

Three-Dimensional CT-Based Glenoid Morphometry in an Indian Trauma Cohort: Sex, Age, and Morphology-Related Variations**Shamim Ahmed Barbhuiya¹, Arijit Dhar², Vanlal Hruaia³**¹Associate Professor, Department of Orthopaedics, Silchar Medical College and Hospital, Assam, India²Professor, Department of Orthopaedics, Silchar Medical College and Hospital, Assam, India³Post Graduate Trainee, Department of Orthopaedics, Silchar Medical College and Hospital, Assam, India

Received: 01-06-2026 / Revised: 15-07-2026 / Accepted: 21-08-2026

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Conflict of interest: Nil

Abstract

Background: Accurate characterization of glenoid morphology is important for understanding shoulder biomechanics and for optimizing preoperative planning and implant selection in reconstructive shoulder surgery. However, population-specific three-dimensional data on glenoid morphology remain limited in Indian populations.

Objectives: This study evaluated glenoid dimensions, version, inclination, and morphological patterns using three-dimensional computed tomography (3D CT).

Methods: This observational study included 60 adults presenting with shoulder injuries or proximal humerus fractures at a tertiary-care centre between October 2024 and September 2025. Patients with glenoid or scapular fractures, glenohumeral arthritis, or other pathology affecting glenoid anatomy were excluded. Thin-slice CT scans with three-dimensional reconstruction were used to measure glenoid height, width, version, and inclination. Glenoid contour was additionally classified as pear-shaped, oval, teardrop, or round. Measurements were compared according to sex and age group using appropriate statistical tests.

Results: The study included 36 males (60%) and 24 females (40%), with a mean age of 52.4 ± 15.8 years. The mean glenoid height was 34.8 ± 3.6 mm and width was 25.1 ± 2.9 mm. Mean glenoid version was $-2.8 \pm 4.5^\circ$, indicating mild retroversion, while mean inclination was $7.4 \pm 3.2^\circ$, and indicating superior inclination. Males had significantly greater glenoid height than females (36.2 ± 3.1 vs 32.7 ± 2.8 mm; $p < 0.001$) and width (26.4 ± 2.4 vs 23.2 ± 2.1 mm; $p < 0.001$). No significant sex-based differences were observed for version or inclination. Participants aged >50 years demonstrated greater glenoid inclination than those aged ≤ 50 years ($7.9 \pm 3.3^\circ$ vs $6.8 \pm 3.0^\circ$; $p = 0.04$). Pear-shaped morphology was predominant (53.3%), followed by oval (28.3%), teardrop (11.7%), and round (6.7%) configurations.

Conclusion: Three-dimensional CT demonstrated distinct glenoid morphometric characteristics in this Indian cohort, including a relatively tall glenoid, mild retroversion, superior inclination, and predominant pear-shaped morphology. Sexual dimorphism was evident primarily in glenoid size rather than orientation, while inclination varied significantly with age. These findings provide population-specific anatomical data that may be relevant to individualized preoperative planning, glenoid component sizing, and implant positioning in shoulder reconstruction.

Keywords: Glenoid Morphology; Glenoid Anthropometry; Three-Dimensional Computed Tomography; Glenoid Version; Glenoid Inclination; Shoulder Anatomy; Sexual Dimorphism; Shoulder Arthroplasty.

DOI: 10.25258/ijcpr.18.9.160

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Introduction

The glenoid is a critical determinant of glenohumeral stability and motion, providing the articular socket against which the humeral head moves through a wide range of functional activities. Despite its relatively small and shallow articular surface, the glenoid must maintain a precise balance between mobility and stability. Variations in its dimensions, contour and

orientation can alter joint congruency and force transmission and may influence the development or management of shoulder instability, degenerative disease and traumatic pathology. In particular, glenoid version and inclination have important biomechanical implications, while accurate assessment of glenoid size and bone morphology is increasingly relevant to reconstructive procedures

and shoulder arthroplasty [1,2]. Conventional two-dimensional radiography provides limited characterization of the complex three-dimensional geometry of the glenoid because of projectional distortion and difficulties in defining its true articular orientation. Computed tomography (CT), particularly with three-dimensional (3D) reconstruction, enables more comprehensive visualization and quantitative assessment of glenoid anatomy. Parameters including glenoid height, width, version, inclination and contour can be measured with greater anatomical precision. Importantly, 3D reconstruction may provide more consistent assessment of version and inclination than conventional 2D measurements, supporting its application in anatomical characterization and preoperative planning [3]. Such information is particularly valuable in patients undergoing shoulder reconstruction or arthroplasty, where accurate characterization of glenoid geometry may influence component positioning and implant selection.

Glenoid morphology is not uniform between individuals and may vary according to sex, age and population. Three-dimensional anthropometric studies have demonstrated significant differences in glenoid dimensions between males and females and between different ethnic populations [4,5]. These differences have direct clinical relevance because prosthetic components are frequently developed using anatomical databases that may not adequately represent all populations. In an Indian population, Bodanki et al. reported a mean glenoid height and width of 32.9 and 23.4 mm, respectively, with significant sex-related differences in linear dimensions. Similarly, Meshram et al. demonstrated that a substantial proportion of Indian glenoids, particularly among females, may be smaller than commonly available reverse shoulder arthroplasty baseplates, highlighting the potential importance of population-specific anatomical data [6]. Comparable population-related differences have also been reported in other Asian populations, reinforcing the importance of regional morphometric characterization [7].

Despite growing use of 3D CT for shoulder assessment, important gaps remain in the characterization of glenoid anatomy within clinically relevant Indian populations. Existing studies differ in population characteristics, imaging methodology and measured parameters, making direct comparison and extrapolation challenging. Moreover, relatively limited data simultaneously examine linear dimensions, angular orientation and 3D contour morphology in Indian patients presenting with shoulder trauma. A better understanding of these relationships may help

establish clinically relevant anatomical reference data for this population. Therefore, this study aimed to evaluate three-dimensional CT-based glenoid height, width, version and inclination in adults presenting with shoulder injuries and proximal humerus fractures, and to determine their association with sex, age and glenoid contour morphology.

Materials and Methods

Study Design and Setting: This observational study was conducted in the Department of Orthopaedics, Silchar Medical College and Hospital (SMCH), over a one-year period from October 2024 to September 2025. Adult patients presenting with shoulder injuries or proximal humerus fractures were screened according to predefined eligibility criteria.

Participants: Patients aged ≥ 18 years presenting with shoulder injuries and demonstrating normal glenoid anatomy, or those with proximal humerus fractures with an intact and morphologically normal glenoid cavity, were eligible for inclusion. Patients younger than 18 years and those with acute or chronic glenoid fractures, scapular fractures, glenohumeral arthritis, or any pathology affecting the glenoid or scapula were excluded.

A minimum sample size of 60 was calculated using Daniel's formula for prevalence estimation, assuming an expected prevalence of 20%, a 95% confidence level and 10% allowable error. The required sample of 60 participants was selected using simple random sampling.

CT Acquisition and Three-dimensional Reconstruction: Following clinical and radiographic assessment, thin-slice CT imaging of the affected shoulder was performed using a 64-slice helical CT scanner (Siemens SOMATOM Perspective, Siemens Healthineers). Axial, coronal and sagittal multiplanar reconstructions were generated, followed by three-dimensional reconstruction using SyngoVia software. For standardized assessment of the glenoid, the proximal humerus was digitally subtracted from the three-dimensional dataset before measurements were obtained. Three-dimensional CT-based reconstruction allows assessment of glenoid geometry using reconstructed anatomical reference planes and may reduce the influence of image-plane selection encountered with conventional two-dimensional assessment [3,8]. All measurements were recorded in a structured data-collection proforma. Imaging findings and anthropometric measurements were reviewed by an experienced orthopaedic surgeon and radiologist.

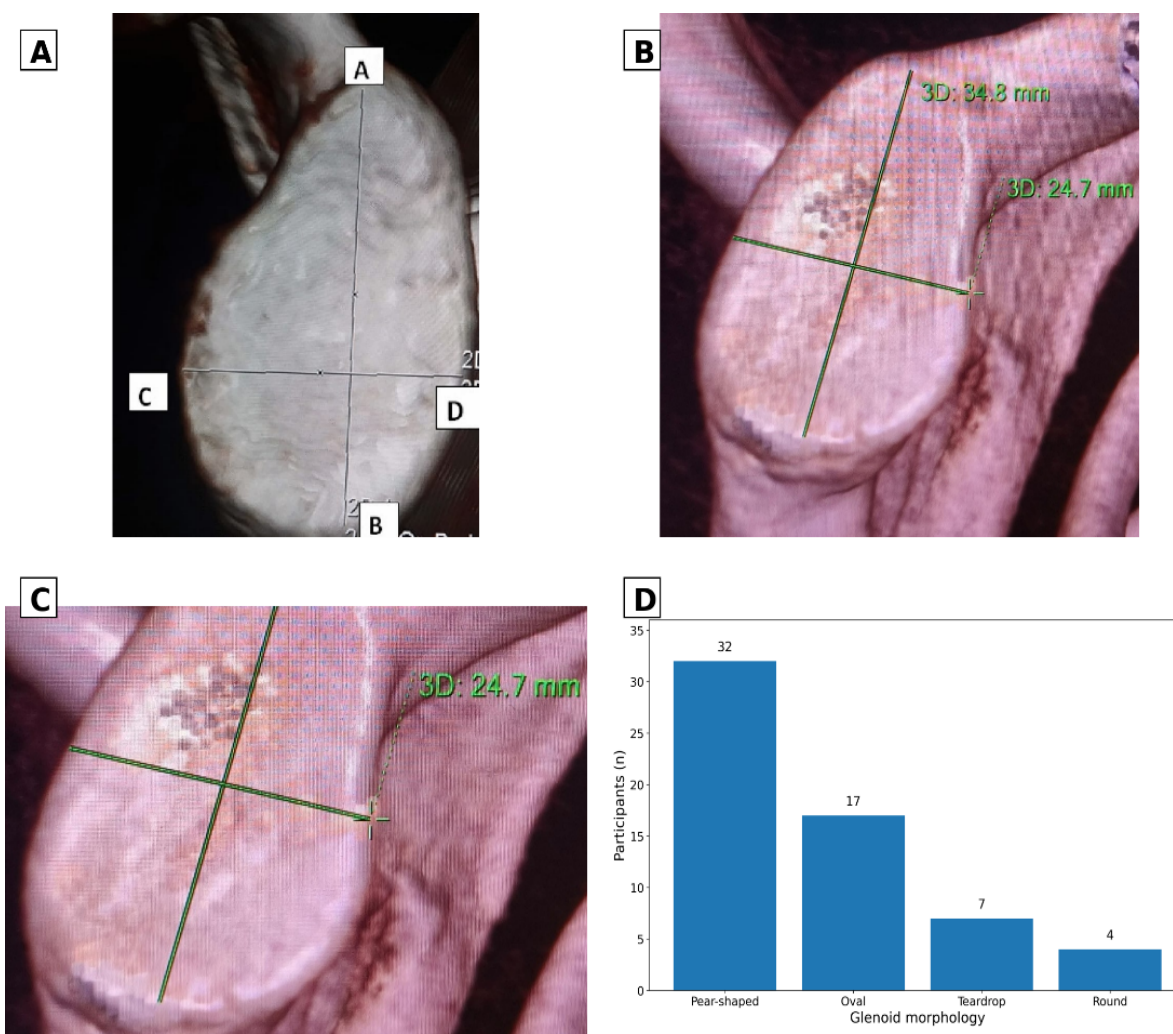


Figure 1: Three-dimensional CT-based assessment of glenoid morphology and dimensions. (A) Three-dimensional reconstruction with anatomical landmarks used for glenoid morphometry. (B) Representative measurement of glenoid height. (C) Representative measurement of glenoid width. (D) Distribution of glenoid morphological patterns identified on three-dimensional contour analysis.

Glenoid Morphometric Assessment: Glenoid morphometry was assessed on reconstructed three-dimensional multiplanar images.

Glenoid height and width Glenoid height was defined as the linear distance between the superior-most and inferior-most points of the glenoid articular surface. Glenoid width was defined as the maximum distance between the anterior and posterior margins of the articular surface, measured perpendicular to the superior-inferior axis. The anatomical landmarks used for measurement of glenoid height and width are demonstrated in Figure 1B and C.

Glenoid Version: Glenoid version was assessed using the Friedman reference axis. On three-

dimensional multiplanar reconstruction, the anatomical scapular axis was defined by a line extending from the most medial point of the scapula to the centre of the glenoid fossa.

A second line was drawn between the anterior and posterior margins of the glenoid articular surface. The angle between these reference lines was used to determine glenoid version.

The Friedman method is an established approach for CT-based assessment of glenoid version, with previous work demonstrating differences between available measurement techniques and supporting standardized reference-axis selection [8].

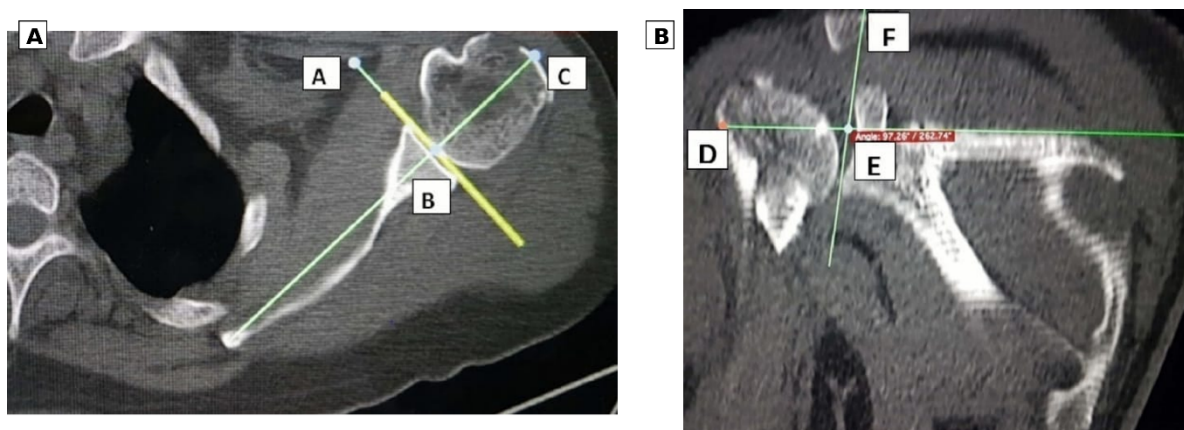


Figure 2: Three-dimensional CT assessment of glenoid orientation. (A) Measurement of glenoid version using the scapular/Friedman reference axis and the anterior-posterior glenoid joint line. (B) Measurement of glenoid inclination using the Maurer method, based on the relationship between the supraspinatus fossa axis and the line joining the superior- and inferior-most points of the glenoid.

Glenoid Inclination: Glenoid inclination was measured using the Maurer method on three-dimensional multiplanar reconstruction. The coronal image demonstrating the largest portion of the scapular spine was selected. The inclination angle was determined from the relationship between the supraspinatus fossa axis and the line joining the superior- and inferior-most points of the glenoid.

The use of standardized three-dimensional anatomical reference axes is important because the selected scapular reference axis can influence measurements of glenoid orientation [3].

The corresponding measurement is illustrated in Figure 2B.

Glenoid Morphology: Three-dimensional glenoid contour morphology was categorized into four patterns: pear-shaped, oval, teardrop and round, based on the reconstructed articular contour. Representative examples of these morphologies are shown in Figure 1D.

Statistical Analysis: Data were compiled and analyzed using SPSS version 22.0. Continuous variables were summarized as mean $\pm$ standard deviation (SD) and range, while categorical variables were presented as frequencies and percentages.

Glenoid parameters were compared between males and females and between age groups (≤ 50 and > 50 years). Independent-samples t-tests were used for continuous variables where appropriate, while chi-square or Fisher's exact tests were used for categorical variables according to expected cell frequencies.

A two-sided $p < 0.05$ was considered statistically significant. Where the raw dataset permitted, comparative analyses were additionally expressed as mean differences with 95% confidence intervals (CIs) alongside p-values to provide an estimate of the magnitude and precision of observed differences.

Results

Participant Characteristics: A total of 60 participants were included in the analysis. The mean age was 52.4 ± 15.8 years, with a range of 21–82 years and a median age of 54 years. Males constituted 60.0% of the study population (36/60), while females accounted for 40.0% (24/60).

The right shoulder was involved in 61.7% of participants and the left in 38.3%. Most participants were right-hand dominant (90.0%). Proximal humerus fracture was the most frequent indication for imaging, accounting for 53.3% of cases. The detailed demographic and clinical characteristics are presented in Table 1.

Table 1: Baseline characteristics of the study population (n = 60)

Characteristic	n (%)
Age group, years	
21–30	7 (11.7)
31–40	9 (15.0)
41–50	12 (20.0)
51–60	14 (23.3)
61–70	12 (20.0)
>70	6 (10.0)
Sex	
Male	36 (60.0)

Female	24 (40.0)
Side involved	
Right	37 (61.7)
Left	23 (38.3)
Hand dominance	
Right	54 (90.0)
Left	6 (10.0)
Type of shoulder injury	
Proximal humerus fracture	32 (53.3)
Anterior dislocation	14 (23.3)
Traumatic rotator cuff tear	9 (15.0)
Posterior instability	5 (8.3)
Mechanism of injury	
Fall from standing height	26 (43.3)
Road traffic accident	18 (30.0)
Sports injury	7 (11.7)
Fall from height	5 (8.3)
Assault	4 (6.7)

(The thesis reports comorbidities and occupation separately; these can be omitted from the main article table to keep Table 1 focused and compact.)

Primary three-dimensional glenoid morphometric findings: The overall three-dimensional CT assessment demonstrated a mean glenoid height of 34.8 ± 3.6 mm (range, 28.2–42.5

mm) and mean glenoid width of 25.1 ± 2.9 mm (range, 20.4–31.3 mm). Mean glenoid version was $-2.8 \pm 4.5^\circ$ (range, -12.4° to $+6.2^\circ$), indicating an overall tendency towards retroversion.

Mean glenoid inclination was $7.4 \pm 3.2^\circ$ (range, 1.1 – 15.6°). The complete morphometric profile is summarized in Table 2.

Table 2: Overall three-dimensional glenoid measurements (n = 60)

Parameter	Mean $\pm$ SD	Range
Glenoid height (mm)	34.8 ± 3.6	28.2–42.5
Glenoid width (mm)	25.1 ± 2.9	20.4–31.3
Glenoid version ($^\circ$)	-2.8 ± 4.5	-12.4 to $+6.2$
Glenoid inclination ($^\circ$)	7.4 ± 3.2	1.1–15.6

Sex-based differences in glenoid morphology:

Sex-based analysis demonstrated significant differences in the linear dimensions of the glenoid. Mean glenoid height was 36.2 ± 3.1 mm in males compared with 32.7 ± 2.8 mm in females ($p < 0.001$). Similarly, mean glenoid width was 26.4 ± 2.4 mm in males and 23.2 ± 2.1 mm in females ($p < 0.001$). In contrast, angular parameters did not differ significantly between sexes. Mean glenoid

version was $-3.1 \pm 4.3^\circ$ in males and $-2.4 \pm 4.8^\circ$ in females ($p = 0.42$), while mean inclination was $7.8 \pm 3.4^\circ$ and $6.9 \pm 2.9^\circ$, respectively ($p = 0.18$).

Thus, sex-related differences were observed predominantly in glenoid size rather than orientation. These comparisons are presented in Table 3.

Table 3: Sex-based comparison of three-dimensional glenoid parameters

Parameter	Male (n=36), mean $\pm$ SD	Female (n=24), mean $\pm$ SD	p-value
Height (mm)	36.2 ± 3.1	32.7 ± 2.8	<0.001
Width (mm)	26.4 ± 2.4	23.2 ± 2.1	<0.001
Version ($^\circ$)	-3.1 ± 4.3	-2.4 ± 4.8	0.42
Inclination ($^\circ$)	7.8 ± 3.4	6.9 ± 2.9	0.18

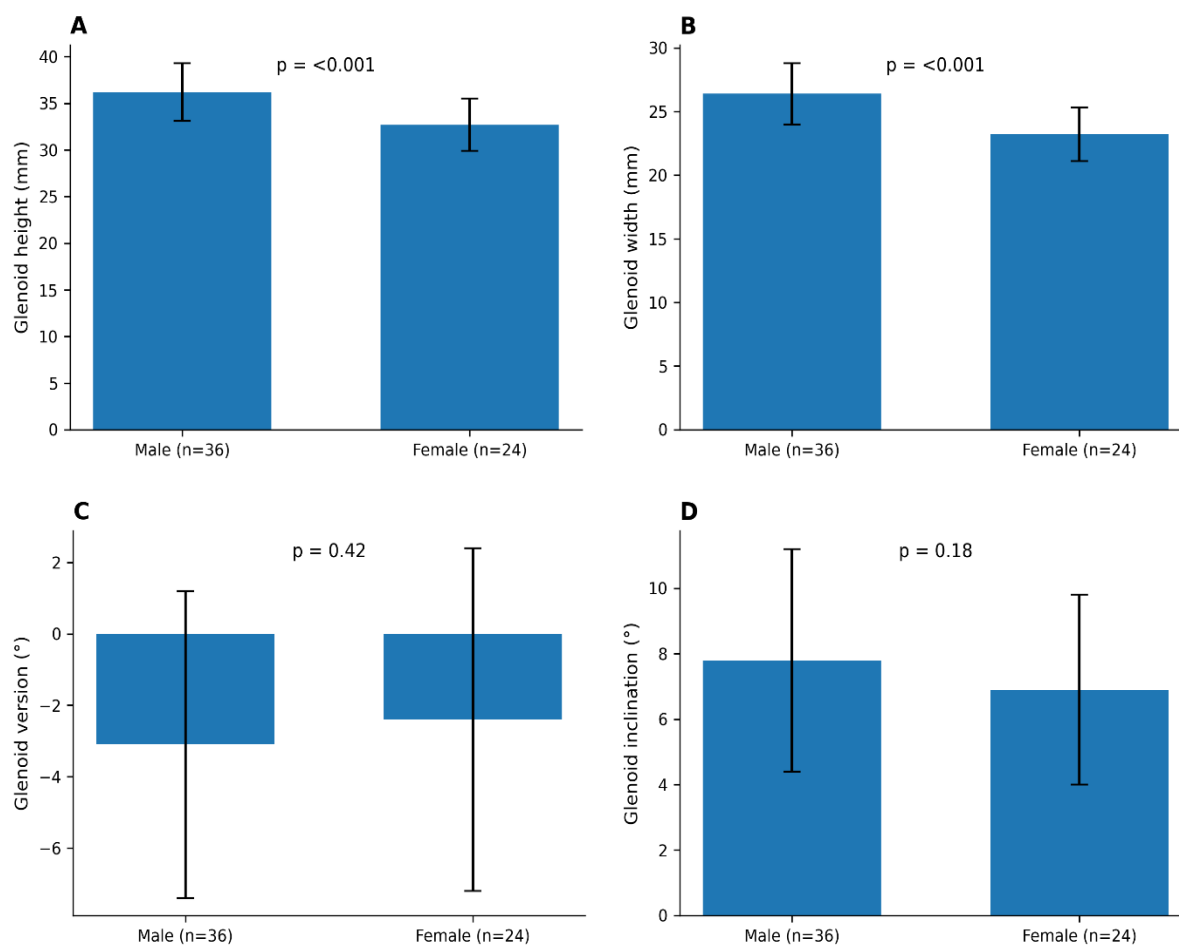


Figure 3: Sex-based differences in three-dimensional glenoid parameters. (A) Glenoid height; (B) glenoid width; (C) glenoid version; and (D) glenoid inclination in male and female participants.

Age-based Differences: Participants were compared according to age (≤ 50 years vs > 50 years). Mean glenoid height was 35.4 ± 3.3 mm in participants aged ≤ 50 years and 34.2 ± 3.7 mm in those aged > 50 years ($p=0.07$). Mean width was 25.6 ± 2.7 mm and 24.7 ± 3.1 mm, respectively

($p=0.11$), while mean version was $-2.1 \pm 4.2^\circ$ and $-3.4 \pm 4.6^\circ$ ($p=0.09$).

A statistically significant difference was observed only for glenoid inclination, which increased from $6.8 \pm 3.0^\circ$ in the ≤ 50 -year group to $7.9 \pm 3.3^\circ$ in participants > 50 years ($p=0.04$).

Table 4: Age-based comparison of three-dimensional glenoid parameters

Parameter	≤ 50 years	> 50 years	p-value
Height (mm)	35.4 ± 3.3	34.2 ± 3.7	0.07
Width (mm)	25.6 ± 2.7	24.7 ± 3.1	0.11
Version ($^\circ$)	-2.1 ± 4.2	-3.4 ± 4.6	0.09
Inclination ($^\circ$)	6.8 ± 3.0	7.9 ± 3.3	0.04

Three-dimensional Glenoid Morphology: Three-dimensional contour analysis identified four morphological patterns. Pear-shaped glenoids were the most frequent, observed in 32 participants (53.3%), followed by oval glenoids in 17 (28.3%), teardrop-shaped glenoids in 7 (11.7%) and round glenoids in 4 (6.7%). Thus, more than half of the assessed glenoids demonstrated a pear-shaped contour.

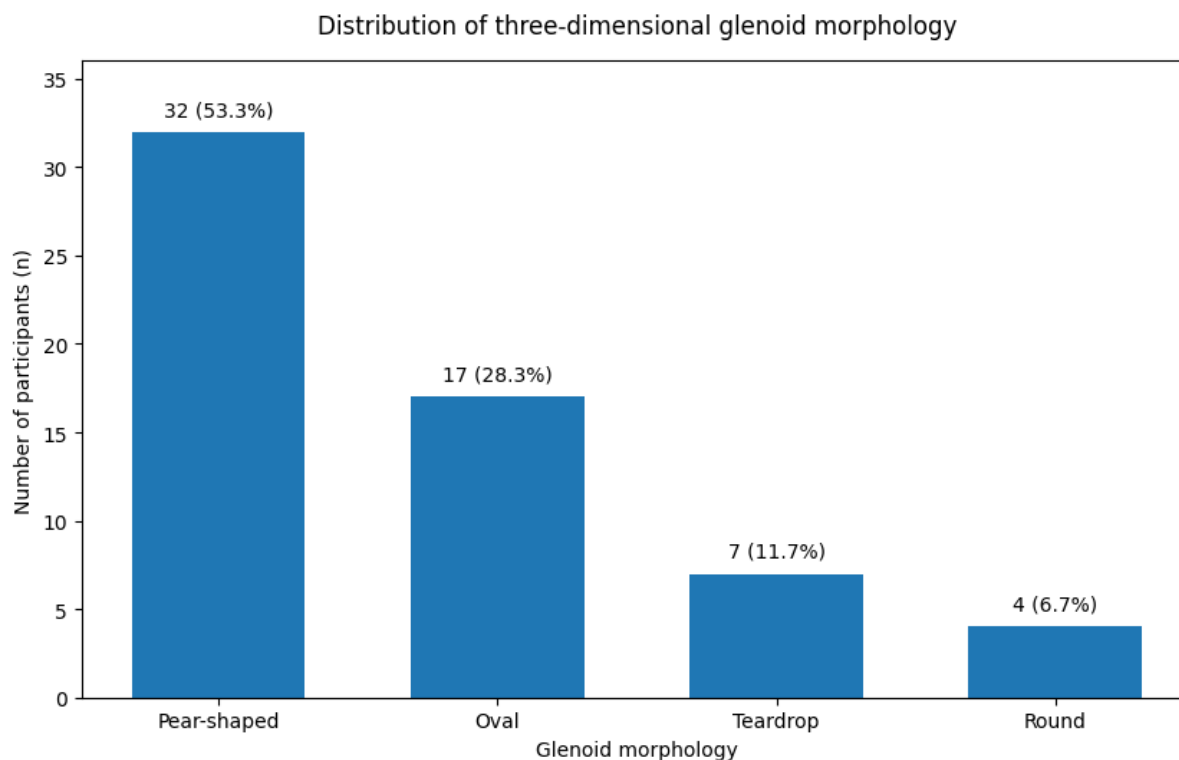


Figure 4: Distribution of three-dimensional glenoid morphology

Proximal Humerus Fracture Subgroup: Among participants with proximal humerus fractures, the mean glenoid height was 35.2 ± 3.4 mm, width was 25.3 ± 2.8 mm, version was $-3.5 \pm 4.7^\circ$, and inclination was $8.2 \pm 3.5^\circ$. These values were within the range observed for the overall study population.

Discussion

Principal Findings: This study provides three-dimensional CT-based glenoid morphometric data from an Indian clinical trauma cohort and demonstrates a consistent anatomical pattern with direct relevance to shoulder reconstruction. The glenoid was substantially taller than wide (34.8 ± 3.6 vs 25.1 ± 2.9 mm), with mild retroversion ($-2.8 \pm 4.5^\circ$) and superior inclination ($7.4 \pm 3.2^\circ$). Sex-related differences were concentrated in linear dimensions: men had greater glenoid height and width than women, whereas version and inclination were comparable. Participants older than 50 years demonstrated greater inclination than younger participants, while height, width and version did not differ significantly. Pear-shaped morphology predominated (53.3%), followed by oval, teardrop and round configurations. This combination of dimensional, angular and morphological characteristics emphasizes that glenoid anatomy is multidimensional and may not be adequately represented by isolated height or width measurements.

Comparison with Previous Studies: The overall dimensions observed in the present study are broadly consistent with reported Indian and Asian populations. Matsumura et al. [9] reported mean glenoid height and width of 31.5 and 23.1 mm, respectively, in a Japanese population, whereas Sahu et al. [2] reported a mean glenoid length of 31.3 mm and width of 24.0 mm in an Indian cohort. Bodanki et al. [4] similarly demonstrated a glenoid that was taller than wide in an Indian population, with mean height and width of 32.9 and 23.4 mm. The slightly larger dimensions in the present cohort may reflect differences in population composition, sample characteristics and measurement methodology rather than a single ethnic effect. These observations are also consistent with a systematic review showing relatively smaller glenoid dimensions in Indian populations compared with many Western datasets [10].

The angular measurements were likewise within the range reported in contemporary three-dimensional studies. The present mild retroversion (-2.8°) lies between the near-neutral values reported by Matsumura et al. [9] and Bodanki et al. [4] and the greater retroversion reported by Gauci et al. [1], while the mean superior inclination of 7.4° was close to that reported by Gauci et al. [1]. Differences between studies are expected because glenoid version is sensitive to the reference axis and measurement technique. Three-dimensional CT approaches can reduce some of the limitations

associated with selecting individual two-dimensional CT slices [11].

Importantly, previous work suggests that glenoid size and orientation are influenced by demographic characteristics. Piponov et al. [12], using multivariable analysis, identified sex as an important predictor of glenoid size and version and also demonstrated associations with ethnicity and body size. The present findings therefore contribute regional anatomical data that can be interpreted within a broader framework of population-specific glenoid geometry rather than as a single universal reference standard.

Sexual Dimorphism: The most coherent subgroup finding was that sexual dimorphism was primarily expressed in size rather than orientation. Male participants had significantly greater glenoid height (36.2 vs 32.7 mm) and width (26.4 vs 23.2 mm), whereas differences in version and inclination were not statistically significant. This pattern agrees with observations from Matsumura et al. [9], Mathews et al. [13] and Bodanki et al. [4], all of whom reported larger glenoid dimensions in men. Piponov et al. [12] similarly identified sex as an important independent predictor of glenoid dimensions.

The clinical relevance lies in the geometric constraints imposed by glenoid size. Smaller glenoids may provide less available surface area for component coverage and fixation, whereas larger glenoids may permit different implant dimensions and positioning strategies. Mathews et al. [13] specifically demonstrated sex-related differences in glenoid dimensions and screw-tunnel anatomy relevant to anatomic and reverse shoulder arthroplasty. These findings support sex-aware and anatomy-driven preoperative planning. However, the present study did not directly assess implant fit, fixation safety or postoperative outcomes and therefore cannot establish inadequacy of currently available implants.

Age-related Inclination: Age produced a more selective effect. Participants older than 50 years had greater mean glenoid inclination ($7.9 \pm 3.3^\circ$ vs $6.8 \pm 3.0^\circ$, $p=0.04$), whereas height, width and version were not significantly different. Yamakado [14] demonstrated that age is associated with measurable changes in glenoid morphology. The increased inclination observed in the present study may reflect cumulative remodeling or degenerative adaptation of the scapulohumeral articulation, although the cross-sectional design does not permit causal attribution. This finding is potentially important because it suggests that age-related anatomical variation may not simply represent progressive enlargement or reduction in glenoid size. Instead, orientation may change independently of linear dimensions. Further longitudinal studies

incorporating cartilage status, bone density and degenerative changes would be required to determine whether the observed association represents biological remodeling, age-related degeneration or differences in the underlying trauma population.

Morphological Variation and Clinical Implications: The predominance of pear-shaped morphology (53.3%) provides an additional anatomical dimension beyond linear measurements. The observed distribution further emphasizes interpopulation variation in glenoid contour morphology. Such differences are clinically relevant because glenoids with similar height and width may nevertheless differ in contour, available bone stock and the geometry available for component positioning.

Three-dimensional assessment therefore has value beyond simply improving measurement precision. Earlier CT-based studies have demonstrated that three-dimensional reconstruction can provide a more faithful representation of glenoid anatomy and can influence assessment of component fit and surgical planning [15,11]. In reverse shoulder arthroplasty, glenoid morphology can directly influence available fixation pathways and component positioning [16].

Accordingly, the present findings support individualized CT-based planning and the development of population-specific anatomical databases. This is particularly relevant in the Indian population, where pooled evidence indicates relatively small glenoid dimensions compared with many Western reference datasets [10]. Importantly, these anatomical observations should be interpreted as supporting improved preoperative characterization rather than establishing superiority of any particular implant design or surgical technique.

Strengths and Limitations: The principal strengths of this study were the use of three-dimensional CT reconstruction, standardized assessment of linear and angular parameters, simultaneous analysis of sex and age, and explicit classification of glenoid morphology. The clinical trauma cohort also provides measurements from patients encountered in routine orthopaedic practice. Nevertheless, several limitations require consideration. The sample was modest ($n=60$), single-centre and derived from a trauma population, limiting generalizability to healthy community populations. The cross-sectional design precludes causal or longitudinal inference, and there was no healthy control group, cadaveric validation or correlation with clinical or arthroplasty outcomes. Body-size variables were not comprehensively incorporated into the analysis. Finally, although measurements were reviewed by

an experienced orthopaedic surgeon and radiologist, interobserver and intraobserver reliability were not formally quantified. This limitation is relevant because previous 3D CT studies have demonstrated high reproducibility when formal reliability testing is undertaken [11].

Conclusion

The present 3D CT-based study demonstrates that the glenoid in this cohort was characteristically taller than wide, mildly retroverted, and superiorly inclined, with pear-shaped morphology being the predominant contour. Significant sexual dimorphism was observed in glenoid height and width, whereas version and inclination did not differ significantly between males and females. Older participants demonstrated significantly greater glenoid inclination, although the cross-sectional design does not permit causal interpretation of this association. These findings highlight measurable population-specific variation in glenoid anatomy and provide regional morphometric data that may support individualized assessment, preoperative planning, glenoid component sizing, and implant positioning in shoulder reconstructive procedures. Further multicentre studies involving larger and asymptomatic populations, with formal measurement reliability and clinical outcome correlation, are warranted to establish more comprehensive Indian normative databases.

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