A Comprehensive Assessment of the Coracoid Process Dimensions in the South Indian Population Using 3D Computer Tomographic Reconstruction

Sandesh Madi S[1], Muthiah Muthu Magesh[1], Sujayendra DM[1], Vivek Pandey[1], Kiran K V Acharya[1]

Abstract

Background: Awareness of the accurate dimensions of the coracoid is essential for (i) coracoclavicular ligament reconstructions and (ii) coracoid transfer procedures (e.g. Latarjet) for shoulder instability. The morphometric assessment of the coracoid process using three-dimensional computer tomography (3-D CT) in the Indian population has not been previously undertaken.

Materials and Methods: The study was aimed to conduct the morphometric assessment of coracoid process using 3-D CT reconstruction in the South Indian population and to compare the gender and side differences. In addition, we compared the dimensions of the coracoid process with the findings in the previous studies performed in different races and ethnicities. We also compared the results of our study with other morphometric studies conducted in India using dry bones. From the records, the 3D CT images of the shoulder (age between 20 and 60 years) were assessed. Fractures of the coracoid or previous history of surgery involving the coracoid were excluded from the study. The dimensions of coracoid were measured on the same final images by two observers using digital calipers, and an average of their measurements was recorded. A two-tailed independent t-test was used to measure the statistical significance.

Results: A total of 187 shoulders (120 males and 67 females), 3D CT images were assessed. The average age of the study population was 30.66 ± 7.21 years. The average length of coracoid was 40.11 ± 1.36 mm. Overall dimensions of tip of coracoid was 20.56 ± 1.67 mm (length), 13.01 ± 0.97 mm (width), and 9.24 ± 1.05mm (height). Overall dimensions of base of coracoid were 20.45 ± 2.26 mm (length) and 14.5 ± 0.86 mm (height). All the measurements were larger in males ($P < 0.05$). The side difference for all measurements was not statistically significant. The mean coracoid width was significantly larger than the mean coracoid thickness ($P < 0.00001$).

Conclusion: This study provides a comprehensive baseline data on the morphometry of the coracoid process in the South Indian population that will be valuable in pre-operative planning for the shoulder surgeons.

Keywords: Coracoid, Three-dimensional computer tomography scan, Tip, Base, Scapula, Shoulder.

Introduction

The coracoid process is considered an important landmark in shoulder surgery. Awareness of the size of the coracoid process is critical, especially for two shoulder procedures:

[1]Kasturba Medical College, Manipal Academy of Higher Education, Manipal, India.

Address of correspondence :
Dr. Sandesh Madi S,
Kasturba Medical College, Manipal Academy of Higher Education, Manipal, India.
E-mail: sandesh.madi@manipal.edu

(I) Coracoclavicular ligament reconstruction– a tunnel is drilled through the coracoid process to accommodate various types of grafts and stabilize the acromioclavicular joint. An eccentrically drilled tunnel through the coracoid would inadvertently lead to a fracture and failure of coracoclavicular and acromioclavicular stabilization. Hence, with the limited width of the coracoid process, the margin of error in drilling this tunnel is potentially narrow. (ii) Shoulder instability, i.e., Latarjet procedure– an osteotomy of the coracoid process is performed, and the coracoid graft is positioned at the inferior surface against the anterior surface of the glenoid neck [1]. This technique restores the glenoid contour and stabilizes the shoulder joint from potential dislocation. There are several morphometric studies performed on the dimensions of the coracoid process in a different population (Table 1) [2-24]. These measurements have been performed either on dry bones, cadaveric specimens, or radiological images and provide baseline data about the

Table I: RACIAL DIFFERENCES IN THE DIMENSIONS OF THE CORACOID PROCESS

Studies	Cases	Method	Total length	Base length	Midpoint height	Tip height	Base height	Tip length	Tip width	Midpoint width
ASIANS										
Present (South India)	n=187	3D CT scan	40.11 ± 1.36	20.45 ± 2.26	10.91 ± 1.02	9.24 ± 1.05	14.5 ± 0.86	20.56 ± 1.67	13.01 ± 0.97	14.41 ± 0.96
Malay [10]	n=15	3D CT scan	37.94 ±4.30	18.96 ±3.71	-	9.24 ± 1.16	15.03 ± 3.65	20.98 ± 2.90	11.63 ±2.12	13.84 ±1.76
Chinese [22]	n=84	3D CT scan	41.60 ± 4.04	-	11.12 ± 1.97	9.05 ± 1.83	-	20.80 ± 2.02	13.09 ± 2.06	14.59 ± 2.07
Chinese [21]	n=14	cadaver	42.47 ± 1.02	23.90 ± 0.76	-	9.08 ± 0.58	15.26 ± 1.18	-	13.17 ± 0.51	-
Myanmarese [21]	n=14	Cadaver	39.19 ± 1.38	22.82 ± 0.78	-	8.58 ± 1.03	14.79 ± 0.88	-	13.02 ± 1.32	-
Japanese [19]	n=28	Cadaver	44.3 ± 4.1	17.3 ± 1.8	-	-	-	-	-	-
Mongolian [18]	n=30	Cadaver	42.10 ± 2.3	-	11.61 ± 1.98	9.1 ± 1.75	-	24.75 ± 7.23	13.61 ± 2	15.29 ± 1.70
Koreans [12]	n= 102	Dry bones					12.8± 1.8 [b]			
Thais [15]	n=97	Dry bones	40.4 ± 4.1		7.4 ± 1.2					14.6 ± 1.9
Turks [3]	n=90	Dry bones	-	-	14.6 ± 2.9	-	-	19.4 ± 7.9#	-	-
Turks [17]	n=62	Dry bones	42.36 ± 4.28				18.59 ± 2.55		13.95 ± 1.73	13.98 ± 1.69
EUROPEANS										
Italian [2]	n=204	Cadaver	38.15 ± 3.97	-	-	7.19 ± 1.04	-	14.62 ± 1.96	-	-
German [4]	n=23	Cadaver	43.1 ± 2.2	14.1 ± 2.9	-	8.2 ± 1	14.9 ± 2.4	20.3 ± 2.6	13.6 ± 2.1	13.9 ± 1.6
Greek [14]	n=101	Dry bones	-	-	-	8.7 ± 1.3	-	23.9 ± 3	13.6 ± 2	-
NORTH AMERICANS										
American [24]	n=5	Cadaver	-	-	-	-	-	22.7 ± 4.5	15.9 ± 2.2	-
American [8]	n=23	3D CT scan	45.0 ± 3.8	27.9 ± 2.5	-	-	-	-	-	-
American [7]	n=10	Cadaver	45.6 ± 4.2	-	13.5 ± 1.6	11.5 ± 0.9	-	22.8 ± 2.1	18.3 ± 1.8	16.1 ± 2.3
Caucasian [20]	n=1082	Dry bones	46.0 ± 3.7	-	-	9.2 ± 1.2	-	-	15.9 ± 1.9	-
African American [20]	n=904	Dry bones	44.4 ± 4.2	-	-	9.4± 1.4	-	-	15.3 ± 2.1	-
American White [5]	n=43	Dry osteology	45.8 ± 4.2	25.1 ± 2.4	-	12.0 ± 2.0 [a]	-	-	-	-
American Black [5]	n=17	Dry osteology	43.7 ± 3.8	24.6 ± 2.4	-	11.6 ± 1.0 [a]	-	-	-	-
Canadian [6]	n=34	3D CT scan	-	-	10.5 ± 1.7	-	-	16.8 ± 2.5#	-	15 ±2.2
Canadian [16]	n=30	Cadaver	45.3 ± 4.7		10.6 ± 1.2					
SOUTH AMERICANS										
Brazilian [9]	n=30	Cadaver	42.6 ± 2.6	-	-	14.9 ± 1.2	-	-	21.1 ± 2	-
Brazilian [11]	n=61	Cadaver			8.37 ± 0.93					14.51 ± 1.90
AFRICANS										
South African [23]	n=164	Dry bones	41.7 ± 4.7	-	-	-	-	-	13.3 ±1.9	-
Egyptian [13]	n=248	Dry bones	41.1 ± 4.6							

 # - described as 'total length'; a – described as 'base height'; b – described as 'coracoid height'

dimensions of the process concerning specific race and ethnicity. It is well known that there are racial differences in bone geometry and dimensions. Further, there are also gender-based differences in the size of the bones. It is imperative to define the morphological differences among distinct races and gender, considering the surgical importance of this bony process. In the Indian population, the morphometric studies on the coracoid process have been predominantly conducted using dry bones (Table 2) [25-33]. Further, anatomic measurements of the coracoid process have been performed using embalmed cadavers, and a safety zone for the osteotomy of the coracoid has been defined [28].

A computer tomography (CT) scan is the investigation of choice for assessing the glenoid bone loss in recurrent shoulder instability. The dimensions of the coracoid process can be measured in the same CT study if a bone block procedure is contemplated for shoulder instability. In such a clinical scenario, an accurate pre-operative assessment of the available coracoid process for the planned transfer procedure becomes critical. Recently, it has been recommended to pre-operatively assess the coracoid dimensions based on which accurate graft position can be contemplated to restore the anatomical anterior-posterior diameter of the glenoid cavity [34].

Table II: DIFFERENCES IN THE DIMENSIONS OF THE CORACOID PROCESS IN THE INDIAN STUDIES

Parameters	Present study	Punjab [26]	Delhi	Delhi	Telangana	Haryana	Bengaluru	Orissa	Maharashtra
	(South India)		31	27	30	33	32	29	25
Cases	(n=187)	(n=100)	(n=69)	(n=64)	(n=50)	(n=50)	(n=60)	(n=42)	n=50
Method	3D CT Scan	Dry bone	Dry Bone	Dry bones	Dry bone	Dry bone	Dry bone	Dry bone	Dry bones
TOTAL LENGTH	40.11 ± 1.36	40.43	40.45 ± 4.434	41.01±3.55 (R)	39.04 ± 4.16	35.54	36.8 ± 3.6	38.73 ± 3.72	40.01 ±4.05
				40.88±3.83 (L)					
BASE LENGTH	20.45 ± 2.26								
MIDPOINT HEIGHT	10.91 ± 1.02			8.59±1.32 (R)					
				8.01±1.16 (L)					
TIP HEIGHT	9.24 ± 1.05	7.83	8.54 ± 1.705			7.95		8.61 ± 1.89	
BASE HEIGHT	14.5 ± 0.86	15.62				20.1		12.91 ± 2.88	
TIP LENGTH	20.56 ± 1.67								
TIP WIDTH	13.01 ± 0.97								
MIDPOINT WIDTH	14.41 ± 0.96	13.77	14.16 ± 2.386	13.93±1.13 (R)		14.5		14.28 ± 2.36	
				13.25±1.26 (L)					

(R) – Right side; (L) – Left side

Table III: GENDER DIFFERENCES IN THE DIMENSIONS OF THE CORACOID PROCESS

VIEW	TOTAL (n=187)	MALES (n=120)	FEMALES (n=67)	P value
AGE (YEARS)	30.66 ± 7.21	30.49 ± 7.15	30.98 ± 7.37	0.65
TOTAL LENGTH (CORONAL VIEW)	40.11± 1.36	40.44 ± 1.29	39.53± 1.28	< 0.001
BASE LENGTH (CORONAL VIEW)	20.45 ± 2.26	21.01 ± 2.31	19.46± 1.78	< 0.001
MIDPOINT HEIGHT (CORONAL VIEW)	10.91 ± 1.02	11.23 ± 1.01	10.24 ± 0.64	< 0.001
TIP HEIGHT (CORONAL VIEW)	9.24 ± 1.05	9.47 ±1.07	8.83±0.88	< 0.001
BASE HEIGHT (LATERAL VIEW)	14.5 ± 0.86	14.92 ± 0.63	13.75 ± 0.7	< 0.001
TIP LENGTH (SUPERIOR VIEW)	20.56 ± 1.67	21.1 ± 1.61	19.58 ± 1.3	< 0.001
TIP WIDTH (SUPERIOR VIEW)	13.01± 0.97	13.28 ± 0.84	12.53± 1.0	< 0.001
MIDPOINT WIDTH (SUPERIOR VIEW)	14.41± 0.96	14.91 ± 0.59	13.5± 0.84	< 0.001

Table IV: SIDE DIFFERENCES IN THE DIMENSIONS OF THE CORACOID PROCESS

VIEW	RIGHT SIDE (n=94)	LEFT SIDE (n=93)	P value
AGE (YEARS)	30.48 ± 7.58	30.84 ± 6.86	0.73
TOTAL LENGTH (CORONAL VIEW)	40.15 ± 1.52	40.08 ± 1.17	0.73
BASE LENGTH (CORONAL VIEW)	20.55 ± 2.31	20.35 ± 2.21	0.55
MIDPOINT HEIGHT (CORONAL VIEW)	10.96 ± 1.01	10.87 ± 1.04	0.55
TIP HEIGHT (CORONAL VIEW)	9.25 ± 0.97	9.24±1.12	0.99
BASE HEIGHT (LATERAL VIEW)	14.5 ± 0.98	14.49 ± 0.72	0.92
TIP LENGTH (SUPERIOR VIEW)	20.57 ± 1.74	20.54 ± 1.61	0.87
TIP WIDTH (SUPERIOR VIEW)	13.06 ± 1.08	12.99 ± 0.85	0.77
MIDPOINT WIDTH (SUPERIOR VIEW)	14.43 ± 0.95	14.39 ± 0.98	0.77

Figure 1: Three-dimensional computer tomography image in coronal view– measurements of total coracoid length and midpoint height (a), base length (b), and tip height (c).

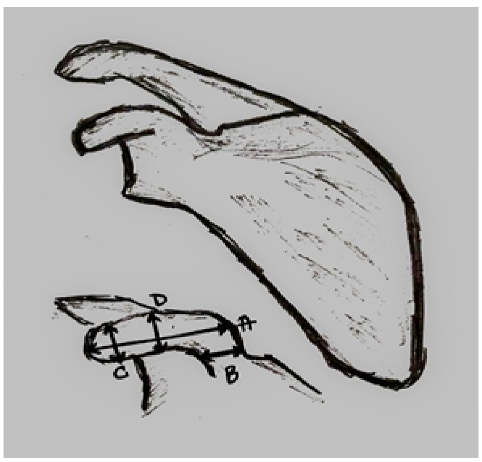

Figure 2: Illustrations showing measurements in coronal view. A – total length; B – base length; C – tip height; D – midpoint height.

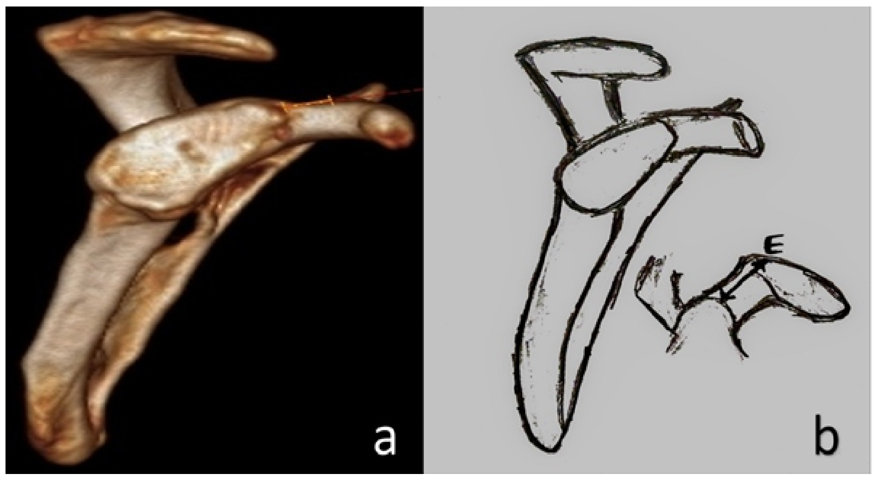

Figure 3: (a) Three-dimensional computer tomography image in lateral view – measurements of the base height. (b): Illustrations showing measurements in lateral view. E – Base height.

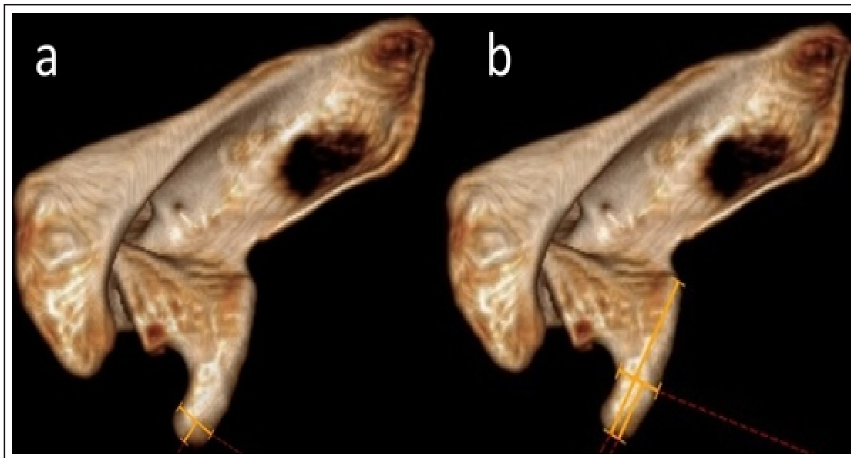

Figure 4: Three-dimensional computer tomography image in superior view – measurements of tip width (a), and tip length and midpoint width (b).

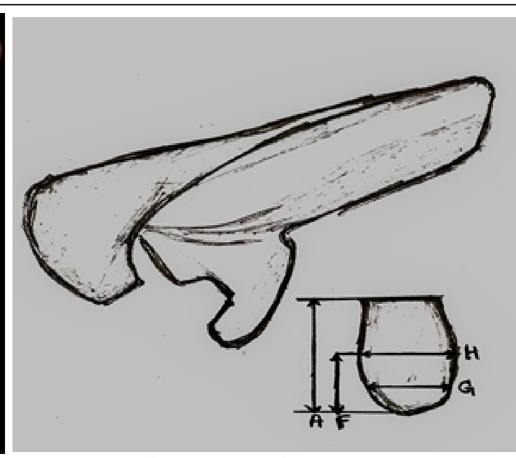

Figure 5: Illustrations showing measurements in superior view. A – Total length; F – tip length; G – tip width; H – midpoint width

Hence, a familiarity with the dimensions of the coracoid process on CT scans and population-based baseline data provided to the shoulder surgeons would be more valuable and clinically relevant. A CT scan based morphometric assessment of the coracoid process has been performed in the Chinese and Malay populations [10, 21, 22]. However, no studies have been conducted in the Indian population using CT scans. Further, we have also compared the coracoid process measurements with other morphometric studies conducted in different races and ethnicities.

Materials and Methods

A retrospective observational single-center study was conducted after obtaining the Institutional Ethical Clearance (IEC:480/2018). The 3D CT images of all the patients that were performed for either shoulder instability or trauma around the shoulder (fractures of the proximal humerus or clavicle with intact scapula) between January 2015 and July 2018 were retrieved from the Archives of Radiology. Images of both gender and skeletally mature patients (age 20–60 years) were included in the study. All the images were from the patients belonging to one of the South Indian states. Any fractures or tumors involving the coracoid process, or previous history of surgery involving the coracoid process were excluded from the study.

All CT scans had been performed on a Philips brilliance 64 slice CT scanner (Netherlands). The scan covered an area from the AC joint through the proximal humeral diaphysis, including the scapula in craniocaudal orientation. The scanning protocol was as follows:

· The scan and display field of view was 150 mm
· Pitch of 0.99
· Collimation of 128 mm × 0.625mm
· Rotation time of 0.75 s
· The window level was 800, and the window width was 2000
· Kilovoltage (kV) 120
· Images were reconstructed at a 0.9 mm thickness with an increment of 0.5 mm.

Post-processing, the images had been reconstructed at a 0.9 mm slice thickness in multiplanar reconstruction and maximum-intensity-projection images and volume rendering. The image analyses were performed using Philips 3D maximum intensity projection with direct body bone removal. The images from 3D reconstructed CT scan of the shoulder joints were cropped and devoid of the humerus. All the measurements were done using digital calipers on the same final images by two observers who were blinded to each other's data, and an average of their measurements was considered.

We adopted the parameters for the morphometric assessment of the coracoid process using 3D CT scans from previously described studies conducted in Malay and Chinese population [10, 22]. The objective was to ensure uniformity in comparison of measurements between the races. In three different views (coronal, superior, and lateral), a total of eight measurements of the coracoid process were measured in millimeters (mm):

· Total length (in coronal view): Was the distance from the tip of the coracoid process to the anterior end of the scapular notch at the superior scapular border (Fig. 1a and Fig. 2)
· Base length (in coronal view): Was the maximum mediolateral distance of the base. (Fig. 1b and Fig. 2)
· Tip height (in coronal view): Was the maximum superoinferior distance 1 cm posterior to the tip (Fig. 1c and Fig. 2)
· Midpoint height (in coronal view): Was the maximum superoinferior distance at the midpoint of the total length (Fig. 1c and Fig. 2)
· Base height (in lateral view): Was the maximum superoinferior distance of the base. (Fig. 3a and 3b)
· Tip length (in superior view): Was the maximum distance from tip to the midpoint (Fig. 4a and Fig. 5)
· Tip width (in superior view): Was the maximum mediolateral distance of the tip. (Fig. 4b and Fig. 5)
· Midpoint width (in superior view): Maximum width at the midpoint of the total length (Fig. 4b and Fig. 5)

The age, gender of the patient, and the side were recorded for making comparisons. A two-tailed independent t-test for each measurement was performed to evaluate the gender and side differences. $P < 0.05$ was considered statistically significant. Each parameter was recorded, and IBM SPSS (version 25) software was used for the final analysis. Similar measurements performed in different races and ethnicities and previous studies conducted on dry bones in India were tabulated and compared with the present study.

Results

The results were presented as mean and standard deviation. The CT images of 208 cases were retrieved from the records, of which 187 cases fulfilled the inclusion criteria. There were 120 males and 67 females. The average age of the study population was 30.66 ± 7.21 years. The average length of coracoid was 40.11 ± 1.36 mm. Overall dimensions of tip of coracoid were 20.56 ± 1.67 mm (length), 13.01 ± 0.97 mm (width), and 9.24 ± 1.05 mm (height). Overall dimensions of the base of coracoid were 20.45 ± 2.26 mm (length) and 14.5 ± 0.86 mm (height). All the measurements were larger in males compared with females ($P < 0.05$) (Table 3). The side difference for all measurements was not statistically significant ($P > 0.05$) (Table 4). The mean coracoid width was greater than the mean coracoid thickness ($P < 0.00001$).

Further, we compared all the measurements between the Indian population and the populations from different races/ethnicities (Table 1) and other morphometric studies conducted in India (Table 2). The coracoid process dimensions in Indian population were smaller than the Western population but similar to the Asian population. Further, the overall coracoid dimensions were also similar to the measurements previously reported in the Indian studies using dry bones.

Discussion

There are several strengths identified in our study. Our study provides a unique baseline data on the coracoid process dimensions in the Indian population based on 3D CT scans. New parameters such as the base length, tip length, and the tip width that was previously unreported in any series from the Indian studies, but reported in other races/ethnicities, have been provided. Among the CT-based morphometric studies, we measured the coracoid process dimensions in the largest number of cases (n = 187) (Table 1). The study images obtained were from exclusively a homogenous South Indian population as compared with mixed races, as seen in some studies [10]. Further, we have compared the coracoid process measurements with other morphometric studies conducted in different races and ethnicities. Finally, we measured the coracoid process dimensions in different views (coronal, superior, and lateral views) to provide a comprehensive morphological assessment.

Gender differences

A vast number of morphometric studies have noted that all the measurements were larger in males than females [4, 5, 8, 21, 22]. Our results concur with these studies. However, Imma et al. noted no significant gender-related differences in the measurements for base height, tip length, and midpoint width [10]. No gender-based differences could be ascertained from previous Indian studies as most of them were conducted predominantly on the dry bones. This gender differences in all the measurements, as noted in the index study, should caution the shoulder surgeons when contemplating interventions involving the coracoid process, especially in females. When the harvested graft length and width is small, the placement of two screws can be challenging and increase the risk of iatrogenic fractures. A smaller implant system to secure the graft has been recommended to maintain a "safe distance" [14].

Side differences

We noted that there were no statistically significant side differences in all the measurements. Similar observations were reported by Fathi et al. where no side differences were observed in the Anatomical study of Formalin-fixed Cadaveric Shoulders of ethnic groups comprising Chinese, Indians, and Myanmarese. Further, in their radiological study of ethnic groups consisting of Chinese and Malays, the side differences in all measurements were also non-significant [21]. In contrast to these findings, in one of the Indian studies, the difference between the two sides in the coracoid breadth was statistically significant (P = 0.026). However, the difference between the sides for the length or thickness of the coracoid process was not statistically significant [27].

Racial/Ethnic differences

It is challenging to make comparisons among different races for three reasons: First, the measurements are performed in diverse specimens comprising of cadaveric shoulders, dry bones, or radiological images. Second, there is a lack of standardization in defining the parameters and the reference points for taking the measurements. Finally, each study has performed a "set" of measurements, and there is a lack of consensus on which "set" of measurements is clinically relevant.

Among all the parameters, the tip length is perhaps the most ambiguous and confusing. According to Lo et al. the coracoid tip was defined as that portion of the bone that was distal to the "elbow" of the coracoid [24]. This "elbow" or "knee" has been described as the bony area that is anterior to the trapezoid ligament [18]. Whereas, others have described it as a "Precipice" – a specific point at which the coracoidal undersurface propagation changes from a horizontal to a vertical direction [4]. Other studies, conducted on the radiological images, considered the "tip" as the part between the coracoid tip and the midpoint of total length [10, 22]. We too have considered the "tip length" in a similar fashion (Fig. 5a and Fig. 6). The objective was to provide uniformity for making comparisons between the races. In the classification of coracoid fractures by Eyres et al., a "tip" fracture is type I and has been considered similar to an epiphyseal fracture [35]. Interestingly, no standard textbooks of anatomy or osteology have attempted to define what exactly constitutes the "tip" of the coracoid process.

Some authors have considered the "total length" of the coracoid process itself as the distance from the tip to elbow region (by measuring the undersurface length) [6, 14, 36]. This consideration results in a smaller measurement as compared with the majority of the studies that considered the "total length" as the distance from tip to the base/anterior end of the scapular notch (by measuring the longer superior surface length) [4, 5, 10, 21-23].

Ideally, we believe, a "tip length" would be clinically relevant when measured between the tip and the anterior margin of the coracoclavicular ligament attachment. This measurement gives the exact value of the harvestable graft for the Latarjet procedure. This measurement is possible either intraoperatively or in cadaver specimens. The accurate identification of the landmark of coracoclavicular ligament attachment in the dry bones or CT scans is not feasible.

Thus, as an alternative, in CT based studies, an arbitrary midpoint of the total length is taken as a landmark, and the distance is measured from the tip to this midpoint. This midpoint is located distal to the coracoclavicular ligament attachment, as noted by Dolan et al. [7]. This value would be suggestive of minimum coracoid graft length available for the transfer procedure. Based on this concept, an average of 20.56 ± 1.67 mm of coracoid graft can be comfortably harvested in our population without violating the coracoclavicular ligament attachment. This observation is similar to the values seen in the Malay and Chinese population, which was assessed in a similar fashion using 3DCT scan [10, 22].

Comparison with Indian studies

Most of the Indian morphometric studies were conducted predominantly on the dry bones, some limited studies on cadaveric specimens, and none on the radiological images. This diversity results in limitations in making suitable comparisons. As noted in the studies conducted in different races and ethnic populations, there is a lack of standardization in defining the reference points and specific "set" of measurements. None of these studies attempted to measure the base length, tip length, and the tip width, making the index series primary baseline data and reference value for the Indian population for future research. We noted that the average total length (40.11 ± 1.36 mm) in the present study was found to be similar to most of the studies conducted in different centers of India [25-27, 31]. Likewise, the average midpoint width (14.41 ± 0.96 mm) in the present study was found to be similar to most of the studies [29, 31, 33]. Only one study had measured the midpoint height (coracoid thickness) and was found to be smaller than the measurement in the present study (10.91 ± 1.02 mm) [27].

Surgical importance

One of the critical steps of the coracoid transfer procedure is obtaining an adequate graft size to compensate for the glenoid bone loss. Recent trends in the United States show that there is a consistent increase in the number of bone block procedures in the management of shoulder instability [37]. Among the different types of bone block procedures, the coracoid transfer appears to be the surgical technique of choice when anterior instability is present in combination with the glenoid bone loss [38]. Although there are no data available on the trends among Indian Shoulder surgeons, the surgical management of shoulder instability is becoming widely popular. A subset of these cases with significant glenoid bone loss necessitates a bone block procedure. Furthermore, bone block procedures have been advocated in patients with significant laxity and failed prior shoulder stabilization surgery [37].

A Latarjet surgery is a technically challenging procedure. Harvesting, preparation, and placement of the coracoid graft are the three crucial steps that determine the successful outcome of the procedure. A Congruent Arc Latarjet is a modification of the original procedure where the harvested graft is turned 90° such that the inferior aspect of the coracoid is used as the glenoid face [39]. Thus, as compared with the thickness (classical Latarjet), the available width of the coracoid, is more crucial in restoring the glenoid bone loss. These parameters can be easily measured from the CT scans and are useful in pre-operative planning. We found that the mean coracoid width was greater than the mean coracoid thickness ($P < 0.00001$), which is similar to the observation made by Armitage et al. [6]. These dimensions make it suitable for a Congruent Arc Latarjet procedure where a larger glenoid bone defect can be reconstituted.

In a cadaveric study, an average length of 2.6 ± 1.1 cm has been defined as a safety margin for the coracoid osteotomy in the Indian population. This value is larger than the Japanese (24.8 ± 3.4mm) [19] and smaller than the Caucasians (28.5 ± 5.1 mm) [7]. However, this measurement is possible only in cadaveric specimens and not helpful for pre-operative assessment. In the morphometric studies using 3D CT scans, including the present study, a tip to midpoint length is used to ascertain the minimum harvestable coracoid graft length. Furthermore, apart from the "ideal" graft length required for the transfer procedure, an accurate measurement of the transverse width is equally essential. A recent study by Boutsiadis et al. observed that using conventional 4.5 mm screws for fixation of the coracoid graft results in a narrow gap from the mediolateral limit of the coracoid and creates risk for fractures. With an average coracoid width of 13.6 ± 2 mm and thickness of 8.7 ± 1.3 mm, they noted that the "safe distance" for a conventional 4.5 mm malleolar screw was present in 56% of the cases, with the 3.75 mm screws in 85%, with the 3.5 mm screws in 87%, and with the 2.8 mm button in 98% of the cases. Thus, they recommended using smaller button implants to avoid the risk of fixation failure due to cortical breach [14]. In comparison, the average midpoint width of 14.41 ± 0.96 mm and a midpoint height (thickness) of 10.91 ± 1.02 mm noted in the present study are larger than the study population of Boutsiadis et al., thereby increasing the margin for "safe distance" in our population.

Similarly, awareness of the average transverse width of the coracoid process would be beneficial when contemplating the coracoclavicular ligament reconstruction/stabilization. A transverse width of the given bone should be sufficient to accommodate the intended drill hole and subsequently, a graft/implant. However, Coale et al. observed that attempts to drill a tunnel (6 mm diameter) at the anatomic footprint of coracoclavicular ligaments resulted in a medial cortical breach of the coracoid in 91.3% of the shoulders [8]. However, most of the modern implant systems used for coracoclavicular ligament reconstruction have evolved and employ smaller diameter drills. For example, AC TightRope® (Arthrex) requires a 3 mm cannulated drill and for the Dog Bone™ Button (Arthrex) a 2.4- or 3-mm cannulated drill is needed. These smaller tunnels minimize the risk from potential fractures without compromising the stabilization. A midpoint width of 14.41 ± 0.96 mm, as noted in this study, would be sufficient to accommodate this tunnel without any significant risk of fractures through the walls.

Finally, there are limited studies that have attempted to define the dimensions of the coracoid base. Eyres et al. had described a classification system for the coracoid fractures and observed that a basal fracture (type III) is the most common type [35]. Conventionally, a 4.0/4.5 mm cancellous screw is used to stabilize a displaced fracture. Thus, awareness about the dimensions of the base of the coracoid that can accommodate the intended screw would be clinically valuable. With an average base length of 20.45 ± 2.26 mm observed in the present study, it is possible to place the desired screw well within the base of the coracoid process.

Limitation

Due to the inherent complex morphology of the coracoid process, there are several measurements employed to define the dimensions, and there is no consensus on the most suitable technique. Moreover, the literature is ambiguous regarding ideal reference points and landmarks on the bone for making suitable measurements. This uncertainty leads to limitations in making an appropriate comparison of measurements between distinct races and ethnicities. Furthermore, comparing the radiological measurements with studies conducted in cadaveric specimens or even dry bones can be challenging due to difficulty in identifying the landmarks accurately. Armitage et al. had observed that the values of their measurements conducted on the 3D CT models were similar to the values previously reported from the cadaveric and imaging studies [6]. However, without a gold standard model, it is difficult to make a comparison of values on different specimens. Thus, to ensure uniformity and facilitate comparisons between the races, we adopted the methodology of using 3D CT scans previously described in the Malay and Chinese population [10, 22]. Finally, as none of the studies had reported all the eight measurements, comparisons between these races/ethnicities would not be accurate or reliable.

Conclusion

This study provides a comprehensive baseline data on the morphometry of the coracoid process in the South Indian population. All the measurements were larger in males. The coracoid process dimensions in the Indian population were smaller than the western population, but similar to the Asian population. Further, the overall coracoid dimensions were also similar to the measurements previously reported in the Indian studies using dry bones. The mean coracoid width was significantly larger than the mean coracoid thickness making the dimensions suitable for a congruent arc Latarjet procedure.

References

1. Latarjet M. Technic of coracoid preglenoid arthroereisis in the treatment of recurrent dislocation of the shoulder. Lyon Chir 1958;54:604-7.
2. Gumina S, Postacchini F, Orsina L, Cinotti G. The morphometry of the coracoid process-its aetiologic role in subcoracoid impingement syndrome. Int Orthop 1999;23:198-201.
3. Coskun N, Karaali K, Cevikol C, Demirel BM, Sindel M. Anatomical basics and variations of the scapula in Turkish adults. Saudi Med J 2006;27:1320-5.
4. Salzmann GM, Paul J, Sandmann GH, Imhoff AB, Schöttle PB. The coracoidal insertion of the coracoclavicular ligaments: An anatomic study. Am J Sports Med 2008;36:2392-7.
5. Rios CG, Arciero RA, Mazzocca AD. Anatomy of the clavicle and coracoid process for reconstruction of the coracoclavicular ligaments. Am J Sports Med 2007;35:811-7.
6. Armitage MS, Elkinson I, Giles JW, Athwal GS. An anatomic, computed tomographic assessment of the coracoid process with special reference to the congruent-arc latarjet procedure. Arthroscopy 2011;27:1485-9.
7. Dolan CM, Hariri S, Hart ND, McAdams TR. An anatomic study of the coracoid process as it relates to bone transfer procedures. J Shoulder Elbow Surg 2011;20:497-501.
8. Coale RM, Hollister SJ, Dines JS, Allen AA, Bedi A. Anatomic considerations of transclavicular-transcoracoid drilling for coracoclavicular ligament reconstruction. J Shoulder Elbow Surg 2013;22:137-44.
9. Terra BB, Ejnisman B, De Figueiredo EA, Cohen C, Monteiro GC, De Castro Pochini A, et al. Anatomic study of the coracoid process: Safety margin and practical implications. Arthroscopy 2013;29:25-30.
10. Imma II, Nizlan MN, Ezamin AR, Yusoff S, Shukur MH. Coracoid process morphology using 3D-CT imaging in a Malaysian population. Malays Orthop J 2017;11:30-5.
11. Bueno RS, Ikemoto RY, Nascimento LG, Almeida LH, Strose E, Murachovsky J. Correlation of coracoid thickness and glenoid width: An anatomic morphometric analysis. Am J Sports Med 2012;40:1664-7.
12. Cho BP. Articular facets of the coracoclavicular joint in Koreans. Acta Anat (Basel) 1998;163:56-62.
13. Gallino M, Santamaria E, Doro T. Anthropometry of the scapula: Clinical and

surgical considerations. J Shoulder Elbow Surg 1998;7:284-91.

14. *Boutsiadis A, Bampis I, Swan J, Barth J. Best implant choice for coracoid graft fixation during the latarjet procedure depends on patients' morphometric considerations. J Exp Orthop 2020;7:15.*
15. *Piyawinijwong S, Sirisathira N, Chuncharunee A. The scapula: Osseous dimensions and gender dimorphism in Thais. Siriraj Hosp Gaz 2004;56:356-65.*
16. *Von Schroeder HP, Kuiper SD, Botte MJ. Osseous anatomy of the scapula. Clin Orthop Relat Res 2001;383:131-9.*
17. *Cirpan S, Yonguc GN, Güvençer M. Morphometric analysis of coracoid process and glenoid cavity in terms of surgical approaches: An anatomical study. Kocaeli Med J 2018;7:131-7.*
18. *Lian J, Dong L, Zhao Y, Sun J, Zhang W, Gao C. Anatomical study of the coracoid process in Mongolian male cadavers using the latarjet procedure. J Orthop Surg Res 2016;11:126.*
19. *Shibata T, Izaki T, Miyake S, Doi N, Arashiro Y, Shibata Y, et al. Predictors of safety margin for coracoid transfer: A cadaveric morphometric analysis. J Orthop Surg Res 2019;14:10-5.*
20. *Knapik DM, Cumsky J, Tanenbaum JE, Voos JE, Gillespie RJ. Differences in coracoid and glenoid dimensions based on sex, race, and age: Implications for use of the latarjet technique in glenoid reconstruction. HSS J 2018;14:238-44.*
21. *Fathi M, Cheah PS, Ahmad U, Nasir MN, San AA, Rahim EA, et al. Anatomic variation in morphometry of human coracoid process among Asian population. Biomed Res Int 2017;2017:6307019.*
22. *Jia Y, He N, Liu J, Zhang G, Zhou J, Wu D, et al. Morphometric analysis of the coracoid process and glenoid width: A 3D-CT study. J Orthop Surg Res 2020;15:1-7.*
23. *Khan R, Satyapal KS, Lazarus L, Naidoo N. An anthropometric evaluation of the scapula, with emphasis on the coracoid process and glenoid fossa in a South African population. Heliyon 2020;6:e03107.*
24. *Lo IK, Burkhart SS, Parten PM. Surgery about the coracoid: Neurovascular structures at risk. Arthroscopy 2004;20:591-5.*
25. *Chavan SR, Bhoir MM, Verma S. A study of anthropometric measurements of the human scapula in Maharashtra, India. Int J Anat 2017;1:23-6.*
26. *Rajan S, Ritika S, K.J S, Kumar S, Tripta S. Role of coracoid morphometry in subcoracoid impingement syndrome. Internet J Orthop Surg 2014;22:1-7.*
27. *Mehta V. Osteometric assessment of coracoid process of scapula-clinical implications. J Surg Acad 2018;8:3-10.*
28. *Jagiasi J, Yeotiwad G, Bhoir M, Sahu D. Anatomic measurements of the coracoid and its implication in the latarjet procedure. Int J Orthop Sci 2017;3:533-5.*
29. *Nayak G, Panda SK, Chinara PK. Acromion, coracoid and glenoid processes of scapula: An anatomical study. Int J Res Med Sci 2020;8:570.*
30. *Lingamdenne PE, Marapaka P. Measurement and analysis of anthropometric measurements of the human scapula in Telangana region, India. Int J Anat Res 2016;4:2677-83.*
31. *Kalra S, Thamke S, Khandelwal A, Khorwal G. Morphometric analysis and surgical anatomy of coracoid process and glenoid cavity. J Anat Soc India 2016;65:114-7.*
32. *Parmar T, Geethanjali BS. A study of anthropometric measurement of human dry scapula and its clinical importance. Sch Int J Anat Physiol 2019;8618:187-93.*
33. *Verma U, Singroha R, Malik P, Rathee SK. A study on morphometry of coracoid process of scapula in North Indian population. Int J Res Med Sci 2017;5:4970.*
34. *Gregori M, Eichelberger L, Gahleitner C, Hajdu S, Pretterklieber M. Relationship between the thickness of the coracoid process and latarjet graft positioning-an anatomical study on 70 embalmed scapulae. J Clin Med 2020;9:207.*
35. *Eyres KS, Brooks A, Stanley D. Fractures of the coracoid process. J Bone Joint Surg Br 1995;77:425-8.*
36. *Ljungquist KL, Butler RB, Griesser MJ, Bishop JY. Prediction of coracoid thickness using a glenoid width-based model: Implications for bone reconstruction procedures in chronic anterior shoulder instability. J Shoulder Elbow Surg 2012;21:815-21.*
37. *Bonazza NA, Liu G, Leslie DL, Dhawan A. Trends in surgical management of shoulder instability. Orthop J Sports Med 2017;5:1-7.*
38. *Zhang AL, Montgomery SR, Ngo SS, Hame SL, Wang JC, Gamradt SC. Arthroscopic versus open shoulder stabilization: Current practice patterns in the United States. Arthroscopy 2014;30:436-43.*
39. *Beer JF, Roberts C. Glenoid bone defects-open latarjet with congruent arc modification. Orthop Clin North Am 2010;41:407-15.*

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