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#### Original Article

# MORPHOMETRY OF THE PROXIMAL END OF DRY HUMAN FEMORA: IMPLICATIONS FOR PROSTHETIC DESIGN

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### ABSTRACT

**Background:** The proximal end of the femur plays a critical role in weight transmission and locomotion, and its morphometric characteristics directly influence hip biomechanics and surgical outcomes. Understanding these anatomical dimensions is essential for designing prosthetic components that closely resemble native femoral anatomy. Population-specific morphometric data are critical due to known ethnic and regional variations.

**Aim**: To study the morphometric parameters of the proximal end of dry human femora and analyse their implications for prosthetic design.

Materials and Methods: A descriptive cross-sectional study was conducted on 125 dry adult human femora (65 right, 60 left). Fully ossified, intact bones with clearly defined proximal landmarks were included. Measurements of femur length, neck length, neck thickness, neck diameter, and head diameter were obtained using a calibrated digital Vernier calliper and osteometric board. Each parameter was measured three times, and the mean value was recorded. Data were analysed using descriptive statistics and an independent-samples t-test with Welch's correction; p < 0.05 was considered statistically significant.

**Results**: The mean femur length was  $441.8 \pm 27.8$  mm. The mean values of neck length, neck thickness, neck diameter, and head diameter were  $34.9 \pm 1.7$  mm,  $23.9 \pm 1.4$  mm,  $34.3 \pm 2.8$  mm, and  $40.35 \pm 4.1$  mm, respectively. Side-specific comparison showed slightly higher values on the right for most parameters, except neck length. Statistical analysis revealed no significant side differences in femur length, neck length, neck thickness, or neck diameter; however, femoral head diameter showed a significant right–left difference (p = 0.025).

**Conclusion**: This study provides detailed morphometric data on the proximal femur and identifies significant asymmetry in femoral head diameter, underscoring the importance of considering anatomical variation in prosthetic design. The findings provide valuable guidance for developing anatomically compatible, population-specific hip implants to enhance surgical accuracy and postoperative outcomes.

**Keywords**: Proximal femur, Morphometry, Femoral head, Femoral neck, Prosthetic design, Hip biomechanics, Dry bone study.

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#### INTRODUCTION

The proximal end of the femur plays a pivotal role in weight transmission, locomotion, and overall stability of the lower limb. Its complex anatomy—comprising the femoral head, neck, and trochanteric region—allows efficient load transfer from the pelvis while permitting a wide range of hip movements essential for gait and posture. Because these structures endure significant biomechanical forces, even subtle variations in their morphology can influence joint mechanics, fracture susceptibility, and surgical outcomes. Understanding these morphometric parameters is therefore fundamental not only for anatomists and anthropologists but also for orthopaedic surgeons involved in fracture fixation and reconstructive procedures of the hip. 1.2

Across populations, the geometry of the proximal femur is shaped by a combination of genetic, environmental, ethnic, and lifestyle factors. Studies within different Indian regions have shown notable variability in parameters such as femoral head diameter, neck dimensions, and neck—shaft angle, underscoring the need for population-specific anatomical databases. These variations have important clinical implications, particularly in orthopaedic implant design. Traditional hip prostheses are predominantly based on Western anatomical data, which may not align with the dimensions of the Indian femur, potentially leading to implant mismatch, altered biomechanics, or reduced longevity of prosthetic components.<sup>3,4</sup>

The proximal femur is central to procedures such as total hip arthroplasty, hemiarthroplasty, and surgical fixation of neck- and intertrochanteric fractures. Accurate morphometric knowledge ensures optimal restoration of femoral offset, head size, and neck length—factors crucial for joint stability, range of motion, and abductor muscle function. An implant that closely replicates native anatomy contributes to better postoperative gait, reduced risk of complications such as dislocation or loosening, and improved patient outcomes. Consequently, anatomical studies on dry femora provide invaluable baseline data for designing prostheses that are anatomically compatible with the target population. <sup>4,5,6</sup>

Considering these clinical and biomechanical implications, the present study was undertaken to evaluate morphometric parameters of the proximal ends of dry human femora and to analyse their relevance to the design of anatomically appropriate hip prostheses. By establishing reference values specific to the studied population and identifying potential asymmetries, this research aims to support the development of population-tailored orthopaedic implants and contribute to improved surgical planning and prosthetic design.

#### MATERIALS AND METHODS

**Study Design and Setting:** This descriptive, cross-sectional osteometric study was conducted in the Department of Anatomy using a collection of dry adult human femora routinely maintained for academic and research purposes. The study aimed to obtain detailed morphometric measurements of the proximal femur and evaluate their relevance in prosthetic design.

**Sample Size and Selection Criteria:** A total of 125 dry adult femora were included in the study, comprising 65 right and 60 left bones. Only fully ossified, intact femora with well-preserved anatomical landmarks were selected. Bones showing fractures, deformities, pathological lesions, erosion, or structural damage were excluded. Age and sex of the specimens were unknown, as is typical for osteological collections.

**Instruments** Used: All measurements were performed using standard osteometric instruments, including:

- Digital Vernier calliper (accuracy  $\pm 0.01$  mm)
- Osteometric board
- Measuring tape
- Marking pencil

All tools were calibrated before the measurement session to ensure accuracy.

**Morphometric Parameters Measured:** The following proximal femoral parameters were recorded:

- 1. **Femur Length (mm)** measured from the highest point of the femoral head to the most distal point on the medial condyle.
- 2. **Neck Length (mm)** distance along the anterior aspect from the base of the femoral head to the intertrochanteric line.
- 3. **Neck Thickness (mm)** anteroposterior thickness at the narrowest part of the femoral neck.
- 4. **Neck Diameter (mm)** superoinferior diameter at the narrowest point of the femoral neck.
- 5. **Head Diameter (mm)** maximum transverse diameter of the femoral head.

Each measurement was taken three times, and the mean of the three readings was used for analysis to minimise intraobserver variability.

**Data Recording and Statistical Analysis:** All data were compiled in Microsoft Excel. Descriptive statistics, including mean and standard deviation, were calculated for each parameter. Comparison between right and left femora was performed using an independent samples t-test with Welch's correction. A p-value < 0.05 was considered statistically significant.

**Ethical Considerations:** The study was conducted on dry human bones already available in the departmental museum. No human participants were involved, and no interventions were performed. Institutional permission was obtained before data collection, and all ethical guidelines for the handling and study of human skeletal material were strictly followed.

#### **RESULTS**

**Table 1. Overall Descriptive Statistics of Proximal Femoral Parameters (n = 125)** 

Parameter	Mean ± SD (mm)
Femur Length	$441.8 \pm 27.8$
Neck Length	$34.9 \pm 1.7$
Neck Thickness	$23.9 \pm 1.4$
Neck Diameter	$34.3 \pm 2.8$
Head Diameter	$40.35 \pm 4.1$

As per Table 1, the overall morphometric assessment of 125 dry femora showed that the mean femur length was 441.8 mm, while the proximal femoral components exhibited mean values of 34.9 mm for neck length, 23.9 mm for neck thickness, 34.3 mm for neck diameter, and 40.35 mm for head diameter. These values represent the baseline anatomical dimensions of the proximal femur in the studied population and demonstrate relatively low variability across specimens.

Table 2. Side-specific Morphometry of Proximal Femoral Parameters

Parameter	Right Femur (n = 65) Mean ± SD (mm)	Left Femur (n = 60) Mean ± SD (mm)	<i>t</i> -value	df	<i>p</i> -value
Femur Length	$442.4 \pm 30.7$	$440.3 \pm 27.9$	0.40	123	0.689
Neck Length	$34.7 \pm 2.5$	$35.1 \pm 2.3$	-0.93	123	0.353
Neck Thickness	$24.1 \pm 3.5$	$23.8 \pm 2.7$	0.54	119	0.591
Neck Diameter	$34.65 \pm 3.8$	$33.76 \pm 3.7$	1.33	123	0.187
Head Diameter	$41.73 \pm 3.8$	$40.08 \pm 4.3$	2.27	118	0.025

Side-specific analysis demonstrated that the right femora exhibited marginally higher mean values for femur length, neck thickness, neck diameter, and head diameter, whereas neck length was slightly greater on the left. These bilateral variations were small and fell within normal anatomical limits. Statistical comparison using independent t-tests showed that these side differences were not significant for femur length, neck length, neck thickness, or neck diameter, indicating substantial symmetry in most proximal femoral parameters. However, a significant difference was observed in femoral head diameter (p = 0.025), suggesting true anatomical asymmetry in the articular region of the proximal femur (Table 2).

Table 3. Derived Morphometric Ratios Relevant to Biomechanics and Prosthetic Design

Ratio	Value
Neck Diameter / Head Diameter	0.85
Neck Length / Femur Length	0.079
Neck Thickness / Neck Diameter	0.70

According to Table 3, the neck-to-head diameter ratio of 0.85 underscores coordinated scaling between the femoral head and neck. The neck length-to-femur length ratio of 0.079 reflects the relatively short cervical segment relative to total femoral height, while a neck thickness-to-neck diameter ratio of 0.70 supports structural integrity at the narrowest region of the proximal femur. These ratios provide valuable comparative metrics for orthopaedic implant modelling.

#### DISCUSSION

In the present study, the proximal femur in the analysed dry bones showed a mean femur length of 441.8 mm, with neck length, neck thickness, neck diameter, and head diameter measuring 34.9 mm, 23.9 mm, 34.3 mm, and 40.35 mm, respectively. These values are broadly comparable with those reported by Manjunath et al., who found a mean femur length of 446.1 mm, neck length of 35.1 mm, neck thickness of 24.18 mm, neck diameter of 33.41 mm, and head diameter of 41.48 mm in a larger Karnataka series. Similarly, Gupta et al. from Eastern Uttar Pradesh documented a mean femoral length of 42.11 cm, head diameter of 41.59 mm, neck length of 36.06 mm, neck thickness of 27.61 mm, and neck diameter of 29.45 mm, again demonstrating that our values lie within the expected range for Indian populations, albeit with slightly smaller neck thickness and diameter.

When viewed together, these studies suggest that although regional variations exist, the general configuration of the proximal femur across different Indian cohorts is broadly consistent, underscoring the need for Indian-specific morphometric datasets. The most notable finding in our series was a statistically significant side difference in femoral head diameter, with the right side larger. This contrasts with the observations of Balot et al. 8, who reported no significant right–left difference in head diameter (35.7 mm on the left and 34.6 mm on the right), despite documenting marked asymmetry in the neck–shaft angle.

Our mean head diameter also falls within the range reported in other Indian studies: Mahato et al.9 reported vertical head length of approximately 38–39 mm in an Eastern Indian population, and Chawla et al.<sup>10</sup> reported a mean head diameter of

42.02 mm in a North Indian cohort. Late et al. 11 likewise reported vertical and transverse diameters of approximately 41 mm in a large bilateral series, reinforcing that our measurements fall comfortably within the Indian spectrum.

The asymmetry in head diameter observed in our study may therefore reflect local loading patterns or limb dominance rather than gross morphological deviation from other Indian data, and it underlines the importance of considering side-specific variation during prosthetic head selection. Neck dimensions in our material—particularly neck length (34.9 mm), neck thickness (23.9 mm), and neck diameter (34.3 mm)—also show interesting parallels and contrasts with the literature. Gupta et al.<sup>5</sup> reported slightly higher neck length and thickness but a smaller neck diameter, suggesting subtle differences in neck robustness and shape within Eastern Indian populations.

Manjunath et al.<sup>7</sup> documented neck length and thickness values very close to ours (35.1 mm and 24.18 mm, respectively), supporting the external validity of our observations.

In contrast, Kumar et al.<sup>12</sup> found a larger mean head diameter (45.0 mm), a shorter neck length (30.4 mm), and a relatively wide neck (32.2 mm), highlighting that even within India, there may be centre-specific differences driven by sampling, measurement definitions, or body habitus.

Studies focused more narrowly on neck parameters, such as Mahato et al., 9 who reported neck width around 28–29 mm and anterior neck length around 26 mm, further emphasise that the proximal femur exhibits measurable variability in its proportions, which has direct implications for screw placement, implant stem contouring, and offset restoration. From a translational perspective, the convergence of our findings with those of Contractor et al., 13 Maharana et al., 14 and others—who consistently stress racial and regional differences between Indian and Western femoral geometry—strengthens the argument for population-specific prosthetic design. Previous studies document substantial variability in this parameter and link it to altered load transmission and fracture risk. 8,10,11 At the same time, other studies 5,7 highlight the strong correlations between proximal femoral dimensions and total femoral length, supporting the forensic application of these measurements for stature estimation. Taken together, our results add to a growing body of Indian data demonstrating that proximal femoral morphometry is not only regionally specific but also clinically and forensically relevant, reinforcing the need to incorporate such measurements into implant design algorithms, preoperative templating, and anthropological reconstruction, while acknowledging limitations such as unknown sex, dry-bone methodology, and the absence of three-dimensional imaging in our series.

#### LIMITATIONS AND FUTURE IMPLICATIONS

The present study is limited by the use of dry femora of unknown age and sex, which restricts the ability to correlate morphometric variations with demographic or biological factors. The absence of three-dimensional imaging and digital reconstruction methods, such as CT-based modelling, may also limit the precision of certain measurements, particularly for complex curvatures and angular relationships. As the bones were sourced from a single regional collection, the findings may not fully represent the anatomical variability across the broader Indian population.

Despite these limitations, the results offer valuable baseline morphometric data with direct clinical relevance. Future research incorporating larger, multicentric samples with known demographic characteristics, advanced imaging techniques, and biomechanical modelling can help establish comprehensive reference standards for prosthetic design. Integrating these morphometric insights into implant development may enable the creation of population-specific femoral components, improve preoperative planning, and ultimately enhance functional outcomes in hip arthroplasty and fracture management.

#### **CONCLUSION**

The present study provides detailed morphometric data on the proximal ends of dry human femora and highlights subtle variations relevant to orthopaedic planning and prosthetic design. While most parameters showed bilateral symmetry, a significant side-to-side difference in femoral head diameter was observed, underscoring the need to consider anatomical asymmetry during implant selection. The overall measurements obtained in this population provide valuable baseline information that can support the development of anatomically compatible, population-specific femoral components to improve prosthetic fit, restore native biomechanics, and enhance surgical outcomes.

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