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Morphometry of proximal femur in South Indian Population

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ABSTRACT

Background: Proximal femur analysis plays a vital role in orthopedic surgery, implant design, fracture care, and research. Studying this complex bone helps surgeons select the right implants, plan fracture treatment, and understand bone strength. This growing field improves clinical outcomes and enhances scientific knowledge. Our study analyzes the morphometry of proximal femur, particularly the head and neck, to further explore its implications. **Aims and Objectives:** To study the morphometric measurements of the proximal end of the femur quantitatively in the South Indian population from the dry femora available in the Department of Anatomy, Government Medical College, Kottayam. **Materials and Methods:** This cross-sectional study was conducted in 101 dry femora available in the Department of Anatomy, Government Medical College, Kottayam. The measurements were taken with digital Vernier calipers and a goniometer. All continuous variables were expressed as mean with standard deviation. Statistical differences between the right and left sides were analyzed with Student's independent sample t-test (for parametric variables) and Mann–Whitney U test (for non-parametric variables). **Results:** The mean vertical and anteroposterior diameter of the femoral head, superior and inferior length of the femoral head, the anteroposterior and vertical diameter of the femoral neck, superior and inferior lengths of the femoral neck, neck-shaft angle, and intertrochanteric length were 39.61±3.29 mm, 40.17±3.14 mm, 33.01±3.6 mm, 23.88±4.32 mm, 24.22±3 mm, 29.59±3 mm, 21.75±3.81 mm, 32.03±5.58 mm, 124.11±6.37, 60.31±7.33 mm, respectively. There was a statistically significant difference in the mean of neck anteroposterior diameter and neck-shaft angle between the right and left sides where the left side had the higher value. **Conclusion:** Notable skeletal metric variations exist amidst different populations. Proximal femoral dimensions can be acquired through either manual means or radiological information. These measurements can be used in designing orthopedic implants for the South Indian population.

Key words: Proximal femur; Osteology; South Indian Population; Morphometry

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INTRODUCTION

The proximal femur, often known as the thigh bone, is an important anatomical element in human mobility and skeletal integrity. The morphometric analysis of the proximal femur is vital in a variety of clinical and scientific fields due to its complicated geometry and biomechanical features. Morphometric analysis is the quantitative evaluation of the shape, size, and structural properties of biological entities. Numerous studies have underlined the importance of proximal femur morphometric analysis in orthopedic surgery, implant design, fracture care, and biomechanical research throughout the last decade.

Pre-operative planning is critical in orthopedic surgery, particularly in interventions involving the proximal femur. Orthopedic surgeons benefit from morphometric analysis of the proximal femur because it aids in accurate implant selection, placement, and alignment. Implant sizing and alignment are essential elements in the success of surgical procedures.[1] With developments in the complexities of surgical procedures and implant designs, it is necessary to have

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a thorough understanding of proximal femur morphology for achieving the best results and limiting complications.[2]

Fractures of the proximal femur, especially in the elderly, provide considerable difficulties with health care. Morphometric study of the proximal femur is important in fracture management because it provides information about fracture patterns, classification systems, and treatment procedures. An accurate assessment of proximal femur morphology allows for better planning of surgical approach, the selection of appropriate fixation devices, and the optimization of fracture reduction strategies. Furthermore, morphometric analysis allows for the formulation of patient-specific treatment plans that take into account individual bone geometry and biomechanical factors, resulting in enhanced fracture healing and functional outcomes.[3] Pre-operative morphometric evaluation influences surgical decision-making and subsequent patient outcomes by assessing the suitability of intramedullary devices against extramedullary fixation.[4]

Apart from clinical consequences, morphometric assessment of the proximal femur adds to biomechanical research by allowing for a better understanding of bone structural integrity, mechanical properties, and functionality. Researchers can predict bone strength, analyze the impacts of osteoporosis, and create preventative strategies to reduce fracture risk by combining morphometric data with computational modeling and finite element analysis.[5] Corrective osteotomies for complex proximal femoral abnormalities can be difficult; thus, assistance in pre-operative planning and during surgical operations is thought to be beneficial. Different orthopedic surgeries already use three-dimensional (3D) planning and patient-specific instrumentation.[6] Furthermore, morphometric parameters of the proximal femur are important in the design and refinement of computational models used in biomechanical simulations and virtual testing of implants to ensure their safety and efficacy.[7]

The morphometric study of the proximal femur has gained increasing importance over the past decade. Its use in orthopedic surgery, implant design, fracture management, and biomechanical research has proved its importance in improving clinical outcomes and enhancing scientific knowledge. The integration of morphometric analysis with modern imaging techniques, computational modeling, and simulation methods yields a thorough awareness of proximal femur morphology and its implications for numerous fields of medicine. In this study, we aimed to conduct a morphometric study of the proximal end of the femur particularly the head and neck of the dry femora quantitatively and to analyze each parameter sidewise.

Aims and objectives

To study the morphometric measurements of proximal end of femur quantitatively in the South Indian population from the dry femora available in Department of Anatomy, Government Medical College, Kottayam.

MATERIALS AND METHODS

This study was conducted as a cross-sectional study using 101 intact adult femora (right-48 and left-53) obtained from the Department of Anatomy, Government Medical College, Kottayam, after getting approval from the Institutional Review Board of the institution (IRB. No. 129/2023 dated May 12, 2023). Bones with any gross deformities or damages were not included in the study. Age, ethnicity, and sex were not known. The measurements were taken with digital Vernier calipers and a goniometer. Ten variables were measured (Figure 1).

(i) Femoral head vertical diameter: It is the vertical diameter of the femoral head measuring the straight distance between the highest and lowest point of the head[8]
(ii) Femoral head anteroposterior diameter: It is the maximum anteroposterior distance of the head of the femur[9]
(iii) Femoral neck vertical diameter: It is the distance between the two extreme points in the middle of the neck in the superioinferior plane (sagittal plane)[10]
(iv) Femoral neck anteroposterior diameter: It is the distance between the two extreme points in the middle of the neck from the center point of the intertrochanteric line to the base of the head in the anteroposterior plane[10]
(v) Femoral head superior length: It is the distance from the center of the femoral head (fovea) to the periphery of the femoral head along the articular cartilage border where it is maximum (superior)[10]
(vi) Femoral head inferior length: It is the distance from the center of the femoral head (fovea) to the periphery of the femoral head along the articular cartilage border where it is minimum (inferior)[10]
(vii) Femoral neck superior length: It is the distance between the superior region of the base of the femoral head and the base of the greater trochanter
(viii) Femoral neck inferior length: It is the distance between the inferior region of the base of the femoral head and the lower end of the intertrochanteric line
(ix) Intertrochanteric length: It is the total length of the intertrochanteric crest from the tip of the greater trochanter to the lesser trochanter
(x) Neck-shaft angle: It is the angle formed by the neck axis and shaft axis of the femur.

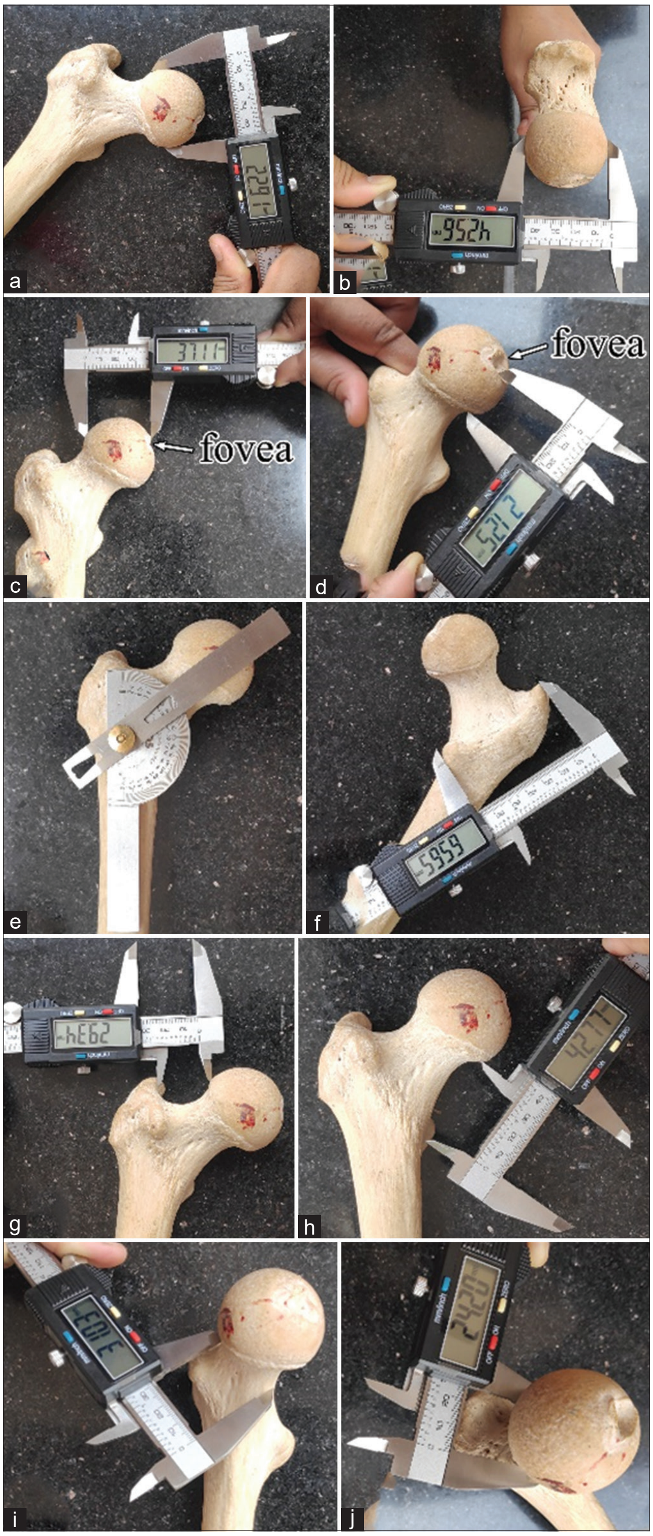

Figure 1: Method of measuring different variables in the present study. (a) Femoral head vertical diameter; (b) femoral head anteroposterior diameter; (c) femoral head superior length; (d) femoral head inferior length; (e) neck-shaft angle; (f) intertrochanteric length; (g) femoral neck superior length; (h) femoral neck inferior length; (i) femoral neck vertical diameter; (j) femoral neck anteroposterior diameter

Quantitative variables were expressed as a minimum, maximum, median, mean, and standard deviation. The distribution of the data was evaluated using a Kolmogorov–Smirnov test. It was observed that certain variables followed a normal distribution, while others did not follow to this pattern. Differences between the right and left sides were analyzed using the Mann–Whitney U-test for variables with non-normal distribution and independent sample t-test for variables with normal distribution. $P<0.05$ was considered statistically significant. Data analysis was performed using version 21 of the Statistical Package for the Social Sciences (SPSS software, IBM Inc, New York, USA).

RESULTS

The different parameters of the proximal end of 101 dry femora (right – 48 and left – 53) were measured, subjected to statistical analysis, and compared. Table 1 shows the mean, standard deviation, median, minimum, and maximum values of the morphological parameters studied. The Kolmogorov–Smirnov test was used to determine the normality of the data distribution of the study variables, and it was found that the HSL, NAPD, and NSA had a non-normal distribution whereas the rest followed the normal distribution. Two observers independently recorded their findings and the mean was taken. Table 2 shows the results of the independent sample t-test to compare the quantitative variables with a normal distribution of the right and left femora. Table 3 shows the results of the Mann–Whitney U test to compare the quantitative variables with the non-normal distribution of the right and left femora.

DISCUSSION

The various parameters measured in the present study and findings in similar other studies are shown in Table 4.

The complex geometry and structural peculiarities of the proximal femur necessitate a thorough understanding to achieve successful surgical outcomes. The importance of studying the morphometry of the proximal femur in different populations lies in the recognition that anatomical variations exist among individuals of diverse ethnicities, age groups, and geographical locations. These variations can have significant implications for orthopedic surgeries, including total hip arthroplasty (THA), hip fracture fixation, revision surgeries, and other interventions involving the proximal femur.[24,25] By understanding the unique morphometric characteristics of different populations, surgeons can tailor their surgical approaches, implant selection, and pre-operative planning to optimize outcomes and minimize complications. Moreover, the study of proximal femur morphometry in different populations contributes to the development

Table 1: Descriptive statistics of measurements of the proximal femur

Side	HVD (mm)	HAPD (mm)	HSL (mm)	HIL (mm)	NAPD (mm)	NVD (mm)	NSL (mm)	NIL (mm)	NSA (degrees)	ITL (mm)
Left side (53 in number)										
Mean	39.39	40.06	32.64	23.25	24.92	29.41	21.67	32.35	125.96	60.79
Std. Deviation	3.17	3.00	3.69	3.72	3.00	2.92	3.49	4.63	6.39	5.80
Median	39.18	40.18	33.00	23.09	25.57	30.00	22.00	32.23	126.00	62.00
Minimum	32.00	33.00	25.00	15.00	17.00	21.46	13.00	24.00	110.00	42.00
Maximum	45.82	46.00	39.66	33.28	31.00	36.95	31.19	44.00	143.00	71.13
Right side (48 in number)										
Mean	39.85	40.29	33.42	24.59	23.45	29.80	21.84	31.67	122.06	59.79
Std. Deviation	3.44	3.32	3.49	4.84	2.85	3.09	4.16	6.50	5.74	8.75
Median	40.31	40.44	34.16	25.00	23.98	29.50	21.00	30.22	122.00	60.88
Minimum	29.00	30.00	26.00	3.00	17.35	23.00	14.00	21.00	110.00	27.00
Maximum	49.00	49.00	41.00	35.00	30.94	37.00	30.80	45.09	137.00	78.00
Total (101)										
Mean	39.61	40.17	33.01	23.88	24.22	29.59	21.75	32.03	124.11	60.31
Std. Deviation	3.29	3.14	3.60	4.32	3.01	2.99	3.81	5.58	6.37	7.33
Median	39.99	40.35	33.98	24.11	24.34	29.58	22.00	31.00	125.00	61.00
Minimum	29.00	30.00	25.00	3.00	17.00	21.46	13.00	21.00	110.00	27.00
Maximum	49.00	49.00	41.00	35.00	31.00	37.00	31.19	45.09	143.00	78.00

HVD: Femoral head vertical diameter, HAPD: Femoral head anteroposterior diameter, NVD: Femoral neck vertical diameter, NAPD: Femoral neck anteroposterior diameter, HSL: Femoral head superior length, HIL: Femoral head inferior length, NSL: Femoral neck superior length, NIL: Femoral neck inferior length, ITL: Intertrochanteric length, and NSA: Neck-shaft angle

Table 2: Independent sample t-test to compare the quantitative variables with the normal distribution of the right and left femora

Parameters	t	P
HVD	−0.693	0.490
HAPD	−0.356	0.723
HIL	−1.573	0.119
NVD	−0.660	0.511
NSL	−0.220	0.826
NIL	−0.612	0.542
ITL	−0.680	0.498

HVD: Femoral head vertical diameter, HAPD: Femoral head anteroposterior diameter, NVD: Femoral neck vertical diameter, HIL: Femoral head inferior length, NSL: Femoral neck superior length, NIL: Femoral neck inferior length, and ITL: Intertrochanteric length

Table 3: Mann–Whitney U test to compare the quantitative variables with non-normal distribution of the right and left femora

Parameters	Z	P
HSL	−1.163	0.245
NAPD	−2.954	0.003
NSA	−3.093	0.002

HSL: Femoral head superior length, NAPD: Femoral neck anteroposterior diameter, and NSA: Neck-shaft angle

of standardized measurement techniques and reference databases, enhancing the reliability and reproducibility of surgical interventions.

Ethical and racial variations in factors such as bone density, bone quality, and hip joint geometry may lead to variations in femoral neck angles, head-neck ratios, and overall femoral dimensions.[26,27] Proximal femur morphometry data obtained from diverse populations aids in the refinement and customization of orthopedic implants to better suit the anatomical variations observed. By considering the differences in proximal femur morphology between populations, implant manufacturers can develop implant designs that offer improved fit, stability, and longevity.[17]

Previous studies have extensively investigated proximal femur morphometry and its significance in orthopedic surgeries. The study by Ravichandran et al. demonstrated the importance of the knowledge of femoral neck morphometry in designing dynamic hip screws tailored to each population.[28] Atilla et al. demonstrated the correlation between femoral head diameter and implant size selection in the Turkish population.[29] According to the study by Stroh et al., larger femoral heads were associated with reduced dislocation rates and increased range of motion.[30] Unnanuntana et al. compared the neck-shaft angle between different populations and concluded that racial differences exist, suggesting the need for individualized surgical approaches.[12] Precise morphometric measurements play a crucial role in selecting appropriate implants, such as intramedullary nails or sliding hip screws, to achieve optimal stability and promote fracture healing. A study by Casper et al. highlighted the importance of obtaining accurate radiographic measurements to guide implant selection and achieve better functional outcomes in patients with proximal femur fractures.[31] Revision surgeries for failed hip arthroplasties require a thorough understanding of the patient's proximal femur morphology to address implant loosening, instability, or bone loss. Multiple research studies emphasized the importance of accurate

Table 4: Comparison of various morphometric measurements of the proximal femur between the present study and similar studies

Author (Location; Year; Type of sample)	HVD (mm)	HAPD (mm)	HSL (mm)	HIL (mm)	NAPD (mm)	NVD (mm)	NSL (mm)	NIL (mm)	NSA (degrees)	ITL (mm)
Current study (South India; 2023; Dry bones)	39.61±3.29	40.17±3.14	33.01±3.60	23.88±4.32	24.22±3.01	29.59±2.99	21.75±3.81	32.03±5.58	124.11±6.37	60.31±7.33
Irdesel et al.[11] (North India; 2006; X-ray images)	52.1±0.2					35.4±0.1			131.52±0.3°	84.2±0.3
Aasis et al.[12] (United States; 2010; dry bones)	52.09±4.43								132.69±5.91	
Sousa et al.[13] (Brazil; 2010; Dry bones)	46.75±3.4					30.95±2.85			131.95±6.2	
Baharuddin et al.[14] (Malaysia; 2011; CT images)	41.24±2.61					27.42±3.85			131.1±3.7	
Iyem et al.[15] (Turkey; 2014; X-ray images)	48.1±3.7					35.4±4.2			130.4±5.1	81.1±7.1
Lakati et al.[16] (Kenya; 2017; Dry bones)	42.6					29.36			129.21	
Verma et al.[17] (North India; 2017; Dry bones)	42.32±4.11				24.01±3.05	33.02±4.22		44.75±8.1	128.90±4.49	
Muley et al.[18] (North India; 2017; Dry bones)						29.12±2.98				
Siwach10 (North India; 2018; Dry bones)	43.95±3.06		36.9±4.11	25.5±4.26	24.9±2.94	31.87±2.91	22.69±3.65	37.23±4.65	123.5±4.34	
Sobana et al.[19] (South India; 2018; Dry bones)	41.7							34.2	129.9	61.3
Mukhia et al.[20] (Nepal; 2019; Dry bones)					23.6±4.2	29.4±3		41.2±3.2	127.1±6.44	
Vinay et al.[9] (South India; 2019; Dry bones)	40.9±3.5								120.13±5.72	
Rajila et al.[21] (South India; 2020; Dry bones)	39.9±3.42								146.25±4.18	
Sengupta et al.[8] (North India; 2020; Dry bones)	38.32±2.97					28.47±2.5			125.72±7.01	

(Contd...)

Table 4: (Continued)

Author (Location; Year; Type of sample)	HVD (mm)	HAPD (mm)	HSL (mm)	HIL (mm)	NAPD (mm)	NVD (mm)	NSL (mm)	NIL (mm)	NSA (degrees)	ITL (mm)
Kamath et al.[22] (South India; 2020; X-ray images)	44.80±4.20								137.80±6.90	
Gupta et al.[23] (North India; 2022; Dry bones)	41.59±3.25					27.61±2.71		36.06±4.94	119.08±5.18	41.92±3.90

HVD: Femoral head vertical diameter, HAPD: Femoral head anteroposterior diameter, HSL: Femoral head superior length, HIL: Femoral head inferior length, NAPD: Femoral neck anteroposterior diameter, NVD: Femoral neck vertical diameter, NSL: Femoral neck superior length, NIL: Femoral neck inferior length, ITL: Intertrochanteric length, and NSA: Neck-shaft angle

pre-operative imaging and measurements to improve the outcomes of revision hip arthroplasty.[32,33] The current study clearly demonstrates the difference in proximal femur morphometry between the South Indian population and other parts of the world including the United States of America, Turkey, Kenya, and Brazil.[12,13,15,16]

The asymmetry between the right and left sides is another important factor to consider in pre-operative planning in orthopedic surgeries, particularly THA. An accurate assessment of the sidewise differences helps determine optimal implant positioning, size, and offset for each side of the hip joint. Considering the individual patient's sidewise morphological variations allows for a precise surgical approach, potentially improving joint stability, and reducing complications. Off-the-shelf implants often assume bilateral symmetry, which may not adequately accommodate the individual's unique sidewise morphometry. Failure to consider sidewise asymmetry can result in implant malpositioning, instability, and increased wear, compromising the long-term success of the surgery. We found statistically significant differences in the mean values of NSA and NAPD between the right and left sides (P value 0.002, 0.003, respectively; Table 3). However, similar studies by Sousa et al.[13] and Rajila et al.[21] found there was no significant difference in the proximal femur parameters between the right and left sides.

Accurate assessment and correction of sidewise asymmetry help minimize leg-length discrepancy, ensuring optimal gait mechanics, and reducing patient discomfort and dissatisfaction post-surgery. Standardized protocols for assessing sidewise asymmetry in proximal femur morphometry are essential to ensure consistency and reproducibility across different surgical centers. Consensus guidelines for radiographic and 3D imaging evaluations should be developed to facilitate reliable comparisons and interpretation of asymmetrical features.

Furthermore, studying proximal femur morphometry in different populations provides valuable insights into the epidemiology and etiology of various orthopedic conditions including population-specific risk factors and pre-dispositions. In addition, understanding the morphological differences in proximal femur among different populations can shed light on the development and progression of conditions such as osteoarthritis and avascular necrosis, which can have varying prevalence and severity across populations.[34] Furthermore, the availability of population-specific normative data promotes standardization and consistency in orthopedic practice, facilitating better communication and collaboration among surgeons globally.

Despite significant progress in proximal femur morphometry, several areas warrant further exploration. Advanced imaging techniques, such as three-dimensional modeling [35] and computer-assisted methods,[36] hold promise for enhancing accuracy in pre-operative planning. In addition, incorporating patient-specific factors, such as bone quality and loading patterns, could lead to personalized treatment strategies and improved outcomes. Long-term follow-up studies are necessary to evaluate the impact of morphometry on implant survivorship and patient satisfaction.

The current study did not include the sex differences in the variations in morphometry of the proximal femur. Future research should focus on standardizing measurement protocols, incorporating large-scale multicenter studies, and developing population-specific morphometric databases to enhance surgical planning and implant selection. To enhance the reliability and reproducibility of proximal femur morphometry, standardization of measurement techniques and the establishment of comprehensive reference databases are crucial.

Limitations of the study

Current study did not include the age and sex differences in the variations in morphometry of proximal femur.

CONCLUSION

Skeletal measurements vary significantly across populations. Understanding these differences is crucial for designing orthopaedic implants that fulfill the needs of the South Indian population. By using tools like manual or radiological methods, we can gather accurate data on proximal femoral morphometric dimensions, paving the way for custom-designed implants that offer optimal surgical outcome for the patients.

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RG- Definition of intellectual content, literature survey, prepared the first draft of the manuscript, implementation of the study protocol, data collection, manuscript preparation, and submission of the article; **NKR**- Design, clinical protocol, data analysis, manuscript preparation, editing, preparation of figures, and manuscript revision.

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