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ORIGINAL ARTICLE

Coracoid graft union: a quantitative assessment by computed tomography in primary and revision Latarjet procedure

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Background: The goal of the Latarjet procedure is restoration of shoulder stability enabled by accurate graft positioning and union. This study aimed to establish a reproducible method of quantitatively assessing coracoid graft osseous union percentage (OUP) using computed tomography (CT) scans and to determine the effect of other factors on the OUP.
Materials and methods: Postoperative CT scans of 41 consecutive patients treated with the open Latarjet procedure (37% primary, 63% revision) for anterior glenohumeral instability were analyzed for the OUP, position of the graft, and screw type and angle. Two musculoskeletal radiologists independently examined the images 2 times, and intraobserver and interobserver reliability was calculated using intraclass correlation coefficient (ICC).
Results: Mean OUP was 66% (range, 0%-94%) using quantitate methods, with good intraobserver reliability (ICC = 0.795) and interobserver reliability (ICC = 0.797). Nonunion and significant graft resorption was found in 2 patients. No significant difference was found in the mean OUP in the primary (63%) vs. revision Latarjet procedure (67%). Grafts were flush in 39%, medial in 36%, and lateral in 8%. The medial and neutral graft position was associated with slightly higher OUP (72% and 69%) compared with lateral (65%). OUP was higher when the superior screw angle was less than 17° and the inferior screw angle was less than 24°. This difference did not reach statistical significance. Screw type was not associated with significant difference in OUP.
Conclusion: Quantitative assessment of osseous union of the graft using a reproducible method that we introduced showed similar OUP in the primary and revision Latarjet procedure.
Level of evidence: Level IV; Case Series Treatment Study

Keywords: coracoid graft; Latarjet; osseous union percentage; graft position; revision Latarjet; CT scan assessment

The Latarjet procedure is a surgical option for patients with anterior shoulder instability[20] and is particularly well-suited for patients with glenoid bone loss.[7] The procedure involves transfer of the horizontal pillar of the coracoid and the attached conjoined tendon to the anterior glenoid. A Latarjet

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procedure is traditionally performed with an open approach through the deltopectoral interval, although it can also be done via arthroscopic technique.[6,27] The Latarjet procedure is indicated for treatment of anterior glenohumeral instability where there is critical glenoid bone loss, failed prior anterior shoulder stabilization procedures,[8] or extensive soft tissue deficiencies.[2] Although there is no consensus on what constitutes critical glenoid bone loss, the literature proposes values that range from 13% to 40% of glenoid bone loss.[22,30,34] The Latarjet procedure has been increasingly recommended as a primary procedure in patients with off-track Hill-Sachs lesions[29] and even in patients without glenoid bone loss,[22] because the success rate is uniformly higher than that of traditional arthroscopic Bankart repairs.[23,26,29,32]

Several prior studies have examined the outcomes and complications of the Latarjet procedure. The recurrent instability rate has been shown to be between 0% and 14%,[1,3,8,16] and the rate of short-term, transient complications, such as infection and neurologic injury, has been shown to be 5% to 25%.[2,8,9,13,29] Several factors can contribute to a successful outcome, including adequate surgical planning, surgical techniques, and appropriate patient selection.

The ultimate goal of the Latarjet procedure is restoration of shoulder stability and function, which is facilitated by accurate bone graft positioning and healing. The ideal graft position should be flush and congruent with the articular surface of the glenoid. Proper graft positioning diminishes the risk of recurrent instability and long-term arthritis.[4] Suboptimal graft positioning, especially placement of the graft too laterally, may interfere with graft osseous healing and substantially increase the risk of glenohumeral arthritis.[16] Nonunion and displacement of the graft can result in a higher rate of persistent apprehension or recurrent shoulder instability and a decreased return to sport participation.[1,6,15] Given this, assessing graft osseous union in postoperative evaluations is critical.

To our knowledge, no reports have been published on how to assess Latarjet graft union quantitatively, which also allows assessment of the effect of other factors on graft union in measurable means. The principle objective of this study was to establish a reproducible method of quantitatively assessing bone graft union using computed tomography (CT) scans. In addition, we aimed to determine the effect of a number of other factors on the graft union, including graft and screw positioning, screw types, and patient demographics. Finally, we studied whether primary vs. revision Latarjet procedures result in different rates of graft healing.

Materials and methods

Between 2006 and 2015, 41 consecutive patients were treated with an open Latarjet procedure for anterior glenohumeral instability at a single tertiary referral center under the direct supervision of the senior author (L.D.H.). Graft behavior and position was assessed in all patients by postoperative CT scans. Patients were eligible for a Latarjet procedure and for this study if the glenoid bone loss was greater than 13.5% and less than 30%, there was a glenoid off-track Hill-Sachs lesion, or if the patient had undergone an unsuccessful prior arthroscopic or open capsule and labral (Bankart) repair for instability. The exclusion criteria were overhead athletes, presence of glenohumeral osteoarthritis, and patients aged older than 45 years.

The 41 patients (35 male, 6 female) were a mean age of 26 years (range, 16-44 years), and 26 of the 41 patients (63%) had undergone prior surgery for glenohumeral instability. The mean number of surgical procedures before the Latarjet procedure was 1.2.

Surgical technique

Our surgical technique has been previously described by Shah et al.[29]

Data collection and CT scan assessment

A CT scan was performed at 5.8 ± 0.7 months postoperatively to assess graft position and union of the coracoid to the glenoid. CT studies were performed with 64-slice CT scanners (LightSpeed Pro16; GE Healthcare, Milwaukee, WI, USA), using the same standardized scanning protocol with filters for bone (single slice thickness, 0.625-1.25 mm). Sagittal and coronal reformatted images were created with 2-mm slice thickness. Additional reconstructed images with soft tissue filters were also required to reduce the effect of beam hardening from the screws. Further assessment and multiplanar reformatting of the images were performed by using the Vitrea Enterprise 6.0 imager workstation (Vital Images, Minnetonka, MN, USA). Images were retrospectively reviewed on the workstation by 2 musculoskeletal radiologists working in consensus.

Image review

Two musculoskeletal radiologists, with 8 (K.M.S.) and 2 (M.S.) years of experience, blindly and independently performed all the measurements of each shoulder, blind to the patient's clinical history and each other's assessment and in a random fashion in 2 separate sessions, separated by more than 4 months.

Glenoid height definition was based on the protocol described by Kraus et al.[19] A craniocaudal axis was drawn between the superior and inferior tubercle of the glenoid in the sagittal slice through the glenoid. This distance was considered the glenoid height, and the heights of 25% and 50% were defined (Fig. 1). Measurements for the graft's position and screw angle were then taken in the axial slices between the 25% and 50% of the glenoid height corresponding to the sagittal slice. The reviewers were blinded to the slices the other selected for all the measurements.

Assessing graft union

The osseous union percentage (OUP) across the graft was measured by readers using a grading system developed by Jones et al.[18] Using 2-mm-thick sagittal multiplanar reformatted images through the coracoid graft, the readers measured the length of the glenoid and graft interface and the length of the successfully osseous fused portion of that graft on the middle selected slices in the center of the graft. Effort was made to select slices that were least affected by the streak artifact from the screws.

Fusion of a graft segment was defined as trabeculation or ossified density crossing the glenoid graft space. The widths of screws

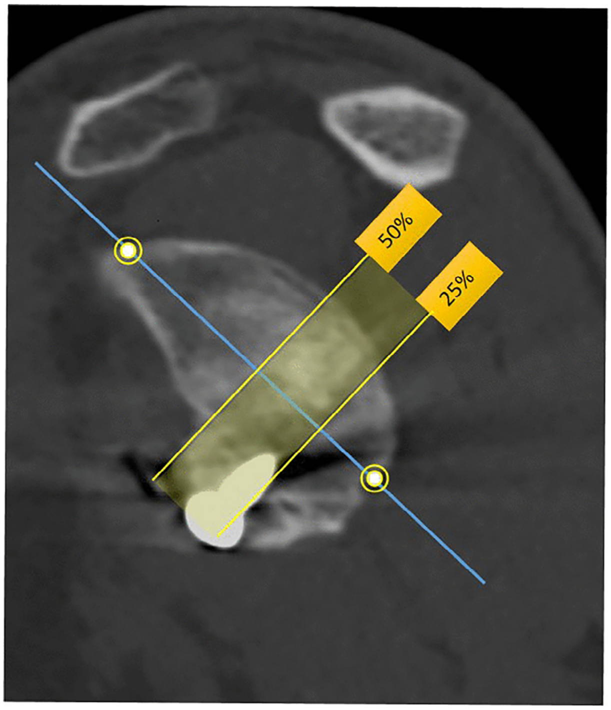

Figure 1 Defining the glenoid height. The glenoid height is defined as a craniocaudal axis drawn between the superior and inferior tubercle of the glenoid in a sagittal slice (*blue line*). The heights of 25% and 50% were determined (*yellow lines*). Measurements for the graft's position and screw angle were then taken in the corresponding axial slices between 25% and 50% of the glenoid height.

that traversed the space were excluded from the measurements of the fusion because fixation hardware provides rigid temporary support for the graft. The lengths of the fused segments and the lengths of graft-glenoid interfaces were recorded. Areas of graft osteolysis involving the graft-glenoid interface were counted as unfused segments in the calculation. Osteolysis that affected the superficial or superior part of the graft and not the interface was not included in the calculation as unfused segment because it had no effect on the OUP calculation. The OUP was calculated using the formula: OUP = 100 × (sum of lengths of fused segments on all slices/sum of lengths of graft-glenoid interfaces) (Fig. 2). Because the ratios were calculated, adjustments for magnification or varying bone size were not necessary.

Position and types of the screws

The angle of screws was formed between the line tangent to the anterior and posterior margin of glenoid and the second line drawn along the length of the screw (Fig. 3). The measurement was obtained within axial images between 25% and 50% of the glenoid height determined by cross-referencing the sagittal image. The screw types were characterized as fully or partially threaded and cannulated or noncannulated screws.

Position and size of the graft

The ideal graft position was defined as below the glenoid equator and flush to the glenoid rim.[6] To determine the position of the graft in relation to the glenoid, a circle best representing the glenoid curvature on axial view was drawn. Assessment of the graft laterality was performed on axial images between 50% and 25% of glenoid height determined by cross-referencing the sagittal image. Because a graft may not have uniform inclination throughout its length and can be flush at one level and medial or lateral on another level, the position of the graft was evaluated in that height range, and the most incongruent slice was selected for measurement.

The following description outlines our method of quantitatively assessing the position of the graft. First, a line was drawn alongside the native glenoid between the anterior and posterior subchondral rim. A second line was then drawn parallel to the first line at the level of the coracoid graft tip. The distance between the second line where it touched the tip of the graft and the glenoid circle was measured perpendicular to the second line. The graft was considered lateral or medial if the second line was lateral or medial to the glenoid circle respectively (Fig. 4).

Size of the graft was measured on the sagittal image. The maximum height of the graft was recorded as its length and the maximum width was recorded as thickness.

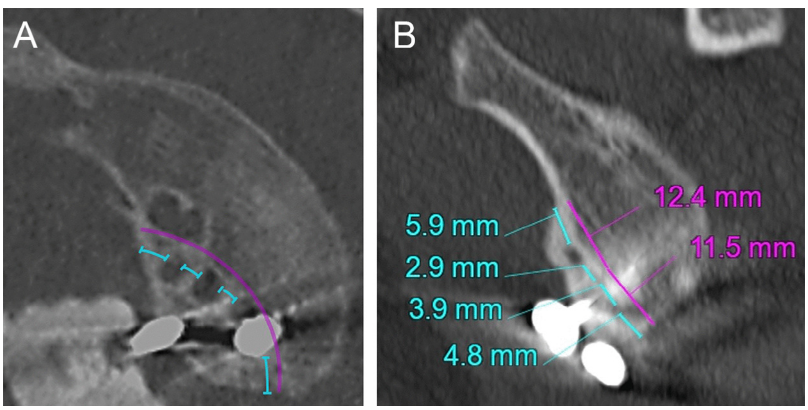

Figure 2 Measurement of graft union percentage. (**A**) Measuring technique. The trabeculation or ossified density crossing the glenoid graft space was measured (*blue lines*). Nonosseous union (lucent areas) and screw are excluded. The sum of the lengths of the osseous fused area was divided by the sum of graft-glenoid interface (*purple line*). (**B**) Measurement example.

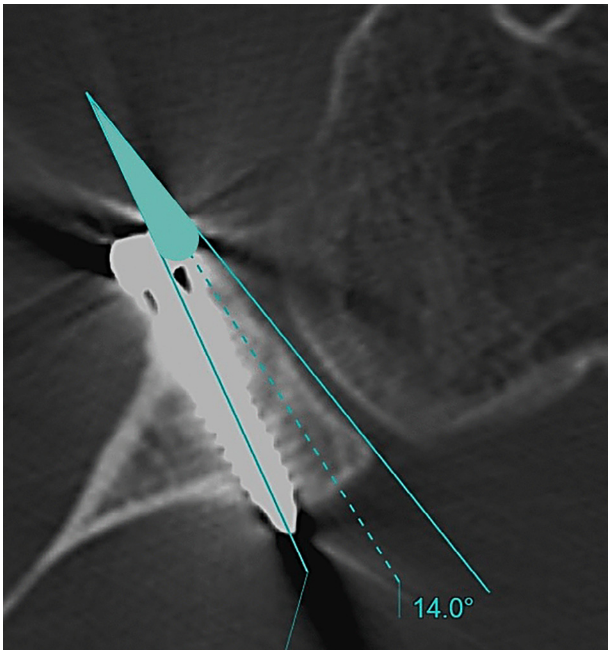

Figure 3 Screw angle measurement. The angle was formed between the line tangent to the anterior and posterior margin of the glenoid and the second line drawn along the length of the screw.

Statistical analysis

Paired and unpaired *t* tests were used to assess the association between demographics, clinical and surgical characteristics, and OUP. If the outcome was skewed, nonparametric tests were used instead of the *t* test, including the Wilcoxon rank sum test for 2-level independent variables and the Kruskal-Wallis test for 3-level independent variables. Reliability measurements were calculated using intraclass correlation coefficients (ICC) using Shrout-Fleiss ICCs for continuous parameters and weighted κ for categoric parameters.

Results

Included were 41 patients: 15 (37%) in the primary group and 26 (63%) in the revision group (Table I). Mean OUP was 66% (range, 0%-94%). Nonunion and significant graft displacement and resorption involving the graft-glenoid interface was found in 2 patients. The average length of the graft was 1.9 cm and the average thickness was 1.7 cm. Thirty-nine percent of the grafts were flush with the glenoid, 36% were medial, and 8% were lateral in relation to the glenoid. The mean distance for the medial or lateral located grafts from the glenoid was 3.0 ± 1.3 mm. Partially threaded screws were used in 24 patients (58%), and fully threaded screws were used in 17 (42%). The mean angle of the superior screw in relation to the glenoid was 20° ± 9.7°. The mean angle of the inferior screw in relation to the glenoid was 24.4° ± 12°.

The mean OUP did not differ significantly in the primary group (63%) vs. revision group (67%; Table II). The OUP was higher in patients with body mass index exceeding 25 kg/m^2 (73%) than the group at 25 kg/m^2 or lower (62%), although this difference was not statistically significant. There was higher OUP when the angle of the superior screw was less than 17° and the inferior screw angle was less than 24°; however, this difference was not statistically significant.

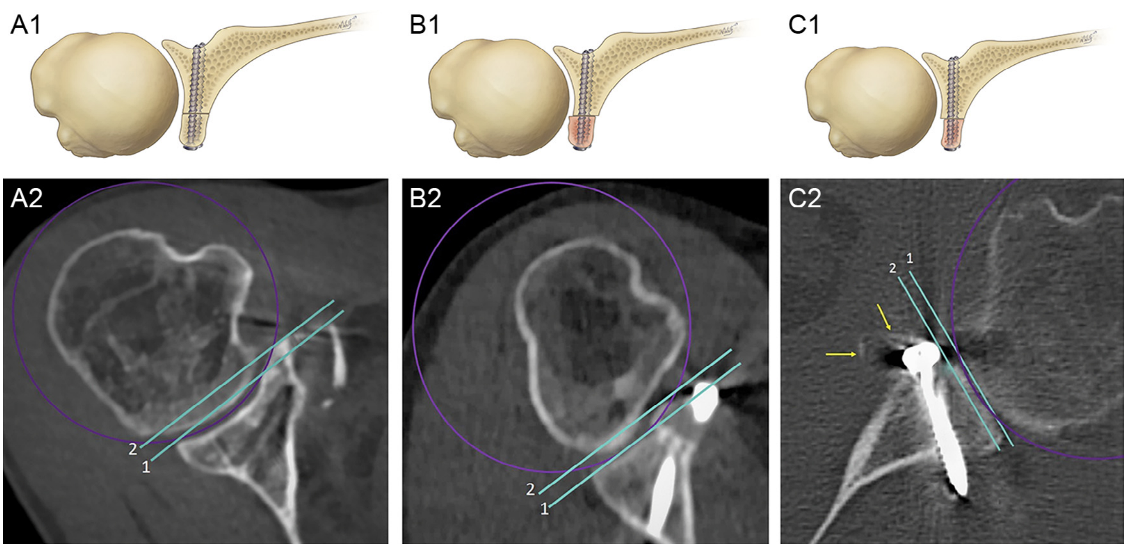

Figure 4 Graft position. (**A**) Flush graft. A best-fit *purple circle* is drawn to best represent glenoid curvature. *Line 1* was drawn alongside the glenoid using anterior and posterior glenoid rim. *Line 2* (parallel to the first line) was drawn along the tip of the coracoid graft. A perpendicular line is drawn between line 2 at the tip of the graft and the glenoid curve to measure distance. (**1**) Schematic demonstrates flush graft. This graft was considered flush because there is no distance between tip of the graft and the glenoid circle. (**2**) Measurement example. (**B**) Lateral graft. (**1**) Schematic demonstrates laterally placed graft. (**2**) Measurement example. *Line 2* is lateral to the glenoid circle. (**C**) Medial graft. (**1**) Schematic demonstrates a medially placed graft. (**2**) Measurement example. Coracoid graft (*yellow arrows*). *Line 2* is medial to both the glenoid circle and line 1. Illustrations by Nicole Wolf, MS, ©2017. Printed with permission.

Table I Demographic data, clinical, and surgical characteristics

Variables	Number (%) or mean (SD)
Sex	
Male	35 (85.4)
Female	6 (14.6)
Age at surgery, yr	26.36 (6.63)
Body mass index, kg/m^2	26.58 (3.70)
Overall osseous union percentage, %	66 (26)
Types of surgery	
Primary	15 (36.6)
Revision	26 (63.4)
Length of graft, cm	1.93 (0.33)
Thickness of graft, cm	1.76 (2.51)
Screw angle, °	
Inferior	24.41 (12.10)
Superior	20.03 (9.75)
Graft position	
Displaced/partially resorbed	2 (4.9)
Medial	15 (36.6)
Neutral (flush)	16 (39.0)
Lateral	8 (19.5)
Mean medial or lateral distance, mm from glenoid surface	3.06 (1.36)
Screw type	
Fully threaded	17 (41.5)
Partially threaded	24 (58.5)
Cannulated	22 (53.7)
Noncannulated	19 (46.3)

Table II Demographic and surgical various and osseous union percentages

Variables	No.	Osseous union percentage	*P* value
		Mean (SD)	
Age group			.5647
<25 yr	19	68 (23)	
≥25 yr	22	64 (28)	
Body mass index group			.1209
≤25 kg/m^2	18	62 (27)	
>25 kg/m^2	20	73 (21)	
Primary/revision			.5420
Primary		63 (28)	
Revision		67 (25)	
Screw angle			.6426
Inferior angle ≤24°	20	73 (14)	
Inferior angle >24°	19	65 (28)	
Superior angle ≤17°	20	74 (12)	.5103
Superior angle >17°	18	63 (29)	
Graft location			.1106
Medial		72 (23)	
Neutral		69 (18)	
Lateral		65 (27)	
Screw type			.5962
Fully threaded		66 (29)	
Partially threaded		66 (24)	
Cannulated		66 (26)	.9270
Noncannulated		66 (27)	

In 1 patient with no osseous fusion and associated graft resorption, the superior and inferior screws (fully threaded and cannulated) angles were 44° and 50°, respectively. In another patient with no osseous fusion and graft resorption, the superior and inferior screws (partially threaded and noncannulated) angles were 19° and 26°, respectively. The medial and neutral position of the graft was associated with slightly higher OUP (72% and 69%) compared with the lateral position (65%). This difference did not reach statistical significance. Screw type was not associated with a significant difference in OUP.

Reliability

The intraobserver and interobserver reliability for overall mean OUP was good (ICC = 0.795 and 0.797, respectively; Table III). There was also good intraobserver and interobserver reliability (ICC = 0.790-0.868) for screw angle measurements. The intraobserver and interobserver reliability was moderate for location of the graft ($\kappa = 0.42$ and $\kappa = 0.49$, respectively).

Discussion

Our results indicate that similar OUP of the graft can be achieved in revision Latarjet procedures (67%) compared with

Table III Intraobserver and interobserver reliability of measurements*

Variable		Intraobserver (ICC)	Interobserver (ICC)
Osseous union percentage	Overall	0.79550	0.79746
	Primaries	0.71814	0.72709
	Revisions	0.83358	0.83485
Screw angle superior	Overall	0.85703	0.79049
	Primaries	0.40354	0.37896
	Revisions	0.93641	0.86548
Screw angle inferior	Overall	0.86891	0.80841
	Primaries	0.57103	0.53046
	Revisions	0.94531	0.89227
		Intraobserver (κ)	Interobserver (κ)
Graft location	Overall	0.4976	0.4206
	Primaries	0.5631	0.7143
	Revisions	0.4286	0.1781
Graft distance	Overall	0.2988	0.1962
	Primaries	0.2688	0.0227
	Revisions	0.2632	0.2475

ICC, intraclass correlation coefficient.
* The Shrout-Fleiss ICC was used for continuous parameters and weighted κ for categoric parameters.

the primary Latarjet procedure (63%) using a reproducible quantitative method.

The role of the Latarjet procedure as a revision surgery has been studied and reported in the literature.[21,28,35] Schmid et al[28] showed the effectiveness of the Latarjet in restoring stability in a study of 49 patients with 1 to 3 previous stabilizations (besides a Latarjet procedure) and recurrence of anterior shoulder instability. Outcomes such as the rate of recurrent instability for the Latarjet procedure as a revision reconstruction are comparable with outcomes of primary repairs reported in the literature.[1,16] Likewise, our quantitative assessment of graft union indicated that similar OUP can be achieved in primary and revision Latarjet procedure.

We have shown a reproducible method for the assessment of coracoid graft osseous union. Although osseous union of the coracoid graft has been investigated in previous studies,[29,33] we are not aware of any previous study of quantitative assessment of the graft OUP. Thus, there is currently no definition in the literature to distinguish between nonunion and partial union in coracoid grafts. Jones et al[18] defined 33% fusion as the threshold to divide nonunion from partial union in their CT grading system of hindfoot arthrodesis. Complete union was defined as a joint fused over more than 67% of its length.[18] Using the Jones definition, we found 67% of patients after primary Latarjet and 67% of patients after revision Latarjet procedure had complete union.

The higher union rates of the coracoid graft in some of the other studies is likely related to the different methods of calculating OUP. Although our study uses a quantitative method, some other reports used radiographic analysis,[6,27,35] which is considered inferior to CT in assessing the fusion.[11,28] In a review of 30 studies of coracoid transfer (1658 cases), Butt and Charalambous[9] reported the collective incidence of graft nonunion, fibrous union, or postoperative graft migration of 10.1% ± 1.6%. Our results are similar to Shah et al,[29] who reported incorporation of the coracoid graft in 72% of 29 patients who underwent a Latarjet procedure and had a CT scan postoperatively at a mean of 6.5 months. However, there was no quantitative measurement of OUP in their study.

The effect of early partial union on patients' outcomes after a Latarjet is not totally clear, and not all patients with postoperative CT scans demonstrating incomplete graft union have postoperative issues such as pain or instability.[29] Shah et al[29] reported that 5 of 8 patients with fibrous union were asymptomatic and were not included as complications because they believed the nonunion did not affect these patients' outcomes. Gordins et al[14] monitored patients who had undergone a Latarjet procedure for 33 years after their operation. Their study showed that some shoulders that had fibrotic union within the first 2 to 4 years had osseous fusion at the 30-year follow-up.[14] Therefore, although most of the union is expected within the first 3 to 6 months after surgery,[16,33] it is possible that our results of 63% and 67% mean OUP would increase if follow-up CT was performed at a later time postoperatively. Our results support the conclusion of Boileau et al[5] that a history of shoulder surgery is not a significant risk factor for nonunion.

The most important factor for determining technical success of the Latarjet procedure is accurate placement of the coracoid bone graft in relation to the glenoid margin.[25] Suboptimal positioning of the graft can result in complications, such as nonunion, the development or progression of pre-existing osteoarthritis if the position is too lateral,[17,28] and recurrent instability if the position is too medial.[24] Although there is no standard method for assessing the positioning of the coracoid graft, CT is generally considered superior to radiographs.[11,28] Several studies have investigated the positioning of the graft using radiographs[1,16] despite discrepancies between radiographs and CTs in the assessment of graft positioning.[12]

With some modification, we used the main protocol principles validated by Kraus et al[19] in the assessment of graft position. Kraus et al[19] used the circle around the humeral head to determine the congruity of the graft and to assess impingent upon the humeral head in rotational shoulder movement when the graft is positioned too lateral. In our study, we used a perfect circle best representing glenoid curvature because the goal of surgery is to place the graft in continuity with the adjacent glenoid curvature. We also modified the level at which the graft position was measured. The graft is in continuum between 50% and 25% of the glenoid height and may not have uniform inclination through its height. In other words, the graft may be flush in one height and lateral or medial in another height. Therefore, the graft position in our study was assessed throughout this height range, and the most incongruent site (medial or lateral) was measured for graft positioning. Contrastingly, the Kraus et al[19] assessment was at 2 levels only, at 25% and 50% of glenoid height.

In our results in the axial plane, 39% of the grafts were flush with the glenoid, 36% were medial (mean, 3.1 mm), and 19% were lateral (mean, 2.3 mm). The small differences in distance in millimeters may have contributed to our lower interobserver and intraobserver reliability for graft distance measurements during our 2 separate sessions. Kraus et al[19] found that 60% of their grafts were flush, 7% were medial, and 33% were lateral. Marion et al[25] had higher ratio of medially placed grafts (87%-90%) and fewer flush grafts (9%-12.5%) when it was measured at the 25% height of the glenoid. Allain et al[1] observed bone blocks that were too lateral in 53% of patients and bone blocks that were too medial in 5% of patients. These differences may be partly due to our difference in measurement technique. In our study, the lateral position of the graft was associated with lower OUP (65%) compared with medial (72%) and neutral (69%) positions, although the difference was not statistically significant. We speculate that the higher chance of impingement in a laterally placed graft can result in early motion and lower OUP of the graft.

Other factors considered to affect the outcome of the Latarjet procedure are the screw types and size.[29] In our study, screw type, including fully vs. partially threaded or cannulated vs. noncannulated screws, was not associated with higher or lower OUP (66% in all types). Our result is in agreement with a recent study that showed screw type and fixation method did not significantly influence biomechanical performance in the Latarjet procedure.[31] Shah et al[29] found a higher rate of instability after the Latarjet procedure in patients with cannulated screw fixation; however, the power of their study was not sufficient for these differences to be statistically significant. Cannulated screws are considered weaker than noncannulated screws from a biomechanics perspective. Shah et al[29] found 4 of 5 shoulders that underwent fixation of the coracoid graft with cannulated screws had recurrent glenohumeral instability after the Latarjet and that 3 of these patients had nonunion on the postoperative CT scan. They postulated that cannulated screws may have inferior purchase in the native scapula than that of the noncannulated screws owing to less thread depth in the partially threaded cannulated screws, resulting in less compression of the graft.[29] However, neither their study nor ours had sufficient power to determine a statistically meaningful correlation between cannula type and OUP.

Although some studies showed older age is a significant risk factor for complications after a Latarjet procedure, others did not find a significantly greater occurrence of adverse events in older patients compared with younger patients.[2,29] Similarly, no significant difference in OUP was shown in our study between patients aged younger or older than 25 years (68% vs. 64%, respectively). These differences in results, including ours, may be due to insufficient sample sizes in these studies to reliably detect small but significant effects of age.

Finally, in addition to the surgical technique, patient selection is a very important factor contributing to the procedure success. Cowling et al[10] found that other than the approach through the subscapularis, their outcome of the Latarjet procedure was independent of the surgical technique. Their outcomes depended more on patient selection.[10] Consistent patient selection criteria in our study may have contributed to relatively higher graft fusion rates.

This study has multiple limitations. The small sample size and the short-term follow-up may have affected the rate of OUP. We did not report clinical outcomes because the objective of this study was to assess osseous fusion of the coracoid graft with a CT at 6 months postoperatively. The quantitative measurement of osseous union is not feasible and perhaps not needed for every Latarjet patient, yet this quantitative study confirms the previous body of evidence that good graft union can be achieved with meticulous surgical planning and execution. All of the operations in this study were performed by an experienced fellowship-trained shoulder surgeon, which may have affected the overall outcome. Further appropriately powered studies are required to determine possible correlation of OUP and the clinical outcomes of the Latarjet procedure.

Conclusion

The Latarjet procedure is becoming a more applicable option for treatment of anterior shoulder instability. It is useful as a revision stabilization procedure in patients with recurrent instability and as a primary stabilization procedure in shoulders with instability with or without glenoid bone loss. The goal of the procedure, restoration of shoulder stability and function, is enabled by accurate bone graft positioning and healing. We have devised a system to quantitate osseous union of the graft. The current study showed that similar union percentage can be achieved in primary and revision Latarjet procedures when proper patient screening is in place. Further investigation and clinical correlation will be necessary to further assess the effect of the OUP on long-term clinical outcome.

Disclaimer

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