

Determination of Gender from Various Measurement of the Humerus**Vivekanand Das¹, Hemlata Sharma², Renu Bharti³**¹PG Resident, Department of Anatomy, Jhalawar Medical College, Rajasthan, India²Professor, Department of Anatomy, Jhalawar Medical College, Jhalawar, Rajasthan, India³Senior Resident, Department of Paediatrics, All India Institute of Medical Sciences, Patna, Bihar, India

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Abstract:**Objective:** To evaluate the effectiveness of various humeral measurements in distinguishing sex from skeletal remains within a North Indian population.**Methodology:** This retrospective cross-sectional study included 100 adult humeri (70 male, 30 female) collected at Jhalawar Medical College and Government Medical College, Kota, Rajasthan, from June 2024 to June 2025. Six parameters (MDH, MLH, VDH, EB, TDH, CB) were measured and compared by sex using Wilks' lambda and Student's t-test for discriminant analysis. Demarking points were calculated as the mean of male and female values, and classification accuracy was assessed for each variable. Statistical analyses were performed using SPSS v23.0, with significance set at $p < 0.05$.**Results:** Significant differences in humeral measurements were observed between the sexes ($p < 0.001$), with males showing greater mean average values for all six parameters than females. Among the variables, maximum humeral length and vertical head diameter provided the highest overall classification accuracy, at 87% and 83% respectively. The accuracy rates for TDH, MDH, EB, and CB were 76%, 79%, 73%, and 75%, respectively, indicating pronounced sexual dimorphism in humeral anatomy in this regional sample.**Conclusion:** These results suggest that maximum vertical head diameter and humeral length are the most reliable measurements for sex estimation in skeletal remains from the South-East Asian population.**Keywords:** Sex determination, Skeletal remains, Humerus, Forensics.

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Introduction

In forensic anthropology, establishing the sex of skeletal remains found during excavations or at crime scenes is a fundamental step. The humerus, a prominent bone in the upper arm, is often favored in such analyses due to its robust nature and resistance to deterioration. Both the overall length of long bones and specific features such as the vertical diameter of the humeral head serve as reliable indicators for sex determination, with several studies underscoring the significance of these metrics [1]. Researchers have conducted extensive measurements on upper limb bones, leading to the development of various metric systems in regions such as South Africa [2], Chile [3], the Dart collection [4], Guatemala [5], Crete [6], Turkey [7], Greece [8], America [9], and along the Eastern Adriatic coast [10].

Identifying unknown individuals involves multiple forensic techniques, with estimating stature and determining sex being especially critical for reconstructing identity. While genitalia can provide immediate answers for sex identification, these indicators are often absent or unrecognizable in advanced decomposition cases [11]. Identifying sex

is also important for evaluating additional biological characteristics, including estimation of stature [12]. Traditionally, the simplest approach is a visual inspection of bones, focusing on features known to differ between males and females. This method yields better accuracy when large skeletal portions are present. However, morphometric analysis—which relies on precise measurements between anatomical landmarks—has proven to be a more reliable technique, even though it does not capture the complex shapes of the bones [13].

Significant variations exist in the size of upper limb bones across populations, with humeral length differing among Africans, Americans, Europeans, and even among distinct Asian groups. For instance, discriminant values for humerus length have been established in Thai, Japanese, and Chinese populations. Besides the humerus, other skeletal elements such as the skull, mandible, pelvis, hyoid bone [14], corpus callosum, and thyroid cartilage have also been employed for sex estimation, notably in Korean studies [15].

Even when the accuracy is modest, it is still possible to estimate sex through quantitative analysis of either intact bones or bone fragments. Despite their relative durability, upper limb bones are frequently recovered as incomplete pieces. This research seeks to establish demarcation values for both complete humeri and their fragments within the South Asian population. The primary objective is to formulate reliable anthropometric standards for sex determination based on different humeral measurements. Addressing a gap in the literature for this region, the study aims to provide foundational data and stimulate further inquiry in this important area.

Materials and Methods

This retrospective analysis included 100 humeri, with male cadavers 70 obtained and female cadaver 30. The specimens were collected from the departments of anatomy at Jhalawar Medical College, Jhalawar, and Government Medical College, Kota, Rajasthan. The study covered a period of one year, from June 2024 to June 2025.

The humeri included in this study were obtained from adult cadavers, with estimated ages ranging from 25 to 75 years. Selection was based on a review of departmental records and available skeletal material. Bones with apparent deformities—including those with healed fractures, neoplastic lesions, or congenital anomalies—were excluded from analysis. Institutional ethical approval was secured prior to data collection.

After removal, each humerus was thoroughly cleaned, and the articular cartilage was dissected using a surgical knife. An osteometric table, digital calipers, and measuring tape were utilized for measurements. Six parameters were recorded for each specimen: maximum diameter of the head (MDH), epicondylar breadth (EB), maximum length (MLH), vertical diameter of the head (VDH), condylar breadth (CB), and transverse diameter of

the head (TDH). Maximum humeral length was measured from the uppermost aspect of the humeral head to the most inferior point of the trochlea. The VDH was determined by measuring the distance between the superior and inferior margins of the articular surface of the humeral head. TDH was assessed as the front-to-back width across this articular margin. Epicondylar breadth was recorded as the span between the outermost points of the lateral epicondyles.

Comparisons of all measurements between male and female bones were performed using the Wilks' lambda test and Student's t-test was applied for further analysis. Demarking points for each variable were determined as the average of male and female means. The accuracy of sex determination was calculated for male, female, and total cases. Data analysis was conducted with SPSS version 23.0 (IBM Corp., Armonk, NY), considering results with a p-value above 0.05 as not statistically significant.

Results

Among the 100 humeri analyzed (70 male, 30 female), the mean (SD) maximum humeral length was 302.20 (13.50) mm and 277.40 (11.10) mm in males and females, respectively ($P < 0.001$). The mean (SD) maximum diameter of the humeral head was 44.70 (1.75) mm and 41.60 (2.05) mm for male and females, respectively ($P < .001$). The vertical diameter of the head measured 44.50 (1.80) mm and 41.15.98 (1.70) mm in males and females, respectively ($P < 0.001$), while the transverse diameter was 40.80 (1.68) mm and 38.40 (1.72) mm in males and females, respectively ($P < 0.001$).

The mean (SD) epicondylar breadth was 59.10 (3.10) mm and 54.70 (2.25) mm for male and females, respectively ($P < 0.001$). The mean (SD) condylar breadth was 41.10 (1.95) mm and 38.85 (1.80) mm for male and females, respectively ($P < 0.001$) (Table 1).

Table 1: Variable comparison between two genders

Variables	Male (n=70)	Female (n=30)	p-value
MLH, mm	302.20 $\pm$ 13.50	277.40 $\pm$ 11.10	<0.001
MDH, mm	44.70 $\pm$ 1.75	41.60 $\pm$ 2.05	<0.001
VDH, mm	44.50 $\pm$ 1.80	41.15 $\pm$ 1.70	<0.001
TDH, mm	40.80 $\pm$ 1.68	38.40 $\pm$ 1.72	<0.001
EB, mm	59.10 $\pm$ 3.10	54.70 $\pm$ 2.25	<0.001
CB, mm	41.10 $\pm$ 1.95	38.85 $\pm$ 1.80	<0.001

Table 2: Demarking point for males and females

Variables	Demarking point	Wilks' lambda	p-value
MLH	F < 289.8	0.510	<0.001
MDH	F < 43.2	0.545	<0.001
VDH	F < 42.8	0.495	<0.001
TDH	F < 39.6	0.670	<0.001
EB	F < 56.9	0.630	<0.001
CB	F < 39.9	0.720	<0.001

Table 3: Percentage of correctly classified cases

Variables	Male	Female	Average
MLH	83	91	87
MDH	71	87	79
VDH	88	78	83
TDH	77	74	76
EB	75	69	73
CB	79	70	75

Discussion

The present study demonstrates significant sexual dimorphism in humeral measurements among adults in a North Indian population, as observed through analysis of 100 humeri (70 male, 30 female). The differences in dimensions between male and female bones were consistent across all parameters measured, including maximum length, humeral head diameters, epicondylar breadth, and condylar breadth [16]. These findings underscore the importance of humeral metrics in the medico-legal identification of unknown individuals and contribute to the growing body of population-specific anthropometric standards.

The identification of skeletal remains is a cornerstone of forensic practice, particularly in contexts where other means of identification, such as soft tissue markers or personal artifacts, are unavailable. Long bones, and the humerus in particular, are commonly utilized for this purpose owing to their resistance to postmortem deterioration and ease of measurement. In this study, the mean (SD) maximum humeral length was 302.20 (13.50) mm and 277.40 (11.10) mm for male and females, respectively with a statistically significant difference ($P < .001$). These findings align with prior reports from diverse populations, although some variations exist. For example, a study in Brazil reported a mean humerus length of 31.3 (2.3) cm [17], whereas studies from southern India and northern Thailand reported mean lengths between 30.3 cm and 30.8 cm [18]. Such variations highlight the necessity for regionally tailored reference data, as bone morphology is influenced by genetic, nutritional, and environmental factors.

Beyond maximum length, the humeral head dimensions and breadth measurements also demonstrated notable differences between sexes. In the present study, the mean (SD) maximum diameter, transverse diameter, and vertical diameter of the humeral head in males were 44.70 (1.75) mm, 44.50 (1.80) mm, and 40.80 (1.68) mm, respectively; corresponding values in females were 41.60 (2.05) mm, 41.15 (1.70) mm, and 38.40 (1.72) mm ($P < .001$ for all comparisons). Epicondylar breadth and condylar breadth were also significantly greater in males than females, with mean (SD) values of 59.10 (3.10) mm and 41.10 (1.95) mm in males and 54.70 (2.25) mm and 38.85 (1.80) mm in

females, respectively. These results are in line with those of Gayatri et al. and Udhaya et al., who similarly reported strong associations between segmental humeral measurements and overall bone length, reinforcing the utility of these parameters in sex estimation [18, 19].

Sex estimation is widely recognized as a primary step in forensic identification protocols. Discriminant function analysis based on skeletal measurements remains a standard method, yet the accuracy of these equations is known to be population-specific.[7] This specificity is particularly pronounced in regions with diverse ethnic backgrounds or where reference standards are lacking. The present study's findings confirm the existence of significant sexual dimorphism in humeral measurements among North Indian adults and provide reference values that may improve the accuracy of future forensic assessments in the region. The discriminant function derived from this cohort correctly classified sex in 85% of cases using maximum vertical diameter and humeral length of the humeral head. These results are consistent with previous research; identified the vertical head diameter as the most reliable single measurement, while other demonstrated the value of humeral length and mid-shaft diameter for sex estimation [20, 21].

Variation in the predictive accuracy of different parameters across studies has been documented. Reported epicondylar breadth as the most accurate single indicator of sex (87.5% accuracy), whereas other authors favored vertical diameter or maximum length [22]. These differences likely reflect underlying population variability as well as the influence of factors such as muscle mass, body size, physical activity, and the biological processes of bone growth and remodeling, which are known to differ between sexes and among populations. It is noteworthy that adolescent development, physical workload, and environmental context can affect skeletal robustness and metric dimensions, underscoring the importance of population-specific data for forensic applications [23].

The findings of this study add to the limited literature on North Indian populations and provide forensic practitioners with empirical standards for sex estimation based on humeral measurements. The clear and statistically significant differences across

all measured parameters support the continued use of the humerus as a principal bone for identification purposes in medico-legal investigations. Furthermore, the discriminant functions derived from this cohort may enhance the accuracy and reliability of forensic analysis in local and regional contexts.

Limitations of the present study include its retrospective design, single-region sampling, and relatively modest sample size, particularly among females. Future research should seek to include greater sample sizes and a broader range samples across multiple geographic regions to improve the generalizability of these findings. Additionally, further investigation into the influence of age, nutritional status, and occupational history on humeral dimensions may offer deeper insights into the observed patterns of sexual dimorphism.

Conclusion

The results of this research highlight clear differences in humeral measurements between males and females in a North Indian population. Among the variables assessed, maximum humeral length and the vertical diameter of the humeral head emerged as the most dependable for distinguishing sex in skeletal remains. The formulas established in this study provide valuable guidance for forensic identification in this region. Broader studies with larger and more varied samples will further improve the accuracy and usefulness of these anthropometric criteria in forensic applications.

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