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Iliac Bone Grafting of the Intact Glenoid Improves Shoulder Stability with Optimal Graft Positioning

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Abstract

Background—Bone grafting procedures are increasingly popular for the treatment of anterior shoulder instability. In cases with high risk of recurrence, open coracoid transplantation is preferred but can be technically demanding. Free bone graft glenoid augmentation may be an alternative strategy for high-risk patients without significant glenoid bone loss. This biomechanical cadaver study aims to assess the stabilizing effect of free iliac crest bone grafting of the intact glenoid and the importance of sagittal graft position.

Methods—Eight fresh frozen cadaver shoulders were tested. The bone graft was fixed on the glenoid neck at three sagittal positions (50%, 75% and 100% below the glenoid equator). Displacement and reaction force were monitored with a custom device while translating the humeral head over the glenoid surface in both anterior and antero-inferior direction.

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Illustrations 2, 3 and 6 require color publication

Results—Peak force (PF) increased significantly from the standard labral repair to the grafted conditions in both anterior (14.7 (±5.5 N) vs. 27.3 (±6.9 N)) and antero-inferior translation (22.0 (±5.3 N) vs. 29.3 (±6.9 N)). PF was significantly higher for the grafts at the 50% and 75% positions, compared to the grafts 100% below the equator with anterior translation. Antero-inferior translation resulted in significantly higher values for the 100% and 75% positions compared to the 50% position.

Conclusions—This biomechanical study confirms improved anterior glenohumeral stability after iliac crest bone graft augmentation of the anterior glenoid. The results also demonstrate the importance of bone graft position in the sagittal plane, with the ideal position determined by the direction of dislocation.

Keywords

Bone graft; glenoid; shoulder; stability; dislocation; biomechanics

Introduction

Risk factors for recurrence of shoulder instability after standard arthroscopic Bankart repair have become more defined recently.[3,24,45] Patient characteristics such as age, physical activity, as well as patho-anatomic lesions such as Hill-Sachs lesions, glenoid bone loss and joint hyperlaxity are associated with a higher risk of recurrence after standard capsulolabral repair.[3] This has led to an increased interest in bone block procedures such as the Bristow-Latarjet procedure[19,23] for the treatment of high-risk patients with important anterior glenoid bone loss.[8,57] Furthermore, various authors have suggested expanding the indication to patients presenting without significant bone loss, such as high-risk contact athletes, patients with engaging Hill-Sachs lesions, anterior labral periosteal sleeve avulsions (ALPSA) or joint hyperlaxity.[1,3,12,29]

Reports of high complication rates however,[11,16,58] have pushed recent research towards less complex or invasive alternatives to the classic Bristow-Latarjet procedure. Arthroscopic glenoid augmentations using either a free iliac crest autograft or a tibial or glenoid osteochondral allograft have already been described as a successful treatment option for high-risk patients.[17,28,31,33,39,46] However, biomechanical data on the effect of these procedures is sparse, particularly concerning cases without significant glenoid bone loss.

The purpose of this biomechanical cadaver study was twofold. First, to compare the effect of standard labral repair to free bone graft augmentation of the glenoid. Secondly, to investigate the influence of sagittal graft position on stability.

Materials and Methods

Eight fresh frozen cadaver shoulders (four male and four female donors) and three pairs of fresh frozen iliac crests (three male donors) were obtained from our institutional anatomic bequest program. The mean age at the time of death was 66.5 years (range: 54 to 87 years) for the shoulder donors, and 55.4 years (range: 51 to 61 years) for the iliac crest donors. There were 4 right and 4 left shoulders. Specimens from donors with a history of shoulder instability and specimens with radiological or clinical evidence of previous surgical treatment, advanced degenerative, traumatic or neoplastic disease were excluded.

Shoulders were thawed overnight before removing all soft tissues with the exception of labrum and articular cartilage, as has been described before.[18,22,53] Removal of the capsule and glenohumeral ligaments was not deemed to compromise the integrity of the experiment because of their minimal role in mid-range instability; rotator cuff action was simulated during all experimental procedures using compressive force on custom testing apparatus.[7,43] The glenoids and humeri were potted in poly-urethane resin (**Smooth-Cast® 65D**, Smooth-on, Inc., Easton, PA, USA) to allow fixation onto a custom testing apparatus, as described previously.[18,22,53] Briefly, the testing device consisted of a load cell mounted on a programmable stepper-motor controlled x-y table driving motion in the superior-inferior (y-axis) and anterior-posterior (x-axis) direction. The humerus was mounted in the scapular plane to a sliding stage connected to a pneumatic cylinder at 60° of abduction and neutral rotation. This allowed free translation of the humerus in the medio-lateral (z-axis) direction while applying a constant (50 N) compressive force. During testing, the specimen was sprayed with saline every 10–15 minutes. Experiments were conducted at room temperature (24°C). Bovine serum was applied to lubricate the articular surfaces.

The reference position was determined by translating the glenoid underneath the humeral head surface until the humerus was seated at the most medial point.[22] From the reference position, the glenoid was first translated posteriorly, resulting in anterior humeral translation, until dislocation occurred. Afterwards, the glenoid was translated from same reference position in a postero-superior direction along a line bisecting the x- and y-axes, resulting in antero-inferior humeral head translation.[54] Displacement and reaction forces in the x-, y- and z-directions were measured and the mean of two trials was used for data analysis.

After testing the intact glenoid, a Bankart lesion was created by elevating the labrum between the 2 o’clock and 8 o’clock positions for right shoulders and the mirrored equivalent for left shoulders as previously described.[22] The repaired condition was tested after reattaching the labrum to the glenoid rim by means of three *2.8*-mm *titanium* suture anchors (*FASTak*; *Arthrex*, Naples, FL, USA) at the 3, 4 and 5 o’clock positions on the anterior glenoid rim a simple suturing technique.[55] The bone grafted condition was tested after removing the previously elevated part of the labrum and the suture anchors. A tri-cortical oblique bone graft was taken from the anterior iliac crest approximately 5 cm from the anterior superior iliac spine with an oscillating saw. The graft was secured to the prepared anterior glenoid rim with two 3.5-mm AO cortical screws[41,50,54] (Figure 1). The graft size (2 cm × 1.5 cm × 1 cm) was selected to match the average harvested coracoid size in Bristow-Latarjet procedures in order to avoid overestimating the effect of the free iliac bone graft.[56] As needed, grafts were shaped with a high-speed burr to fit the glenoid neck, but the articular (inner) side of the iliac grafts was not reshaped. The bone graft was positioned such that the concave (inner) side was flush with the glenoid cartilage, creating a smooth continuation of the articular surface (Figure 2). Three graft positions in the sagittal plane were tested in random order: grafts were positioned such that 50%, 75% or 100% of the graft surface area was below the glenoid equator (see Figure 3).

The primary outcome measure was peak translational force (PF), defined as the greatest force in N recorded in the direction opposing translation. Absolute force values were reported instead of stability ratios[14] because a uniform compressive force of 50 N was applied in all conditions for this study. In addition to the instantaneous PF value, the ‘energy to dislocate’ (ETD) in N.mm or milliJoule (mJ) was calculated by numerically integrating the instantaneous translational force vs. anterior displacement of the humeral head curve from the start of the motion until the point of dislocation, as described previously.[26] The point of dislocation was determined as the position where the most medial part of the humeral head reaches the most lateral part of the glenoid surface.[30,49]

One-way repeated-measures analysis of variance was used to compare the PF and the ETD between the intact, the Bankart lesion, labral repair and the mean bone grafted condition. Similarly, the three bone-grafted positions were compared to one another using the same statistical analysis. A Bonferroni correction was applied to the post hoc test for comparisons of more than three groups. (SPSS, IBM corp. Armonk, NY, USA). The level of significance α, was set at 0.05.

Results

Anterior translation of the humeral head resulted in a mean (standard deviation) PF of 14.9 N (±3.9 N) for the intact condition, 12.0 N (±5.0 N) for the Bankart lesion condition, 14.7 N (±5.5 N) for the labral repair condition and 27.3 N (±6.9 N) for the bone graft augmented condition. There was a significant decrease in PF after creation of a Bankart lesion ($p=0.048$) and a significant increase between the repaired and the grafted condition ($p=0.028$). The mean ETD was 118.4 mJ (±35.8 mJ) in the intact condition, and 87.2 mJ (±48.6 mJ) after creating the Bankart lesion, 117.0 mJ (±52.4 mJ) after labral repair and 305.1 mJ (±77.5 mJ) after bone grafting. A significant decrease in ETD was seen after the creation of a Bankart lesion ($p=0.009$) and a significant increase between the repaired and the grafted condition ($p<0.001$) (Figure 4, Table I). PF values for the positions 50%, 75% and 100% below the glenoid equator were 30.7 N (±8.4 N), 28.3 N (±7.3 N) and 23.0 N (±7.3 N), respectively. The 50% and the 75% position had significantly higher PF than the 100% position ($p=0.008$ and $p=0.029$) respectively. ETD showed a similar trend with respective values of 328.6 mJ (±85.3 mJ), 314.7 mJ (±73.9 mJ) and 271.9 mJ (±86.5 mJ). Comparing the three grafted conditions, grafts positioned 50% and 75% below the equator had significantly higher ETD values than grafts in the 100% below the equator position, ($p=0.029$ and ($p=0.044$) respectively (Figure 5 and Table II).

Antero-inferior translation of the humeral head resulted in a mean (standard deviation) PF of 21.7 N (±4.9 N) for the intact condition, 16.8 N (±4.9 N) for the Bankart lesion condition, 22.0 N (±5.3 N) for the labral repair condition and 29.3 N (±6.9 N) for the bone graft augmented condition. There was a significant decrease in PF after creation of a Bankart lesion ($p=0.022$) and a significant increase between the repaired and the grafted condition ($p=0.024$). The mean ETD was 213.6 mJ (±51.4 mJ) in the intact condition, and 143.3 mJ (±53.6 mJ) after creating the Bankart lesion, 221.5 mJ (±57.3 mJ) after labral repair and 375.3 mJ (±86.4 mJ) after bone grafting. A significant decrease in ETD was seen after the creation of a Bankart lesion ($p=0.002$) as well as a significant increase between the repaired and the grafted condition ($p<0.001$) (Figure 4, Table I). PF values for the positions 50%, 75% and 100% below the glenoid equator were 25.6 N (±6.4 N), 30.4 N (±6.8 N) and 32.0 N (±9.0 N), respectively. Both the 100% and the 75% positions had significantly higher PF than the 50% position ($p=0.031$ and $p=0.028$, respectively). ETD showed a similar trend with respective values of 307.1 mJ (±73.4 mJ), 401.9 mJ (±94.6 mJ) and 413.3 mJ (±101.5 mJ). The 100% and 75% below the equator positions had significantly higher ETD values than grafts in the 50% below the equator position, ($p=0.001$ and $p<0.001$, respectively) (Figure 5 and Table II). An example of the translational force vs. anterior displacement curves for all 6 conditions in both directions of translation from a representative specimen is given in Figure 6.

Discussion

This biomechanical study confirms the positive stabilizing effect of free iliac crest graft augmentation of the intact glenoid, with a significantly higher PF and ETD in the bone grafted conditions compared to standard labral repair. Additionally, the vertical position of the graft was shown to have an important effect on stability. Bone grafts centered on the equator and 75% below the equator, displayed a significantly greater PF and ETD than grafts positioned 100% below the equator when translating in the anterior direction. Translations in the antero-inferior direction, however, revealed higher PF and ETD for grafts 100% and 75% below the equator compared to grafts in 50% position.

Despite reports of reductions in recurrence rates to as low as 0% after Bristow-Latarjet procedures as a treatment for recurrent anterior instability,[8,12,21,27,35] a high incidence of complications.[10,11,16,34,37,58] has generated interest in surgical alternatives. Free bone grafting of the anterior glenoid has been used to restore the glenoid articular arc with both allogeneic[39,47,52] and autologous[33,44,46,50] bone grafts. In the treatment of posterior instability, several authors advocate augmentation of the posterior glenoid with a free bone graft, even in the absence of glenoid erosion or dysplasia.[5,36,38] In such cases, the bone graft is intended to act as an extension of the glenoid surface, rather than as an anatomic repair. Recent biomechanical studies have stressed the importance of the conjoint tendon dynamic sling effect as the primary stabilizing contributor of the Bristow-Latarjet procedure.[13,15,51] However, these studies all have limitations as to how closely they can recreate the sling effect. Interestingly, a recent study by Dines et al, could not demonstrate a stabilizing influence of the conjoint tendon on inferior glenohumeral translation.[13] Clinical research has shown a correlation between glenoid width and risk of recurrence.[3,6,9] This may be why many surgeons still strongly believe in the value of a bone graft. Additionally, in revision surgery for recurrent instability after a Bristow-Latarjet procedure, remnants of the conjoint sling are often found in situ, suggesting that the sling alone may not be sufficient to prevent instability.[25]

Free-graft bone block procedures may be less complicated than the Bristow-Latarjet procedure and recent clinical and cadaveric studies have shown their feasibility using an all-arthroscopic approach through the rotator interval.[48] The advantages of an arthroscopic procedure include a careful exploration of intra-articular pathology, precise positioning of the graft and possibly non-violation of the subscapularis muscle.[34,48] In addition to the bony augmentation, simultaneous capsulolabral reconstruction can be performed as an all-arthroscopic procedure. Furthermore, in case of recurrence after a free bone graft procedure, conversion to a Bristow-Latarjet procedure remains possible, while revision surgery after a coracoid transfer can be technically challenging and result in inferior clinical outcomes.[25,58] Carefully selected patients could benefit from this type of bone block procedure resulting in a stronger repair than standard soft tissue reconstructions while avoiding the technical difficulties and risks associated with traditional coracoid transfer procedures. Further clinical studies are needed to confirm these advantages and to identify the ideal indication.

Positioning of the graft is shown to variably influence stability. The increase in PF and ETD between labral repair and bone grafted condition is more pronounced when translating anteriorly than antero-inferiorly. We assume this is mainly due to the relatively thicker and stronger morphology of the labrum found in the antero-inferior quadrant of the human glenoid.[18,40]

Although most chondrolabral lesions are found on the antero-inferior glenoid rim,[4] superior labrum anterior and posterior (SLAP)[42] as well as pan-labral lesions have been described.[32] This indicates that anterior instability may not always follow a strict antero-inferior direction. We would advise positioning the bone graft at the level of the most evident site of capsulolabral or chondrolabral detachment as observed perioperatively, assuming this location to correspond to the path of the dislocating humeral head. Future research may provide more detailed positioning guidelines when glenohumeral instability kinematics are better understood.

Graft position on the glenoid neck and congruity with the glenoid articular surface are equally critical. A proud graft reduces contact area and increases contact pressure, which is thought to correlate to the development of early osteoarthritis.[2,20] Medialized grafts, on the other hand, are associated with persistent instability.[21] In this study we aimed to align the bone graft with the glenoid cartilage, creating a smooth continuation of the articular curvature. Although current surgical technique sometimes advises positioning the graft flush with the level of the subchondral bone[44] in anticipation of fibrocartilage forming over the graft, others have suggested that positioning the graft flush with the cartilage is appropriate as well.[50]

Despite several inherent limitations (e.g. age of donors), a cadaver model was selected for this biomechanical study because human cadaver studies yield reliable results which are more easily extrapolated to the *in vivo* condition than finite element analysis or animal studies. The biomechanical testing setup used in this study was chosen because of the proven record in accurate analysis of concavity-compression mechanisms such as that present in the shoulder joint during mid-range motion.[18,22,53] The methodology is limited, however, in the evaluation of end-range and dynamic glenohumeral stabilizers.

Conclusion

This biomechanical study confirms improved anterior and antero-inferior glenohumeral stability after free iliac crest bone graft augmentation of the anterior glenoid. The results also demonstrate the importance of bone graft position in the sagittal plane, with significant differences in glenohumeral stability, depending on the direction of dislocation. Further research is needed to explore the intra-articular kinematics of the unstable shoulder as well as to determine specific clinical scenarios where patients suffering from shoulder instability may benefit from these appealing arthroscopic bone grafting procedures while avoiding the technical difficulties and risks associated with classic coracoid transfers.

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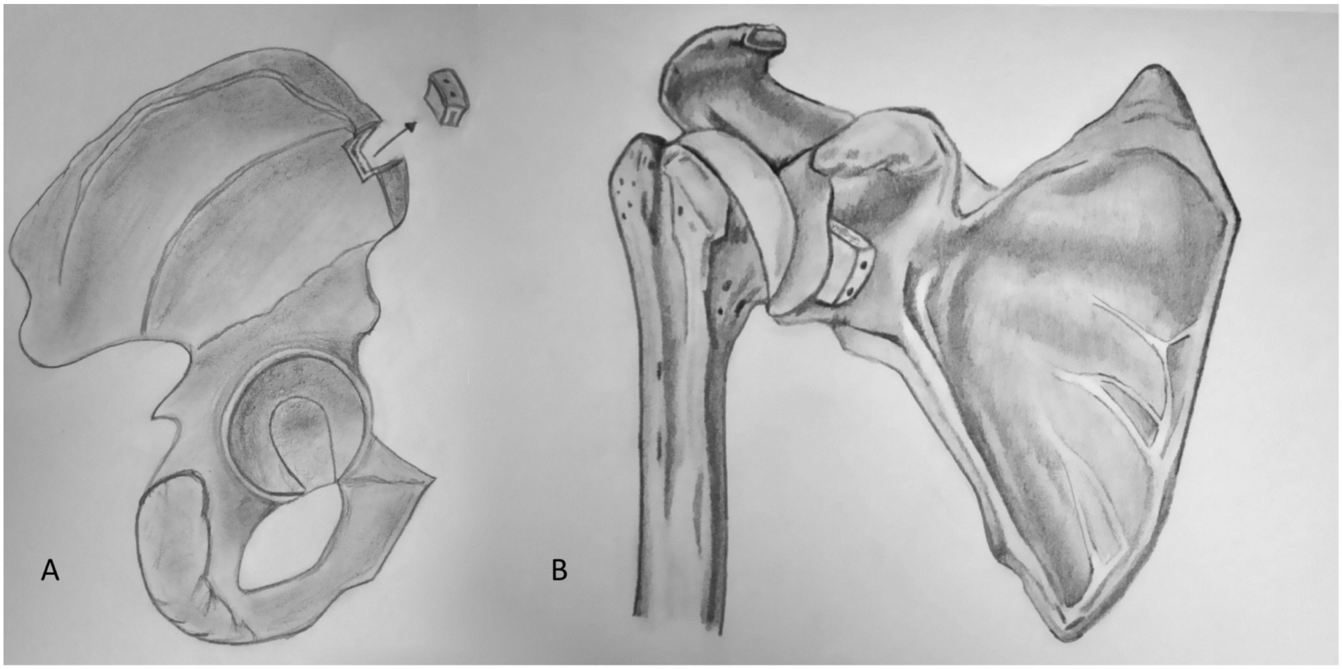

Figure 1.

Drawing of bone graft donor site on the anterior iliac crest and recipient site on the anterior glenoid neck.

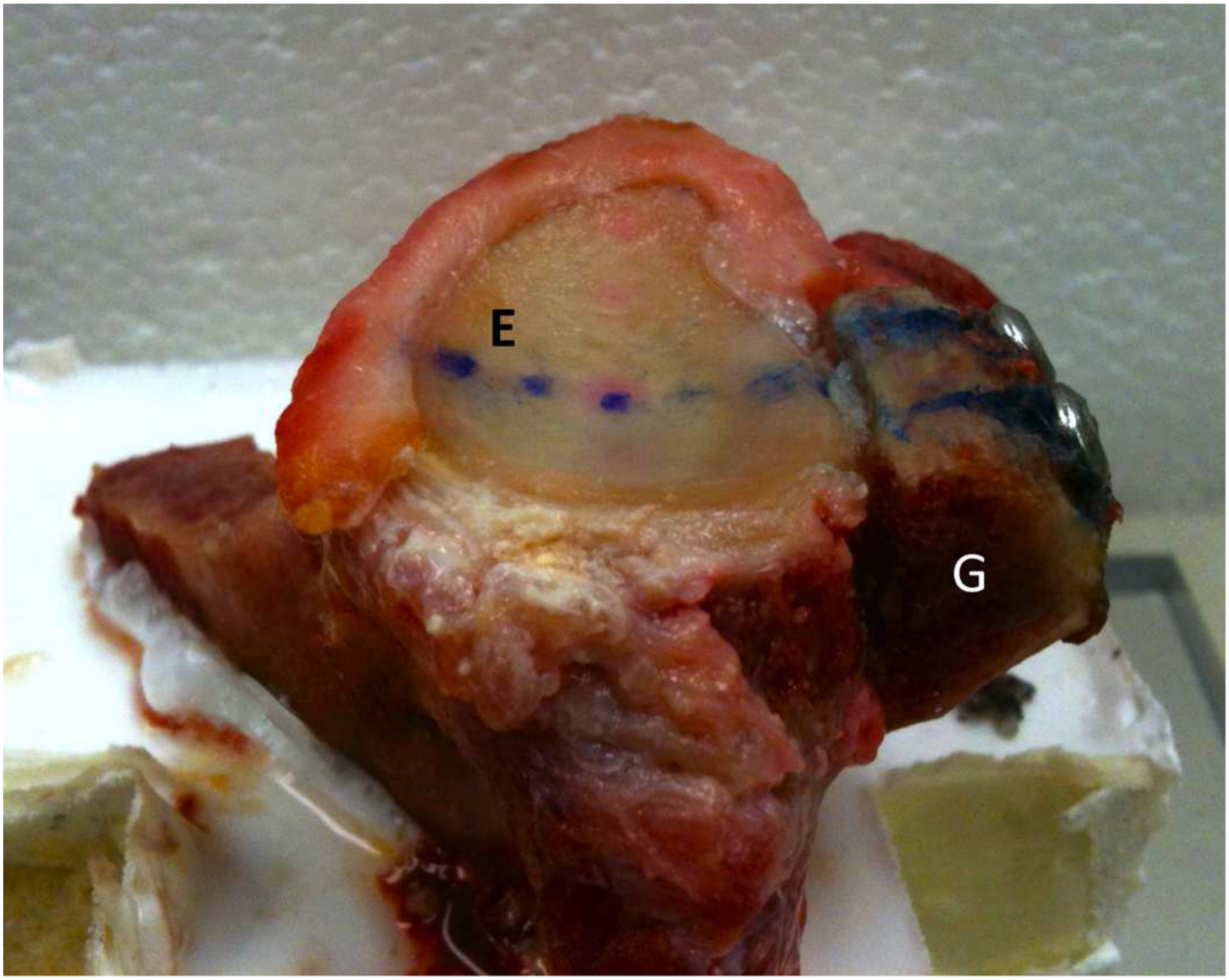

Figure 2.

Graft position in the axial plane on a right glenoid, viewed from inferior. The inner side of the iliac crest graft is placed flush with the articular surface as an extension of the native glenoid concavity. E=Equator, G=Graft.

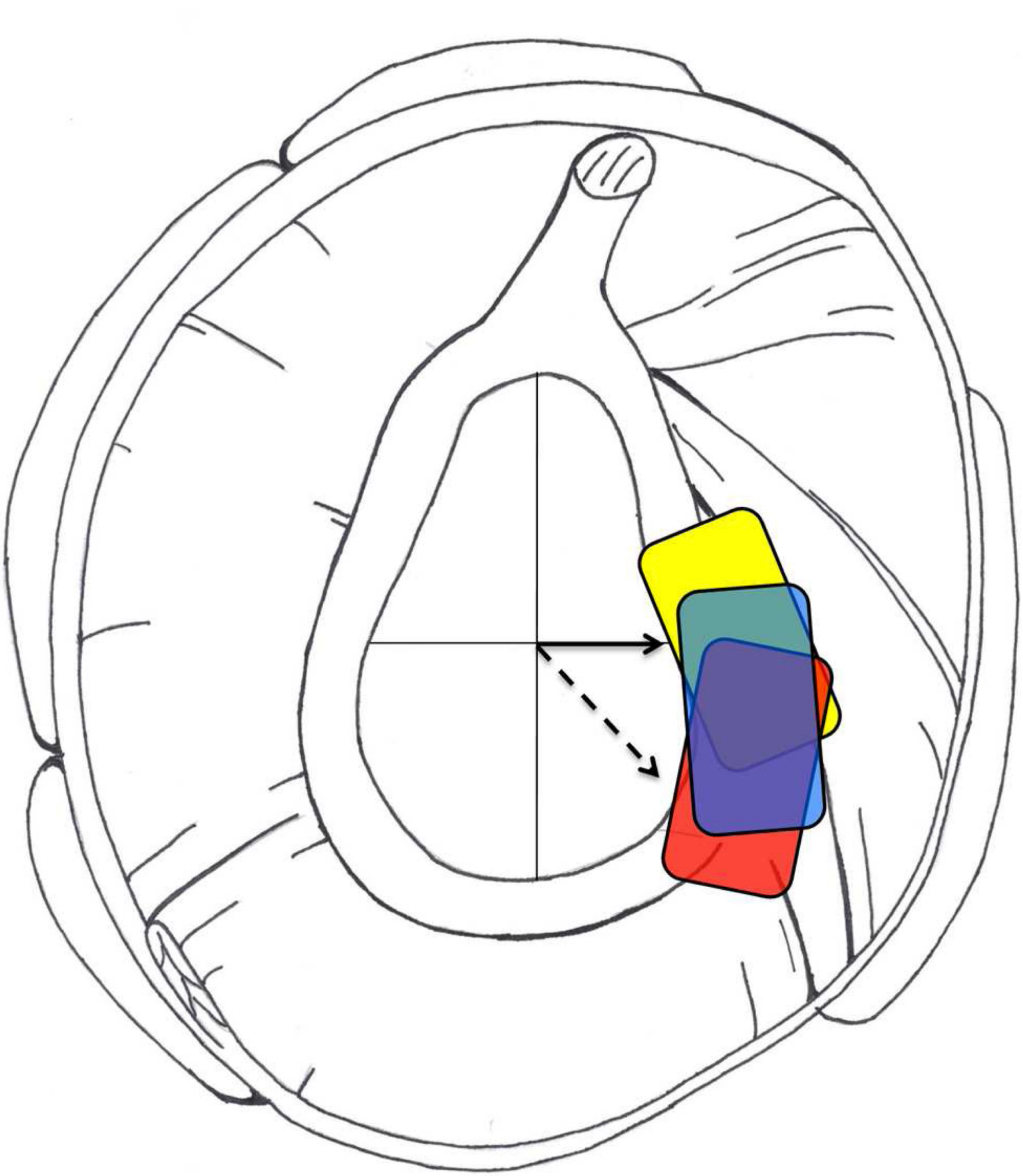

Figure 3.

Sagittal view of a right glenoid with labrum and rotator cuff tendons. Bone grafts depicted in three positions: 50% below equator (yellow); 75% below equator (blue) and 100% below equator (red). Full arrow indicates translation in the anterior direction, dotted arrow indicates translation in the antero-inferior direction.

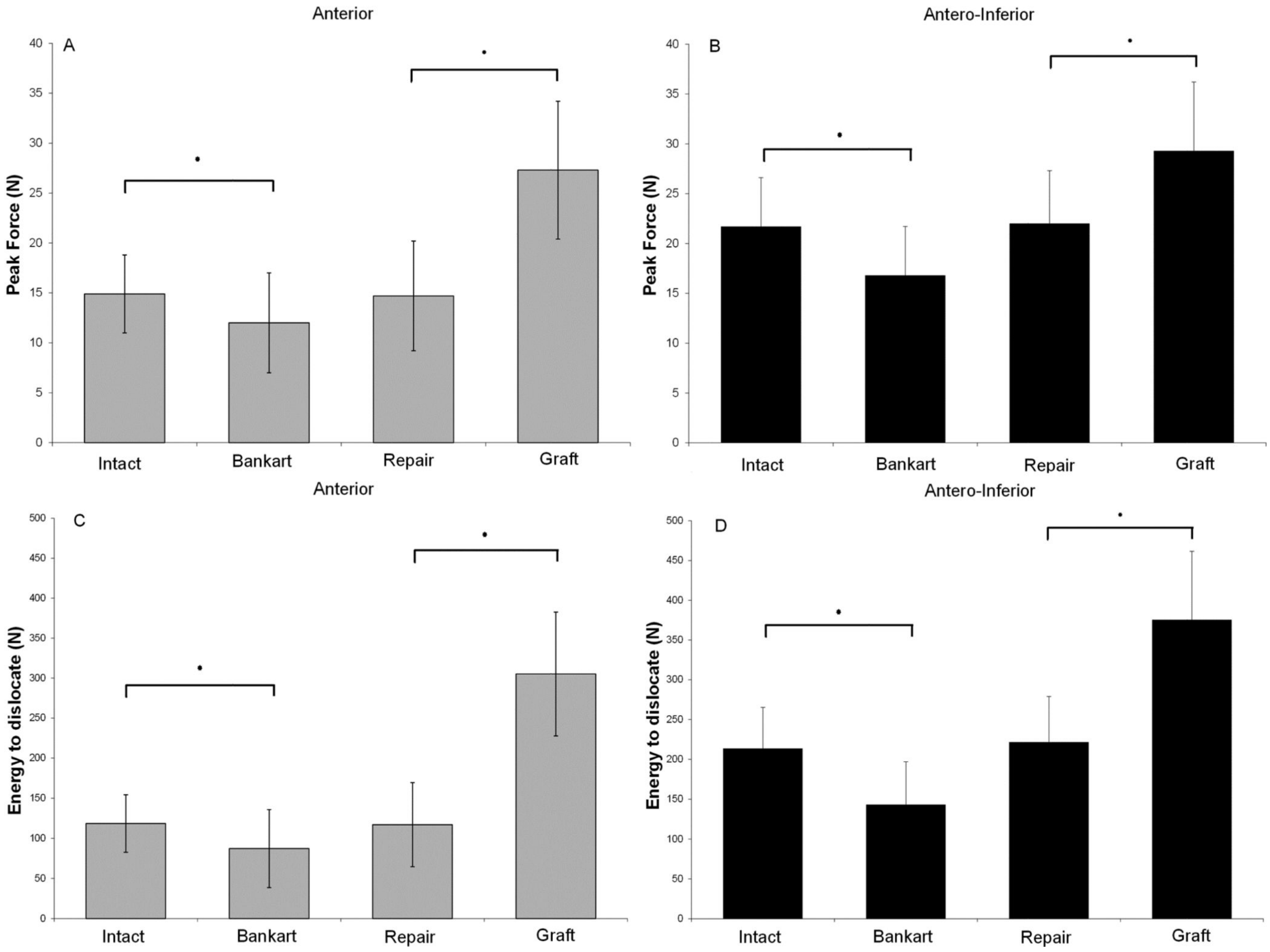

Figure 4.

Mean peak Force (PF) and mean energy to dislocate (ETD) for the intact, Bankart lesion, labral repair and mean bone grafted condition. Anterior translation shown in grey (A–C) and antero-inferior translation shown in black (B–D). * indicates $p<0.05$. Error bars mark SD.

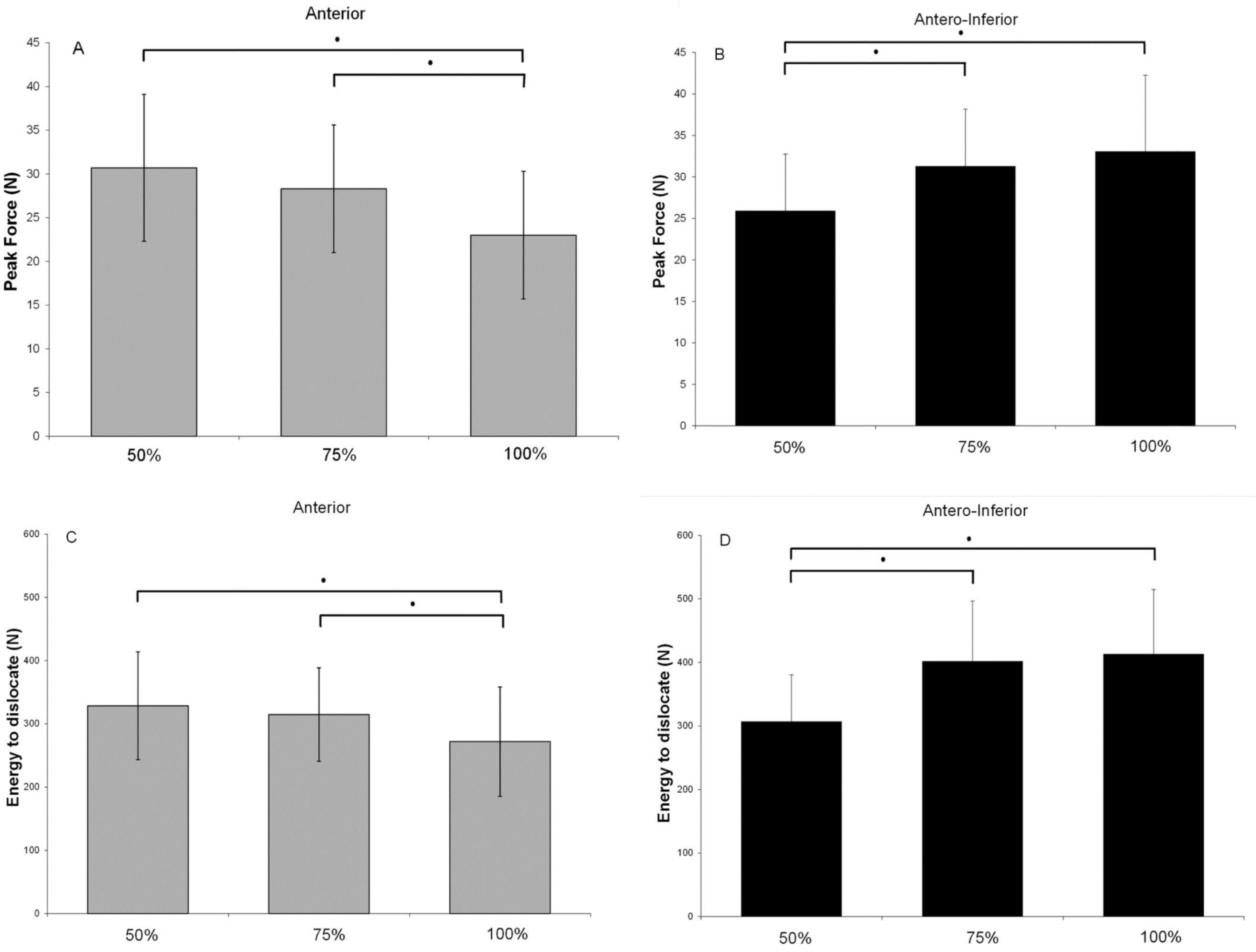

Figure 5.

Mean peak Force (PF) and mean energy to dislocate (ETD) for the three bone grafted conditions. Anterior translation shown in grey (A–C) and antero-inferior translation shown in black (B–D). * indicates $p<0.05$. Error bars mark SD.

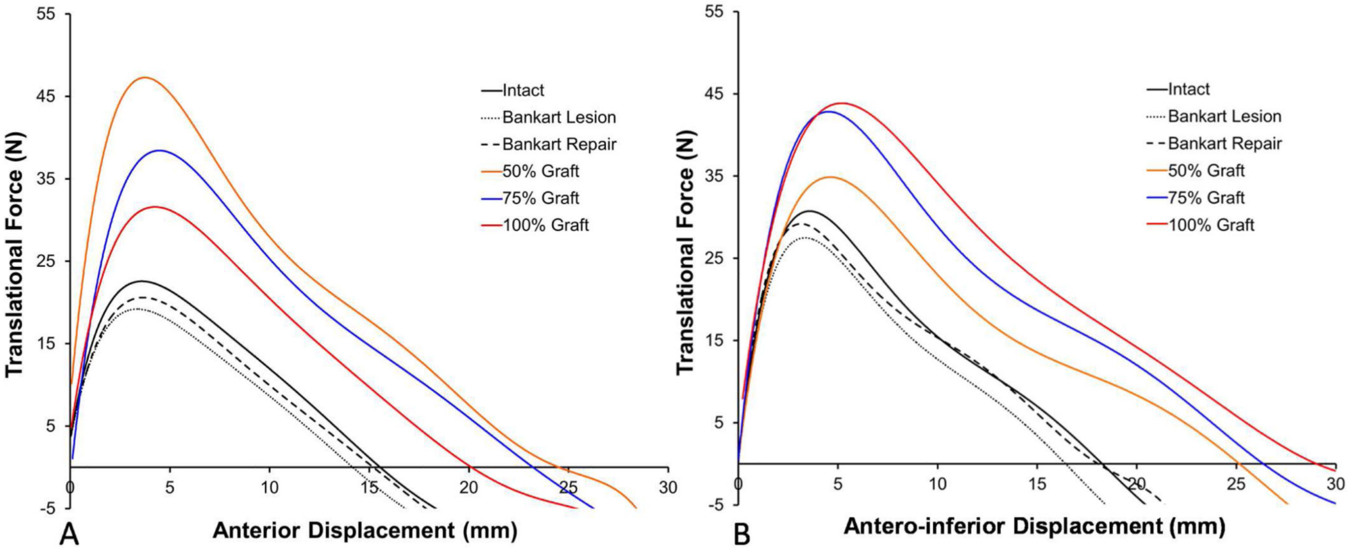

Figure 6.

Translational force vs. anterior (A) and antero-inferior (B) displacement for all 6 conditions in a representative specimen.

Table I

PF and ETD for the intact, Bankart lesion, labral repair, mean bone-grafted conditions in both translational directions. Values given as mean and (SD).

		Intact	Bankart Lesion	Labral repair	Bone Graft
Anterior	PF (N)	14.9 (3.9)	12.0 (5.0)	14.7 (5.5)	27.3 (6.9)
	ETD (mJ)	118.4 (35.8)	87.2 (48.6)	117.0 (52.4)	305.1 (77.5)
Antero-inferior	PF (N)	21.7 (4.9)	16.8 (4.9)	22.0 (5.3)	29.3 (6.9)
	ETD (mJ)	213.6 (51.4)	143.3 (53.6)	221.5 (57.3)	375.3 (86.4)

PF; peak force, ETD; energy to dislocate.

Table II

PF and ETD for the 50%, 75% and 100% below the equator positions in both translational directions. Values given as mean and (SD)

		50% under equator	**75% under equator**	**100% under equator**
Anterior	PF (N)	30.7 (8.4)	28.3 (7.3)	23.0 (7.3)
	ETD (mJ)	328.6 (85.3)	314.7 (73.9)	271.9 (86.5)
Antero-inferior	PF (N)	25.6 (6.4)	30.4 (6.8)	32.0 (9.0)
	ETD (mJ)	307.1 (73.4)	401.9 (94.6)	413.3 (101.5)

PF; peak force, ETD; energy to dislocate.