Original Article

The Radius of Curvature of the Inferior Distal Clavicle Is Similar to That of the Glenoid in Both the Axial and Coronal Planes and Similar to the Inferior Coracoid

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Purpose: The purposes of this study were to use computed tomography (CT) scans to compare the radius of curvature (ROC) of the inferior concave surface of the distal clavicle to the glenoid, determine graft dimensions, and compare the ROC of the congruent-arc distal clavicle autograft (DCA) to the congruent-arc Latarjet graft. **Methods:** Patients who underwent bony glenoid reconstruction via a Laterjet procedure between January 2018 and January 2023 at a single institution were retrospectively identified. CT scans were used to measure the ROC of the glenoid on the axial and coronal sequences, measure the ROC of the distal clavicle on the sagittal oblique sequences, and determine the dimensions of the distal clavicle and coracoid graft. **Results:** A total of 42 patients were included (Latarjet, n = 22; control, n = 20). The mean ROC of the inferior surface of the distal clavicle was not significantly different from the ROC of the glenoid in the coronal ($P = .15$) or axial planes ($P = .65$). The ROC of the coracoid when measured in the sagittal plane was not significantly different from the ROC of the distal clavicle ($P = .25$). The length, depth, and surface area of the coracoid in the congruent arc orientation were significantly larger than the distal clavicle ($P < .005$). Patients in the control group tended to have both a larger inferior clavicle ROC and a larger coracoid ROC compared to the Latarjet group (32.8 mm vs 29.6 mm, $P < .0001$; 31.8 mm vs 30.9 mm, $P = .02$). **Conclusions:** The ROC of the inferior distal clavicle is similar to that of the glenoid in both the axial and coronal planes and similar to the inferior coracoid. **Clinical Relevance:** CT analysis reveals that the congruent-arc DCA technique provides a robust graft with dimensions that are suitable for reconstruction of the anterior glenoid.

For young patients with anterior shoulder instability and glenoid bone loss (GBL), several graft options exist for anterior glenoid reconstruction. These include the coracoid autograft, distal tibial allograft, iliac crest autograft, scapular spine autograft, and distal clavicle autograft (DCA).[1-6] Numerous prior studies have evaluated and compared the radius of curvature (ROC), contact area, and graft dimensions between these techniques and various graft options.[7-11] The articular distal clavicle surface has emerged as a popular graft option due to its adequate dimensions, limited harvest site morbidity, and osteochondral surface.[5] However, this graft option has its weaknesses, including varying incidences of rounded and trapezoidal convex morphologies, the need for graft shaping to ensure that the superior cortical surface is flattened adequately for

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The authors report the following potential conflicts of interest or sources of funding: This study was partially funded by the following: S.A.P. is a paid consultant and receives institutional research support from Exactech Inc. (Gainesville, Florida). He is a consultant for Arthrex, Inc. and is a board or committee member for AAOS and ASES. P.B. is a paid consultant and receives royalties from CONMED Linvatec (Utica, New York), Smith & Nephew (London, United Kingdom), and Wright Medical Technology, Inc. (Memphis, Tennessee). IRB exempt at Augusta University [1933382]. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received March 13, 2023; accepted June 15, 2023.

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2666-061X/23348

https://doi.org/10.1016/j.asmr.2023.100777

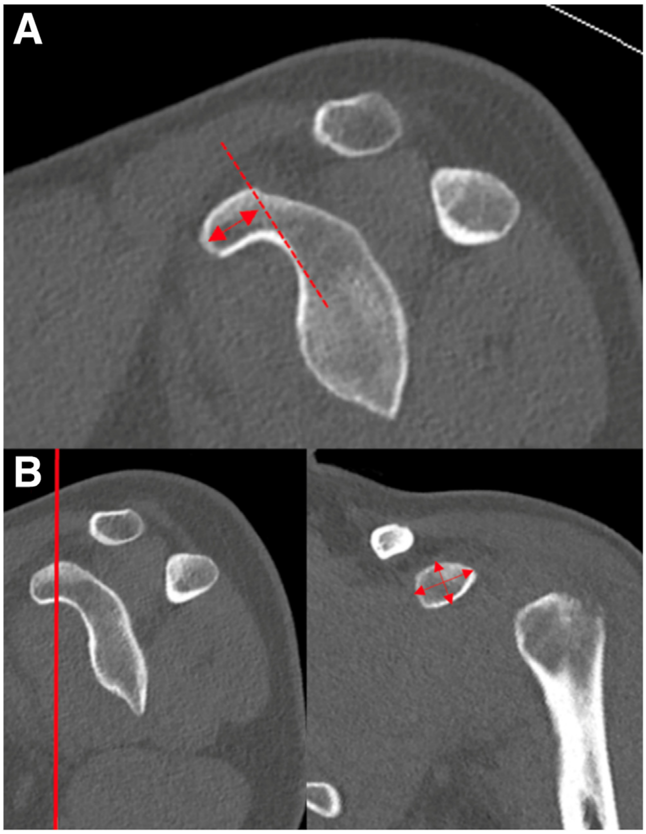

Fig. 1. Multiplanar reconstruction was performed by manipulating the sagittal sequence (A) to measure the length of the coracoid (25.5 mm) (solid red line) from the tip to the elbow (red dotted line). The midsagittal view of the coracoid was found and the medial-lateral (13.9 mm) and superior-inferior (11.5 mm) thickness of the coracoid was measured on the corresponding coronal image (B).

healing to the anterior glenoid neck, a lower bone mineral density, and the potential for degenerative changes of the articular cartilage surface in young, active patients.[5,10]

Prior studies have revealed that the distal clavicle is oriented with its articular surface adjacent to the glenoid surface, providing a quite robust graft, with 11 to 14 mm of thickness.[10,12] Recently, Boileau et al.[2] developed an all-arthroscopic technique that instead uses the inferior, concave surface of the distal clavicle to reconstruct the anterior glenoid. The purposes of this study were to use computed tomography (CT) scans to compare the ROC of the inferior concave surface of the distal clavicle to the glenoid, determine graft dimensions, and compare the ROC of the congruent-arc DCA to the congruent-arc Latarjet graft. We hypothesize that the ROC of the inferior concave surface of the DCA is similar to the glenoid and congruent-arc Laterjet graft.

Methods

A retrospective chart review was performed on all patients undergoing bony glenoid reconstruction via a Latarjet procedure during a 5-year period (January 2018 to January 2023) at a single institution. After initial query of the institution's medical record, an age-matched control cohort was identified for chart and imaging review. The following demographic information was retrieved from both the Latarjet and the control cohort: age (years), sex (male/female), laterality (left/right), height (cm), weight (kg), and body mass index (BMI). Exclusion criteria for the control cohort included patients with bony or articular cartilage glenoid pathology and patients with no CT scan in the medical record.

The CT scans that were retrospectively reviewed were performed at our institution by a standard shoulder protocol during the 5-year period to ensure that the scan was in the plane of the scapula. Specifically, the arm was positioned in adduction, with elbow extension and forearm supination, and with the shaft of the humerus positioned parallel to the floor. All CT scans were performed with a Phillips Brilliance iCT 256 system (Philips Healthcare), with 1-mm slice thickness. The institution's imaging software (IntelliSpace Picture Archiving and Communications System [PACS] Enterprise 4.4.541.1; Phillips Medical System) was used to view all images.

Measurement Technique

The multiplanar reconstruction function of our PACS was used to obtain an oblique sagittal view in the plane of the coracoid to allow measurement of its length from the tip to the elbow (Fig 1A). The multiplanar reconstruction function was again used to obtain an image perpendicular to the axis of the coracoid, providing a cross-sectional view of the coracoid at its midpoint. The medial-lateral width and inferior-superior depth of the coracoid were measured (Fig 1B). The width of the distal clavicle was held constant at 10 mm (Fig 2A). The length of the clavicle was measured on the axial image at its midpoint (Fig 2B). The multiplanar reconstruction function was again used to obtain an image perpendicular to the axis of the clavicle, providing a cross-sectional view of the clavicle that did not exceed 10 mm in length. The depth of the clavicle was then measured (Fig 2C).

The ROC was found by a function in our PACS. The multiplanar reconstruction function was used to identify the anteroinferior glenoid rim for the ROC of the glenoid on the axial sequence (Fig 3A). The ROC of the glenoid was measured about the anterior third of the glenoid on the coronal sequence (Fig 3B). The ROC of the inferior surface of the coracoid was measured where the entire graft length could be visualized on the

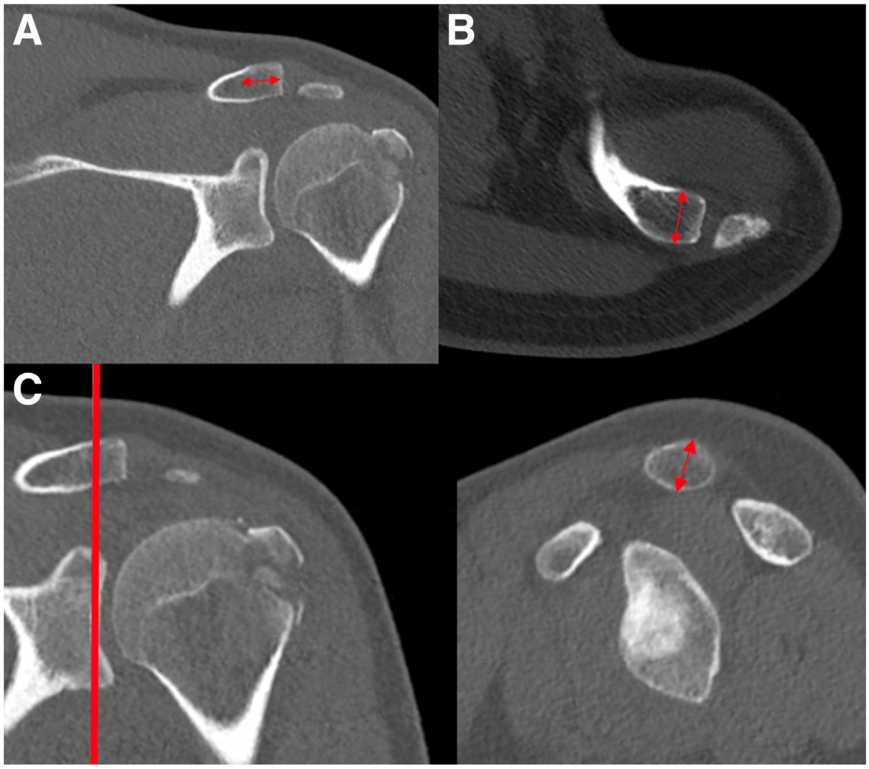

Fig. 2. The midcoronal view of the clavicle was found and the width of the distal clavicle was held constant at 10 mm (A). The length of the clavicle (22.5 mm) was measured on the axial image at its midpoint (B). Multiplanar reconstruction was performed by manipulating the coronal sequence (C) to obtain an image perpendicular to the axis of the clavicle, providing a cross-sectional view of the clavicle that did not exceed 10 mm in length. The depth of the clavicle (11.5 mm) was then measured on the corresponding sagittal sequence (red line).

sagittal oblique sequence (Fig 4A). Again, the multiplanar reconstruction function was used to identify the inferior surface of the midpoint of the clavicle, and the ROC was obtained on the sagittal oblique sequences, at a length that did not exceed 10 mm (Fig 4). The distal clavicle articular surface morphology was also categorized as square (type I), trapezoidal (type II), and rounded (type III), which has been described by Larouche et al.[9]

Statistical Methods

Measurements for each variable were taken twice, 4 weeks apart by a single observer (B.G.G.) to determine intrarater reliability using the intraclass correlation coefficient (ICC). Additional measurements were taken by a supporting author (M.J.S.) to measure inter-rater reliability. Correlation was judged as poor (0 to 0.3), fair (0.3 to 0.5), moderate (0.5 to 0.7), strong (0.7 to 0.9), or very strong (0.9 to 1). The normality was verified with the Shapiro-Wilk test, and the significance was assessed with the Student paired *t* test. Alpha risk was set to 5% ($\alpha = 0.05$). Statistical analysis was performed with EasyMedStat (version 3.21.5; www.easymedstat.com).

Results

Initial query of the institution's electronic medical records yielded 22 patients who underwent bony glenoid reconstruction via the Latarjet procedure. Query for the control group yielded 20 patients, finalizing a total cohort of 42 patients. Diagnoses for the control cohort can be found in Table 1. The average age of the entire cohort was 29.4 years (22 males and 20 females; 24 right and 18 left shoulders). The demographic data of the Latarjet cohort were not significantly different from the control cohort and are summarized in Table 2.

For the entire cohort, the mean ROC of the glenoid in the axial and coronal planes was 31.0 ± 2.5 mm (range, 24.4-35.2 mm) and 31.7 ± 1.5 mm (range, 27.5-34.5 mm), respectively. The mean ROC of the distal clavicle in the sagittal plane was 31.1± 2.45 mm (range, 25.0-36.0 mm). The mean ROC of the congruent-arc coracoid was 31.3 ± 1.18 mm (range, 28.8-32.9 mm). Significant differences were seen between the Latarjet cohort and the control cohort in axial glenoid ROC (30.1 ± 2.5 mm vs 32.1 ± 1.7 mm) ($P = .05$), distal clavicle sagittal plane ROC (29.6 ± 2.2 mm vs 32.8 ± 1.5 mm) ($P < .001$), and congruent-arc coracoid ROC (30.9 ± 1.2 mm vs 31.8 ± 0.97 mm) ($P = .02$) (Table 3).

The mean ROC of the inferior surface of the distal clavicle was not significantly different from the ROC of the glenoid in the coronal ($P = .15$) or axial planes ($P = .65$). The ROC of the coracoid when measured in the sagittal plane was not significantly different from the ROC of the distal clavicle ($P = .25$) (Table 4).

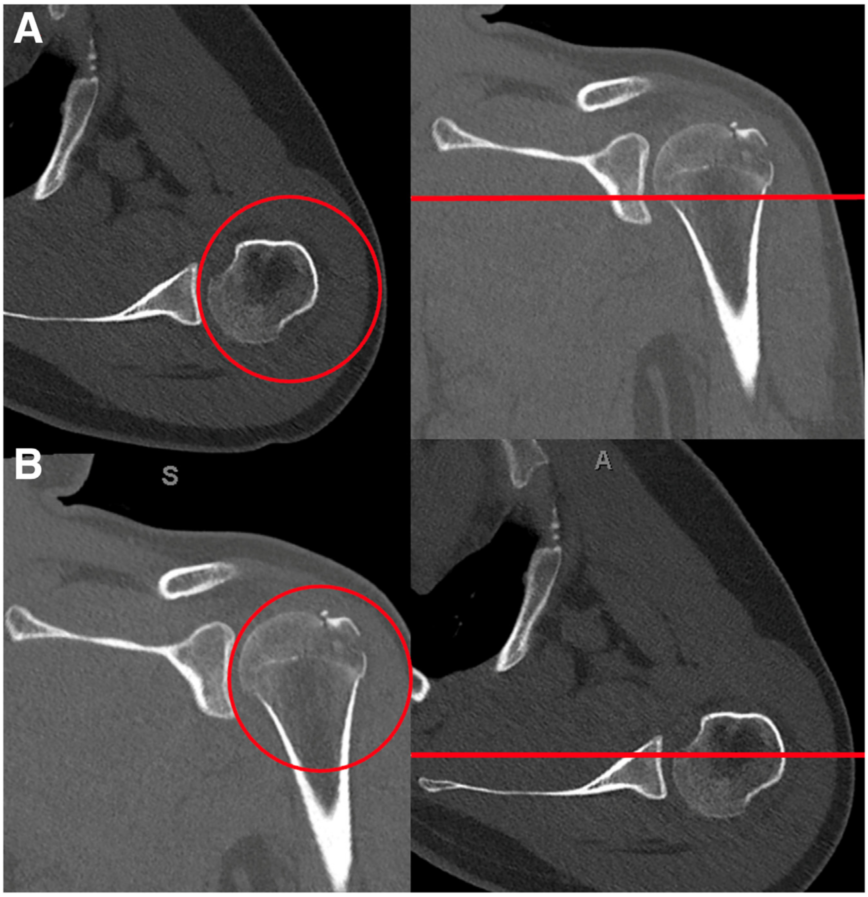

Fig. 3. Multiplanar reconstruction was used to identify the inferior glenoid rim (red line) on the coronal sequence, at which point the radius of curvature of the glenoid (27.0 mm) was measured on the corresponding axial sequence (A). Multiplanar reconstruction was used to identify the anterior third of the glenoid (red line) on the axial sequence, at which the radius of curvature of the glenoid (31.4 mm) on the coronal view was measured on the corresponding coronal sequence (B).

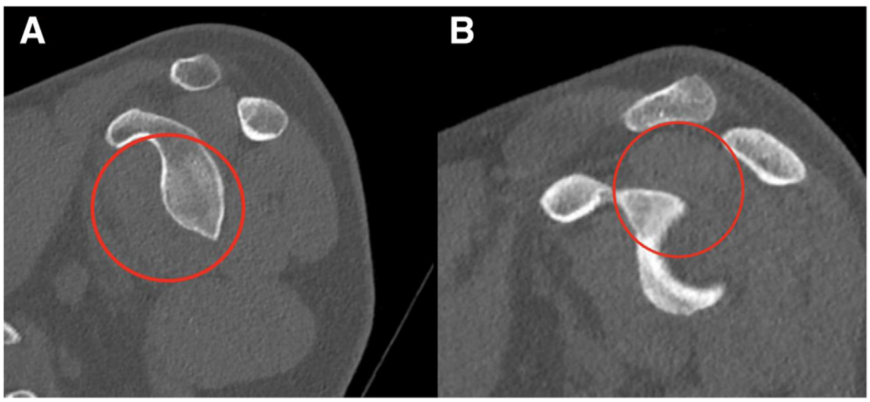

Fig. 4. The entire coracoid graft length was visualized on the sagittal oblique sequence and the radius of curvature of the inferior surface of the coracoid was measured (33.5 mm) (A). Multiplanar reconstruction was used to identify the inferior surface of the midpoint clavicle on the sagittal oblique sequences at a length that did not exceed 10 mm; radius of curvature of the distal clavicle was then obtained (32.0 mm) (B).

Table 1. Diagnoses of the Control Cohort

Diagnosis	n = 20
Humerus fracture	6
Instability (singular dislocation)	4
Scapula fracture	3
Rotator cuff pathology	3
Scapular winging	2
Malignancy	1
Quadrilateral space syndrome with axillary nerve impingement	1

The mean graft dimensions for the distal clavicle congruent-arc technique were 22.6 mm × 10 mm × 11.4 mm (length × width × depth) with a mean volume of 2,607.02 mm^3. The mean graft dimensions for the coracoid in the congruent-arc orientation were 24.9 mm × 11.5 mm × 11.7 mm (length × width × depth) with a mean volume of 3,334.92 mm^3. The length, depth, and volume of the coracoid were significantly greater than those of distal clavicle ($P < .005$) (Table 5).

Table 2. Demographic Information

Demographic	Total Cohort (n = 42)	Latarjet Cohort (n = 22)	Control Cohort (n = 20)	*P* Value
Age, y	29.4	28 ± 9.7	30.9 ± 9.5	.273
Sex (male/female), n	22/20	18/11	11/9	.09
Laterality (right/left), n	24/18	12/10	12/8	.76
Height, cm	174.1 [157-192]	174 ± 8.4	173.5 ± 6.8	.63
Weight, kg	82.1 [52-135]	83.2 ± 17.2	80.7 ± 21.2	.67
BMI	26.9 [19-47]	27.1 ± 3.9	26.7 ± 6.7	.43
Distal clavicle classification (1/2/3)	15/12/15	9/7/6	6/5/9	.49

NOTE. Data in brackets refer to the range for the given statistic. Data following the ± refer to the standard of deviation for the given statistic.

The inter-rater reliability for all ROC measurement was good to very good (ICC = 0.85-0.91). The intrarater reliability for all ROC measurement was also good to very good (ICC = 0.81-0.90).

Discussion

The primary findings of this study are that the ROC of the inferior concave aspect of the clavicle is similar to that of both the inferior surface of the coracoid and the native glenoid. Additionally, our CT analysis identified the robust graft dimensions of the distal clavicle when placed in the congruent-arc orientation. A robust graft option would be one that is similar in size to previously proven treatment options for anteroinferior glenohumeral instability, such as the Laterjet. Young et al.[13] found a mean length of the coracoid graft to be approximately 26.4 mm with a 9.3-mm thickness, a 14.1-mm width at the level of the superior drill hole, and a 13.3-mm width at the level of the inferior drill hole. The distal clavicle autograft with the graft oriented with the osteochondral surface adjacent to the native glenoid has emerged as a popular graft due to its robust dimensions, local availability and henceforth low cost, and osteochondral surface.[5]

However, this graft option has its weaknesses, including varying incidences of rounded and trapezoidal convex morphologies, the need for graft shaping to ensure that the superior cortical surface is flattened adequately for healing to the anterior glenoid neck, a lower bone mineral density, and the potential for degenerative changes of the articular cartilage surface in young, active patients.[5,10] Although we could not account for the cartilage contour of the distal clavicle in our CT-based study, we found a high rate of distal clavicle rounded and trapezoidal morphology. This convex morphology does not match the concave ROC of the anterior glenoid. Therefore, the congruent-arc distal clavicle reconstruction technique provides a robust graft with a similar ROC to the glenoid. The senior author routinely performs an arthroscopic Bankart repair at the conclusion of the surgery to make the graft extra-articular.

Prior studies have identified the biomechanical importance of reconstructing the concavity and arc of the anterior glenoid.[14] Moroder et al.[11] conducted a finite element analysis of 30 patients with anterior shoulder instability. The authors developed a mathematical model and found that bone loss has the most considerable effect at the edge of the glenoid rim. Additionally, those patients with an increasingly concave-shaped glenoid have an increase in loss of the stability ratio (SR) provoked by the same extent of bone loss. Therefore, restoration of bony support and concavity are critical to shoulder stabilization. Armitage et al.[1] evaluated the ROC of the coracoid as it is positioned in the congruent-arc Latarjet and found the ROC to be truly congruent in relation to the intact anterior rim. In the current study, 64% of patients showed either a type II (trapezoidal) or type III (rounded) distal clavicle, which is not a concave surface (Table 2).

Table 3. Radius of Curvature Measurements of the Glenoid, Clavicle, and Coracoid

Characteristic	Total Cohort	Latarjet Cohort	Control Cohort	*P* Value
Glenoid ROC coronal, mm	31.7 ± 1.5 [27.5-34.5]	31.6 ± 1.5	31.7 ± 1.5	.76
Glenoid ROC axial, mm	31.0 ± 2.5 [24.4-35.2]	30.1 ± 2.5	32.1 ± 1.7	.05*
Inferior clavicle ROC, mm	31.1 ± 2.45 [25.0-36.0]	29.6 ± 2.2	32.8 ± 1.5	<.001*
Congruent-arc coracoid ROC, mm	31.3 ± 1.18 [28.8-32.9]	30.9 ± 1.2	31.8 ± 0.97	.02*

NOTE. Data in brackets refer to the range for the given statistic. Data following the ± refer to the standard of deviation for the given statistic.
ROC, radius of curvature.
*Denotes significance.

Table 4. Mean Radius of Curvature Differences for the Glenoid and Coracoid vs the Distal Clavicle

ROC Comparison	Mean Difference	*P* Value
Coronal glenoid—distal clavicle	0.59	.15
Axial glenoid—distal clavicle	0.1	.65
Coracoid—distal clavicle	0.4	.25

ROC, radius of curvature.

However, the ROC of the inferior surface of the clavicle and coracoid for the entire cohort were 31.1 ± 2.45 mm and 31.3 ± 1.18 mm, respectively, while the ROC of the glenoid was 31.0 ± 2.5 mm. The mean difference between the ROC of each of these was not found to be significantly different (Table 4). These findings support the notion that the congruent-arc DCA provides a ROC that is highly congruent to the inferior glenoid. This has also been shown in the senior author's (P.B.) practice (Fig 5).

In our experience, the optimal graft size for arthroscopic graft passage through the rotator interval is approximately 10 to 11 mm. The current study reveals that the average distal clavicle size is 22.6 mm × 10 mm × 11.4 mm (Fig 2), which makes it suitable for arthroscopic passage. This is in contrast to the larger coracoid in the congruent-arc orientation (3,335.92 ± 936.25 mm^3 vs 2,607.02 ± 788.31 mm^3; $P < .001$), which may increase the difficulty of an arthroscopic glenoid reconstruction. Moreover, a larger graft size is arguably unnecessary to reconstruct GBL, as a 10-mm bone graft is typically sufficient to reconstruct up to 30% GBL and can re-create a percentage of the glenoid comparable to that of the classic Latarjet.[5,6,10] Petersen et al.[15] found that the mean distal clavicle articular surface orientation was 14 mm, whereas the inferior clavicle congruent-arc orientation allows the surgeon to preselect the graft at 10 mm. Larouche et al.[9] found that when the DCA is orientated in the inferior surface adjacent to the anterior glenoid vault, using the osteoarticular portion to re-create the glenoid provided a greater surface area than when orientated with its superior surface toward the glenoid (congruent-arc method). This would likely also be the case for the current study, as Larouche et al.[9] used 15 mm for the graft width, and the current study used 10 mm for the graft width. The width of the graft was conservatively selected to be 10 mm since the true morbidity of a 15-mm resection of distal clavicle is unknown.[16]

Table 5. Mean Graft Dimensions for the Coracoid vs the Distal Clavicle

Characteristic	Coracoid (n = 44)	Distal Clavicle (n = 44)	*P* Value
Length, mm	24.9 [17.9-31.6]	22.6 [12.3-39.0]	.008
Width, mm	11.5 [7.1-18.4]	10 [10-10]	<.001*
Depth, mm	11.7 [8.4-16.2]	11.4 [7.8-15.4]	.495
Volume, mm^3	3,335.92 ± 936.25	2,607.02 ± 788.31	<.001*

NOTE. Data in brackets refer to the range for the given statistic. Data following the ± refer to the standard of deviation for the given statistic.
*Denotes significance.

Limitations

This study is not without limitations. One of the limitations of this study includes its image-based nature; however, the current study does correlate with previous CT and cadaveric studies. Although we cannot account for the cartilage on CT scan, these are interesting findings for DCA glenoid reconstruction. Also, volume was calculated by multiplying the 3 dimensions of each graft together, which likely overestimated the graft size since the grafts are not perfect rectangles. Finally, the difference in anatomy in general between the control and Laterjet group suggests the study is not adequately powered and that there may be individual variation in patient anatomy that may limit a small sample study paper. Alternatively, this could have resulted from small differences in the particular plane the study was protocolled on or what was determined to be the "center" of the structure measures. Actual anatomic correlation would enhance the data gathered.

Conclusions

The ROC of the inferior distal clavicle is similar to that of the glenoid in both the axial and coronal planes and similar to the inferior coracoid.

Fig. 5. Postoperative axial computed tomographic scan of a glenoid reconstruction with congruent-arc distal clavicle autograft revealing the similarities of radius of curvature and the reconstruction of the glenoid concavity.

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