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Models for estimating age and sex from variables of the proximal femur in a Ghanaian population

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ABSTRACT

Age and sex estimation models from the proximal femur are population-specific due to genetic and environmental variabilities. Extrapolating a femur-based age or sex estimating model from one population to another will be problematic. Proximal femur-specific age and sex estimation models are limited in Ghana. The study aimed to estimate the age and sex of an adult Ghanaian population using osteometric measurements from the proximal femur. The study was cross-sectional from January to June 2019 at the Korle-Bu Teaching Hospital (KBTH). There were 125 (male=51, female=74) participants, aged from 31 to 82 years. The head diameter-left (HDL), neck diameter-left (NDL), neck-shaft angle-left (NSAL) and the Hip axis length-left (HALL) were measured twice using a standardized radiographic technique. Discriminant and logistic regression models were formulated for sex estimation while linear regression models were formulated for age estimation and these models were then tested for reliability. Males had longer HDL and NDL than females ($P < 0.050$). The average sex estimation accuracy in the discriminant analysis ranged from 58.4% to 64.0% (in the original sample) and 56.8% to 62.4% (in the cross-validation sample) while in the logistic regression analysis it ranged from 58.4% to 64.0%. The HDL was better than the NDL in sex attribution but only marginal. The multivariate model (HDL+NDL) marginally improved sex estimation accuracy (64.0%) over the univariate models for HDL (61.6%) and NDL (60.0%). In general, females were better classified than males. There was no significant difference between the chronological age and the estimated age of males using HALL although the confidence interval (95%CI) was wider than expected [Bias: 1.133 (95%CI: −25.280 to 27.540). The femoral head and neck diameters or their combination are poor attributors of sex on average. Also, male adult age estimation using HALL is less precise. The use of these models in the Ghanaian population is not advised

1. Introduction

Age and sex estimation, aside from stature and ethnicity, are cardinal parameters in medico-legal and archaeological profiling [5,8,20,22]. The profiling of an unidentified body is made easier where the complete body or skeletal remains is available. It, however, becomes cumbersome where dismembered body parts may be the only material available to the investigator and that is usually the case in most situations [8,18]. The human cranial and pelvic bones are the most preferred bones for sex attribution by osteometry and may also be considered for age estimation [8]. However, these bones (cranial and pelvic) may not always be available or may not be well preserved due to the effect of anthropic and taphonomic processes [4,7,12]. Postcranial skeletal bones such as the femur are suitable alternatives to the cranial and pelvic bones for age and sex estimation [7]. The femur has the advantage of being better preserved than the cranial and pelvic bones given to its tubular morphology, robusticity and being surrounded by a massive muscle mass. Also, the structure of the femur allows for easy morphometric measurements than the pelvis or cranial bones [7,8].

The male femur tends to be longer, heavier and bulkier than the female due to its special adaptation for increased muscle attachment and the effect of androgens [5]. The adaptation of the femur tends to also differ significantly between the sexes around the proximal region than its length or shaft due to the special obstetric adaptations for

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reproduction in females [13]. Moreover, the femoral neck is more sexually dimorphic than the head due to the pronounced biomechanical relationship with the pelvis as a special adaptation for bipedalism [4]. However, previous studies have shown that these observations are not universal [4,5].

Aside from the general observation that the male's femur is larger and longer than the female, there is intra- and inter-population variabilities due to genetic and environmental factors [5,22]. The femur of people of Asian origin tend to be smaller than Blacks or Caucasians and a South African study observed that South African Whites had higher femoral dimensions than their Black counterparts [1,18]. Adult age estimation from long bones tends to be subjective resulting in significant differences between the chronological and estimated ages. The age estimation process is further compounded by inter-individual, ethnic and population variabilities as well as the burden of chronic diseases of metabolism [2]. Osteological age and sex estimation models are population-specific and the extrapolation of such a model from one population to another may be problematic [4,18]. Although global age and sex estimation models have been proposed, there is the need for population-based studies to validate these global models [24]. Age and sex estimations models from the proximal femur are limited in the Ghanaian population. This study aimed to estimate the age and sex of individuals using osteometry from radiographic images of the proximal femur of Ghanaians.

2. Materials and methods

2.1. Study design and settings

The study was cross-sectional from January to June 2019 at the Korle-Bu Teaching Hospital (KBTH). The KBTH is the premier and the largest hospital in Ghana and it is located in the capital city, Accra. It is the main referral hospital for all other hospitals in the country including hospitals from neighboring countries such as Burkina Faso and Togo.

2.2. Participants and selection

The study involved 125 participants with males constituting 40.8% (n = 51) and the remainder were females (n = 74). The participants were aged between 31 and 82 years. The target populations were Ghanaian men and women (people born in Ghana and living in Ghana at the time of this study) whose anteroposterior (AP) plain X-Rays were taken from April 2017 to May 2018 for various indications other than pelvic problems. The radiographs were normal without distortions. The images were clear enough and had the required bony landmarks for the estimation of proximal femur indices. Images in which the indications included any conditions such as tumors, trauma, chronic condition or fractures that could potentially affect the shape and dimension of the proximal femur were excluded.

2.3. Measurements

The proximal femur indices were measured on X-Ray equipment (AGFA NX model/version 2.0, type: 8900 SUI). The X-Ray equipment had in-built software which included calibration tools and a ruler for both linear and angular measurements. The Radiographs were taken following standard operating procedure for anterior-posterior (AP) pelvic films which employed a 15–20 degrees internal rotation of the hips in the supine position with a film distance of 100 cm with the beams centered on the symphysis pubis [14–16]. Table 1 shows the definitions of the anatomical measurements that were made. A board-certified Radiographer performed the measurements by locating the appropriate points using a mouse-operated cursor at the defined anatomical coordinates. The distance/angle between the coordinates, in standardized units, were then read from the results window from the screen. Each measurement was taken twice by one observer after a week's interval and the two measurements were then averaged. The intra-class correlation coefficient (ICC) was then calculated using the two-way-mixed, single measures, absolute agreement model [8]. The ICC were 0.98, 0.97, 0.98 and 0.99 respectively for HDL, NDL, NSAL and HALL.

Table 1
Variables of the proximal femur and their anatomical definitions.

Measurement	Anatomical definition
HDL	Maximum head diameter of the left femur acquired in the horizontal plane
NDL	Maximum neck diameter of the left femur
NSAL	The angle between the neckline of the left femur and a line through the shaft
HALL	The length from the greater trochanter of the left femur to the top of the femur head through the neckline

2.4. Statistical analysis

The data were first collected onto an Excel spreadsheet (RRID: SCR_016137) before statistical analysis in SPSS(v23) (RRID: SCR_019096), and GraphPad Prism(v8) (RRID: SCR_002798). The assumptions of linear regression (LR) and discriminant function analysis (DFA) were tested. The Shapiro-Wilk's test was used for the test of normality while the ROUT test was used to check for outliers in GraphPad Prism. Multicollinearity between the variables was tested using the variance inflation factor (VIF) test while the Box's M test was used to test for homoscedasticity or the homogeneity of covariance matrices in SPSS. Levene's test was used to test for the homogeneity of variance within each sex category. Descriptive statistics were performed for each variable. The continuous variables were presented as mean ± SD. The standardized mean differences (SMD) between males and females were reported as Hedge's *g* due to differences in sample sizes. The variables were assigned randomly into training (70%) and holdout (30%) samples. The training sample did not yield significant discriminant and logistic regression models in the univariate analysis. The total sample was therefore used for the sex-estimation models. Using direct and stepwise discriminant and logistic regression (LogR) analysis, four univariate and one multivariate sex-estimation models were formulated. Also, direct and stepwise linear regression (LR) analysis produced four univariate age-estimation models using the training sample separately for males and females. The validity of the DFA models was tested on the total sample using the leave-one-out method in the cross-validation while the Bland-Altmann method was used to test the reliability of the age-estimation model in the holdout sample. All statistical analyses were 2-tailed at $P < 0.050$.

2.5. Ethical declaration

The study followed the guidelines of the 1964 Declaration of Helsinki and its later amendments regarding human subject studies. The study was approved by the ethics review board of the University of Ghana (IRB Ref. No.: CHS-Et/M.7-P2.10/2017-2018). Informed written consent was sought from all the participants before the study.

3. Results

3.1. Tests of assumptions

The Shapiro-Wilk's test showed that female's age ($W=0.985$, $P = 0.522$), HDL ($W=0.985$, $P = 0.523$) and NSAL ($W=0.970$, $P = 0.077$) were normally distributed while NDL ($W=0.955$, $P = 0.010$) and HALL ($W=0.966$, $P = 0.043$) were skewed but without extreme values. Also, in males the age ($W=0.973$, $P = 0.291$), HDL ($W=0.966$, $P = 0.150$), NDL ($W=0.979$, $P = 0.487$) and NSAL ($W=0.972$, $P = 0.272$) were normally distributed while HALL ($W=0.932$, $P = 0.006$) was skewed but without extreme values. The assumption that there was no multicollinearity between the variables was not violated (VIF< 10 all). The Box's M test showed that the observed homogeneity of the covariance matrices (homoscedasticity) for the dependent variables were equal across the sexes ($\chi^2 = 1.053$, df = 4, P = 0.395). The Levene's test showed that all dimensions were statistically homogeneous for each sex category for the HDL (F=1.113, P = 0.293), NDL (F=0.269, P = 0.605), NSAL (F=2.945, P = 0.089) and HALL (F=1.259, P = 0.264).

3.2. General characteristics of the study population

The general characteristics of the study population are summarized in Table 2. Males had significantly higher HDL (P = 0.021) and NDL (P = 0.018) than females. The standardized mean difference between males and females were medium for HDL (*g*=0.54) and small for NDL (*g*=0.42).

3.3. Age-estimation models

Univariate linear regression models for age estimation were formulated separately for males and females using each variable (Table 3). Only the model from HALL (4 M) in males was statically significant and accounted for about 15.6% of the variability of height in males (adjR^2 =0.156, P = 0.010). Stepwise analysis using all four variables yielded a univariate model (HALL) in males and no model in females.

3.4. Validity of the age-estimation model

The validity of the age-estimating linear regression model was tested using the Bland-Altmann method (Fig. 1). There was no significant difference in the chronological age and the model-estimated age using model 4 M (HALL) in males, however, the confidence interval (95%CI) was wider than expected for an age-estimating model [Bias= 1.133(95% CI: −25.280 to 27.540)].

3.5. Discriminant sex-estimation models

There were four univariate and one multivariate models. Models from HDL and NDL were statistically significant with P = 0.021 and P = 0.018 respectively. When HDL and NDL were combined in a multivariate analysis, the resulting model achieved statistical significance (P = 0.040). A stepwise analysis involving all four (4) variables yielded a univariate model (NDL) the same as in the direct analysis (Table 4).

3.6. Reliability of the discriminant sex-estimation models

The reliability of the sex-estimation models was determined by cross-validation (Table 5). The multivariate discriminant model (HDL+NDL) gave the best average sex classification accuracy of 62.4%, slightly better than the univariate models. In general, females were better classified than males.

Table 2
Descriptive statistics of the study population.

Variable	Male n = 51	Female n = 74	P-value	*g*
HDL (mm)	50.6 ± 5.60	48.4 ± 5.21	0.021	0.54
NDL (mm)	39.6 ± 5.22	37.5 ± 4.77	0.018	0.42
NSAL (degrees)	131.4 ± 2.360	131.8 ± 3.211	0.457	0.14
HALL (mm)	117.4 ± 11.55	114.9 ± 9.77	0.185	0.24

Results were presented as mean ± SD. The standardized mean differences were reported
in Hedge's *g*: similar ($g<0.20$), small ($0.20 \leq g<0.50$), moderate ($0.50 \leq g<0.80$), large ($g \geq 0.80$). HDL= head diameter-left, NDL = neck diameter-left, NSAL = neck shaft angle-left,
HALL = hip axis length-left.

3.7. Logistic sex-estimation models

The univariate models, HDL and NDL were statistically significant with P = 0.031 and P = 0.017 respectively. The multivariate model from the combination of NDL and NDL was also statistically significant. A stepwise analysis yielded the same univariate model (NDL) just as in the direct analysis. The multivariate model achieved a better sex classification (64.0%) than the univariate models although marginal. Also, females were better classified than males (Table 6).

4. Discussion

The study aimed to estimate the age (years) and sex of a Ghanaian population using radiographic measurements from the proximal femur in adult males and females. Males had significantly higher HDL and NDL than females. The estimated age was not significantly different from the chronological age using HALL but only in males. However, the 95% confidence interval was wider than expected. The HDL was slightly better than the NDL in sex estimation. The multivariate model performed better than the univariate model although this was marginal. In general, females were better classified than males.

Males had higher neck and head diameters of the femur than females. Similar findings have been reported in Brazilian, Thai, South African and Danish populations [1,8,18,19]. There is sexual dimorphism in the human femur of which males, on average, tend to have longer, larger, heavier and more robust femurs than females due to the special adaptations of the male femur for more muscle attachment [9]. The sex differences in the human femur may also be due to functional adaptations in the biomechanics for bipedalism, reproduction and also due to the influence of androgenic hormones [3,6,10,25]. According to Rissech et al. [22], sexual dimorphism in the femoral head diameter begin to appear by the age of 15 years, and sex-estimation from femoral head diameter below this age may therefore be less precise.

The average sex-estimation accuracies were generally low (<80.0%). Sex-estimation accuracies from femoral head dimensions were higher in other population-specific studies as compared to the current study [4,5,8,21]. There are inter-ethnic and inter-population variabilities in the human femur [9,18,21]. People of Asian descent have been shown to possess a smaller femur compared to Europeans and Black Africans [18]. Also, White South Africans tend to have significantly higher femoral head diameter than South African Blacks [1], an indication that the femoral head diameter may be less sexually dimorphic among Blacks than Whites South Africans [17]. Also, climatic stress has been suggested as a possible cause of sexual dimorphism in the human skeleton, as climate changes may also lead to special adaptations for heat retention or release [11].

It was observed that females were better classified than males. This was contrary to other studies [4,5]. The finding may indicate that there were more males with female characteristics than females with male characteristics in the study sample. While the female femoral head dimensions were clustered, that of males were widely distributed, overlapping with female values, resulting in a substantial number of males being misclassified as females. The femoral head diameter was a marginally better attributor of sex than the neck diameter in the univariate models, which was consistent with previous studies [5,8]. But some authors rather found the femoral neck diameter to be better than the head diameter in sex estimation. Djorojevic et al. [4,9], had suggested that the sexual dimorphism in the femoral neck may be more marked than the head due to the effect of the combination of the selective forces of reproduction and bipedalism [4].

It is common in anthropometry research to combine multiple variables in a multivariable model to improve prediction accuracy. However, there was no substantial improvement in sex-estimation accuracy between univariate and multivariate models. Previous studies have indicated that multivariate models do not always lead to improved sex estimation accuracies [8,21] and that the decision to use multivariable

Table 3
Linear regression models for the estimation of age using variables of the proximal femur.

LR Model	Equation	r	R^2	$adjR^2$	SEE	F	P-value
1M	y = 2.851*HDL + 36.404	0.135	0.018	-0.110	11.717	0.627	0.434
2M	y = 0.898*NDL + 47.431	0.044	0.002	-0.027	11.813	0.066	0.799
3M	y = 0.902*SAL - 67.617	0.204	0.042	0.013	11.577	1.473	0.233
4M	y = 3.995*HALL + 3.765	0.425	0.180	0.156	10.706	7.474	0.010
1F	y = 4.665*HDL + 32.843	0.237	0.056	0.037	10.226	2.973	0.091
2F	y = 1.579*NDL + 49.663	0.076	0.006	-0.014	10.495	0.288	0.594
3F	y = 0.382*NSAL + 5.217	0.127	0.016	-0.003	10.440	0.823	0.369
4F	y = 1.795*HALL + 34.810	0.168	0.028	0.009	10.377	1.447	0.235

The results were presented as correlation coefficient (r), coefficient of determination (R2), adjusted R2 (adjR2), standard error of estimation (SEE) and F-value (F). LR = linear regression, M = male, F = female, HDL = head diameter-left, NDL = neck diameter-left, NSAL = neck shaft angle-left, HALL = hip axis length-left.

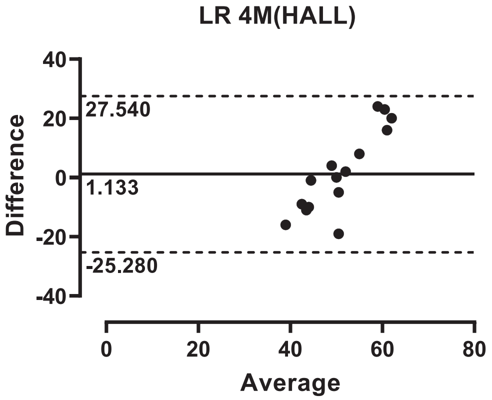

Fig. 1. Bland-Altmann plot comparing the estimated age and the chronological age in males.

Table 4
Sex estimation models using discriminant function analysis.

Variable	Unstandardized coefficient Direct				
	DF1	DF2	DF3	DF4	D5
HDL (cm)	1.861				0.927
NDL (cm)		2.016			1.188
NSAL (degrees)			0.345		
HALL (cm)				0.950	
Constant	-9.174	-7.733	-45.472	-11.005	-9.126
Group centroids					
Male	0.251	0.259	-0.080	0.143	0.278
female	-0.173	-0.179	0.055	-0.099	-0.191
Sectioning point (S.P)	0.078	0.080	-0.025	0.044	0.087
Eigenvalue	0.044	0.047	0.005	0.014	0.054
Canonical correlation coefficient	0.206	0.212	0.067	0.119	0.226
Wilk's Lambda	0.958	0.955	0.995	0.986	0.949
Chi-square	5.299	5.629	0.553	1.754	6.423
P-value	0.021	0.018	0.457	0.185	0.040

Univariate, multivariate and stepwise discriminant analysis. Significant univariate models were combined to create a multivariate model. The stepwise analysis yielded a univariate model. The sectioning point was calculated as the difference between the male and female group centroids. DF=discriminant function, HDL=head diameter-left, NDL=neck diameter-left, NSAL=neck shaft angle-left, HALL=hip axis length-left.

Table 5
Sex classification accuracies from the discriminant function analysis.

DF	Tested on the total sample (%)					
	Original			Cross-validation		
	Male	Female	Average	Male	Female	Average
1 (HDL)	25.5	86.5	61.6	25.5	86.5	61.6
2 (NDL)	25.5	74.5	60.0	25.5	74.5	60.0
3 (NSAL)	0.0	98.6	58.4	0.0	95.9	56.8
4 (HALL)	11.8	97.3	62.4	11.8	95.9	61.6
5(HDL+NDL)	29.4	87.8	64.0	29.4	85.1	62.4

The leave-one-out method was used to produce the sex classification accuracies in the cross-validation sample. DF = discriminant function, HDL = head diameter-left, NDL = neck diameter-left, NSAL = neck shaft angle-left, HALL = hip axis length-left.

Table 6
Binary logistic regression analysis for sex classification accuracy.

LogR	Nagelkerke R^2	P-value	Classification (%)		
			Male	Female	Average
y = 0.792*HDL - 4.292	0.057	0.031	25.5	86.5	61.6
y = 0.876*NDL - 3.748	0.060	0.017	25.5	83.8	60.0
y = −0.047*NSAL + 5.873	0.006	0.453	0.0	98.6	58.4
y = 0.231*HALL - 3.057	0.019	0.183	11.8	97.3	62.4
y = 0.436*HDL + 0.550 *NDL-4.647	0.068	0.039	29.4	87.8	64.0

Univariate, multivariate and stepwise analysis models. Significant univariate models were combined in the multivariate model. The stepwise analysis yielded a univariate model. LogR = logistic regression, HDL = head diameter-left, NDL = neck diameter-left, NSAL = neck shaft angle-left, HALL = hip axis length-left.

models should be at the discretion of the investigator [27].

The Bland-Altmann method comparison showed that the age estimated using the linear regression model from HALL was not significantly different from the chronological age in males. However, the confidence intervals were too wide, which may reduce the precision of the age-estimating models [23,26]. It has been argued that age estimation by osteometry is more observer-dependent than automated techniques and this may increase bias. The reduced precision of osteometric age estimation from the proximal femur may be due to the stability in proximal femoral dimensions after the attainment of maturity as opposed to bone mineral density (BMD) which tend to decline with age [2]. The early bone maturation in females than males may lead to less variation in femoral head dimensions in adult females than males and may have accounted for the lack of a significant age-estimation model for females [22].

The current study has some strengths: sex and age estimation from the proximal femur are essential for medico-legal investigations globally. However, such models are population-specific due to genetic and environmental variabilities. Only a few proximal femur-specific sex and age estimation models exist in Ghana and this study adds to the limited data available. However, the authors acknowledge that the findings of this study cannot be generalized for the entire Ghanaian population due to inter-population variabilities. Further studies should focus on specific cultural groups in the Ghanaian population.

5. Conclusion

The study showed that femoral head and neck diameters were the significant variables in sex estimation while the hip axis length was significant for age estimation in only males. However, the femoral head, neck diameters or their combination are poor attributors of sex on average. Also, male adult age estimation using the hip axis length is less precise. The use of femoral head and neck diameter for sex estimation and the femoral hip axis length for age estimation is not advised in the Ghanaian population.

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Authors contribution

A.R.A conceived the idea, designed the study and collected the data. **M.B** and **Y.A** analyzed the data, interpreted the results and wrote the first draft manuscript. All authors gave critical feedback for the final draft and approved its content.

Competing interest

The authors declare no conflict of interest.

Data availability

The data supporting the results will be available upon reasonable request from the corresponding author.

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