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Preoperative imaging predicts coracoid graft size and restoration of the glenoid track in Latarjet procedures

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Background: Glenoid bone grafting procedures are often utilized to address glenoid bone loss in patients with recurrent shoulder instability. The purpose of this study was to determine if preoperative advanced imaging can accurately predict coracoid graft size and conversion of off-track to on-track Hill-Sachs lesions in patients undergoing Latarjet procedures.

Methods: Patients who underwent Latarjet procedure for shoulder instability at a single institution from 2012 to 2020 with preoperative and postoperative advanced shoulder imaging (computerized tomography or magnetic resonance imaging scans) were retrospectively reviewed. Glenoid diameter, Hill-Sachs interval (HSI), and measurements of the coracoid length, depth, and height were measured on preoperative imaging. Glenoid track (GT), percent glenoid bone loss, predicted restoration of GT, and the difference between HSI and GT (ΔHSI-GT) were calculated.

Results: Seventeen patients with a mean age of 25 ± 9 years met inclusion criteria. Average glenoid bone loss preoperatively was 24 ± 7% and average HSI was 27 ± 5mm. The Latarjet procedure reconstructed 116 ± 8% of the native glenoid, and 104 ± 8% of the predicted diameter. Of the 15 patients that had off-track lesions preoperatively, 11 were successfully converted to on-track lesions (73%). The 4 persistent off-track lesions had a significantly higher HSI (32 ± 2 mm vs. 26 ± 4 mm, $P = .002$). Preoperative measurements accurately predicted postoperative GT status in 94% of cases. At a mean follow-up of 2 years, there was no significant difference in recurrence rate or rate of revision stabilization procedures between patients with on-track versus persistent off-track humeral lesions.

Conclusion: Preoperative advanced imaging measurements can accurately predict whether an off-track Hill-Sachs can be converted to on-track after Latarjet procedure, further enhancing shoulder stability.

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Recurrent shoulder instability can result in bipolar bone deficiency with both humeral and glenoid lesions. Glenoid bone grafting procedures have historically been recommended when bone loss constitutes 20-25% or more of the glenoid width,[7,11,22,25,26,35] although more recent studies have suggested a lower cutoff of 13.5% bone loss as the critical point at which bony stabilization procedures should be considered.[9,28,29] In the traditional congruent arc Latarjet technique, which is commonly used to address glenoid bone loss in cases of anterior shoulder instability, the coracoid is harvested and transferred to the glenoid, fixing the inferior surface of the coracoid to the anterior surface of the glenoid.[1,21,33,37] This bony transfer augments the remaining glenoid thereby increasing joint surface area, helps to restore glenoid contour, provides a dynamic sling effect with the conjoint tendon during shoulder abduction external rotation (ABER), and augments stability with capsular repair, but it does not specifically address humeral bone lesions (Hill-Sachs lesions).

More recent studies have recognized that the anatomic relation of the humeral and glenoid bone loss in different positions throughout the shoulder arc of motion plays an important role in shoulder stability and can predict failure of arthroscopic stabilization.[2,7,13] The concept of the glenoid track (GT) has been described to predict which bipolar bone lesions contribute to shoulder instability.[16,34] The GT refers to the zone of articulation between the glenoid and the humeral head as the arm is moved.[8,34] Di Giacomo et al used the concept of the GT to quantify a method of

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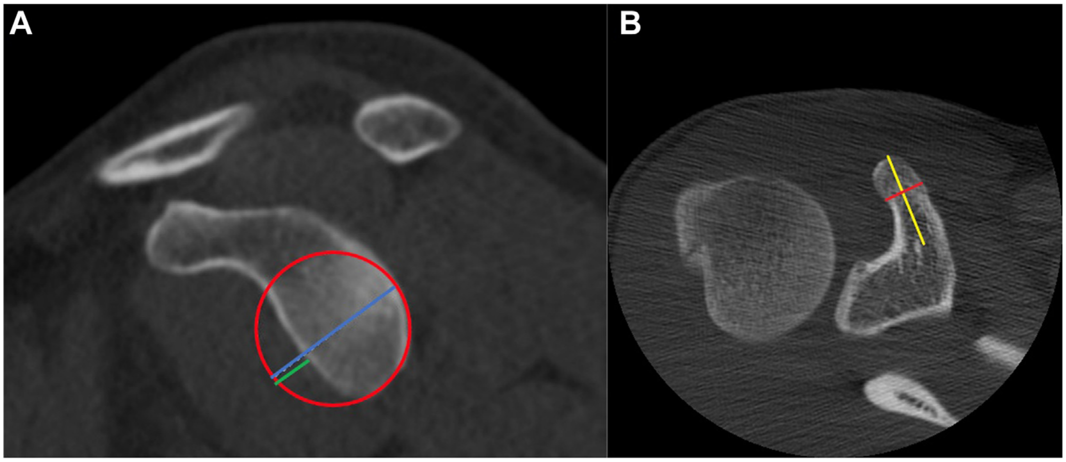

Figure 1 (**A**) Demonstration of best-fit circle (◯) method (circle diameter: —) utilized for measurement of glenoid bone loss (—). (**B**) Sample measurement of coracoid length and width. The image with the longest, continuous view of the coracoid was chosen for length, which was measured from the tip to its junction with the scapular body (—). Coracoid width was measured at the widest part of the coracoid on an axial image slice where the entire length of the coracoid was also visualized (—).

determining whether a Hill-Sachs lesion is "on-track" or "off-track," signifying bony stability, and therefore the nature of operative management required.[8] In patients with significant bipolar bone loss and off-track lesions, it is crucial to restore shoulder stability with bony augmentation thereby converting the off-track lesion to an on-track lesion, as persistent off-track lesions are associated with higher failure rates.[3] It has, therefore, been suggested that if the coracoid transfer alone does not convert an off-track lesion to an on-track lesion that concomitant humeral-sided procedures be considered, such as humeral bone graft or remplissage.[1,8,26,30]

While a handful of studies have looked at the use of preoperative imaging for predicting coracoid graft morphology and glenoid restoration,[20,27,31] our study uses postoperative advanced imaging to compare preoperative measurements with postoperative glenoid restoration and on-track conversion rates. The purpose of this study was to determine if preoperative advanced imaging can predict coracoid graft size and conversion of off-track to on-track Hill-Sachs lesions in patients undergoing Latarjet procedures. We hypothesized that coracoid graft size, amount of glenoid reconstructed, and ability to convert off-track to on-track HS lesion can be accurately predicted based on preoperative advanced imaging.

Methods

After receiving approval from our institution's Institutional Review Board, all patients who underwent surgery for anterior shoulder instability via the classic open Latarjet procedure[1,21] at a single institution between January 2012 and December 2020 were retrospectively reviewed. All procedures were conducted by four fellowship-trained orthopedic sports medicine surgeons. Inclusion criteria consisted of both preoperative and postoperative advanced imaging of the operative shoulder, consisting of either computerized tomography (CT) or magnetic resonance imaging (MRI) scans. Estimates of bone loss have been shown to have negligible differences when using the circle method on CT and MRI.[4] Patients were excluded if either preoperative or postoperative advanced imaging was not available. Advanced imaging was reviewed, and measurements were performed by 3 separate reviewers on all patients: a fellowship-trained orthopedic sports medicine surgeon, an orthopedic sports medicine fellow, and an orthopedic surgery resident. Interrater reliability was then determined.

Preoperative imaging was reviewed and measurements of the Hill-Sachs interval (HSI) and glenoid diameter were performed as previously described using the circle of best fit method.[15] The glenoid bone loss was then measured (Fig. 1, *A*).[15] Coracoid length and width were measured on axial images (Fig. 1, *B*). The image with the longest, continuous view of the coracoid was chosen for length, which was measured from the tip to its junction with the scapular body. Coracoid width was measured at the widest part of the coracoid on an axial image slice where the entire length of the coracoid was also visualized. For coracoid height, a coronal image was used at the mid-point of the coracoid.

Preoperative measurements were used for several calculations. The GT was then calculated as described by Di Giacomo et al ($GT = 0.83 \times D - d$; where D represents the native glenoid diameter and d is the anterior glenoid defect).[8] On-track vs. off-track lesions were determined by comparing the GT to the HSI, as previously described ($HSI < GT$ = on-track; $HSI > GT$ = off-track).[8] The graft size needed to convert off-track lesions to on-track was calculated by subtracting the GT from the HSI (ΔHSI-GT). This value was compared to the coracoid width; if the coracoid width was greater than this calculation, there was sufficient coracoid to convert the lesion to on-track. The predicted final glenoid size as calculated by subtracting the bone loss from the diameter, and then adding the coracoid width.

Postoperative measurements were performed in a similar fashion as described for preoperative measurements. Glenoid diameter was measured using the circle of best fit method. Coracoid graft size (height and width) was measured on the sagittal images. Postoperative calculations consisted of determining the amount of the glenoid reconstructed, which corresponded to the size of the coracoid graft that was harvested and used for glenoid augmentation. This calculation was done by dividing the postoperative GT measurement by the preoperative value and multiplying by 100 to determine the percent.

Basic demographic data was obtained via chart review. This included patient sex, extremity involved, prior stabilization procedure, and age at surgery. Clinical notes were reviewed to obtain clinical outcomes including postoperative instability recurrence, need for revision stabilization surgery, and need for return to OR for nonstabilization surgery. Recurrence of anterior shoulder instability was defined as subjective return of instability symptoms, reported subluxation or dislocation events. Duration of clinical follow-up was recorded, with a minimum of 2 years.

All deidentified patient information was compiled into a secured Excel spreadsheet (Microsoft Corp., Redmond, WA, USA). Excel was

Table I
Average preoperative coracoid measurements from advanced imaging.

	Mean ± SD (mm)
Hill-Sachs interval	27 ± 5
Glenoid diameter	32 ± 3
Glenoid bone loss	8 ± 3
% glenoid bone loss (%)	24 ± 7
Glenoid track	19 ± 3
Predicted restoration (%)	104 ± 8
Coracoid width	12 ± 2
Coracoid length	30 ± 3
Coracoid height	13 ± 2

SD, standard deviation.

used to carry out all calculations, as described above. Continuous variable data was reported as mean ± standard deviation. Student's t tests were used to compare continuous data, respectively. Fisher's exact tests were used to compare binary data. A *P* value of <.05 was considered statistically significant.

Results

Sixty-five open Latarjet procedures were performed during the study period, of which 17 patients met inclusion criteria and were included for analysis. All 48 excluded patients did not have postoperative advanced imaging. Of these, 13 were males and 4 were females, with an average age of 25 ± 9 years at time of surgery. Latarjet was performed after prior failed anterior stabilization procedure in 65% of cases and for primary stabilization procedure in 35% of cases. Postoperative scans were obtained at a mean of 19 ± 27 months after surgery. Preoperatively, the average HSI was 27 ± 5 mm with an average GT of 19 ± 3 mm (Table I). Overall, 15 patients had off-track lesions preoperatively. The average glenoid bone loss was 24 ± 7% (Table I). Preoperative coracoid dimensions averaged a length of 30 ± 3 mm, width of 12 ± 2 mm and a height of 13 ± 2 mm (Table I). By adding the measured coracoid width to the native preoperative glenoid diameter (glenoid diameter − bone loss), the Latarjet procedure was predicted to restore an average of 113% of the native glenoid.

Based on postoperative scans, the reconstructed GT measured 31 ± 3 mm, which corresponds to 116 ± 8% of the native glenoid (Table II). Using postoperative measurements, the harvested coracoid graft was 99 ± 1% of the width and 68 ± 14% of the height of the coracoid (Table II). The new glenoid reconstructed 104 ± 8% of the predicted diameter. Overall, 11 patients had their lesions converted from off-track to on-track lesions and 4 remained off-track (Table III). For the 11 patients that were successfully converted to on-track lesions, the difference between their postoperative HSI and GT was smaller than the preoperatively measured coracoid graft size in all cases (ΔHSI-GT < coracoid graft size). For 3 of the 4 patients that remained off-track after Latarjet, the preoperative measurements were able to predict that the lesions would remain off-track postoperatively (ΔHSI-GT > coracoid graft size). One of the 4 patients with a persistent postoperative off-track lesion had sufficient coracoid by 1mm based on preoperative calculations. Measurements from preoperative advanced imaging accurately predicted conversion of off-track to on-track lesions in 9% of cases.

The interobserver reliability was strong to almost perfect for all measurement variables except for reconstructed glenoid diameter, which was weak (intraclass correlation coefficient [mean]: 0.94 for Hill Sachs interval, 0.94 for glenoid diameter, 0.95 for glenoid bone loss, 0.83 for coracoid length, 0.89 for coracoid depth, 0.90 for coracoid height, 0.50 for reconstructed glenoid diameter, 0.95 for graft width, and 0.90 for graft length/height).

Table II
Average postoperative measurements from advanced imaging, including the percent of glenoid diameter and track reconstructed and percent of coracoid utilized in graft.

	Mean ± SD (mm)	Amount reconstructed (%)
Glenoid diameter	37 ± 4	116 ± 8
Glenoid track	31 ± 3	164 ± 23
Graft width	11 ± 2	99 ± 1
Graft length	21 ± 2	68 ± 1

SD, standard deviation.

Mean clinical follow-up after surgery was 2 years. In our study population, we found a 29% recurrence rate of instability after Latarjet, defined by patient subjective report of instability postoperatively (Table IV). Of the patients with persistent off-track lesions, 25% reported recurrent instability, compared to 31% of patients with on-track lesions postoperatively ($P > .05$). Only 1 patient had a postoperative dislocation event. Overall, 18% of patients underwent revision stabilization, with no significant difference in rates of revision between patients with persistent off-track versus on-track lesions (25% vs. 15%, respectively; $P > .05$). Only 1 patient returned to OR for a related nonstabilization procedure which was related to symptomatic graft prominence postoperatively.

Discussion

The major finding in this study is that preoperative advanced imaging measurements can accurately predict graft size, restoration of the GT, and ability to convert off-track to on-track lesions. The Latarjet was able to reconstruct 116 ± 8% of the native glenoid and convert 73% of off-track lesions to on-track lesions. The 4 off-track lesions that were not converted to on-track had the largest HSI on preoperative imaging, and in 3 of the 4, the coracoid was not large enough for conversion. Importantly, this was predictable based on the preoperative measurements of the HSI, GT, and coracoid size.

Studies have shown significant variation in coracoid size among patients, which has shown to be clinically relevant in the Latarjet procedure.[27,36] The Latarjet procedure relies on the size of the coracoid, as it must be sufficient to improve stability by restoration of the glenoid defect and maintain this stability without graft fracture or screw malposition.[5,18,27,36] Studies have shown that glenoid defects between 36-40% of the glenoid width can be managed with the classic Latarjet technique, and those that reached 50-53% of the glenoid width can be managed with the modified congruent-arc Latarjet technique.[24,27] However, these studies did not evaluate for conversion of off-track to on-track Hill-Sachs lesions, which has been shown to be clinically important as persistent off-track lesions after Latarjet are associated with higher failure rates.[3,25]

Our findings corroborate the results of Calvo et al,[3] who retrospectively evaluated the conversion of off-track to on-track lesions after arthroscopic Latarjet procedures in 51 patients via preoperative MRI or CT and postoperative CT imaging and found that 11.8% of shoulders had persistent off-track lesions postoperatively. Similar to our results, they found that the patients whose lesions remained off-track had significantly greater HSI width (29.8 ± 2.4 mm vs. 22.9 ± 3.5 mm) and a higher ΔHSI-GT value (12.2 ± 3.8 mm vs. 4.8 ± 3.2 mm).[3] However, they performed only on- and off-track measurements, and not of the coracoid or coracoid graft. Additionally, they postulated that successful conversion of off-track to on-track lesions could be predicted by comparing graft size to the difference between the HSI and GT size.[3] Our study supported this

Table III
Patients and measurements for shoulders that were on-track vs. off-track postoperatively.

	On-track	Off-track	P value
Number of patients	13	4	
Preoperative glenoid bone loss (%)	22 ± 6	28 ± 9	.31
Hill-Sachs interval (mm)	26 ± 4	32 ± 2	.002
Coracoid width (mm)	11 ± 2	12 ± 1	.79
Graft needed to convert to on-track (ΔHSI-GT)* (mm)	6 ± 5	15 ± 4	.005

HSI, Hills-Sachs interval; *GT*, glenoid track.
*Difference between Hill-Sachs interval and glenoid track.

hypothesis, as we were able to successfully predict conversion of off-track to on-track lesions using this comparison.

While we have demonstrated that patient-specific preoperative measurements using advanced imaging can accurately predict coracoid graft size, restoration of the GT, and therefore ability to convert off-track to on-track lesions, the question remains regarding optimal management for the case of persistent off-track lesions. Di Giacomo et al, described three patterns of off-track lesions; (1) Hill-Sachs defect is too medial or medially-enlarged, (2) difficult to determine reason lesion is persistently off-track, and (3) off-track due to significant glenoid bone loss.[6] For lesions that are predicted to remain off-track after Latarjet, it is important to consider these patterns when determining the optimal management course for the individual patient. For instance, if the lesion is predicted to remain off-track because the coracoid size is insufficient, one might consider using a free bone block procedure to ensure adequate restoration of the GT.[12] On the other hand, if the lesion is predicted to remain off-track due to the size or location of the Hill-Sachs lesion, concomitant humeral-sided procedures such as remplissage and humeral grafting should be considered to reduce the risk of recurrent instability.[1,7,17]

Overall, there was no statistically significant difference amongst clinical outcomes between patients, regardless of postoperative GT status at a mean follow-up of 2 years. Our study found high rates of recurrent subjective instability postoperatively in patients with both persistent off-track and on-track lesions (25% and 31%, respectively). These rates are much higher than those reported in the literature, with recent studies showing recurrent instability rates less than 3% after Latarjet.[10,19] It is important to note that recurrence of instability was subjective, and therefore likely overestimates rates of objective postoperative instability. Similarly, we found revision rates of 25% and 15% for persistent off-track and on-track lesions, respectively. The high recurrence and revision rates found in our study are likely related to the small sample size, as well as selection bias inherent in our population; patients at our institution do not routinely get postoperative advanced imaging, and therefore those with available advanced imaging were more likely to have postoperative instability symptoms or pain.

The results of this study should be interpreted with consideration of certain limitations. This was a retrospective review of prospectively collected data and only patients with both preoperative and postoperative advanced imaging studies were included, which introduces the risk for selection bias. This may also reduce the generalizability of the clinical outcomes of this study, as our population of patients with postoperative advanced imaging likely represents a distinct subset of the population of patients who undergo Latarjet procedures for anterior shoulder instability. While the clinical outcomes of recurrent instability found in this study may not be generalizable, the predictability of coracoid graft size and postoperative GT status from preoperative advanced imaging is generalizable, as it is unlikely affected by confounding patient variables. Additionally, the modality of advanced imaging (CT or MRI) was not always consistent among patients preoperative and postoperatively. Despite this incongruence, numerous studies have validated the use of both MRI and CT for measurement of humeral, glenoid, and coracoid variables.[14,20,23,27,31,32] Another limitation of this study is the small sample size, which reduces the power of the study and increases the possible margin of error. Despite these limitations, our study provides an important basis for future studies. Future research should incorporate this predictive process preoperatively and evaluate if additional or alternative procedures can improve clinical outcomes in the unique and difficult instability patient population that has persistent off-track lesions with the Latarjet procedure.

Table IV
Clinical outcomes after latarjet procedure.

	On-track	Persistent off-track	P value
Number of patients	13	4	
Recurrent instability, n. (%)	4 (31)	1 (25)	1.0
Revision stabilization procedure, n. (%)	2 (15)	1 (25)	1.0
Other return to OR, n. (%)	1 (8)	0 (0)	1.0

OR, operating room.

Conclusion

This study shows that preoperative advanced imaging measurements of the coracoid can reliably predict Latarjet coracoid graft width and the amount of glenoid that can be reconstructed with a Latarjet. The glenoid bony diameter was restored to 104% of the preoperatively calculated size. By performing these measurements, one can confidently predict whether an off-track Hill-Sachs can be converted to on-track, further enhancing shoulder stability.

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