osteotomized 15 cm from the most distal portion of the articular head surface. The glenoid was preserved on the scapular body with the acromion osteotomized >2 cm medial to the glenoid surface. The coracoid was grafted from each specimen at the base to ensure adequate length. All cuts were made with an oscillating saw.

The scapula was potted in a steel box with Wood metal (42.5% bismuth alloy; McMaster-Carr), with the lateral 3 cm protruding from the metal and the articular surface in neutral tilt. Tilt and angulation were assessed with a custom positioning apparatus. The humeral shaft was potted with the same Wood metal in an aluminum tube with the humeral shaft perpendicular to the base. The aluminum tube was placed in the testing apparatus and secured, allowing for rotation to account for measured internal rotation and external rotation (ER) of the glenohumeral joint as well as change in the abduction (ABD) angle.

The humeral head and glenoid defects were created based on previously described techniques.[12,13,35] Briefly, the longitudinal axis of the glenoid was identified from proximal to distal, marked, and verified with a digitizer (MicroScribe; Solution Technologies Inc). The diameter of the inferior circle of the glenoid was then measured. Glenoid defects were created by using an oscillating saw to make cuts parallel to the long axis at increasing percentages of the previously measured glenoid diameter. A custom cutting jig was secured with 2 K-wires to allow the cuts to be created congruent to the articular surface. Two

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different sizes of the glenoid defect were measured and created in addition to the intact joint: 20% and 30% of the width of the glenoid. The previously osteotomized coracoid graft was prepared for augmentation. The inferior surface of the coracoid was flattened and placed anteriorly on the glenoid defect. The base of the coracoid remained superior, while the tip was positioned at the distal aspect of the defect. Medial-lateral positioning of the graft was based on congruency of the articular bone block junction. The coracoid was held in place with 2 K-wires and then secured with 2 bicortical subchondral screws secured with washers and nuts on the posterior side. The washers and nuts provided strong fixation in cadaveric bone and helped prevent loosening through multiple trials. The mean length of the coracoid graft was 38 mm (range, 31-46 mm). The humeral head defects were made in a progressive fashion following the protocol outlined by Kaar et al.[13] Four different sizes of humeral head defects were created, representing 6%, 19%, 31%, and 44%, respectively, of the humeral head diameter. The position of the defects was centered at 209° from the anterior humeral head articular cartilage, placing the lesion in the typical posterosuperior location (Figure 1).[20] A line was drawn from the center of the humeral head articular surface to the 209° point, and defects were made by osteotomizing perpendicular to this line with a customized jig. The jig was secured with K-wires and adjusted sequentially to allow for resection based on the humeral head diameter and defect size.

The customized testing apparatus allowed for changes in rotation and ABD of the humerus relative to the glenoid (Figure 2). The glenoid-scapula pot was placed on a horizontal linear drive (Zaber Technologies Inc), and a 6 degrees of freedom load cell (Mini45; ATI Industrial Automation) was placed in between the drive and the pot. A 50-N medial force applied to the glenoid was verified by the load cell. The potted end of the humeral shaft was mounted to the vertical jig with 3 degrees of freedom, allowing for modification of ABD and humeral rotation. A laser displacement sensor (Renishaw Inc) with an accuracy of 0.4 μm was attached to the vertical reaction frame to measure the medial-lateral displacement of the humeral head. Testing was then performed by translating the glenoid posteriorly (x-axis) at a constant velocity of 0.5 mm/s (to minimize viscoelastic effects) under a medial centering load of 50 N (z-axis) to cause anterior dislocation. The load of 50 N has been used in past studies, and it simulates a static soft tissue load.[12,13] Moreover, it has been demonstrated that during dislocation, the 50-N force does not cause any damage to the humeral head.[12] The y-axis was parallel to the superior-inferior axis of the glenoid. The real-time readings of the forces and displacements were recorded using a custom-developed LabVIEW code (National Instruments Corp). All of the data were sampled at a 50-Hz frequency.

Before testing, neutral rotation was defined relative to the trunk, which was equivalent to 20° of ER relative to the scapular plane. Then, a reference position (home) was defined for each arm position configuration by translating the humeral head 7 mm along both the superior-inferior and anterior-posterior axes. The reference position was defined as the position at which the humeral head was most medial. This step also helped to precondition the specimen before testing.

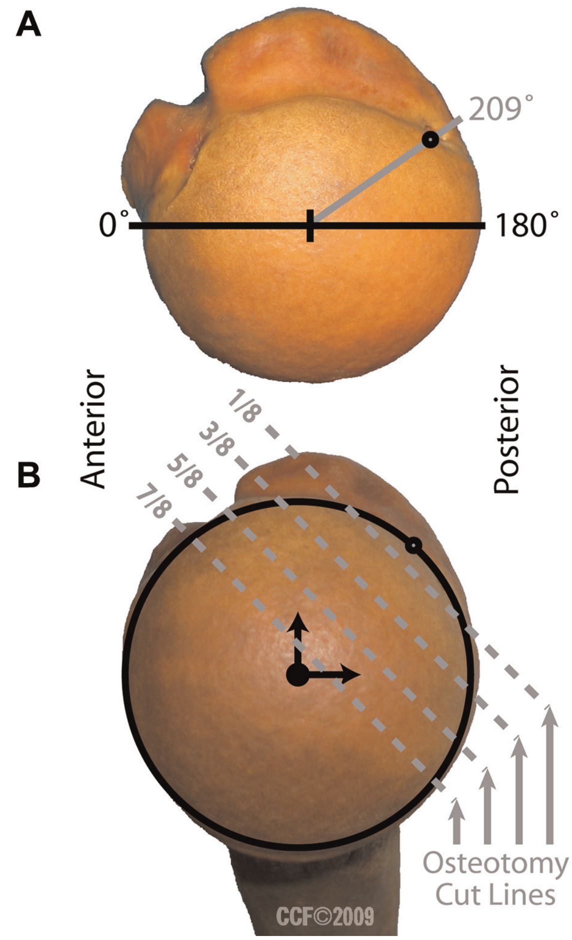

Figure 1. (A) Superior view of a humeral head with the 209° point from the anterior margin of the articular surface marked as the center of the osteotomy site. (B) View looking directly at the articular surface, demonstrating the progressive series of osteotomy cuts used to mimic humeral head defects. Osteotomy cuts were made at 6%, 19%, 31%, and 44% of the projected diameter of the humeral head, respectively. (Image reprinted with the permission of the Cleveland Clinic Center for Medical Art and Photography, © 2009. All rights reserved.)

Experimentation was conducted at 3 levels of ABD angles relative to the scapula, which were 20°, 40°, and 60°. These ABD angles simulated the arm in ABD relative to the trunk at 30°, 60°, and 90°, respectively, when considering scapulothoracic motion. Additionally, 3 different ER angles of 0°, 40°, and 80° were tested for each condition. Again, neutral rotation was defined relative to the trunk, which was equivalent to 20° of ER relative to the scapular plane. The arm at 60° of ABD and 80° of ER simulated the apprehension position of 90° of ABD and >90° of ER relative to the trunk. This position is considered a more functional position than 20° of ABD and 0° of ER, which is considered a resting nonfunctional position. After testing the intact joint at different positions of ABD and ER, the specimen was examined to ensure no gross damage, and

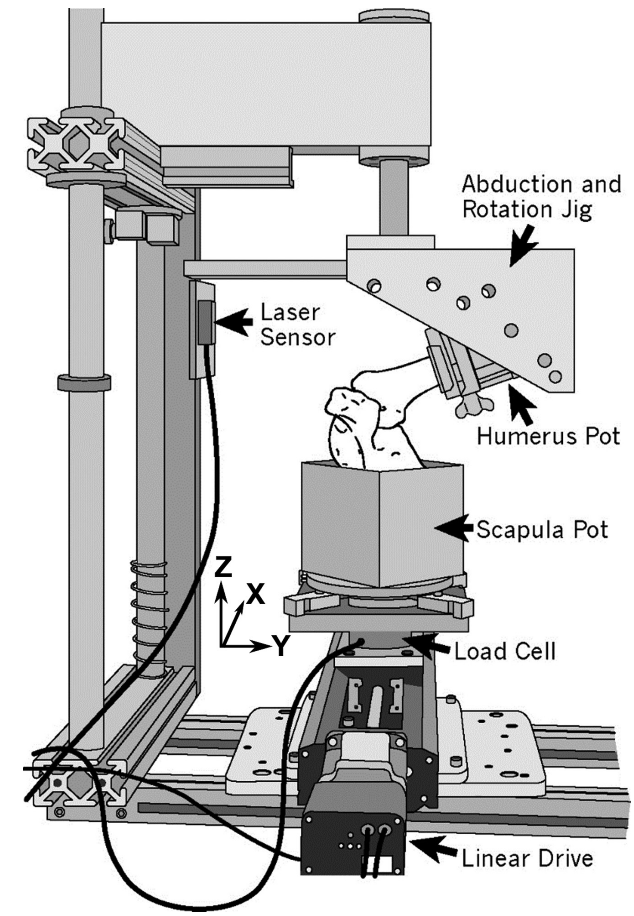

Figure 2. Illustration of the custom jig that allowed displacement of the glenoid in a posterior direction (x-axis) relative to the humeral head, simulating anterior shoulder dislocation.

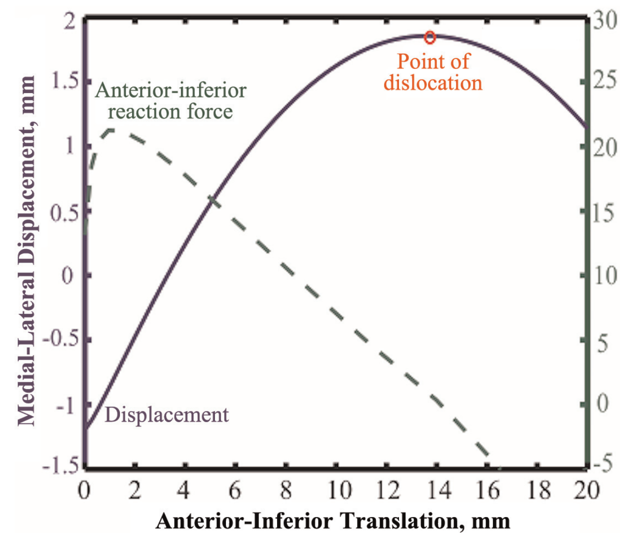

Figure 3. The methodology determining the point of dislocation (peak lateral displacement) and the associated distance to dislocation on the x-axis.

then defects were created for both the humeral head and glenoid with and without Latarjet reconstruction.

For each trial, the outcome of interest was defined as the normalized distance to dislocation. The distance to dislocation was defined as the distance between the reference position (home) and the point of dislocation of the humeral head along the anterior axis. This was normalized relative to the corresponding distance to dislocation from the intact specimen without bony defects, which is known as the percentage of intact translation. The point of dislocation was computed where the humeral head achieved a peak lateral position before a descent (medial displacement) (Figure 3). Reaction forces were calculated using MATLAB 10.1a (The MathWorks Inc). Gross dislocation was observed but typically manually prevented to preserve the specimens.

A balanced repeated-measures analysis of variance (ANOVA) was used to identify the significance of each factor (humeral head defect, bony glenoid defect, ABD angle, rotation angle) on the normalized distance to dislocation. A 2-way ANOVA was performed with the R statistical package (R Core Team, 2014; R Foundation for Statistical Computing). Tukey post hoc analyses were completed to determine the significance of differences between factor levels. Statistical significance was set at alpha (α) = .05. A priori power analysis was performed, and based on prior data, an SD of 20% was selected; to detect a <30% difference in force required for displacement with 80% power, 6 shoulders were required for each group (n = 18).

RESULTS

Results depended on the position of the arm and are summarized in Figure 4. At 20° of ABD and 0° of ER, a 20% glenoid defect decreased the percentage of intact translation similarly regardless of the humeral head defect size ($P \leq .0001$). In this same setting, Latarjet reconstruction restored translation greater than the native intact joint for all sizes of humeral head defects (Figure 4A). There was no significant difference in the percentage of intact translation among the increasing humeral head defect sizes at this glenohumeral position of 20° of ABD and 0° of ER ($P \leq .0001$).

With the same 20% glenoid defect without the Latarjet procedure, and the humerus position changed to 40° of ABD and 40° of ER (midrange of motion), the percentage of intact translation decreased with the 19% humeral head defect (Figure 4B). This trend ($P \leq .0001$) was evident after Latarjet reconstruction; however, the normalized percentage of intact translation remained over 100%, even with a 44% humeral head defect.

Maintaining a 20% glenoid defect and changing the humerus position to 60° of ABD and 80° of ER led to an overall decrease in translation with increasing humeral head defect sizes, for both the defect state and trials after the Latarjet procedure (Figure 4C). Nevertheless, Latarjet augmentation resulted in increased translation for all humeral head defect sizes. However, even with the Latarjet procedure, the normalized percentage of intact translation trended inversely to the size of the humeral head defect.

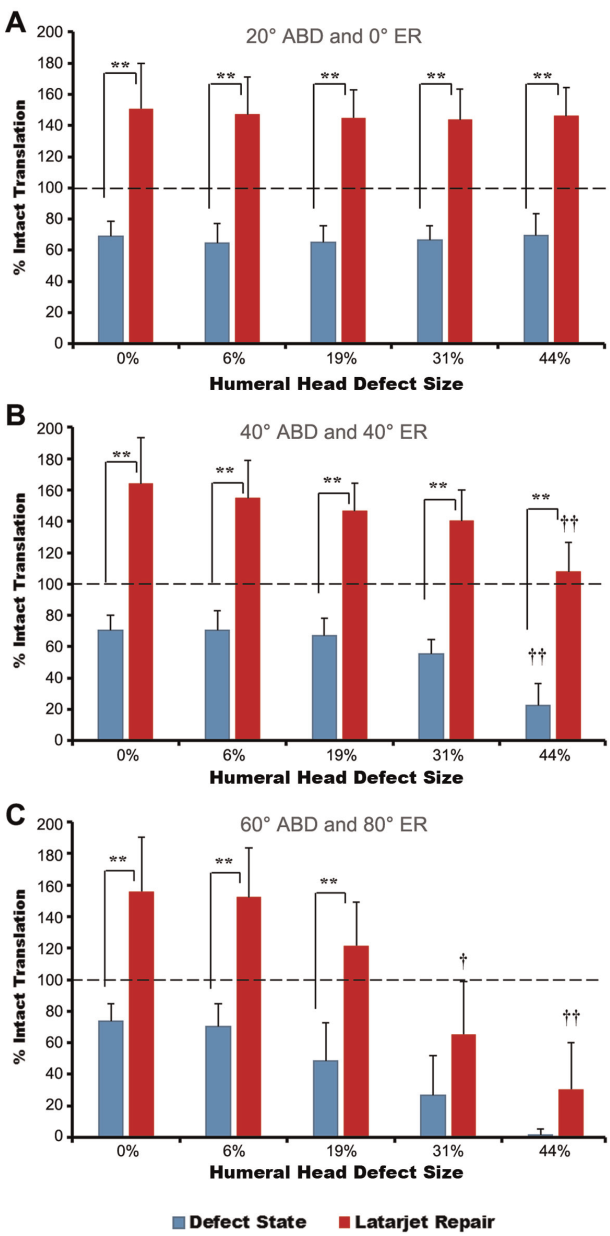

Figure 4. Interaction of a 20% glenoid defect with various sized humeral head (HH) defects before and after Latarjet reconstruction at (A) 20° of abduction (ABD) and 0° of external rotation (ER), (B) 40° of ABD and 40° of ER, and (C) 60° of ABD and 80° of ER. The vertical axis represents the normalized distance to dislocation with respect to the values of the intact joint, and the horizontal axis represents the varying sizes and combinations of bony defects. Statistically significant difference between states: $^{**}P \leq .0001$. Statistically significant difference from either a 20% glenoid/0% HH defect combination or a 30% glenoid/6% HH defect combination: $^{\dagger\dagger}P \leq .0001$ and $^{\dagger}P < .05$.

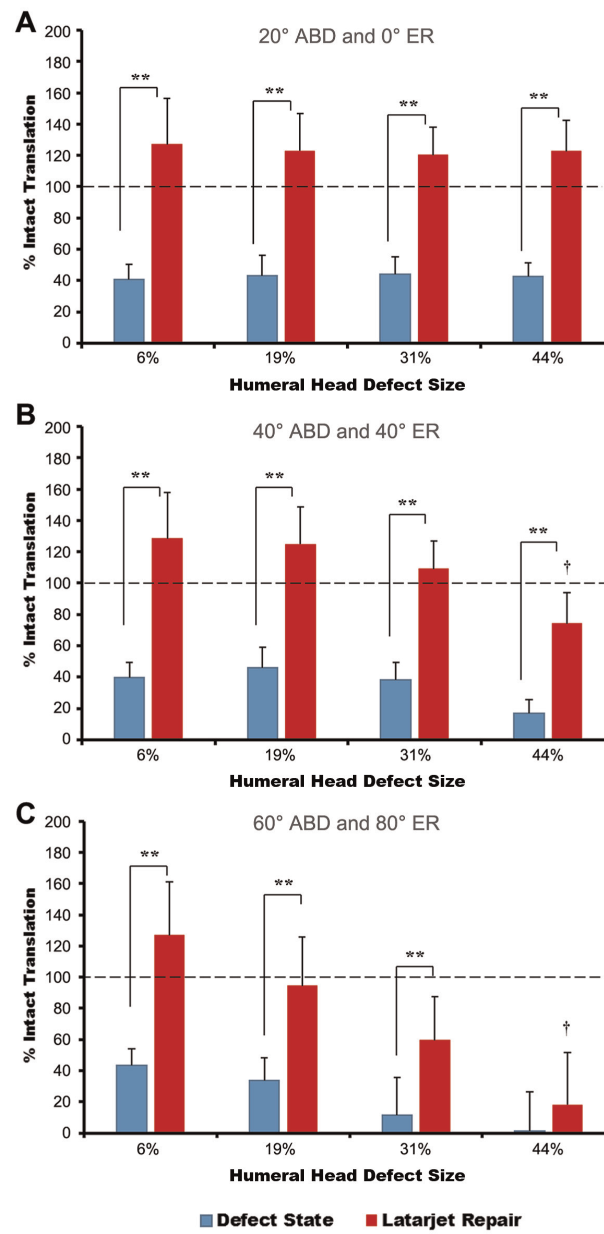

Figure 5. Interaction of a 30% glenoid defect with various sized humeral head (HH) defects before and after Latarjet reconstruction at (A) 20° of abduction (ABD) and 0° of external rotation (ER), (B) 40° of ABD and 40° of ER, and (C) 60° of ABD and 80° of ER. The vertical axis represents the normalized distance to dislocation with respect to the values of the intact joint, and the horizontal axis represents the varying sizes and combinations of bony defects. Statistically significant difference between states: $^{**}P \leq .0001$. Statistically significant difference from either a 20% glenoid/0% HH defect combination or a 30% glenoid/6% HH defect combination: $^{\dagger\dagger}P \leq .0001$ and $^{\dagger}P < .05$.

For large humeral head defects (31% and 44%), the values were significantly below the intact state (65% and 30%, respectively). The results were similar for the trials with 30% glenoid defects and are summarized in Figure 5.

DISCUSSION

This study illustrates the efficacy of Latarjet repair for augmenting glenoid defects. However, for combined defects with humeral head defects greater than 30%, translation was below what would be expected in a normal intact shoulder, suggestive of ongoing instability. The presence of these bony defects is well documented in shoulders with recurrent glenohumeral instability.[3,10,32] Untreated bony lesions of a significant size can lead to the failure of soft tissue repair and recurrent instability. The size of a significant lesion has been studied in isolation for both the glenoid and humeral head. Yamamoto et al[35] found the critical size of the glenoid defect to be greater than 20% of the glenoid length. Kaar et al[13] determined that the critical size for humeral head defects was greater than 5/8 of the humeral head radius (31.5% of the diameter). Similarly, Sekiya et al[24] determined that humeral head defects of up to 25% in isolation result in significantly less anterior translation before dislocation. However, defects greater than 37.5% could benefit from reconstruction to restore shoulder stability. It is clear that Latarjet reconstruction can be successful in restoring stability to the shoulder in many cases in which there is bone deficiency on either the glenoid or humerus. However, it also appears that there are some cases in which complete stability is not achieved and that those patients may benefit from further augmentation of their stability by directly addressing the humeral defect. Having the ability to measure and understand the outcome of all these combined lesions is paramount to improve the treatment of complex shoulder instability. The lack of validated techniques has led to variations in the assessment of humeral head lesion sizes and has led to difficulty in quantifying and treating these defects. Furthermore, lesions typically do not occur in isolation, and quantifying glenoid lesions, although slightly more accurate, still is not as precise as needed.[2,14]

Yamamoto et al[34] were the first to establish a method to predict an engaging humeral head lesion on the anterior glenoid with the "glenoid track" concept. Kurokawa et al[15] further explored the glenoid track with a clinical computed tomography–based model in patients with recurrent anterior instability. The authors found that the medial extent of the humeral head lesion determined whether a lesion was engaging or not. Furthermore, all 7 patients (of 100) with engaging humeral head lesions had glenoid bone loss greater than 20%, and Latarjet reconstruction re-established a glenoid track width that prevented the same humeral head lesions from engaging. However, the size of these humeral head lesions was not documented. Theoretically, a large humeral head lesion may extend medially past the glenoid track width after Latarjet reconstruction.

Latarjet reconstruction restored translational distance to dislocation with smaller sized humeral head defects even in functional positions of maximal ABD and ER. However, as the humeral defects became larger, intact translation decreased. It appears that when humeral head lesions are greater than 31%, Latarjet augmentation failed to restore translation to dislocation in functional arm positions, which suggests that with humeral head lesions of this size, additional humeral augmentation is needed. In addition, when humeral head lesions were 19%, the distance to dislocation started to decrease, suggesting more stress and less stability to the whole construct. In this biomechanical study, assessments of translation and the kinematics of bipolar bone loss in cadaveric specimens serve as clinical indicators of shoulder instability. Establishing critical defect values in biomechanical studies can heighten awareness of the problem and allow for increased clinical evaluations.

The critical defect value in the treatment of combined glenoid and humeral head bony defects appears to be about 31%. Anterior glenoid augmentation with a bone block can provide increased translation to dislocation in the presence of humeral defect sizes of 19% to 31%. What remains unanswered is what happens to the surgical construct of the bone graft and screws if the humeral anatomy is not restored. It may be possible that even if stability is initially restored, the increased stress seen after 19% may result in some of the hardware and union problems that have been previously reported.[8,9]

Various treatment strategies exist to address humeral head lesions, including remplissage, allograft transplantation, and prosthetic resurfacing. Remplissage has been used to convert an intra-articular defect into an extra-articular defect, with the known adverse effect of restricted motion postoperatively. Miniaci and Gish[18] described reconstruction of the humeral head with an allograft wedge of a matched donor specimen. Partial resurfacing similarly attempts reconstruction of the humeral head but with a metallic implant. Giles et al[7] investigated these 3 methods in 8 cadaveric specimens with 30% and 45% humeral head defects. They found that while all procedures improved stability, remplissage led to significant reductions in range of motion. Humeral head allograft reconstruction led to nearly intact values for all biomechanical properties tested. This study represents only 1 surgical technique for each procedure. Leroux et al[16] performed a systematic review including 7 studies (evidence levels 2-4) of combined arthroscopic remplissage with anterior labrum repair, with an average 26-month follow-up and a pooled rate of recurrent dislocations of 3.4%. The authors found no clinically significant loss of range of motion. Miniaci and Gish[18] and Miniaci and Martineau[19] performed humeral head allograft transfer in 18 patients who had failed previous attempts at surgical stabilization, with an average follow-up of 50 months. There were no episodes of recurrent instability, and 16 of 18 (89%) patients returned to work. However, complications of graft collapse, screw penetrance, and subluxation must be considered.

Despite the lack of high-quality research providing the correct treatment method for instability repair in the presence of bony glenoid and humeral head defects, acknowledging these lesions and looking for them in cases of multiple recurrences, revision surgeries, epilepsy, and high-contact injuries are vital in their management. Increased awareness should lead to lower rates of recurrent instability and reoperation while providing more cases to analyze outcomes.

There are limitations to this study, including the inherent limitations of any cadaveric study. The mean age of our cadaveric specimens was 57.4 years; most patients with shoulder instability are in their second or third decade of life. It should be noted that our model was devoid of all soft tissue, negating any effects of the capsulolabral complex and the sling effect of coracoid transfer. Not all angles of ABD and ER were tested, and our defects were created in a step-wise pattern rather than a continuous sequence of defects. Lastly, we chose to place our coracoid in a coronal fashion against the anterior glenoid with the superior-inferior surface facing anteriorly-posteriorly; many surgeons place the graft in a sagittal manner. Future research should assess for variance with maintenance of soft tissue restraints (ie, sling effect). Outcomes should be tracked in patients who undergo remplissage, partial resurfacing, or allograft transfer to better evaluate these different treatment methods.

In conclusion, in the presence of combined defects, the overall translation distance before dislocation increased after Latarjet augmentation. For combined defects with a humeral head bone loss greater than 31% of the diameter, gain in the translation distance was not sufficient even after coracoid transfer.

REFERENCES

1. Boileau P, Villalba M, Hery JY, Balg F, Ahrens P, Neyton L. Risk factors for recurrence of shoulder instability after arthroscopic Bankart repair. *J Bone Joint Surg Am*. 2006;88(8):1755-1763.
2. Bois AJ, Fening SD, Polster J, Jones MH, Miniaci A. Quantifying glenoid bone loss in anterior shoulder instability: reliability and accuracy of 2-dimensional and 3-dimensional computed tomography measurement techniques. *Am J Sports Med*. 2012;40(11):2569-2577.
3. Burkhart SS, De Beer JF. Traumatic glenohumeral bone defects and their relationship to failure of arthroscopic Bankart repairs: significance of the inverted-pear glenoid and the humeral engaging Hill-Sachs lesion. *Arthroscopy*. 2000;16(7):677-694.
4. Calandra JJ, Baker CL, Uribe J. The incidence of Hill-Sachs lesions in initial anterior shoulder dislocations. *Arthroscopy*. 1989;5(4):254-257.
5. Cofield RH, Kavanagh BF, Frassica FJ. Anterior shoulder instability. *Instr Course Lect*. 1985;34:210-227.
6. Edwards TB, Boulahia A, Walch G. Radiographic analysis of bone defects in chronic anterior shoulder instability. *Arthroscopy*. 2003;19(7):732-739.
7. Giles JW, Elkinson I, Ferreira LM, et al. Moderate to large engaging Hill-Sachs defects: an in vitro biomechanical comparison of the remplissage procedure, allograft humeral head reconstruction, and partial resurfacing arthroplasty. *J Shoulder Elbow Surg*. 2012;21(9):1142-1151.
8. Griesser MJ, Harris JD, McCoy BW, et al. Complications and reoperations after Bristow-Latarjet shoulder stabilization: a systematic review. *J Shoulder Elbow Surg*. 2013;22(2):286-292.
9. Griesser MJ, Harris JD, McCoy BW, et al. Glenoid fracture after Bristow-Latarjet shoulder stabilization: a case report and review of the literature. *J Shoulder Elbow Surg*. 2013;22(3):e17-e20.
10. Griffith JF, Antonio GE, Yung PS, et al. Prevalence, pattern, and spectrum of glenoid bone loss in anterior shoulder dislocation: CT analysis of 218 patients. *AJR Am J Roentgenol*. 2008;190(5):1247-1254.
11. Hill HA, Sachs MD. The grooved defect of the humeral head. *Radiology*. 1940;35(6):690-700.
12. Itoi E, Lee SB, Berglund LJ, Berge LL, An KN. The effect of a glenoid defect on anteroinferior stability of the shoulder after Bankart repair: a cadaveric study. *J Bone Joint Surg Am*. 2000;82(1):35-46.
13. Kaar SG, Fening SD, Jones MH, Colbrunn RW, Miniaci A. Effect of humeral head defect size on glenohumeral stability: a cadaveric study of simulated Hill-Sachs defects. *Am J Sports Med*. 2010;38(3):594-599.
14. Kodali P, Jones MH, Polster J, Miniaci A, Fening SD. Accuracy of measurement of Hill-Sachs lesions with computed tomography. *J Shoulder Elbow Surg*. 2011;20(8):1328-1334.
15. Kurokawa D, Yamamoto N, Nagamoto H, et al. The prevalence of a large Hill-Sachs lesion that needs to be treated. *J Shoulder Elbow Surg*. 2013;22(9):1285-1289.
16. Leroux T, Bhatti A, Khoshbin A, et al. Combined arthroscopic Bankart repair and remplissage for recurrent shoulder instability. *Arthroscopy*. 2013;29(10):1693-1701.
17. Lo IK, Parten PM, Burkhart SS. The inverted pear glenoid: an indicator of significant glenoid bone loss. *Arthroscopy*. 2004;20(2):169-174.
18. Miniaci A, Gish MW. Management of anterior glenohumeral instability associated with large Hill-Sachs defects. *Tech Shoulder Elbow Surg*. 2004;5(3):170-175.
19. Miniaci A, Martineau PA. Humeral head bony deficiency (large Hill-Sachs). In: ElAttrache NS, Harner CD, Mirzayan R, Sekiya JK, eds. *Surgical Techniques in Sports Medicine*. Philadelphia: Lippincott Williams & Wilkins; 2007:189-194.
20. Richards RD, Sartoris DJ, Pathria MN, Resnick D. Hill-Sachs lesion and normal humeral groove: MR imaging features allowing their differentiation. *Radiology*. 1994;190(3):665-668.
21. Robinson CM, Dobson RJ. Anterior instability of the shoulder after trauma. *J Bone Joint Surg Br*. 2004;86(4):469-479.
22. Rowe CR, Zarins B. Recurrent transient subluxation of the shoulder. *J Bone Joint Surg Am*. 1981;63(6):863-872.
23. Saito H, Itoi E, Sugaya H, Minagawa H, Yamamoto N, Tuoheti Y. Location of the glenoid defect in shoulders with recurrent anterior dislocation. *Am J Sports Med*. 2005;33(6):889-893.
24. Sekiya JK, Wickwire AC, Stehle JH, Debski RE. Hill-Sachs defects and repair using osteoarticular allograft transplantation: biomechanical analysis using a joint compression model. *Am J Sports Med*. 2009;37(12):2459-2466.
25. Taylor DC, Arciero RA. Pathologic changes associated with shoulder dislocations: arthroscopic and physical examination findings in first-time, traumatic anterior dislocations. *Am J Sports Med*. 1997;25(3):306-311.
26. Trivedi S, Pomerantz ML, Gross D, Golijanan P, Provencher MT. Shoulder instability in the setting of bipolar (glenoid and humeral head) bone loss: the glenoid track concept. *Clin Orthop Relat Res*. 2014;472(8):2352-2362.
27. VandenBerghe G, Hoenecke HR, Fronek J. Glenohumeral joint instability: the orthopedic approach. *Semin Musculoskelet Radiol*. 2005;9(1):34-43.
28. Voos JE, Livermore RW, Feeley BT, et al. Prospective evaluation of arthroscopic Bankart repairs for anterior instability. *Am J Sports Med*. 2010;38(2):302-307.
29. Walia P, Miniaci A, Jones MH, Fening SD. Influence of combined Hill-Sachs and bony Bankart defects on range of motion in anterior instability of the shoulder in a finite element model. *Arthroscopy*. 2015;31(11):2119-2127.
30. Walia P, Miniaci A, Jones MH, Fening SD. Theoretical model of the effect of combined glenohumeral bone defects on anterior shoulder instability: a finite element approach. *J Orthop Res*. 2013;31(4):601-607.
31. Walton J, Paxinos A, Tzannes A, Callanan M, Hayes K, Murrell GA. The unstable shoulder in the adolescent athlete. *Am J Sports Med*. 2002;30(5):758-767.
32. Widjaja AB, Tran A, Bailey M, Proper S. Correlation between Bankart and Hill-Sachs lesions in anterior shoulder dislocation. *ANZ J Surg*. 2006;76(6):436-438.
33. Wilk KE, Arrigo CA, Andrews JR. Current concepts: the stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther*. 1997;25(6):364-379.
34. Yamamoto N, Itoi E, Abe H, et al. Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: a new concept of glenoid track. *J Shoulder Elbow Surg*. 2007;16(5):649-656.
35. Yamamoto N, Muraki T, Sperling JW, et al. Stabilizing mechanism in bone-grafting of a large glenoid defect. *J Bone Joint Surg Am*. 2010;92(11):2059-2066.