Humeral Head Reconstruction for Hill-Sachs Defects: A Biomechanical Comparison of 2 Fixation Techniques for Bone Grafting


Purpose: The purpose of this biomechanical study was to compare anterograde with retrograde screw fixation for allograft reconstruction of Hill-Sachs defects. Methods: In 8 pairs of fresh-frozen humeral heads, a 40% Hill-Sachs defect was created. The resultant wedge-shaped osteochondral fragment was used as allograft. For each technique, two 3.75-mm screws were used for fixation. To test the strength of fixation, a custom tool was used that would apply load to the graft. By use of a materials testing machine, a staircase cyclic loading protocol was performed (500 cycles at 10, 20, 30, and 40 N) and then load to failure. Graft displacement was measured by an optical tracking system. Results: For the 2 techniques, graft displacement increased with increasing load and increasing number of cycles up to a mean of 0.9 /C6 0.42 mm for anterograde fixation and 1.1 /C6 0.79 mm for retrograde fixation. This increase was significant within each technique across all 4 loading levels (P < .05). However, there were no significant differences in graft displacement between the 2 techniques at any loading level or number of cycles (P = .16 to P = .96). In addition, the load to failure between the anterograde and retrograde techniques (98.5 N and 95.6 N, respectively) was not significantly different (P = .706). Conclusions: The initial fixation and failure strength of anterograde and retrograde graft fixation techniques for substantial Hill-Sachs defects do not significantly differ in a biomechanical cadaveric model. Clinical Relevance: This biomechanical study supports that in an engaging Hill-Sachs defect, both anterograde and retrograde screw fixation techniques can be used for fixation of humeral head allografts.
The purpose of this study was to compare the fixation stability and failure strength of a graft after anterograde or retrograde fixation in a biomechanical cadaveric model. We hypothesized that retrograde fixation would yield comparable fixation strength to the anterograde technique.

**Methods**

Sixteen fresh-frozen proximal humeri (8 paired specimens; mean age, 69 years) were tested in this protocol. Institutional review board approval was not required because this was a biomechanical study. A computed tomography scan and visual inspection were performed to ensure that all specimens showed no signs of degeneration, trauma, or prior surgery. Each humerus was transected 10 cm distal to the humeral head. After being allowed to thaw for 24 hours, all soft tissues were removed.

For all 16 humeri, a Hill-Sachs defect was created in a standardized manner modified from the technique described by Kaar et al. with the center of the osteotomy at 209° from the anterior border of the humeral head articular cartilage viewed superiorly. The size of the created Hill-Sachs defect was defined to be 40% of the humeral head width as measured perpendicular to the orientation of the Hill-Sachs defect described earlier. After the orientation and size of this defect were marked, a humeral head bone fragment was cut away with a micro-sagittal saw. To ensure complete contact between the humeral head graft and the simulated Hill-Sachs lesion, the wedge-shaped osteochondral fragment resulting from creation of the defect was used to function as the graft for the same humerus. In addition, to ensure accurate fragment position after fixation, 2 screw holes were predrilled in accordance with the technique to which the specimen was randomized; however, screws were only inserted once the graft was replaced. Technique randomization was performed with an online randomization program (www.randomization.com). Block randomization was used for each pair of humeri to define 1 of 4 possibilities: right, anterograde; right, retrograde; left, anterograde; or left, retrograde. This enabled a randomized balanced equal distribution of right and left specimens between the 2 techniques.

Cannulated partially threaded 3.75-mm titanium screws (Arthrex, Naples, FL) were used to secure the graft. The direction of the 2 drill holes was parallel to each other and perpendicular to the deep edge of the Hill-Sachs defect. For the anterograde technique, the screw entry points were chosen to be at one-fourth and three-fourths of the longitudinal midline of the created wedge, at a distance of 24 mm from each other. The far cortex of the humeral metaphysis was not engaged with the antegrade screws. The drill tunnels at the articular surface were overdrilled to the size of the screw heads to enable countersinking (Fig 1). In the retrograde technique, 2 parallel screws were inserted in a distal-to-proximal direction, the first starting just lateral to the bicipital groove and the second more lateral over the greater tuberosity. With the use of a targeting guide (C-Ring Pin Guide; Arthrex), 2 guidewires were placed in such a manner that they pierced the humeral head at the same points that were defined as screw entry points in the anterograde technique. The screw length was measured to avoid penetration of the articular surface. Screw tip placement was visually confirmed to remain 5 mm under the articular surface (Fig 2).

To test the strength of graft fixation, a 1-cm slot was created in the intact humerus at the humerus-graft interface to allow insertion of a custom tool that
would apply load directly to the graft (Fig 3). The custom tool was fixed to a materials testing machine (Instron, Norwood, MA). Once the specimen was in place, the custom tool was inserted into the slot adjacent to the graft and the specimen was rigidly fixed in a pot with dental cement. The specimen was mounted to the materials testing machine with the custom tool aligned perpendicular to the graft interface to ensure a repeatable direction of load application.

To quantify fragment stability (i.e., displacement), a 6-df optical tracking marker (Optotrak Certus; Northern Digital, Waterloo, Canada) was rigidly fixed to the intact specimen and the fixated graft using custom mounts and small fragment fixation screws (Fig 3). Digitizations were then taken to establish a humeral head coordinate system. The integrity of each optical marker’s fixation was verified throughout testing, and no instances of fixation failure were observed. Placement of these markers on the intact humerus and the graft allowed for measurement of the graft’s initial fixated position before testing and for the continuous recording of its position throughout testing. The distance between this initial position and the
fragment’s current position during each test was termed “interface displacement” and was calculated continuously throughout testing.

After the application of a 5-N preload, cyclic testing consisted of applying 500 cycles of loading to the graft at a rate of 1 Hz with sequential magnitudes of 10, 20, 30, and 40 N.21-23 Throughout cyclic testing, the graft was loaded with a minimum force of 5 N. We chose 500 cycles because pilot testing showed that this was the level at which displacement typically plateaued to an acceptable extent. In addition, multiple load magnitudes were tested, rather than traditional single-load protocols, to fully characterize graft displacement. The magnitude of these loads was chosen based on pilot testing and an analytical analysis of the transverse loads applied to the humeral head during normal motions. Loading was applied with the materials testing machine, which recorded the applied load and the graft displacement. Displacement of the graft was continuously tracked by the optical system throughout testing, with individual data points extracted during peak load application during the 100th, 200th, 300th, 400th, and 500th cycles during post hoc analysis. After completion of the cyclic loading protocol, a ramp load was applied until graft failure occurred, which was predefined as 2 mm of interface displacement. A magnitude of 2 mm was considered unacceptable displacement because this is the amount of displacement that is commonly used in upper extremity intra-articular fractures to define unacceptable.

Data Analysis and Statistics
Displacement data for the cyclic loading protocol were calculated at the end of cycles 1, 100, 200, 300, 400, and 500 for each loading level and were taken as the difference in displacement from the initial graft position before load application. Failure load was taken as the force magnitude required to displace the graft by 2 mm from its initial position.

The retrograde and anterograde datasets were statistically compared by use of paired-samples t tests with significance defined as $P < .05$. In addition, the effects of increasing cycles and load level were assessed for the 2 techniques with a 2-way repeated-measures analysis of variance for each, again with significance defined as $P < .05$.

Results
Effect of Load Level and Cycles
For both techniques, graft displacement increased with increasing load (retrograde, $P = .011$; anterograde, $P = .004$) and increasing number of cycles (retrograde, $P = .054$; anterograde, $P = .013$) (Fig 4). When comparisons between cycle levels were performed, there were no
significant comparisons in graft displacement for the retrograde technique whereas significant comparisons did exist for the anterograde technique between the 100th cycle and the 300th and 500th cycles (0.02 ± 0.01 mm [P = .029] and 0.03 ± 0.01 mm [P = .023], respectively) across all 4 tested loads; however, their significance can be largely attributed to the relative size of the difference to its variance rather than the actual magnitude of the difference.

Comparison of Techniques

There were no statistically significant differences in graft displacement between the 2 fixation techniques at any load and cycle level (≤0.13 mm, P ≥ .155) (Figs 4 and 5). In addition, the load to failure was not significantly different between the 2 techniques (2.9 ± 20.8 N, P = .706) (Fig 6, Table 1).

Discussion

Moderate to large Hill-Sachs defects in patients with recurrent instability can be surgically managed with allograft reconstruction by anterograde or retrograde screw fixation techniques. The results of this study indicate that the initial graft fixation stability and failure strength between the 2 techniques were not significantly different. In addition, it was shown that the 2 fixation methods have similar trends in how graft displacement changes with increasing load and number of cycles. With regard to the trends in displacement with increasing load application, it was found that both techniques exhibited similar progressions in displacement without any major differences in the load at which the rate of graft displacement changed. From previous experience with fixation stability testing, it was believed that a point would exist at which the 2 techniques’ rates of displacement would differ; however, because the fixation methods proved to be equivalent throughout loading, it makes sense that no such point occurred. With an increasing number of cycles at the same load level, no substantial differences were noted in the change in graft displacement between techniques. This finding is not surprising because the graft construct contains no viscoelastic properties, which would allow displacement over time to occur after an initial bedding-in period. It should be noted that the 2 exceptions to this finding were not clinically relevant because the differences were very small, at 0.03 mm or less, and their statistical significance was more an effect of the extremely small variance (≤0.006) than the magnitude of the difference.

Because the antegrade and retrograde techniques showed biomechanical equivalence, other parameters may be used to influence the decision to use 1 technique over the other. In general, allograft reconstruction of Hill-Sachs defects has the potential disadvantage of graft resorption with screw loosening, leading to exposed intra-articular hardware that could cause articular damage.6,24 For patients with prominent screws but a stable substantially integrated allograft, screw removal may be the only treatment required. For removal of screws after anterograde insertion, the use of the previous approach would be necessary, including surgical glenohumeral dislocation after tenotomy of the subscapularis tendon. Alternatively, removal of anterograde screws could be achieved through a percutaneous technique using arthroscopic assistance; however, this may be technically challenging. Screws inserted in a retrograde manner, however, can be removed by an open or percutaneous technique without the need for an arthrotomy or joint dislocation. In addition, localization of the screw heads might be easier and removal could be performed with or even without the need for an image intensifier.

For anterograde screw placement, the articular cartilage and subchondral bone have to be drilled to allow screw head countersinking. The articular drill tunnels

![Fig 5](image-url)
may provide a bony channel for synovial fluid ingress, which may have an effect on graft healing or resorption. The retrograde technique described in this study used a targeting device to assist with optimal screw placement. This technique, however, may also be performed freehand.

A strength of our testing protocol that may warrant further investigation is the analysis of hysteresis effects as a metric for evaluating the quality of fixation during cyclic loading at various load levels. In addition, the use of multiple load levels has enabled the loading characteristics of the 2 fixation techniques to be described in greater detail, which may allow the development of improved postoperative rehabilitation protocols. This would not be possible with a single-level loading protocol, which in contrast can only describe the limit of the fixation’s performance rather than providing a full characterization.

Limitations

Some limitations are inherent to this in vitro biomechanical study. To directly test the fixation technique with minimizing confounders, a perfect match of graft and defect was obtained by using the resected osteochondral fragment used to create the Hill-Sachs defect as the graft. This is a limitation; however, its effects would apply to both fixation scenarios equally. The screw holes were predrilled in the intact humeral head before the defect was resected, once again providing an optimum fit of the graft to the defect. The mean age of the tested specimens was markedly higher than the age of patients who would typically undergo allograft reconstruction. This might not influence the comparison of the 2 techniques but may result in stronger fixation in the clinical setting with younger patients. In addition, the results represent an unhealed state and cannot be fully extrapolated to determine final clinical results. We believe, however, that the results have value in judging initial fixation strength for the 2 techniques and that because initial fixation is equivalent, the fully healed state will also have equal strength.

A further limitation was the use of paired specimens instead of a fully repeated-measures design. This was necessary because of the destructive nature of testing for each graft fixation technique, but it is believed that the use of paired specimens was unlikely to affect the results.

Conclusions

The initial fixation and failure strength of anterograde and retrograde graft fixation techniques for substantial Hill-Sachs defects do not significantly differ in a biomechanical cadaveric model.

References

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