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Original Article

Anatomy Section

Morphometric Analysis of the Proximal and Distal Ends of Adult Dry Femur Bone: A Cross sectional Study in the Population of North Karnataka, India

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ABSTRACT

Introduction: Orthopaedic surgeons require anatomical knowledge of the proximal and distal ends of the femur when performing knee replacement or knee arthroplasty procedures. The application of morphometric analysis is advantageous to biochemical research. It enhances the understanding of many other factors that influence bone, such as its strength, structural integrity, and functions.

Aim: To quantify the morphometric parameters of the proximal and distal ends of the adult femur, including measurements of size, shape, and angular relationships.

Materials and Methods: A cross-sectional study on 102 adult dry femur bones of unknown gender and age collected from Department of Anatomy, JN Medical College, Belagavi, Karnataka, India from October 2024 to January 2025. The femur specimens were analysed using different methods. This includes osteometric board, Vernier caliper, Goniometer and thread. The data collected was statistically analysed using software International Business Machine (IBM) Statistical Packages of Social Sciences (SPSS) Statistics 27.0.

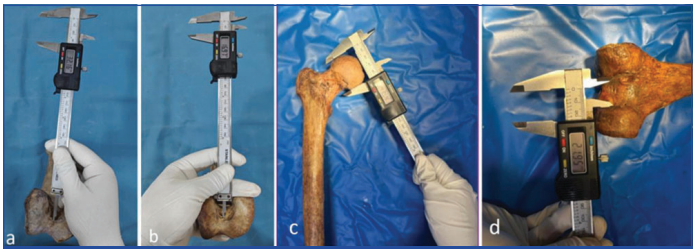
Results: The current study found that the average femur length was 433±31.3 mm. The proximal part of femur showed femoral torsion averages 19.63±4.3 degrees, while the Neck Shaft Angle (NSA) has a mean of 125.35±16.86 degrees. Transverse diameter of head (in mm) measured 39.59±3.78 mm, and neck (mm) 25.65±3.42. Vertical diameter of head (in mm) is 40.01±3.69 and neck (in mm) is 29.44±4.07. The distal part of femur, showed bicondylar width (in mm), 66.41±7.46, intercondylar width (in mm) 21.32±5.03 and intercondylar depth (in mm) 24.97±2.54, medial condyle thickness (in mm) 23.84±3.86 and lateral condyle thickness (in mm) 23.93±3.16, medial condyle length (in mm) 56.06±4.77 and lateral condyle length (in mm) 57.29±4.21.

Conclusion: The study's measurements of the proximal and distal femur revealed population-specific values, particularly for North Karnataka. These findings have significant implications for forensic identification, anthropological studies, and clinical applications. Population-specific morphometric data enhances accuracy and relevance in these fields.

Keywords: Arthroplasty, Measurements, Orthopaedic, Replacement

INTRODUCTION

The longest, largest, and strongest bone in the body is the femur, sometimes referred to as the thigh bone. It plays a significant part in posture and movement. Forensic specialists, orthopaedic surgeons, and athletes value the femur clinically [1]. The femur is composed of a proximal end, shaft, and distal end. The head, neck, greater and lesser trochanters, intertrochanteric crest, and intertrochanteric line make up the proximal end. The acetabulum and head articulate to form the hip joint in the proximal region. The femur bone's neck plays a significant modifying function in preserving the body's posture [1]. The neck is about 50 mm long and joins the head to the shaft. In adults, it results in a NSA that is roughly 125° to 127°, sometimes referred to as the inclination angle. The angle formed by the femur's diaphyseal axis and femoral neck axis is known as the NSA. This is less common in women because of a larger pelvis, which is significant since it allows the hip joint to move more freely [1]. The femoral torsion angle, also called the anteversion angle, is located between the transverse axes at the upper and lower ends, transverse axes at a distance of roughly 10° to 15° [1]. The capacity to move steadily is provided by the proximal end of the femur, which articulates and forms the hip joint. Hip fractures, in particular, involving the proximal end of the femur, are quite prevalent and primarily affect the elderly [1]. The extended distal end of the femur is made up of two condyles called the lateral and medial condyles [Table/Fig-1], which are divided by the intercondylar notch [1].



[Table/Fig-1]: a) Maximum intercondylar depth; and b) Minimum intercondylar depth; c) Measuring vertical head diameter using vernier caliper; d) Measuring intercondylar width using vernier caliper.

The majority of the body weight is transferred to the tibia by the flattened lateral condyle. Although it is stronger, it is not as noticeable as the medial condyle [1]. A number of fractures and degenerative processes can occur in the femur bone, depending on its location, structure, and function. The knee is the most crucial joint for movement, yet it is also the most complicated synovial kind of joint, making it unstable due to articulations. Problems such as arthritis can also damage the knee joint. Consequently, in the modern world, knee replacement procedures are very important [2].

Everybody has a femur, with different lengths, positions, and functions. As a result, particularly in the elderly population, the bone is susceptible to numerous bone-related or degenerative disorders, especially in the elderly population [2]. For knee replacement or knee arthroplasty procedures, orthopaedic surgeons must possess

a thorough understanding of the anatomy of the proximal and distal ends [3]. Additionally, bone fractures are highly common in both the younger and older populations. Hip joint arthroplasty is one of the most common orthopaedic surgeries that results from hip osteoarthritis, therefore understanding the bone is helpful for treatment. Treatment regimens that are patient-centric and incorporate measurements of bones, their geometry, etc., benefit from morphometric analysis. Thus, all of this affects the surgical choices. Numerous parameters of the dry femur specimen's proximal and distal ends can be analysed with its assistance [2,4].

The utilisation of morphometric analysis is beneficial to biochemical research endeavours. It aids in comprehension of the numerous other elements that affect bone, such as its strength, structural integrity, and functions. Osteoporosis and femur fractures can be prevented by using preventive techniques that predict bone strength. Additionally, it is helpful for designing and building the models that are used for stimulations, as well as for testing implants to ensure their safety and effectiveness [4].

The study's primary goal was to measure the many characteristics for the proximal and distal end of femur in order to create a population-specific prosthesis. This type of study has not previously been done in the North Karnataka region. As a result, this research will contribute to the existing body of knowledge.

MATERIALS AND METHODS

The present cross-sectional study was conducted on 102 adult dry femur bones of unknown gender and age collected from Department of Anatomy, JN Medical College, Belagavi, Karnataka, India from October 2024 to January 2025 [Table/Fig-2]. It was approved by the Institutional Ethics Committee for Human Subjects' Research at Jawaharlal Nehru Medical College, Belagavi, Karnataka, India and ethical clearance was obtained (Reference No. MDC/JNMCIEC/502 dated 25/10/2024).

[Table/Fig-2]: Adult dry femur specimens of unknown gender and age.

Inclusion criteria: Dried femur bones which were intact, non-pathological, and undamaged.

Exclusion criteria: Femur bones that have suffered any form of trauma, including fractures, breaks, or cracks, were excluded from present study. This exclusion criterion is necessary to ensure that the morphometric analysis of the proximal and distal ends of the femur is conducted on intact and undamaged bones, providing accurate and reliable data.

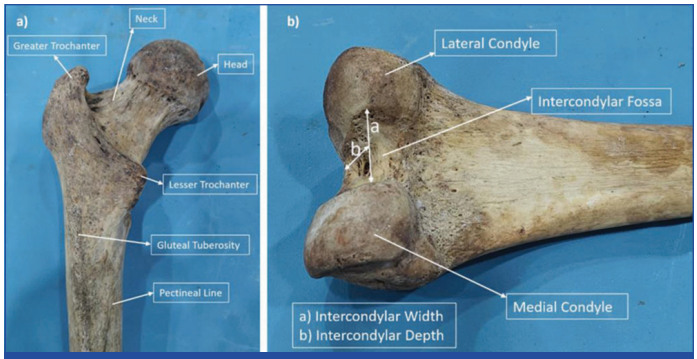
Study Procedure

The femur bones were analysed by using different methods. The instruments used were hepburn osteometric board, Vernier calliper, goniometer, and thread.

With the help of above instruments, the following parameters were measured and recorded [Table/Fig-1a-d,3a,b]:

Proximal Femoral End [Table/Fig-1c,3a]:

- Head circumference (in mm)
- Femoral torsion (in degrees)
- Neck Shaft Angle (NSA) (in degrees)
- Proximal width (in mm)
- Transverse diameter of head (in mm)



[Table/Fig-3]: a) Proximal end of the femur; b) Distal end of the femur.

- Vertical diameter of head (in mm)
- Neck vertical diameter (in mm)
- Neck transverse diameter (in mm)
- Anterior neck length (in mm)
- Posterior neck length (in mm)

Distal Femoral End [Table/Fig-1a,b,d,3b]:

- Medial condyle thickness (in mm)
- Bicondylar width (in mm)
- Intercondylar width (in mm)
- Intercondylar depth (in mm)
- Lateral condyle thickness (in mm)
- Medial condyle length (in mm)
- Lateral condyle length (in mm)

STATISTICAL ANALYSIS

The study's data analysis was conducted using software IBM SPSS Statistics 27.0, utilising measures such as the mean, standard deviation, and Interquartile Ranges (IQR). Additionally, graphical representations were generated using box plot system.

RESULTS

Data on femur length, showing a mean of 433±31.33 mm. The maximum recorded length was 497 mm, while the minimum length is 357 mm, indicating a range of variation. The IQR is 39.3 mm, suggesting moderate variability in femur lengths within the sample has been depicted in [Table/Fig-4].

Parameter	Mean±SD	Maximum	Minimum	IQR
Femur length (in mm)	433±31.3	497	357	39.3

[Table/Fig-4]: Femur length.

The mean range of head circumference is 13.48±1.21 cm, with IQR of 1.925 cm, indicating a relatively consistent range. Femoral torsion averages 21.64±4.3 degrees and NSA 116.71±16.86 degrees, showing moderate variability. The transverse diameter and vertical diameter of the head parameters indicates a relatively narrow range of variability. The neck vertical diameter has a mean of 29.44±4.07 mm and transverse diameter averages 25.65±3.42 mm. The anterior neck length and posterior neck length has a mean of 26.08±5.66 mm and 33.86±5.37 mm, respectively [Table/Fig-5].

Statistical data for various parameters related to the femoral condyles. The bicondylar width averages 66.41±7.46 mm, with an IQR of 7.1425 mm, suggesting substantial variability. For the intercondylar width is 21.32±5.03 mm, while the intercondylar depth averages 24.97±2.54 mm has been depicted in [Table/Fig-6]. The lateral condyle thickness has a mean of 23.93±3.16 mm, and the medial condyle thickness has a mean of 23.84±3.86 mm. The medial condyle length averages 56.06±4.77 mm, and the lateral condyle length has a mean of 57.29±4.21 mm, with an IQR of 4.4025 mm, indicating moderate consistency.

Parameters	Mean±SD	Maximum	Minimum	IQR
Head circumference (in mm)	134.8±12.1	165	11	19.25
Femoral torsion (in degrees)	19.63±4.3	36	10	5
Neck Shaft Angle (NSA) (in degrees)	125.35±16.86	137	117	6.25
Proximal width (in mm)	82.24±8.94	97.39	31.95	11.9375
Transverse diameter of head (in mm)	39.59±3.78	49.56	31.54	5.175
Vertical diameter of head (in mm)	40.01±3.69	48.64	26.02	4.46
Neck vertical diameter (in mm)	29.44±4.07	39.47	20.94	5.705
Neck transverse diameter (in mm)	25.65±3.42	36.19	18.27	4.575
Anterior neck length (in mm)	26.08±5.66	39.94	14.48	9.365
Posterior neck length (in mm)	33.86±5.37	49.45	19.57	7.355

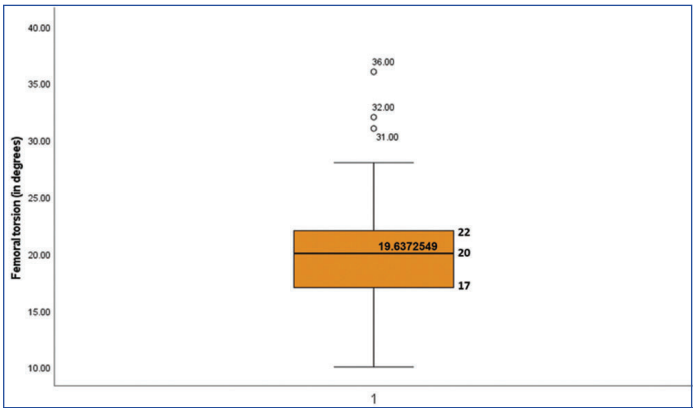
[Table/Fig-5]: Proximal femoral measurement.

Parameters	Mean±SD	Maximum	Minimum	IQR
Medial condyle thickness (in mm)	23.84±3.86	34.25	17.41	4.5525
Bicondylar width (in mm)	66.41±7.46	81.22	17.18	7.1425
Intercondylar width (in mm)	21.32±5.03	44.42	14.15	4.5925
Intercondylar depth (in mm)	24.97±2.54	32.16	16.97	3.4075
Lateral condyle thickness (in mm)	23.93±3.16	32.46	17.69	4.0775
Medial condyle length (in mm)	56.06±4.77	68.32	40.27	6.5575
Lateral condyle length (in mm)	57.29±4.21	67.51	43.27	4.4025

[Table/Fig-6]: Distal femoral measurement.

Parameters having significant representation using Interquartile Range (IQR):

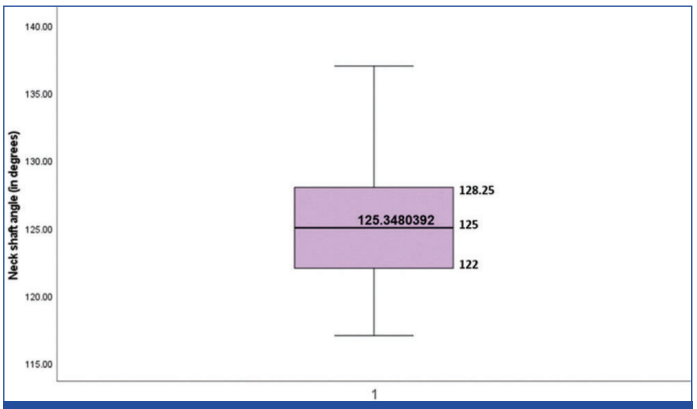
The box plot illustrates the distribution of femoral torsion measurements (in degrees). The mean value is approximately 19.64 degrees, with the IQR spanning from 17 degrees (lower quartile) to 22 degrees (upper quartile), indicating where the central 50% of the data lies. The minimum femoral torsion is 10 degrees, and the maximum is 36 degrees. Notably, there are three outliers above the whisker at 31, 32, and 36 degrees; variation in femoral torsion affects the gait of a person [Table/Fig-7] [5].



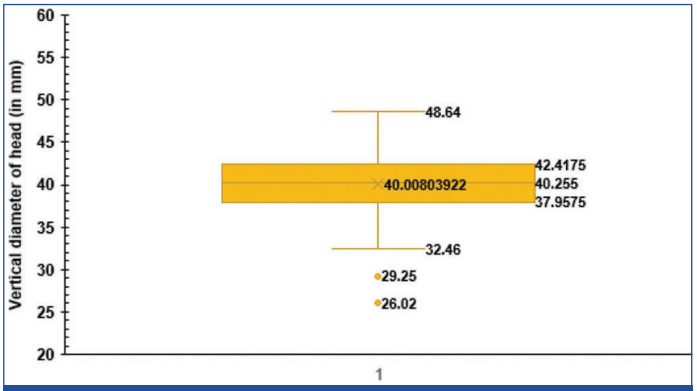
[Table/Fig-7]: Distribution of femoral torsion.

The box plot shows the distribution of NSA measurements (in degrees). The mean angle is approximately 125.34 degrees, with the IQR spanning from 122 degrees to 128.25 degrees, capturing the central 50% of the data. The minimum value is 117 degrees, and the maximum is 137 degrees. There is no significant outlier [Table/Fig-8].

The box plot illustrates the distribution of vertical diameter of head. The mean value is approximately 40 mm, with the IQR spanning from 37.95 mm (lower quartile) to 42.41 mm (upper quartile), indicating where the central 50% of the data lies. The minimum distribution of the vertical diameter of head is 32.46 mm, and the maximum is 48.64 mm. Notably, there are two outliers below the whisker at 29.25 mm and 26.02 mm, which is a significant factor in hip replacement surgery and range of movements [Table/Fig-9] [1].

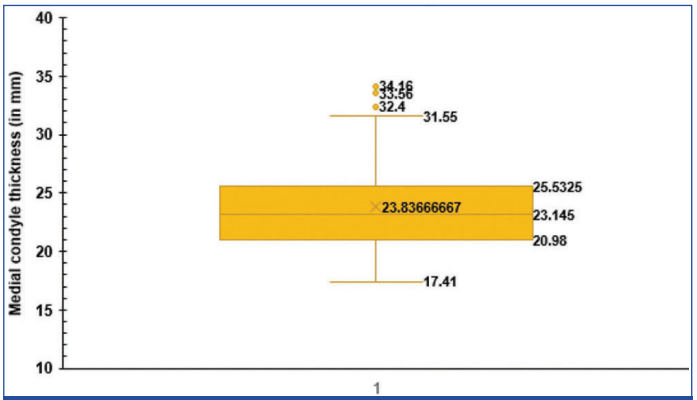


[Table/Fig-8]: Distribution of Neck Shaft Angle (NSA).



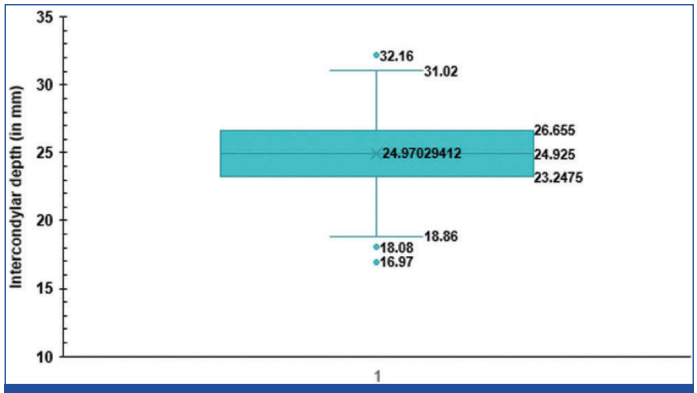
[Table/Fig-9]: Distribution of vertical diameter of head.

The box plot illustrates the distribution of medial condyle thickness. The mean value is approximately 23.83 mm, with the IQR spanning from 20.98 mm (lower quartile) to 25.53 mm (upper quartile), indicating where the central 50% of the data lies. The minimum distribution of medial condyle thickness is 17.41 mm, and the maximum is 31.55 mm. Notably, there are three outliers above the whisker at 32.4 mm, 33.56 mm, and 34.16 mm; medial condyle thickness deals with bearing body weight and transmitting it to the tibia [Table/Fig-10] [1].



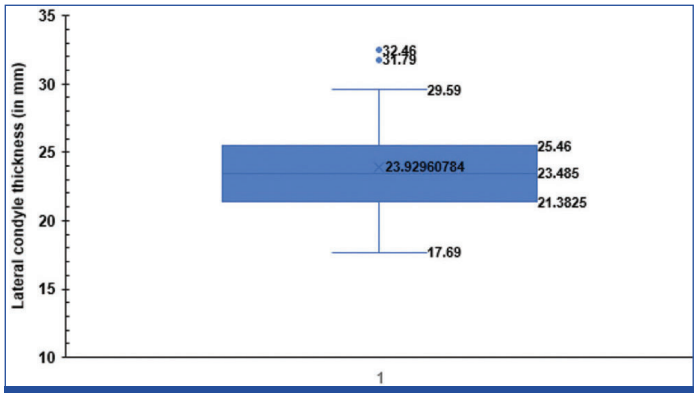
[Table/Fig-10]: Distribution of medial condyle thickness.

The box plot illustrates the distribution of intercondylar depth. The mean value is approximately 24.97 mm, with the IQR spanning from 23.24 mm (lower quartile) to 26.65 mm (upper quartile), indicating where the central 50% of the data lies. The minimum intercondylar depth is 18.86 mm, and the maximum is 31.02 mm. Notably, there is one outlier above the whisker at 32.16 mm, indicating values significantly higher than the rest of the data. And there are two outliers below the whisker at 18.08 mm and 16.97 mm, indicating values significantly lower than the rest of the data. The intercondylar notch contains the posterior and Anterior Cruciate Ligaments (ACL), which are very important for knee stability [Table/Fig-11] [6].



[Table/Fig-11]: Distribution of intercondylar depth.

The box plot illustrates the distribution of lateral condyle thickness. The mean value is approximately 23.92 mm, with the IQR spanning from 21.38 mm (lower quartile) to 25.46 mm (upper quartile), indicating where the central 50% of the data lies. The minimum lateral condyle thickness is 17.69 mm, and the maximum is 29.59 mm. Notably, there are two outliers above the whisker at 31.79 mm and 32.46 mm, indicating values significantly higher than the rest of the data [Table/Fig-12].



[Table/Fig-12]: Distribution of lateral condyle thickness.

DISCUSSION

The understanding of morphometric analysis of proximal and distal parts of femur will help the orthopaedicians, surgeons and radiologists for their treatment outcomes. The long bones of upper limb and lower limb contribute for the stature of the person. The morphometric understanding of these bones helps the forensic medicine experts and anthropologists for stature estimation in identification of a person. Regional differences of stature can be seen, so the implant has to be designed according to the stature of the person. The morphometry of bone is influenced by race, gender, environment and lifestyle of the person [7].

The femoral head, neck length, NSA these parameters have significant effect on range of motion of hip and stability of hip articulation [4]. Understanding the proximal part of femur is necessary for diagnosing, treating many conditions affecting the hip joint like hip fractures, developmental issues and some degenerative diseases.

Femur length varies according to region, environmental factors, genetic, and nutritional factors. In a study done by Vinay G et al., and Gupta M et al., the authors observed the femoral length range similar to current studies while the range is observed to be lesser in a study done by Babacan S and Deniz M [8-10]. The femur length ranged from 400 to 430 mm in general Indian population [9]. In a study conducted by Kamath SU et al., the authors found the diameter of head of femur to be 44.8±4.2 mm, while in other study by Sharma A and Lal RK the author found the range to be 44 mm, Siwach R as 43.95 mm [11-13], while in the present study the diameter of head of femur is observed to be 39.59±3.78 which shows marked difference in the range compared to other studies [Table/Fig-13] [7-15].

Understanding and assessing the femoral NSA are very much essential in diagnosing and treating hip joint disorders, planning some surgical interventions and also evaluating hip joint mechanics. The average NSA in the present study was observed to be 125.35±16.86. This is consistent with the findings of studies done by Sharma A and Lal RK [12], Verma M et al., [7], and Vinay G et al., [8], with value ranging of 124.5 degree, 128.90±4.49 degrees, and 120.13±5.72 degrees, respectively. While in studies conducted by Vaishnavi H et al., [14], Babacan S and Deniz M [10], and Kamath SU et al., [11], the femoral NSA was reported to be a little larger range of 137.2±5.1 degrees, 134.11±6.25 degrees, and 137.80±6.90 degrees, respectively. Variation in NSA can cause difficulty while fixing the prosthesis during arthroplasty [9].

Femoral torsion refers to the rotation of the femur along its axis and varies across different age groups; in adults, it ranges between

Authors	Year of the study and the population	Sample size	Mean length of femur (mm)	Mean neck length (mm)	Diameter of head (mm)	Neck Shaft Angle (NSA) of femur (in degrees)	Femoral torsion (in degrees)
Vinay G et al., [8]	Telangana population 2020	180 dry femur	431.5±29.8	26.4±3.7		120.13±5.72	_
Gupta M et al., [9]	Eastern Uttar Pradesh 2022	96 dry femora	421.1±29.1	36.06±4.94	41.59±3.25	119.08±5.18	_
Kamath SU et al., [11]	South west coast of India 2020	50 unpaired dry femur bone	–	–	44.8±4.2	137.80+-6.90	_
Manjunath TH and Santosh CS [15]	South Indian 2023	346 adult dry femur	446.1+30.4	35.1+1	41.48+5.2	137.4o+3.5o	_
Babacan S and Deniz M [10]	Turkey 2022	33 dry femur	400.27+39.15	_	46+-3.02	134.11+6.25	16.59 +1.04
Vaishnavi H et al., [14]	Gujarat 2019	285 Femurs	435.8+27.32	38.2+6.8	_	137.2+5.1	
Sharma A and Lal RK [12]	South Bihar 2019	200 dry adult femur bone	–	Anterior-34.5 Posterior-38.5	44.0	124.5	
Siwach R [13]	Haryana 2020	150 bones		Superiorly-37.32 Inferiorly-22.69	43.95	123.5	13.68
Verma M et al., [7]	New Delhi 2017	91 dry bones	428.2+28.7	44.75+8.097	42.32+4.11	128.90+4.49	
Present study	Karnataka 2024-2025	102 dry femur bones	433±31.3	Anterior-26.08±5.66 (mm) Posterior-33.86±5.37	39.59±3.78	125.35±16.86	19.63±4.3

[Table/Fig-13]: Comparison of present study with other studies on proximal end of femur [7-15].

Authors	Year of the study and population	Sample size	Intercondylar notch width (mm)	Intercondylar notch dept (mm)	Bicondylar width (mm)	Medial condyle thickness (mm)	Medial condyle length (mm)	Lateral condyle thickness (mm)	Lateral condyle length (mm)
Shweta J and Renu C [19]	2017/North India	100 dry bones	21.12+2.83	26.8+2.88	72.64+6.34	-	-	-	-
Sahu SK et al., [17]	2022/Odisha	111 human adult bones	Right- 19.98+3.24 Left- 19.82+3.14	-	R-69.31+6.72 L- 70	R- 22.20 +2.25 L- 23.57+4.80	R- 53.70+4.91 L- 54.68+5.00	R- 21.56 L- 22.16	R- 54.80 L- 55.84
Rajan M and Ramachandran K [18]	2020/Chennai	100 femur bones	Right- 21.60+2.69 Left- 21.5+4.64	-	72.82+3.89	R- 22.64 +3.96 L- 23.12+2.17	R- 56.6+4.19 L-57.14+4.18	R-23.12 L- 21.16	R- 58.52 L- 56.92
Janani SV and Ramachandran K [21]	2024/Chennai	100 femur Bones	Right- 21.5 +4.64 Left- 21.66+2.69	-	71.62+ 5.67	R- 21.56 L- 23.3	R- 57.14 L- 56.62	R-23.12+2.17 L- 22.64+3.96	R- 58.52 L- 55.52
Biswas A and Bhattacharya S [22]	2017/West Bengal	70 bones	-	-	R-71.71±4.50 L-70.71±5.25	R- 25+48 L-27+28	L-52.97±3.77 58.7±4.1-- R	R-23.12±2.17 L-27.28±2	R-56.20±3.36 L-58.52±3.44
Present study	2024-2025/ Karnataka	102 bones	21.32±5.03	24.97±2.54	66.41±7.46	23.84±3.86	56.06±4.77	23.93±3.16	57.29±4.21

[Table/Fig-14]: Comparison of the current study with other studies on distal end of femur [7-19,21,22].

10 to 20 degree and in children it ranges more than 20 degree. Abnormal femoral torsion, whether excessive or lower level can lead to many abnormalities like gait issues, can lead to have hip and knee pains, if sometimes femoral torsion causes functional impairment corrective surgery may be required [16]. In the present study, the femoral torsion ranged 19.63±4.3 while in another study conducted by Siwach R the range observed was 13.68 degree [13], and by Babacan S et al., study it was observed to be 16.59±1.04 [10], whereas all studies showed normal range between 10 to 20 degree in Indian population.

The stability of the knee joint is known by understanding the normal morphometry of femoral condyles and intercondylar notch [1]. In any of the diseases like knee joint degenerative diseases or osteonecrosis, osteoarthritis, any damage to knee, knee joint replacement surgery is the treatment. To move on with such surgeries and for the proper selection of implants for the surgery, the surgeons should have a through anatomic knowledge of the knee joint. In the present study, the average bicondylar width of femur is found to be 66.41±7.46. Similar result was observed in a study conducted by Sahu SK et al., showed R-69.31±6.72 L-70 of range [17]. In other studies conducted by Rajan M and Ramachandran K and Shweta J and Renu C found ranges quite higher than the current study, which is not statistically significant [18,19].

Intercondylar notch plays a role in accommodating the ACL if there is narrower notch, ACL tears are common [20]. Studies have told that females have narrower notch as compared to males so ACL tears are more common in females as compared to males [6]. Osteoarthritis is also observed in narrow intercondylar notch [19]. In the current study, the intercondylar notch width is 21.32±5.03 mm and depth is 24.97±2.54 with similar observations found in other studies done by Rajan M and Ramachandran K and Janani SV and Ramachandran K [18,21]; while in a study conducted by Sahu SK et al., the notch range showed lesser range of right-19.98±3.24 mm and left-19.82±3.14 mm, which is not statistically not major variable [17]. The differences found in the measurements amongst different studies from different regions could be due to effect of heredity, race, environment, lifestyle, and effects of civilisation, which may in turn, alter the build, stature, and bony dimensions of individuals [17].

In the current study medial condyle thickness 23.84±3.86 and length is observed to be 56.06±4.77 with a similar result observed in Rajan M and Ramachandran K and Biswas A and Bhattacharya S with a lateral condyle thickness of 23.93±3.16 mm and length of 57.29±4.21 mm [18,21], with approximately similar result observed in other study conducted by Sahu SK et al., [17] thickness of R-21.56 L- 22.16 and length of R-54.8 L-55.84 [Table/Fig-14] [17-19,21,22].

Limitation(s)

The sample size of present study was limited, which may not be representative of the entire population. Demographic data, such as age, gender, and ethnicity, were not collected in present study. This limited the ability of the current study to analyse the results in relation to these factors. There may have been measurement errors in the morphometric analysis of the femur bones. However, steps were taken to minimise these errors by using standardised protocols and calibrated instruments.

CONCLUSION(S)

The study included the measurements of proximal and distal parts of femur. The findings observed in the present study on femoral head diameter, neck length, neck shaft angle, and femoral torsion in the proximal end of femur showed values which were population specific especially of North Karnataka region. Population-specific morphometric enhances forensic identification and for anthropological studies, and also will help the clinicians to improve their clinical relevance. Knowledge of the morphometric data is lower end of femur in the present study on bicondylar width, intercondylar notch diameter, and condylar thickness and length, can aid in designing implants suitable for Indian population, particularly for those in the Karnataka region. The present study emphasise the importance of considering morphometric differences in clinical practices and can enhance the applicability of these findings in orthopaedic and forensic medicine.

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