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Proximal Femoral Morphometry: New Morphometric Parameters for Prediction Proximal Femoral Fracture.

Bob-Manuel, IF, Didia BC, and Udoaka AI
Department of Anatomy, Faculty of Basic Medical Sciences, College of Health Sciences, University of Port Harcourt, Port Harcout, Nigeria.

Corresponding Author: Bob-Manuel IF
Email: ibinabo.bob-manuel@uniport.edu.ng; +234 803 6724 965

ABSTRACT

Understanding the morphometry of human skeleton is requisite in anatomical sciences and in the anticipation and management of femoral neck and trochanteric fractures. This study is aimed at developing proximal morphometric parameters that will conform to the biomechanical and anatomical features of the neck, proximal shaft (intertrochanteric or epiphyseal area) and shaft of the femur from radiographs of Nigerians. A total number of 1709 normal anteroposterior radiographs of the femur of Nigerians collected from Radiology Departments of selected Hospitals in Nigeria. From the obtained radiographs, angular parametric landmarks were measured utilizing standard instruments and protocols described in literatures. For males, mean±SEM values of FNSA, FNIA, FSIA and FIT_{area} are 132.38±0.310, 93.87±0.310, 39.21±0.210, 105.99±03.59mm^2 and 131.96±0.26°, 92.87±0.29°, 40.26±0.22°, 98.77±3.75mm^2 for left and right sides of *os femora* respectively while for females, the mean+SEM values for the same parameters are 132.38±0.310, 93.87±0.31°, 39.21±0.210 79.62±3.13mm2 and 131.96+0.26°, 92.87+0.29°, 40.26±0.22°, 84.45±2.18mm^2 for left and right sides of *os femora* respectively. The result obtained showed variation in FNSA with other populations. Also, the result showed the *os femora* as sexually dimorphic (p<O.05). Femoral neck intertrochanteric angle (FNIA) or collo-epiphyseal angle, femoral shaft intertrochanteric angle (FSIA) or diaphseal-epiphyseal angle and the area of femoral intertrochanteric triangle (FIT) or epiphyseal triangle are introduced in this study to define the neck intertrochanteric relationship and shaft-intertrochanteric relationship, and the strength and brittleness of the proximal *os femora* respectively. This study concludes robust understanding of the geometry of the proximal end of the *os femora* requires parameters that conform to anatomical facts between neck, proximal epiphysis and shaft of the *os femora* such as introduced in this study. We recommend the possibility of using the parameters introduced in this study to improve prediction and management of susceptibility to proximal femoral fractures.

Keywords: Proximal Femoral Morphometry, Femoral Intertrochanteric Triangle, Fracture

INTRODUCTION

Fractures amply and greatly increase the danger of death and incapacitate individuals with highly expensive cost of medical management[1,2,3]. Fractures of the articulating bones in the coxal region are one of the foremost problems in the aging and senescence of the skeletal system. As the population of elder increases, the number of coxal fractures rises. Their bones get weaker due to the natural factors of aging and senescence, side effect of medications and environmental hazards. Hence, postural and gait balance is reduced making them susceptible to fall leading to bone breakage. An imperative peril and danger factor for fractures of the neck of the *os femora* is the form and structure of the upper portion of the *os femora*[3]. Fractures or bone breakage occur when a human bone is disposed to a stress more than its biomechanical strength provided by its cortical and trabecula properties. The stress within a bone depends on the structural configuration and cortical and trabecula composition of the bone, as well as on the amount and direction of the force applied[4,5,6,7].

Since the middle of the 19th century, understanding the relationship in the structural arrangement of the head, neck and upper or proximal shaft of the *os femora* has been the mainstay of anatomical, anthropologic, forensic and orthopaedic researches[8]. As a region prone and inclined to fracture and many childhood and adult disorders, several of which might be related to differences in proximal femoral morphometry or whose therapy might require or entail a thorough understanding of its anatomy, numerous scientific research targeting the definition and measurement of its structural parametric landmarks have been developed. Healthy terminology and ample methodology for describing and quantifying the structural linear and angular parametric landmarks of the features of the proximal portion or end of the thigh bone has been advanced from these efforts.

The earliest attempt at numerically quantifying the structural landmarks of the organizational arrangement of the components of the proximal segment of the *os femora* started with observing and analyzing its neck and shaft relationship possibly because of their simplicity or straightforwardness of understanding. These attempts yielded two renowned parametric landmarks, feinoral neck-shaft angle (FNSA) and neck version, which defines this relationship. The FNSA has an extensively acknowledged theoretical description with mean value 135.0 and standard radiogrammetric methodology[9] however, the neck version has produced over a century worth elaborate investigations concerning or about its true description and meaning, normal average value, and best measurement methodology[10]. Not minding the amount of scientific investigative research each has spawned, both are resolutely and strongly grounded canons of contemporary orthopaedics.

Despite the fact that the neck-shaft relationship of the *os femora* has been quantitatively assessed by several scientific investigators for over a century, analytical and decisive appraisal of the neck head relationship is even now relatively in infancy[10]. Besides, numerous controversies are extant in literatures among established proximal morphometric parametric landmarks (HAL, FNAL, FNSA, FNW) of the *os fernora* in their ability to predict and manage proximal femoral fractures as these measures are not conforming with anatomical facts of the head-neck-shaft relationship of the proximal *os femora*[11]. These parameters consider only relationship between femoral neck and diaphysis and see the head as a mere extension. For this reason contemporary scientific investigators have introduced and quantified new morphometric parameters in a bid to improving the understanding of the morphology and biomechanics of the proximal extremity of the *os femora* and defined its neck-head relationship. Such parametric landmarks introduced include moment arm[12], head-neck offset[13], alpha and gamma angle[14], true moment arm (TMA)[15], anterior offset (AOS), posterior offset (POS), superior offset (SOS), inferior offset (IOS), anteroposterior (AP) physeal angle and Lateral physeal angle[10], height of head (HH), offset (OFF), altitude difference from head center to the top of great trochanter (TRH), thickness of femur (TOF), diameter of neck (ND), length of neck (NL), where NSA is an angle of skew lines between shaft axis and neck axis[16].

However, Gasper and Crnkovic[11] recommended that further research should include head, neck and proximal shaft (epiphysis) relationship that will be compatible with anatomical facts. This echoes Cooper[8] and Toogood and Skalak[10]. Researchers have shown that the femoral trabecular bone provides the biomechanical strength of the proximal femur[4,17,18]. Hence, this study is aimed at developing proximal morphometric parameters that will conform to the biomechanical and anatomical features of the head, neck, proximal shaft (intertrochanteric or epiphyseal area) and shaft of the femur, which will be useful in anticipating or predicting femoral neck and intertrochanteric fractures

MATERIALS AND METHODS

This scientific investigation is a non-experimental, analytic study, investigating the radiogrammetry of the proximal portion of the *os femora* in the Radiology Departments of selected University Teaching Hospitals in Nigeria. One thousand, seven hundred and nine (1709) {seven hundred and eighty-seven (787) male and nine hundred and twelve (912) female} normal standard anteroposterior (AP) radiographs of the hip joint/*os femora* were selected from the Radiology Department of University of Port Harcourt Teaching Hospital, Port Harcourt; Olabisi Onabanjo University Teaching Hospital, Ago-Iwoye, Ogun State; Ladoke Akintola University of Technology Teaching hospital, Qgbomosho; National Orthopedic Hospital Igbobi, Lagos; University of Jos Teaching Hospital, University of Ahuja Teaching Hospital, Abuja and University of Nigeria Teaching Hospital, Ituku-Ozalla Enugu after approval was taken from the Ethics and Research committee of the University of Port Harcourt. Samples included for radiogrammetric assessment were only standard anteroposterior radiographs of the coxal region displaying the proximal portion or part of the *os femora* with no visible deformity or disease. Besides, only radiographs reported normal with bio-data indicating adult Nigerian origin were included. Pelvic radiographs showing incomplete proximal end of *os femora*, incomplete ossification, deformed or diseased, reported abnormal and bio data not indicating Nigerian origin were excluded in this study.

The angular morphometric parameters or landmarks of the proximal end or portion of the *os femora* measured are femoral neck shaft angle (FNSA), femoral neck intertrochanteric angle (FNIA) and femoral shaft intertrochanteric angle (FSIA) and the sides of femoral intertrochanteric triangle. The area of the Femoral Intertrochanteric Triangle (FIT_{AREA}) in mm^2calculated from its measured sides using Heron's formula. The later three morphometric landmarks or parameters are introduced and measured in the study.

The Femoral Neck-Shaft Angle (FNSA): The femoral Neck-shaft angle formed at the intersection of the femoral shaft axis and the femoral neck axis lines. The femoral shaft axis line was drawn through the midpoint of the body (shaft) of the *os femora* just below the minor trochanter and the midpoint of its distal end while the femoral neck axis line was drawn through midpoints of the narrowest part of the femoral neck and head of the *os femora*. The Goniometer was then placed on the lines at their intersection. The red lines on the two arms of the goniometer were then made to align with the femoral neck axis and femoral shaft axis lines and the angle between the red lines was measured[19,20,21,22,23].

Femoral Neck Intertrochanteric Angle (FNIA): This is the angle formed at the junction of axis of the neck of the *os femora* and the intertrochanteric axis. The intertrochanteric axis is a line passing though superior margin of Intertrochanteric line and the superomedial margin of the lesser trochanter. This parameter is being introduced and measured in this study as this parameter has not been measured as revealed by literature available.

Fernoral Shaft Intertrochanteric Angle (FS1A): This is the angle formed at the junction of the femoral shaft axis and the intertrochanteric axis. This parameter is being introduced and measured in this study as this parameter has not been measured as revealed by literature available.

Femoral Intertrochanteric Triangle (FIT): This is a scalene triangle formed by the intersection of the lines passing through the shaft, neck and intertrochanteric axis at the intertrochanteric area of the proximal *os femora*. The sides of the FIT were measured as follows: FIT_{AB} - Distance between intersection point of the shaft and neck axis lines and the intersection point of the intertrochanteric and neck axis lines, FIT_{BC} - Distance between the intersection point of the intertrochanteric and neck axis lines and the intersection point of the shaft and intertrochanteric axis lines, and FIT_{AC} — Distance between the intersection point of the shaft and neck axis lines and the intersection point of the shaft and intertrochanteric axis lines. The area of the Femoral Intertrochanteric Triangle (FIT_{AREA}) was calculated using Heron's formula: Area = $\sqrt{\ }$ p(p-a)(p-b)(p-c). Where p = (a+b+c)/2: a, b, and c are sides of the triangle[24].

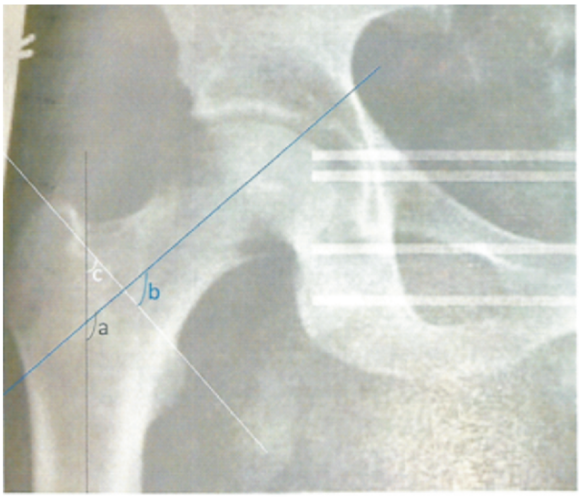

Figure 1: Diagram showing angular morphometric parameters of the proximal end of the os femora. NB: a = Femoral Neck Shaft angle (FNSA), b = Femoral Neck intertrochanteric angle (FNIA), c = femoral shaft intertrochanteric angle (FSIA); black line = shaft axis line, blue line = neck axis line, white line = intertrochanteric line.

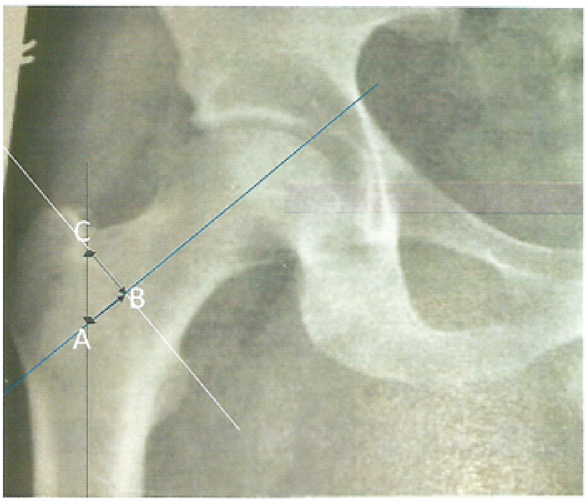

Figure 2: Diagram showing femoral intertrochanteric triangle (FIT) of the proximal end of the os femora. NB: AB = FIT_{AB}, BC = FITBC, AC = FITAC; ΔABC = FIT; black line = shaft axis line, blue line = neck axis line, white line = intertrochanteric line.

All measurements were taken repeatedly until same values were obtained and recorded. Data collected for this study were analyzed with the help of Statistical Package for Social Science (SPSS) versionl6.0 to establish baseline descriptive statistical data. Two tailed z -test was used to compare mean values to establish gender and side differences and Pearson correlation was done to show relationship between measured parameters. P < 0.05 was taken as statistically significant while P-value less than 0.01 were taken as highly significant. All linear measurements were taken in millimeters, area calculated in mm^2 and angles in degree.

RESULTS

The mean±SEM of the measured angular morphometric parameters of left and right *os femora* of males and females are shown in table 1. Statistical analysis of obtained result showed significant (p>O.O5) sexual dimorphism in all measured parameters of left and right sides except in FNIA of the left side. Table 3 show correlation of the measured new morphometric parameters to femoral neck shaft angle. Highly significant correlation (p<0.0l) was observed between FNSA, and the new angular morphometric parameters, FNIA and FSIA, though negatively significant (p<0.0l) correlation exist between FNIA and FSIA (Tables 3).

Table 1: Test for sexual dimorphism in measured angular radiographic morphometric parameters of proximal end of left femur in males & females

PARAMETERS	*SIDE*	*SEX*	Mean±SEM	z cal	z Critical	INFERENCE (0.05 level)
FNSA	*LEFT*	*MALE*	134.01±0.32	3.67	1.96	SIGNIFICANT
		FEMALE	132.38±0.31			
	RIGHT	*MALE*	133.84±.030	4.8	1.96	SIGNIFICANT
		FEMALE	131.96±0.26			
FNIA	*LEFT*	*MALE*	94.30±0.34	0.93	1.96	NOT SIGNIFICANT
		FEMALE	93.87±0.31			
	RIGHT	*MALE*	93.86±0.35	2.18	1.96	SIGNIFICANT
		FEMALE	92.87±0.29			
FSIA	*LEFT*	*MALE*	40.00±0.25	2.42	1.96	SIGNIFICANT
		FEMALE	39.21±0.21			
	RIGHT	*MALE*	39.29±0.26	2.88	1.96	SIGNIFICANT
		FEMALE	40.26±0.22			
FIT_{AREA}	*LEFT*	*MALE*	105.99±3.59	5.51	1.96	SIGNIFICANT
		FEMALE	79.62±3.13			
	RIGHT	*MALE*	98.77±3.75	3.3	1.96	SIGNIFICANT
		FEMALE	84.45±2.18			

Table 2: Comparison of the measured angular parameters of the proximal femur in different studies

Authur,year & country	Sex	Side	FNSA	FNIA	FSIA	FITAB
Gomez et al (2000), Spain	Females		124.6			
Brego et al (2002), France	Females		125.5			
Nisen et al (2005), Denmark	Males		131			
	Female		129			
De Sousa et al (2010), Brazil		Right	132.1			
		Left	131.8			
Baharuddin et al (2011), Malaysia	Males		132			
	Female		129			
Irdesel and Ari (2006), Turkey	Female		131.5			
Tahir et al (2001), Nigeria	Males		136.7			
	Females		126.65			
Udoaka and Agi (2010), Nigeria	Males		132			
	Females		130.2			
Present study (Nigeria)	Females	Right	131.96	92.87	40.26	84.45
	Males	Right	133.84	93.86	39.29	98.77
	Females	Left	132.38	93.87	39.21	79.62
	Males	Left	134.01	94.3	40	105.91

Table 3: Correlations of measured radiographic morphometric parameters of proximal end of left female.

PARAMETERS		FNSA	FNIA	FSIA	FIT_{AREA}
FNSA	Pearson Correlation	1			
	Sig. (2-tailed)				
FNIA	Pearson Correlation	.704**	1		
	Sig. (2-tailed)	0			
FSIA	Pearson Correlation	.384**	-.216**	1	
	Sig. (2-tailed)	0	0		
FIT_{AREA}	Pearson Correlation	-0.189**	0.008	-0.205**	1
	Sig. (2-tailed)	0	0.862	0	
N		460	460	460	460
**. Correlation is significant at the 0.01 level (2-tailed).					
*. Correlation is significant at the 0.05 level (2-tailed).					

DISCUSSION

Femoral neck and intertrochanteric fractures are significant, familiar and public health problems disrupting the quality of life of patients and families; and greatly increase the danger of death and incapacitate individuals with highly expensive cost of medical management[1,2,3,11]. Understanding the dimensions of the structural configuration of human skeleton is requisite in anthropologic and forensic anatomy, radiologic anatomy and orthopaedics. Besides, it is essential in extrapolating the likelihood and management of proximal fractures of the *os femora*. To properly anticipate or predict proximal femoral fractures such parameters must conform to the anatomic and biomechanical facts of the neck, intertrochanteric or epiphyseal region and diaphysis of os femora. This radiogrammetric study was aimed at providing a comprehensive baseline metric data of the superior segment of the os femora from radiographs of Nigerians that conform to its anatomic facts.

Comparing the means of the morphometric parameters (particularly FNSA) obtain with the outcome of the work[19,20,21,22,23] on dissimilar and distinct population revealed variations in the values. Hence, utilizing or employing orthopaedic implants and screws designed by Caucasian manufacturers, presumably using femoral structural metric values of their population, won't be suitable for other populations like Nigeria as inter- and intra-population differences exist.

In this study, new morphometric parameters of proximal *os femora* (femoral neck intertrochanteric angle (FNIA) or collo-epiphyseal angle, femoral shaft intertrochanteric angle (FSIA) or diaphyseal-epiphyseal angle and the femoral intertrochanteric triangle or epiphyeal triangle are introduced and quantified to improve the understanding of the proximal shaft-intertrochanteric area-neck relationship of the *os femora*. From the outcome of this investigation, highly significant positive correlation exists between FNSA and FNIA while a highly significant negative correlation exist between FNSA and FSIA. This suggests how useful the FNIA and FSIA would be when used alongside the FNSA in forecasting or foretelling and managing proximal femoral fractures. Besides, the FNIA and FSIA correlated significantly with FIW, FNW, HAL and FNAL.

Dalaere et al[17] stated that the cancellous bone of the proximal femoral extremity should be regarded as an important factor contributing to the mechanical strength of the neck, due not only to its bone mineral content but also to the particular architecture of its trabecular groups. Pasi and Gafen[18] brought to light that the trabecular bone in epiphyses of long bones contributes to the power and ability of the proximal *os femora* by resisting and distributing impact loads applied to the epiphyseal or metaphyseal cortex. This function may be analogous to the function of the trabecular lattice in distributing functional joint and muscle loads; however, since trabecular paths are aligned to provide maximal support in line with the physiologic joint/muscle loads, the trabecular lattice is unlikely to be optimized for supporting non-functional impacts as during traumatic injury. The proximal *os femora* alter and modify its structure to suit loads it is exposed such that its trabeculae orientate along the direction of the principal stress achieving full stiffness and strength[4]. Djuric et al[4] studied the peripheral geometry and microscopically examined the intertrochanteric area and neck of the *os femora* and showed that the trabacular pattern at this region depicts altering and varying complex loading model of the proximal *os femora* during growth.

Putting together the findings of Dalaere et al[17], Pasi and Gafen[18] and Djuric ct al[4] suggest that the size of the intertrochanteric area could determine the proximal *os femora* strength thus can predict femoral neck and intertrochanteric fractures. The area of the femoral intertrochanteric triangle (FIT_{AREA}), a scalene triangle formed at the intertrochanteric area of the proximal *os femora* by the intersection of the shaft axis, neck axis and intertrochanteric axis lines, has been introduced and quantified in this study. This new triangle suggests the biomechanical relationship between the proximal shaft, intertrochanteric area, and neck of the os femora and depicts the region of maximum stiffness and strength of the proximal *os femora*.

CONCLUSION

We conclude that the FNIA, FSIA and FIT_{AREA} have been documented for the first time in this study to meet anatomical facts about the relationship between the shaft, proximal epiphysis and neck of the *os femora.* These parameters introduced in this study along with other parameters will improve prediction and management of susceptibility to proximal femoral fractures.

REFERENCES

1. Faulkner KG, Cummings SR, Black D, Palermo L, Gluer CC, Genant HK. Simple measurement of femoral geometry predicts hip fracture: the study of osteoporotic fractures. *J Bone Miner Res*. 1993; 8(10): 1211- 1217.
2. Boonen S, Koutri R, Dequeker J, Aessens, J., Lowet, G., Verbeke, G., Lesaffre, E., Guesens, P. Measurement of femoral geometry in type I and type II osteoporosis: differences in hip axis length consistent with heterogeneity in the pathogenesis of osteoporotic fractures. *J Bone Miner Res* 1995;10:1908–1912.
3. Gregory JS, Testi D, Stewart A, Undrill PE, Reid M, Aspden RM. A method for assessment of the shape of the proximal femur and its relationship to osteoporotic hip fracture. *Osteoporousis International* 2004; 15(1): 5-11.
4. Djuric M, Milovanovic P, Djonic D, Minic A, Hahn M. Morphological Characteristics of the Developing Proximal Femur: A Biomechanical Perspective. *Srp. Arch. Ortho Trauma Surg.* 2012; 140(11-12): 738-745.
5. Ravn P, Cizza G, Bjarnason NH, Thompson D, Daley M, Wasnich RD, Mcclung M, Hosking D, Yates AJ, Christiansen C. Low body mass is an important risk factor for low bone mass and increased bone loss in early postmenopausal women. Early postmenopausal intervention study group. *J Bone Miner Res* 1999; 14:1622-1627.
6. Testi D, Cappello A, Chiari L, Viceconti M, Gnudi S. Comparison of logistic and Bayesian classifiers for evaluating the risk of femoral neck fracture in osteoporotic patients. *Med Biol Eng* 2001; 39:633–637
7. Liu JM, Zhao HY, Ning G, Zhang LZ, Sun LH, Xu MY, Chemg JL. Relationship between body composition and bone mineral density in healthy and postmenopausal Chinese women. *Osteoporos Int* 2004; 15:238-242
8. Cooper AA. Treatise on dislocations and fractures of the joints. 2nd ed. Boston, MA: Lilly and Wait et al; 1932.
9. Hoaglund FT, and Low WD. Anatomy of the femoral neck and head, with comparative data from caucasians and Hong Kong Chinese. *Clin. Orthop. Rel. Res.* 1980; 152:10-6.
10. Toogood PA, Skalak A, Daniel R. Cooperman D. Proximal Femoral Anatomy in the Normal Human Population. *Clin Orthop Relat Res.* 2009; 467(4): 876–885.
11. Gaspar D and Crnkovic T. Hip geometry measures can predict femoral neck and intertrochanteric fractures. Controversies in literature. *Med Jad.* 2014; 44(3-4): 101-106.
12. Faulkner KG, Wacker WK, Barden HS, Simonelli C, Burke S, Ragi PK and Delrio L. Femur strength index predicts hip fracture independent of bone density and hip axis length. Osteoporos Int. 2006; 17:593–9
13. Ito K, Minka M, II, Leunig M, Werlen S, Ganz R. Femoroacetabular impingement and the cam effect: a MRI-based quantitative anatomical study of the femoral head-neck offset. *J Bone Joint Surg.* 2001; 83B:171-6.
14. Notzli H, Wyss T, Stoecklin C, Schmid M, Treiber K, Hodler J. The contour of the femoral head-neck junction as a predictor for the risk of anterior impingement. *J Bone Joint Surg (Br).* 2002; 84B:556-60.
15. Ulosoy H, Bilqici A, Kuru O, Sarica N, Arslan S, Erkorkmas U. A new value of proximal geometry to evaluate hip fracture risk: True momento arm. *Hip International* 2008; 18:101-107.
16. Linwei LV, Guangwei M, He Gong, Dong Zhu and Weimen-Zhu. A new method for the measurement and analysis of the three -dimensional morphological parameters of proximal male femur Biomedical Research. 2012;23(2):219-226.
17. Dalaere O, Dhem A, Bourgois R. Cancelous bone and mechanical strength of the femoral Neck. *Arch Orthop Trauma Surg.* 1989; 108:72-75.
18. Passi N, and Gefen A. Trabecular bone contributes to strength of the proximal femur under mediolateral impact in the avian. *Journal of Biomechanical Engineering* 2005; 127:198-203.
19. Irdesel J and Ari I. The proximal femoral morphometry of Turkey women on radiographs. *Eur J. Anat*. 2006; 10(1):21-26.
20. De Sousa E, Fernandes RMP, Mathias MB, Rodrigues MR, Ambram AJ, Babinski MA. Morphometric study of the proximal femur extremity in Brazilians. *Int. J. Morphol.,* 2010; 28(3):835-840.
21. Igbigbi PS. and Msamati BC. The femoral collodiaphyseal angle in Malawian adults. *Am. J. Orthop.,* 2002; 31(12):6825.
22. Udoaka, A.I. and Agi, C.E. A study of the collo-diaphyseal angle in an adult population in Southern Nigeria. *Afr J Med Phy Biomed Eng & Sci.* 2010; 2: 67-70.
23. Bob-Manuel, IF, Didia BC, Udoaka AI. Radiogrammetric analysis of the proximal portion of the Femur in Nigerian Population. J Ant Sci. 2017; 8(1):142-146.
24. Page JD. Area of triangle given three sides – Heron's formula. From Open Math Reference. http;/www.mathopenref.com/heronsformula.html