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Research Article

Morphometry of the Proximal End of Dry Adult Human Femora from the East African Population: A Cross-Section Study

Tumusiime G[1]*, Kirum GG[2] and Kukiriza J[3]

[1]Department of Anatomy, Uganda Christian University School of Medicine, Uganda

[2]Department of Anatomy, Makerere University College of Health Sciences, Uganda

[3]Department of Anatomy, Ernest Cook Ultrasound Research and Education Institute, Uganda

***Corresponding author:** Tumusiime G, Department of Anatomy, Uganda Christian University School of Medicine, Post Box 36724 Kampala, Uganda

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Abstract

Introduction: Proximal femur morphometry is important in the stability of the hip joint, the design of implants for hip replacement and forensic identification of unknown human remains. This study aimed at determining the proximal femur morphometry and factors associated with their variation.

Materials and Methods: This was a cross-sectional study of the proximal end of 333 dry human femora from persons aged 20 to 75 years from the East African population. All the femora were observed macroscopically for the presence of the third trochanter, and the age, sex and nationality documented. The femoral head and neck circumferences were measured using a tape measure and the neck-shaft angle and the angle of anteversion measured using a goniometer. Data were entered in an Excel sheet and exported to STATA 14 for analysis. Univariate, bivariate and multivariable analyses were performed. A p-value of less than 0.05 was considered statistically significant.

Results: Of the 333 dry femora, 7.21% (24/333) had a third trochanter. The mean femoral head circumference was 134.91 ± 8.91 mm, the mean neck-shaft angle was 118 ± 6 degrees, the mean angle of anteversion was 17 ± 4 degrees, the mean femoral neck circumference was 91.71 ± 7.40 mm. Statistical significance was achieved between each of the proximal femur measurements and: sex, nationality and third trochanter status.

Conclusion: The morphometry of the proximal femur varies with age, sex and nationality. These variations are pertinent in the design of tailored proximal femur implants, assessing the risk of fractures, forensic practice and regional comparisons.

Keywords: Implants; Morphometry; Neck-shaft angle; Proximal femur; Third trochanter

Abbreviations

CI: Confidence Interval; IQR: Interquartile Range; SD: Standard Deviation

Introduction

The femur is the strongest, longest and principal weight-bearing bone in the human body; it forms the hip joint proximally and knee joint distally. The proximal end of the femur entails the femoral head, the neck, and the greater and lesser trochanters. Modifications in proximal femur such as the presence of the third trochanter may be due to functional adaptation [1,2]. The third trochanter is a rounded, oblong or conical elevation present on the upper end of gluteal tuberosity. Since the gluteal tuberosity provides the insertion of part of the gluteus maximus, it may exert a mechanical loading on the gluteal tuberosity leading to development of the third trochanter. Presence of the third trochanter modifies the proximal femur morphometry to improve functionality [1]. The proximal femur forms two important angles responsible for the stability of the hip joint: the neck-shaft angle and the angle of anteversion. The neck-shaft angle is formed by the long axis of the femur and the femoral neck axis [3]; while the angle of anteversion is a measure of how the femoral neck deviates forwards from the axis of the femoral condyles projected on the horizontal plain [4]. Developmental studies suggest that the neck-shaft angle reduces with age while the angle of anteversion increases with age [5].

Knowledge of the proximal femur morphometry contributes to the reduction in complications related to the proximal femur surgical procedures and understanding the stability of the hip joint and how it bears the body weight transmitted through the pelvis [6]. Proximal femur morphometry is significant in the design of implants for partial and total hip replacement; assessing the risk of proximal femur fractures; geographical comparisons; and forensic identification of unknown human remains, especially in complete adult skeletons from a population with known morphometric variables [2]. The sexual dimorphism of some proximal femur characteristics may be used in sex forensic diagnosis of unknown human remains [7]. Morphometric studies on the proximal femur in different populations and regions suggest the existence of regional and ethnic differences [8]. Therefore, standardization of the proximal femur morphometry for a given population contributes to the determination of the risk

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for proximal femur fractures, preoperative planning, the design of tailored implants and forensic diagnosis [9].

Because of the limited data on the morphometry of the proximal femur among the East African population, this study aimed at determining the proximal femur morphometry and factors associated with its variation, so as to contribute to the reference data for the East African population.

Materials and Methods

This was a cross-sectional study of the proximal part of 333 dry human femora. These were obtained from the Galloway osteological collection at the Department of Anatomy, Makerere University college of Health Sciences. The study was conducted after obtaining ethical approval from Makerere University School of Biomedical sciences research and Ethics committee. All femora with complete records of age, sex and nationality were included in the study. Only femora from East Africans aged 20 years and above were included in the study. Deformed and damaged bones were excluded. All the femora were observed macroscopically for the presence of the third trochanter and the status was documented. For each femur, the corresponding age in years, sex and nationality from the records were documented. The femoral head circumference and femoral neck circumference were measured using a tape measure; while the neck-shaft angle and the angle of anteversion were measured using a goniometer as previously described [10,11]. All the three authors took the measurements and reached an agreement.

Data were entered in an Excel sheet and exported to STATA 14 for analysis. Univariate, bivariate and multivariable analyses were performed to obtain the summary statistics, the measures of association and the strength of association. At bivariate analysis, simple linear regression was performed to establish the association between each of the morphometric measurement and: body side, sex, age, nationality and the third trochanter status after converting them to numerical variables. Factors that had a p-value of less than 0.05 at bivariable analysis were fit in the multiple linear regression model. At all levels of analysis, a p-value of less than 0.05 was considered statistically significant.

Results

Descriptive statistics of the morphometric characteristics and their variation

A total of 333 dry femora were studied, 167 (50.15%) were right femurs, 291 (87.39%) from males, and 200 (60.06%) were from non-Ugandans. The non-Ugandans were defined as Kenyans, Tanzanians, Rwandese and Burundians. The femur bones were from persons aged 20 years to 75 years with mean age of 35 (SD± 12) years and median age of 32 (IQR: 25 to 40). Overall, 7.21% (24/333) of the femora had a third trochanter. The prevalence of third trochanter was higher in femurs from the right side, males and non-Ugandans (Table 1). The mean femoral head circumference was 134.91 ±8.91mm and ranged from 111mm to 162mm; the mean neck-shaft angle was 118 ± 6 degrees and ranged from 102 to 132 degrees; the mean angle of anteversion was 17 ± 4 degrees and ranged from 7 to 38 degrees and the mean femoral neck circumference was 91.71 ± 7.40mm and ranged from 70mm to 112mm. The femur head circumference was higher in femora from the left side, males, Ugandans and femora with a third trochanter. The neck-shaft angle was greater in femurs from females, non-Ugandans and femora with no third trochanter. The femoral neck circumference was higher in femora from males, Ugandans and those with the third trochanter. The means (SD) for all the parameter are summarized in Table 2.

Factors associated with variations in proximal femur morphometry

Table 3 shows the factors that achieved statistical significant at bivariate analysis. The results suggest that on average, the femoral head circumference is 7.50mm greater in males compared to females; 2.99mm greater among Ugandans compared to non-Ugandans, and 3.87mm greater among femur bones with a third trochanter compared to femurs without the third trochanter. There was no statistically significant association between the femoral head circumference and: body side (p=0.797; 95% CI: -2.176 to 1.672), and age (p=0.756; 95% CI: -0.093 to 0.068). On average, for every one-year increase in age, the femur neck-shaft reduces by 0.09 degrees; the femur neck-shaft angle is 1.29 degrees lower among Ugandans compared to non-Ugandans; and 3.10 degrees lower among femur bones with a trochanter compared to those without. There was no statistically significant association between the neck-shaft angle and: body side (p=0.881; 95% CI: -1.128 to 1.314); and sex (p=0.075; 95% CI: -3.494 to 0.167). On average, the femur neck circumference is 4.71mm greater among femurs from males compared to femurs from females; and 3.496mm greater among femurs with a third trochanter compared to those without. There was no statistically significant association between the femur neck circumference and: femur side (p=0.843; 95% CI: -1.758 to 1.437), age (p=0.409; 95% CI: -0.039 to 0.095), and nationality (p=0.143; 95% CI: -0.412 to 2.839). There was no statistically significant association between the femur angle

Table 1: Prevalence of third trochanter by femur side, sex and Nationality.

Variable	Number of Femur Bones	Number of Femur Bones with Third Trochanter	% With Third Trochanter
Femur side (n=333)			
Left	166	9	5.42
Right	167	15	8.98
Sex (n=333)			
Female	42	0	0.00
Male	291	24	8.25
Nationality (n=333)			
Non-Ugandan	200	20	10.00
Ugandan	133	2	3.01

Table 2: Variation of the Proximal Femur Morphometric parameters with femur side, nationality, sex and third trochanter status.

Variable	Femoral Head Circumference (mm)	Neck-Shaft Angle (Degrees)	Angle of Anteversion (Degrees)	Femoral Neck Circumference (mm)
Mean ± SD				
Overall	134.91 ± 8.91	118 ± 6	17 ± 4	91.71 ± 7.40
Left Femur	135.04 ± 8.85	118 ± 6	17 ± 5	91. 80 ± 7.33
Right Femur	134.78 ± 8.99	118 ± 6	17 ± 4	91.63 ± 7.49
Female	128.35 ± 9.73	119 ± 7	18 ± 5	87.60 ± 8.13
Male	135.86 ± 8.39	117 ± 5	17 ± 4	92.31 ± 7.11
Non-Ugandans	133.72 ± 7.98	118 ± 6	17 ± 4	91.23 ± 6.87
Ugandans	136.71 ± 9.91	117 ± 6	17 ± 5	92.44 ± 8.09
No Third Trochanter	134.63 ± 8.87	118 ± 6	17 ± 4	91.46 ± 7.38
With Third Trochanter	138.50 ± 8.86	115 ± 4	16 ± 5	94.96 ± 7.06

Table 3: Factors associated with variations in proximal femur with statistical significance at Bivariable Analysis.

Variable	Regression Coefficient	t-statistic	P-value	95% CI
Femoral Head Circumference				
Sex	7.499	5.30	0.000	4.717 to 10.280
Nationality	2.992	3.04	0.003	1.054 to 4.929
Third Trochanter Status	3.869	2.06	0.040	0.173 to 7.565
Femur Neck-Shaft Angle				
Age	-0.092	-3.64	0.000	-0.142 to -0.043
Nationality	-1.286	-2.04	0.042	-2.525 to -0.047
Third Trochanter Status	-3.104	-2.61	0.009	-5.441 to -0.766
Femoral Neck Circumference				
Sex	4.714	3.94	0.000	2.363 to 7.065
Third Trochanter Status	3.496	2.24	0.026	0.430 to 6.561

Table 4: Factors associated with variations in proximal femur morphometry with statistical significance at Multivariable Analysis.

Variable	Regression Coefficient	t-statistic	P-value	95% CI
Femoral Head Circumference				
Sex	8.103	5.80	0.000	5.356 to 10.849
Nationality	4.091	4.31	0.000	2.223 to 5.959
Third Trochanter Status	3.794	2.12	0.035	0.277 to 7.310
Femur Neck-Shaft Angle				
Age	-0.087	-3.25	0.001	-0.139 to -0.034
Third Trochanter Status	-3.600	-3.07	0.002	-5.908 to -1.291
Femoral Neck Circumference				
Sex	4.476	3.74	0.000	2.120 to 6.832

of anteversion with the body side, age, sex, nationality, and third trochanter status.

At multivariable analysis, proximal femur morphometry was statistically significantly associated with: sex, nationality and third trochanter status. Results in Table 4 suggest that on average, the femoral head circumference is: 8.10mm higher among males compared to females controlling for nationality and third trochanter status; 4.09mm higher among Ugandans compared to non-Ugandans controlling for sex and third trochanter status; and 3.79mm higher in femurs with the third trochanter compared to those without controlling for sex and nationality. On average, the neck-shaft angle reduces by 0.09 degrees for every one-year increase in age controlling for third trochanter status; and on average the neck-shaft angle is 3.6 degrees lower in femurs with the third trochanter compared to those without, controlling for age. On average, the femur neck circumference is 4.48mm higher among femurs from males compared to those from males, controlling for age.

Discussion

This study determined the variation of the femora head circumference, the femora neck circumference, the neck-shaft angle and the angle of anteversion with the body side, age, sex, nationality and the third trochanter status. The third trochanter is an osseouscartilaginous complex usually confined below the greater trochanter in the superior end of gluteal tuberosity. It is used as a non-metric variation of the post-cranial skeleton in anthropometric studies of various populations [12]. In this study, the third trochanter was present in 7.21% (24/333) of the femora with right side, male and non-Ugandan predominance (Table 1). This prevalence is lower than studies that noted 14.28% with a right side predominance among 56 dry human femora among the Indian population [1], 21.66% with a left side predominance among 60 dry human femora among the Indian population [12], and 21.31% with right side predominance among 61 dry human femora from the Bulgarian population [13]. Since the third trochanter results from increased pull of the gluteus maximus to improve effective function, its variation may be an indication of the differences in physical activities among different populations. Genetic factors were previously thought to regulate the development of phenotypic skeletal traits like the third trochanter of femur [14]. However, recent studies suggest the influence of environmental and biological factors such as age, sex, nutrition and side-dependence on non-metric traits like the third trochanter in human population [12]. The sexual dimorphism of the third trochanter could be utilized in forensic diagnosis of the sex of unknown human remains in specified populations [7]. The third trochanter may also reduce the risk of fractures in the proximal femur since it increases the bone mass [2].

The size of the femoral head determines the stability of the hip joint. In this study, the average femoral head circumference was 134.91 ± 8.91mm. On average, the femoral head circumference was higher among femora from: the right side compared to left side, male compared to females, Ugandans compared to Non-Ugandans, and femora with the third trochanter compared to those without (Table 2). There were statistically significant associations between the femoral head circumference and: sex, nationality and third trochanter status (Table 3 and 4). The right side and male dominance may be due to the differences in the physical activities that promote differential bone growth. The third trochanter is associated with increased bone mass [1]; this partly explains why femora with the third trochanter had higher head circumference than those without. On average, the femur neck circumference was 91.71 ± 7.40mm. The average femur neck circumference was higher among femora from: the left side, males, Ugandans; and femora with the third trochanter. At all levels of analysis, the femur neck circumference was greater among femora from males compared to females, and this was a statistically significance (p <0.001). Since the femoral neck circumference is a measure of the thickness of the femoral neck, it is possible that femoral neck fractures are less among left femurs, males, Ugandans and femora with the third trochanter. The sex dimorphism may also be due to hormonal differences and variation in the aging process among males and females.

The neck-shaft angle and the angle of anteversion are important in hip joint function and of clinical significance in orthopedic surgery. The neck-shaft angle is formed between the long axis of the femoral shaft and the long axis of the femoral neck; and the normal range is 1200 to 1400 [15]. The femoral angle of anteversion measures the anterior rotation of the femoral neck around the shaft; its variation among population groups is due to hereditary, environmental, diet and lifestyle factors [4]. Developmental studies have demonstrated that the neck-shaft angle decreases with age while the angle of anteversion increases [5]. This study suggested that the neck-shaft angle reduces by 0.09 degrees for every one-year increase in age controlling for third trochanter status (Table 4); and this was statistically significant (p=0.001; 95% CI: -0.139 to -0.034). This finding is in agreement with developmental studies that suggest that the neck-shaft angle reduces with age [5]. The average neck-shaft angle for all the 133 femora was 118 ± 6 degree, ranging from 102 to 132 degrees. The neck-shaft angle was greater among femora from females compared to males, non-Ugandans compared to Ugandans, and femora without the third trochanter compared to those with the third trochanter (Table 2). The neck-shaft angle in this study was on average less than the 132.5 ± 7.31 degrees average neck-shaft angle among the 716 dry femora from the Igbos of South Eastern Nigeria [16], the average of 129.21 degrees among the Kenyan population [17], the average of 127.1 ± 6.44 degrees among the 75 dry femora from the Nepalese population [11], and among the Bihar's 60 dry femora where the average neck-shaft angle was 130 ± 4.86 degrees and ranged from 119 to 141 degrees [15]. However, all these studies concur that the neck-shaft angle is greater among females than males although there was no statistically significant association between the neck-shaft angle and sex in this study sex (p=0.075; 95% CI: -3.494 to 0.167). The regional variations in the neck-shaft angle attest to the role of genetic, environmental, nutritional and lifestyle differences across regions.

The femoral angle of anteversion is a measure of how the femoral neck deviates forwards from the axis of the femoral condyles projected on the horizontal plain; and it ranges from 4 to 20 degrees with an average of 12 degrees [4,18]. In this study, the overall average angle of anteversion was 17 ± 4 degrees, ranged from 7 to 38 degrees and was greater among femora from females compared to males. These results are contrary to a study in Sarajevo that noted a mean angle of anteversion of 9.31 ± 8.07 degrees and a greater angle among femora from males than females [18]. These variations are due to environmental, genetic, dietary and lifestyle factors. The differences by sex and across regions may explain the variation in the risk of hip dislocations and other hip joint diseases.

The limitation of this study is that it was not possible to ascertain if the observed proximal femur morphometry was due to disease processes. Being a cross-sectional study, it is not possible to conclude that the factors that achieved statistical significance are causal. However, this study had a relatively bigger sample size compared to other studies in other regions of the world.

Conclusion

The findings demonstrate that the prevalence of third trochanter, the femoral neck-shaft angle and angle of anteversion are lower among the East African population compared to some regions of Africa and Asia. The results also suggest that the morphometry of the proximal femur varies with age, sex and nationality. The femur head and neck circumferences exhibit significant sex dimorphism of potential forensic application. This data for the East African population is of significance in the design of tailored proximal femur implants, assessing the risk of fractures, identification of unknown human remains and comparison with other regions.

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