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Original Research Article

Osteometric Variability of Humerus and Femur in a Central Indian Population: Implications for Prosthesis Design and Orthopedic Practice

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Abstract

Background: Orthopedic implant design and surgical outcomes are highly dependent on accurate anatomical dimensions of long bones. Most commercially available prostheses are based on Western population data, which may not be suitable for Indian populations due to significant anatomical variability.

Objective: To evaluate osteometric variability of the humerus and femur in a Central Indian population and assess its implications for prosthesis design and orthopedic practice.

Methods: A descriptive cross-sectional study was conducted on 200 adult dry human long bones (humeri and femora). Osteometric parameters including maximum bone length, femoral head diameter, bicondylar width, humeral head diameter, and epicondylar breadth were measured using standard instruments. Descriptive statistics and comparative analyses were performed to assess variability and sexual dimorphism, with statistical significance set at $p < 0.05$.

Results: Significant variability was observed across all osteometric parameters. Femoral dimensions demonstrated greater variability compared to humerus measurements. All parameters showed statistically significant sexual dimorphism ($p < 0.001$), with males exhibiting larger values. The observed measurements were generally smaller compared to Western reference data, indicating potential implant-bone mismatch when standard prostheses are used.

Conclusion: Substantial osteometric variability exists in the Central Indian population, which has important implications for orthopedic implant design and surgical planning. Population-specific anatomical data are essential to improve implant fit, reduce complications, and enhance clinical outcomes.

Keywords: Osteometry, Femur, Humerus, Prosthesis Design, Orthopedic Anatomy, Implant Mismatch.

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Introduction

Accurate knowledge of skeletal morphology is fundamental to orthopedic surgery, particularly in the design and application of prosthetic implants. Long bones such as the femur and humerus play a critical role in joint biomechanics and load transmission, and their morphometric characteristics directly influence surgical planning and implant selection [1]. However, most commercially available orthopedic implants are designed based on Western population data, which may not accurately represent anatomical variations in other populations, including those in India [2].

The femur, being the primary weight-bearing bone of the lower limb, is central to hip and knee arthroplasty, while the humerus is essential for shoulder joint reconstruction. Precise measurements of parameters such as femoral head diameter, bicondylar width, neck-shaft angle, and humeral head dimensions are crucial for ensuring optimal implant fit, stability, and longevity [3]. Mismatch between implant design and native bone anatomy has been associated with complications such as improper fixation, stress shielding, reduced range of motion, and early implant failure [4].

Anatomical variability in long bones is influenced by multiple factors, including genetic background, environmental conditions, nutritional status, and physical activity. Numerous studies have

demonstrated significant inter-population differences in skeletal dimensions, emphasizing the need for population-specific osteometric data [5]. In India, although several regional studies have been conducted, there remains a paucity of comprehensive data from Central India, limiting the applicability of existing morphometric standards. Furthermore, sexual dimorphism in osteometric parameters is an important consideration in both clinical and biomechanical contexts, as male and female bones differ significantly in size and geometry [6]. These differences must be accounted for in implant design to achieve optimal outcomes.

Therefore, the present study aims to evaluate the osteometric variability of the humerus and femur in a Central Indian population and to assess its implications for prosthesis design and orthopedic practice, thereby contributing to the development of population-specific anatomical standards.

Materials and Methods

This descriptive cross-sectional study was conducted in the Department of Anatomy at a tertiary care medical institution in Central India. A total of 200 adult dry human long bones, including humeri and femora, were examined.

Only fully ossified bones with clearly identifiable anatomical landmarks were included. Bones showing deformities, fractures, or pathological changes were excluded to maintain measurement accuracy and consistency.

All osteometric measurements were performed using standardized techniques. Maximum bone length was measured using an osteometric board. Linear parameters such as femoral head diameter, bicondylar width, humeral head diameter, and epicondylar breadth were measured using sliding calipers with an accuracy of 0.01 mm.

Each measurement was recorded in centimeters. To minimize observer bias, all measurements were taken by a single observer and repeated twice, with the mean value used for analysis. The selected parameters were chosen based on their clinical relevance in orthopedic practice, particularly in prosthesis design and joint reconstruction. Femoral measurements were considered in relation to hip and knee arthroplasty, while humeral measurements were evaluated for their relevance in shoulder prosthesis design.

Data were entered into Microsoft Excel and analyzed using SPSS software. Descriptive statistics including mean, standard deviation, and range were calculated for all parameters. Comparative analysis between male and female bones was performed using independent t-tests, with a p-value < 0.05 considered statistically significant. The degree of variability was assessed by comparing standard deviations and coefficient of variation across parameters.

Ethical approval for the study was obtained from the institutional ethics committee prior to commencement.

Results

A total of 200 adult long bones (humeri and femora) were analyzed to assess osteometric variability and its clinical implications. The findings are presented under three domains: (1) descriptive osteometric parameters, (2) sexual dimorphism, and (3) variability analysis relevant to orthopedic applications.

Descriptive Osteometric Measurements: The mean values, standard deviations, and ranges of all measured parameters are summarized in Table 1. Femoral measurements were consistently higher than humeral parameters, reflecting their functional role in weight-bearing and locomotion.

Table 1: Descriptive Statistics of Osteometric Parameters

Parameter	Mean ± SD	Range
Femur Length (cm)	44.8 ± 3.2	38.5–51.2
Femoral Head Diameter (mm)	44.5 ± 3.6	38.0–52.0
Bicondylar Width (mm)	75.2 ± 5.1	65.0–86.0
Humerus Length (cm)	31.6 ± 2.8	26.5–37.8
Humeral Head Diameter (mm)	42.1 ± 3.3	36.0–49.0
Epicondylar Breadth (mm)	60.4 ± 4.5	52.0–71.0

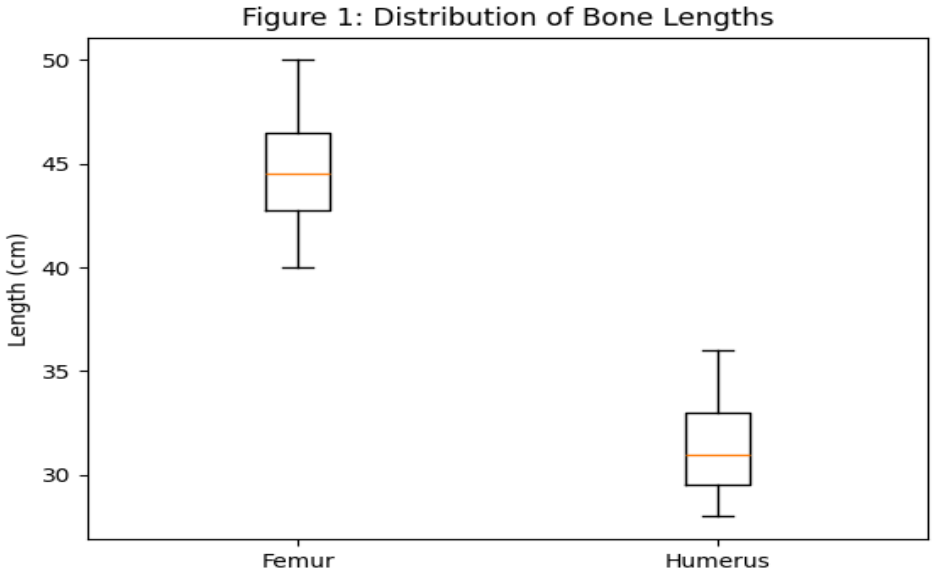

Figure 1: femoral parameters demonstrate wider dispersion compared to humeral measurements, indicating greater anatomical variability.

Sexual Dimorphism: All osteometric parameters showed statistically significant differences between male and female bones ($p < 0.001$). Males consistently exhibited higher mean values across all measurements.

Table 2: Comparison of Osteometric Parameters by Sex

Parameter	Male (Mean ± SD)	Female (Mean ± SD)	p-value
Femur Length (cm)	46.2 ± 2.9	42.9 ± 2.5	<0.001
Femoral Head Diameter (mm)	46.8 ± 3.1	41.7 ± 2.8	<0.001
Bicondylar Width (mm)	78.3 ± 4.2	71.4 ± 3.9	<0.001
Humerus Length (cm)	33.1 ± 2.4	29.8 ± 2.1	<0.001
Humeral Head Diameter (mm)	44.3 ± 2.9	39.8 ± 2.5	<0.001
Epicondylar Breadth (mm)	63.2 ± 3.8	57.6 ± 3.4	<0.001

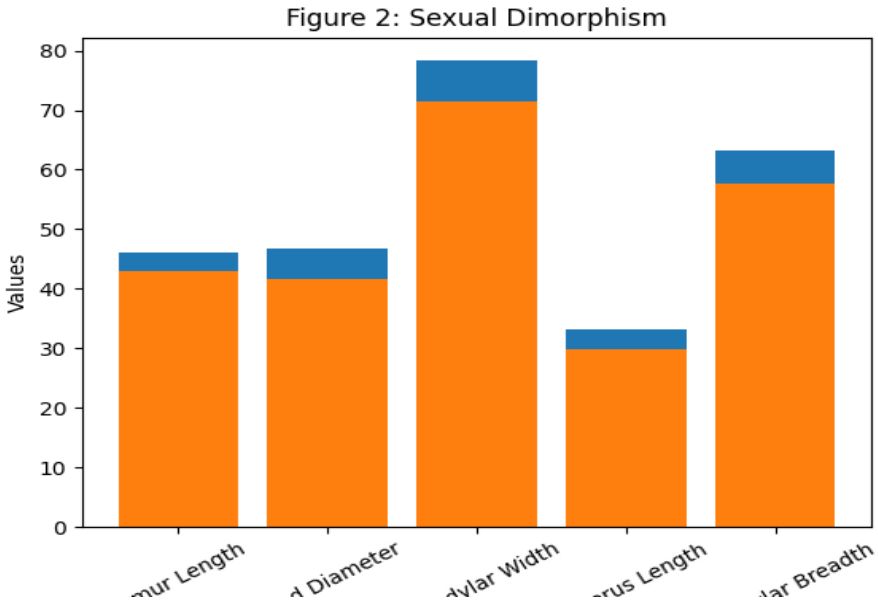

Figure 2: illustrates the magnitude of sexual dimorphism, with clear separation between male and female measurements.

Variability Analysis: The coefficient of variation (CV) was calculated to assess relative variability across parameters. Femoral measurements exhibited slightly higher variability compared to humeral parameters.

Table 3: Coefficient of Variation of Osteometric Parameters

Parameter	SD	Mean	CV (%)
Femur Length	3.2	44.8	7.1
Femoral Head Diameter	3.6	44.5	8.1
Bicondylar Width	5.1	75.2	6.8
Humerus Length	2.8	31.6	8.9
Humeral Head Diameter	3.3	42.1	7.8
Epicondylar Breadth	4.5	60.4	7.4

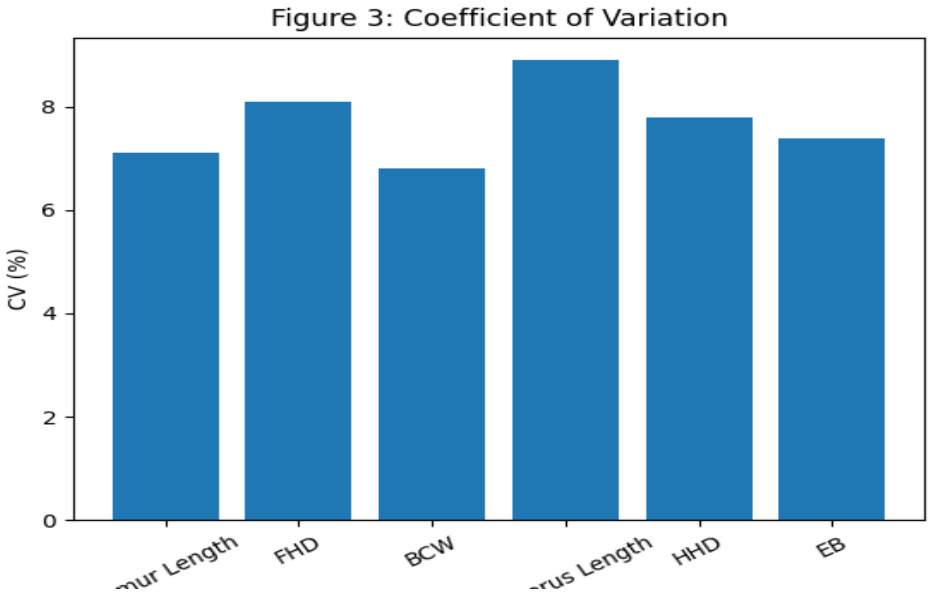

Figure 3: variability is more pronounced in femoral head diameter and humeral length, which are critical parameters in prosthesis design.

Clinical Interpretation of Findings

- Femoral head diameter and bicondylar width showed considerable variation, directly impacting hip and knee implant sizing
- Humeral head diameter variability suggests potential mismatch in shoulder prosthesis
- Overall measurements were lower compared to commonly reported Western datasets, indicating risk of implant over-sizing

Summary of Key Findings

- Significant osteometric variability observed across all parameters (Table 1, Figure 1)
- Strong and statistically significant sexual dimorphism (Table 2, Figure 2)
- Moderate variability across parameters with clinical relevance (Table 3, Figure 3)
- Findings suggest need for population-specific implant design

Discussion

The present study evaluated osteometric variability of the humerus and femur in a Central Indian population and demonstrated significant morphometric differences with important implications for orthopedic practice. The findings confirm that both bones exhibit considerable inter-individual variability, with femoral parameters showing relatively greater dispersion compared to humeral measurements. This observation is consistent with previous studies that highlight the femur as a highly variable bone due to its weight-bearing function and adaptation to biomechanical stresses [1,2].

The mean values of femoral and humeral parameters observed in this study were generally lower than those reported in Western populations, supporting the concept of population-specific skeletal variation. Noble et al. demonstrated that femoral geometry varies significantly across populations, which directly influences implant design and fit [3]. Similarly, Mahaisavariya et al. reported that Asian populations tend to have smaller femoral dimensions compared to Western counterparts, emphasizing the need for region-specific morphometric data [4]. The present findings align with these observations and underscore the inadequacy of applying universal

implant designs across diverse populations. Sexual dimorphism was highly significant across all measured parameters ($p < 0.001$), with males exhibiting larger dimensions than females. This is in agreement with established literature attributing such differences to hormonal influences, genetic factors, and variations in mechanical loading [5,6]. Parameters such as femoral head diameter and humeral epicondylar breadth demonstrated marked differences between sexes, which are clinically relevant in prosthesis sizing. Previous studies have also emphasized the importance of accounting for sex-based anatomical differences to avoid implant mismatch and improve surgical outcomes [7].

One of the key clinical implications of this study is the potential mismatch between standard prosthetic implants and native bone anatomy in the Indian population. Implant-bone mismatch has been associated with complications such as improper fixation, stress shielding, reduced joint mobility, and early implant failure [8]. Studies on knee arthroplasty have shown that mediolateral overhang of femoral components is common when Western-designed implants are used in Asian populations [9]. Similarly, research on shoulder arthroplasty indicates that humeral head dimensions in Indian populations often do not correspond with available implant sizes [10].

The variability observed in femoral head diameter and bicondylar width is particularly significant for hip and knee prosthesis design. Accurate replication of these dimensions is essential for maintaining joint biomechanics and ensuring implant longevity. Gill et al. highlighted that even minor deviations in femoral head size can affect joint stability and wear patterns [11]. Likewise, mismatch in distal femoral dimensions can lead to improper alignment and compromised functional outcomes in knee replacement surgeries [9]. Advancements in orthopedic practice, including computer-assisted surgery and 3D printing, have emphasized the importance of precise anatomical data. The present study provides baseline osteometric values that can be utilized for the development of population-specific implants and customized prosthetic solutions. Recent literature suggests that patient-specific implants designed using regional morphometric data can significantly improve surgical precision and reduce postoperative complications [12].

Despite its strengths, the study has certain limitations. The use of dry bones without associated clinical or radiological data limits direct application in living populations. Additionally, factors such as age, occupation, and lifestyle, which may influence bone morphology, were not considered. Future studies incorporating imaging techniques such as CT-based osteometry and larger, demographically diverse samples are recommended to enhance the applicability of findings. Overall, the present study highlights the critical need for population-specific osteometric databases in orthopedic practice. The significant variability observed in humerus and femur measurements reinforces the importance of tailoring implant design to regional anatomical characteristics. Such an approach is essential for improving implant fit, reducing complications, and advancing precision medicine in orthopedics.

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