ORIGINAL RESEARCH

Morphometric Analysis of the Proximal Femur and Its Role in Prosthesis Design: A Cross-Sectional Study

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ABSTRACT
Background: The present study aims to analyze the morphometric parameters of the proximal femur and explore their applications in prosthesis designing. Understanding these anatomical variations is essential for optimizing implant fit and stability in total hip arthroplasty and other orthopedic procedures.
Materials and Methods: This cross-sectional study was conducted on 100 dry adult human femora, including both right and left sides, obtained from the osteology laboratory of a medical institution. Specimens with visible deformities, fractures, or pathological changes were excluded. Various morphometric parameters, including femoral head diameter, neck-shaft angle, femoral neck length, femoral neck width, and intertrochanteric distance, were measured using a Vernier caliper, osteometric board, and goniometer. Measurements were taken three times by two independent observers to ensure accuracy. Descriptive and inferential statistical analyses were performed, with differences between right and left femora assessed using an independent t-test ($p < 0.05$).
Results: The mean femoral head diameter was 45.2 ± 3.5 mm on the right and 44.8 ± 3.3 mm on the left, with an overall mean of 45.0 ± 3.4 mm. The femoral neck length was 30.6 ± 2.8 mm on the right and 30.2 ± 2.9 mm on the left, with a total mean of 30.4 ± 2.8 mm. The neck-shaft angle measured 127.4 ± 4.2° on the right and 126.8 ± 4.5° on the left, with an overall mean of 127.1 ± 4.3°. The femoral neck width was 32.5 ± 3.1 mm on the right and 31.9 ± 2.9 mm on the left, with a total mean of 32.2 ± 3.0 mm. The intertrochanteric distance was 70.8 ± 5.6 mm on the right and 71.2 ± 5.2 mm on the left, with an overall mean of 71.0 ± 5.4 mm. These findings indicate significant individual and population-specific variations.
Conclusion: The study underscores the importance of morphometric analysis in prosthesis design. Significant variations in femoral head diameter, neck length, neck-shaft angle, femoral neck width, and intertrochanteric distance suggest the necessity of anatomically tailored implants for better fit, stability, and function. These findings contribute to the development of region-specific prosthetic designs, ultimately improving surgical outcomes and patient mobility.
Keywords: Proximal femur, Morphometry, Hip prosthesis, Total hip arthroplasty, Femoral neck angle.

INTRODUCTION

The proximal femur plays a crucial role in weight-bearing and mobility, forming an essential part of the hip joint. It consists of key anatomical structures, including the femoral head, femoral neck, greater trochanter, and lesser trochanter, all of which contribute to joint function, stability, and biomechanics. Understanding the morphometry of the proximal femur is critical for various medical applications, particularly in orthopedic surgery and prosthesis design. Morphometric variations exist due to genetic, environmental, and ethnic factors, making it imperative to study the dimensions of the proximal femur in different populations to optimize the design of hip implants and prosthetic components.[1]

Hip-related disorders such as osteoarthritis, fractures, and congenital deformities necessitate surgical interventions, including total hip arthroplasty (THA) and hemiarthroplasty. In such procedures, the compatibility between the patient's anatomy and the prosthetic components is crucial to ensure successful outcomes. An ill-fitting prosthesis can lead to complications such as implant loosening, dislocation, altered biomechanics, and joint instability. Therefore, accurate morphometric analysis of the proximal femur is essential to design prostheses that closely mimic natural anatomical dimensions and provide optimal function.[2]

The femoral head diameter is one of the most significant parameters in prosthesis design as it determines the articulation between the femoral component and the acetabular socket. A mismatch between the femoral head size and the acetabular cup may lead to dislocation, increased wear, or limited range of motion. Similarly, the femoral neck length plays a pivotal role in maintaining the offset of the hip joint, which directly influences hip biomechanics, muscle efficiency, and joint stability. A shorter or longer neck length may alter the abductor lever arm, affecting gait and increasing the risk of mechanical failure.[3]

Another essential morphometric parameter is the neck-shaft angle, which defines the alignment between the femoral shaft and the femoral head. Variations in the neck-shaft angle can significantly influence load distribution and joint congruency. A reduced angle, known as coxa vara, results in increased stress on the femoral neck and a higher risk of fractures, whereas an increased angle, known as coxa valga, can alter hip mechanics and contribute to instability. The design of femoral prostheses should account for these variations to ensure proper implant placement and longevity.[4]

Femoral neck width is also a crucial factor, as it influences the strength and load-bearing capacity of the femur. A wider femoral neck provides better resistance against fractures and improves implant stability, whereas a narrower neck may predispose individuals to fractures, especially in osteoporotic patients. Understanding these variations aids in the selection of suitable implant dimensions, reducing the risk of peri-prosthetic fractures and improving long-term outcomes.[5]

The intertrochanteric distance, which represents the width between the greater and lesser trochanters, is an important consideration in prosthesis design. This parameter influences the positioning of femoral stems and the overall stability of the implant. An optimal intertrochanteric distance ensures a proper fit of the prosthesis within the femoral canal, reducing stress shielding and enhancing load transmission. Any discrepancy in this measurement can impact the effectiveness of implant fixation and lead to implant failure over time.[6]

Given the variations in proximal femoral morphometry across populations, the development of region-specific prostheses is gaining increasing attention. Traditional prosthetic designs are often based on data derived from Western populations, which may not be suitable for individuals from different ethnic backgrounds. Population-specific studies help in the customization of implants to match anatomical variations, leading to better surgical outcomes, improved mobility, and enhanced patient satisfaction.[7]

AIM & OBJECTIVES

The present study aims to analyze the morphometric parameters of the proximal femur in a selected population and explore their applications in prosthesis designing. By obtaining precise measurements of the femoral head diameter, neck length, neck-shaft angle, femoral neck width, and intertrochanteric distance, this study seeks to provide valuable data that can contribute to the optimization of femoral prostheses. The findings will be useful in orthopedic surgery, particularly in THA and fracture fixation procedures, where prosthetic components need to align with the natural anatomy of the femur.

MATERIALS & METHODS

Study Design

This is a cross-sectional study analyzing the morphometric parameters of the proximal femur to aid in prosthesis design.

Study Population

A total of 100 dry adult human femora, including both right and left sides, were examined. The bones were sourced from the Department of Anatomy.

Study Place

The study was conducted in the Department of Anatomy at, Kanti Devi Medical College, Hospital & Research Centre, Mathura, Uttar

Pradesh, India, where the bones were housed and examined.

Duration of Study

The study was carried out over a period of one year from April 2021 to March 2022.

Ethical Considerations

Approval was obtained from the Institutional Ethics Committee (IEC) before the commencement of the study. Since the study involved dry bones from an institutional collection, informed consent was not applicable. However, all procedures adhered to ethical guidelines for anatomical research.

Inclusion Criteria

- Intact, well-preserved adult human femora.
- Both right and left femora included.
- Bones without any visible deformities, fractures, or pathological changes.

Exclusion Criteria

- Bones with deformities, fractures, or signs of pathological changes.
- Femora with incomplete anatomical landmarks.
- Pediatric femora or those with indeterminate age.

Methodology

- Standardized morphometric measurements of the proximal femur were taken using **digital vernier calipers** osteometric board and **goniometers** for precision.
- Parameters assessed included:
    - Femoral Head Diameter (FHD)
    - Neck Shaft Angle (NSA)
    - Femoral Neck Length (FNL)
    - Femoral Neck Width (FNW)
    - Greater Trochanter Height (GTH)
    - Intertrochanteric Distance (ITD)
    - Proximal Femoral Canal Diameter (PFCD)
- Measurements were taken by two independent observers to minimize errors.
- Data were recorded and categorized based on laterality (right vs. left femora).

Outcome Measures

- Morphometric variations of the proximal femur and their implications for designing femoral prostheses.
- Comparison of right and left femoral morphometric differences.
- Establishing normative reference values for prosthesis development.

STATISTICAL ANALYSIS

- Data were analyzed using SPSS version 20.0.
- Descriptive statistics, including mean, standard deviation, and range, were calculated.
- Independent t-tests were used to compare morphometric differences between right and left femora.
- Pearson's correlation was applied to assess relationships between different parameters.
- A p-value <0.05 was considered statistically significant.

All measurements were taken three times by two independent observers to minimize inter observer and intra observer variability, and the mean values were recorded. Digital imaging techniques and software-assisted analysis were employed for certain angular and linear measurements to enhance precision.

RESULTS

The present study analyzed the morphometric parameters of the proximal femur using 100 dry adult femora to evaluate their implications in prosthesis design. The findings for each parameter are discussed below.

Table 1: Descriptive Statistics of Femoral Head Diameter

Femoral Head Diameter (mm)	Mean ± SD	Range
Right Femur	45.2 ± 3.5	39.5 - 50.8
Left Femur	44.8 ± 3.3	40.2 - 49.5
Total	45.0 ± 3.4	39.5 - 50.8

Table 1 and graph I, shows that the mean femoral head diameter was found to be 45.2 ± 3.5 mm for the right femur and 44.8 ± 3.3 mm for the left femur, with an overall mean of 45.0 ± 3.4 mm. The observed range varied from 39.5 mm to 50.8 mm, indicating considerable individual variations. The p-value for the comparison of **Femoral Head Diameter** between right and left femora is **0.558**. Since the p-value is greater than 0.05, the difference in Femoral Head Diameter between right and left femora is not statistically significant.

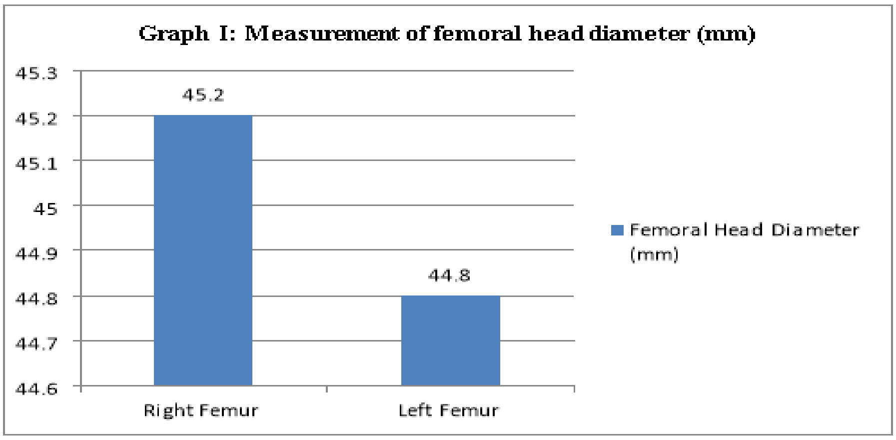

Table 2: Descriptive Statistics of Femoral Neck Length

Femoral Neck Length (mm)	Mean ± SD	Range
Right Femur	30.6 ± 2.8	25.4 - 36.1
Left Femur	30.2 ± 2.9	26.0 - 35.8
Total	30.4 ± 2.8	25.4 - 36.1

Table 2 shows that the mean femoral neck length was 30.6 ± 2.8 mm on the right side and 30.2 ± 2.9 mm on the left, with an overall mean of 30.4 ± 2.8 mm. The range extended from 25.4 mm to 36.1 mm. The neck length is an essential determinant of the offset in hip biomechanics, influencing the leverage of hip muscles and overall stability of the joint. The p-value for the comparison of Femoral Neck Length between right and left femora is 0.485(not significant).

Table 3: Descriptive Statistics of Neck-Shaft Angle

Neck-Shaft Angle (°)	Mean ± SD	Range
Right Femur	127.4 ± 4.2	120.1 - 135.5
Left Femur	126.8 ± 4.5	118.5 - 134.2
Total	127.1 ± 4.3	118.5 - 135.5

Table 3 shows that the neck-shaft angle was measured as 127.4 ± 4.2° on the right and 126.8 ± 4.5° on the left, with an overall mean of 127.1 ± 4.3°. The range of values was 118.5° to 135.5°. This parameter is crucial in determining the mechanical alignment of the femur and its articulation with the pelvis. Since the p-value is **0.492**, the difference in **Neck-Shaft Angle** between right and left femora is not statistically significant.

Table 4: Descriptive Statistics of Femoral Neck Width

Femoral Neck Width (mm)	Mean ± SD	Range
Right Femur	32.5 ± 3.1	28.0 - 38.2
Left Femur	31.9 ± 2.9	27.5 - 37.5
Total	32.2 ± 3.0	27.5 - 38.2

Table 4 shows that the femoral neck width was found to be 32.5 ± 3.1 mm on the right and 31.9 ± 2.9 mm on the left, with a total mean of 32.2 ± 3.0 mm. The observed range was 27.5 mm to 38.2 mm. The neck width plays a vital role in load transmission and structural strength of the proximal femur. Since the p-value is **0.320**, the difference in **Femoral Neck Width** between right and left femora is not statistically significant.

Table 5: Descriptive Statistics of Intertrochanteric Distance

Intertrochanteric Distance (mm)	Mean ± SD	Range
Right Femur	70.8 ± 5.6	60.2 - 80.1
Left Femur	71.2 ± 5.2	61.5 - 79.8
Total	71.0 ± 5.4	60.2 - 80.1

Table 5 shows that the intertrochanteric distance was measured as 70.8 ± 5.6 mm on the right and 71.2 ± 5.2 mm on the left, with an overall mean of 71.0 ± 5.4 mm. The range extended from 60.2 mm to 80.1 mm. Since the p-value is **0.712**, the difference in Intertrochanteric Distance between right and left femora is not statistically significant.

DISCUSSION

The present study analyzed the morphometric parameters of the proximal femur using 100 dry adult femora to assess their significance in prosthesis design.

In the present study, the mean femoral head diameter was 45.2 ± 3.5 mm for the right femur and 44.8 ± 3.3 mm for the left femur, with an overall mean of 45.0 ± 3.4 mm. The range of values extended from 39.5 mm to 50.8 mm, indicating individual variations. These findings are larger than those reported by Nayak et al. (2021), who observed a mean femoral head diameter of 39.28 ± 3.87 mm in an Indian population.[8] Similarly, Smajic et al. (2021) recorded an average diameter of 38.84 ± 5.32 mm in a Croatian population, showing a smaller femoral head dimension compared to our study.[9]

Additionally, Rawal et al. (2012) found a mean femoral head diameter of 44.5 ± 4.1 mm, which is close to our results but still slightly smaller. These variations could be attributed to ethnic and genetic differences, as well as differences in measurement techniques.[10,11]

The femoral neck length in our study was 30.6 ± 2.8 mm for the right femur and 30.2 ± 2.9 mm for the left femur, with a total mean of 30.4 ± 2.8 mm. The range varied from 25.4 mm to 36.1 mm. Smajic et al. (2021) reported a mean femoral neck length of 44.29 ± 4.31 mm, which is significantly longer than our findings.[9] In contrast, Mahaisavariya et al. (2018) reported a shorter neck length of 29.1 ± 3.6 mm in a Thai population, which is more comparable to our results. The discrepancy in femoral neck length may influence the offset in hip biomechanics, affecting joint stability and muscle function, which is a critical factor in hip prosthesis design.[10]

Our study recorded a mean neck-shaft angle of 127.4 ± 4.2° on the right side and 126.8 ± 4.5° on the left, with an overall mean of 127.1 ± 4.3°. These values are higher than those reported by Nayak et al. (2021), who found an average neck-shaft angle of 119.08 ± 5.18° in an Indian sample.[8] Similarly, Rawal et al. (2012) recorded a lower mean neck-shaft angle of 124.6 ± 4.2°, while Unnanuntana et al. (2010) found a slightly higher mean angle of 128.3 ± 5.1° in a Caucasian population. The neck-shaft angle plays a crucial role in determining the mechanical alignment of the femur and its articulation with the pelvis, affecting implant positioning in total hip arthroplasty. A higher neck-shaft angle may reduce hip impingement but could also impact the weight-bearing capacity of the femoral head.[11,12]

The femoral neck width in our study was 32.5 ± 3.1 mm on the right and 31.9 ± 2.9 mm on the left, with a total mean of 32.2 ± 3.0 mm. The range varied from 27.5 mm to 38.2 mm. Nayak et al. (2021) reported a mean femoral neck width of 29.03 ± 3.8 mm, which is smaller than our findings.[8] Meanwhile, Hernandez et al. (2004) observed a mean width of 34.1 ± 3.2 mm, indicating a larger femoral neck in their study population. The femoral neck width is a key determinant in load transmission and the structural integrity of the femur. A narrower femoral neck is associated with a higher risk of fractures, particularly in osteoporotic individuals, while a wider neck provides increased resistance to mechanical stress.[13]

The intertrochanteric distance in our study was 70.8 ± 5.6 mm on the right side and 71.2 ± 5.2 mm on the left, with an overall mean of 71.0 ± 5.4 mm. The range extended from 60.2 mm to 80.1 mm. Comparative data on intertrochanteric distance from previous studies are limited. However, Unnanuntana et al. (2010) reported an intertrochanteric distance of 68.5 ± 4.7 mm, which is slightly lower than our findings. The intertrochanteric region is an important site for implant fixation, and variations in this measurement impact the design of femoral stems used in hip arthroplasty.[12]

LIMITATIONS OF THE STUDY

1. **Small Sample Size**
   - The study included only 100 dry adult human femora, which may not be sufficient to represent variations in a larger population. A larger sample size could improve the generalizability of the findings.
2. **Lack of Demographic Data**
   - The study did not account for age, sex, ethnicity, or geographical background of the specimens. These factors could influence femoral morphology and impact prosthesis design.
3. **Absence of Clinical Correlation**
   - While the morphometric data are useful for prosthesis design, clinical validation through patient-based studies (e.g., radiographic or cadaveric studies) is necessary for practical applications.
4. **Use of Dry Bones**

- Measurements were taken on dry femora, which may differ from in vivo conditions due to the absence of soft tissues, cartilage, and physiological loading effects.

5. **Potential Measurement Errors**
   - Despite standard methodologies, minor human or instrumental errors in measurement could affect accuracy. Digital imaging techniques such as CT or MRI could provide more precise morphometric data.
6. **Side-to-Side Variability**
   - The study focused on comparing right and left femora, but individual variations could be influenced by lifestyle, handedness, or activity levels, which were not accounted for.
7. **Limited Application to Prosthesis Design**
   - While the study provides essential morphometric data, practical implications for prosthesis fitting require additional biomechanical studies, load distribution analysis, and clinical trials.

CONCLUSION

This study provides a comprehensive morphometric analysis of the proximal femur, which is crucial for designing anatomically accurate and well-fitting hip prostheses. Key parameters such as femoral head diameter, femoral neck length, neck-shaft angle, femoral neck width, and intertrochanteric distance were measured and compared between the right and left femora.

The findings indicate that no statistically significant differences exist between the right and left femora for any of the measured parameters ($p > 0.05$), suggesting a generally symmetrical morphology. These results contribute valuable baseline data for orthopedic surgeons, prosthesis designers, and biomechanical engineers in developing implants tailored to the anatomical variations of the femur to ensure better implant fit, biomechanical stability, and long-term success in hip arthroplasty.

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