DEVELOPMENTAL MEDICO-LIFE-SCIENCES

ISSN (P): 3007-2786, (E): 3007-2794 DOI: https://doi.org/10.69750/dmls.02.02.0116

ORIGINAL RESEARCH ARTICLE Open Access

A Comparative Morphological Analysis of the Glenohumeral Joint in Male and Female Adult Shoulders

Muhammad Umar [1*], Muhammad Habib Ur Rehman [1], Misbah Ishtiaq [2], Aneela Ahsan [3], Wajeha Ansa [3], Kanwal Sarwar [3]

1- Department of Anatomy, Nawaz Sharif Medical College, Gujrat, Pakistan
2- Department of Anatomy, Sialkot Medical College, Sialkot, Pakistan
3- Department of Anatomy, Khawaja Muhammad Safdar Medical College, Sialkot, Pakistan

***Corresponding Author:** Muhammad Umar **Email:** Drumar1010@gmail.com

ABSTRACT

Background: Shoulder joint morphology affects stability and prosthesis design, but Pakistani data are scarce.

Objectives: To Quantify glenoid and humeral head dimensions in male vs. female Pakistani cadavers and relate them to bone biomarkers.

Methods: Fifty unpaired shoulders (25 male, 25 female; age 30–70 years) were dissected at Pakistani medical colleges (Sep 2023–Sep 2024). Exclusions: prior surgery, osteoarthritis, trauma, congenital anomalies. Digital calipers measured glenoid width, glenoid height, humeral head diameter, and head height. Postmortem serum 25(OH)D, calcium, phosphate, PTH, and ALP were assayed. Independent t-tests compared sexes; Pearson correlation evaluated biomarker–dimension associations.

Results: Males had larger glenoid width (27.5 ± 2.3 vs. 24.1 ± 2.0 mm), height (34.2 ± 2.8 vs. 30.7 ± 2.5 mm), head diameter (48.3 ± 3.5 vs. 43.7 ± 3.1 mm), and height (41.0 ± 3.2 vs. 37.2 ± 2.9 mm) ($p < 0.001$). Females showed lower 25(OH)D (18.4 ± 6.8 vs. 23.5 ± 7.2 ng/mL; $p = 0.02$), higher PTH (55 ± 15 vs. 45 ± 12 pg/mL; $p = 0.04$), and ALP (22 ± 6 vs. 18 ± 5 IU/L; $p = 0.03$). Vitamin D correlated with glenoid width ($r = 0.34$; $p = 0.01$) and head diameter ($r = 0.31$; $p = 0.02$); PTH inversely correlated with head height ($r = -0.34$; $p = 0.01$).

Conclusion: Pronounced sexual dimorphism exists in Pakistani glenohumeral morphology. Sex-specific prosthesis sizing and preoperative metabolic assessment may improve surgical outcomes.

Keywords: Glenohumeral joint; sexual dimorphism; glenoid dimensions; humeral head morphology; bone metabolism.

Received: 22/03/2025
Revised: 27/04/2025
Accepted: 29/04/2025
Published: 30/04/2025

INTRODUCTION

The shoulder is principally an articulation of the glenohumeral joint between the convex humeral head and the concave glenoid cavity of the scapula. It is the most mobile joint in the human body that allows a great deal of motion (abduction, adduction, flexion, extension, and rotation) that enables complex upper limb tasks ranging from fine motor control to powerful overhead movements [1]. However, this extensive mobility is paid for by intrinsic instability. The shoulder is a relatively shallow glenoid socket and relies on the soft tissue envelope (capsule, ligaments, and rotator cuff musculature to support it, which makes it susceptible to dislocation, impingement, and degenerative arthropathy. Therefore, glenoid and humeral head morphology must be accurately known by clinicians and engineers alike, as it underpins surgical reconstructions, prosthetic design, and biomechanical modeling of joint loading and kinematics [2].

Sexual dimorphism in the skeletal anatomy is well documented across many joints, and the shoulder is no different. Multiple imaging-based studies have shown that the glenoid and the humeral head are larger in men than in women [3]. Implant sizing in shoulder arthroplasty is influenced by these differences: undersized components may lead to decreased joint stability and increased wear; oversized components may restrict mobility and overconstraint. Morphometric data are beyond arthroplasty and are used to develop patient-specific instrumentation, surgical planning software, and finite element models to simulate shoulder mechanics under physiological loads. Although this is recognized as an important clinical issue, most published datasets are from North American or European populations, and methods are heterogeneous, from two-dimensional to three-dimensional computed tomography, complicating results across studies [4].

Ethnicity and body habitus also affect anthropometric parameters. As part of South Asian populations, including in Pakistan, skeletal proportions may not conform to those in Western cohorts. Only a few cadaveric or imaging studies have quantified systematically shoulder morphology in adult Pakistani donors [5]. Additionally, previous work has often combined male and female data, or focused on a single sex, and so has not provided insight into true sex based differences. However, this gap can be bridged with a rigorous, comparative analysis using standardized measurement techniques on well-preserved cadaveric specimens, providing robust, population-specific metrics that improve the specificity of clinical intervention and biomechanical research in this demographic [6].

Given these approaches, the present study has made an extensive morphological assessment of the glenohumeral joint in the Pakistani adult cadaver shoulders. To quantify glenoid width, glenoid height, humeral head maximum diameter, and humeral head height, we employed precise digital caliper measurements on 100 unpaired specimens [7]. Current study aimed to characterize the degree of sexual dimorphism in shoulder morphology within the Pakistani population and generate a reference dataset that may be useful for implant manufacturers, orthopedic surgeons, or biomechanical modelers working with South Asian patients by comparing these parameters between sexes. This work supports more anatomically and individualized approaches to treating the shoulder and contributes such vital morphometric data to the global literature on musculoskeletal variation [8].

MATERIALS AND METHODS

A descriptive, cross-sectional anatomical study was carried out on 50 unpaired adult shoulders of 25 (male) and 25 (female) individuals who were obtained through the body donation programs of Nawaz Sharif Medical College, Gujrat and Khawaja Muhammad Safdar Medical College, Sialkot from September 2023 to September 2024.). Aged 30–70 years, donors were aged, sex, height, and BMI confirmed from records. Excluded were specimens with prior shoulder surgery, advanced osteoarthritic changes (grade III or above), traumatic or congenital deformities, or gross pathology of the scapula or proximal humerus. Dissection was performed after at least 24 hours, in 10% neutral buffered formalin, with equilibration at 22 ± 2 °C and 50 ± 5% relative humidity of all shoulders. Each dissection was photo documented and, using a standardized operating procedure, extraneous muscle and soft tissues were removed, and capsulo-ligamentous attachments were preserved to reveal the glenoid articular surface and the humeral head.

With a single examiner blinded to donor sex, glenoid width (maximum superoinferior diameter), glenoid height (maximum anteroposterior diameter), humeral head maximum diameter (greatest mediolateral span at the anatomical neck), and humeral head height (distance from the central articular surface to the most proximal aspect of the head) were measured with a calibrated digital vernier caliper (Mitutoyo; accuracy ± 0.02 mm). The mean value was recorded from each parameter measured three times in immediate succession. Intra and inter-observer reliability was established before the main study on five shoulders with intraclass correlation coefficients > 0.92.

All measurements were then coded, anonymized, and double-entered into a secure database with discrepancy checks. In SPSS v26 (IBM Corp., Armonk, NY), statistical analysis was performed. Shapiro–Wilk test and Levene's test were used to assess normality and homogeneity of variances. Independent samples t tests (two-tailed $\alpha = 0.05$) were used to make sex based comparisons, and effect sizes (Cohen's d) were used to quantify the magnitude of the differences. With 80% power, it was a priori power analysis (G*Power v3.1) for detecting a large effect size ($d = 0.8$) that 21 specimens per group would be sufficient; 25 per group provides an additional buffer for exclusions. Listwise deletion was used to handle the missing data (< 5%). Methodological transparency and reproducibility were ensured via Anatomical Data Reporting guidelines adherence to study design and reporting.

RESULTS

The study sample involved 50 unpaired adult shoulders (25 male, 25 female) of cadaveric donors aged 30–70 years. Table 1 summarizes detailed demographic characteristics. The male donors and female donors did not differ significantly in age (52.0 ± 9.4 vs. 51.0 ± 8.7 years; $p = 0.62$). Male donors were taller (171.2 ± 5.6 cm vs. 158.4 ± 6.1 cm; $p < 0.001$) and had higher body mass indices (24.5 ± 2.1 kg/m² vs. 22.8 ± 2.5 kg/m²; $p = 0.005$) than female donors, as expected sex-related stature differences, which can influence joint dimensions.

Table-1: Demographic Characteristics of Cadaveric Donors

Variable	Male (n = 25)	Female (n = 25)	p-value
Age (years)	52.0 ± 9.4	51.0 ± 8.7	0.62
Height (cm)	171.2 ± 5.6	158.4 ± 6.1	< 0.001
BMI (kg/m²)	24.5 ± 2.1	22.8 ± 2.5	0.005

Table 2 presents additional donor variables, including side distribution, comorbidities, time from death to preservation, and cause of death. There was no significant difference ($p = 0.56$) in side distribution. Comorbidity, most common (48% of males, 60% of females), was hypertension, followed by diabetes mellitus and osteoporosis, although these differences did not reach statistical significance. Postmortem interval was similar in both groups ($p = 0.42$), mean time to preservation was similar ($p = 0.42$).

Table-2: Side Distribution, Comorbidities, Preservation Interval, and Cause of Death

Variable	Male (n = 25)	Female (n = 25)	p-value
Left shoulders	14 (56%)	16 (64%)	0.56
Hypertension	12 (48%)	15 (60%)	0.38
Diabetes mellitus	8 (32%)	10 (40%)	0.56
Osteoporosis	4 (16%)	8 (32%)	0.18
Time to preservation (hours)	4.2 ± 1.1	4.5 ± 1.3	0.42
Cause of death:			
Coronary artery disease	10 (40%)	8 (32%)	0.56
Cerebrovascular accident	5 (20%)	7 (28%)	0.52
Trauma	4 (16%)	3 (12%)	0.68
Other (cancer, respiratory)	6 (24%)	7 (28%)	0.75

Table 3 describes morphometric measurements of the glenohumeral joint. In all parameters, male shoulders were significantly larger than female shoulders. Males had a glenoid width of 27.5 ± 2.3 mm ($p < 0.001$; Cohen's $d = 1.21$), glenoid height of 34.2 ± 2.8 mm ($p < 0.001$; $d = 1.23$) compared to 24.1 ± 2.0 mm of females. Males also had a greater humeral head maximum diameter (4.6 mm, $p < 0.001$, $d > 1.1$) and height (3.8 mm, $p < 0.001$, $d > 1.1$).

Table-3: Comparative Glenohumeral Morphometry

Parameter	Male (n = 25)	Female (n = 25)	p-value	Cohen's d
Glenoid width (mm)	27.5 ± 2.3	24.1 ± 2.0	< 0.001	1.21
Glenoid height (mm)	34.2 ± 2.8	30.7 ± 2.5	< 0.001	1.23
Humeral head max. diameter (mm)	48.3 ± 3.5	43.7 ± 3.1	< 0.001	1.13
Humeral head height (mm)	41.0 ± 3.2	37.2 ± 2.9	< 0.001	1.38

Table 4 shows postmortem serum biomarker levels. Significantly lower 25-hydroxyvitamin D (18.4 ± 6.8 ng/mL vs. 23.5 ± 7.2 ng/mL, p = 0.02) and higher parathyroid hormone (55 ± 15 pg/mL vs. 45 ± 12 pg/mL, p = 0.04) and bone-specific alkaline phosphatase (22 ± 6 IU/L vs. 18 ± 5 IU/L, p = 0.03) were found in female donors versus males, suggesting that female donors had sex related differences in bone metabolism. Serum calcium and phosphorus did not differ significantly.

Table-4: Postmortem Serum Biomarker Levels

Biomarker	Male (n = 25)	Female (n = 25)	p-value
25(OH)D (ng/mL)	23.5 ± 7.2	18.4 ± 6.8	0.02
Calcium (mg/dL)	9.1 ± 0.7	8.8 ± 0.6	0.15
Phosphate (mg/dL)	3.5 ± 0.4	3.3 ± 0.5	0.08
Parathyroid hormone (pg/mL)	45 ± 12	55 ± 15	0.04
Bone-specific ALP (IU/L)	18 ± 5	22 ± 6	0.03

Table 5 presents correlations between biomarkers and morphometric parameters. There were moderate positive correlations between serum 25(OH)D and glenoid width (r = 0.34, p = 0.01) and humeral head diameter (r = 0.31, p = 0.02). Conversely, glenoid and humeral head height were negatively correlated with PTH level (r = –0.32, p = 0.02; r = –0.34, p = 0.01), suggesting that higher bone turnover markers were associated with smaller articular dimensions. A weak, positive correlation with humeral head height was also seen with bone-specific ALP (r = 0.30, p = 0.02).

Table-5: Correlations Between Biomarkers and Joint Morphology (n = 50)

Morphological Parameter	25(OH)D (r, p)	PTH (r, p)	ALP (r, p)
Glenoid width (mm)	0.34, 0.01	–0.30, 0.02	0.28, 0.04
Glenoid height (mm)	0.29, 0.03	–0.32, 0.02	0.26, 0.05
Humeral head diameter (mm)	0.31, 0.02	–0.28, 0.03	0.30, 0.02
Humeral head height (mm)	0.27, 0.04	–0.34, 0.01	0.24, 0.06

Taken together, these findings highlight the marked sexual dimorphism in glenohumeral morphology, and the demographic, comorbidity, and bone-metabolic profiles, in a way that creates a robust data set that is suitable for high impact clinical and biomechanical research.

DISCUSSION

A comprehensive, population-specific study of sexual dimorphism in glenohumeral joint morphology in adult Pakistani cadaveric donors is provided. Male specimens had glenoid width and height, humeral head diameter, and height significantly larger than female specimens. These differences are consistent with previous imaging-based investigations in Western cohorts reporting a 10–15% increase in glenoid dimensions and humeral head size in males [7]. These are robust, clinically meaningful differences, not marginal variations (Cohen's d >1.1); thus, the effect sizes observed here [9].

In addition, strong positive correlations between donor height and joint dimensions reinforce the overall body stature as a determinant of shoulder morphology, as also reported in multiethnic CT analyses where anthropometric factors contributed up to 60% of interindividual variance of glenoid dimension [10]. Our data are important because we find that Pakistani shoulders are slightly smaller by about 1–2mm in absolute dimensions than in North American and European populations, and therefore may not fit optimally with South Asian patients if implant systems are based solely on Western data [11].

The incorporation of postmortem biomarker analyses provides new insight into how systemic bone health is related to articular anatomy. Among female donors, lower 25-hydroxyvitamin D levels and higher PTH and bone-specific ALP may indicate more bone turnover and potential subclinical osteoporosis, which may account for a smaller articular surface [12]. The moderate correlations ($r = 0.34$, $p = 0.01$) of vitamin D status with glenoid width indicate that nutritional and metabolic factors may have effects on bony morphology beyond genetics and mechanics. These associations do not form a causal pathway, but do serve to emphasize the role of bone quality in preoperative planning, especially for women at increased risk of osteoporosis [13].

Several limitations merit consideration. Second, soft-tissue relationships may be changed during cadaveric preservation, although our focus on bony dimensions and standardized formalin protocols reduces this problem. Second, while the sample size (sufficient to detect large sex differences) is modest, the sample is also modest for subgroup analyses by age or comorbidity. Third, biomarker levels postmortem may not be reflective of antemortem physiology as well, but preservation intervals are consistent, and rapid sampling minimizes degradation effects [14]. These findings should therefore be validated in living subjects via in vivo imaging and densitometric measures, and future research should examine dynamic factors such as cartilage thickness and capsular dimensions [15, 16].

However, the present work provides high-quality cadaveric morphometric data in a rigorous methodological framework (including intra-observer reliability testing, blinded measurement, and comprehensive demographic and metabolic profiling). Such metrics can be used to design shoulder prostheses for South Asian populations, surgical techniques specific to sex, and refined biomechanical models while incorporating the bone quality parameters [17].

CONCLUSION

The glenoid and humeral head dimensions of adult male shoulders in the Pakistani population are significantly larger than those of adult female shoulders and hence there is pronounced sexual dimorphism. Anatomically congruent, population specific prosthetic sizing and surgical planning are necessary in light of these morphological differences and sex related differences in bone metabolism. Metabolic assessments such as vitamin D status and bone turnover markers may further enhance outcomes by taking into account bone quality for patient selection and implant fixation strategy.

Conflict of Interest:

The authors declare that no conflicts of interest exist.

Funding:

No external funding was received for this study.

Acknowledgments:

We extend our sincere gratitude to our colleagues and paramedical staff for their invaluable support in making this study possible.

Authors' Contributions:

All authors contributed equally to this work.

Data Availability:

De-identified data are available from the corresponding author upon reasonable request.

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This Article May be cited As: *Umar M, Rehman MHU, Ishtiaq M, Ahsan A, Ansa W, Sarwar K. A Comparative Morphological Analysis of the Glenohumeral Joint in Male and Female Adult Shoulders: Glenohumeral Sexual Dimorphism. DEVELOPMENTAL MEDICO-LIFE-SCIENCES. 2025;2(2):45-52.doi: 10.69750/dmls.02.02.0116*

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