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Bone defect–induced alteration in glenoid articular surface geometry and restoration with coracoid transfer procedures: a cadaveric study

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Background: This study analyzed the alteration in glenoid articular geometry with increasing anterior bone loss, as well as its subsequent correction with 2 modifications of the Latarjet procedure.
Methods: Anterior defects were simulated by creating glenoid osteotomies (10%, 20%, 30%, and 40%), and defects were reconstructed using 2 Latarjet modifications (classic and congruent arc). A total of 108 computed tomography scans were performed (1) on intact scapulae (n = 12), (2) after each bone defect (n = 48), and (3) after each reconstruction (n = 48). Glenoid parameters (width, area, arc length, and version) were analyzed on computed tomography scans. Statistical analysis was used to determine significant differences between intact, deficient, and reconstructed glenoids.
Results: All parameters were reduced with every 10% defect increment (mean change in width, 2.5 mm; area, 64 mm^2; version, 2.2°; and arc length, 2.2 mm). Width correction with the classic Latarjet procedure was not statistically significant in 30% and 40% defects. Area correction in 30% defects was not significant with the classic Latarjet procedure and was significantly undercorrected in 40% defects. Version correction was not significant after the classic Latarjet procedure in 20%, 30%, and 40% defects. Arc-length correction was not significant in 20% and 30% defects with the classic Latarjet procedure and was significantly undercorrected in 40% defects. The congruent-arc Latarjet procedure overcorrected glenoid parameters in all defects; however, area and arc length were not significantly different from intact glenoids in 40% defects ($P < .05$).
Conclusion: Glenoid articular geometry is progressively altered with a sequential increase in anterior bone defects from 0% to 40%. The classic Latarjet procedure provided significant correction in bone defects of 10% and 20%. The congruent-arc Latarjet procedure restored and overcorrected most parameters even in 40% glenoid defects.
Level of evidence: Basic Science Study; Surgical Technique; Imaging

Keywords: Glenoid articular surface; glenoid width; glenoid version; Latarjet procedure; bony instability; cadaveric study

No institutional review board approval was required for this cadaveric study. A waiver of review was obtained from the Institutional Ethics Committee (IEC-II), Seth GS Medical College and KEM Hospital, Mumbai, India (study No. EC/OA-158/2016).

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Anterior shoulder instability that occurs in combination with glenoid bone defects is associated with a higher recurrence rate of dislocations, and bone-grafting options are necessary to restore stability.[3] Two modifications of the coracoid transfer procedure, that is, the classic Latarjet (CL) procedure and the congruent-arc Latarjet (CAL) procedure, are commonly used for reconstruction of glenoid defects. The CAL procedure provides a greater surface area for reconstruction and may be better suited for instability associated with greater bone loss. However, both procedures are associated with excellent clinical outcomes, and comparative biomechanical studies have shown possible advantages of 1 modification over another.[2,3,5,9,15] Glenoid bone loss is known to alter the glenoid articular surface geometry by modifying linear and angular dimensions (width, area, arc length, and version), and a combination of these factors is responsible for higher failure rates of soft-tissue repairs.[6,12,14,16-18] A significant glenoid defect has been defined as 25% of the glenoid width (GW), and most studies have restricted analysis to the 25% bone loss level.[17,18] However, glenoid bone defects are variable in size and extent, and articular defects ranging between 10% and 40% are known to occur in patients with chronic instability and seizures.[7,10] Moreover, a recent study suggested that ‘‘critical’’ glenoid bone loss should be lower than the 20% to 25% threshold, and the authors found that glenoid bone loss above 13.5% led to unacceptable outcomes.[13] An analysis of sequential changes in the progressive bone loss–induced alteration in glenoid articular geometry is necessary to optimize the reconstruction algorithm. Moreover, a quantification of the corrective potential of the 2 common modifications of the Latarjet procedure is necessary to select the optimal restoration procedure.

This cadaveric study was designed to analyze the alteration in glenoid articular surface geometry for each experimental simulation of intact and sequential glenoid bone loss conditions, as well as to quantify the correction obtained with 2 common modifications of the coracoid transfer procedure in anterior shoulder instability. The purpose of this cadaveric study was twofold: (1) to quantify changes in 4 specific glenoid articular parameters (width, area, arc length, and version) in intact and sequential glenoid bone loss conditions (0%, 10%, 20%, 30%, and 40%) and (2) to quantify the correction obtained with 2 modifications of the Latarjet procedure (CL and CAL). We hypothesized that both modifications would result in complete correction or overcorrection of articular geometry for each level of sequential glenoid bone loss.

Materials and methods

This study was part of a larger cadaveric study. Twenty cadaveric scapulae were retrieved from embalmed cadaveric shoulders in the anatomy department of our institute and underwent screening for the presence of arthritic changes, instability, fractures, and surgery. Of these scapulae, 8 were excluded whereas 12 unpaired male human cadaveric scapulae (6 right and 6 left) were used for the study. All soft tissues (muscles, tendons, ligaments, and labra) were dissected off the cadaveric specimens. All 12 scapulae underwent an initial computed tomography (CT) scan prior to creation of glenoid defects.

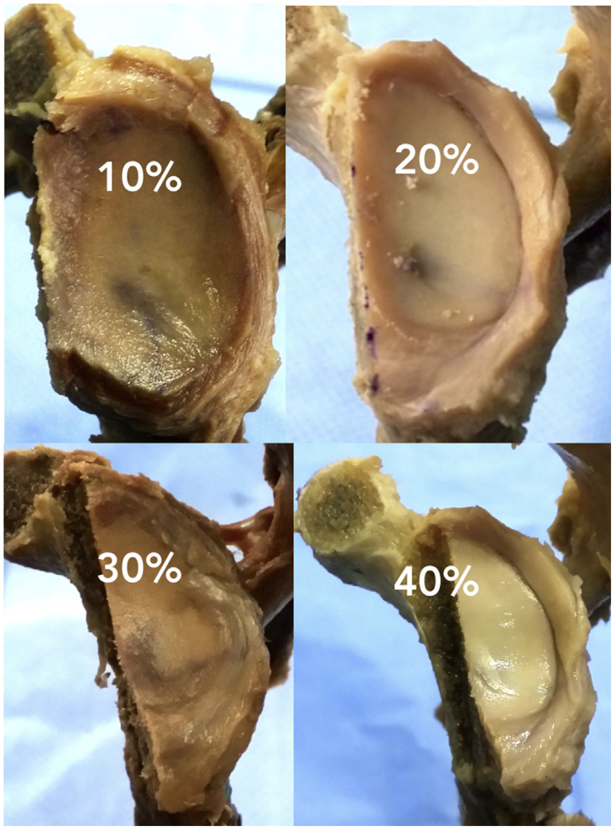

Figure 1 Sequential anterior glenoid bone defects (10% to 40%) in cadaveric scapulae.

Simulation of glenoid bone loss

Glenoid defects were simulated by creating sequential glenoid bone osteotomies as follows: The glenoid length (GL) was marked by a line joining the midpoints of the supraglenoid and infraglenoid tubercles. The GW was drawn perpendicular to the GL and was defined as the maximum anteroposterior diameter of the glenoid. The osteotomy lines were marked by drawing 4 parallel superoinferior lines along the anterior GW at 10%, 20%, 30%, and 40% of the GW. A standardized digital device (Vernier caliper; Vertex Tools, Staffordshire, United Kingdom) with precision to 0.01 mm was used for these measurements. Sequential glenoid bone defects were then created with an oscillating sagittal saw along each line to simulate 10% to 40% anterior glenoid bone loss (Fig. 1). A total of 48 glenoid defect simulations were performed on 12 scapulae, and imaging was performed after each simulation.

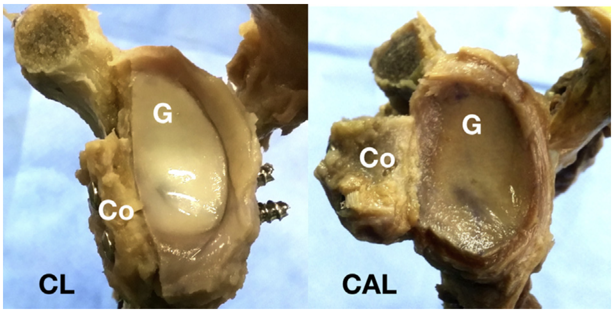

Figure 2 Glenoid (*G*) reconstructive procedures: classic Latarjet (*CL*) and congruent-arc Latarjet (*CAL*). *Co*, coracoid graft.

Glenoid reconstruction

The 12 scapulae were divided into 2 groups of 6 specimens each. Osteotomy of the coracoid process was performed at the junction of the superior coracoid pillar and the junctional surface area as described by Bhatia et al.[1] The articular surface was reconstructed using the CL procedure (n = 6) or CAL procedure (n = 6). The CL procedure was performed by rotating the harvested coracoid pillar by 90° so that the inferior surface of the coracoid was in contact with the glenoid neck and defect and the lateral cortex of the coracoid was aligned with the glenoid face.[14] The CAL procedure was performed, as described by Burkhart and De Beer,[3] by rotating the harvested coracoid such that the medial surface of the coracoid was in contact with the glenoid neck and defect and the inferior surface of the coracoid was aligned with the glenoid face.[15] The apposing coracoid surface was not decorticated. The coracoid was fixed to the glenoid at the bone-cartilage junction using two 4-mm cannulated cancellous screws to achieve compression (Fig. 2). The same surgeon performed a total of 48 reconstructions in 6 scapulae in 8 experimental bone loss conditions: (1) CL with 10%, (2) CAL with 10%, (3) CL with 20%, (4) CAL with 20%, (5) CL with 30%, (6) CAL with 30%, (7) CL with 40%, and (8) CAL with 40%.

Glenoid imaging

CT scans were performed on 12 intact scapulae prior to creation of defects. Thereafter, sequential scans were performed after simulation of 4 levels of bone loss and after each of the 8 reconstructions. A total of 108 scans (12 intact glenoids plus 48 bone defect simulations plus 48 Latarjet reconstructions) were performed on 12 specimens. The data were obtained in DICOM (Digital Imaging and Communications in Medicine) format and analyzed using a DICOM viewer with 3-dimensional (3D) volumetric rendering capability (OsiriX, version 5.8.1; Pixmeo, Bernex, Switzerland). The images were analyzed in both 2-dimensional and 3D reconstructions, and the following measurements were performed (Fig. 3): (1) GL was measured on the 3D reconstructed en face glenoid view (intact, bone-deficient, and reconstructed specimens) and was defined as the maximum superoinferior distance (in millimeters) measured between the supraglenoid and infraglenoid tubercles. (2) GW was measured on the 3D reconstructed en face glenoid view and was defined as the maximum anteroposterior glenoid distance (in millimeters) measured perpendicular to the GL between the anterior and posterior glenoid rims. (3) Glenoid area (GA) was measured on the 3D reconstructed en face glenoid view and was defined as the area of the entire glenoid bony articular surface (in square millimeters) measured using the open polygon tool function in the DICOM software. (4) Glenoid version (GV) was defined as the tilt of the articular surface in relation to the body of the scapula and was measured on 2-dimensional axial sections using the conventional method described by Friedman et al.[4] (5) Glenoid arc length (GAL) was defined as the length of the arc (in millimeters) formed by the articular surface of the intact or bone-deficient and reconstructed glenoid. GAL was calculated using the formula $\theta \times 2 \times \pi \times r/360$ (in which θ is the glenoid angle, ie, the virtual angle subtended by the anterior and posterior rims of the glenoid, on the center of the circle that exactly matches and passes through the curvature of the glenoid on the axial multiplanar reformation (MPR) CT scan image; r is the radius of the circle that exactly matches and passes through the curvature of the glenoid on the axial MPR CT scan image; and π is a constant value of 3.14). GAL was calculated at 2 levels of the glenoid that were localized using the multiplane reconstruction tool of the DICOM software: GAL measured at the junction of the upper and middle thirds of the GL (GAL1), and GAL measured at the junction of the middle and lower thirds of the GL (GAL2). These 2 levels represented the changes in the arc length along the entire length of the bone defect. We documented values to 2 decimal points for ease of reporting. Each measurement was performed 3 times by 1 investigator, and the mean of the 3 values was recorded.

Statistical analysis was performed using SPSS software (IBM, Armonk, NY, USA). Mean, median, standard deviation (SD), maximum, and minimum values, as well as the 95% confidence interval, were calculated for each variable. In addition, we used the Student unpaired t test for independent samples to determine significant differences between the intact glenoid group and each of the deficient and reconstructed glenoid groups. For all tests, $P < .05$ was considered significant.

Results

Glenoid width and area

Tables I and II list the overall mean, SD, range, and confidence intervals and the mean percentage change in GW and GA in sequential glenoid defects. GW was reduced by approximately 2.5 mm and GA was reduced by approximately 64 mm^2 for every 10% increase in glenoid defect. GW and GA were significantly different from intact glenoids for each defect, however, GA in 10% defects was not statistically different from intact glenoids. Loss of GW was adequately restored and significantly overcorrected by both the CL and CAL procedures; however, correction with the CL procedure was not statistically significant in 30% ($P = .07$) and 40% ($P = .9$) defects. GA restoration in 30% defects was not statistically significant ($P = .7$) with the CL procedure and was significantly undercorrected in 40% defects ($P = .037$). The CAL procedure adequately corrected the GA in all defects; however, the restoration was not significant ($P = .9$) in 40% defects (Fig. 4, *A*).

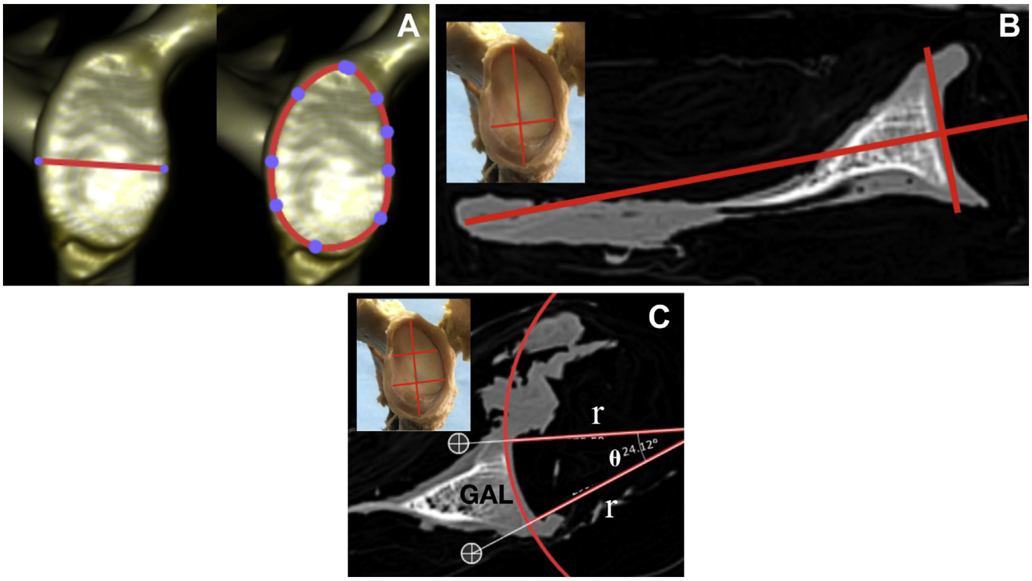

Figure 3 Glenoid articular surface parameters in intact glenoids as measured on computed tomography scans. **(A)** Glenoid width (*left*) and glenoid area (*right*) are measured on 3-dimensional reconstructions. **(B)** Glenoid version is measured on reformatted 2-dimensional images at the lower-third glenoid level. **(C)** Glenoid arc length (*GAL*) is measured on reformatted 2-dimensional images at the upper-third and lower-third glenoid levels. *θ*, glenoid angle; *r*, radius of curvature.

Glenoid version

Table III lists the overall mean, SD, range, and confidence intervals and the mean percentage change in GV in sequential glenoid defects. GV changed significantly by approximately 2.2° for every 10% increase in glenoid defect; however, GV in 10% defects was not statistically different from intact glenoids. GV restoration was not

Table I Comparative glenoid width after sequential bone defects and reconstruction

Parameter	Glenoid width						*P* value
	Mean (minimum-maximum), mm	SD, mm	95% CI, mm		Mean change, mm	% Change	
			Lower	Upper			
Intact (n = 12)	24.1 (21.1-27.3)	2.1	22.7	25.4	—	—	—
10%							
Defect (n = 12)	21.4 (18-24)	2	20.1	22.6	2.7	11	.004*
CL (n = 6)	31.9 (28.6-35.9)	2.4	29.5	34.4	7.7	32	<.001†
CAL (n = 6)	37 (35.4-39.5)	1.7	35.3	38.8	13.1	54	<.001†
20%							
Defect (n = 12)	18.7 (16.1-21.5)	1.7	17.6	19.8	5.4	22	<.001*
CL (n = 6)	28.9 (23.5-33.3)	2.5	26.3	31.5	4.7	19	.003†
CAL (n = 6)	33.5 (32.2-36)	1.4	31.9	34.8	9.4	39	<.001†
30%							
Defect (n = 12)	16.5 (13.8-19.2)	1.6	15.5	17.5	7.6	32	<.001*
CL (n = 6)	26.3 (23.5-30.6)	2.5	23.6	28.9	2.4	10	.071
CAL (n = 6)	30.9 (29.5-33.4)	1.4	29.5	32.3	6.9	29	<.001†
40%							
Defect (n = 12)	14.4 (11.4-17)	1.5	13.4	15.3	9.8	40	<.001*
CL (n = 6)	24 (21.3-28)	2.4	21.5	26.6	1.7	7	.944
CAL (n = 6)	28.7 (27.4-30.7)	1.1	27.6	29.8	4.7	20	<.001†

SD, standard deviation; *CI*, confidence interval; *CL*, classic Latarjet procedure; *CAL*, congruent-arc Latarjet procedure.
Mean change is the average difference between the parameter measured in the intact glenoid and that in the bone defect or graft-reconstructed group.
* Significantly less.
† Significantly more.

Table II Comparative glenoid articular area after sequential bone defects and reconstruction

Parameter	Glenoid area						P value
	Mean (minimum-maximum), mm^2	SD, mm^2	95% CI, mm^2		Mean change, mm^2	% Change	
			Lower	Upper			
Intact (n = 12)	666 (477-808)	102	602	731	—	—	—
10%							
Defect (n = 12)	621 (469-756)	87	566	676	50	7	.254
CL (n = 6)	853 (693-1011)	107	741	966	181	27	.006*
CAL (n = 6)	960 (784-1084)	104	852	1069	300	45	<.001*
20%							
Defect (n = 12)	551 (434-668)	79	502	602	114	17	.006†
CL (n = 6)	817 (656-951)	112	699	934	145	22	.021*
CAL (n = 6)	870 (754-961)	71	795	944	209	31	<.001*
30%							
Defect (n = 12)	481 (377-557)	62	442	520	185	28	<.001†
CL (n = 6)	655 (535-731)	71	581	730	41	6	.794
CAL (n = 6)	754 (677-847)	65	685	822	93	14	.044*
40%							
Defect (n = 12)	411 (298-500)	65	369	452	255	38	<.001†
CL (n = 6)	564 (447-676)	79	481	648	107	16	.037†
CAL (n = 6)	663 (581-748)	61	598	727	62	9	.929

SD, standard deviation; *CI*, confidence interval; *CL*, classic Latarjet procedure; *CAL*, congruent-arc Latarjet procedure.
Mean change is the average difference between the parameter measured in the intact glenoid group and that in the bone defect or graft-reconstructed group.
* Significantly more.
† Significantly less.

statistically significant after the CL procedure in 20% (*P* = .253), 30% (*P* = .539), and 40% (*P* = .898) defects. The CAL procedure resulted in consistent and complete correction of the GV in all glenoid defects (Fig. 4, *B*).

Glenoid arc length

Table IV lists the overall mean, SD, range, and confidence intervals and the mean percentage change in GAL in sequential glenoid defects. GAL at the upper glenoid level (GAL1) changed by approximately 1.6 mm for every 10% increase in glenoid defect, and the overall mean change from intact glenoids to 40% defects was 6.4 mm. GAL at the lower glenoid level (GAL2) changed by approximately 2.2 mm for every 10% increase in glenoid defect, and the overall mean change from intact glenoids to 40% defects was approximately 9 mm. GAL in 10% defects at both levels was not statistically different from intact glenoids. The CL procedure adequately corrected GAL1 in all glenoid defects; however, the correction was not significant in 40% defects. GAL2 restoration was not statistically significant in 20% (*P* = .168) and 30% (*P* = .867) defects with the CL procedure and was significantly undercorrected in 40% defects (*P* = .033). The CAL procedure adequately corrected GAL1 and GAL2 in all defects; however, GAL2 restoration was not significant (*P* = .78) in 40% defects (Fig. 4, *C*).

Discussion

The results of this cadaveric study suggest that sequential anterior glenoid bone loss results in progressive deformation of GW, GA, GV, and GAL. The 2 modifications of the Latarjet procedure can correct most parameters in progressive sequential defects ranging from 10% to 40%. The CL procedure provides consistent correction of most parameters in bone defects of 10% and 20%. The CAL procedure restores and overcorrects articular geometry parameters even in 40% glenoid defects.

The osseous anatomy of the glenoid has been shown to be a major contributing factor to shoulder instability.[18] Shoulder instability algorithms have focused on the GW as a measure of articular deformation; however, independent associations between anterior instability and the other 3 glenoid parameters (GA, GV, and glenoid articular curvature) have been described. Yamamoto et al[17,18] defined the critical glenoid defect as loss of 25% of the width; their study demonstrated that a 6-mm defect in GW resulted in the critical defect that necessitated bony reconstruction for stability. GV has been implicated as a risk factor in anterior instability, and correction of version has been suggested for restoration of stability.[6,8,11] GV is an underestimated factor in the pathogenesis of anterior shoulder instability. Several authors have described an association between glenoid anteversion and anterior

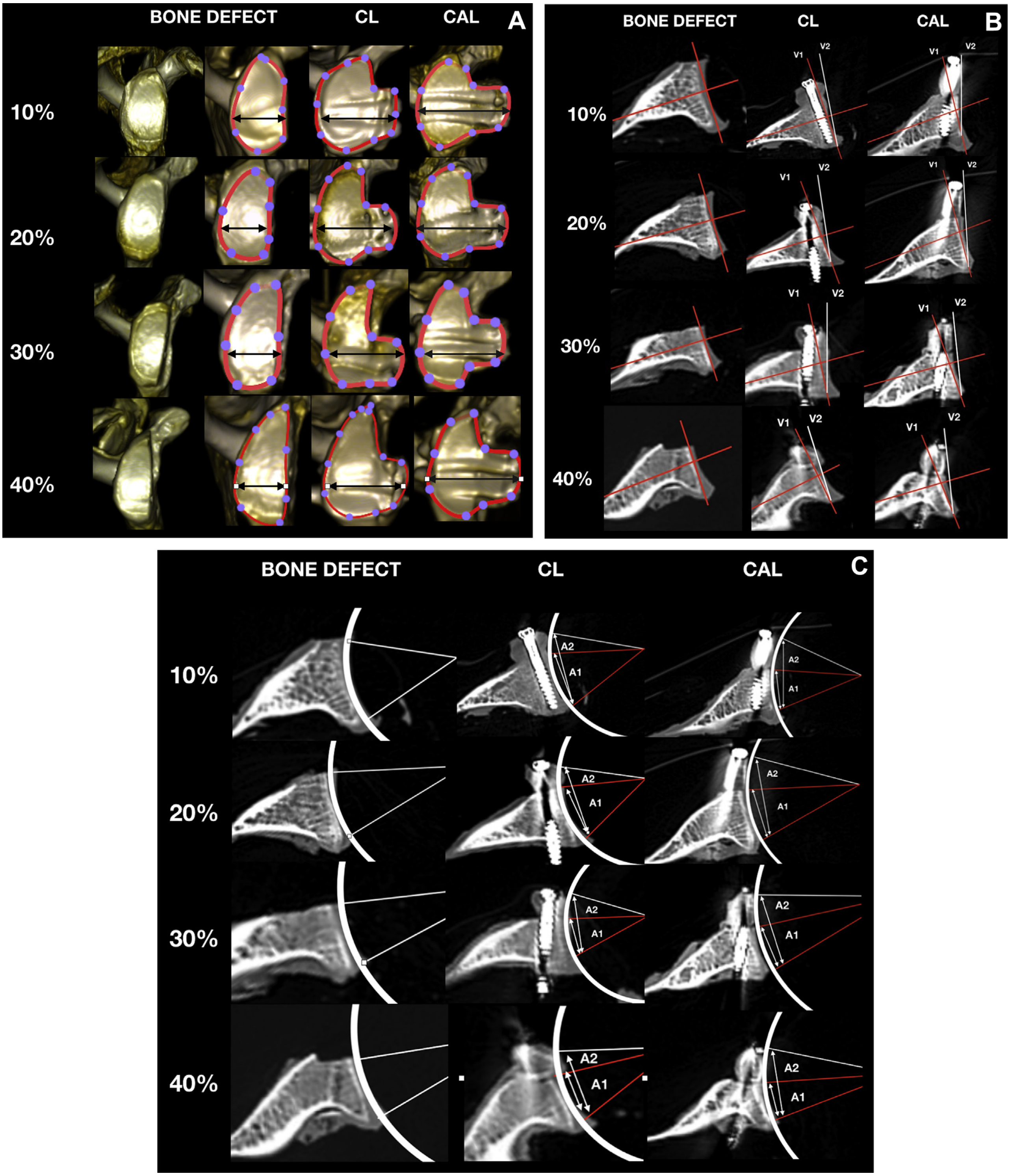

Figure 4 Glenoid articular surface parameters in glenoids with bone loss and bone-grafted glenoids are demonstrated for each level of bone defect (10%-40%) as measured on computed tomography scans. **(A)** Glenoid width (*arrows*) and area measurements demonstrate a progressive reduction with sequential bone defects (*first and second columns*); both parameters are restored in bone-grafted glenoids via the classic Latarjet (*CL*) and congruent-arc Latarjet (*CAL*) procedures (*third and fourth columns*). **(B)** Glenoid version measured at the lower-third glenoid level demonstrates a progressive loss of normal retroversion with sequential defects (*first column*) and its subsequent correction with the CL and CAL procedures (*second and third columns*). **(C)** Glenoid arc length measured at the lower-third glenoid level demonstrates a progressive loss of arc length and concavity with sequential defects (*first column*) and its subsequent correction with the CL and CAL procedures (*second and third columns*). *A1* (*short arrow*), arc length in bone defect glenoid; *A2* (*long arrow*), arc length after bone-graft procedure.

Table III Comparative glenoid version after sequential bone defects and reconstruction

Parameter	Glenoid version						*P* value
	Mean (minimum-maximum), °	SD, °	95% CI, °		Mean change, °	% Change	
			Lower	Upper			
Intact (n = 12)	−5.6 (−12.3 to 0.3)	3.9	−8	−3	—	—	—
10%							
Defect (n = 12)	−3 (−9 to 2)	3.3	−5.1	−0.9	2.6	46	.093
CL (n = 6)	−10.7 (−13.7 to −4.4)	3.6	−14.5	−6.9	5.2	94	.019*
CAL (n = 6)	−13 (−20.8 to −3.7)	5.6	−18.9	−7	7.3	131	.022*
20%							
Defect (n = 12)	−0.7 (−4.4 to 6.3)	3.4	−2.9	1.4	4.8	87	.004*
CL (n = 6)	−7.7 (−12.8 to −4.4)	3.2	−11.1	−4.3	2.2	40	.253
CAL (n = 6)	−11.7 (−15 to −8.4)	2.2	−13.9	−9.4	6	107	.001*
30%							
Defect (n = 12)	1.7 (−3.7 to 6.9)	3	−0.2	3.6	7.3	130	<.001*
CL (n = 6)	−6.8 (−11.2 to −2.1)	4	−11	−2.7	1.4	25	.539
CAL (n = 6)	−10.1 (−13.6 to −7.6)	2.2	−12.4	−7.8	4.4	79	.006*
40%							
Defect (n = 12)	3.1 (−1.9 to 7.7)	2.6	1.5	4.8	8.7	157	<.001*
CL (n = 6)	−5.3 (−9.5 to 0.2)	3.7	−9.2	−1.4	0.1	2	.898
CAL (n = 6)	−8.4 (−9.8 to −7.1)	1.1	−9.5	−7.2	2.7	48	.038*

SD, standard deviation; *CI*, confidence interval; *CL*, classic Latarjet procedure; *CAL*, congruent-arc Latarjet procedure.
Negative values denote retroversion. Mean change is the average difference between the parameter measured in the intact glenoid group and that in the bone defect or graft-reconstructed group.
* Significant change.

instability.[8,11] Griffin et al[6] found an alteration in GV with anterior and posterior glenoid defects in a computer-modeled cadaveric analysis; however, their analysis was performed with digital rendering of glenoid cuts and therefore may not present true intraoperative bone loss situations. Willemot et al[16] studied alteration of glenoid articular geometry with 25% defects; however, they did not include GV as a study parameter. Articular concavity contributes to glenohumeral instability; glenoid bony curvature in the transverse plane is a more accurate measure (in comparison with GW) of the actual glenoid surface available for articulation and represents an indirect measure of glenoid concavity and depth.

We performed our study in an attempt to quantify all 4 articular surface parameters and to provide an integrated model of articular surface deformation and restoration in anterior instability. The results of this study may be used to grade glenoid bone deficiency based on alteration of a combination of the 4 articular parameters (width, area, version, and arc length). Glenoid deficiency of up to 10% did not significantly alter GA, GV, and GAL compared with intact glenoids (grade 1, insignificant deficiency). Glenoid bone loss at 20% significantly altered all 4 articular parameters. The arc-length loss (approximately 5 mm) was close to the previously described critical width loss of 6 mm (grade 2, significant deficiency). Glenoid bone loss at 30% and 40% resulted in a severe loss of curvature (up to 10 mm); in addition, GV changed from retroversion to anteversion (grade 3, severe deficiency). The articular geometry restorative capability of the CAL procedure was greater than that of the CL procedure. The CL procedure was restorative in most defects; however, both procedures were performed without decortication of the apposing coracoid surface. The CL procedure involves decortication of 2 to 4 mm of the curved inferior surface of the coracoid to create a flat surface for apposition to the flat bone defect region on the anterior glenoid. In contrast, the CAL procedure uses the flatter medial coracoid surface for apposition, and hence, decortication is less extensive than with the CL procedure; the actual intraoperative restorative capability of the CL procedure may therefore be less than that shown by the results of this study. Classification of glenoid bone deficiency based on articular geometry has implications in the management of anterior shoulder instability: Grade 1 glenoid deficiency may be adequately corrected with soft-tissue repairs (labral repair and remplissage). Grade 2 glenoid deficiency is probably better restored with a bone-grafting procedure, and a CL procedure provides enough bone for correcting articular geometry. Other patient profile factors (age, hyperlaxity, and sports) may be used to further determine a cohort that may benefit from a soft-tissue procedure (labral repair, capsular shift, or remplissage). Grade 3 glenoid deficiency is probably best restored with the CAL procedure. Alternative bone-graft procedures (distal tibial allograft or iliac crest graft procedures) may also be useful when larger graft dimensions

Table IV Comparative glenoid arc length after sequential bone defects and reconstruction

Parameter	Mean (minimum-maximum), mm	SD, mm	95% CI, mm		Mean change, mm	% Change	*P* value
			Upper	Lower			
GAL1							
Intact (n = 12)	19.7 (14.6-22.8)	2.5	18.1	21.3	—	—	—
10%							
Defect (n = 12)	19.9 (17.2-22.9)	1.9	18.7	21.1	1.8	9	.805
CL (n = 6)	27.8 (24.4-32.3)	2.8	24.9	30.8	7.8	39	<.001*
CAL (n = 6)	33.1 (28.8-39.3)	3.8	29.1	37	13.8	70	<.001*
20%							
Defect (n = 12)	17.7 (15.7-19.7)	1.5	16.8	18.7	2.8	14	.035†
CL (n = 6)	25.2 (20.8-28.5)	3.2	21.9	28.5	5.1	26	.005*
CAL (n = 6)	29.3 (25.5-33.9)	2.8	26.3	32.3	10	51	<.001*
30%							
Defect (n = 12)	14.5 (11.9-17.8)	1.9	13.3	15.7	5.1	26	<.001†
CL (n = 6)	23.9 (19.9-27.7)	2.8	21	26.8	3.8	19	.012*
CAL (n = 6)	27.8 (24.2-31.7)	3.2	24.5	31.2	8.6	44	.001*
40%							
Defect (n = 12)	13.3 (9.8-16.4)	2.2	11.9	14.6	6.4	33	<.001†
CL (n = 6)	18.4 (12-23.6)	4.3	13.8	22.9	2.7	14	.519
CAL (n = 6)	25.2 (20.4-33.1)	4.5	20.6	29.9	6	31	.026*
GAL2							
Intact (n = 12)	23.8 (19-27.4)	2.6	22.1	25.5	—	—	—
10%							
Defect (n = 12)	22 (17.9-26.5)	2.6	20.3	23.7	3	13	.11
CL (n = 6)	28.7 (25.5-31.7)	2.7	25.8	31.5	4.7	20	.005*
CAL (n = 6)	36.6 (31.6-41.9)	4	32.5	40.8	13.1	55	<.001*
20%							
Defect (n = 12)	19.4 (16.1-22.4)	1.9	18.2	20.6	4.5	19	<.001†
CL (n = 6)	26 (22.6-30.1)	3	22.8	29.1	2.7	11	.168
CAL (n = 6)	32.4 (32-34.9)	1.6	30.8	34.1	8.8	37	<.001*
30%							
Defect (n = 12)	17 (14.5-18.7)	1.4	15.7	17.4	7.3	30	<.001†
CL (n = 6)	23.6 (20.6-28)	2.6	20.9	26.3	2.7	20	.867
CAL (n = 6)	28.8 (23.7-30.9)	2.7	26	31.6	5.3	22	.003*
40%							
Defect (n = 12)	15.2 (12-20.8)	2.3	13.8	16.7	8.6	36	<.001†
CL (n = 6)	20.9 (18.3-24.6)	2.2	18.6	23.3	3.3	14	.033†
CAL (n = 6)	23.3 (17.3-28)	3.7	19.4	27.2	2.9	12	.78

SD, standard deviation; *CI*, confidence interval; *GAL1*, glenoid arc length measured at junction of upper and middle thirds of glenoid length; *CL*, classic Latarjet procedure; *CAL*, congruent-arc Latarjet procedure; *GAL2*, glenoid arc length measured at junction of middle and lower thirds of glenoid length. Mean change is the average difference between the parameter measured in the intact glenoid group and that in the bone defect or graft-reconstructed group.

* Significantly more.

† Significantly less.

are needed. Further studies are necessary to assess the utility of correction of these parameters on clinical outcomes.

This study had limitations, some of which are inherent to all cadaveric studies. First, we used only 12 cadaveric specimens for analysis, and the values described are representative of the limited sample size of convenience. Second, we did not include glenoid depth as a measure of articular restoration. Glenoid depth is more a function of the cartilage layer, and the bony radius is significantly greater than that of cartilage.[19] We therefore measured GAL at the upper and lower levels of the bony glenoid as a measure of the actual length available for articulation. Third, we did not decorticate the apposing coracoid surface, and the measurements may therefore vary with the extent of intraoperative decortication performed. Fourth, progressive anterior glenoid bone loss would also alter screw lengths, purchase, and angulations; however, these were not assessed in this study. Lastly, we did not use iliac crest or distal tibial allografts for analysis; instead, we preferred to analyze the modifications of the Latarjet procedure as this is the most common bone-grafting surgical procedure for bony instability.

This study has advantages over previous studies, and we attempted to improve on the limitations of previous studies that analyzed glenoid articular geometry.[6,16] First, we used more cadaveric specimens than in previous studies. Second, we analyzed 4 defect levels at 10% increments vs. a single critical level of 25%. Third, we placed the graft at the bone-cartilage junction exactly as it would be placed during surgery. Finally, we included 4 parameters including GV and GAL at 2 levels, and this has not been done in previous studies.

Conclusion

Glenoid articular surface geometry is progressively altered with a sequential increase in anterior bone defects from 0% to 40%. The CL procedure provided consistent correction of most parameters only in bone defects of 10% and 20%. The CAL procedure restored and overcorrected most articular geometry parameters even in 40% glenoid defects.

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