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ORIGINAL RESEARCH ARTICLE

A comprehensive study on the morphometric analysis of the human femur with anatomical and clinical correlations

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Abstract

Introduction: The femur bone is the longest and strongest bone, which is crucial for locomotion, transmission of weight and maintains stability. The morphometric characteristics are significant for the orthopaedic surgery, design of the prosthesis and identification of forensic details. The study aims to evaluate the femoral measurements and the establishment of the anatomical variations with clinical significance.

Method: This was a descriptive cross-sectional study which was conducted among 50 dry human femora, where the intact bones were only included. The digital Vernier caliper was used to take measurements, an osteometric table, and a goniometer. Data analysis was done by SPSS. The descriptive statistics and correlation analysis were performed with $p < 0.05$.

Result: The study findings showed that the diameter of the head and the neck parameter showed moderate variation, while the length of the femur showed low variation. The positive correlations were noted between the head diameter, neck diameter, intertrochanteric line length and the length of the femur. The regression model showed moderate fit with $R^2 = 0.271$, $p = 0.001$, along with 27.1% variance.

Conclusion: The study concluded that the significant morphometric variation in the human femur bone, with the diameter of the head as 41.83 ± 3.12 mm and the neck parameter showed moderate dispersion, while low variation was noted for the length of the femur.

Key words: Femur morphometry, Neck-shaft angle, Osteometric analysis, Femoral dimensions, Orthopaedic relevance

1 | INTRODUCTION

The femur is the longest and strongest bone in the body, which is clinically significant to anatomists, forensic experts, orthopaedic surgeons, and sports physicians. The length of the femur is related to gait, and the strength required is influenced by the weight and forces of the muscles. Structurally, the femur consists of a proximal end, shaft, and distal end. The former one consists of the head and neck. The spheroidal head of the femur articulates with the acetabulum of the hip bone for the formation of the hip joint and is present inside the joint capsule. The head represents a small and rough depression like structure in the postero-inferior portion in the centre, referred to as the fovea. Length of the femoral is 5 cm, and it get connected with the head to the shaft, which is measured at around 127° on average. The neck shaft angle facilitated the movement at the hip joint, which enabled the limb to swing. The neck provides the lever of the muscle action, which acts on the hip joint, which is associated with the proximal femur. The neck is rotated laterally, with respect to the shaft in 10-15°, which is called as the angle of anteversion. This varies between individuals and populations. The greater trochanter is a structurally large quadrangular projection that arises from the junction of the

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shaft and neck. While the lesser trochanter is the projection of the conical posteromedial of the shaft. The intertrochanteric line decreases medially from the anterior portion of the greater trochanter to the lower portion of the neck, which is situated anterior to the lesser trochanter part (1). It is widely observed that the femur is the bone which showed highest correlation with the stature (2). The linear regression formulae on the basis of the length of the extreme bones, specifically the femur, have been regarded as the estimator for the stature (3). In case of unavailability of the entire bone, it becomes essential to estimate the length of the femur from the fragments. The proximal fragment of the femur increases with the density of the cortical bone, and the improved muscular cover is preserved. The procedure involved the estimation of the femur length from the fragments, which is followed by the estimation of the stature, demonstrated as the indirect process of stature estimation (4). Various studies have shown the positive correlation between the measurement of the proximal femoral fragment and the total length of the femur (5). The most common orthopedic surgical procedure is Hip joint arthroplasty, due to the prevalence of hip osteoarthritis and associated with impaired hip conditions. The treatment modality requires stable fixation of the anatomy. The morphometric parameters of the femur have been impacted by various parameters like race, sex, environmental and lifestyle factors (6). The aims and objective of the study is to evaluate the comprehensive morphometric analysis of the human femur bone and the establishment of the anatomical variation associated with the clinically significant correlation.

2 | METHOD

Research design

This was a descriptive, cross-sectional morphometric analysis of the human femur bone to investigate both anatomical and clinical correlations. The study was conducted in Vedantaa Institute of Medical Sciences, Dahanu ,Palghar (Maharashtra) for the duration of 7 Months(November 2023 to May 2024). A total of 50 dry human femora were collected, which consisted only of the intact and undamaged bone. The broken or deformed femur was identified and excluded. Both of the right- and left-sided femora were considered for the comparative analysis. Standard osteometric methods were employed for the measurements. The digital Vernier caliper was utilised for the linear measurements, and the osteometric table was used to measure the length of the femur. The neck-shaft angle was measured by the analogue goniometer. Data were analysed to evaluate the morphometric variations.

Inclusion criteria

- Dry adult human femur bones taken from the institution was included.
- Only intact and preserved bones were included.
- Both right- and left-sided femora were considered.
- Femora with identified marks of anatomical structure were included.

Exclusion criteria

- All broken or fractured femora was identified and excluded.
- Eroded bone structures are observed pathological changes like tumours deformities were excluded from the study.

Procedure

The procedure includes the detailed morphometric evaluation of the dry human femora by standard osteometric techniques. Each of the femur bone was analysed and was placed appropriately and accurately to identify the anatomical landmark. Appropriate measurements were taken for various parameters. The diameter of the head was measured along the craniocaudal axis, and the maximum distance was measured between the superior and inferior margins of the femoral head. The depth of the fovea capitis was evaluated as the maximum depression vertically, while the transverse and longitudinal diameters were evaluated as the greatest extension along the horizontal and vertical axes. The diameter of the neck was recognised as the distance between the superior and inferior borders. The length of the neck was measured from the inferior part of the femoral head to the lower end of the intertrochanteric line. The thickness of the neck was measured along the anteroposterior axis. The neck-shaft angle was estimated as the angle developed between the longitudinal axis of the neck with the shaft by means of a goniometer. The total length of the intertrochanteric line was measured, and the total length of the femur bone was recorded from the highest point on the head to the medial femoral condyle by the use of an osteometric table. The measurements were obtained with instruments to maintain the reliability and reproducibility of the data.

Statistical analysis

Data collected were entered into Microsoft Excel. Statistical analysis was done by IBM SPSS software version 27. Descriptive statistics were estimated, and the comparative analysis was done between right- and left-sided femora. The p-value was maintained at less than 0.05 for statistical significance. The results were represented in the form of tables and charts.

3 | RESULTS

Table 1 showed the mean diameter of the head was 41.83 ± 3.12 mm, which indicated moderate variability. TheFoveal depth was estimate to be 3.02 ± 0.70 mm, while transverse and longitudinal diameters measured to be 11.52 ± 2.28 mm (6.8–17.4 mm) and 16.10 ± 3.25 mm (7.1–25 mm), showed wide dispersion. The neck parameters showed the mean value to be 29.72 ± 3.20 mm as neck parameters. The neck-shaft angle was 119.65° ± 5.05° (109.5°–128.5°), which showed variation. The length of the intertrochanteric line was 42.20 ± 3.75 mm, and the maximum length of the femur was estimated to be 42.45 ± 2.80 cm, showed low variation .The intertrochanteric line length was 42.20 ± 3.75 mm (34.5–52 mm). The maximum femur length measured 42.45 ± 2.80 cm (35.8–54.8 cm), demonstrating relatively lower variability compared to other parameters.

Table 1. Descriptive statistical summaries of all the measurements of the femur

Parameter	Mean ± SD	Minimum	Maximum
Head diameter (mm)	41.83 ± 3.12	34.5	47.8
Foveal depth (mm)	3.02 ± 0.70	1.5	5.8
Foveal transverse diameter (mm)	11.52 ± 2.28	6.8	17.4
Foveal longitudinal diameter (mm)	16.10 ± 3.25	7.1	25
Neck diameter (mm)	29.72 ± 3.20	23.4	36.1
Neck length (mm)	36.40 ± 4.75	26	46.5
Neck thickness (mm)	27.85 ± 2.60	22.5	33.9
Neck shaft angle (°)	119.65 ± 5.05	109.5	128.5
Intertrochanteric line length (mm)	42.20 ± 3.75	34.5	52
Maximum femur length (cm)	42.45 ± 2.80	35.8	54.8

The Table 2 showed the correlation that head diameter is positively correlated with the neck diameter, intertrochanteric line length **(**r = 0.358**)**, and the femur length **(**r = 0.341**)** (p < 0.01). Foveal transverse and longitudinal diameters are positively related. The thickness of the neck and the diameter of the neck are also associated. The neck-shaft angle was weak, without any significant correlation with the variables. The Regression analysis revealed the moderate model fit, which explained the 27.1% variance, with the statistical significance as **(**F = 3.45, p = 0.001**)**.

The Table 3 revealed the regression analysis as a moderate model fit, with correlation coefficient as R = 0.521, and the coefficient of determination R^2 = 0.271, which indicated the 27.1% as the variation of the dependent variable. The adjusted R^2 (0.192) suggested the reduction in the multiple variables. The model is indicated by ANOVA, which confirms that predictors contributed to the outcome. The total variance (807.372) is partitioned into regression and residual, of values as (214.532) and (592.84) respec-

Table 2. Pearson correlation analysis between the femur length and other femoral parameters

Parameters	Head diameter (mm)	Foveal depth (mm)	Foveal transverse diameter (mm)	Foveal longitudinal diameter (mm)	Neck diameter (mm)	Neck length (mm)	Neck thickness (mm)	Neck shaft angle	Intertrochanteric line length (mm)	Femur length (cm)
Head diameter (mm)	r = 1	0.225*	0.258*	0.338**	0.512**	0.058	0.266*	-0.12	0.358**	0.341**
	p	0.031	0.012	0.001	0	0.601	0.01	0.21	0.001	0.001
Foveal depth (mm)	r = 0.225*	1	0.19	0.255*	0.308**	0.102	0.271*	-0.085	0.125	0.251*
	p	0.031	0.072	0.014	0.003	0.32	0.009	0.395	0.24	0.015
Foveal transverse diameter (mm)	r = 0.258*	0.19	1	0.462**	0.228*	-0.028	0.126	-0.02	0.289**	0.098
	p	0.012	0.072	0	0.029	0.79	0.23	0.84	0.005	0.35
Foveal longitudinal diameter (mm)	r = 0.338**	0.255*	0.462**	1	0.04	0.055	0.158	-0.098	0.268*	-0.015
	p	0.001	0.014	0	0.71	0.61	0.14	0.35	0.011	0.88
Neck diameter (mm)	r = 0.512**	0.308**	0.228*	0.04	1	-0.005	0.305**	0.005	0.372**	0.245*
	p	0	0.003	0.029	0.71	0.96	0.003	0.95	0	0.02
Neck length (mm)	r = 0.058	0.102	-0.028	0.055	-0.005	1	0.235*	0.035	0.145	0.18
	p	0.601	0.32	0.79	0.61	0.96	0.025	0.73	0.18	0.085
Neck thickness (mm)	r = 0.266*	0.271*	0.126	0.158	0.305**	0.235*	1	-0.07	0.255*	0.235*
	p	0.01	0.009	0.23	0.14	0.025	0.48	0.022	0.025	
Neck shaft angle	r = -0.120	-0.085	-0.02	-0.098	0.005	0.035	-0.07	1	0.05	0.198
	p	0.21	0.395	0.84	0.35	0.95	0.73	0.48	0.66	0.06
Intertrochanteric line length (mm)	r = 0.358**	0.125	0.289**	0.268*	0.372**	0.145	0.255*	0.05	1	0.175

tively. The standard error of estimate was 2.58, which reflected the moderate accuracy of prediction. The result findings indicated the significance.

4 | DISCUSSION

The study assessed the nine proximal femoral parameters, and the clinical significance has been noted. The mean value for the femoral head diameter was 41.59 mm, while the diameter of the neck, length and thickness showed consistency in the measurement. The average value of neck shaft angle was 119.08°, which indicated the variation related to population. Foveal dimensions and intertrochanteric line length were also noted. A strong positive correlation was noted between the length of the femur and the proximal parameters. These result findings highlighted the significance of the region-specific information to design the implant. The study supported the usage of the proximal femoral measurements to accurately measure the estimated value of forensive investigation (7). The dimension of the proximal femur among 140 dry adult femora was observed to support the design of the implant. The mean diameter value of the head transverse was 33.88 mm on the right and 33.31 mm on the left side. Neck transverse diameter and proximal breadth were comparable parameters for both of the sides. Statistical analysis showed insignificant differences in the case of measured values. The findings of the study suggested the symmetry of the proximal femoral morphology. The results provided baseline data, where the morphometric consistency is significant to standardise the size of the implant. The study supported the formation of the appropriate size of the orthopaedic prostheses for more improved surgical outcome (8). The distal femoral morphometry was evaluated among 70 healthy adult by MRI, to help with the design of the total knee arthroplasty. Certain crucial parameters include the anteroposterior diameter and condylar dimensions. Result findings showed a high value for males rather than females. Young males showed higher accuracy of measurements than females. The findings noted the gender- and age-related anatomical differences, which showed that the variations are important for the size of the implant for proper fitting. The study emphasised the significance of population- and sex-specific prosthetic designs. This increases the stability of the implant, with better functional outcomes and enhances the prolonged outcome of total knee arthroplasty procedures (9). The study analyses the morphometric analysis based on CT scan, for better total knee arthroplasty outcomes. Males have highly mediolateral and anteroposterior dimensions rather than females. Also, males have high anterior lateral condylar height rather than females. The variation indicated the sexual dimorphism. The findings emphasised the impact of variations in the anatomy. Complications arise due to a mismatch between the bone and the implant. The study supported the requirement for sex- and population-specific prosthesis design. This customisation increases the customisation, which can enhance implant compatibility, stability, and long-term surgical success (10). Among the anthropometric factors to be considered, anatomic differences in the distal femur and intercondylar notch have been implicated as a cause of the different rates of anterior cruciate ligament (ACL) rupture between men and women. Measurements of the intercondylar height (ICH), intercondylar width (ICW), medial condylar width (MCW), lateral condylar width (LCW) and epicondylar width (EW) were obtained. The notch shape index (NSI) was also calculated. Statistical analysis for comparisons was done by Student's t-test. Correlations between the parameters studied were calculated by Pearson correlation coefficients. Significant bilateral differences were not found ($p > 0.05$). No difference was seen in the NSI between males and females ($p > 0.05$). Also, a significant association was obtained between age and all parameters (11).

Table 3. Summary of Regression Model and ANOVA

Model	R	R^2	Adjusted R^2	Std. Error of Estimate	R^2 Change	F Change	df1	df2	Sig. F Change	Sum of Squares	df	Mean Square	F	Sig.
1 (Regression)	0.521[a]	0.271	0.192	2.58	0.271	3.45	9	86	0.001	214.532	9	23.837	3.45	0.001
Residual	—	—	—	—	—	—	—	—	—	592.84	86	6.893	—	—
Total	—	—	—	—	—	—	—	—	—	807.372	95	—	—	—

5 | CONCLUSION

The study concluded that the significant morphometric variation in the human femur bone, with the diameter of the head as 41.83 ± 3.12 mm and the neck parameter showed moderate dispersion, while low variation was noted for the length of the femur. The positive correlations were observed for the head diameter and neck diameter ($r = 0.512$), intertrochanteric line length ($r = 0.358$), and femur length ($r = 0.341$), which indicated the pattern of growth as the crucial components. The foveal transverse and longitudinal diameters showed an association, which suggested anatomical associations. Contrastingly, the neck-shaft angle showed a weak and non-significant correlation, which indicated the relative independence. The regression model showed 27.1% of the variance. The study findings emphasised the significance of the femoral morphometry, specifically in the design of the prosthesis, orthopaedic interventions, and forensic identification.

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