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Osteoarticular distal clavicle autograft for the management of instability-related glenoid bone loss: an anatomic and cadaveric study

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Background: The reconstructive options for instability-related anterior glenoid bone loss include iliac crest autograft, allograft, or coracoid transfer. The use of distal clavicle autograft (DCG) has also been described. The purpose of this imaging and cadaveric study was to examine the dimensions, morphology, and bone density of the DCG and compare it with the Latarjet procedure.

Methods: We used 49 computed tomography scans from patients with anterior glenoid bone loss to measure the distal clavicle dimensions and bone density. Four glenoid reconstructions were simulated to compare techniques: DCG inferior surface toward glenoid (DCG inferior), DCG superior, classic Latarjet, and congruent-arc Latarjet. In addition, the morphology of the DCG was assessed on computed tomography and confirmed in 27 cadavers.

Results: The mean width of the DCG (11 mm) was significantly greater ($P < .001$) than that of the classic Latarjet orientation (9 mm) but less ($P = .002$) than that of the congruent-arc orientation (12 mm). The DCG had a lower bone density than the coracoid ($P < .001$). The mean articular surface area of the DCG-inferior orientation was 208 mm^2, which was greater ($P = .013$) than that of the DCG-superior orientation (195 mm^2) and not significantly different ($P = .44$) than that of the classic Latarjet orientation (214 mm^2). The surface area of the congruent-arc orientation was greater (285 mm^2, $P < .001$) than that of all other graft orientations. The DCG-inferior orientation was able to reconstruct 22% of the glenoid articular surface; DCG-superior orientation, 21%; classic Latarjet orientation, 23%; and congruent-arc orientation, 30%. Three DCG morphologies were identified: square (34%), trapezoidal (53%), and rounded (13%).

Conclusions: The distal clavicle osteoarticular graft was able to reconstruct 22% of the glenoid face. Three morphologies of the distal clavicle were identified, with the square and trapezoidal morphologies most amenable for glenoid reconstruction.

Level of evidence: Anatomy Study; Imaging and Cadaveric Dissection

Keywords: Shoulder; instability; bone loss; Bankart; Latarjet; bone graft; dislocation; distal clavicle

Recurrent anterior glenohumeral joint instability is frequently associated with anterior glenoid bone loss and humeral head Hill-Sachs defects.[5] Standard open or arthroscopic soft-tissue repairs have been associated with higher failure rates when the related bone defects are substantial. The critical values of glenoid and humeral head bone loss that are contraindications to soft-tissue procedures are controversial. In general, anterior glenoid bone loss in excess of 13% to 20% would be considered substantial, and the literature would recommend bone-reconstituting procedures,[4-6,8,13,15,17] such as iliac crest bone grafting, distal tibial allograft, the Bristow procedure, or the Latarjet

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procedure. Recently, coracoid transfer procedures (Bristow and Latarjet) have experienced a resurgence in popularity because of their ability to restore bone stock and to provide an additional soft-tissue stabilizing effect from the conjoint tendon, referred to as the ‘‘sling effect.’’

Although conjoint tendon transfer procedures are very effective at managing anterior shoulder instability, they are not without limitations and complications. Shah et al[16] reported a 25% complication rate with the open Latarjet procedure. Although they found that most complications were transient, 2 patients continued to have neurologic symptoms. Athwal et al[2] reported a 18% problem rate and a 10% complication rate with the Latarjet procedure performed arthroscopically. Overall, the rates of adverse events after coracoid transfer procedures are not insignificant. Alternatives to the Latarjet procedure exist that are more anatomic reconstructions, such as iliac crest bone grafting[12] and distal tibial allograft.[14] The advantage of iliac crest bone graft is that it is relatively inexpensive and is an autograft; however, it does not have articular cartilage and is associated with some donor-site morbidity. The distal tibial allograft has articular cartilage and no donor-site morbidity; however, it is an allograft and has an increased cost.

To address the disadvantages of the commonly used bone grafting options, Tokish et al[18] described the autologous osteoarticular distal clavicle graft. The advantage of this bone grafting option is that it is locally available, it is an autograft, and it has articular cartilage. The disadvantages, however, are that the anatomy of the distal clavicle is not well known, there are concerns with the quality of the bone, and associated donor-site morbidity still occurs. In addition, it has been observed that the distal clavicle has variable morphologic shapes, some of which may be less conducive to bone graft reconstruction of the glenoid.

As such, the purpose of this anatomic study was to investigate the osteoarticular distal clavicle graft to determine its dimensions, surface area, morphologic shapes, and bone density, as well as to compare it with a Latarjet coracoid graft. This study consisted of a computed tomography (CT)–based anatomic assessment for all of the aforementioned metrics, and in addition, a cadaveric dissection study was performed to confirm the various morphologic shapes identified on CT.

Materials and methods

Patients

A study group was created to be representative of patients in whom autologous osteoarticular distal clavicle bone grafting would be considered for recurrent anterior instability. As such, to create a representative group for anatomic assessment, 45 male and 4 female patients who had undergone a Latarjet procedure for anterior shoulder instability between 2013 and 2015 with complete preoperative CT scans were included. All patients must have undergone their preoperative CT scans on the same clinical multislice helical CT scanner (GE Discovery CT750 HD; GE Medical Systems, Milwaukee, WI, USA) with the same clinical settings (120 kV [peak], 200 mAs). The mean age of the 49 patients was 27 years (range, 15-45 years).

The Digital Imaging and Communications in Medicine (DICOM) data from the preoperative CT scans of the 49 subjects were uploaded to medical imaging software (Mimics, version 20.0, and 3-Matic, version 12.0; Materialise, Leuven, Belgium) and analyzed. To simulate anterior glenoid reconstruction with distal clavicle autograft (DCG), a virtual osteotomy of the ipsilateral distal clavicle was conducted in the 3-dimensional (3D) medical imaging software program. The osteotomy was conducted 15 mm medial to the acromioclavicular joint to avoid injury to the coracoclavicular ligaments.[10] In the same patient cohort, for comparative purposes, anterior glenoid reconstruction was also performed with the Latarjet procedure. A virtual osteotomy of the coracoid was conducted at the angle of the coracoid, which is also referred to as the ‘‘elbow’’ of the coracoid. This virtual osteotomy was conducted in a manner that replicates the clinical harvest of the coracoid during the Latarjet procedure. The osteotomy was planned such that it was distal to the coracoclavicular ligaments.

Four different anterior glenoid reconstruction conditions were simulated and assessed in each patient (2 distal clavicle and 2 Latarjet orientations). For the DCG transfer, the first orientation consisted of the inferior surface of the distal clavicle adjacent to the anterior glenoid vault (DCG-inferior orientation) with the distal clavicular joint surface parallel to the native glenoid joint surface (Fig. 1). The second distal clavicle graft orientation involved the superior surface of the distal clavicle placed adjacent to the anterior glenoid vault (DCG-superior orientation). For comparison purposes, 2 Latarjet orientations were examined: the classic orientation and the congruent-arc orientation (Fig. 2).[7] The classic Latarjet orientation involves the inferior surface of the coracoid being placed against the anterior glenoid vault, whereas the congruent-arc modification involves the inferior surface of the coracoid being placed flush with and parallel to the articular surface of the glenoid (congruent-arc Latarjet orientation).[1,3]

For each of the 4 graft orientation conditions, the length, width, and surface area of the bone graft were determined and compared with the patient's glenoid surface area as a percentage. These measurements were obtained from the built-in Mimics and 3-Matic software tools. The glenoid and articular sides of the graft were marked by the built-in surface highlighting tools. This allowed for automated calculation of the surface area of the selected regions on the glenoid articular surface.

As each patient in the study group had clinically undergone a Latarjet procedure, most had some degree of instability-related anterior glenoid bone loss. To estimate the amount of bone deficiency, the regression formula of Giles et al[9] was used. This formula allows estimation of the native glenoid width based on the native glenoid height.

Density assessment

The density of cortical and cancellous bone in the distal clavicle bone graft fragment was compared with that in the coracoid fragment. The cortical and cancellous bone densities were

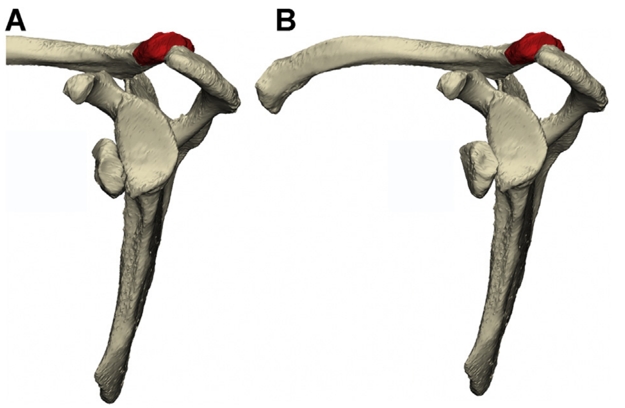

Figure 1 Three-dimensional images of a left shoulder with instability-related anterior glenoid bone loss. The clavicle and acromioclavicular joint are depicted, and the distal 15 mm of the clavicle, which would be used as a graft, is shaded *red*. (**A**) Distal clavicle osteochondral reconstruction for anterior glenoid bone loss with the graft oriented such that the inferior surface of the distal clavicle is adjacent to the glenoid. The inferior surface nomenclature is based on the native position of the distal clavicle prior to osteotomy. (**B**) Graft with the superior surface of the distal clavicle adjacent to the anterior glenoid vault. In both **A** and **B**, the articular surface of the distal clavicle is adjacent to the glenoid articular surface such that it reconstructs the deficient osteoarticular anterior glenoid segment.

determined using Hounsfield units (HU) with established threshold values of greater than 600 HU for cortical bone and 200-600 HU for cancellous bone as found using the Mimics software tools.

Distal clavicle morphology

The morphology of the distal clavicle has been clinically observed to be variable. As such, a qualitative evaluation of the various shapes of the distal clavicle was completed using the 3D CT images. The shape of the distal clavicle was assessed from the axial (superior) and coronal (anterior) vantage points. The axial (superior) views of all the 3D distal clavicles were compared to find similarities in the articular surface shape, orientation, and size. Then, the coronal (anterior) view was visually examined and compared between specimens. A morphologic classification was created based on the observations.

For the purpose of confirming the CT imaging–based morphologic classification described earlier, an additional cadaveric assessment was performed. A total of 27 unpaired acromioclavicular joints from cadaveric specimens (mean age, 71 years; range, 56-92 years) were examined. The cadaveric assessment involved removal of all of the muscular, tendon, and ligament attachments to the distal clavicle and acromioclavicular joint. The axial and coronal vantage points were visually assessed and classified. The presence of articular cartilage on the distal aspect of the clavicle permitted a more precise assessment of the shape of its articular surface.

Statistics

To statistically compare the 4 orientation conditions, a repeated-measures analysis of variance with Bonferroni correction ($P < .05$) was performed for each of the 3 metrics (length, width, and surface area). To compare bone density between the distal clavicle fragment and the Latarjet coracoid fragment, a paired *t* test ($P < .05$) was used. No statistics were used for the observational morphologic assessment of the distal clavicle.

Results

Dimensions, surface area, and density

In the transferred position on the anterior aspect of the glenoid (Fig. 1), the mean height and width of the distal clavicle articular surface were 18 mm (range, 12-26 mm; standard deviation [SD], 3 mm) and 11 mm (range, 7-18 mm; SD, 2 mm), respectively. The mean height and width of the classic Latarjet coracoid graft oriented on the glenoid were 20 mm (range, 16-29 mm; SD, 3 mm) and 9 mm (range, 6-14 mm; SD, 2 mm), respectively, whereas the height and width of the congruent-arc Latarjet orientation were 21 mm (range, 16-27 mm; SD, 3 mm) and 12 mm (range, 9-15 mm; SD, 1 mm), respectively. When the grafts were compared statistically, the mean width of the distal clavicle was significantly greater ($P < .001$) than that of the classic Latarjet orientation but significantly less ($P = .002$) than that of the congruent-arc orientation.

The mean articular surface area of the distal clavicle in the inferior orientation on the anterior glenoid was 208 mm^2, which was significantly greater ($P = .013$) than the distal clavicle–superior orientation surface area (195 mm^2) and not significantly different ($P = .44$) than the classic Latarjet orientation surface area (214 mm^2). The surface area of the congruent-arc Latarjet orientation at 285 mm^2 was significant greater ($P < .001$) than that of all other graft orientations.

By use of the method of Giles et al,[9] the estimated glenoid bone deficit of the 49 patients in the CT study cohort was 18% ± 7% (range, 4%-36%). When we compared the percentage glenoid surface area that the 4 grafts could restore, the distal clavicle–inferior orientation reconstructed a mean of 22% of the glenoid surface area; distal clavicle–superior orientation, 21%; classic Latarjet orientation, 23%; and congruent Latarjet orientation, 30% (Table I).

When bone density of the grafts was compared in the 49-patient study cohort, the distal clavicle grafts had statistically lower within-specimen cancellous and cortical bone densities than the Latarjet coracoid grafts: 359 HU vs. 393 HU ($P < .001$) and 814 HU vs. 854 HU ($P < .001$), respectively.

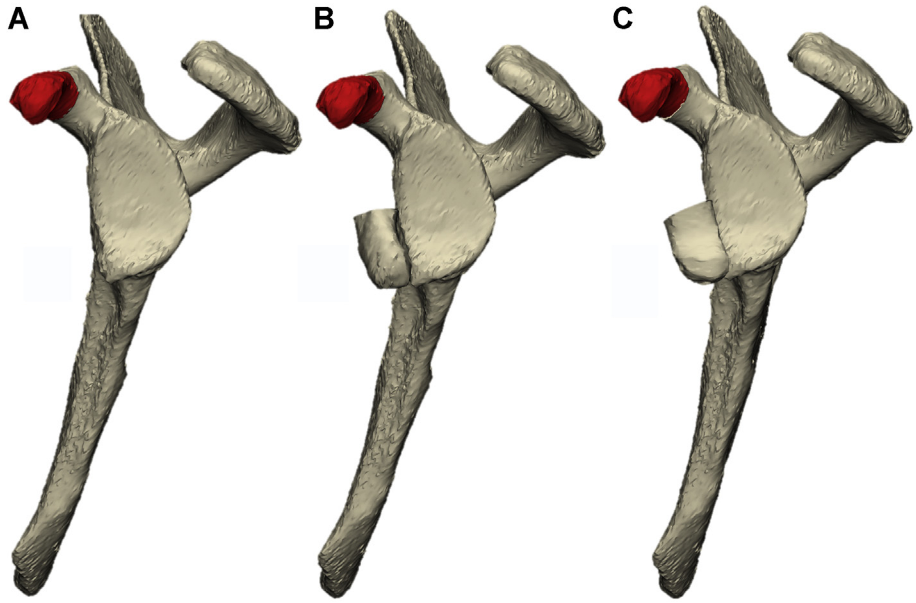

Figure 2 Three-dimensional images of a left shoulder with anterior glenoid bone loss and the coracoid highlighted in *red* (**A**). (**B**) Classic Latarjet technique with the coracoid graft transferred to the anterior glenoid vault, oriented with the inferior surface of the graft opposed to the glenoid. (**C**) Congruent-arc Latarjet technique with the coracoid graft rotated 90° such that the inferior surface now reconstructs the deficient glenoid articular surface.

Distal clavicle morphology

The qualitative visual assessment of the distal clavicles on 3D CT resulted in 3 distinct morphologic shapes (Fig. 3). The first morphologic type (type I) consisted of distal clavicles with a square shape (n = 14, 29%) in the axial plane. The second (type II) consisted of clavicles with a trapezoidal distal clavicular articular shape (n = 28, 57%). The third (type III) was a rounded distal clavicle articular shape (n = 7, 14%).

To corroborate the morphologic types of distal clavicles identified on 3D CT scans, an assessment of 27 unpaired cadaveric specimens was conducted. All 27 cadavers could be classified into 1 of the 3 types. Of the 27 cadavers, 12 (44%) had distal clavicles classified as type I, 12 (44%) were classified as type II, and 3 (11%) were classified as type III. The overall outer dimensions of the DCG did not vary by morphologic shape ($P > .254$).

Discussion

The distal clavicle has been described as a local osteoarticular autograft for glenoid reconstruction. The clavicle graft is particularly attractive as it is local to the shoulder, has minimal donor-site morbidity, and contains articular cartilage. Our results indicate that the distal clavicle oriented with its inferior surface adjacent to the anterior glenoid vault provides a significantly ($P < .013$) greater surface area (208 mm^2) than when oriented with its superior surface toward the glenoid (195 mm^2). In addition, the surface area of the articular portion of the distal clavicle that is used to reconstruct the glenoid face is similar to the surface area of the Latarjet orientation in the classic manner, albeit without the sling effect of the Latarjet procedure.[8,19] Moreover, the overall mean percentage glenoid surface area that the distal clavicle can restore (22%) is similar to that of the classic Latarjet orientation (23%); however, both percentages are much less than that of Latarjet positioning in the congruent-arc fashion (30%). As such, DCG is an option for osteoarticular reconstruction of small to moderate amounts of instability-related glenoid bone loss. An advantage of the distal clavicle procedure over the Latarjet procedure is that the former can be used for both anterior and posterior glenoid bone deficiencies. In addition, the distal clavicle graft can be inserted arthroscopically without splitting the subscapularis tendon, as with the Latarjet procedure.

Although our results suggest that the distal clavicle is a reasonable option for graft choice, it does have some disadvantages. The distal clavicle does not have the sling effect provided by the Latarjet procedure.[8,19] In addition, the distal clavicle is believed to have poorer bone quality, which was supported by our density results. Our data demonstrated that the coracoid graft had substantially greater cortical and trabecular bone density than the clavicle: 393 HU vs. 359 HU ($P < .001$) and 854 HU vs. 814 HU ($P < .001$), respectively. Although these density values were statistically significant, we are unable to determine whether they are clinically relevant. Another potential disadvantage is the variable morphology of the

Table I Mean distal clavicle and coracoid graft dimensions and percentage glenoid reconstruction

Autograft type	Graft orientation	Mean % glenoid surface area restoration	Standard error	Lower bound, %	Upper bound, %	Height/width, mm	Articular surface area, mm^2
Distal clavicle	Inferior	22	0.9	20	24	18/11	208
	Superior	21	0.9	19	22		195
Latarjet/ coracoid	Classic	23	0.7	21	24	20/9	214
	Congruent	30	0.9	29	32	21/12	285

distal clavicle identified. The type I, square morphology has the best articular reconstruction characteristics, as the entire distal articular surface of the clavicle can be used for glenoid reconstruction. The type II, trapezoidal morphology has 2 distal facets. As such, either one or the other facet can be placed flush with the glenoid, or the graft can be positioned in between. The type III, rounded distal clavicle morphology has likely the least usable articular surface, as only the apex of the graft will be flush with the glenoid, with the superior and inferior aspects tapering medially. Fortunately, the type III morphology is the least prevalent, with rates of only 14% in our CT study and 11% in our cadaveric study. Another disadvantage of the distal clavicle graft is the normal age-related degenerative changes that occur in the articular cartilage. As such, the articular cartilage from the distal clavicle may not function as true articular cartilage once the graft has healed. However, most complex shoulder instability procedures are performed in younger patients, and such patients are less likely to have age-related degenerative changes to the distal clavicle articular cartilage.

Donor-site morbidity is also a factor to consider when using autologous distal clavicle graft. An open incision is required to harvest the distal clavicle; as such, this would be in addition to any arthroscopy portals or an extension superiorly of an open deltopectoral approach. Alternatively, resection of the distal clavicle is a known treatment for acromioclavicular arthritis. The true morbidity of resection of a 15-mm-long aspect of the distal clavicle, however, is still unknown but believed to be negligible.[11] In addition, errors may occur, and too much distal clavicle may be resected, which could have a destabilizing effect on the acromioclavicular joint.

The limitations of this study include the relatively smaller sample size of 49 patients in the 3D CT anatomy

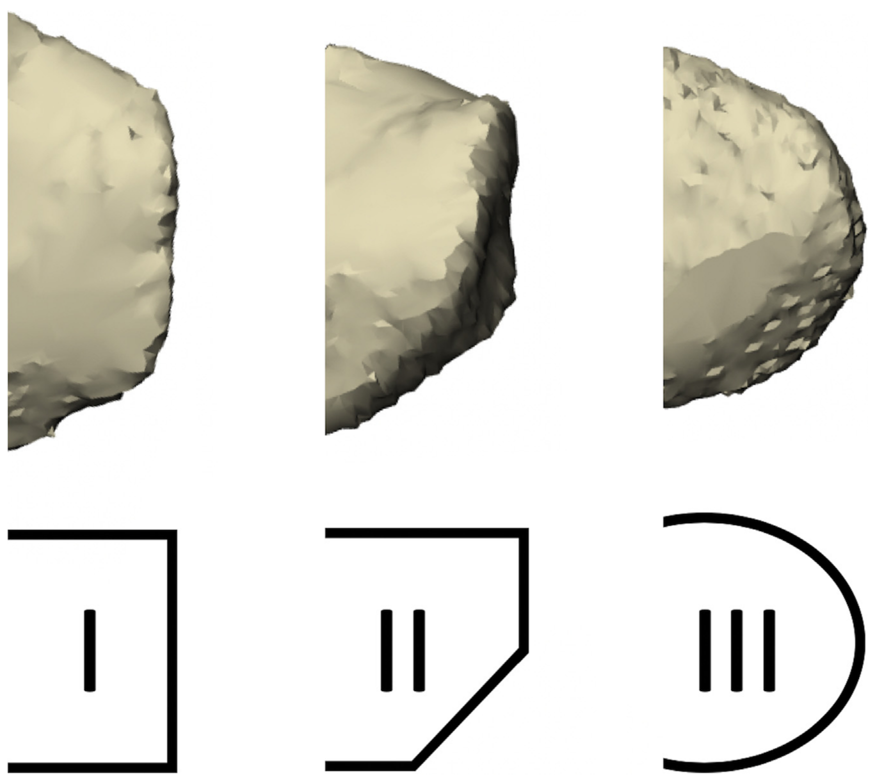

Figure 3 Three morphologic shapes of the distal clavicle were identified: square (type I, 34%), trapezoidal (type II, 53%), and rounded (type III, 13%) distal clavicle articular surface.

group. In addition, in the open cadaveric dissection study, only 27 unpaired cadavers were available for assessment. In our results, several statistically significant differences were identified in the anatomic measurements of the various grafts and orientations. Although these differences were statistically different, this does not imply that such differences in graft dimensions are clinically important. Finally, this study is an imaging-based study and a cadaveric assessment; as such, we cannot comment on the clinical stabilizing effect of the DCG used in patients with anterior or posterior instability–related bone loss. Overall, however, we postulate that the DCG would have similar stabilizing effects to the established technique of iliac crest bone grafting when performed for glenoid bone loss.

Conclusion

DCG is a reconstructive option for instability-related glenoid bone loss with the dimensions and surface area of the graft being similar to those of the classic Latarjet procedure. The distal clavicle graft is local to the shoulder, results in a more anatomic reconstruction than the Latarjet procedure, and has the added advantage of articular cartilage. Our results indicate better glenoid reconstruction with the graft placed with the inferior side toward the glenoid, rather than the superior side. The limitations of the DCG include the absence of the sling effect of the Latarjet procedure and potential donor-site morbidity. Finally, further clinical studies are required to better understand the advantages and disadvantages of DCG for instability-related glenoid bone loss reconstruction.

Disclaimer

John M. Tokish is a consultant for Arthrex and DePuy Mitek.

George S. Athwal is a consultant for Wright Medical–Tornier, ConMed, and Exactech.

No company had any input into the study design, protocol, testing, data analysis or manuscript preparation.

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