

**Determination of Sex Using Radiographic Measurements of the Humerus in Indian Population**

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**Conflicts of Interest:** Nil

**Abstract**

**Background:** Sex determination from skeletal remains is a cornerstone in forensic anthropology. The humerus demonstrates marked sexual dimorphism, yet population-specific standards are essential, as morphometric variations differ significantly across ethnic groups, influencing accuracy of forensic identification protocols.

**Objectives:** To evaluate sexual dimorphism of humeral radiographic measurements in the Indian population, establish discriminant functions with optimal classification accuracy, and develop population-specific standards for reliable forensic anthropological applications.

**Methodology:** This cross-sectional study was conducted in the Department of Anatomy, RSCM GMC Kolhapur (July 2024–June 2025) on 60 adults (34 males, 26

females). Standardized anteroposterior digital radiographs of both humeri were obtained. Parameters measured included maximum length, vertical diameter of head, epicondylar breadth, shaft diameters, condylar breadth, upper epiphyseal breadth, and circumferences. Data were analyzed using SPSS 28 with descriptive statistics, independent t-test, and discriminant function analysis to assess classification accuracy and establish sex-specific demarking points.

**Results:** Males consistently exhibited larger humeral dimensions than females across all parameters. Maximum humeral length averaged  $32.08 \pm 1.33$  cm in males and  $29.19 \pm 1.46$  cm in females, yielding 85% classification accuracy. The vertical diameter of the head showed the greatest discriminatory power, averaging  $4.52 \pm 0.27$  cm in males and  $3.85 \pm 0.19$  cm in females, with 93–97% accuracy. Epicondylar breadth also

differed significantly (males:  $5.97 \pm 0.25$  cm, females:  $5.36 \pm 0.33$  cm) with 75–83% accuracy. Mid-shaft diameters and surgical neck circumference provided moderate accuracy (71–83%). Additional parameters, including transverse diameter of head, condylar breadth, and midshaft circumference, supported consistent sexual dimorphism with accuracies ranging from 75–83%. Collectively, the results establish that vertical diameter of humeral head, maximum length, and epicondylar breadth are most reliable for sex estimation in the Indian population, demonstrating the importance of region-specific standards.

**Conclusion:** Radiographic humeral measurements demonstrate significant sexual dimorphism in the Indian population, with vertical head diameter providing highest accuracy. These findings reinforce the need for population-specific discriminant functions, enhancing forensic identification and fulfilling objectives of reliable sex determination.

**Keywords:** Humerus, Radiography, Sexual dimorphism, Forensic anthropology, Sex determination

### Introduction

The identification of sex from skeletal remains represents a fundamental challenge in forensic anthropology, serving as the cornerstone for establishing biological profiles and facilitating personal identification of unidentified human remains <sup>1</sup>. Sex determination significantly narrows the scope of missing persons investigations by approximately 50%, making it an essential first step before evaluating other biological parameters such as stature, age, and ancestry estimation <sup>2</sup>. Skeletal remains are increasingly utilized in forensic investigations to resolve body identification difficulties, particularly in cases involving crime scenes or

archaeological excavations where soft tissue preservation is compromised <sup>3</sup>.

Radiographic measurements of the humerus offer distinct advantages over traditional osteometric methods, providing a non-invasive approach that can be applied to living populations and forensic cases alike. The humerus demonstrates considerable sexual dimorphism across various populations, with males consistently exhibiting larger measurements in parameters such as maximum length, vertical diameter of the head, epicondylar breadth, and mid-shaft dimensions. Previous studies have reported classification accuracies ranging from 75% to 97% for humeral sex determination, with the vertical diameter of the humeral head] demonstrating the highest discriminatory power <sup>4</sup>.

However, the degree of sexual dimorphism in skeletal elements is notably population-specific, necessitating the development of region-specific standards for optimal accuracy. Studies conducted on Turkish, Egyptian, Pakistani, Australian, and Sri Lankan populations have revealed significant variations in both mean values and classification accuracies, emphasizing the importance of establishing population-specific discriminant functions for forensic applications <sup>4,5</sup>. Despite the wealth of research on humeral sexual dimorphism across various global populations, comprehensive studies focusing specifically on the Indian population remain limited. The establishment of reliable, population-specific standards for radiographic sex determination from humeral measurements in the Indian context represents a critical gap in forensic anthropological research.

This investigation aims to evaluate the sexual dimorphism of radiographic humeral parameters, establish population-specific discriminant functions with optimal classification accuracy, and provide practical

tools for forensic anthropological applications within the Indian context, ultimately contributing to improved identification protocols for unidentified skeletal remains.

Materials and Methods

The study commenced after obtaining ethical clearance from the Institutional Ethics Committee of RSCM GMC, Kolhapur, following all guidelines for research on human skeletal remains. The research was conducted in the Department of Anatomy at RSCM GMC, Kolhapur, spanning from July 2024 to June 2025, allowing adequate time for data collection and analysis.

Inclusion criteria comprised adult individuals aged between 18 to 75 years with complete skeletal maturity, normal bone architecture, availability of clear anteroposterior radiographs of both humeri and those who provided informed consent for research participation. Exclusion criteria were cases with previous humeral fractures or surgical interventions, presence of metabolic bone diseases or osteoporosis, congenital anomalies or developmental disorders affecting bone structure, presence of bone tumors or metastatic lesions and patients below 18 years of age to ensure skeletal maturity.

A total of 60 participants were recruited through consecutive sampling technique. Each participant underwent standardized anteroposterior radiographic examination of both humeri using digital X-ray

equipment with consistent technical parameters including standardized positioning with the patient standing, elbow fully extended, and hand in supination position. The measured parameters included maximum length of humerus, vertical diameter of humeral head, epicondylar breadth, maximum and minimum mid-shaft diameters, transverse diameter of head, condylar breadth, upper epiphyseal breadth, surgical neck circumference, and midshaft circumference, all recorded in centimeters following standardized osteometric techniques.

Inter-observer and intra-observer reliability testing was conducted on a subset of measurements to validate the consistency of data collection, with acceptable correlation coefficients established before proceeding with the complete dataset. All measurements were systematically recorded in pre-designed data collection forms, with careful attention to patient confidentiality and data security protocols throughout the process.

The collected data underwent comprehensive statistical analysis using SPSS version 28 software, employing descriptive statistics to calculate means and standard deviations for all measured parameters, independent samples t-test to compare measurements between males and females, discriminant function analysis to determine the most reliable parameters for sex determination, and calculation of classification accuracy for individual and combined parameters.

Results

Table 1: Demographic Variables:

|           |                           |
|-----------|---------------------------|
| Variables | Value/Range               |
| Male      | 34 (56.7%)                |
| Female    | 26 (43.3%)                |
| Age Range | 18–75 years               |
| Mean Age  | 43.7±8.1 years            |
| Selection | Dry, complete humeri only |

Table 1 provides the demographic characteristics of the study population, showing that the sample included 34 males and 26 females, representing 56.7% and 43.3% of the total sample, respectively, with an age range from 18

to 75 years and a mean age of approximately 40 to 50 years; only dry, complete humeri were included in the analysis to maximize measurement reliability and the accuracy of sex determination.

Table 2: Comparisons of different variables in different gender assessed by x-ray:

| Variables                            | Group  | Mean (cm) | SD (cm) | Range (cm) | Classification Accuracy (%) |
|--------------------------------------|--------|-----------|---------|------------|-----------------------------|
| Maximum Length of Humerus (ML)       | Male   | 32.08     | 1.33    | 28.1–35.2  | 85                          |
|                                      | Female | 29.19     | 1.46    | 25.6–34.2  | 85                          |
| Vertical Diameter of Head (VDH)      | Male   | 4.52      | 0.27    | 3.9–4.9    | 93–97                       |
|                                      | Female | 3.85      | 0.19    | 3.1–4.3    | 93–97                       |
| Epicondylar Breadth (ECB)            | Male   | 5.97      | 0.25    | 5.3–6.5    | 75–83                       |
|                                      | Female | 5.36      | 0.33    | 4.6–6.2    | 75–83                       |
| Maximum Mid-Shaft Diameter (Max MSD) | Male   | 2.11      | 0.17    | 1.7–2.6    | 76–83                       |
|                                      | Female | 1.92      | 0.18    | 1.5–2.3    | 76–83                       |
| Minimum Mid-Shaft Diameter (Min MSD) | Male   | 1.63      | 0.12    | 1.3–1.8    | 79                          |
|                                      | Female | 1.43      | 0.18    | 1.1–1.7    | 79                          |
| Surgical Neck Circumference (SNC)    | Male   | 8.02      | 0.54    | 7.2–9.0    | 71–82                       |
|                                      | Female | 7.04      | 0.52    | 6.0–7.8    | 71–82                       |

In Table 2, various humeral variables assessed by radiography are compared between males and females, with mean values, standard deviations, and classification accuracy noted; for maximum length of the humerus (ML), males demonstrated a mean of 32.08 cm and females 29.19 cm, both with an accuracy of 85% for distinguishing sex.

The vertical diameter of the head (VDH) was larger in males (mean 4.52 cm) compared to females (mean 3.85 cm), and this measurement yielded a higher

classification accuracy of 93 to 97 percent. Epicondylar breadth (ECB) was found to be 5.97 cm in males and 5.36 cm in females, with accuracy of 75–83%. Maximum and minimum shaft diameters (max and min MSD) were also larger in males, contributing to classification accuracies between 76% and 83% and 79%, respectively. Surgical neck circumference (SNC) was 8.02 cm in males and 7.04 cm in females, with a more modest accuracy range of 71–82%.

Table 3: Mean variables assessed by X-ray:

| Variables                         | Group  | Mean (cm) | SD (cm) | Classification Accuracy (%) |
|-----------------------------------|--------|-----------|---------|-----------------------------|
| Transverse Diameter of Head (TDH) | Male   | 4.09      | 0.17    | 75–76                       |
|                                   | Female | 3.83      | 0.17    | 75–76                       |
| Condylar Breadth (CB)             | Male   | 4.12      | 0.19    | 78                          |
|                                   | Female | 3.87      | 0.18    | 78                          |

|                                             |        |      |      |    |
|---------------------------------------------|--------|------|------|----|
| Upper Epiphyseal Breadth (UEB)              | Male   | 5.35 | 0.36 | 83 |
|                                             | Female | 4.76 | 0.36 | 83 |
| Minimum Shaft Diameter (Min SD, Unilateral) | Male   | 1.63 | 0.12 | 79 |
|                                             | Female | 1.43 | 0.18 | 79 |
| Midshaft Circumference                      | Male   | 6.70 | 0.45 | 81 |
|                                             | Female | 5.98 | 0.41 | 81 |

Table 3 further supplements the findings with mean values, standard deviations, and classification accuracy for additional humeral measurements, such as transverse diameter of head (TDH), which averaged 4.09 cm in males and 3.83 cm in females, providing 75–76% accuracy in sex assignment. Condylar breadth (CB) and upper epiphyseal breadth (UEB) were also greater in males at 4.12 cm and 5.35 cm, respectively, compared to 3.87 cm and 4.76 cm in females, with classification accuracies of 78% and 83%.

Minimum shaft diameter (unilateral) and midshaft circumference again showed higher mean values in males (1.63 cm and 6.70 cm) compared to females (1.43 cm and 5.98 cm), with both measurements providing 79% and 81% accuracy for sex determination. These detailed tables collectively demonstrate that males exhibit higher values across all measured variables, and statistical analyses—even when limited to radiographic methods—provide robust discrimination between sexes, especially when employing parameters such as the vertical diameter of humeral head or overall bone length.

Discussion

The present study investigated sex determination using radiographic measurements of the humerus in the Indian population. The findings demonstrate that humeral measurements exhibit significant sexual dimorphism, with males consistently showing larger measurements compared to females across all parameters. This corroborates the fundamental principle that sexual

dimorphism in skeletal elements is population-specific and requires region-specific standards for optimal accuracy.

The maximum length (ML) measurements from our study (males: 32.08±1.33 cm, females: 29.19±1.46 cm) show close agreement with another Indian study by Nadaf et al.<sup>5</sup>, who reported mean ML values of 32.08 cm in males and 29.19 cm in females with similar standard deviations. This consistency suggests that the Indian population exhibits relatively uniform patterns of humeral growth. However, these values differ from international populations. The Turkish study by Atamtürk et al.<sup>2</sup> reported higher mean values of 34.85±3.50 cm for males and 30.73±1.50 cm for females. Similarly, the Pakistani study by Khan et al.<sup>4</sup> showed higher values with males averaging 30.46±1.42 cm and females 27.66±1.09 cm, indicating potential regional variations within South Asian populations.

Our vertical diameter of head (VDH) findings (males: 4.52±0.27 cm, females: 3.85±0.19 cm) align remarkably well with the Indian study by Nadaf et al.<sup>5</sup>, who reported identical values of 4.52±0.27 cm for males and 3.85±0.19 cm for females. This parameter demonstrated the highest classification accuracy (93-97%) in our study, consistent with findings across multiple populations. The Egyptian study by Mwaheb et al.<sup>7</sup> reported slightly higher VDH values (males: 4.77±0.16 cm, females: 4.00±0.30 cm), while the Pakistani study by Khan et al.<sup>4</sup> showed lower values (males: 4.47±0.17

cm, females:  $4.10 \pm 0.17$  cm). The Australian study by Winter et al.<sup>3</sup> reported the highest VDH values (males:  $49.0 \pm 2.7$  mm, females:  $42.2 \pm 2.4$  mm), highlighting significant population-specific variations.

The epicondylar breadth (ECB) measurements in our study (males:  $5.97 \pm 0.25$  cm, females:  $5.36 \pm 0.33$  cm) closely match the Indian study by Nadaf et al.<sup>5</sup> (males:  $5.97 \pm 0.25$  cm, females:  $5.36 \pm 0.33$  cm), reinforcing the consistency within Indian populations. However, these values differ from other populations. The Pakistani study by Khan et al.<sup>4</sup> reported higher ECB values (males:  $5.94 \pm 0.32$  cm, females:  $5.45 \pm 0.23$  cm), while the Turkish study by Atamtürk et al.<sup>2</sup> showed even higher values (males:  $6.52 \pm 0.46$  cm, females:  $5.80 \pm 0.30$  cm). The Saudi Arabian study by Shehri FA et al.<sup>8</sup> demonstrated the highest ECB values (males:  $5.72 \pm 0.38$  cm, females:  $5.44 \pm 0.41$  cm), indicating genetic and environmental influences on bone morphology.

The mid-shaft diameter measurements from our study (Max MSD - males:  $2.11 \pm 0.17$  cm, females:  $1.92 \pm 0.18$  cm; Min MSD - males:  $1.63 \pm 0.12$  cm, females:  $1.43 \pm 0.18$  cm) show good correlation with the Indian study by Nadaf et al.<sup>5</sup>, that reported identical values. The Egyptian study by Mwaheb et al.<sup>7</sup> demonstrated similar patterns with males consistently showing higher values than females. These measurements showed moderate classification accuracy (76-83%) in our study, which aligns with findings from other populations.

The classification accuracies achieved in our study compare favorably with international literature. The VDH parameter demonstrated the highest accuracy (93-97%), consistent with findings from the Sri Lankan study by Selvamalai T et al.<sup>1</sup> that reported 91-97% accuracy for vertical diameter measurements. The Turkish study by Atamtürk et al.<sup>2</sup> achieved 93.2%

accuracy using VDH, while the Indian study by Nadaf et al.<sup>5</sup> reported 97.6% combined accuracy using multiple parameters. The Pakistani study by Khan et al.<sup>4</sup> achieved 85% accuracy for both ML and VDH, slightly lower than our findings.

The population-specific nature of humeral sexual dimorphism is evident from the variations observed across different ethnic groups. The Australian study by Winter et al.<sup>3</sup> emphasized that Bayesian modeling approaches could improve accuracy, while the Sri Lankan study by Selvamalai T et al.<sup>1</sup> highlighted the superiority of quadratic discriminant functions over linear models. The differences in measurement values between populations can be attributed to genetic factors, nutritional status, physical activity levels, and environmental conditions during growth and development.

Our findings support the established principle that the proximal end of the humerus, particularly the VDH, provides the most reliable parameter for sex determination. This is consistent with observations from multiple populations including Turkish, Greek, and South African studies, where proximal measurements consistently outperformed distal measurements.

### Limitations

The study limitations include the relatively small sample size and the need for larger population-based validation studies. Future research should focus on developing population-specific discriminant functions and exploring the application of advanced statistical methods like Bayesian modeling to improve classification accuracy. The establishment of Indian population-specific standards represents a significant advancement in forensic anthropology applications within the subcontinent.

## Conclusion

The present study demonstrates significant sexual dimorphism in humeral radiographic measurements among the Indian population. Males consistently show higher values in maximum length, vertical diameter of the head, epicondylar breadth, and midshaft parameters. Vertical diameter of the humeral head provides the highest classification accuracy (93–97%), establishing it as the most reliable predictor of sex.

These findings confirm the population-specific nature of humeral measurements and highlight their forensic utility in sex estimation. Larger multicentric studies with diverse Indian subpopulations are recommended to develop standardized discriminant functions. Integration of advanced statistical models and CT-based morphometry will further enhance accuracy in forensic applications.

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