The Addition of Remplissage to Free Bone Block Restores Translation and Stiffness Compared to Bone Block Alone or Latarjet in a Bipolar Bone Loss Model


**Purpose:** The purpose of this study was to compare glenohumeral stability following a Latarjet, a free bone block (FBB), and a FBB with remplissage for bipolar bone loss. **Methods:** Nine matched pairs of fresh frozen cadavers were tested in a custom biomechanical apparatus with rotation and progressive translational loading. The free bone block group consisted of a distal tibial allograft with an all-suture tape construct. The Latarjet group was performed with the native coracoid and two partially threaded cannulated screws. A bipolar bone loss model was created with 20% glenoid bone loss and an off-track Hill-Sachs lesion. Testing conditions included the 1) native state, 2) bipolar bone loss model, 3) Latarjet, 4) FBB with distal tibial allograft secured with cerclage sutures, and 5) FBB with remplissage. Each condition was tested for translation, humeral head apex shift, stiffness, and dislocation force. **Results:** There were no differences in translation, stiffness, or dislocation force between the FBB alone and Latarjet groups. The FBB with remplissage group demonstrated the lowest anterior-inferior translation at 90° of ER, which was statistically significant compared to Latarjet 20N \((P = .013)\) and compared to the FBB alone at 40N \((P = .024)\) and 50N \((P = .011)\). The FBB with remplissage group was significantly stiffer compared to FBB alone at 90° ER with approximately 60% change in stiffness \((P = .028)\). The force required to dislocate the humeral head after treatment was highest in the FBB with remplissage group, which was statistically significant compared to the FBB alone \((P = .003)\) and Latarjet groups \((P = .018)\). **Conclusion:** The addition of remplissage to a FBB restores translation and stiffness closer to the intact state compared to a FBB alone or Latarjet in a bipolar bone loss model with an off-track Hill-Sachs lesion. In this model, dislocation force significantly increased with the addition of remplissage to the FBB. **Clinical Relevance:** This biomechanical study provides evidence that Latarjet and FBB are both acceptable forms of treatment for bipolar bone loss, but stability can be enhanced with the addition of remplissage following glenoid reconstruction.

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Introduction

Recurrent anterior glenohumeral instability is often associated with bipolar bone loss, and the complexity of management increases as bone loss increases. Anterior instability with minimal bone loss can be successfully treated with a soft tissue procedure alone.1 Large bipolar bone loss lesions, however, require a bony augmentation procedure to restore stability.1,2 Options for bony reconstruction of the glenoid include either a free bone block (FBB) or Latarjet, the latter of which is often considered the standard of care.

The Latarjet procedure is a nonanatomic procedure that restores glenoid bone loss and provides a potential soft-tissue sling effect via the conjoint tendon. Long-term results have indicated that excellent outcomes can be obtained with low rates of recurrent instability.3 However, the complication rate following Latarjet ranges from 6 to 15%.3-6 FBB procedures with graft sources such as the iliac crest or distal tibia allograft are a more anatomic alternative to Latarjet. Short-term outcomes are encouraging;7,8 however, neither Latarjet nor FBB procedures alone address the humeral side of bone loss.

In addition to glenoid bone loss, patients with large glenoid defects present with engaging Hill-Sachs lesions. The concept of the glenoid track introduced by Yamamoto et al. has been used by some to provide guidelines on the addition of remplissage to arthroscopic Bankart repair.9,10 In a 15% glenoid bone loss model, Hartzler et al. reported that the addition of a remplissage to a Bankart repair restored stability.11 Therefore, the addition of remplissage to a bony reconstruction of the glenoid may improve stability in the setting of large bipolar bone loss. This may be particularly clinically relevant in combination with a FBB procedure, which is often performed arthroscopically.

The purpose of this study was to compare gleno-humeral stability following Latarjet, a free bone block (FBB), and a FBB with remplissage for bipolar bone loss. The hypothesis was that the addition of remplissage would improve stability compared to FBB alone and provide equivalent results to that of Latarjet.

Materials and Methods

Eighteen fresh-frozen cadaveric shoulders (9 matched pairs) were used. There were 4 male and 5 female donors, with an average donor age of 59.7 years (range: 52 to 67 years). The rotator cuff of all specimens was macroscopically intact and verified by an orthopedic surgeon (JC). Institutional Review Board approval was not required for this study.

Following testing on 2 specimens, a power analysis was performed in order to determine the total required sample size. In these 2 specimens the FBB with remplissage had a 2.5 N/mm average increase in stiffness during dislocation compared to Latarjet. Assuming a standard deviation of 2 N/mm, it was determined that a sample size of 9 was required to achieve a power of 80% and a level of significance of 5%.

Testing Setup

A previously described custom shoulder testing system was used for testing.11 The skin and all muscles except for the rotator cuff and conjoint tendon were removed. The coracoacromial ligament and gleno-humeral joint capsule were also preserved. No. 2 FiberWire sutures (Arthrex, Inc., Naples, FL) were placed through subdivisions of the rotator cuff tendons (supraspinatus, 2; subscapularis, 3; infraspinatus, 2; teres minor, 1). The scapula was bolted to a plate positioned in the infraspinatus fossa with the medial border aligned parallel with the mounting bracket. The scapula was then rigidly fixed to the testing system in 20° of anterior tilt and 30° of abduction (Fig 1). The humerus was secured in a cylinder with an intramedullary rod for centering and attached to the arc of the testing system. This arc allowed for positioning and locking abduction angle, as well as the plane of testing. Five newtons (N) were applied through each of the rotator cuff sutures, providing a total of 40 N of gleno-humeral joint compressive force, which was held constant for all testing conditions. Additionally, the conjoint tendon was sutured distally with a running locking stitch and left intact on the native coracoid. No. 2 FiberWire sutures were used to attach the tendon to a cord to which 10 N was applied parallel to the humerus with a cable pulley attachment. The tendon was aligned with the bicipital groove for the intact condition and did not change to maintain a native line of pull on the tendon during loading. The humerus was positioned parallel to the ground in 60° of glenohumeral abduction. Once the muscle load was applied, the humerus

Fig 1. Photograph of the custom biomechanical testing apparatus.
was adjusted 30° posterior to the scapular plane to simulate the coronal plane.

Small screws were fixed into the scapula (anterior acromion, posterior acromion, and middle acromion) and humerus (proximal bicipital groove, distal bicipital groove, and posterior humeral shaft). A Microscribe 3DLX instrument (Revware Inc, Raleigh, NC) was used to record the static 3-dimensional location of the screws in space to calculate humeral position translation during testing.

**Repair Conditions**

Each side of the matched cadaveric pairs was randomized to receive either a FBB or Latarjet.

Four conditions were tested in the FBB group: 1) intact, 2) bipolar bone loss, 3) bipolar bone loss with FBB, and 4) bipolar bone loss with FBB and remplissage. Three conditions were tested in the Latarjet group: 1) intact, 2) bipolar bone loss, and 3) bipolar bone loss with Latarjet. Capsular repair was not performed in any case since the capsular injury in this model was a cutting model and does not represent stretching of the capsule seen clinically and previous biomechanical model demonstrating that capsular repair did not contribute any additional stability in the setting of a 20% glenoid defect. 12

The intact condition included a transverse split in the posterior rotator cuff and capsule that was used to access the posterior aspect of the humeral head, assess engagement, and create the Hill-Sachs defects similar to that reported by Hartzler et al.11 The capsular split was made before testing the intact condition to hold this defect constant throughout the testing protocol. This split was made parallel to the rotator cuff muscle fibers in the interval between the infraspinatus and teres minor.

The bipolar bone loss model consisted of a 20% glenoid bone loss with a Bankart capsulolabral lesion and an off-track Hill-Sachs lesion. The Bankart lesion was created through a transverse split in the inferior 1/3 of the subscapularis. The lesion was created by elevating the anterior labrum from the 12 to 6 o’clock position. To determine the amount of bone resection needed, the largest diameter of the intact inferior glenoid (D) was measured with a Microscribe 3DLX. The amount of bone loss to achieve a 20% defect was then calculated (d). A microsagittal saw was then used to resect the bone parallel to the long axis of the glenoid to the desired amount. The defect was then verified with a Microscribe 3DLX. The width of the glenoid track (GT) following resection was calculated as GT = 0.83D – d. To ensure engagement, a Hill-Sachs defect 5 mm wider than the glenoid track was made in the posterior humeral head. Using a microsagittal saw, we made a wedge-shaped defect with the medial cut parallel to the plane of the glenoid with the arm in 60° of abduction, as described by Hartzler et al.11 All lesions were visually confirmed to engage and be off-track on initial testing (Fig 2).

The FBB was taken from a distal tibia allograft using a harvesting station (Distal Tibia Allograft Workstation; Arthrex) to create an 18 x 13 x 8 mm graft with 10 mm between the drill holes. The graft was secured to the glenoid with a suture-based construct (FiberTape Cerclage; Arthrex). First, a drill guide was placed from posterior to anterior and positioned in the center of the glenoid defect. Two 3.0-mm cannulated drills were used to create bone tunnels through the glenoid, 7 mm lateral to the articular surface. Nitinol wires were passed through the cannulation of the drills. The guide and drills were then removed. The wires were then used to shuttle two sets of FiberTape cerclage suture constructs through the superior bone tunnel from posterior to anterior, through the holes in the FBB, and then back through the inferior glenoid bone tunnel. Posteriorly the free suture limbs were shuttled into the half-racking hitch of one another and manually advanced down to bone. The free limbs were then tensioned to the bone to a maximum of approximately 50 pounds-force (lbf). Three half-hitch knots were tied on top of each cerclage after tensioning was completed (Fig 3).

Remplissage of the Hill-Sachs lesion was completed at the articular margin of the defect. Dissection through the previous posterior capsular split was completed down to the bone. While the soft tissues were gently retracted, two threaded anchors (4.75 mm SwiveLock, Arthrex, Inc.) were placed at the superior and inferior medial margins of the defect. Sutures from each anchor were passed through the posterior capsule and rotator cuff. Then, a knotted double-pulley mattress technique was used to secure the tissue into the defect.

Latarjet was performed through the anterior subscapularis split with a dedicated instrument set (Glenoid Bone Loss Set; Arthrex). Using a guide, we placed 2 K-wires into the coracoid and then over-drilled with a 4-mm cannulated drill. After both tunnels were created, a microsagittal saw was used to osteotomize the coracoid from the scapula as close to the base as possible. Using an offset guide, the inferior aspect of the coracoid was placed to rest against the anterior glenoid, and the lateral aspect of the coracoid was oriented flush with the articular surface. The coracoid graft was placed at the center of the defect, and the graft was secured with two fully threaded 3.75-mm bicortical screws.

**Biomechanical Testing**

Maximum external rotation was measured using a torque wrench (Proto Industrial Tools, Norcross, GA) with 1.5 Newton-meters (Nm) applied to passively, externally rotate the shoulder. The shoulder was preconditioned with 5 cycles to 1.5 Nm. Maximum internal rotation was not measured due to the inferior capsular...
split. Using the Microscribe, we measured the humeral head position relative to the scapula at 0°, 30°, 60°, 90°, and max ER. Anterior-inferior translation was then measured at 60° and 90° of external rotation by applying 0 N, 20 N, 30 N, 40 N, and 50 N of force on the proximal humerus perpendicular to the humerus and at a 20° inferior angle. Before each test, the specimen was preconditioned five times with 50 N load. Translational stiffness was also calculated as a line fit of the translational load versus total glenohumeral translation. Following testing of all conditions, force and stiffness during dislocation on the final surgical construct (either Latarjet or FBB with remplissage) were measured. This was achieved by applying incrementally increasing force to the proximal humerus perpendicular and 20° inferior to the humerus while measuring translation at each load.

After testing was completed, the specimens were disarticulated, and anatomical geometrical measurements were performed, as described by Lee et al. Measurements using the Microscribe 3DLX were obtained from both the glenoid and humeral head. Circumferential, anterior to posterior, and superior to inferior points were obtained for both bones. Measurements of both the Latarjet grafts and the free bone block grafts were obtained in the same manner. The Hill-Sachs lesion was measured for circumference and depth.

All trials were performed twice to ensure repeatability. If repeatability was greater than 1.0 mm for any measurement, an additional trial was performed, and the two most repeatable trials were averaged. This was based on previous methodology used in the same laboratory and previously published. This was only used if an obviously spurious result was obtained. Averaging in a spurious result was felt to be misleading, as it would skew the data.

**Statistical Analysis**

Four main outcomes were measured between the three groups (FBB, FBB with remplissage, and Latarjet): amount of translation, stiffness, humeral head apex shift in both the anterior-posterior and superior-inferior directions, and the force and stiffness required to dislocate. All nine specimens for each testing group were then averaged together, and each group was analyzed for statistical significance within each group, using a repeated measures analysis of variance with a Bonferroni correction for multiple comparisons. In order to directly

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**Fig 2.** Photos of a right shoulder demonstrating The subscapularis (SSc) used to create the glenoid defect (A), and the posterior split used to create the Hill-Sachs defect (B). G, glenoid defect; H, humerus; HH, humeral head; IS, infraspinatus; SSc, subscapularis; TM, Teres minor.

**Fig 3.** Free bone block (FBB) technique. (A) Guide is inserted from posterior to hook onto the center of the anterior glenoid defect. (B) Two tunnels are drilled through the glenoid from posterior to anterior. Then, nitinol wires or passing sutures are shuttled through the drill holes. (C) Cerclage sutures are shuttled through the superior glenoid tunnel, the FBB, and then back through the inferior glenoid tunnel. (D) The FBB is shuttled into place as the cerclage sutures are tensioned down. (E) Final construct.
compare the Latarjet to the FBB with remplissage, the percent difference from bipolar bone loss and from intact state to both repairs was calculated. These results were then statistically compared using a paired $t$-test. $P < .05$ was used for significance for all comparisons.

**Results**

**Translation**
The percentage change in anterior-inferior translation at 90° ER following each procedure compared to the intact state is demonstrated in Fig 4. There were no significant differences between the Latarjet and FBB at any load. The FBB with remplissage demonstrated the lowest anterior-inferior translation at 90° ER, which was statistically significant compared to Latarjet at 20 N ($P = .013$) and compared to the FBB alone at 40 N ($P = .024$) and 50 N ($P = .011$). During power analysis calculations, there was a 69.1% decrease in translation with a standard deviation of 59.4%, which also yielded a sample size of 9 to achieve a power of 80%.

**Stiffness**
Stiffness during translational testing compared to the intact state is demonstrated in Fig 5. There was no difference in stiffness between the Latarjet and FBB or between the Latarjet and FBB with remplissage at either 60° or 90° ER. The FBB with remplissage was significantly stiffer compared to FBB alone at 90° ER ($P = .028$)

**Dislocation Force and Stiffness to Dislocation**
Representative force—displacement curves during dislocation are presented in Fig 6. There was no
significant difference between the Latarjet and FBB for stiffness or force to dislocation. The force to dislocate and the stiffness with dislocation was highest for FBB with remplissage, which was statistically significant compared to FBB alone and Latarjet.

**Humeral Head Apex Shift**

Compared to the intact state, the humeral head apex shifted posteriorly following the repairs when the humerus was in 0° or 30° of ER, with no difference in humeral head position between any of the repair groups at 0° or 30° of ER. At 60° of ER, the humeral head shifted anteriorly in the FBB and FBB with remplissage group, whereas it remained posterior in the Latarjet group ($P < .05$). At 90° of ER the humeral head shifted back posteriorly in the FBB with remplissage group, and there were no differences between any of the groups.

There was no difference in superior-inferior head position between the repair groups in any arm positions.

**Discussion**

The primary findings of this study were that the addition of remplissage to a FBB reduced translation closest to the intact state and increased the dislocation force compared to FBB alone or Latarjet in a bipolar bone loss model with an off-track Hill-Sachs lesion. These findings may have implications for the management of bipolar bone loss associated with recurrent anterior glenohumeral instability.

As bone loss increases, surgical management becomes increasingly complex. Elkins et al. previously found that a 15% Hill-Sachs lesion without glenoid bone loss could be adequately treated with a soft tissue procedure (Bankart repair) alone. Hartzler et al. reported that bipolar bone loss lesions involving 15% glenoid bone loss and a 15% Hill Sachs lesion could also be adequately stabilized with a Bankart repair. When the lesions became off-track, however, a remplissage was required to prevent engagement of the lesion. In general, it is felt that larger amounts of glenoid bone loss require bony reconstruction.

Traditionally, bipolar glenoid bone loss has been managed with glenoid reconstruction alone. Despite the theoretical advantages of the sling effect with Latarjet, in the current study, there were no biomechanical differences between the FBB and Latarjet groups. Clinical studies have also suggested equivalent outcomes between the two procedures. In a systematic review of 3,917 Latarjets and 623 FBBs, no differences were found in recurrent instability, progression of osteoarthritis, complication rate, or return to sport in the Latarjet versus FBB groups. Thus, biomechanical and clinical evidence suggests that either option is suitable for managing glenoid bone loss associated with recurrent anterior instability. Taverna et al. treated 26 patients with recurrent anterior instability with a free bone block with cortical button fixation and reported that 96% remained stable at 2-year follow-up. Of the 12 patients who played sports prior to their injury, 8 of them were able to return to their preinjury level of competition.

The addition of remplissage to Bankart repair has been shown to reduce the risk of recurrence. It follows that a remplissage may be a useful addition to glenoid reconstruction in certain situations. In the current study, the addition of a remplissage to a FBB would be expected to provide improved stability for patients with bipolar bone loss.
resulted in the highest resistance to translation and the highest force required to dislocate the glenohumeral joint. Although remplissage was not required to prevent engagement after the FBB alone, the addition of remplissage increased stiffness and resulted in a higher force required to cause dislocation. This theoretically may contribute to a reduced rate of recurrent instability. While the overall recurrence rate following glenoid reconstruction alone is low, there is evidence that recurrent instability is a persistent problem in patients with large amounts of bone loss. Yang et al., for instance, reported a 15% rate of recurrence following Latarjet in a cohort of patients with an average glenoid bone loss of 20%. In a series of 38 patients with bipolar bone loss treated with Latarjet, Mook et al. reported a 23% rate of recurrence. They reported that lesions that remained off-track following Latarjet were 4 times more likely to have postoperative instability and they suggested that the glenoid track concept should be considered even in the setting of Latarjet. Case reports have described the combination of Latarjet and remplissage, but clinical series are lacking. On the basis of the aforementioned reports, as well as the findings of the current study, the addition of remplissage to bony reconstruction of the glenoid appears to warrant clinical evaluation.

One reason that remplissage is not commonly performed with Latarjet may be that it is not practical to perform remplissage in conjunction with an open procedure. Although remplissage could theoretically be added to either arthroscopic Latarjet or a FBB, the FBB procedure may be appealing because of its technical ease compared to arthroscopic Latarjet. In particular, the need for coracoid graft harvest and passage through the subscapularis is absent with an FBB. Wong et al. previously described an arthroscopic bone block technique, in which the graft is passed through a medial portal and into the joint through the rotator interval, thus avoiding subscapularis violation. Ekhtiari et al. performed a systematic review on the learning curve for Latarjet and reported a large decrease in operative time after a mean of 20-40 arthroscopic Latarjet procedures. The study also found that operative time for all phases of the procedure decreased with additional experience except for the graft transfer phase. Similarly, Valsamis et al. reported a learning curve of 30-50 cases for arthroscopic Latarjet. In addition, graft size with Latarjet is limited to the coracoid anatomy, and precise graft sizing may be difficult to perform arthroscopically. Conversely, with a FBB approach, the desired graft size can be measured in advance and then harvested appropriately and sized to match the glenoid defect. While distal tibia was used in the current study, other graft options are available for FBB use, including coracoid allograft, iliac crest autograft or allograft, or other sources. Finally, it is important to consider that posttraumatic arthritis requiring shoulder arthroplasty following Latarjet often necessitates reverse shoulder arthroplasty (RSA) due to the nonanatomic nature of the procedure and violation of the subscapularis. It is possible that the need for RSA would be reduced in this setting if the initial treatment were with an arthroscopic FBB.

Graft resorption is a major consideration after bony reconstruction of the glenoid. Zhu et al. performed a CT scan study after Latarjet and found graft resorption rates approaching 90.5% 1 year out from the procedure. In this series, 10% of patients had graft resorption with complete screw exposure. This is thought to be due to remodeling of the glenoid, according to Wolff’s Law. Following graft resorption, screws may become prominent, particularly at the superior aspect. Multiple studies have shown that continued anterior shoulder pain after Latarjet can be relieved with screw removal. In one systematic review, hardware removal was required in 35% of all reoperations following Latarjet. The fixation technique of the FBB in this study avoids metal hardware and instead uses high-strength sutures placed in a cerclage technique. Hachem et al. recently reported on clinical outcomes suture-based bone block fixation in a series of 21 patients using a combination of iliac crest autograft or allograft. At a 12-month follow-up there were significant improvements in WOSI and Rowe scores. Excellent functional results were obtained. Postoperative CT scans demonstrated over 95% consolidation of the grafts at the glenoid margin. Although further clinical evaluation is required to determine whether the technique reduces the need for hardware removal, it appears that graft healing is obtainable in the majority of cases with this type of technique. With a biomechanical study, we cannot make a conclusion about the use of distal tibia versus other free bone block sources.

**Limitations**

There are several limitations to this study. The findings are limited to time 0 and do not reflect biologic healing. We did not evaluate load to failure of the repair constructs. The bone blocks were cut with a 5° offset guide, as this was determined to be the best fit when cutting the grafts to size. Increased graft offset may increase the slope of the graft when lined up at the glenohumeral articular surface, although smaller allograft angles may be better opposed to the glenoid defect surface during fixation. The clinical significance of this increased slope in the treatment of recurrent instability is unknown. During testing, all trials were performed twice to ensure repeatability; if the difference were greater than 1.0 mm, another trial was performed. We averaged the two most repeatable trials. This was only used if a spurious result was obtained, as
we thought this would be misleading and potentially skew the data. However, discarding data as an outlier may theoretically introduce bias. Finally, during power analysis calculations, there was a large standard deviation calculated during translation testing.

**Conclusion**

The addition of remplissage to a FBB restores translation and stiffness closer to the intact state compared to a FBB alone or Latarjet in a bipolar bone loss model with an off-track Hill-Sachs lesion. In this model, dislocation force significantly increased with the addition of remplissage to the free bone block.

**References**


