E-ISSN 2250-0944
ISSN 2250-1150
doi: 10.31838/ijprt/16.02.431

Research Article

Morphometric Analysis of the Glenoid Cavity in Adult Human Dry Scapulae from Central India: A Population-Specific Reference Study with Surgical and Forensic Correlation

Shailendra Singh[1], Avantika Bamne[2*]
[1,2*]Department of Medical Anatomy, Malwanchal University, Indore, Madhya Pradesh, India.
Corresponding Author: Dr. Avantika Bamne
Department of Medical Anatomy, Index Medical College, Hospital and Research Center, Indore (M.P.) 452016, India.
Received: 29.06.26, Revised: 02.08.26, Accepted: 31.08.26

ABSTRACT
Background: Glenoid cavity morphometry underlies the sizing of prosthetic glenoid components in shoulder arthroplasty and carries independent forensic value, yet reference values are well documented to vary between populations and between neighbouring regions within India. No dry-bone morphometric dataset previously existed for the Malwa region of Madhya Pradesh.
Objective: To determine the linear dimensions, glenoid cavity index, shape distribution, and surface area of the glenoid cavity in adult dry scapulae from Central India, and to compare findings with published national and international series.
Methods: An observational, cross-sectional osteometric study examined 150 fully ossified adult dry scapulae (75 right, 75 left) using a dual-examiner, triplicate-measurement protocol. Supero-inferior (SI) and antero-posterior (AP-D1, AP-D2) diameters, glenoid cavity (GC) index, shape (pear/oval/inverted-comma), and surface area were recorded. Side-wise comparison used the independent t-test or Mann-Whitney U test; shape distribution used the chi-square test; one-way ANOVA compared GC index across shape categories.
Results: Mean SI diameter was 36.22 ± 1.71 mm and mean GC index was 67.08 ± 5.21% (range 55.08-81.18%). The pear shape predominated (51.3%), followed by oval (25.3%) and inverted-comma (23.3%) configurations. No parameter differed significantly between sides (all $p > .05$), and GC index did not differ significantly across shape categories ($F(2,147) = 0.733$, $p = .482$).
Conclusion: Glenoid dimensions in this Central Indian population are bilaterally symmetrical and broadly consistent with, yet numerically distinct from, other published Indian series, supporting the need for regionally specific reference data in prosthesis design and forensic identification.

Keywords: Glenoid Cavity, Morphometry, Scapula, Glenoid Cavity Index, Shoulder Arthroplasty, Forensic Anthropology, Dry Bone, India.

INTRODUCTION
The glenoid cavity of the scapula is the principal determinant of native glenohumeral stability and the seating surface for every prosthetic glenoid component implanted in total and reverse shoulder arthroplasty[9]. Because the glenoid articulates with only a fraction of the disproportionately larger humeral head[7], its size, shape, and derived indices carry direct consequences for implant sizing, and mismatch between prosthetic and native glenoid geometry is a recognised cause of component malposition and early loosening[10].
The glenoid cavity index (antero-posterior diameter ÷ supero-inferior diameter × 100) and the three-category shape classification (pear, oval, inverted-comma), based on the presence and configuration of the glenoid notch, remain the most widely reported summary descriptors in the comparative literature, building on a descriptive tradition of using scapular ratios as comparative anatomical characters dating to the nineteenth century[12], and formalised in cadaveric reference studies establishing normative humeral head-glenoid relationships[7-8]. A substantial body of Indian dry-bone literature has documented genuine inter-regional variability in these parameters, with reported glenoid cavity index values ranging from approximately 63% to 73% across series from Uttar Pradesh[1], Western Rajasthan[2], Karnataka[3], Odisha[4], and Bihar[6], extending further to series from Gujarat[21], Andhra Pradesh[17], Telangana[18], and other Indian regions[16,19-20,22], as well as internationally in Bangladesh[5], Egypt[23],

China[15,25], and Japan[26]. This body of work has been consolidated in reviews of glenoid morphology and its clinical significance[24]. Despite this expanding literature, no dedicated dry-bone morphometric study of the glenoid cavity had previously been conducted in the Malwa region of Madhya Pradesh, a region with substantial and growing tertiary orthopaedic care infrastructure. This study was undertaken to generate a quality-controlled, population-specific reference dataset for this region and to interpret it against the existing national and international literature.

MATERIALS AND METHODS

Study Design and Specimens

This observational, descriptive, cross-sectional osteometric study examined 150 fully ossified, intact adult human dry scapulae (75 right-sided, 75 left-sided) from the departmental bone bank and osteology museum, Department of Medical Anatomy, Index Medical College, Hospital and Research Center, Indore. Sample size was estimated using the continuous-data variant of the standard formula for estimating a population mean with specified precision[27] ($Z\alpha/2 = 1.96$, $\sigma = 3.5$-4.6 mm based on published Indian series, $d = 1$ mm), yielding a minimum requirement of 55-80 specimens; a target of 150 was set to remain consistent with comparable published series[2,4-5] and was achieved in full. Scapulae with unfused epiphyses, gross pathology, fracture, osteophyte formation, or ambiguous laterality were excluded. Institutional Ethics Committee clearance was obtained; as the specimens were previously accessioned, unclaimed osteological material, individual informed consent was not applicable.

Measurement Protocol

Using a digital Vernier caliper (least count 0.01 mm) and osteometric board, the following parameters were recorded in triplicate by two independent examiners: supero-inferior (SI) diameter, the maximum distance between the most superior and inferior points of the glenoid articular margin; antero-posterior diameter above (AP-D1) and below (AP-D2) the glenoid notch; and maximum scapular length and breadth. The glenoid cavity (GC) index was calculated as (AP diameter ÷ SI diameter) × 100. Glenoid shape was classified as pear-shaped (distinct notch), inverted-comma-shaped (indistinct notch), or oval (absent notch)[13-14] by consensus of two observers, with a third senior observer adjudicating disagreement. Glenoid surface area was estimated by digital planimetric tracing of calibrated photographic images (ImageJ v1.54). Any inter-observer discrepancy exceeding 5% of the mean value triggered repeat measurement.

Statistical Analysis

Data were analysed in SPSS v26.0. Normality was assessed with the Shapiro-Wilk test. Continuous variables are expressed as mean ± SD and range. Right-left comparisons used the independent-samples t-test (or Mann-Whitney U test where normality was not met); glenoid shape distribution by side was compared using the chi-square test; GC index across shape categories was compared using one-way ANOVA. Pearson correlation examined associations between glenoid and scapular parameters. Two-tailed $p < .05$ was considered significant throughout.

RESULTS

All 150 specimens (75 right, 75 left) met inclusion criteria. Descriptive statistics for all linear and derived parameters are presented in Table 1. Mean SI diameter was 36.22 ± 1.71 mm (range 32.78-40.98), mean AP-D1 was 22.73 ± 1.52 mm, mean AP-D2 was 24.24 ± 1.45 mm, and mean GC index was 67.08 ± 5.21% (range 55.08-81.18%). Mean glenoid surface area was 632.82 ± 47.29 mm².

Table 1. Descriptive Statistics of Glenoid Cavity and Scapular Morphometric Parameters (N = 150)

Parameter	n	M	SD	Min	Max
SI diameter (mm)	150	36.22	1.71	32.78	40.98
AP-D1 — above notch (mm)	150	22.73	1.52	18.87	26.49
AP-D2 — below notch (mm)	150	24.24	1.45	20.81	28.03
Glenoid cavity index (%)	150	67.08	5.21	55.08	81.18
Surface area (mm²)	150	632.82	47.29	519.07	772.47
Scapular length (mm)	150	136.03	6.57	119.49	159.99
Scapular breadth (mm)	150	98.17	5.29	85.43	111.04

Note. SI = supero-inferior; AP = antero-posterior.

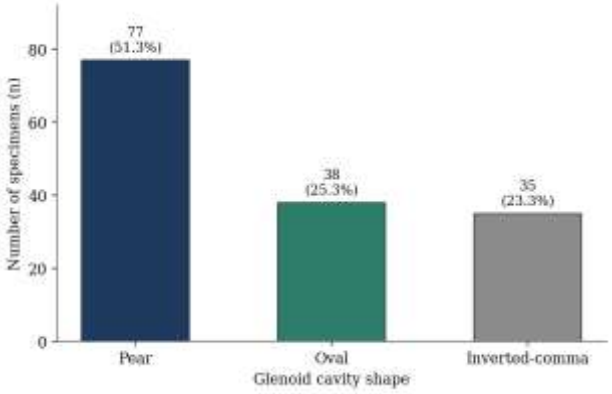
Right-left comparison of all parameters is shown in Table 2. No parameter differed significantly between sides (all p > .05), and effect sizes were uniformly small (Cohen's d = 0.085-0.232).

Table 2. Side-Wise Comparison of Glenoid and Scapular Parameters

Parameter	Right (n=75)	Left (n=75)	Test	p	d
SI diameter (mm)	36.33 ± 1.82	36.11 ± 1.60	t = 0.801	.424	0.131
AP-D1 (mm)	22.90 ± 1.44	22.57 ± 1.60	t = 1.299	.196	0.212
AP-D2 (mm)	24.40 ± 1.38	24.09 ± 1.51	U = 3077.5	.320	0.213
GC index (%)	67.31 ± 5.01	66.86 ± 5.42	t = 0.519	.604	0.085
Surface area (mm²)	638.29 ± 49.58	627.35 ± 44.55	t = 1.422	.157	0.232

Note. d = Cohen's d. None of the ten parameters examined reached statistical significance.

Figure 1. Frequency Distribution of Glenoid Cavity Shape in the Total Sample (N = 150).



The pear shape predominated (51.3%), followed by oval (25.3%) and inverted-comma (23.3%) configurations (Figure 1). Shape distribution did not differ significantly by side ($\chi^2(2, N = 150) = 5.514$, p = .063), although the right side showed a numerically higher proportion of inverted-comma shapes (28.0% vs 18.7%). GC index did not differ significantly across shape categories (pear 67.48 ± 4.82%, oval 66.23 ± 5.41%, inverted-comma 67.15 ± 5.81%; $F(2,147) = 0.733$, p = .482). Correlation analysis found no significant association between GC index and scapular breadth (r = -0.090, p = .272) or scapular length (r = -0.035, p = .668); a regression of GC index on scapular breadth explained under 1% of variance ($R^2 = 0.0082$, p = .272).

Figure 2. Mean Supero-Inferior and Antero-Posterior Glenoid Diameters by Side, With Error Bars Representing ±1 SD.

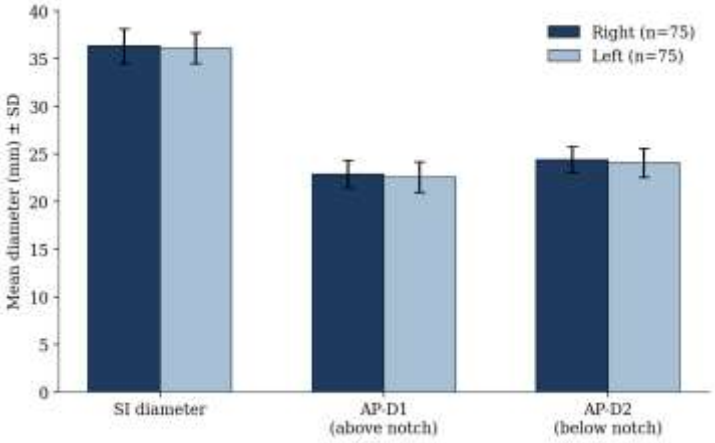


Table 3. Comparative Glenoid Cavity Index and Predominant Shape Across Indian and South Asian Dry-Bone Series

Study (population)	n	GC index — right	GC index — left	Predominant shape
Present study (Malwa, M.P.)	150	67.31 ± 5.01%	66.86 ± 5.42%	Pear (51.3%)
Singh (2020)[1] (North India)	—	72.16%	68.14%	Pear
Philip & Dakshayani (2018)[3] (Mysore)	100	68.05 ± 4.87%	—	Pear (65.3%)
Kataria et al. (2022)[2] (W. Rajasthan)	120	64.57 ± 6.91%	68.33 ± 6.29%	Pear
Latif et al. (2024)[5] (Bangladesh)	150	62.89 ± 4.39%	64.61 ± 4.74%	Pear (45.2%)
Kumar et al. (2024)[6] (Bihar)	120	68.82 ± 10.33%	—	Pear

Note. En-dashes indicate values not separately reported by side in the cited source

DISCUSSION

The mean GC index of 67.08 ± 5.21% recorded here occupies a position broadly midway within the range reported across the Indian and South Asian literature (Table 3), closely comparable to the North Indian[1] and Bihar[6] values, modestly higher than the Western Rajasthan value[2], and higher still than the Bangladeshi value[5]. This ordering is consistent with the well-documented pattern of inter-regional variability in glenoid proportions across the Indian subcontinent[1-2], reinforcing the principle that morphometric reference values cannot be safely extrapolated from one region to another. The pear shape predominated in the present sample (51.3%), replicating the single most consistent finding across the international glenoid morphometric literature[1-5]. A recently proposed five-category CT-based classification, derived from three-dimensional reconstruction in a Chinese population[15], subdivides the traditional pear and oval categories further; the present three-category dry-bone classification, consistent with the majority of the Indian literature[13-14], should accordingly be read as a coarser, though clinically and forensically informative, grouping.

No statistically significant right-left difference was found for any parameter, consistent with the specific bilateral comparison reported for a North Indian population[1] and with radiological evidence of excellent glenoid side-to-side symmetry. This finding supports pooling of side for reference-value generation and indicates that side need not be treated as a stratifying variable in prosthesis sizing or forensic applications drawn from this population. Similarly, the near-zero correlation between glenoid dimensions and scapular size, consistent with comparative population studies showing that morphological differences are not reducible to a uniform scaling factor[25-26], indicates that glenoid geometry cannot be inferred from gross scapular size or body habitus and must continue to rely on direct measurement for arthroplasty planning, since mismatch between prosthetic and native glenoid geometry - including pathological version change of the kind systematised in the Walch classification of osteoarthritic glenoid erosion - remains a recognised cause of component malposition and early loosening[10-11].

Beyond its surgical relevance, glenoid and scapular morphometry retains established forensic value for the estimation of side and, in combination with other skeletal parameters, sex from fragmentary remains[28-29]. The present dataset extends this evidentiary base to the Malwa region specifically, although the absence of a significant bilateral asymmetry here suggests that side estimation from an isolated fragment should rely on multivariate combinations of parameters rather than any single diameter.

Limitations

Age and sex of individual specimens were unknown, precluding stratified analysis. Findings derive from a single institutional bone bank and may benefit from future multi-centric validation. Dry-bone measurement, while validated against CT-based measurement in prior work[30], does not capture living soft-tissue relationships.

CONCLUSION

This study provides the first dry-bone morphometric reference dataset of the glenoid cavity from the Malwa region of Madhya Pradesh. Glenoid dimensions were bilaterally symmetrical and independent of scapular size,

and the predominant pear shape and mid-range glenoid cavity index were broadly consistent with, yet numerically distinct from, other Indian series. These findings support population-specific reference data as a precondition for safe glenoid component sizing in shoulder arthroplasty and provide baseline data of forensic value for this region.

Declarations

Ethics Approval Consent to Participate: And Institutional Ethics Committee, Malwanchal University (Ref: MU/IEC/2026/xxx). As the study used previously accessioned, unclaimed osteological specimens, individual consent was not applicable.

Consent for Publication: Not applicable.

Availability of data and materials: The datasets analysed are available from the corresponding author upon reasonable request.

Competing Interests: The authors declare no competing interests.

Funding: This research received no specific grant from any funding agency.

Authors' contributions (CRediT): Shailendra Singh: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing - original draft. Avantika Bamne: Supervision, Conceptualization, Methodology, Writing - review & editing, Project administration.

Acknowledgements: The authors thank the Department of Medical Anatomy, Index Medical College, Hospital and Research Center, Indore, for access to the departmental bone bank.

Reporting Guideline: This study is reported in accordance with the STROBE statement for cross-sectional studies.

REFERENCES

1. Singh R. Surgical anatomy of the glenoid cavity and its use in shoulder arthroplasty among the North Indian population. Cureus. 2020;12(12):e11940.
2. Kataria SK, Shekhawat M, Gehlot K, Goyal S. Morphological and morphometric study of glenoid cavity and its clinical application in Western Rajasthan population. Int J Health Clin Res. 2022;5(1):222-6.
3. Philip SE, Dakshayani KR. A morphometric study of glenoid cavity and its implication in shoulder arthroplasty and prosthetic designs. Natl J Clin Anat. 2018;7(4):190-4.
4. Tankala M, Senapati S, Behera SS, Shamal S. The glenoid fossa's morphometric investigation and its clinical implications. Cureus. 2023;15(6):e39981.
5. Latif MS, Ara JG, Ara R, Ismatsara M, Haque SMA, Bose SK, et al. A morphometric study of glenoid cavity of scapula in Bangladeshi population. Mymensingh Med J. 2024;33(2):334-40.
6. Kumar S, Chandan CB, Yadav RS, Kumar B, Sinha RR, Kumar A. Morphological and morphometric study of glenoid cavity of scapula in the population of Bihar and its implication in shoulder arthroplasty and prosthetic design. Eur J Cardiovasc Med. 2024;14(2):993-8.
7. Iannotti JP, Gabriel JP, Schneck SL, Evans BG, Misra S. The normal glenohumeral relationships. An anatomical study of one hundred and forty shoulders. J Bone Joint Surg Am. 1992;74(4):491-500.
8. McPherson EJ, Friedman RJ, An YH, Chokesi R, Dooley RL. Anthropometric study of normal glenohumeral relationships. J Shoulder Elbow Surg. 1997;6(2):105-12.
9. Neer CS 2nd. Replacement arthroplasty for glenohumeral osteoarthritis. J Bone Joint Surg Am. 1974;56(1):1-13.
10. Gustas-French C, Petscavage-Thomas J, Bernard SA. Imaging of shoulder arthroplasties. AJR Am J Roentgenol. 2018;211(3):485-95.
11. Walch G, Mesiha M, Boileau P, Edwards TB, Levigne C, Moineau G, Young A. Three-dimensional assessment of the dimensions of the osteoarthritic glenoid. Bone Joint J. 2013;95(10):1377-82.
12. Flower WH, Garson JG. The scapular index as a race character in man. J Anat Physiol. 1879;14(1):13-7.
13. Patil GV, Kolagi SI, Ramdurg U. Morphometrical study of scapular glenoid cavities. Glob J Med Res Orthop Musculoskelet Syst. 2014;14(2):9-14.
14. Dhindsa GS, Singh Z. A study of morphology of glenoid cavity. J Evol Med Dent Sci. 2014;3:7036-43.
15. Chen Y, Xiong J, Chen W, Xie D, Zhang Y, Mo Y, Gu X, Zhang L. Morphological classification and measurement of the glenoid cavity using three-dimensional reconstruction in a Chinese population. Folia Morphol. 2023;82(2):325-31.
16. Gosavi SN, Jadhav SD, Garud RS. Morphometric study of scapular glenoid cavity in Indian population. IOSR J Dent Med Sci. 2014;13(9):67-9.

17. Krishnaiah M, Nagaraj S, Praveen Kumar M, Sherke AR. Study of scapular measurements and scapular indices of Andhra Pradesh region. IOSR J Dent Med Sci. 2014;13(6):117-20.
18. Lingamdenne PE, Marapaka P. Measurement and analysis of anthropometric measurements of the human scapula in Telangana region, India. Int J Anat Res. 2016;4(3):2677-83.
19. Sinha P, Bhutia KL, Tamang B, Sarda RK. Morphometrical study of glenoid cavity of dry human scapula. Int J Med Res Prof. 2016;2(3):86-90.
20. Akhtar J, Kumar B, Fatima N, Kumar V. Morphometric analysis of glenoid cavity of dry scapulae and its role in shoulder prosthesis. Int J Res Med Sci. 2017;4(7):2770-6.
21. Singhal G, Rathod H, Patel A, Modi P, Prajapati S, Parmar R. A study of measurements and indices of human scapula at Jamnagar Medical College. Int J Res Med. 2013;2(1):65-8.
22. Patel SM, Shah MA, Vora RK, Goda JB, Rathod SP, Shah S. Morphometric analysis of scapula to determine sexual dimorphism. Int J Med Public Health. 2013;3(3):207-10.
23. Nasr El-Din WA, Hassan MM. A morphometric study of the patterns and variations of the acromion and glenoid cavity of the scapulae in Egyptian population. J Clin Diagn Res. 2015;9(8):AC08-11.
24. Gandhi KR, Verma VK, Ubbaida AS, Satpute SS. The glenoid cavity: its morphology and clinical significance. Int J Curr Res Med Sci. 2015;1(6):1-5.
25. Cabezas AF, Krebes K, Hussey MM, Santoni BG, Kim HS, Frankle MA, Oh JH. Morphologic variability of the shoulder between the populations of North American and East Asian. Clin Orthop Surg. 2016;8(3):280-6.
26. Matsuki K, Sugaya H, Hoshika S, Ueda Y, Takahashi N, Tokai M, Banks SA. Three-dimensional measurement of glenoid dimensions and orientations. J Orthop Sci. 2019;24(4):624-30.
27. Cochran WG. Sampling Techniques. 3rd ed. New York: John Wiley & Sons; 1977.
28. Frutos LR. Determination of sex from the clavicle and scapula in a Guatemalan contemporary rural indigenous population. Am J Forensic Med Pathol. 2002;23(3):284-8.
29. Özer I, Katayama K, Sagir M, Gulec E. Sex determination using the scapula in medieval skeletons from East Anatolia. Coll Antropol. 2006;30(2):415-9.
30. Zhou J, Zhong B, Qu R, Qian L, Li Z, Liu C, Xiao Z, Xu G, Liang H, Wei K, Ouyang J, Dai J. Anatomic measurement of osseous parameters of the glenoid. Sci Rep. 2022;12:13424.