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Research Article

Morphometric Analysis of Coracoid Process Using Multiplanar 2D CT and Its Implications for Graft Size and implant selection in Latarjet Procedure: A Retrospective and Prospective Study in an Indian Population

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Abstract

Background and Aims: The Latarjet procedure is widely used for recurrent anterior shoulder instability with glenoid bone loss. However, anatomical variations in coracoid morphology may influence graft adequacy, especially in different ethnic populations. The study aimed to evaluate coracoid and glenoid morphometry using 2D CT and assess its implications for graft sizing in classical and congruent arc Latarjet techniques in an Indian population. **Methods:** This cross-sectional study was conducted over 18 months at a tertiary care center in Dehradun, India. A total of 65 patients (100 shoulders) with intact coracoid and glenoid anatomy on CT were included. Measurements included glenoid width (GW), coracoid length (CL), surgical graft length (SGL), superior-inferior coracoid width (CWSI), medio-lateral width (CWML), and coracoid thickness (CT). Statistical analysis was performed using SPSS. **Results:** Significant sexual dimorphism was observed, with males having larger dimensions ($p < 0.05$). Strong positive correlations were noted between coracoid dimensions and glenoid width. The classical Latarjet technique could adequately address glenoid defects up to ~30%, while the congruent arc technique could cover defects up to ~50%. However, the classical technique provided significantly greater surface area for bony contact ($p = 0.03$). **Conclusion:** Coracoid morphology varies significantly in the Indian population and influences graft adequacy in Latarjet procedures. Preoperative CT-based morphometric assessment is essential for selecting the appropriate surgical technique and minimizing complications.

Keywords: Coracoid process, Glenoid width, Latarjet procedure, Congruent arc, Shoulder instability, CT morphometry

Introduction

The glenohumeral joint is a highly mobile ball- and-socket joint stabilized by the capsule-labral complex and the conjoint tendon, which functions as a dynamic sling during abduction and external rotation. Owing to the mismatch between the humeral head and glenoid cavity, and injury to stabilizing structures following trauma, the shoulder is prone to recurrent anterior instability, often requiring surgical management [1]. Variations in glenoid anatomy and version have been extensively described in literature and are important determinants of shoulder stability [2,3].

Arthroscopic Bankart repair and the Latarjet procedure are the most commonly performed operations [4,5]. The Latarjet procedure is particularly indicated in cases with significant glenoid bone loss, as it restores stability by augmenting the glenoid articular arc and providing a dynamic sling effect [6,7].

In the classical Latarjet technique, the inferior surface of the coracoid is fixed to the glenoid, whereas in the congruent arc technique, the coracoid is rotated 90° and its medial surface is utilized. Accordingly, the classical technique uses the superior-inferior coracoid width (CWSI), while the congruent arc technique relies on the medio-lateral width (CWML). [4] This study aims to evaluate the morphometric dimensions of the coracoid process and glenoid, including glenoid width (GW), coracoid length (CL), surgical graft length (SGL), coracoid thickness (CT), and coracoid widths (CWSI, CWML), and to assess their implications for graft adequacy in Latarjet procedures.

Accurate assessment of coracoid dimensions is essential for ensuring graft adequacy and avoiding complications such as graft fracture and non-union [8–11]. Previous studies have demonstrated smaller glenoid dimensions in Asian populations, highlighting the need for population-specific data [12-14]. Similar morphometric variations in coracoid have been reported in Indian and Asian populations, further emphasizing the need for population- specific data [2,8].

Furthermore, adequate graft length is necessary to allow safe screw placement and prevent iatrogenic fracture. Therefore, understanding the relationship between coracoid dimensions and glenoid width is crucial for optimizing surgical technique selection in the Indian population.

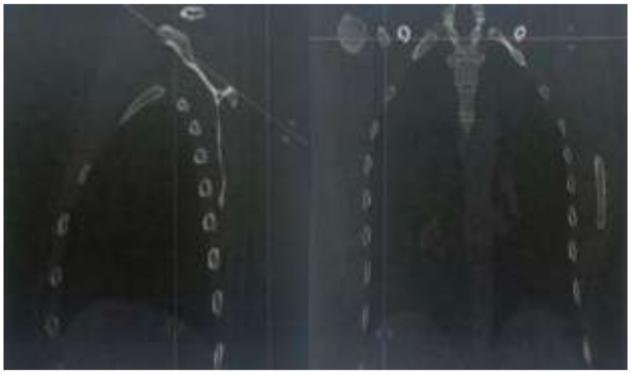
Material and Methods:

This cross sectional study was conducted at the Department of Orthopaedics & Radiology, Shri Mahant Indresh Hospital, located in Dehradun. The study utilized patients who had presented to the Orthopaedics Outpatient Department (OPD) with various ailments involving the shoulder and for whom CT scans were recommended. Additionally, it used an existing database of 2D CT scans of the shoulder available in the Department of Radiology. The duration of study was 18 months. Patients with glenoid cavity & coracoid process fractures (old/new), glenohumeral arthritis, any shoulder pathology involving Scapula's Coracoid process & Glenoid cavity, skeletally immature radiological scans and with any previous surgeries involving Glenoid cavity or Coracoid process were excluded. The inclusion criteria for these CT scans were carefully defined, requiring that all selected scans show both the coracoid and glenoid processes in an intact state. Consent was obtained from the patients who had presented to the Orthopaedics Outpatient Department (OPD). Measurements were taken using a multidetector 128-slice CT scanner (Ingenuity CT, Philips Healthcare, Best, The Netherlands). NCCT Thorax and Shoulder scans were used and bone windows were utilized. A thoracic CT examination was conducted by elevating the patient's arms over their head. The parameters for the thorax CT were as follows: 120kV, 80mAs, collimation: 1.25 X 1.25 mm2, pitch: 1, FOV: 20 X 20 cm2, matrix: 512 X 512, and slice thickness: 1

mm. The Thoracic CT planes were generated using the Multiplanar reconstruction technique, which involved obtaining an oblique sagittal view.

The measurements were conducted collaboratively by an Orthopaedist and a Radiologist, utilizing the axial and oblique sagittal planes on CT scans that encompassed both shoulders in the majority of patients. The specific measurements taken from the collected CT scans included -

Anatomy of Coracoid and Glenoid dimension



Coracoid Measurements-

Coracoid length - The length from the coracoid tip to the base was considered as the “total length”. Surgical Graft length- The length from the coracoid tip to the knee, where the horizontal and vertical parts of the coracoid bone meet, was accepted as the “surgical graft length.

Superior-inferior Coracoid width (CWSI) - Highest measurement of glenoid width on the axial sequences.

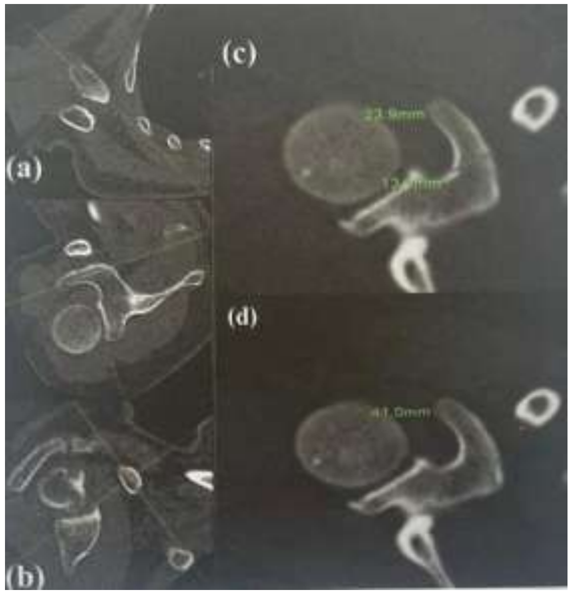


Figure 2. The CT was used to create a multiplanar reconstruction (MPR)by adjusting the axial (a) and oblique coronal (b) views of the right shoulder. This resulted in a correct sagittal view of Coracoid process length.

The measurements of Coracoid process were displayed on the oblique sagittal view. The Green Longitudinal line represents the surgical length in image (c) while the Green longitudinal line indicated the Coracoid length (d).

MPR: multiplanar reconstruction; CT: computed tomography.

Superior-inferior Coracoid width (CWsr)- Highest measurement of glenoid width on the axial sequences (Fig.3) (c) Green Longitudinal oblique line in true oblique coronal view [6].

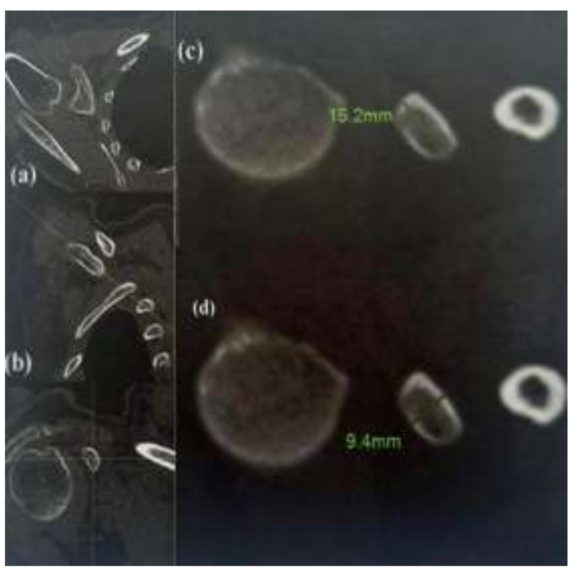


Figure 3. A true oblique coronal plane was constituted in MPR of oblique axial (a) and sagittal (b) views of the right shoulder.

The medial-lateral width (black arrow) and superior-inferior thickness (white arrow) of Coracoid process were assessed on true oblique coronal view (c). In the same MPR configuration at oblique sagittal view, the width was measured by determining the superior and inferior points and the thickness was determined by determining

the halfway point (b). MPR:
Coracoid process thickness- The measurement of thickness was made halfway between the coracoid tip and the knee.

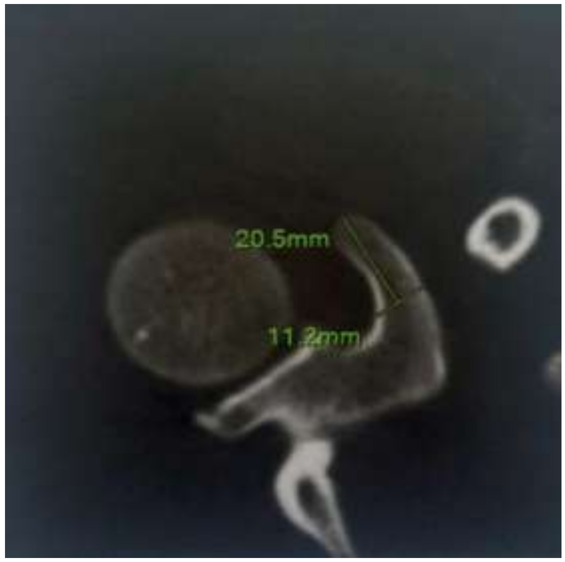


Figure 4. CT axial section indicates the Coracoid Thickness (CT) (Horizontal green line)

Glenoid width/Glenoid cavity width (GW) Maximum distance between the ventral border and the dorsal border of the glenoid, usually around the midpoint of the glenoid fossa. (Fig.5)

Figure 5. CT axial section indicates the glenoid width. CT: computed tomography.

Multi-Planar function was used in order to measure the mediolateral width and superior-inferior width of Coracoid Process, a true oblique coronal image perpendicular to the axis of Coracoid Process was obtained. The coronal sections were matched with the axial sections and the superior-inferior and medial lateral widths were measured at 1 cm intervals on the graft. These measurements provided a comprehensive overview of the anatomical features relevant to the study's focus, laying the groundwork for subsequent analysis and interpretations.

For comparison, the age, side, gender, hand dominance figures were documented.

To assess the ability of the transferred coracoid to restore the width of the glenoid in the classic Latarjet and Congruent arc technique we created a hypothetical bone model, and we calculated the glenoid width in the setting of 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50% bone loss. We next calculated, the hypothetical glenoid bone loss using the Diameter-Based Method as follows: Percent bone loss = Glenoid Defect width (GDW)/Diameter of glenoid (GW) × 100%.

Fig 6: The hypothetical glenoid bone loss was calculated using the Diameter-Based Method as follows: Percent bone loss =

(Glenoid Defect width (GDW)/Diameter of glenoid (GW) × 100%

Glenoid width- Marked in Fig 5 as yellow line (14).

On the constructed hypothetical model, the mean widths of the coracoid in both superior-inferior and medial-lateral directions have been estimated. These measurements were then utilized to determine the ratio of bone available to restore the glenoid loss in scenarios ranging from 10% to 50% bone loss using the Latarjet and Congruent arc techniques. The ratio of bone available to restore Glenoid Bone loss was defined as CWSI/GDW for the Traditional Latarjet technique, and CWML/GDW for the Congruent arc technique. The percentage of shoulder samples that could be corrected by coracoid graft in both the Latarjet (CWSI) and Congruent arc technique (CWML) was calculated by comparing the coracoid width in both techniques to the amount of Glenoid defect width (GDW) from 10% to 50%.

Table 1: Percentage of Glenoid Bony defect that can be filled by Coracoid process in Traditional vs Congruent arc technique.

Glenoid Bone Loss	10%	15%	20%	25%	30%	35%	40%	45%	50%
Glenoid Defect Width	2.682mm ± 0.262	4.02mm ± 0.39	5.364mm ± 0.524	6.705mm ± 0.655	8.054mm ± 0.786	9.41mm ± 0.919	10.728mm ± 1.048	12.081mm ± 1.180	13.42mm ± 1.32
Ratio of bone available to restore Glenoid Bone loss in Latarjet technique (CWSI/GD W)	3.533 ± 9.42	2.35 ± 6.33	1.76 ± 4.71	1.41 ± 3.77	1.17 ± 3.14	1.01 ± 2.68	0.88 ± 2.35	0.783 ± 2.09	0.705 ± 1.871
Percentage of shoulder samples that can be covered by Coracoid graft using Latarjet technique in our study.	100%	100%	100%	100%	67.7 %	44.61%	32.30%	20%	16.92%
Ratio of bone	5.45 ± 8.8	3.64 ± 5.9	2.72 ± 4.4	2.81 ± 3.5	1.81 ± 2.93	1.55 ± 2.5	1.36 ± 2.2	1.14 ± 1.95	1.08 ± 1.74
available to restore Glenoid Bone loss in Congruent arc technique (CWML/GD W)									
Percentage of shoulder samples that can be covered by Coracoid graft using Congruent arc technique in our study.	100%	100%	100%	100%	100%	100%	98.46%	87.69%	64.61%

This table presents an analysis of Glenoid bone loss percentages ranging from 10% to 50%, detailing the corresponding defect widths and the efficacy of restoration using two surgical techniques: the Latarjet and Congruent arc techniques. As Percentage of Glenoid bone loss increases, the Glenoid Defect Width (GDW) also increases, ranging from approximately 2.682mm at 10% loss to 13.42mm at 50% loss. The ratio of bone available for restoration using the Latarjet technique decreases with greater bone loss, indicating diminishing efficiency in severe cases. Despite this, the potential coverage of the shoulder by the Coracoid graft remains high until a 25% loss, beyond which it drops significantly. Conversely, the Congruent arc technique maintains high restoration potential across most percentages, with the ratio of bone available for restoration slightly increasing as the defect widens, and only showing notable decrease at higher bone loss levels, maintaining high percentages of shoulder coverage throughout the study.

In our hypothetical model, two implants (screws) were utilized to fix the coracoid to the glenoid, with the distance between the two holes maintained at 10 mm for all types of fixations. Subsequently, the distances from the superior-inferior and medio-lateral limits of the coracoid during the Latarjet procedure were computed as follows:

- Distance from the Superior-Inferior Limit = [CL - (10 + Implant Diameter)] / 2
- Distance from the Medial-Lateral Limit

= (CWML - Implant Diameter) / 2.

Fig. 7: Art design showing the harvested coracoid graft. The distance from the center of the two holes was set at 10 mm. Y = Distance from the Superior-Inferior Limit. X = Distance from the Medio-Lateral Limit (14).

According to AO principles, at the apex of a fracture fragment, the minimal distance between the screw head and the fracture line must be at least equal to the diameter of the screw head. In the context of the Latarjet procedure, it was hypothesized that the "safe distance" between the implant used, and the coracoid osteotomy point should be at least equal to the diameter of the implant .

As recommended by Walch, in the open Latarjet procedure, a coracoid bone graft length of more than 25mm was recommended to enable screw insertion of 4.5mm screws (the largest implant size in the study). Taking his findings into account, the percentage of shoulder samples with coracoid lengths adequate for placing various screws was calculated.

Table 2. Distance from Coracoid Borders According to Implant Type

Implant Type (Screw)	Supero-Inferior Distance	Medio-Lateral Distance	P values
3.5 mm Screw	4.7175 ± 1.903 mm	5.65 ± 1.095 mm	0.004
3.75 mm Screw	4.467 ± 1.903 mm	5.52 ± 1.903 mm	0.02
4.5 mm Malleolar Screw	3.717 ± 1.903 mm	5.15 ± 1.903 mm	0.005

This study evaluated supero-inferior and medio-lateral distances for various implant types. The 3.5 mm Screw recorded distances of 4.7175 ± 1.903 mm and 5.65 ± 1.095 mm, with a P value of 0.004. The 3.75 mm Screw had distances of 4.467 ± 1.903 mm and 5.52 ± 1.903 mm with a P value 0.02. Lastly, the 4.5 mm Malleolar Screw showed distances of 3.717 ± 1.903 mm and 5.15 ± 1.903 mm, with a P value of 0.005, indicating smaller distances with larger screws, which increase the probability of graft fracture on placement of larger size screws and decreasing trend of values for Medio-lateral distance signify the accuracy needed to centrally place larger size screw for prevention of the same.

The following equations computed the surface area for bony connection of the coracoid to the anterior glenoid:

- For the Traditional Latarjet technique:
- Surgical graft length (SGL) x Medial-Lateral Coracoid width (CWML).
- For the Congruent Arc Latarjet technique:
- Surgical graft length (SGL) x Superior-Inferior Coracoid width (CWSI).
- The width of the bone on each side of a centrally inserted 3.5mm screw (the smallest graft size taken in the study) was also calculated:
- For the Traditional Latarjet technique:
- Medial-Lateral Coracoid width (CWSI) - 3.5mm/2.
- For the Congruent Arc Latarjet technique:
- Superior-Inferior Coracoid width (CWML) - 3.5mm/2.
- Additionally, the glenoid defect width in the setting of 10%, 15%, 20%, 25%, and 30% bone loss was calculated.

STATISTICAL ANALYSIS:

Statistical analysis was performed using SPSS software. Descriptive statistics were expressed as mean, standard deviation, and median. Categorical variables were analyzed using Pearson's chi-square test or Fisher's exact test. Parametric data were compared using the independent samples t-test, while non- parametric data were analyzed using the Mann–Whitney U test. Correlations between continuous variables were assessed using Spearman's rank correlation coefficient. A p-value <0.05 was considered statistically significant.

Results:

This study involved 65 participants with 100 shoulder samples (Bilateral shoulder samples were collected of most participants), distinct age-related prevalence trendswer. Notably, in the majority of sample, 31 individuals (47.70%) were over the age of 50. This group was followed by individuals aged 18-30 years, which constituted 21.51% (14 individuals) of the study population. Those in the 31-40 and 41-50 age brackets accounted for 15.38% (10 individuals) and 15.38% (10 individuals) each with a trend in increasing dimensions with age. The gender distribution among participants was balanced, with females slightly outnumbering males: 52.30% (34 females) compared to 47.70% (31 males). When comparing anatomical dimensions of Coracoid to gender differences between males and females, CWSI in males was 15.41 mm ± 2.58 SD and CWSI in females was 13.96 mm ±1.80 SD, showing a significant difference ($p < 0.01$). Similar patterns were noted in CWML, where in males was 11.64 ± 2.70 and in females was 8.69 ± 1.71 showing a significant difference ($p < 0.01$). all coracoid dimensions displayed significant variations between genders . The correlation coefficients for the medio-lateral coracoid width with glenoid width were 0.612 in males and 0.598 in females, both statistically significant at $p<0.001$. The superior-inferior coracoid width showed a stronger correlation in males ($r=0.675$, $p<0.001$) than in females ($r=0.602$, $p<0.001$). Additionally, the true length of the coracoid also correlated significantly with the glenoid width in both males ($r=0.524$, $p<0.001$) and females ($r=0.554$, $p<0.001$). The superior-inferior (Sup-Inf) coracoid width showed a mild positive correlation with the glenoid width ($r=0.19$), suggesting that as the coracoid width increases, there tends to be a slight increase in the glenoid width as well. The medio-lateral (Medio-Lat) coracoid width had a notable positive correlation with the surgical graft length (r=0.19).

Discussion:

This study evaluated coracoid and glenoid dimensions using 2D-CT and assessed their implications for classical and modified Latarjet techniques. A positive correlation between age and coracoid dimensions was observed, with larger measurements seen in older individuals, consistent with previous studies. However, the predominance of older participants may limit generalizability. Significant gender differences were noted, with males demonstrating larger coracoid dimensions than females ($p < 0.01$), highlighting the importance of considering sexual dimorphism during surgical planning. Our findings were comparable to prior studies and aligned closely with measurements reported in Indian populations, supporting the influence of ethnicity on coracoid morphology. No significant association was found between hand dominance and coracoid dimensions ($p > 0.05$), consistent with existing literature. Strong positive correlations were observed between coracoid and glenoid dimensions, indicating their interdependent anatomical relationship, which is relevant for preoperative planning. From a surgical perspective, the congruent arc technique allowed reconstruction of a larger proportion of glenoid defects (~50%) compared to the classical Latarjet technique (~35%). However, the classical technique provided a greater surface area for graft healing, suggesting better union potential. Additionally, the mean available coracoid graft length was limited, with more than half of cases falling below the ideal length of 25 mm. This raises concerns regarding the safe use of standard 4.5 mm screws, as shorter grafts may increase the risk of graft fracture. Overall, these findings emphasize the importance of individualized surgical planning based on patient-specific anatomical variations, including age, gender, and ethnicity, to optimize outcomes in Latarjet procedures. [4]

Conclusion

This study demonstrates significant variability in coracoid and glenoid dimensions influenced by age, gender, and ethnicity. A positive correlation between coracoid and glenoid measurements highlights their anatomical interdependence, which is crucial for preoperative planning in Latarjet procedures. The congruent arc technique allows reconstruction of a larger proportion of glenoid defects; however, the classical Latarjet technique provides a greater surface area for graft healing, suggesting better union potential. Additionally, the relatively shorter coracoid graft length observed in a substantial proportion of cases raises concerns regarding the safe use of standard fixation methods, particularly 4.5 mm screws. These findings underscore the importance of individualized surgical planning, careful technique selection, and appropriate implant choice to optimize surgical outcomes and minimize complications. Limitations

This study has several limitations. First, the sample size was relatively small and may not fully represent the general population. Second, there was a predominance of older individuals, which could introduce bias and limit the generalizability of age-related findings. Third, the study utilized two-dimensional CT imaging, which may not capture the full complexity of three-dimensional anatomical variations. Additionally, being a single-center study, the findings may not be universally applicable across different populations. Interobserver variability in radiological measurements was not assessed, which may affect measurement accuracy. Finally, clinical correlation with surgical outcomes was not performed, limiting the ability to directly translate anatomical findings into functional or procedural success.

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