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A multiplanar tomographic modeling-based comparison of coracoid process transfer techniques for anterior shoulder instability

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ABSTRACT

Aims: This study aimed to compare the standard and congruent arc Latarjet techniques in anterior shoulder instability using a multiplanar computed tomography (CT)-based modeling approach, with particular focus on coracoid process morphology, glenoid reconstruction capacity, and graft contact surface area.

Methods: A total of 200 patients were included for coracoid measurements and 156 patients for glenoid measurements. Coracoid length, width, and thickness were evaluated, and glenoid width was measured on CT images. The potential glenoid bone defect reconstruction capacity and graft to glenoid contact surface area were calculated for both techniques. Gender-based anatomical differences were also analyzed.

Results: Coracoid dimensions were significantly larger in males than in females. The congruent arc Latarjet technique allowed reconstruction of a larger proportion of the anterior glenoid bone defect (mean 55%) than the standard Latarjet technique (mean 37%). In contrast, the standard technique provided a larger contact surface area between the transferred coracoid graft and the glenoid (452±126 mm^2 vs. 292±105 mm^2, $p<0.001$). Smaller coracoid dimensions, particularly in female patients, were associated with a smaller graft to glenoid contact area and the need for smaller fixation screws, which may reduce the mechanical stability of graft fixation.

Conclusion: While the congruent arc Latarjet technique allows reconstruction of larger glenoid bone defects, the standard technique offers a greater contact surface area that may favor graft healing and fixation stability. Coracoid process morphology, especially in smaller-sized coracoids, should be considered during surgical planning. Preoperative evaluation of coracoid process dimensions may help optimize technique selection and reduce the risk of complications.

Keywords: Shoulder dislocation, Latarjet procedure, bone transplantation, coracoid process

INTRODUCTION

Anterior shoulder instability is one of the most common forms of joint instability and accounts for the majority of shoulder dislocations. Recurrent instability is frequently associated with anteroinferior glenoid bone loss, which directly affects treatment outcomes.[1] Biomechanical studies have demonstrated that increasing glenoid defects significantly compromise shoulder stability.[2] Although soft tissue repairs may be effective in selected cases, failure rates increase in the presence of substantial bone loss.[3] Therefore, both soft tissue and bony structures should be considered together in the evaluation of anterior shoulder instability. Accurate analysis of anatomical and biomechanical factors is critical in determining the most appropriate surgical approach.

In the surgical management of anterior shoulder instability, various techniques have been described, particularly in cases with significant bone defects. Among these, the Latarjet procedure, based on coracoid process transfer, is widely preferred due to its ability to provide both static and dynamic stability.[4] In the classic Latarjet technique, the inferior surface of the coracoid is fixed to the anteroinferior glenoid, whereas in the congruent-arc modification, the coracoid is rotated by 90° to achieve a reconstruction that better conforms to the native glenoid curvature. This modification has been shown to restore larger glenoid defects and improve articular congruency.[5] However, there is ongoing debate regarding graft fixation strength, union potential, and the risk of complications.[6] Although favorable clinical outcomes have been reported for both techniques[7,8] their biomechanical differences have not yet been fully clarified.

Although both the standard and congruent-arc Latarjet techniques are widely used in clinical practice, studies comparing these methods from anatomical and biomechanical perspectives remain limited. In particular, the impact of coracoid morphology on surgical feasibility has not been sufficiently investigated in detail.[9] Existing studies suggest that while the congruent-arc technique may restore

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larger defects, it may also present disadvantages in terms of contact surface area and fixation stability.[10] Furthermore, the influence of anatomical differences between male and female patients on surgical outcomes has not been adequately evaluated in the literature.[11] This issue should not be overlooked, as smaller coracoid dimensions may increase the risk of intraoperative fracture and inadequate fixation. Therefore, further detailed investigation of the effects of coracoid anatomy on different surgical techniques is warranted.

The aim of this study was to compare the standard and congruent-arc Latarjet techniques using a multiplanar computed tomography (CT)-based modeling approach. In this context, coracoid measurements, glenoid reconstruction capacity, and graft contact surface area were evaluated. In addition, the impact of anatomical differences between male and female patients on surgical feasibility and fixation stability was analyzed. We hypothesized that the congruent-arc technique would be able to restore larger glenoid defects, whereas the standard technique would provide a greater bone contact surface area. Furthermore, it was anticipated that fixation parameters and the risk of complications could be affected, particularly in patients with smaller coracoid dimensions.

METHODS

Ethics

In this retrospective study, shoulder joint CT images of 200 patients who presented between 2000 and 2020 were analyzed. Ethical approval was obtained the Ankara University Human Researches Ethics Committee (Date: 13.02.2020, Decision No: I1-72-20), and the study was conducted in accordance with the principles of the Declaration of Helsinki.

Study Design

Patients with acute or healed fractures involving the proximal humerus, clavicle, or scapula, radiographic evidence of glenohumeral osteoarthritis, previous shoulder surgery, congenital or acquired shoulder deformities, or CT images with motion artifacts, incomplete visualization of the anatomical landmarks, or insufficient image quality for reliable measurements were excluded.

A total of 200 patients were included for coracoid measurements, while 156 patients were included for glenoid measurements. CT images were transferred to appropriate imaging software and analyzed using the multiplanar reconstruction function. Using this method, an oblique sagittal view of the coracoid was obtained, and the distance from the tip of the coracoid to its "elbow" was measured (Figure 1). Additionally, cross-sectional images perpendicular to the axis of the coracoid were generated to obtain a mid-section view; on this section, the medial-lateral width and superior-inferior thickness of the coracoid were measured (Figure 2).

Glenoid width was measured on CT images of 156 patients, and mean values were calculated. At this stage, patients with glenoid bone defects were excluded. The presence of glenoid bone loss was assessed on sagittal CT sections using the "best-fit circle" method. For this purpose, an optimal circle was fitted to the posterior and inferior margins of the glenoid,

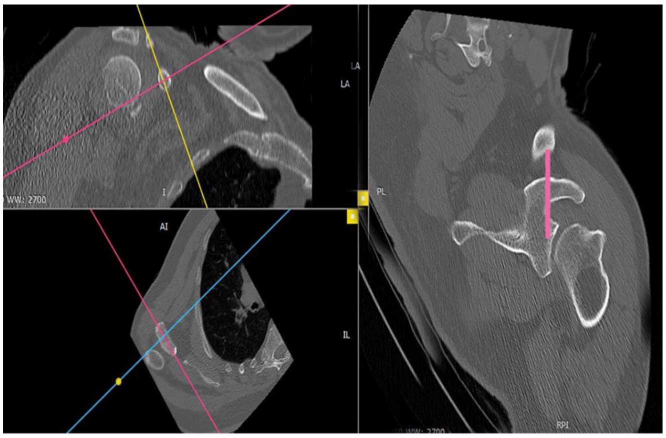

Figure 1. Oblique sagittal view of the coracoid process. The reference line was drawn through the region corresponding to the "elbow" of the coracoid

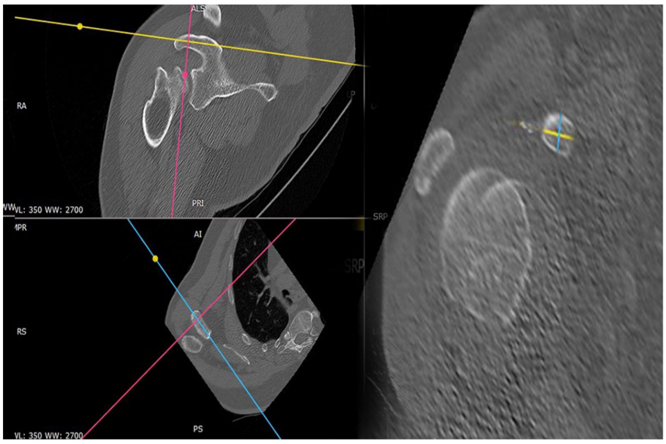

Figure 2. Measurement of thickness (vertical) and width (horizontal) on the oblique axial view of the coracoid process

and the presence of a defect was determined based on this reference (Figure 3). In these patients, the potential glenoid defect restoration ratios were calculated for both surgical techniques.

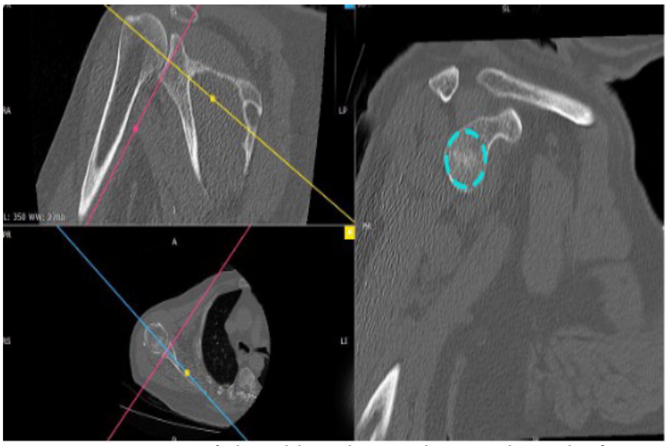

Figure 3. Assessment of glenoid bone loss on the sagittal view by fitting a best-fit circle to determine the presence of a defect

The contact surface area between the coracoid and the anteroinferior glenoid region, which is critical for bone union, was calculated based on the method described by Michel Latarjet. In the standard technique, the contact area was determined by multiplying the coracoid length by its medial-lateral width, whereas in the congruent-arc modification, it was calculated by multiplying the coracoid length by its superior-inferior thickness (Figure 4).

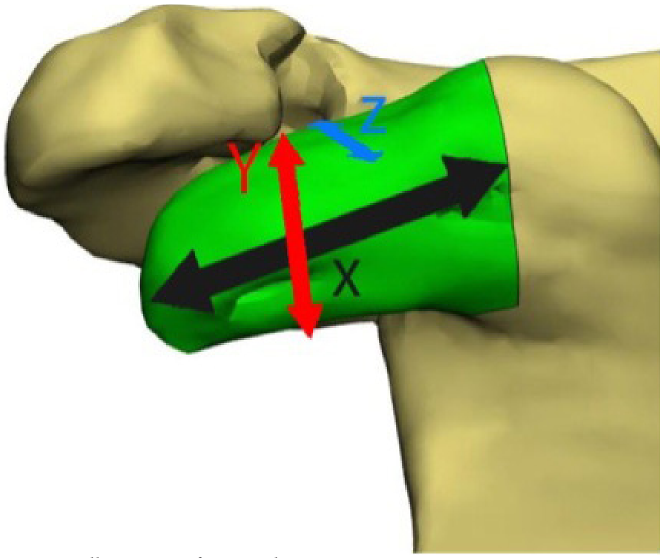

Figure 4. Illustration of coracoid process measurements

Maximum screw diameters applicable for both techniques in male and female patients were calculated based on the 40% rule for safe fixation of bone with screws.[12]

Three-dimensional visualizations of the coracoid transfer procedures were generated using Mimics Innovation Suite 22.0 (Materialise, Leuven, Belgium).

Statistical Analysis

All data analysis of the data was performed using IBM SPSS Statistics version 15.0. Descriptive statistics were expressed as mean and standard deviation (SD) for normally distributed continuous variables, and as number (n) and percentage (%) for categorical variables. Student's *t*-test was used to compare coracoid measurements between male and female patients, as well as the contact surface areas between the coracoid and the anteroinferior glenoid in both techniques. A p-value of <0.05 was considered statistically significant.

RESULTS

A total of 200 patients (129 males, 71 females) were included for coracoid measurements, and 156 patients (94 males, 62 females) for glenoid measurements. The mean age of the patients was 42 years (range, 17-70). When all patients were evaluated, the mean coracoid length was 27.4±3.6 mm, the medial-lateral width was 16.2±2.7 mm, and the superior-inferior thickness was 10.4±2.7 mm (Table 1).

Table 1. Coracoid process measurements

	Coracoid length (X) (mm)	Coracoid width (Y) (mm)	Coracoid thickness (Z) (mm)
Mean	27.4±3.6	16.2±2.7	10.4±2.7
Minimum	20.6	11.1	5.8
Maximum	32.8	20.1	14.9

Values are presented as mean±standard deviation

In the gender-based analysis, coracoid length (29.4±1.6 mm), width (17.4±1.4 mm), and thickness (11.5±1.5 mm) were significantly greater in males compared to females. In females, these values were 23.1±1.9 mm, 13.0±1.4 mm, and 7.0±1.4 mm, respectively (Table 2). The mean glenoid width was 28.1±1.3 mm, with values of 30.5±1.3 mm in males and 24.6±1.0 mm in females (Table 3).

Table 2. Comparison of coracoid process measurements between males and females

	Male (mm)	Female (mm)	p-value
Coracoid length	29.4±1.6	23.1±1.9	<0.001
Coracoid width	17.4±1.4	13.0±1.4	<0.001
Coracoid thickness	11.5±1.5	7.0±1.4	<0.001

Values are presented as mean±standard deviation

Table 3. Glenoid width measurements

	All patients (mm)	Males (mm)	Females (mm)
Glenoid width	28.1±1.3	30.5±1.3	24.6±1.0

Values are presented as mean±standard deviation

The proportion of glenoid bone defect that could potentially be reconstructed by the coracoid process was found to be a mean of 37% (23-44%) with the standard Latarjet technique and 55% (44-61%) with the congruent-arc technique (Table 4). When analyzed by sex, these values were 37% (25-44%) and 57% (47-61%) in males, and 28% (23-41%) and 52% (44-61%) in females for the standard and congruent-arc techniques, respectively (Table 5, 6).

Table 4. Restorable glenoid ratios with both techniques

	Mean (%)	Min (%)	Max (%)
Standard Latarjet	34	23	44
Congruent-arc Latarjet	55	44	61

Min: Minimum, Max: Maximum

Table 5. Restorable glenoid ratios with both techniques in male patients

	Mean (%)	Min (%)	Max (%)
Standard Latarjet	37	25	44
Congruent-arc Latarjet	57	47	61

Min: Minimum, Max: Maximum

Table 6. Restorable glenoid ratios with both techniques in female patients

	Mean (%)	Min (%)	Max (%)
Standard Latarjet	28	23	41
Congruent-arc Latarjet	52	44	61

Min: Minimum, Max: Maximum

Regarding the bone contact surface area, the mean value was 452±126 mm² for the standard Latarjet technique and 292±105 mm² for the congruent-arc technique (Table 7), with a statistically significant difference between the two (p<0.001).

Table 7. Mean screw diameters applicable for both techniques in males and females

	Male (mm)	Female (mm)
Standard Latarjet	7.0	5.0
Congruent-arc Latarjet	4.5	2.8

Based on the mean coracoid values in male and female patients, the maximum screw diameters applicable for both surgical techniques were calculated. Accordingly, in the standard Latarjet technique, the use of screws with a mean diameter of 7 mm in males and 5 mm in females was considered appropriate. In the congruent-arc Latarjet technique, these values were calculated as 4.5 mm in males and 2.8 mm in females (**Table 8**).

Table 8. Statistical comparison of coracoid contact surface area between both techniques

	Standard Latarjet (mm^2)	Congruent-arc Latarjet (mm^2)	p-value
Coracoid contact area	452±126	292±105	<0.001

Values are presented as mean±standard deviation

DISCUSSION

In this study, the standard and congruent-arc Latarjet techniques were compared using a multiplanar tomographic modeling approach. Coracoid and glenoid morphology were evaluated in detail, and for both techniques, glenoid reconstruction capacity, contact surface area, and potential fixation parameters were analyzed. In addition, the impact of anatomical differences between male and female patients on surgical feasibility was investigated. The findings demonstrated notable biomechanical differences between the two techniques.

In the literature, coracoid morphology has been reported to differ between genders, with males generally exhibiting larger coracoid dimensions than females. Studies by Young et al.[13] and Ljungquist et al.[14] have demonstrated that coracoid length typically ranges between approximately 26 and 28 mm. In our study, the mean coracoid length was 29.4 mm in males and 23.1 mm in females, with this difference being statistically significant. Similarly, width and thickness measurements were also significantly greater in males. These findings are consistent with the existing literature and support the reliability of the multiplanar reconstruction method used in our study.

The impact of glenoid bone defects on shoulder stability is well established, and it is widely accepted that soft tissue repair alone is insufficient in defects exceeding 25-30%.[15] Previous studies have reported that the congruent-arc technique can restore larger defects, whereas the classic Latarjet technique typically achieves reconstruction rates of approximately 30-36%.[16] In our study, the mean glenoid reconstruction was 37% with the standard technique and 55% with the congruent-arc technique. These results are consistent with the literature and suggest that the congruent-arc technique provides an advantage in the management of larger defects. However, this advantage should be interpreted in conjunction with other biomechanical parameters.

Although glenoid reconstruction is important, it has been shown that stability is not solely dependent on bony restoration. Yamamoto et al.[17] reported that the dynamic sling effect plays a significant role in the Latarjet procedure. Furthermore, while increased restoration of the glenoid surface may theoretically normalize contact pressures, articular incongruity may pose a risk for the development of osteoarthritis. Our findings indicate that although the congruent-arc technique provides greater reconstruction, its potential clinical implications should be carefully considered.

Previous studies have demonstrated that the standard Latarjet technique provides greater primary fixation stability, whereas the congruent-arc technique may fail under lower loads.[16,18] This difference is thought to be related to the contact surface area between the graft and the glenoid. In our study, consistent with these findings, the contact surface area was 452 mm^2 in the standard technique and 292 mm^2 in the congruent-arc technique. A smaller contact surface area may represent a disadvantage in terms of both bone union and fixation stability, and this issue may be particularly relevant in patients with smaller coracoid dimensions.[16]

In terms of screw fixation, the literature generally reports the use of screws with diameters ranging from 3.5 to 4.5 mm. However, according to AO principles, the screw diameter should not exceed 40% of the bone diameter.[12] In our study, coracoid thickness was significantly lower in female patients, and smaller screw diameters were required, particularly in the congruent-arc technique. This may compromise fixation stability and increase the risk of intraoperative fracture and nonunion. Therefore, consideration of coracoid dimensions during surgical planning is of great importance.

Studies evaluating Latarjet outcomes specifically in female patients are limited in the literature.[11] Available data suggest that the incidence of instability in females is not markedly different from that in males.[19,20] However, our findings indicate that smaller coracoid dimensions in female patients may lead to biomechanical disadvantages, particularly with the congruent-arc technique. Accordingly, gender-related anatomical differences should be taken into account when selecting patients and determining the surgical technique.

Limitations

This study has several limitations. First, its retrospective design and reliance on data from a single center may limit the generalizability of the findings. Additionally, the analyses were based on static measurements, and physiological loading conditions as well as dynamic muscle forces were not incorporated into the model. Furthermore, the lack of clinical outcome assessment restricts the direct clinical applicability of the results.

Despite these limitations, the study also has notable strengths. The use of multiplanar tomographic analysis enabled a detailed and quantitative evaluation of coracoid and glenoid morphology, thereby enhancing the reliability of the findings. Moreover, the comparison of both the standard and congruent-arc Latarjet techniques within the same model allowed for a clearer demonstration of biomechanical differences between the techniques. In addition, the evaluation of sex-related anatomical differences provides a unique contribution to the existing literature.

CONCLUSION

This study demonstrated that the standard and congruent-arc Latarjet techniques used in anterior shoulder instability exhibit distinct biomechanical characteristics. While the congruent-arc technique was found to restore larger glenoid bone defects, the standard Latarjet technique provided a greater contact surface area. In addition, significant differences in coracoid measurements were observed between male and female patients, suggesting that these anatomical variations may influence surgical feasibility. The smaller coracoid dimensions observed particularly in female patients result in the need for smaller screw diameters and a more limited contact surface area in the congruent-arc technique. This may reduce fixation stability and increase the risk of complications. Our findings indicate that surgical decision-making should consider not only the size of the glenoid defect but also the morphology of the coracoid process. In patients with smaller coracoid dimensions, techniques that provide a larger contact surface area may be more appropriate.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Ankara University Human Researches Ethics Committee (Date: 13.02.2020, Decision No: İ1-72-20).

Informed Consent

This retrospective study used pre-existing anonymized patient data. No additional intervention was performed, and there was no direct patient contact. The study was approved by the Ethics Committee, and the requirement for written informed consent was waived by the ethics committee.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

Concept: AA, MA; Design: AA, AM, SNA; Control: MK, MA; Resources: AA; Materials: AA; Data Collection and/or Processing: AA; Analysis and/or Interpretation: AA; Literature Review: AA, MK, SNA; Writing the Article: AA, MK, MA; Critical Review: AA, MK, SNA, MA.

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