

Does Repair of a Hill-Sachs Defect Increase Stability at the Glenohumeral Joint?

Neil K. Bakshi,* MD, John T. Jolly,[†] MS, Richard E. Debski,[†] PhD, and Jon K. Sekiya,*[‡] MD

Investigation performed at Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan, USA

Background: The effect of osteoallograft repair of a Hill-Sachs lesion and the effect of allograft fit on glenohumeral translations in response to applied force are poorly understood.

Purpose: To compare the impact of a 25% Hill-Sachs lesion, a perfect osteoallograft repair (PAR) of a 25% Hill-Sachs lesion, and an “imperfect” osteoallograft repair (IAR) of a 25% Hill-Sachs lesion on glenohumeral translations in response to a compressive load and either an anterior or posterior load in 3 clinically relevant arm positions.

Study Design: Controlled laboratory study.

Methods: A robotic/universal force-moment sensor testing system was used to apply joint compression (22 N) and an anterior or posterior load (44 N) to cadaveric shoulders (n = 9) with the skin and deltoid removed (intact) at 3 glenohumeral joint positions (abduction/external rotation): 0°/0°, 30°/30°, and 60°/60°. The 25% bony defect state, PAR state, and IAR state were created and the loading protocol was performed. Translational motion was measured in each position for each shoulder state. A nonparametric repeated-measures Friedman test with a Wilcoxon signed-rank post hoc test was performed to compare the biomechanical parameters ($P < .05$).

Results: Compared with the defect shoulder, the PAR shoulder had significantly less anterior translation with an anterior load in the 0°/0° (15.3 ± 8.2 vs 16.6 ± 9.0 mm, $P = .008$) and 30°/30° (13.6 ± 7.1 vs 14.2 ± 7.0 mm, $P = .021$) positions. Compared with IAR, the PAR shoulder had significantly less anterior translation with an anterior load in the 0°/0° (15.3 ± 8.2 vs 16.6 ± 9.0 mm, $P = .008$) and 30°/30° (13.6 ± 7.1 vs 14.4 ± 7.1 mm, $P = .011$) positions, and the defect shoulder had significantly less anterior translation with an anterior load in the 30°/30° (14.2 ± 7.0 vs 14.4 ± 7.0 mm, $P = .038$) position.

Conclusion: PAR resulted in the least translational motion at the glenohumeral joint. The defect shoulder had significantly less translational motion at the joint compared with the IAR. An IAR resulted in the most translational motion at the glenohumeral joint. This demonstrates the biomechanical importance of performing an osteoallograft repair in which the allograft closely matches the Hill-Sachs defect and fully restores the preinjury state of the humeral head.

Clinical Relevance: This study demonstrates the importance of performing an osteoallograft repair of a Hill-Sachs defect that closely matches the preinjury state and restores normal humeral head anatomy.

Keywords: Hill-Sachs lesion; osteoallograft repair; shoulder; glenohumeral translation

A capsulolabral repair is a commonly performed surgical treatment for an unstable shoulder with a Hill-Sachs lesion.^{1,4,39} Although a standard capsulolabral repair may

[‡]Address correspondence to Jon K. Sekiya, MD, Department of Orthopaedic Surgery, University of Michigan, MedSport, 24 Frank Lloyd Wright Drive, Lobby A, Ann Arbor, MI 48106, USA (email: sekiya@med.umich.edu).

*Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan, USA.

[†]Department of Bioengineering, University of Pittsburgh, Pittsburgh, Pennsylvania, USA.

One or more of the authors have declared the following potential conflict of interest or source of funding: J.K.S. received a grant from OREF to support this research.

The Orthopaedic Journal of Sports Medicine, 4(5), 2325967116645091

DOI: 10.1177/2325967116645091

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suffice for a small, nonengaging Hill-Sachs lesion, multiple studies have linked larger Hill-Sachs lesions to failed shoulder instability repairs and recurrent instability.[§] Burkhart and De Beer⁴ described the large, engaging Hill-Sachs lesion and noted a 100% failure rate for arthroscopic Bankart repairs when these large lesions were present. Similarly, Boileau et al¹ reported results of arthroscopic shoulder stabilization and found that a large Hill-Sachs lesion was associated with recurrent instability after a standard arthroscopic capsulolabral repair. Failure with a large Hill-Sachs lesion is likely due to engagement of the Hill-Sachs defect with the anterior glenoid rim when the arm is abducted and externally rotated.⁴ This occurs secondary to an articular arc length deficit on the humeral side

[§]References 1, 4, 7, 16-18, 24, 26, 29, 30, 33-35, 37-39

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caused by the Hill-Sachs lesion and manifests itself as catching, popping, apprehension, and instability.^{3,4}

Failure due to a large, engaging Hill-Sachs lesion generally requires one to address the Hill-Sachs defect itself through 1 of multiple techniques.⁴ One method that attempts to restore normal anatomy and articular arc of the humeral head is an osteoallograft augmentation of the bony defect.^{3-5,25,30} Studies have shown that a large Hill-Sachs lesion results in the loss of sphericity and convexity of the humeral head and decreases the stabilizing effect of compression into the concave glenoid.^{22,27,28,38} It has also been shown that the stabilizing effect of concavity compression was restored after osteoallograft transplantation, demonstrating the importance and validity of this anatomic surgical repair.³⁸

The response of the glenohumeral joint to applied loads after an osteoallograft repair of a Hill-Sachs lesion has been examined by a few studies.^{15,38} However, none of these studies have examined how an osteoallograft repair of a Hill-Sachs lesion affects the glenohumeral translations in response to an applied force. Furthermore, no studies have examined how the fit of the allograft affects the glenohumeral translations in response to an applied force.

As a result, the purpose of this study was to compare the impact of a perfect osteoallograft repair (PAR), an "imperfect" osteoallograft repair (IAR), and a 25% Hill-Sachs lesion (D) on glenohumeral translations in response to a compressive load and either an anterior or posterior load in 3 clinically relevant arm positions. Our hypothesis was that the PAR would result in significantly less translational motion at the glenohumeral joint than the IAR or D because it fully restores normal glenohumeral anatomy and most closely approximates the preinjury state.

METHODS

Experimental Testing Apparatus

A robotic/universal force-moment sensor (UFS) testing system was used to determine the translational motion at the glenohumeral (GH) joint in response to a combined compressive and anterior or posterior load. The robot was a 6-axis, serial-articulated manipulator (PUMA model 762; Unimate Inc) with repeatability of 0.2 mm for position and 0.2° for orientation.^{10,14,36} The UFS (model 4015; JR3 Inc), which is the same model used by the other studies, achieved repeatability of better than 0.2 N and 0.1 Ncm for forces and moments, respectively.^{2,10,14,31,36} The robotic testing system can determine the motion of a joint in response to specified external loads. By using the position control mode, the robotic manipulator can also reproduce the recorded joint motion at any time, including after the specimen has been altered (eg, after repair of the capsule) and measure the resulting in situ forces at the joint.^{9,10,13}

Specimen Preparation

Nine fresh-frozen cadaveric shoulders (age range, 60-84 years) were wrapped in gauze soaked in saline solution and

stored in plastic bags at -20°C until dissection. Before testing, each shoulder was thawed for 24 hours and then dissected of all soft tissue below the deltoid tuberosity of the humerus and the inferior half of the scapula. No shoulders included in this study had signs of osteoarthritis or other pathological joint conditions. The scapula was fixed in epoxy putty and rigidly attached to the end effector of the robotic manipulator through a specially designed clamp and the UFS. The humeral shaft was then potted in epoxy putty, secured within an aluminum cylinder, and fixed to the base of the robotic manipulator.

Experimental Testing Protocol

Initially, the joint was vented to atmospheric pressure through a simulated arthroscopic portal in the rotator interval, and standard reference positions were then obtained for application of each loading condition. The GH joint was initially positioned in the test system at 0° of horizontal abduction, 60° of abduction in the scapular plane, and neutral humeral rotation, which was defined as equal amounts of internal and external shoulder rotation when the humeral head was centered on the glenoid. Force control was then used to apply a 22-N compressive force to the humerus, while the forces in the 2 orthogonal directions were minimized (approximately 0 N). This compressive force centered the humeral head within the glenoid cavity and determined the joint position at 60° of abduction (AB) and 0° of external rotation (ER). The ER angle was then increased to 60° by applying an ER moment about the long axis of the humerus while maintaining the 22-N compressive force and minimizing the forces in the other directions. Rotation about the shoulder abduction and flexion axes was fixed, while the control system "learned" and then recorded the position of the joint at 60° of ER. This process was repeated at 30° of AB to obtain 30° of ER. Once the reference positions of GH AB and ER were determined, the skin and deltoid muscle were removed, leaving the remaining soft tissues intact, including the glenoid labrum, the GH capsule, the coracoacromial ligament, and the rotator cuff muscles (Figure 1).^{9,38}

The experimental protocol was designed to examine the effect of the following independent variables: (1) orientation of the defect with respect to the glenoid, achieved by utilizing 3 joint-testing positions and (2) shoulder state: perfect allograft repair (PAR), imperfect allograft repair (IAR), and a 25% Hill-Sachs lesion (defect, D), the creation of which is discussed below. These joint positions were chosen because of their clinical significance.^{4,11,19,20,28,38} The position most commonly associated with anterior shoulder instability is 90° of shoulder AB and 90° of shoulder ER. This was achieved in our specimens with 60° of GH AB and 60° of GH ER because of motion at the scapulothoracic joint (for every 90° of shoulder AB and ER, 30° occurs at the scapulothoracic joint^{4,19,20,28}). Therefore, this GH joint position corresponds to approximately 90° of shoulder AB and 90° of shoulder ER. A 25% Hill-Sachs defect was chosen as multiple clinical studies have identified this size lesion or larger as clinically relevant to recurrent shoulder instability.^{6,22,29,30,38} A perfect allograft repair (one that fully

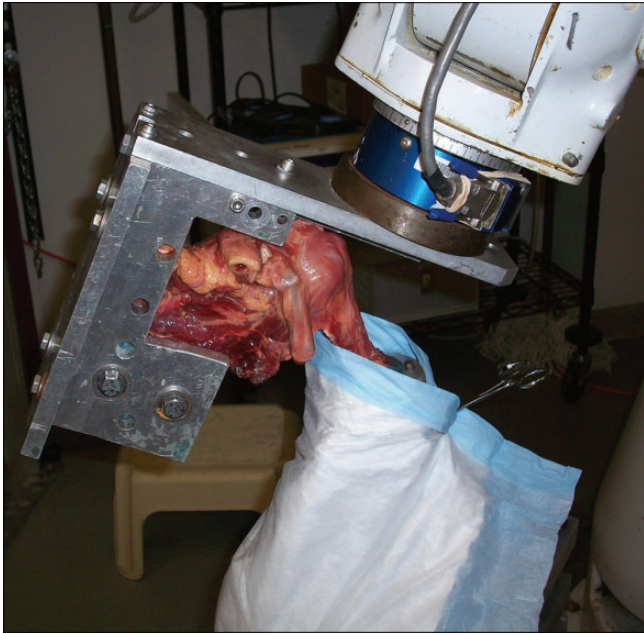


Figure 1. Experimental setup showing the glenohumeral joint fixed to the robotic testing device.

restores normal anatomy and matches the preinjury state) and an imperfect allograft repair (one that is 5%-10% prominent compared with the PAR) were chosen to determine how the quality of an osteoallograft repair affects the translational motion at the glenohumeral joint.

A compressive load of 22 N was applied to the intact shoulder in 60° of GH AB and 60° of GH ER. A 44-N load was then applied to the intact shoulder in the anterior and posterior directions at 60° of GH AB and 60° of GH ER. The joint was then moved to 30° of GH AB and 30° of GH ER, the loading conditions were applied again, and the same process was followed at 0° of GH AB and 0° of GH ER. This loading protocol was then repeated after the creation of the defect, PAR, and IAR states. To ensure capsular integrity, capsular tension was measured in the intact state and after each capsular repair to ensure that it was the same as that of the intact state.

The GH translations in the anterior-posterior (AP), superior-inferior (SI), and medial-lateral (ML) directions were measured during application of the loading conditions in the 3 joint positions (Figure 2).

Creation of Hill-Sachs Defect

The 25% Hill-Sachs defect was created on the posterolateral side of the humeral head, as this is the most common position in which they occur clinically.³⁸ The defect was created through a small posterior capsulotomy. The defect of the humeral head has been described as significant if it engages the anterior rim of the glenoid when the arm is brought into a position of athletic function, most commonly 90° of shoulder AB combined with 90° of ER (60° of AB and 60° of ER at the GH joint).^{4,19,20} Therefore, each shoulder

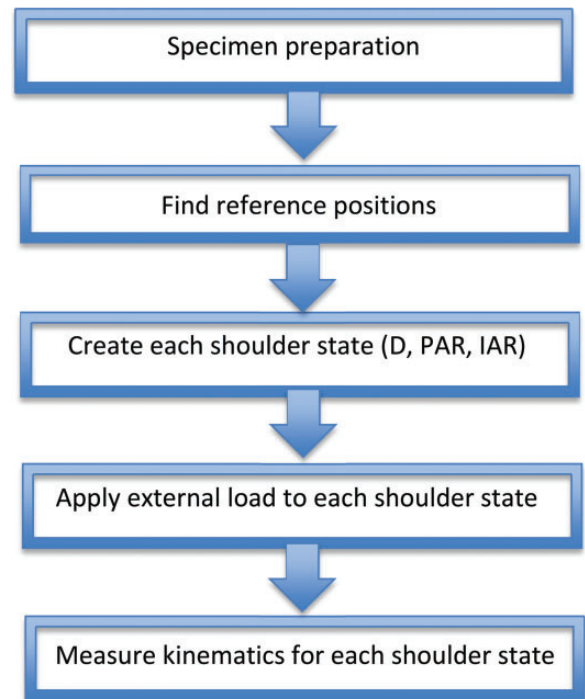


Figure 2. Flowchart of the experimental steps followed to obtain the glenohumeral joint translations for all 3 shoulder states: 25% Hill-Sachs lesion (defect, D), perfect allograft repair (PAR), and imperfect allograft repair (IAR).

was moved to this GH joint position, and a line was then drawn down the center of the humeral head parallel to the anterior glenoid rim, representing the orientation of the defect as if it had actually been created by impaction on the glenoid rim during a forceful dislocation.^{4,23} Using this line and the posterolateral half of the humeral head, 25% of the humeral head diameter was marked and removed using an oscillating saw (Figure 3). After defect creation, the humeral head diameter and the depth of the Hill-Sachs defect were measured again to ensure a 25% defect. This method of defect creation most closely approximated the *in vivo* condition of an engaging Hill-Sachs defect and defects previously described in multiple clinical studies.^{4,21,23,32,40} This protocol was used to ensure reproducible creation of Hill-Sachs defects between shoulders in the most common position that they occur clinically.³⁸

After defect creation was completed, the posterior capsulotomy was repaired prior to testing. Careful attention was directed to maintain the initial capsular tension (prior to capsulotomy). This was done by approximating the capsulotomy with no. 2 braided nonabsorbable simple sutures (Ethicon) with careful attention that each side of the capsulotomy was approximated without any overtightening/overlap (Figure 4). To ensure capsule integrity throughout all parts of the testing protocol, we performed position-control testing before and after the capsular repair to verify that no significant *in situ* force changes developed. This was done for each specimen throughout our entire experimental protocol.

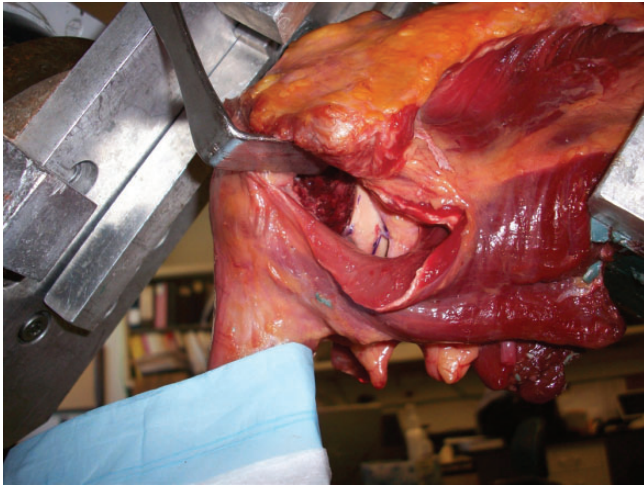


Figure 3. The created Hill-Sachs lesion viewed through the posterior capsulotomy.

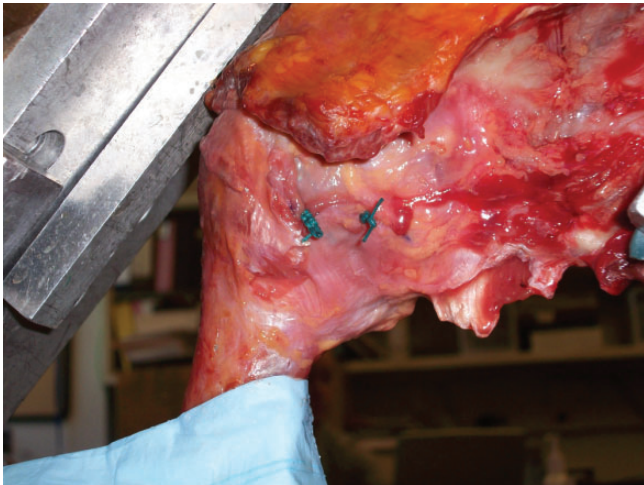


Figure 4. The repaired posterior capsulotomy and posterior rotator cuff muscles.

Creation of the Perfect Allograft Repair State

The perfect allograft repair state was created in each specimen by using the following protocol. The wedge-shaped piece of bone removed during defect creation was inserted back into the defect. Guide pins were drilled into the wedge to hold the wedge in place. Finally, using Kirschner wires as guides, two 3.5-mm headless self-tapping cortical bone screws (Acutrak; Acumed) were screwed into the wedge, fixing the wedge into the defect (Figure 5). This most closely approximated the intact state and mimicked a perfect allograft repair. Similar to the defect creation state, the posterior capsulotomy was repaired before testing, as discussed above.

Creation of the Imperfect Allograft Repair State

The IAR state was created in each specimen by using the following protocol. The wedge-shaped piece of bone used to

create the PAR state was removed. In its place, a wedge-shaped piece of bone removed during defect creation from a different humeral head was inserted. Of the 8 wedges from the other specimens, the wedge that filled the defect and was 5% to 10% prominent off the articular surface was chosen, creating an “imperfect” allograft repair. A wedge 5% to 10% larger than the defect was chosen. This wedge of bone was inserted using the same wedge insertion procedure discussed for the perfect allograft repair. Similar to the defect creation state and the PAR state, the posterior capsulotomy was repaired before testing, as discussed above.

Statistical Analysis

A power analysis was performed using SamplePower 2.0 (SPSS Inc). Based on previous studies examining GH translation using our robotic technology,^{9,38} the standard deviation of the GH translation was assumed to be 3 mm for each joint position and state. Therefore, a minimum sample size of 9 shoulders was found to provide a power of greater than 0.80, for an alpha of .05. A 2-factor nonparametric repeated-measures Friedman test (SPSS Inc) with a Wilcoxon signed-rank post hoc test (significance level, $P < .05$) was used to assess the effects of orientation (60° AB/60° ER, 30° AB/30° ER, and 0° AB/0° ER) and humeral head condition (PAR vs IAR vs 25% Hill-Sachs defect) on GH translations.

RESULTS

Intact Versus Perfect Allograft Repair

The intact shoulder and shoulder with the PAR were observed to have the same degree of translation with an anterior/compressive load as well as a posterior/compressive load in the 0°/0° position (anterior, 15.3 ± 8.2 mm; posterior, 16.1 ± 7.9 mm). The intact and PAR shoulders were observed to have the same degree of translation with an anterior/compressive load and a posterior/compressive load in the 30°/30° position (anterior, 13.6 ± 7.1 mm; posterior, 15.7 ± 5.8 mm). The intact and PAR shoulders were observed to have the same degree of translation with an anterior/compressive load and a posterior/compressive load in the 60°/60° position (anterior, 11.5 ± 7.5 mm; posterior, 11.7 ± 6.5 mm). Although these values were not identical, the degree of uncertainty in our experimental protocol was to the tenths digit, and these small differences between the intact and PAR were not captured as a result.

Perfect Allograft Repair Versus 25% Hill-Sachs Defect

The shoulder with the PAR had significantly less anterior translation with an anterior/compressive load in the 0°/0° (15.3 ± 8.2 mm vs 16.6 ± 9.0 mm, $P = .008$) and 30°/30° (13.6 ± 7.1 mm vs 14.2 ± 7.0 mm, $P = .021$) positions compared with the shoulder with a 25% Hill-Sachs defect. The shoulder with the PAR also had significantly less posterior translation with a posterior/compressive load in the 30°/30° position compared with the shoulder with a 25% Hill-Sachs

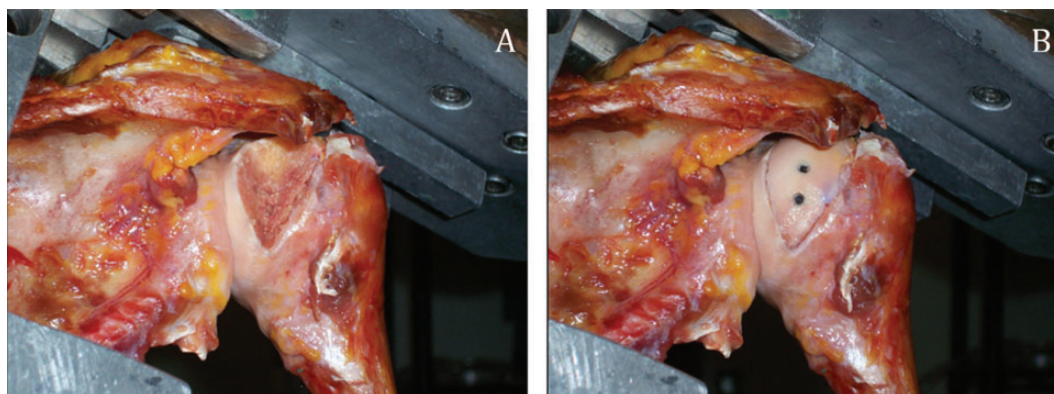


Figure 5. (A) Hill-Sachs defect. (B) Perfect allograft repair (PAR) state created by reinserting the wedge of bone removed during Hill-Sachs defect creation.

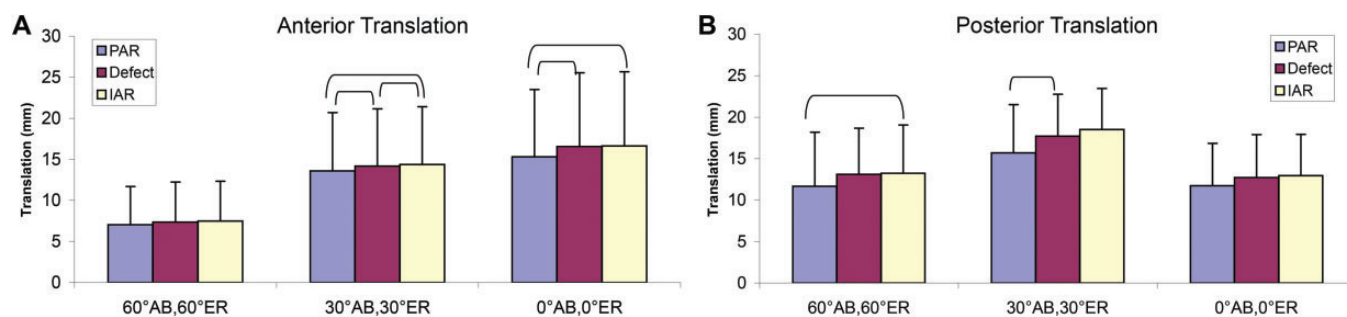


Figure 6. (A) Anterior and (B) posterior translational motion in response to a 44-N anterior and 22-N compressive load for all 3 shoulder states—perfect allograft repair (PAR), imperfect allograft repair (IAR), and 25% Hill-Sachs lesion (defect)—in 3 abduction/external rotation (AB/ER) testing positions: 0°/0°, 30°/30°, 60°/60°. Statistical parameter is 1 standard deviation; significant difference, $P < .05$.

defect (15.7 ± 5.8 mm vs 17.7 ± 5.1 mm, $P = .008$). All other differences in translational motion in the AP and SI directions were not statistically significant.

Perfect Allograft Repair Versus Imperfect Allograft Repair

The shoulder with the PAR had significantly less anterior translation with an anterior/compressive load in the 0°/0° (15.3 ± 8.2 mm vs 16.6 ± 9.0 mm, $P = .008$) and 30°/30° (13.6 ± 7.1 mm vs 14.4 ± 7.1 mm, $P = .011$) positions compared with the IAR. The shoulder with the PAR also had significantly less posterior translation with a posterior/compressive load in the 60°/60° position compared with the IAR (11.7 ± 6.5 mm vs 13.2 ± 5.8 mm, $P = .008$). All other differences in translational motion in the AP and SI directions were not statistically significant.

Imperfect Allograft Repair Versus 25% Hill-Sachs Defect

The shoulder with the 25% Hill-Sachs lesion had significantly less anterior translation with an anterior/compressive

load in the 30°/30° position compared with the IAR (14.2 ± 7.0 mm vs 14.4 ± 7.0 mm, $P = .038$). All other differences in translational motion in the AP and SI directions were not statistically significant (Figure 6).

DISCUSSION

These findings indicate that the perfect allograft repair state results in significantly less glenohumeral translational motion with applied load compared with the imperfect allograft repair and 25% Hill-Sachs defect states. In addition, the 25% Hill-Sachs defect state results in significantly less glenohumeral translational motion with applied load compared with the imperfect allograft repair state. Therefore, the imperfect allograft repair state results in the most glenohumeral translation in response to applied loads, making it the most unstable shoulder state. The IAR state most likely results in the most translational motion because of its prominence off the articular surface. This small (5%-10%) prominence from the articular surface may be highly disruptive to the normal convexity of the humeral head, resulting in significantly increased translation at the glenohumeral junction.

As shown by this study, the improvement in glenohumeral translations after an osteoallograft repair is gained only if the chosen allograft is very closely matched to the Hill-Sachs lesion. If it is not and the normal humeral head anatomy is not fully restored, it may not be worthwhile to perform an osteoallograft repair. Therefore, thorough measurement of the size and shape of the Hill-Sachs defect should be performed preoperatively and intraoperatively to ensure an anatomic reconstruction with a close fit of the osteoallograft. Emphasis should be placed on producing an osteoallograft that is flush with the curvature of the humeral head to better restore its normal convexity, rather than prominent or recessed. In addition, every attempt should be made to match the allograft donor and recipient with regard to sex, shoulder side, and size of the shoulder bones. Procuring an allograft from a donor who is similar to the recipient could result in a closer fit that better restores the normal glenohumeral anatomy. Although no studies have shown this to be of clinical benefit, our personal experiences with osteoallograft repairs of Hill-Sachs lesions have demonstrated the advantages of matching the donor and recipient with regard to these variables. In addition, only fresh cadaveric bone (within 30 days) should be utilized for the creation of the allograft due to its superior biological and biomechanical characteristics.⁸

The biomechanics of the glenohumeral junction after an osteoallograft repair have been examined by a few other studies. Sekiya et al³⁸ examined the anterior translation until dislocation and the stability ratios (peak translational force in anterior direction/compressive load) in cadaveric shoulders with differently sized Hill-Sachs defects and after osteoallograft repair. The authors found that the anterior translation until dislocation and the stability ratio at the glenohumeral joint decreased with increasing size of the Hill-Sachs defect and were restored to that of the intact state after osteoallograft repair.³⁸ Giles et al¹⁵ compared stability and range of motion after humeral head osteoallograft repair, remplissage repair, and partial resurfacing arthroplasty in cadaveric specimens with 30% and 45% Hill-Sachs defect. All 3 methods of repair improved stability, but only the osteoallograft repair and partial resurfacing arthroplasty returned range of motion to that of the intact state.¹⁵ Although both studies were well planned and executed, neither measured glenohumeral translations with applied force in all 3 axes of motion. In addition, neither study examined how the fit of the allograft affects the translational motion at the glenohumeral joint.^{15,38}

This study has a few limitations. For example, the absolute differences in translation between shoulder states were relatively small. Nevertheless, these differences were statistically significant. The small, but significant, absolute differences may have resulted due to relatively low applied loads in the study compared with the forces acting on the shoulder during athletic activity. Loads applied to the dynamic shoulder of an overhead athlete during throwing have been shown to be significantly higher than the loads applied in this study. These higher loads during pitching and other overhead activities may result in increased absolute translational differences between the tested shoulder states.¹² Future testing with greater applied loads may

need to be performed to further assess this hypothesis. Furthermore, cadaveric shoulders from an older population were studied rather than the shoulders of patients. Although every attempt was made to simulate the in vivo condition of a joint compression model, certain aspects do not exactly replicate the in vivo model (including the lack of proprioception or muscle forces). In addition, the joint capsule of each specimen was altered multiple times during our experimental protocol, which could have resulted in minor capsular deterioration. These measurements were also obtained at 1 point in time (immediately after the repairs), and conclusions regarding postoperative healing and long-term outcomes cannot be made as a result. Finally, although statistical significance was evaluated and established in the study, clinical significance was not examined and cannot be commented on.

CONCLUSION

In our study, the PAR resulted in the least translational motion at the glenohumeral joint. The defect shoulder had significantly less translational motion at the joint compared with the IAR. An IAR resulted in the most translational motion at the glenohumeral joint. This demonstrates the biomechanical importance of performing an osteoallograft repair in which the allograft closely matches the Hill-Sachs defect and fully restores the preinjury state of the humeral head.

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