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Original Research Article

Sex and Age Estimation using the Morphometric Assessment of the Femur

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Abstract

Anthropological assessment becomes the sole available medium for identification of the deceased in most forensic cases. We hope therefore to assess metrically if the femur bone could be used to estimate the age and sex of individuals by focusing on some rare morphological parameters. The skeletal samples of the right femur from 105 individuals (78 males and 27 females), who are within the age range of 21 and 60 years were harvested. The male samples had 53 profiled and 25 specimens non-profiled for age, while the females had 10 profiled and 17 specimens non- profiled for age. Direct measurements were taken for the marrow cavity diameter (MCD) and cortical thickness or radius (CT or Cr) using a centimeter rule and a sliding digital caliper to the nearest 0.1mm.The Marrow Cavity Diameter in our study is higher in the male population (1.70± 0.05) than the female population (1.43± 0.05). This variation was statistically significant (P<0.05) using the student t-test. The radius or thickness of the cortex decreases with age in females but is higher in the female population (0.73±0.03) than the males (0.68±0.03). ANOVA shows that there is a significant variation across male age groups (P=0.00) for the MCD, MA and Area of cortex. The marrow cavity diameter increases with age in males while area of cortex reduces with age in females. It is imperative therefore that the marrow cavity diameter, the medullary area and area of cortex are good assessors of age and sex.

Keywords: Marrow cavity, Cortex of bone, Femur, Age and sex, Nigerians.

INTRODUCTION

Thorough investigation of the dead requires knowledge of the biography and cultural stay of the victim in order to make informed and correct conclusions. These details regarding the victim may not be readily available as what may be present at crime scenes are the skeletal remains of the victim. Therefore anthropological assessment becomes the sole available medium for identification. Paramount and foremost among these indices is the study of the age and sex of the individual, whose information the bones can tell. In fact, once the age and sex is determined, the identity of any skeletal remain is almost about 80% established (Lynnerup *et al.*, 1998; Maat *et al.*, 2006; Kosior 2016). It is obvious however that most of the anatomical landmarks available for investigation of the deceased could be influenced by diet, disease, genes, sex and racial peculiarities (Aiello *et al.*, 1993, Keough, 2007; Purves *et al.*, 2011). Also for this known fact and considering the need for racial specific studies, our study focused on bones of African ancestry and to be more précised for a Nigerian population with paucity of data regarding such studies. We hope therefore to assess metrically if the femur bone could be used to estimate the age and sex of individuals by focusing on some rare morphological parameters. Population-specific studies have been conducted to decipher if variations in these anthropological and histological features exist. Although it is logically expected that such variations could exist with gross anatomical features hinged on genetic and geographical differences.

The unique anatomy of the long bones makes them a common tool in the hand of forensic experts for their easy-to-study approach and possession of several features for sex and age estimation. Although research has shown that some bones other than the long bones serve for distinction in sex and age estimation. However because of their length and robustness, they appear to be some of the skeletal remnants found at crime scenes. In fact most studies requiring compact bones have utilized the long bones (Keough, 2007; Thomas *et al.*, 2000; Sobol *et al.*, 2014, Simone, 2015). Some authors have however documented that some of the long bones especially the radius and femur show high accuracy in sex estimation (Spradley *et al.*, 2011, Simone, 2015). Again because long bones provide researchers the means to study its various regions, some authors have also investigated the effect of physical and mechanical stressors on these different regions to look to know if variations exist following remodeling rates at different levels (Ingraham, 2004, Tersigni, 2005, Gocha *et al.*, 2016). Some of these studies were able to investigate the possibility of estimating age and sex from the characteristics of the histomorphometric features present at various levels.

MATERIALS AND METHOD

The study was conducted in the Anthropology laboratory of the Department of Anatomy, University of Port Harcourt and the Histology laboratory of the Department of Human Anatomy, Rivers State University. Skeletal remains and bone specimen were collected from the Pathology Department of the University of Port Harcourt Teaching Hospital (UPTH). Bone samples were collected from individuals who are all Nigerians. The age, sex and ethnic origin of the cadavers were documented except for a very few whose bio data was missing from the hospital records. There were no accounts however as to the cause of deaths (this information was excluded from our study), however they were majorly individuals with low socio-economic status.

The skeletal samples of the right femur from 105 individuals (78 males and 27 females), who are within the age range of 21 and 60 years were harvested. The male samples had 53 profiled and 25 specimens non-profiled for age, while the females had 10 profiled and 17 specimens non-profiled for age.

Two-three bone sections were collected from the mid-shaft of the right femur using a hacksaw with the cadaver in supine position. Cross sections were made to a thickness of about 0.5mm to 1.0cm. The sections were cut within 5 to 15 degrees perpendicularly to the longitudinal axis of the long bone. Bone sections were cleared of marrow tissue and subjected to morphometric measurements. Measurements were done with a centimeter rule and a sliding digital vernier caliper (Kales Industry and Trade Co., Ltd, Jinhua, Zhejiang, China) to the nearest 0.1mm. Direct measurements were done for the marrow cavity diameter and cortical radius or thickness. The marrow cavity diameter was taken at the maximum ends of the concentric circle, from one end to the opposite end of the circle and/or sphere. The cortical thickness was taken from the inner edge of the cortical plate to the outer edge of the cortical plate.

Direct measurements were taken for the marrow cavity diameter (MCD) and cortical thickness or radius (CT or Cr) using a centimeter rule and a sliding digital caliper to the nearest 0.1mm. Derived measurements were obtained for the marrow or medullary area (MA), cortical area (CA) and Total cross-sectional area (TCA). The marrow cavity diameter is obtained by measuring the distance from one end of the cavity at its maximum point to the opposite end. The cortical thickness is obtained by measuring the distance from the inner border of the cortex to the outer border of the cortex or periosteal border, and is designated as r1. The marrow area is first obtained by dividing the marrow cavity diameter by 2 to obtain the radius, and is designated as r2. This is then inserted into the formula for the area of a circle πr2, in order to calculate the marrow area. The cortical area is obtained by using the cortical thickness, r1, and then inserted into πr2. The total cross sectional area is obtained by the sum of the marrow area and the cortical area (TCA=MA+CA).

RESULTS

The results are shown in tables 1 to 8.

Table 1: Descriptive statistics of the Mean metric parameters of the femur

PARAMETERS (cm)	MALES (n= 88)	FEMALES (n= 27)	BOTH (n= 115)
MCD	1.70 ± 0.05	1.43 ± 0.05	1.63 ± 0.04
Radius of cortex	0.68 ± 0.03	0.73 ± 0.03	0.70 ± 0.02
Area of cortex (CA)	1.63 ± 0.13	1.72 ± 0.12	1.65 ± 0.10
Radius of MC	0.88 ± 0.02	0.78 ± 0.02	0.86 ± 0.02
MA	2.57 ± 0.17	1.91 ± 0.12	2.41 ± 0.14

Values for MCD, Ratio of cortex, Area of cortex, Ratio of MC, Area of MC were expressed as mean ± SEM; for males, females and both. MCD: Marrow Cavity Diameter, MA: Marrow area, n: number of subjects/samples.

Table 1 shows the metrical parameters of the femur of Nigerians. The MCD is higher in the male population (1.70± 0.05) than the female population (1.43± 0.05). The area of cortex (CA) is higher in the female population (1.72± 0.05) than the males (1.63± 0.05).

Table 2: Determination of Sex variation in the femoral metric parameters using the Student T-test

Parameters (cm)		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
MCD	Equal variances assumed	5.570	.020	2.947	114	.004**	.27070	.09184	.08876	.45265
	Equal variances not assumed			4.045	84.753	.000**	.27070	.06692	.13764	.40376
Radius cortex	Equal variances assumed	6.329	.013	-1.027	114	.307	-.05019	.04889	-.14704	.04666
	Equal variances not assumed			-1.331	73.200	.187	-.05019	.03770	-.12531	.02494
Area of cortex	Equal variances assumed	5.314	.023	-.365	114	.716	-.08818	.24162	-.56683	.39047
	Equal variances not assumed			-.503	85.795	.616	-.08818	.17522	-.43652	.26016
MA	Equal variances assumed	3.927	.050	2.044	114	.043**	.65888	.32228	.02046	1.29731
	Equal variances not assumed			3.153	109.758	.002**	.65888	.20895	.24478	1.07299

MCD-marrow cavity diameter, MA-medullary area, ** - significant

Table 2 shows the determination of sexual differences in the femoral metric parameters. Student T-test was able to show that the differences for males and females for the MCD and MA were statistically significant while those of area of cortex and radius of cortex were not significant.

Table 3: Descriptive statistics of the various Age distribution for males

AGE RANGE (years)	MCD(cm)	Radius of cortex(cm)	Area of cortex(cm)	Radius of MC(cm)	MA(cm)
20-22	1.73 ± 0.12	0.44 ± 0.02	0.61 ± 0.06	0.90 ± 0.07	2.60 ± 0.33
23-25	1.78 ± 0.15	0.53 ± 0.04	0.91 ± 0.11	0.93 ± 0.07	2.95 ± 0.61
26-28	1.70 ± 0.10	0.83 ± 0.03	2.17 ± 0.17	0.87 ± 0.03	2.33 ± 0.17
29-31	1.47 ± 0.04	0.90 ± 0.06	2.59 ± 0.34	0.76 ± 0.03	1.79 ± 0.15
32-34	1.10 ± 0.00	0.47 ± 0.03	0.70 ± 0.10	0.60 ± 0.00	1.10 ± 0.00
35-37	1.30 ± 0.00	0.60 ± 0.00	1.10 ± 0.00	0.70 ± 0.00	1.50 ± 0.00
38-40	2.50 ± 0.00	0.50 ± 0.00	0.80 ± 0.00	1.30 ± 0.00	5.30 ± 0.00
41-43	1.40 ± 0.00	0.60 ± 0.00	1.10 ± 0.00	0.70 ± 0.00	1.50 ± 0.00
44-46	1.80 ± 0.00	0.80 ± 0.00	2.00 ± 0.00	0.90 ± 0.00	2.50 ± 0.00
50-52	2.78 ± 0.28	0.40 ± 0.00	0.50 ± 0.00	1.43 ± 0.13	6.53 ± 1.23
59-61	1.50 ± 0.00	1.10 ± 0.00	3.80 ± 0.00	0.80 ± 0.00	2.00 ± 0.00

Values for MCD, Radius of cortex, Area of cortex, Radius of MC, MCA were expressed as mean ± SEM; for different age range. MCD: Marrow cavity diameter, MA: Marrow area.

Table 3 shows the various age distribution and the change in the femoral metric parameters for the males. The MA and MCD appears to increase with age increase from above age 44 and with a marked reduction in the cortical area and radius from age 50. The isolated increase in the MCD and MA from age 38 and the subsequent reduction after age 59, even after a further increase from age 50 is seen in the table.

Table 4: Test of variation between male Age groups using ANOVA

Parameters (cm)		Sum of Squares	Df	MS	F value	P-value
MCD	Between Groups	9.185	11	.835	6.956	.000
	Within Groups	9.244	77	.120		
	Total	**18.429**	**88**			
Radius cortex	Between Groups	2.788	11	.253	8.422	.000
	Within Groups	2.317	77	.030		
	Total	**5.105**	**88**			
Area of cortex	Between Groups	56.728	11	5.157	5.590	.000
	Within Groups	71.040	77	.923		
	Total	**127.768**	**88**			
MCA	Between Groups	109.489	11	9.954	6.070	.000
	Within Groups	126.270	77	1.640		
	Total	**235.759**	**88**			

MCD: Marrow cavity diameter, MA: Marrow area

Table 4 shows the use of ANOVA in determining the degree of variation in the MCD, MA, Cortical radius, area of the cortex and radius of the marrow cavity between the various age groups among the male population. F value was seen to be greater than F critical for an alpha level of 0.05 in all the metric parameters. This shows that there is a significant variation across age groups (P=0.00) and the P value (0.00) been less than the alpha level chosen (0.05) shows a very significant variation.

Table 5: Correlation coefficient for Age and MCD/Radius of Cortex in males

Parameters	Correlation coefficient (r)	Significance (2-tailed)
MCD	0.210	0.008
Radius of cortex	0.330	0.000

MCD- marrow cavity diameter

Correlation coefficient (r) values were determined using Pearson correlation. Correlation is significant at the 0.01 level (**) and 0.05 level (*) (2-tailed).

Table 5 shows that there is a weak positive correlation between age and the MCD for males and as well a weak positive correlation with radius of cortex.

Table 6: Descriptive statistics of the various Age distribution for females

AGE RANGE (years)	MCD(cm)	Radius of cortex(cm)	Area of cortex(cm)	Radius of MC(cm)	MA(cm)
22-25	1.75 ± 0.03	0.85 ± 0.03	2.25 ± 0.17	0.92 ± 0.02	2.60 ± 0.10
42-43	1.40 ± 0.00	0.80 ± 0.00	2.00 ± 0.00	0.70 ± 0.00	1.50 ± 0.00
50-52	1.40 ± 0.00	0.70 ± 0.00	1.50 ± 0.00	0.70 ± 0.00	1.50 ± 0.00

MCD-marrow cavity diameter, MCA-medullary area

Values for MCD, Radius of cortex, Area of cortex, Radius of MC, MA were expressed as mean ± SEM; for different age range.

Table 6 shows the MCD, MA, Area of cortex and Radius of cortex all reduced with age. Also from age 42 and above 50 years, the change was either not significant or rather a ceasation of reduction.

Table 7: Test of variation between female Age groups using ANOVA

Parameters		Sum of Squares	Df	MS	F value	P value
MCD	Between Groups	.832	3	.277	9.671	.000**
	Within Groups	.660	23	.029		
	Total	**1.492**	**26**			
Radius cortex	Between Groups	.127	3	.042	2.366	.097
	Within Groups	.413	23	.018		
	Total	**.540**	**26**			
Area of cortex	Between Groups	2.595	3	.865	2.651	.073
	Within Groups	7.506	23	.326		
	Total	**10.101**	**26**			
Radius MC	Between Groups	.156	3	.052	5.676	.005**
	Within Groups	.211	23	.009		

	Total	**.367**	**26**			
MA	Between Groups	3.917	3	1.306	5.362	.006**
	Within Groups	5.601	23	.244		
	Total	**9.519**	**26**			

MCD-marrow cavity diameter, MA-marrow area, ^{xx}- very significant

Table 7 shows F value greater than F critical for MCD, MA and Radius of marrow cavity. This shows a significant variation (P<0.05) among the female age groups for the MCD, MA and Radius of MC. The Area of cortex and Radius of cortex shows no statistically significant variation between the female age groups.

Table 8: Correlation coefficient for Age and MCD/Radius of Cortex in females

Parameters	Correlation coefficient (r)	Significance (2-tailed)
MCD	-0.925**	0.000
Radius of cortex	-0.656*	0.011

MCD- marrow cavity diameter

Correlation coefficient (r) values were determined using Pearson correlation. Correlation is significant at the 0.01 level (**) and 0.05 level (*) (2-tailed).

Table 8 shows a strong negative correlation between age and MCD for the females and a strong negative correlation for the radius of cortex. This suggests that for the female population, radius of cortex reduces with age increase and as well MCD reduces with age increase.

DISCUSSION

The estimation of sex and age using the long bones have proven to be useful, although there are yet many features that are yet to be explored. The femur bone in our research has proven to be a very remarkable and most reliable subject of study. The Marrow Cavity Diameter in our study (Table 1) is higher in the male population (1.70± 0.05) than the female population (1.43± 0.05). This variation was statistically significant (P<0.05) using the student t-test (Table 2). Wang *et al.*, 2004 also reported that the levels of estradiol were negatively correlated with the size of the medullary cavity. This would infer that postmenopausal women would tend to have larger medullary cavity like their male counterparts. Takeuchi *et al.*, 1998 reported on the contrary that the marrow cavity enlargement is greater in the females as compared to the male subjects. It is possible by deductive reasoning that his female subjects were predominantly postmenopausal. The area of cortex (CA) is higher in the female population (1.72± 0.05) than the males (1.63± 0.05). This is however not statistically significant (P>0.05). Takahashi *et al.*, 1966 stated in their study that the area of cortical bone is greater in the females at younger age but reduces faster especially after age 50. Most of the female subjects in our study are under 50, which could have impacted on the size of the cortical area. Some authors in previous works on western population had documented that the area of cortex of bones is greater in males than females (Sedlin *et al.*, 1963, Sedlin 1964a & 1964h, Takahashi *et al.*, 1966).

The medullary area (MA) is higher in the males (2.57 ± 0.17) than the females (1.91 ± 0.12) and it was shown to be statistically significant (P<0.05) (Table 2). It is therefore evident from our study that the marrow cavity diameter and marrow or medullary area can be reliably used to estimate the sex of an individual, especially for Nigerians since our study populations were Nigerians. These findings are in consent with the study by Spradley *et al.*, 2011 and Simone 2015 who stated that the radius and femur have high accuracy in sex estimation. Our findings also agree with that of Feik *et al.*, 1996 & 1997 who documented that the medullary area and subperiosteal area showed a fair increase in males as compared to their female counterparts. Also same authors stated in their work that the medullary area and subperiosteal area in the females showed no change until menopause. The findings in our study for the female population as seen in table 6 could be an affirmative to this, where the parameters studied- marrow cavity diameter, area of cortex as well as the medullary area all showed no significant change until after the age of 40 years. In fact the metrical parameters were relatively constant within the age ranges of 40 – 42 and 50 – 52. The marked drop in the values obtained (Table 6) as against the values between age 20 and 30 could have been occasioned by the onset of a new hormonal adaptation, which Feik and co-researchers stated to have been as a result of menopause. They also documented that in the older age group, the area of cortex and periosteal area had decline in both sexes. Our findings though not exactly as stated for Feik *et al.*, 1996 & 1997, showed that the area of cortex decreased steadily for the males and females with age increase (Tables 3 and 6), except for an isolated difference in the male age group of 59-61 years. The reason for this increment variation cannot be explained as at yet. However other parameters like the marrow cavity diameter and medullary area increased with age in males as affirmed by earlier studies, and yet for an isolated difference in the male age group of 59-61 years.

Our findings in table 3 shows that MCD and MA increases with age while area and radius of cortex decreases with age increase, except for few isolated age groups. For instance the mean MCD for males at age 20-22 and 50-52 is 1.73± 0.12 and 2.78± 0.28 respectively, showing a rise with age. Also for ages 38-40 and 59-61, the mean MCD is 2.50±0.00 and 1.50±0.00 respectively, indicating isolated diversions from the findings of more age groups. However ANOVA to determine variation among male age groups (Table 4) shows a statistically significant variation ($P<0.05$) for MCD, MA, radius and area of cortex across the age groups. This could therefore infer that these parameters can be reliable for age estimation in males. Although test of the relationship of MCD and radius of cortex with age using Pearson's correlation coefficient (r) showed a weak correlation with age at $r = 0.210$ and $r = 0.330$ respectively. Hence though MCD increases with age, our population of study reflects a weak increase. Likewise the reduction of the radius of cortex with age reflects a weak correlation for our male population. Although these findings could be subject to many uncertain factors, it is evident that these femoral parameters could be good assessors of age, and as well weak age indicators depending on the amount of data available to the investigator.

The data in table 6 shows that the female population had decrease with age for the MCD, MA, radius and area of cortex. For instance at age 22-25 and 50-52, the mean MCD is 1.75±0.03 and 1.40±0.00 respectively, while the mean area of cortex is 2.25±0.17 and 1.50±0.00 respectively. In fact from age 42 and above, the mean MCD, MA, radius and area of cortex were almost constant, with little or no further reduction. This was confirmed by earlier studies by Feik *et al.*, 1997 while documenting on findings on the female parameters. ANOVA test between female age groups (Table 7) shows statistically significant variation for MCD ($P=0.00$) and MA ($P=0.006$). The radius and area of cortex were not statistically significant ($P>0.05$). This could infer however that the MCD and MA could be reliable indicators for age assessment in females. Again the determination of correlation (r) with age (Table 8) shows that the MCD and radius of cortex have a strong negative correlation with age at $r = -0.925$ and $r = -0.656$ respectively. This suggests that as age increases, both the MCD and radius of cortex decreases with age. Feik *et al.*, 1996 & 1997 consents with our findings that the cortical parameters decreased with age for both males and females. They also affirmed that the males showed a fair increase in the medullary area as age increases, and our work confirms weak positive correlation with age.

CONCLUSION

Our findings have shown that the femur bone has very reliable parameters for sex and age estimation. The marrow cavity diameter increases fairly with age in males and is relatively stable in females until after the age of menopause when it begins to decline. The marrow cavity diameter and medullary area are higher in males than the females, and this variation is statistically significant. The area of cortex reduces with age in females and whereas it rises as age advances in males and drops in more advanced males. It is imperative therefore that the marrow cavity diameter, the medullary area and area of cortex are good assessors of age and sex.

Ethical Approval

Ethical approval was sought from the University of Port Harcourt Research Ethics committee and was granted with the ethical number UPH/CEREMAD/REC/MM83/012

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REFERENCES

- Aiello, L., & Molleson, T. (1993). Are microscopic ageing techniques more accurate than macroscopic ageing techniques? *Journal of Archaeological Science*, 20, 689-704.
- Feik, S. A., Thomas, C. D. L., & Clement, J. G. (1996) Age trends in remodeling of the femoral midshaft differ between the sexes. *Journal of Orthopaedic Research*, 14, 590–597.
- Feik, S. A., Thomas, C. D. L., & Clement, J. G. (1997) Age-related changes in cortical porosity of the midshaft of the human femur. *Journal of Anatomy*, 191, 407–416.
- Gocha, T. P., & Agnew, A. M. (2016). Spatial variation in osteon population density at the human femoral midshaft: histomorphometric adaptations to habitual load environment. *J. Anat.*, 228, 733—745.
- Hideaki, T., & Harold, M. F. (1966). Age and Sex Related Changes in the Amount of Cortex of Normal Human Ribs, *Acta Orthopaedica Scandinavica*, 37(2), 122-130, DOI: 10.3109/17453676608993272

- Ingraham, M. R. (2004). Histological age estimation of the midshaft clavicle using a new digital technique. M.Sc Thesis (Biology), University of North Texas.
- Keough, N. (2007). Estimation of age at death from the microscopic structure of the femur. MSc Thesis submitted to the School of Medicine, Faculty of Health Sciences, University of Pretoria, South Africa.
- Kosior, W. (2016). Age and Notions related to it in Greek Non – legal sources – The contribution to the Research of Roman law 1. *Roc2niki Administracji prawa nr*, XVI (1), S.85 – 96
- Lynnerup, N., Thomsen, J. L., & Frohlich, B. (1998). Intra- and Inter-observer variation in histological criteria used in age at death determination based on femoral cortical bone. *Forensic Science International*, *91*(3), 219-230.
- Maat, G. J. R., Maes, A., Aarents, M. J., & Nagelkerke, N. J. D. (2006). Histological age at death prediction from the femur in a contemporary Dutch sample* The decrease of non-remodeled bone in the anterior cortex. *Journal of Forensic Sciences*, 51, 230-237.
- Purves, S., Woodley, L., & Hackman, L. (2011). Age determination in the Adult. In Black, S & Ferguson, E (Eds), *Forensic Anthropology 2000-2010*. Pp 29-60.
- Sedlin, E. D. (1964 h) Uses of bone as a model system in the study of aging. In Bone Biodynamics, ed. H. M. Frost; Little, Brown and Co., Boston, pp. 655-668.
- Sedlin, E. D. (1964a) The ratio of cortical to total cross section area of ribs. *Cliii. orthop.*, 36, 161-168.
- Sedlin, E., Frost, H. M., & Villanueva, A. R. (1963) Variations in cross section area of rib cortex with age. *J. Geront.*, 18, 9-13.
- Simone, L. (2015). Sex Estimation in Forensic Anthropology Using the Radius, Femur, and Scapula. Honour Thesis, Texas State University, San Marcos, Texas.
- Sobol, J., Ptaszyńska-Sarosiek, I., Charuta, A., Oklota-Horba, M., Żaba1, C. Z., & Niemcunowicz-Janica, A. (2015). Estimation of age at death: examination of variation in cortical bone histology within the human clavicle. *Folia Morphol*, 74(3), 378–388.
- Spradley, M. K., Jantz, R. (2011). Sex Estimation in Forensic Anthropology: Skull versus Postcranial Elements. *Journal of Forensic sciences*, 56(2), 289-296.
- Takeuchi, S., Kageyama, I., Awatake, T., Kato, S., & Yamashita, H. (1998). Enlargement of the femoral marrow cavity with aging. *Kaibogaku Zasshi*, 73(3), 259-64.
- Tersigni, M. A. (2005). Serial Long Bone Histology: Inter- and Intra-Bone Age Estimation. PhD diss., University of Tennessee.
- Thomas, C. D. L., Steyn, M. S., Feik, S. A., Wark, J. D., & Clement, J. G. (2000). Determination of age at death using combined morphology and histology of the femur. *Journal of Anatomy*, 196, 463 – 471.
- Wang, Q., Patrick, H., Nicholson, F., Miia, S., Arja, L. I., Erkki, H., Markku, A., Harri, S., & Sulin, C. (2004). Relationship of Sex Hormones to Bone Geometric Properties and Mineral Density in Early Pubertal Girls. *The Journal of Clinical Endocrinology & Metabolism*, 89(4), 1698–1703.