Morphometry Of The Proximal Femur In A Kenyan Population: Relevance To Component Placement In Total Hip Arthroplasty.

by Dr Catherine Kwamboka Nyabuto

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Abstract

Background: The morphometry of the proximal femur has an influence on the morphology and therefore, the biomechanics of the hip joint. Significant variations in these parameters are attributed to age, sex, race, ethnicity and lifestyle. Where indicated, total hip arthroplasty aims at restoring native parameters, and therefore preserve biomechanics.

Objective: To determine the morphometry of the proximal femur in the Kenyan population and to relate it to component placement in total hip arthroplasty.

Material and Methods: Two hundred and sixteen dry femurs from adults of both sex were used. The bones were selected from the osteology collection of the National Museums of Kenya. The parameters of the proximal femur measured included, the diameter of the femoral head, the neck-shaft angle, the angle of femoral neck version, the neck length and the horizontal and vertical offsets using digital photography, and the images were processed for measurements using open source analytical ImageJ® tool software. The overall femoral length was measured on an osteometric board. All measurements were taken in centimeters, and the angles were measured in degrees, all to the nearest two decimal points. The data was tabulated and all measurements entered into a computer. Statistical analyses comparing morphological features between males and females were performed using unpaired *t*-tests and rank sum tests for parametric and non-parametric data, respectively. The level of significance was set at $p < 0.05$. Correlations between variables were calculated using correlation coefficient and interpreted as degree of correlation. Data on locally available implants was tabulated and compared to the morphometry of the proximal femur in the select Kenyan population.

Results: The mean neck length was 3.38 cm (range, 1.54 - 4.99), the horizontal offset was 5.61cm (range, 2.37 - 7.55), the vertical offset was 5.41cm (range, 3.51 - 6.99), the head diameter was 4.67cm (range, 3.55- 5.65), the neck-shaft angle was 123.21 (range, 113.89 -135.89˚), the overall length of the femur was 49.26 cm (range, 38.10 -61.39) and the anteversion angle was 22.04˚ (range 10.42 - 39.98˚). The male had a longer neck length (p value 0.02), and longer horizontal offset (p-value 0.006), larger head diameter (p-value 0.04). The female had larger anteversion angles (p-value 0.04). There were no differences in overall length and vertical offset for male and female (p-value 0.52 and 0.09 respectively).

Conclusion: Locally available implants have a standard neck-shaft angle of 135˚ (range 126-145˚). In this study the mean neck-shaft angle was found to be 123.21˚. The average horizontal offset in this study was 5.61 cm but routinely used femoral stem sizes have horizontal offsets ranging from 3.83 cm to 4.64 cm.

There was a significant difference between the males and females in all parameters but side to side differences were of no statistical significance. The guideline values obtained for the parameters, particularly the femoral head offsets, anteversion angle and neck-shaft angle are a basis for larger studies and for recommending the design of femoral stems in the Kenyan population.

Chapter 1

Introduction

1.1 Background

The normal anatomy of the proximal femur forms the anatomical basis for the femoral component design in Total Hip Arthroplasty (THA) and in designing of implants used in trauma. The proximal femur comprises of the femoral head which forms the ball of the hip joint. The femoral head is attached to the femoral shaft by the neck which varies in length according to the body size (1).

The femoral neck has two angular relationships with the femoral shaft that are important to hip joint function: the neck to shaft angle in the frontal plane and the angle of anteversion in the transverse plane. The neck-shaft angle is usually 125˚ ± 5˚ and it offsets the femoral shaft from the pelvis laterally, thus influencing the horizontal offset, which is the distance from the center of the femur shaft to the center of the femoral head (2). There is a slight anterior rotation in relation to the coronal plane in the femoral neck. This is called femoral anteversion. The angle of anteversion is measured as the angle between the medio-lateral line through the knee and a line through the femur head and shaft (3). The average range for femoral anteversion is from 15˚ to 20˚ (4).

At the junction of the femoral neck and shaft, the greater trochanter projects supero-lateraly and the lesser trochanter projects postero-medially. The orientation of these bony prominences significantly influences the function of the muscles that insert on them. The vertical hip offset is the distance between the proximal extent of the lesser trochanter and the center of the femoral head (5).

The femur head diameter is important as it influences the stability of the joint, a large head has a larger jumping distance for dislocation (6). An increase in the head-neck ratio increases stability by reducing the chances of impingement (7).The femur neck length influences the overall length of the femur, resulting in limb length discrepancy if not restored (8). The neck length is a diagonal thus altering it affects the horizontal and vertical offsets. The hip offsets improve abductor strength thus enhancing joint range of motion. A decrease in offset leads to instability whereas increased offset causes excessive tension on the abductors and could lead to trochanteric bursitis (9).

In a normal population, with no disease of either limb, there is symmetry of the left and right femurs and it is not affected by demographics or size of the proximal femur (10). The contralateral limb is often used for pre-operative templating for procedures around the proximal femur. Many studies evaluating the parameters of the proximal femur have shown substantial variations in the values obtained because of the differences in ethnic groups, sex, age and lifestyle (11).

1.2. Statement of the problem

The American Academy of Orthopedic Surgeons (AAOS) in 2014 reported 370,770 total hip arthroplasties (THA) done that year and projected a 171 % growth in primary THA, 142 % increase in revision surgery by the year 2030 with the mean age at 65 years from 68 years and more than 300,000 proximal femur fractures occurring annually in the United States (12). Similarly, there is an increasing number of cases of hip arthroplasties and proximal femur fractures in Kenya. All the implants used are imported, despite the design being based on Caucasian data. There is scarcity of data on the proximal femur in the Sub-Saharan region.

1.3 Study questions

i. How does the proximal femur morphometry in the Kenyan population vary from that of Caucasians, which currently forms the basis of implant design?

ii. Are there significant differences in parameters for sex, and for right and left femur that would affect component positioning in total hip arthroplasty?

iii. Are the implants locally available suitable for the Kenyan population?

iv. Is there a correlation between the length of the femur neck and the overall length of femur, or neck-shaft angle and anteversion angle?

1.4 Aim and objectives

The aim of this study was to describe the morphometry of the proximal femur in the Kenyan population by measuring the head diameter, femur neck length, femoral offsets, neck-shaft angle, anteversion angle, and the overall length. The specific objectives are as follows:

i. To highlight the differences within the select Kenyan population for sex and side.
ii. To compare the proximal femur parameters in the select Kenyan population with that obtained from other populations.
iii. To survey locally available implants and establish compatibility of the prostheses with the morphometry of the Kenyan population and its effects on total hip arthroplasty.

1.5 Justification of the study

Several studies have evaluated the morphology of the proximal femur in adult cadavers and revealed differences in morphology of the proximal femur in population studies and races. The proximal femur dimensions have a direct influence on the normal biomechanics of the hip joint. Alteration of these parameters are indicative of a disease process or could result in pathology. Understanding of the normal measurements of a specific population aids in pre-operative planning and templating for the orthopedic surgeon, thus avoiding complications related to improper sizing of implants and prosthesis. Studies in India have shown statistically significant differences in measurements obtained prompting a different design of implants for their population (13).

Local studies on the proximal femur have been limited to only two parameters i.e. the neck-shaft angle and head diameter or femur neck anteversion using photography and ImageJ® software (14,15). The utility of their study was mainly for trauma fixation implants with the exclusion of total hip arthroplasty implants.

With the advent of total hip arthroplasty, the need for surgery on degenerative hips has increased 40 fold thus necessitating the evaluation of the additional parameters. These parameters include anteversion angle, horizontal and vertical offsets, femur lengths and their correlations for optimal component positioning. Information from local studies is insufficient to guide on the choice of implants and positioning intraoperatively.

The increase in the number of orthopedic surgeries carried out in Sub-Saharan Africa, necessitated the need for a proper understanding of the proximal femur morphometry. There is a paucity of data as to whether or not the values used to design implants based on Caucasian parameters tally with that of Africans. To address the problem, this study focuses on a wider sample size and broader description of the proximal femur morphometry. The values measured will be used by biomedical engineers to design implants specific to the population, and for pre- operative planning by the orthopedic surgeon.

Chapter 2

Literature review

The goals of stem placement in Total Hip Arthroplasty are to restore medial offset, restore leg length by altering the vertical height contribution in the proximal femur, and to restore femoral anteversion which ranges from 5 to 25° in adults (16). Of the studies quoted and used in the design of the prosthesis, Noble *et al.,* study in 1988 on Caucasians is the most cited (17).

2.1 Femoral head diameter

The femoral head size is an important technical consideration in the design of the femoral component in THA (18). Larger heads increase hip stability in different ways. An increase in the head: neck ratio reduces chances of impingement by increasing arc motion (19). Impingement causes dislocation by levering the head out of the socket (20). Larger heads also stabilize the joint by increasing the jumping distance, that is, the distance the head must cover before it fully dislocates (19).

Differences among races exist in the diameter of the femoral head as demonstrated in studies carried out by various authors (21–23). Lakati and co-workers in their study done in Kenya found the mean femoral head diameter was 44.18 mm (range, 36.5-50.9) with no significant difference between the left and right sides (14). The mean values differed from other populations; it was lower than 52.09 mm obtained by Unnanuntana *et al.,* in a similar study on American femora and another study on a select Malaysian population with values of 44.90 mm by Lee and co-workers (24,25). Baharuddin *et al*., in a radiographic study in a Malay population found a mean diameter of 43.6 mm for males and 38.9 mm for females (26), whereas studies by Noble *et al.,* on Caucasians found an average of 45.9 mm.

The femoral head sizes commercially available for modular prostheses are fixed size options of 26, 28, 32, 36, and 40 mm with modifiable neck lengths. In bilateral hip arthroplasty, the same size of femur head prosthesis could be used since there is no significant difference between the left and right side (27).

2.2 Femur Neck Length

The incidence of Limb Length Discrepancy (LLD) after THA has been reported to be as high as 50% (28). This results in chronic lumbago, sciatic nerve palsy, gait anomalies, dislocation of the hip, implant loosening as well as increased patients dissatisfaction (29). Within each femoral head size, there are a variety of neck lengths, to allow for adjustments to soft tissue tension and leg length symmetry. It is important to recognize that the neck length is a diagonal therefore increasing neck length affects the horizontal offset and vertical offset subsequently the overall leg length (8,30).

Femoral neck osteotomy is a crucial step in THA when correcting LLD. The level of the neck cut affects component positioning as well as NSA, angle of anteversion, femoral offset, and limb length relative to the native anatomy (31,32).

On average the neck length is said to be 50 mm, but several studies have shown that this value varies from one population to another (30). In a number of Indian studies, the average length recorded was 34 mm, 30 mm in Brazil, 35 mm in Chile, 22 mm in Turkey and 28 mm in Belagavi (8,26,33–36). There is no consensus on the cause of this but a multifactorial reason based on genetics, environment, lifestyle activities have been implicated. There is scarcity of data on the average femur neck length in the African population.

2.3 Femoral neck offset

Restoration of femoral neck offsets reduces the incidence of prosthetic failure by preventing early migration of the stem and loosening (37) . It improves abductor strength and enhances joint range of motion. It also reduces risk of wear, dislocation and mechanical failure (29). A decrease in offset leads to increased instability, which is often compensated for by the use of long neck femoral heads that lead to limb length discrepancy (28). Very high offsets 9 place excessive tension on the abductors and can cause trochanteric bursitis.

Failure to restore the femoral offset has led to poor functional outcome and pain following THA (32,38–41) emphasizing the need for templating prior to surgery. Locally available modular prostheses have offsets ranging from 38.3 mm to 64 mm and are classified as standard and high offset implants. There is a scarcity of published data on the femur offset measurements in the African population.

2.4 Femur Neck shaft angle

The NSA is important in the control of lateral balance during mobility. It ranges from 125˚ to 132˚ in adults (42) and is a diagnostic criterion used to detect femoral neck fractures (43). The effect of this angle is to lateralize the abductors from the center of rotation. This increases the torque generated by the abductors and reduces the overall force needed to balance the pelvis during single-leg stance (44). The NSA is smaller (average of 120-125˚) in females due to a wider pelvis thus greater inclination of the femoral shaft on the neck (45).

Several studies have shown significant variations in the NSA based on different ethnic groups. The mean value for a select Pakistan population was at 134˚ (46) followed by the French at 132˚ (47) whereas one done in a select Nigerian population showed an average of 121˚ (2).

In a local study by Lakati and co-workers in 70 femora using digital photography to analyze the NSA a mean value of 129.82˚ which is closer to that found by De Farias *et al.*, in a Brazilian study was obtained (14,48). In India, anatomic specimens have shown lower neck-shaft angle ranging from 124.95 to 126.55˚ unlike similar studies on American femora with a higher mean NSA of 132.69° (34,49,50).

Otsyianyi and co-workers measured NSA among select Kenyan ethnic groups using radiography, and found a mean of 127.56˚±3.75˚ (range of 104 to 145˚), (15), which was similar to what Lakati *et al.*, obtained. Differences seen among the ethnic groups could be explained by the varying day to day activities of the different groups. A survey of locally available implants of commonly used companies namely Smith and Nephew, Johnson and Johnson, and Depuy Synthes found that the neck-shaft angle of the prostheses was set at 135˚.

2.5 The femur neck anteversion angle (FNA angle)

The femoral neck anteversion angle averages between 8-14° in adults (51), with males having a slightly less femoral anteversion than females (8). Studies have shown that change in FNA angle exacerbates degenerative disease of the hip (52–54) by altering congruency of the hip joint leading to osteoarthritis (4,52,55). Repeated acetabular impingement causes injury to the labrum in the hip with decreased anteversion and neck-shaft angle. A torn labrum increases the risk for the development of degenerative hip joint disease (55).

The assessment of the anteversion angle is crucial for positioning in THA (7,56). The native anatomy of the femur often dictates the version for a press-fit stem. Many surgeons use the posterior cortex of the femur at the femoral neck cut as their guide to setting the version (3).

The mean anteversion angle in Kenya was found to be 22.04° with a range of 1.17 to 39.43° (14). Indian studies by Verma *et al*., reported 14° and 9° as reported by Zalawadia *et al*., (34,57). Unnanuntana and co-workers in a study on American specimens reported 10.41° (58). The results of the study done by Lakati *et al*., is closer to that done in Bengali specimens by Debnath *et al*., who obtained an angle of 20.05° (59). In a select German population, a CT based study yielded a lower angle of 14.2° unlike a mean of 28° from Umbese co-workers' studies on Nigerian hips with similar study methods (48,2). The assumption would thus be, the anteversion angle is notably higher in Africans compared to Indians and Caucasians.

2.6 Lifestyle and Proximal femur parameters

There are subtle yet important anatomical differences in the proximal femur based on lifestyle adaptations. Studies have shown that the FNA remodels because of different stress placed on the adult femurs diaphysis by twisting forces such as sitting positions adapted by different ethnic groups (60–64). This results in asymmetrical changes in the connective tissue around the hip, shortening the hip joint capsule and muscles on the contralateral side.

Otsianyi *et al*., in their study on interethnic differences of NSA in Kenya revealed a higher NSA among the nomadic group (129.72° + 4.76) than (127.25° + 4.15) among the highland Bantu (49). Other studies have demonstrated similar disparities based on inter-population and individual differences (22,65–67). In Kenya varying activity levels and types were determined as the reason for the differences (49). Anderson and Trinkaus compared NSA across different populations from modern, historic and prehistoric human population samples and demonstrated larger angles in modern societies in comparison to non-industrialized societies, (65) emphasizing the effect habitual loads on the proximal femur as pertains its morphometry. Geography, climate and race, however, did not appear to affect patterns of femoral neck-shaft angles. Other factors that may explain inter-population variation include genetics, environment and dietary factors (34, 66, 67).

2.7 Techniques employed in the measurement of proximal femur dimensions

The use of CT scan images, for anatomic measurements, are reported to be convenient and rapid for routine diagnosis as well as preoperative analysis if necessary. In combination with 3D reconstruction, CT has numerous advantages over cadaveric studies with a greater number of cases, accessible demographic data, ideal magnification and spatial orientation of bone structure but its availability and costs make it unfavorable in developing countries (68). Use of CT scan and 3D reconstruction imaging on cadaveric specimens may have been accurate but based on specimens of asymmetrically mixed ages and genders, it is difficult to integrate information as parameters are defined differently by the different investigators (36).

The level of accuracy of conventional radiographs is acceptable in the distal femur, but not the proximal. This is attributed to factors such as incorrect positioning of the patient caused by pain or contracture, or small variations in leg rotation, which significantly alters the neck-shaft angle and isthmus width (69). The absence of precise radiological data may result in insufficient accuracy to perform pre-operative design for custom made prostheses (6,70). This has led to, wrong implant selection and poor functional outcomes post THA (71).

Other studies have used standard specimen positioning and digital photography to evaluate the geometry of the proximal femur but with limitations in user knowledge and interpretation of the software used to obtain the final readings. Reproducibility by the use of a consistent and reliable landmark and ease of positioning improves the accuracy of digital photography over radiographs and direct measurement (58). Comparing the data from both manual morphometry and digital morphometry, the technique, using ImageJ® software, is more faithful to the real values and was thus selected for this study (72).

2.8 Summary of Literature review

Regional differences exist in the stature of human beings, such variations demonstrated in the proximal femur are in the neck lengths, head diameter, horizontal and femoral offsets, neck-shaft angles and anteversion angles. For this reason, implants should be designed according to a specific population. Reddy *et al*., highlighted that an ill-fitting implant results in micro motion leading to thigh pain, osteolysis and aseptic loosening in THA (73). Large implants increase the tendency to fracture and under-sizing may lead to failure of integration of implant and bone (74). There is insufficient data in Sub-Saharan Africa on the proximal femur to conclusively state similarities and differences with the Caucasians where most implants are sourced.

Chapter 3

Materials and Methods

3.1 Study material

Samples of femurs were selected from the osteological collection at the National Museum of Kenya, a collection containing over a thousand complete disarticulated human skeletons gathered between 1952 and 1990 in the Central Kenya region. Of the samples selected we studied two hundred and sixteen femora (107males, 109 females).

The materials used in this study were the Paleo-Tech Laboratory Osteometric Board ©2005 which was used to measure femur lengths and the AbergBest 21 Mega pixels 2.7" LCD Rechargeable HD Digital Camera from Foshan, China to capture images of the femurs.

3.2 Sample size determination and formula

The Sample size was determined using equations 3.1 and 3.2 and a given Standard Deviation

$$n = \frac{Z^2 \sigma^2}{e^2} \qquad (3.1)$$

where

n = Sample size

σ = Population Standard deviation

e = Margin of error

Z = The value for the given confidence Interval

$$n = \frac{1.96^2 x 3.75^2}{0.5^2} \qquad (3.2)$$

=216 femurs

3.3 Sampling procedure

Normal adult femur bones without any obvious pathology were included in the study. The parameters of interest were the femur head diameter (cm), femur neck length (cm), neck-shaft angle (˚), femoral offsets: horizontal and vertical offsets (cm) and femur neck anteversion angle (˚)

3.3.1 Inclusion criteria

Adult femurs with no evidence of fracture, arthritic changes or deformity of both right and left sides.

3.3.2 Ethical considerations

Approval was sought from the KHN-UON Ethics and Research Committee and the National museums of Kenya through The Chair, Department of Human Anatomy, Chiromo Campus, University of Nairobi. It was a descriptive cadaveric study on dry femora and the specimens were handled in accordance with the Human Anatomy Act 19 Cap 249.

3.4 Data collection

Photographic Technique (Adopted from *Unannuntana et al study J Orthop Res 2010 Nov* (58).

Each specimen was digitally photographed using AbergBest 21 Mega pixels 2.7" LCD Rechargeable HD Digital Camera, China, in two standardized views, from superior level for its anterior surface and cephalocaudal.

Each femur, with the anterior surface facing up was placed on a table. By rotating the shaft internally and externally with support to the lateral condyle and medial condyle respectively, the neck was aligned parallel to the surface of the bench. Pictures were taken from a superior position, 30 cm from the specimen and centralized to the bone (Figure 1).

A line along the femoral shaft axis was drawn. A circle was drawn around the femoral head and the center determined using ImageJ®® software. The diameter of the circle was then measured as the diameter of the head. The center of the line connecting the greater and lesser trochanters marked the center of the base of the femoral neck. The lesser trochanter was then marked on its superior edge at its junction with the femoral neck. Using an open source image analysis software, ImageJ®® (National Institutes of Health, Bethesda, Maryland) these measurements were obtained: the angle formed by the neck and shaft (NSA), the diameter of the head, horizontal and vertical offsets (Figure 1).

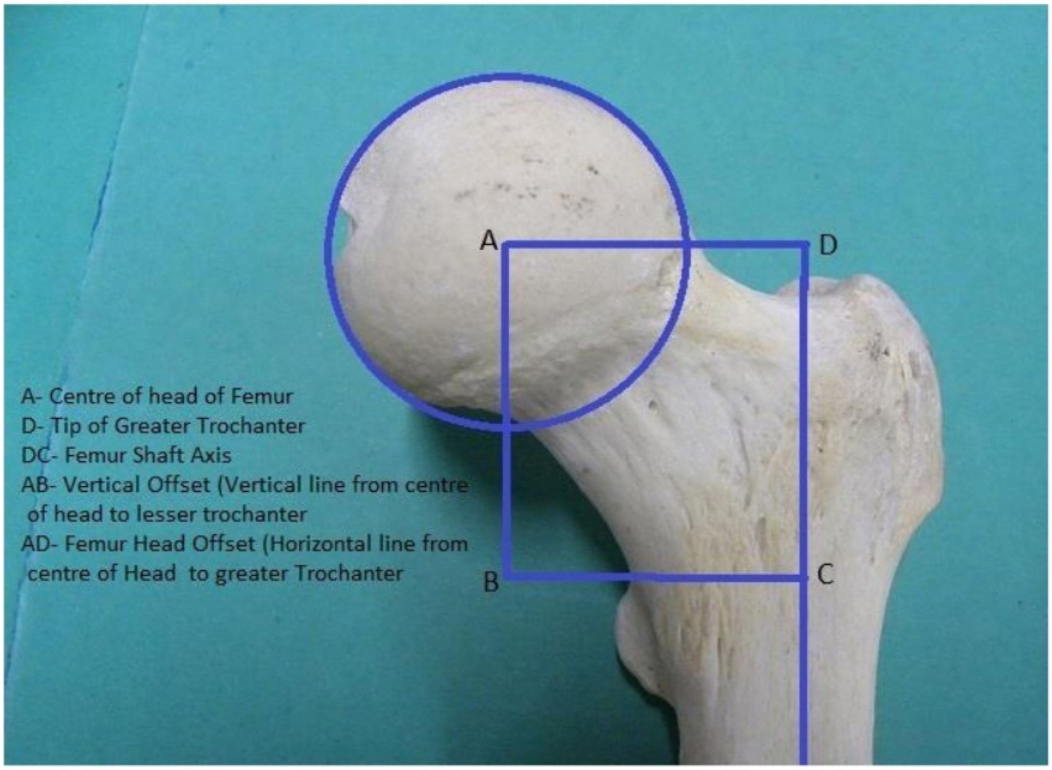

Figure 1. Positioning of the specimen

The femoral neck-shaft angle was measured as the angle between the femoral shaft axis and the line joining the center of the head and the base of neck. (Figure 2).

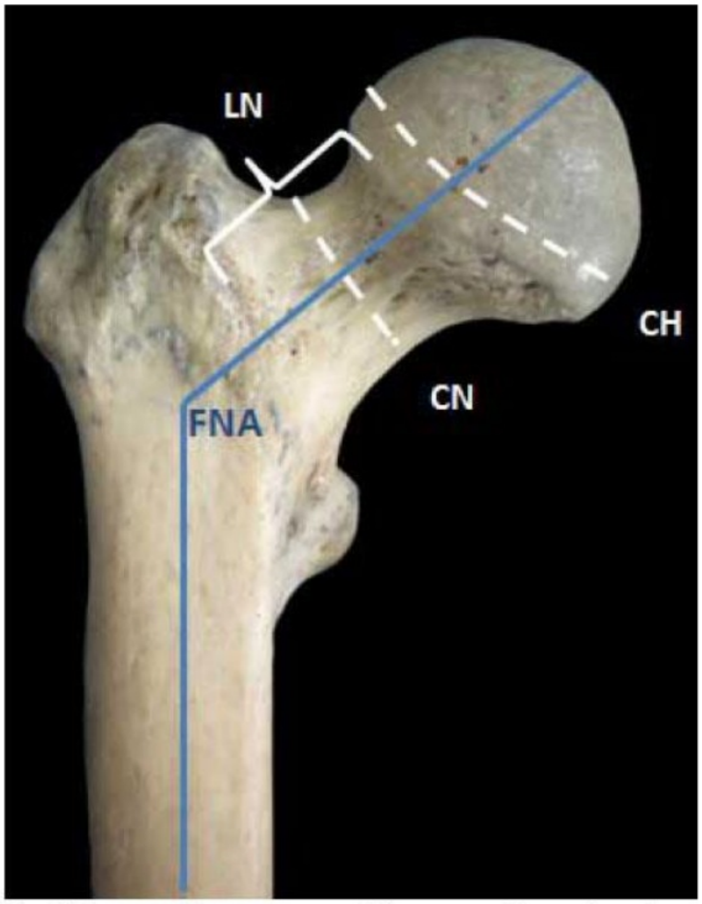

Figure 2. Photomacrograph of the proximal femur taken superiorly

Horizontal hip offset was measured as the distance from the axis of the femoral shaft to the center of femoral head (line CF, Figure 3). The vertical hip offset was measured as the distance between the proximal extent of the lesser trochanter and the center of the femoral head (line AD, Figure 3).

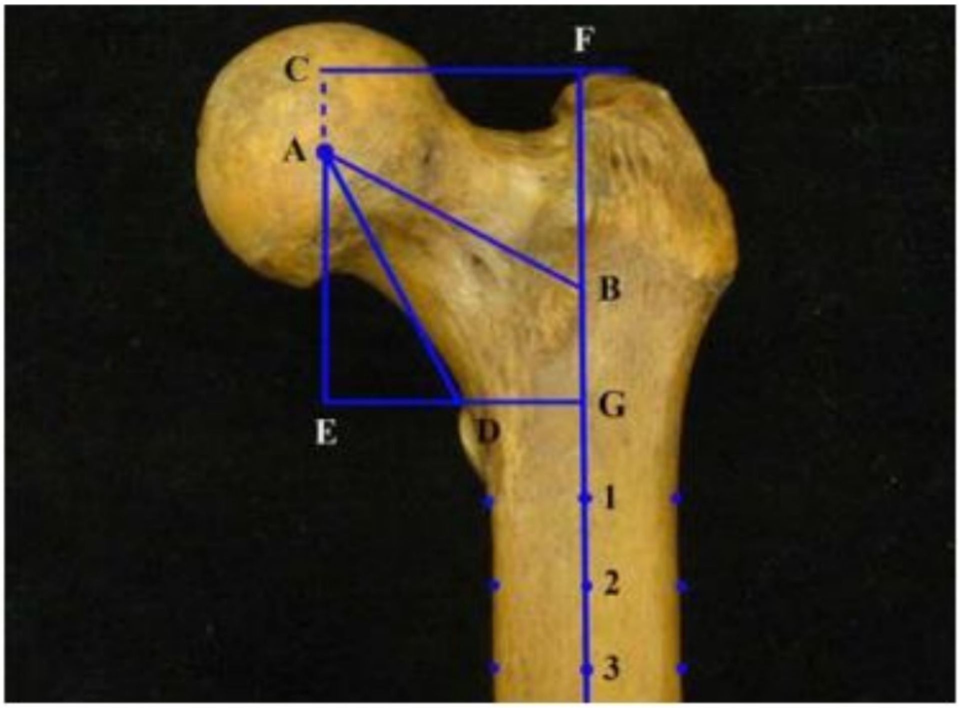

Figure 3. Measurement of offset

Each femur was placed on the edge of the table with anterior surfaces facing up as illustrated in Figure 4. The femur was abducted to make the femur neck parallel to shorter edge of the board and parallel to the lens of the camera; so that the view would be perpendicular to the femoral neck axis. To get the femoral neck axis, three pairs of points were plotted on the anterior and posterior cortex, the center of the lines joining these points marked 1,2, and 3 gave the femoral neck axis (AE). Another line (AB), parallel to the board—representing the intercondylar plane—was drawn. Femoral neck anteversion was measured from this view (angle EAB, Figure 4). Angles inferior to the plane of the board was recorded as negative, and vice versa. Measurements of distance on photos was first recorded as pixels then converted to millimeters by the use of standard rulers on every photograph.

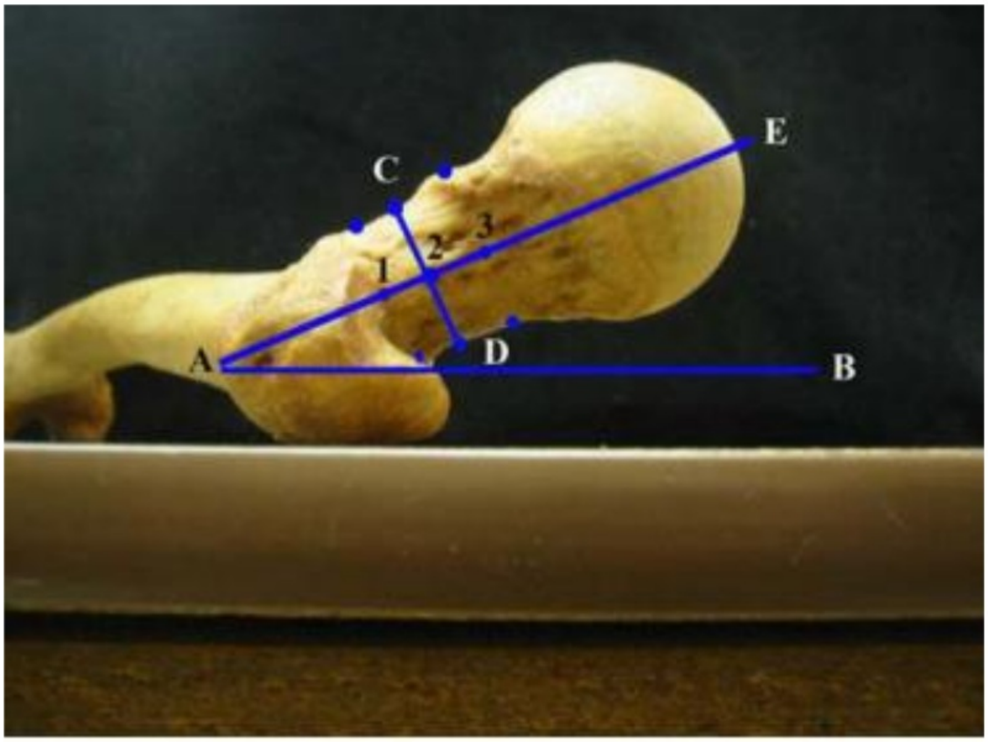

Figure 4. Measurement of anteversion angle

To minimize inter and intra observer errors two measurements were taken by two different researchers at different times. Pearson's coefficient was used to calculate reliability. The data was tabulated and all measurements entered into a computer. Statistical analyses using t tests and rank sum tests to compare morphological features were performed. The level of significance was set at $p < 0.05$. The correlation coefficients upon calculation were interpreted as degrees of correlation.

Figure 5. An osteometric board used to measure the overall length of the femur.

3.5 Data Analysis

All data sheets were carefully inspected for errors by the principal researcher. Results were then entered into a data base for analysis using SPSS software version 25 with the aid of a qualified statistician. Data variables were summarized as percentages and frequencies and correlations between the variables demonstrated separately. The descriptive statistics (frequency, range, mean and standard error) for the variable were presented in tables.

Independent t tests were performed to assess the differences in the means of variables between sexes and population by comparison with data from previous studies after the data was tested for normality of distribution using non parametric tests (Kolmogorov- Smirnov test). A p value < 0.05 was set as the level of significance. Using correlation coefficient, any correlation between variables was established and interpreted as degree of correlation.

Chapter 4

Results

Two hundred and sixteen normal adult femora of both sexes were studied in the present work. They were distributed into 107 of males (49.5 %) and of females 109 (50.5 %) with 108 (50 %) right and 108 (50 %) left femora. The mean, median and standard deviation of the parameters measured are summarized in the table below

Table 1. Mean and SD values of all parameters

Statistics		**Neck Length (cm)**	**Horizontal offset (cm)**	**Vertical offset (cm)**	**Head diameter (cm)**	**Neck shaft angle (º)**	**Overall length (cm)**	**Anteversion angle (º)**
Mean		3.38	5.61	5.41	4.67	123.21	49.26	22.04
Median		3.40	5.69	5.44	4.70	123.86	48.84	20.90
Std. Deviation		0.69	0.99	0.72	0.48	5.13	6.21	6.51
Minimum		1.54	2.37	3.51	3.55	113.09	38.10	10.42
Maximum		4.99	7.55	6.99	5.65	135.89	61.39	39.98
Percentiles (%)	25	3.09	5.23	5.04	4.31	119.79	45.58	17.26
	50	3.40	5.69	5.44	4.70	123.86	48.84	20.90
	75	3.77	6.35	5.96	4.96	126.41	52.71	26.95

There were statistically noted differences in parameters for male and female samples as shown in the table.

Table 2. Mean and SD values of variables with sex

VARIABLE	MALE (MEAN±SD)	FEMALE (MEAN±SD)	P VALUE
NECK LENGTH (cm)	3.63 ± 0.59	3.13± 0.70	**0.02**
HORIZONTAL OFFSET(cm)	6.00± 0.62	5.21 ± 1.13	**0.006**
VERTICAL OFFSET(cm)	5.60 ± 0.61	5.22 ±0.80	0.09
HEAD DIAMETER(cm)	4.82 ± 0.40	4.53 ± 0.81	**0.04**
NECK SHAFT ANGLE(˚)	125.8 ±7.62	122.47±6.15	**<0.001**
OVERALL LENGTH (cm)	49.88 ± 6.43	48.65 ± 6.03	0.52
ANTEVERSION ANGLE(˚)	20.07 ± 5.64	24.02 ± 6.84	**0.04**

From the present study, it was noted that males had longer neck lengths, vertical and horizontal offsets, head diameters and larger neck shaft angles. The females however were found to have larger anteversion angles in comparison to the males. Despite average overall length of males being longer than the females the difference was not statistically significant.

Table 3. Correlations by sex and side

Parameter	Right side		Left side		P VALUE
	MALE	FEMALE	MALE	FEMALE	
NECK LENGTH (cm)	3.29 ± 0.31	3.1 ± 0.83	3.96 ± 0.62	3.16 ± 0.56	0.08
HORIZONTAL OFFSET (cm)	5.89 ± 0.48	5.19 ± 1.08	6.11 ± 0.74	5.23 ± 1.23	0.67
VERTICAL OFFSET(cm)	5.28 ± 0.44	5.15 ± 0.93	5.91 ± 0.60	5.29 ± 0.68	0.07
HEAD DIAMETER(cm)	4.64 ± 0.32	4.46 ± 0.59	5.00 ± 0.41	4.60 ± 0.45	0.09
NECK SHAFT ANGLE (°)	124.75 ± 4.33	125.0 ± 6.51	121.04 ± 4.16	122.05 ± 4.68	**0.03**
OVERALL LENGTH(cm)	49.92 ± 6.68	48.86 ± 6.48	49.83 ± 6.51	48.45 ± 5.92	0.90
ANTEVERSION ANGLE (°)	18.13 ± 4.85	20.94 ± 6.54	22.02 ± 5.92	27.09 ± 5.89	**0.009**

Right and left side measurements differed slightly for neck length, head diameter, offsets and overall length but the differences were of no statistical significance. Significant differences were seen for neck shaft angle and anteversion angles for right and left sides.

Neck shaft angle *vs*. anteversion angle

Pearson's correlation coefficient, r, was -0.13, p=0.06

There was a negative correlation which was not significant statistically

Neck length *vs*. overall length

Neck length was significantly correlated with overall length, r=0.43, p<**0.001**

Chapter 5

Discussion

The biomechanical goals of total hip arthroplasty are to create a stable anatomical articulation with an optimized range of motion, to restore normal biomechanics for muscular efficiency, and to equalize limb lengths(9,16,28). To achieve these goals a thorough understanding of the anatomy is necessary. The current study used digital photography and software analysis technique to accurately quantify the proximal femur measurements for gender and side-to-side difference in the Kenyan population. The accuracy of the measurements is improved over radiographs and direct measurement because of the ease of positioning the cadaveric femora and the reproducibility of consistent landmark identification (58).

The results support that significant variation exists in femoral anteversion, neck-shaft angles, horizontal and vertical offsets, and femoral head diameter within subjects in the same populations. Analysis of the dimensions from the local population is essential as it provides crucial information required to design a more suitable size and shape femoral prosthesis for THA (17,47,73).

In the present study the average head diameter was found to be 48.2 mm in males and 45.30 mm in females, however there was no significant difference observed for both male and female regarding side. The mean of head diameters found in this study compares with values obtained by Lakati *et al.,* study with of a mean of 44.18 mm that had a range of 36.5 mm to 50.9 mm (14). In addition, Noble and co-workers in their study on Caucasians also found almost similar value of 45.9 mm (17).

The neck length obtained in the local population was 36.3 mm in males and 31.3 mm in females, demonstrating that overall males have longer neck lengths than females, with no statistically significant difference in left and right femora. Several studies have shown that these values differ from one population to another with the lowest value at 28 mm in Begelavi, and the highest recorded 50 mm in certain Indian ethnic groups (11,34,70,75,76). There is no consensus on the cause of this but multifactorial based on genetics, environment and lifestyle activities.

The average horizontal offset was 60 mm in males and 52.1 mm in females, and vertical offset of 56 mm in males and 52.2 mm in females. The present study demonstrates longer offsets in males than in females. There was no difference in the horizontal or the vertical offset for either left or right side.

The mean neck-shaft angle obtained was 125.80˚ in males and 122.47˚ in females, demonstrating a statistically significant difference in male and female morphology. The difference has been attributed to the female's larger pelvis as compared to that of their male counterparts. The right side of both sexes had a larger NSA compared to the left, and habitual practices could attribute to this. Results of a similar study in Kenya showed the average value of NSA was 129.82˚, which is higher than the present study of 123.21˚ (21).

The average anteversion angle was lower at 20.07˚ in males and 24.02˚ in females. The angles varied significantly one side to another supporting literature that rotational differences of less than 10˚ are considered variations of normal (77). Several studies have demonstrated larger anteverson angles in African population compared to other ethnicities(22,67). The table below compares values obtained from the present study with that of other populations.

Table 4. Proximal femoral geometry in different populations

Parameter	Rubin et al [13] Swiss	Husmann et al [14] French	Mahaisavariya et al [15] Thai	Noble et al [3] Caucasian	Rawal BR et a1 [5] Indian	Siwach et al [2] Indian	Sendhoorani et al s. indian	Present study Kenyan
Femoral head offset (mm)	47+ 7.2	40.5 +7.5	Parameter not studied	43 + 6.8	40.23 ± 4.85	38 + 5.52	40.75 + 0.32	Vo ;54.10 +0.72 Ho 56.10 + 0.99
Femoral head diameter	43.4 + 2.6	Parameter not studied	43.98 + 3.47	46.1 ± 4.8	45.41 ± 3.66	43 .53 ± 3.4	41.77 ± 0.36	46.70 +0.48
Anteversion angle (degrees)	Parameter not studied	Parameter not studied	Parameter not studied	Parameter not Studied	10.9 + 4.22	13.68 + 7.92	10.69 + 2.63	22.04+6.51
Neck shaft angle (degrees)	122.9 ± 7.6	129.2 + 7.8	128.04 + 6.14	124.7 ± 7.4	124.42 ± 5.49	123.5 ± 4.34	131.4 + 9.47	123.21 +5.13

In comparison to other populations, the head diameter and neck-shaft angle of the select Kenyan population was similar to that of Caucasians. Noble *et al.*, studies did not measure vertical offset but there is a significant difference in the horizontal offset of that study compared to this study. It was not possible to compare the anteversion angle as this was not a studied parameter in the Caucasian study. The mean overall length in the local population was seen to be 49.88 cm in males and 48.65 cm in females' p-value of 0.52, not statistically significant.

A survey of the commonly used implants for total hip arthroplasty was done and the findings tabulated as follows, and compared to the values found in this study.

Table 5. Locally available implants

Company	Head diameter	Neck length	Horizontal offset	Neck-shaft angle	Stem length
Smith and Nephew. (Polarstem)	28 – 36mm	27 - 42mm	34 - 57 mm	126 - 145°	129 – 154mm
Johnson and Johnson (Corail)	28 – 36mm	39 – 43mm	38.3 – 52.9mm	125 - 135°	95 – 180mm
AK hip system	28 – 36mm	30 – 41mm	36 – 56mm	127 - 132°	110 – 145m
Parameters in this study	36 – 57 mm	15 – 50 mm	24 – 76mm	113 - 135°	-

Chapter 6

Conclusion, Recommendation and Limitations

6.1 Conclusion

It could be concluded that the mean values of the main parameters of the proximal femur of Kenyans differed from values found in other populations. The average female skeleton is shorter and less robust than the average male, although the magnitude of the difference varies from one population to another.

There was a significant difference between the males and females for all variables and for the left and right sides. The females presented lower values of neck length, offsets and head diameter, larger anteversion angles and smaller neck shaft angles. A significant side difference of the anteversion angle and neck shaft angle was also observed in the local population.

A survey of locally available implants shows a wide variety of implant selection for head size (28 mm to 36 mm), neck lengths that can be adjusted with modular prostheses, neck horizontal offset (range, 34 mm to 64 mm) but with standard neck shaft angles of 135°and limited prostheses with neck-shaft angles of 126° and 145°. The potential change in neck-shaft angle significantly influences the horizontal offset, thus soft tissue tensioning. This also would cause increased wear rates and thus affect longevity of the implants.

Studies have shown that the horizontal offset is determined by the neck shaft angle and the vertical offset is determined by the anteversion angle. Therefore, these parameters, femoral offsets, neck shaft angle play a crucial role in the design of the femoral prosthesis. A correlation has been shown with femoral offset restoration and abductor muscle lever arm and strength. Restoring near normal parameters improves longevity of the implant and minimizes risk of failure.

European data based hip prosthesis are mismatched in Kenyans. For Kenyan population best fit prosthesis can be made with the help of the published data and larger studies of proximal femur. These prostheses can also be used by other African countries as morphologically they are similar to Kenyan population. Structurally and functionally the femur horizontal offset, vertical offset, femur neck length and head diameter are the detrimental parameters for designing the hip prosthesis and correlation coefficient among these variables was moderate to high in our study which proves relationship among these mentioned variables.

Although this study has shown significant differences in the proximal femur morphometry of the Kenyan population, and its influence on total hip arthroplasty, we cannot make definite conclusions without data on the morphometry of the acetabuli. Thus, there is need for elaborate studies on the morphometry of the acetabular in the Kenyan population.

6.2 Recommendations

1. Further research should be carried out on the proximal femur and the acetabuli using 3D CT scans on healthy adult individuals and with a larger sample size to support the findings of the present study. This data with emphasis on neck-shaft angle, horizontal and vertical offsets will be used as a guideline to design a more suitable implant for the Kenyan population. This will give better information to engineers and clinicians in the development of implants and practice related to the hip joint.

2. A Kenya National Joint Registry, to allow ease of follow up on total hip arthroplasty patients and determine longevity of the implants used in the local population.

6.3 Limitations

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This study should be evaluated in light of these limitations.

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1. Due to the cadaveric nature of this study, it was not possible to retrieve information regarding limb dominance and activity level, factors that could potentially correlate with femoral asymmetry.
2. Due to the 3D dimension of the proximal femur, 3D CT analysis would have been a better method of study but in light of insufficient funds and resource availability this method of analysis was selected.

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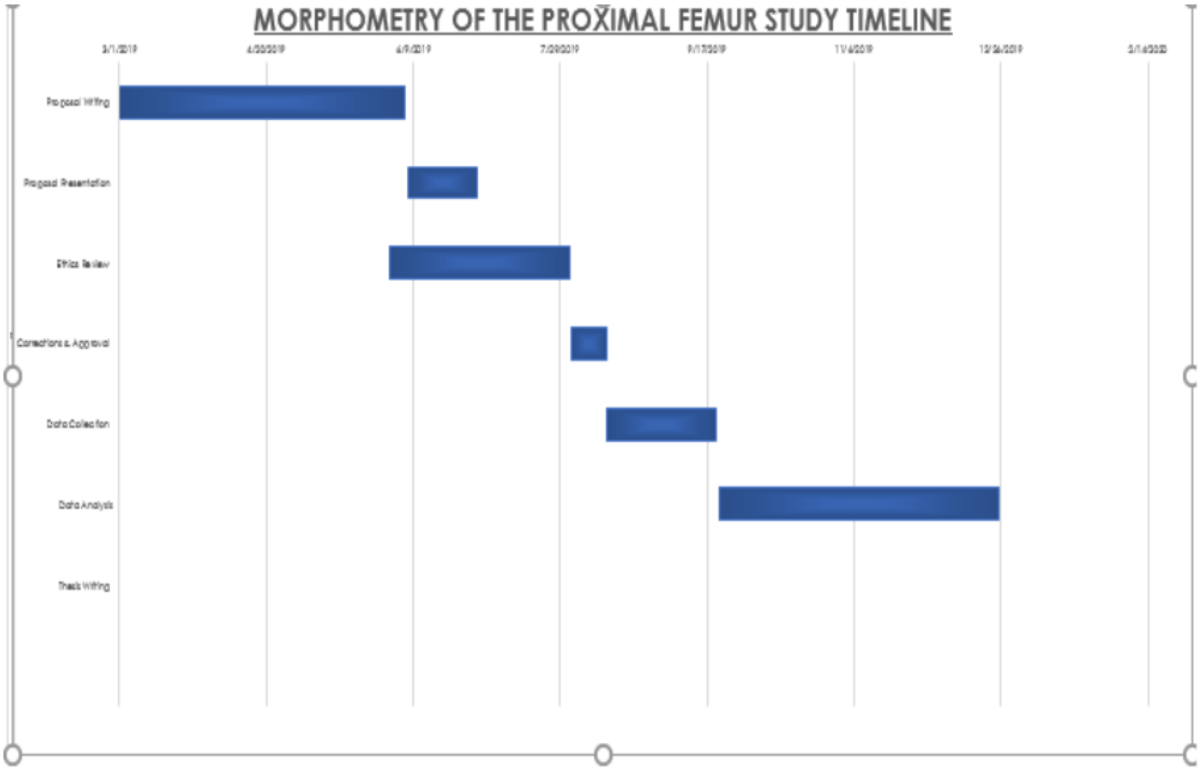
Unfortunately, there is no "gold standard "method to study the proximal femur morphometry, but different methods that can faithfully reproduce the morphometric values of anatomical structures, depending on the purpose of the research, the anatomical structures and experience of the researcher.

Study timeline


MORPHOMETRY OF THE PROXIMAL FEMUR STUDY TIMELINE
3/1/2019
4/20/2019
6/9/2019
7/29/2019
9/17/2019
11/6/2019
12/26/2019
2/14/2020
Proposal Writing
Proposal Presentation
Ethics Review
Corrections & Approval
Data Collection
Data Analysis
Thesis Writing

Morphometry Of The Proximal Femur In A Kenyan Population: Relevance To Component Placement In Total Hip Arthroplasty.

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