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ORIGINAL RESEARCH

MORPHOLOGICAL MORPHOMETRIC VARIATIONS OF THE GLENOID CAVITY OF THE HUMAN SCAPULA: A DESCRIPTIVE OSTEOMETRIC STUDY

Nilesh S. Rakate[1], **Gajbhiye VM**[2]

[1] *Professor, Department of Anatomy, RKDF Medical College, Bhopal, Madhya Pradesh, India*

[2] *Professor and Head, Department of Anatomy, RKDF Medical College, Bhopal, Madhya Pradesh, India*

ABSTRACT

Background: The glenoid cavity varies considerably in outline and dimensions. Knowledge of this variation is important for shoulder arthroplasty, the management of recurrent glenohumeral instability and the design of glenoid prosthetic components, particularly in populations with limited normative data.

Methods: Sixty dry, intact adult human scapulae of unknown age and sex (30 right, 30 left) were examined. The shape of the glenoid cavity was classified by macroscopic inspection as pear-shaped, inverted comma-shaped or oval, based on the configuration of the anterior margin and the glenoid notch. The supero-inferior (height) and antero-posterior (width) diameters were measured with a digital vernier caliper, and the glenoid cavity index (width/height × 100) was calculated. Right and left sides were compared with the independent-samples Student t-test.

Results: The glenoid cavity was pear-shaped in 27 specimens (45%), inverted comma-shaped in 21 (35%) and oval in 12 (20%). The mean supero-inferior diameter was 36.42 ± 2.65 mm on the right and 35.81 ± 2.48 mm on the left ($p = 0.36$); the mean antero-posterior diameter was 25.24 ± 2.10 mm and 24.65 ± 1.95 mm, respectively ($p = 0.26$). The glenoid cavity index was similar on the two sides (69.3% right, 68.8% left).

Conclusion: The pear shape was the most common variant, and the inverted comma shape was more frequent than in most other Indian series. Glenoid dimensions did not differ significantly between sides and lie within the range reported for other Indian populations. These data provide a regional osteometric reference for shoulder arthroplasty planning and glenoid prosthesis design.

Keywords: Glenoid cavity; Glenoid cavity index; Morphometry; Scapula; Shoulder arthroplasty

INTRODUCTION

The shoulder is a multiaxial, synovial ball-and-socket joint with a range of motion greater than that of any other joint in the body. This mobility is achieved at the cost of inherent bony stability, because a large, near-hemispherical humeral head articulates with the comparatively shallow glenoid cavity of the scapula. The glenoid cavity is a pyriform articular depression at the lateral angle of the scapula; it is bordered anterosuperiorly by the glenoid notch, whose depth and configuration account for much of the variation in cavity outline [1]. Its supero-inferior dimension exceeds its antero-posterior dimension, and the cavity is broader inferiorly than superiorly, an asymmetry that gives the most common morphological variant its characteristic pear-like outline.

A diverse range of shoulder pathologies, including primary glenohumeral osteoarthritis, rheumatoid arthritis, rotator cuff tear arthropathy, post-traumatic arthritis, fracture-dislocation and avascular necrosis of the humeral head, may progress to a stage at which joint replacement becomes necessary [2]. Shoulder arthroplasty options include hemiarthroplasty, anatomical total shoulder arthroplasty (aTSA) and reverse total shoulder arthroplasty (rTSA), the last of which has become the dominant procedure over the past decade [3]. Whichever option is chosen, the success and longevity of the reconstruction depend on an accurate match between implant geometry and the native anatomy of the

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glenoid. Components that are improperly sized or positioned create eccentric loading, promote micromotion at the bone–cement or bone–implant interface, and accelerate glenoid component loosening, one of the most frequent causes of failure of anatomical total shoulder arthroplasty [4].

Detailed morphometric knowledge of the glenoid cavity is therefore essential for prosthesis design, surgical planning and clinical decision-making in glenohumeral disorders. Such data are also relevant to the management of recurrent anterior shoulder instability, since the presence and depth of the glenoid notch influence the anteroinferior bony support of the humeral head: a deeply notched, comma-shaped anterior margin reduces the articular surface available to resist anterior translation. The morphology and dimensions of the glenoid cavity have been studied extensively in Western populations, but data from Indian subpopulations remain comparatively sparse. Glenoid dimensions differ between ethnic and geographic groups, and a recent systematic review found that average Indian glenoid dimensions are smaller than those of commercially available glenoid components [5], which limits the applicability of implants designed for other populations. The present study was therefore conducted to document the morphological and morphometric characteristics of the glenoid cavity in a series of dry human scapulae from Central India and to compare the findings with those of similar studies, as a contribution to the population-specific osteometric evidence needed for safe and effective shoulder arthroplasty. Aim of the current study t o document the morphological and morphometric characteristics of the glenoid cavity of the human scapula in a series of dry specimens and to compare the findings with those reported in analogous published studies.

MATERIALS AND METHODS

Study design and specimens

This was a descriptive, cross-sectional osteometric study. Sixty dry, intact adult human scapulae (30 right and 30 left) were obtained from the bone bank of the Department of Anatomy, RKDF Medical College, Bhopal. The age and sex of the individuals from whom the bones were derived were not recorded in the bone bank records; the side of each scapula was determined from its anatomical features. The scapulae were not matched into right–left pairs from the same individual, and right and left specimens were therefore analysed as independent samples. The study was approved by the Institutional Ethics Committee of RKDF Medical College Only anonymised dry bones from a departmental collection were used, so individual consent was not applicable, in accordance with national ethical guidelines [6].

Inclusion and exclusion criteria

Scapulae were included if they were fully ossified, completely dry, macerated and structurally intact. Specimens showing any evidence of structural damage, pathological change (e.g., healed fracture, erosive disease, dysplasia) or incomplete ossification were excluded. None of the 60 available specimens met an exclusion criterion, and all were included in the study.

Parameters assessed

Two categories of measurement were made for each specimen:

Shape of the glenoid cavity. The outline of the anterior margin and the depth of the glenoid notch were assessed by direct macroscopic inspection, and each cavity was classified into one of three types following Mamatha et al. [1]: pear-shaped (a distinct but shallow notch, with the cavity narrow superiorly and broad inferiorly); inverted comma-shaped (a markedly deep notch producing a comma-like outline); and oval (no discernible notch on the anterior margin).

Linear dimensions. (i) Supero-inferior diameter (height, H): the maximum distance between the highest point of the supraglenoid tubercle and the lowest point of the inferior margin of the glenoid cavity. (ii) Antero-posterior diameter (width, W): the maximum distance between the anterior and posterior margins of the lower half of the cavity, below the glenoid notch. These landmarks follow the measurement protocol of Churchill et al. [7]. All measurements were made in millimetres with a digital vernier caliper (least count 0.01 mm); each measurement was repeated three times, and the mean of the three readings was recorded. The glenoid cavity index (GCI), which expresses width as a proportion of height, was calculated for each specimen as GCI (%) = (W/H) × 100.

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Statistical analysis

Data were entered into Microsoft Excel and analysed with SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables are expressed as mean ± standard deviation (SD), and the frequencies of morphological types as numbers and percentages, overall and by side. Right and left sides were compared for the supero-inferior diameter, antero-posterior diameter and GCI with the independent-samples Student t-test. A two-sided p value < 0.05 was considered statistically significant [8].

RESULTS

Morphological variation (shape)

Macroscopic examination revealed three distinct morphological patterns, defined by the configuration of the anterior margin and the depth of the glenoid notch (Figure 1). The pear shape was the most common, observed in 27 of 60 specimens (45.0%; 14 right, 13 left). The inverted comma shape was present in 21 specimens (35.0%; 11 right, 10 left). The oval shape, characterised by the absence of a discernible anterior notch, was the least frequent, observed in 12 specimens (20.0%; 5 right, 7 left) (Table 1).

Table 1. Distribution of glenoid cavity morphological types (n = 60)

Shape	Right (n = 30)	Left (n = 30)	Total (n = 60)	Percentage (%)
Pear-shaped	14	13	27	45.0
Inverted comma-shaped	11	10	21	35.0
Oval-shaped	5	7	12	20.0
Total	30	30	60	100.0

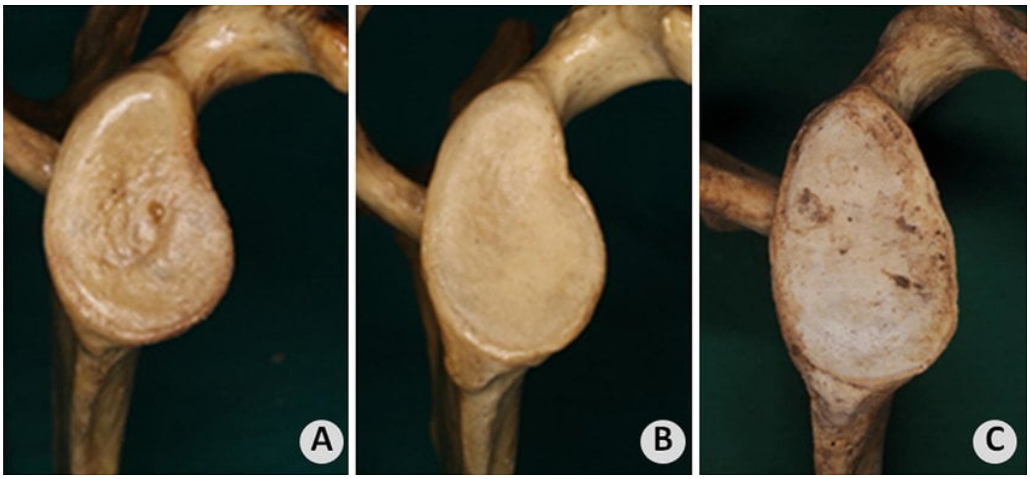


Figure 1. Representative photographs of the three morphological types of glenoid cavity: (A) pear-shaped, with a distinct but shallow anterior notch; (B) inverted comma-shaped, with a deep anterior notch; (C) oval, with no anterior notch.

Morphometric variation (dimensions)

The mean supero-inferior diameter (height) was 36.42 ± 2.65 mm on the right and 35.81 ± 2.48 mm on the left (combined mean 36.11 mm; p = 0.36). The mean antero-posterior diameter (width) was 25.24 ± 2.10 mm on the right and 24.65 ± 1.95 mm on the left (combined mean 24.94 mm; p = 0.26). Neither diameter differed significantly between sides. The mean glenoid cavity index was [69.3 ± SD]% on the right and [68.8 ± SD]% on the left (p = [value]) (Table 2).

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Table 2. Morphometric measurements of the glenoid cavity by side

Parameter	Right (n = 30)	Left (n = 30)	Combined mean	p value
Supero-inferior diameter, mm	36.42 ± 2.65	35.81 ± 2.48	36.11	0.36
Antero-posterior diameter, mm	25.24 ± 2.10	24.65 ± 1.95	24.94	0.26
Glenoid cavity index, %	[69.30 ± SD]	[68.83 ± SD]	[69.06]	[p]

Values are mean ± SD. p values from the independent-samples Student t-test. Glenoid cavity index = (antero-posterior diameter / supero-inferior diameter) × 100, calculated for each specimen.

DISCUSSION

Precise anatomical knowledge of glenoid cavity morphology has become increasingly important as shoulder replacement surgery has expanded in volume and complexity. In the present series of 60 dry adult human scapulae, three morphological types were identified: pear-shaped (45%), inverted comma-shaped (35%) and oval (20%). Glenoid dimensions were slightly greater on the right than on the left, but neither diameter differed significantly between sides.

The predominance of the pear shape is consistent with previous Indian studies (Table 3). Mamatha et al. [1] found the pear shape in 45% of South Indian scapulae, and frequencies of 44–50% have been reported in other Indian series [9–13]; the 45% found in the present study lies within this range. The present series differs, however, in the relative frequency of the other two types. The inverted comma shape was the second most common type here (35%), similar to the frequencies reported by Mamatha et al. [1] (33%) and Akhtar et al. [13] (36%) but higher than the 17–22% reported in several other series [9–12], in which the oval shape was the second most common type (34–37%). These differences may reflect genuine regional variation, but they probably also reflect differences between observers in the threshold at which a notch is judged to be deep, since the classification is made by visual inspection.

The morphological classification has clinical relevance beyond its anatomical interest. A deeply notched anterior rim (the inverted comma shape) reduces the articular surface opposing anterior translation of the humeral head and has been associated with a higher likelihood of anterior glenohumeral instability [14]. Awareness of this variant is therefore important when planning surgery for recurrent dislocation, since the deficient anterior bony support may need to be addressed by bone grafting or a bone-block procedure.

The mean supero-inferior diameter of 36.11 mm and antero-posterior diameter of 24.94 mm recorded in this study lie within the range reported in other Indian series (Table 4). They are larger than the values reported by Mamatha et al. [1] (33.8 mm and 23.2 mm) and Singh et al. [11] (34.2 mm and 23.9 mm), close to those reported by Joshi and Pakhale [9], Kataria et al. [10] and Akhtar et al. [13] (34.9–35.8 mm and 23.2–24.1 mm), and smaller than the supero-inferior diameter reported by Vaishnani et al. [12] (38.3 mm). This moderate inter-study variation probably reflects both regional differences in skeletal size within India and methodological factors such as specimen source, landmark definition, measurement technique and sample size. A systematic review of Indian studies has shown that average Indian glenoid dimensions are smaller than those of all commercially available glenoid components [5]; population-specific normative data of the kind reported here are therefore valuable for regional implant planning.

Both diameters were slightly larger on the right than on the left, but the differences were small (about 0.6 mm) and not statistically significant, and the glenoid cavity index was almost identical on the two sides. Mamatha et al. [1] and Akhtar et al. [13] likewise found no significant bilateral differences in glenoid dimensions, although Kataria et al. [10] reported a significant side difference in antero-posterior diameter. Asymmetric loading of the dominant upper limb is known to influence the skeletal morphology of the shoulder region, as shown for humeral torsion in throwing athletes [15], and a small right-sided predominance would be compatible with right-hand dominance. However, handedness was not known for the present specimens, and the data do not establish any such effect.

The glenoid cavity index is also of practical relevance in shoulder arthroplasty. A relatively narrow, more pyriform glenoid (lower index) provides less bone to support a symmetric glenoid component or baseplate and increases the risk

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of component overhang, whereas a relatively wide glenoid (higher index) accommodates a round or oval component more readily. Knowledge of the expected glenoid size and index in a given population therefore allows the size range and aspect ratio of glenoid components to be matched to native anatomy, reducing the risk of component mismatch, edge loading and eccentric wear [5,7].

Comparison with previously published studies

The shape distributions and mean dimensions observed in the present study are compared with those of six published Indian series in Tables 3 and 4. Where a study reported right and left sides separately, combined values were calculated from the side- specific data. The pear shape was the most common type in every series (44– 50%), whereas the frequencies of the inverted comma shape (17– 36%) and the oval shape (14– 37%) varied more widely, which may reflect both population differences and differences in how strictly a deep notch was defined by individual investigators.

Table 3. Comparison of glenoid cavity shape distribution with published studies

Author(s)	Year	n	Pear (%)	Inverted comma (%)	Oval (%)
Present study	2026	60	45.0	35.0	20.0
Joshi M, Pakhale SV [9]	2023	180	46.1	17.2	36.7
Kataria SK et al. [10]	2022	120	45.8	19.2	35.0
Singh A et al. [11]	2019	100	44.0	22.0	34.0
Vaishnani H et al. [12]	2018	74	45.9	17.6	36.5
Akhtar MJ et al. [13]	2016	228	50.4	36.0	13.6
Mamatha T et al. [1]	2011	202	44.6	33.2	22.3

n, number of scapulae. Percentages for Joshi and Pakhale [9], Vaishnani et al. [12] and Mamatha et al. [1] were calculated from the side-specific counts reported in the original papers; other values are as published.

Table 4. Comparison of mean glenoid cavity dimensions (combined, mm) with published studies

Author(s)	Year	Supero-inferior diameter (mm)	Antero-posterior diameter (mm)
Present study	2026	36.1	24.9
Joshi M, Pakhale SV [9]	2023	35.5	24.1
Kataria SK et al. [10]	2022	34.9	23.2
Singh A et al. [11]	2019	34.2	23.9
Vaishnani H et al. [12]	2018	38.3	24.5
Akhtar MJ et al. [13]	2016	35.8	23.6
Mamatha T et al. [1]	2011	33.8	23.2

Antero-posterior diameter refers to the maximum width of the lower half of the glenoid cavity (AP-1 where two widths were reported). Where only side-specific means were published, combined values were calculated as means weighted by the number of specimens on each side.

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Limitations

The main limitation of this study is the sample of 60 specimens, which, although comparable to that of other osteometric studies of the glenoid, limits the precision of the shape frequency estimates and the power of the bilateral comparison. The age, sex and handedness of the individuals from whom the scapulae were derived were not available, which prevented adjustment for these covariates; in particular, the possible influence of hand dominance on glenoid dimensions could not be examined. Classification of glenoid shape by visual inspection, although the standard approach in the literature, is inherently subjective, and inter-observer and intra-observer reliability were not assessed. Comparison with published series is further limited by differences in landmark definitions and in the criteria used to classify shape. Future studies with larger, demographically characterised samples and computed-tomographic measurement allowing three-dimensional analysis would strengthen the osteometric evidence base for this region.

CONCLUSION

The glenoid cavity of the human scapula is morphologically diverse. In this series of 60 dry adult scapulae from a Central Indian collection, the pear-shaped cavity was the most frequent type (45%), followed by the inverted comma (35%) and oval (20%) types. The mean supero-inferior and antero-posterior diameters (36.11 mm and 24.94 mm) did not differ significantly between sides and lie within the range reported for other Indian series. These data add to the population-specific osteometric evidence needed to inform the sizing and design of glenoid prosthetic components and the surgical management of glenohumeral disorders.

Conflicts of interest: The authors declare no conflict of interest.

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Data availability: The data supporting the findings of this study are available from the corresponding author on reasonable request.

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