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Height and sex estimation using percutaneous humeral length among Ghanaians

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ABSTRACT

Introduction: Humerus is a long bone that contributes significantly to the total height of an individual. It is sexually dimorphic and is a well-preserved bone postmortem. Height and sex are essential in establishing one's identity and can be estimated from long bones when standing height cannot be easily obtained. Previous studies report that sex and height are population-specific. Hence, the present study sought to establish the relationship between percutaneous humeral lengths and height and formulate models for height and sex determination for the Ghanaian population.
Materials and methods: Measurement of standing height and percutaneous humeral lengths were taken from 286 Ghanaian consented participants with no noticeable lower and upper extremities traumas or pathologies. The data was analysed using Microsoft Excel 2013 and SPSS version 23.0 edition. Correlation analysis was done to determine the correlation of the percutaneous humeral length with height, linear regression and binary logistic analyses were used to derive equations for predicting height and sex from percutaneous humeral length. An independent samples t-test was used to determine the means between males and females, left and right percutaneous humeral lengths.
Results: There was a strong positive correlation between standing height and left ($r = 0.774$) and right ($r=0.759$) humeral lengths. The left humeral length regression equation was a good height estimator in males (75.4%) and females (71.%). The left and right humeral lengths best predicted the sex for the population, with an accuracy of 78.0% and 77.8% for males and 53.8% and 54.6% for females, respectively.
Conclusion: This study has added to the limited data on the use of percutaneous humeral length as a substitute for the determination of standing height and sex in the Ghanaian population, and it is also a significant identification tool which can be employed in the field of forensic anthropometry.

Introduction

The humerus, which exists bilaterally in the upper limb of the human body, is an essential long bone. It has been studied widely in different populations due to its numerous forensic, morphological, and anthropometric importance [1]. Humerus correlates significantly with the height of an individual, and it is sexually dimorphic [2]. It is an easily palpable bone that can be measured where one's standing height cannot be readily determined. It is also a retrievable and preserved bone in fragmented and decomposed bodies for identification [3], necessary in natural and man-made accidents [4–6].

Height and sex are essential in establishing one's identity [7]. Height has a proportional relationship with various body parts since it is the sum of certain bones and appendages of the body [8]. Previous studies have reported the existence of sexual dimorphism in the anatomy of an individual attributable to hormones [9]. These reasons above form the basis of establishing height and sex from different body parts in situations like bedridden and sedated patients, individuals with spinal deformities such as kyphosis, scoliosis and those with amputated lower limbs, fragmented and decomposed bodies when one's total height or sex cannot be readily estimated and identified.

Long bones such as the femur and tibia have been shown to be

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directly related to height [7,10]. On the other hand, the skull and the pelvis are the traditional bones for sex determination in the event that the sex of the person cannot be determined directly [11]. Without these bones for height and sex determination, other bones, like the humerus, can be utilised [12].

Previous studies have reported that sex and height can be estimated from the humerus. Mashali et al. [5] and Abimola [13] indicated that humeral length was the best parameter for estimating height in Jordanian and Nigerian populations, respectively. Kshirsagar [14], on the other hand, reported that the humerus was very effective in sexing among an Indian population, and these estimations are population-specific, as reported by Ahmed *et al.* [3]. Since genetic and environmental factors influence them [10]. Therefore, it is necessary to develop regression models to determine height and sex among the Ghanaian population to identify victims quickly. Armah et al. [8] in their preliminary study with a sample size of 100, estimated height and sex from the humeral length. Their sample size was low which might have resulted in their low prediction accuracies (54% and 55%) for the right and left male humeri respectively. In their study, there was no significant correlation for the female with an overall sex prediction accuracy of 81%. Therefore, this study aimed at estimating standing height and sex from percutaneous humeral length using a greater sample size. It specifically sought to establish the relationship between right and left percutaneous humeral lengths and height in male and female participants and formulate models for height and sex determination in the Ghanaian population.

Materials and methods

This cross-sectional study was carried out at the School of Medicine and Dentistry, Kwame Nkrumah University of Science and Technology, Kumasi. A total of 286 individuals, 167(58.39%) males and 119 (41.61%) females, participated in this study. A convenience sampling method was used. The data collection was from September 2019 to March 2020.

Inclusion and exclusion criteria

Participants with no apparent traumas or pathologies such as amputees and previous fractures in the lower and upper extremities and Ghanaian by birth were included in the study. People with suspected hormonal conditions such as childhood dwarfism and gigantism and individuals who were obese and hence their bony landmarks could not be easily palpated were excluded.

Data Collection

The Shahe's stature meter (Shanghai, China) was used to measure the participants' height in the Frankfurt plane. In contrast, the fibreglass measuring tape (Shanghai, China) was used to determine the percutaneous length of the humerus. All measurements were to the nearest 0.1 centimetres (cm).

Measurement of standing height

The participants were barefooted and stood vertically close to a wall with the heels of their feet touching the wall. The stature meter was then pulled down to touch the participants' heads, and the value was read and recorded.

Measurement of humeral length

Percutaneous humeral length was measured from the clavicle's acromial end along the arm's posterior lateral aspect to the lateral epicondyle of the humerus (Fig. 1). Percutaneous measurements of the right and left humeri were taken. The readings were taken twice to minimise intra-observer errors, and their respective means were calculated. The same individual was allowed to take the measurements. This was done to prevent inter-observer errors.

Fig. 1. A photograph showing percutaneous humeral length measurement using a fibreglass tape measure.

Statistics

The data obtained were then analysed using Microsoft Excel 2013 and SPSS version 23.0 edition. Correlation analysis was done using bivariate analysis to determine the correlation of the percutaneous humeral lengths with height. Linear regression and binary logistic analyses were used to derive equations for predicting height and sex from percutaneous humeral length. An independent samples t-test was used to determine the means between males and females, left and right percutaneous humeral length.

Ethics

The Committee on Human Research, Publications, and Ethics of the School of Medicine and Dentistry, Kwame Nkrumah University of Science and Technology, and the Komfo Anokye Teaching Hospital gave ethical approval with reference number CHRPE/AP/129/20 for the study. Codes were generated for the participants, which were used to identify the participants.

Results

The measured indices of both males and females are shown in Table 1. A total of 286 individuals participated in the data collection for this study, with 167 (58.39%) males and 119 (41.61%) females. It also shows the results of the independent t-test performed to ascertain the difference between the male and female parameters. The height of the male participants was significantly higher ($p < 0.001$) than the female participants. The left and right male humeri were significantly longer than the female ($p < 0.001$).

Table 1
A: Descriptive Statistics of Measured Indices of Participants.

Parameter	Sex	Number	Mean	SD	Range	t	**P-value**
Height (cm)	Male	167	171.77	6.61	156.10 – 188.80	11.69	<0.001
	Female	119	162.54	6.55	146.10 – 180.60		
	Pooled	286	167.93	8.00	146.10 – 188.80		
Left humerus (cm)	Male	167	33.17	2.01	28.10 – 40.05	6.74	<0.001
	Female	119	31.60	1.88	26.40 – 37.60		
	Pooled	286	32.52	2.09	26.40 – 40.05		
Right humerus (cm)	Male	167	33.14	2.04	28.00 – 39.95	6.67	<0.001
	Female	119	31.56	1.88	26.50 – 37.45		
	Pooled	286	32.48	2.12	26.50 – 39.95		

cm = centimeter, Difference, **SD** = Standard Deviation, **t** = t-statistic, **p** = probability

Table 2 shows the results of the paired samples t-test to see a difference between the means of the left and right humeral lengths. The mean difference between the male and female left and right humeri was 0.034 ± 0.241 cm and 0.039 ± 0.546 cm, respectively. This difference was insignificant (males;p = 0.067, female; p = 0.436). The mean difference between the pooled left and right humeri was also not statistically significant (p = 0.122)

The correlation between height, sex and the pooled sample of the bilateral humeral lengths were all strong and statistically significant (p<0.001), with the left humerus having a stronger correlation than the right. However, the humeral length of the pooled population showed a stronger correlation with height than the sex-specific ones (Table 3).

A linear regression analysis was performed for males, females, and the pooled population to estimate height from humeral length. The equation for the left humeral length of the pooled population had the highest coefficient of determination (R^2) value (59.8%). The equation with the highest SEE was that for the right humeral length of the pooled population (5.22). The equation for the right humeral length for the female population had the lowest coefficient of determination (R^2) value (47.9%), whereas the lowest SEE value of 4.35 was obtained by the model derived for the left humeral length of the male population (Table 4).

The right and left humeri were assessed for sex determination using binary logistic analysis. Binary logistic formulae were also derived using the model Log (p/1-p) = a + bx where Log (p/1-p) is$P = \frac{e^{b_0+b_1x}}{1+e^{b_0+b_1x}}$, a represents regression constant, b represents co-efficient of regression, and x represents the independent variable. The binary logistic regression generated equations for sexual dimorphism. The values generated by the equation, if negative, indicate a male, whereas a positive value indicates a female (Table 5).

The left humeral length correctly estimated the sex of 78.0% males and 53.8% females, whereas the right humeral length effectively estimated the sex of 77.8% males and 54.6% females.

Table 3
Correlation between Body Height and left and right humeral length of the Study Participants.

		R	95% Confidence Interval	p-value
Male	Left Humerus	0.754	0.653–0.855	< 0.001
	Right Humerus	0.737	0.633–0.841	< 0.001
Female	Left Humerus	0.710	0.582–0.839	< 0.001
	Right Humerus	0.692	0.560–0.824	< 0.001
Pooled	Left Humerus	0.774	0.700–0.848	< 0.001
	Right Humerus	0.759	0.683–0.835	< 0.001

r = Correlation Coefficient, **p** = probability, statistically significant difference ($p < 0.05$)

Table 4
Linear Regression Analysis for the Prediction of Height Using Measured Indices.

	Parameter	R^2	Adj. R^2	SEE	Regression Equation	p-value
Male	LH	0.569	0.566	4.350	89.399 + (2.483*LH^m)	< 0.001
	RH	0.543	0.540	4.480	92.494 + (2.392*RH^m)	< 0.001
Female	LH	0.505	0.500	4.630	83.158 + (2.512*LH^f)	< 0.001
	RH	0.479	0.474	4.750	86.402 + (2.412*RH^f)	< 0.001
Pooled	LH	0.598	0.597	5.080	71.679 + (2.96*LH^P)	< 0.001
	RH	0.576	0.574	5.220	74.799 + (2.867*RH^P)	< 0.001

R^2 = regression coefficient of determination, **Adj. R^2** = adjusted coefficient of determination, LH = Left Humerus, RH = Right Humerus, **SEE** = Standard Error of Estimate, ^{m} = Male, ^{f} = Female, ^{P} = Pooled, **p** = probability, statistically significant difference ($p < 0.05$)

Discussion

Height

The human skeleton's development is influenced by genetics, hormones, and nutrition [9]. These invariably affect the height of an individual. Oestrogen and testosterone play critical roles in height development among males and females. High oestrogen levels accelerate the growth mechanism of the chondrocytes at the growth plates, resulting in early epiphyseal fusion through the resorption of the growth plates, which brings about a halt in the elongation of long bones earlier in females [9,15]. Males possess lower levels of oestrogen coupled with higher levels of testosterone. This enables the growth process to continue in males even after that of females has ceased. This could account for the males being significantly taller than the females (p <

Table 2
Paired Samples t-test to see the existence of a mean difference between the means of the left and right humeral length.

	Parameters	MD (cm)	SD (cm)	SED	**95% CI**		T	**P - value**
					Lower	Upper		
Male	Left Humerus – Right Humerus	0.034	0.241	0.019	- 0.002	0.071	1.840	0.067
Female	Left Humerus – Right Humerus	0.039	0.546	0.05	- 0.06	0.138	0.781	0.436
Pooled	Left Humerus – Right Humerus	0.036	0.397	0.023	- 0.001	0.083	1.551	0.122

cm = centimeter, **SD** = Standard Deviation, **t** = t-statistic; **p** = probability, statistically significant difference ($p < 0.05$), **MD** = Mean Difference, **SED** = Standard Error of Difference, **CI** = Confidence Interval

Table 5
Binary logistic formulae for sex determination.

Equation	S.E	p-value	Exponent	95% CI Lower	95% CI Upper
Log (p/1-p) = 13.78 + (-0.436*LH)	0.075	< 0.001	0.646	0.558	0.748
Log (p/1-p) = 13.336 + (-0.423*RH)	0.073	< 0.001	0.655	0.568	0.756

SEE = Standard Error of Estimate, **p** = probability

0.001) in this study. This finding is in agreement with the findings of the Indian population [2], the Ethiopian population [16] and the Nigerian population [17]. Borkar [2] reported the mean male height as 173.80 ± 8.50 cm and that for females as 157.60 ± 7.98 cm in Maharashtra.

Percutaneous Humeral Length and Height

The humerus, which exists bilaterally in the upper limbs of the human body, is an essential long bone. It has been studied widely in different populations due to its numerous forensic, morphological, and anthropometric importance [1]. This study showed that mean values of right humeral length (RHL) were non-significantly higher than those of left humerus among both sexes. This bilateral asymmetry of humeral length, with a higher value on the right, could be because most participants were right-handed. This is similar to findings reported by some earlier studies in other geographical settings such as Nigeria [18], South Africa [19], India [20], and Nepal [21]. The results of this study showed a statistically significant strong correlation between left ($r = 0.774$) and right (0.759) humeral lengths and the measured standing height of the pooled study participants (Table 3). However, males reported a higher correlation of the humeri with height than females (Table 3). The probable cause of the longer mean humeri in males compared to females could be hormonal differences [8]. These findings agree with other studies [22,23]. In a study conducted by Armah et al. [8] in a Ghanaian population, humeral length was longer in males than in females. In another study conducted in the Maharashtra region of India, Borkar [2] concluded that there was a significant ($p < 0.05$) correlation between height and humeral length in both males and females, with the highest correlation found between height and left humeral length of males ($r = 0.852$), followed by the right humeral length of males ($r = 0.849$). Prateek [24], in a Northern Indian population, estimated height using humeral length and recorded a statistically significant ($p < 0.05$) correlation between height and length of the humerus in both males and females, with the correlation being higher in males ($r = 0.845$) than in females ($r = 0.665$). The findings of this study also conformed to other humeral morphometrics reported by other studies. These studies concluded on the existence of sexual dimorphism in humeral length, with males having significantly higher values among Iranian [25], Indian [2], Malaysian [23], Egyptian [11], and South African [26] populations.

Height Estimation from Percutaneous Humeral Length Using Regression Analysis

Using regression analysis, researchers have used humeral lengths among various populations to estimate stature. A study conducted in Germany [27] and another in Nigeria [17] concluded that humeral lengths have a statistically significant ($p < 0.001$) positive correlation with stature. Using long bones for estimating height with regression equations has produced a positive correlation with a small standard error of estimation [8,28]. In the present study, the regression equation of the left humeral length estimated height in males (75.4%), females (71%), and the pooled population (77.4%). These equations when tested on a small sample proved effective.Abimbola [13], in a study using 634 Nigerian participants, concluded that the humerus was a good predictor of height (males; $r = 0.142$, $p < 0.05$; females; $r = 0.214$, $p < 0.05$), which the present study is in agreement with. Borkar [2] also concluded that the humerus was a better height predictor in a study conducted in Maharashtra. Other research works in Telangana of Southern India and Nigeria reported similar results [29,30]. The regression models designed using the humerus suit a particular population [3]. Inaccurate height estimation could be obtained when these equations are applied to other populations [31].

Sex Determination from Percutaneous Humeral Length Using Binary Logistic Analysis

The present study assessed the right and left humeral lengths for sex determination using binary logistic regression analysis. The right and left humeral lengths yielded statistically significant ($p > 0.001$) models for sex determination. The left and right humeral lengths best predicted sex for the male population, with a prediction accuracy of 78.0% and 77.8%, respectively. On the other hand, the prediction accuracy for the female population produced moderate accuracies of 53.8% and 54.6% for the left and right humeral lengths, respectively. The values for the females are moderate and are therefore not accurate enough to be employed in the field of forensics. Mall et al. [27], in their work, recorded an accuracy of 80.58% in the German population. A study by Iscan et al. [32] suggested that discriminant functional analysis is more accurate than qualitative methods, such as bony landmarks used for sex determination, and would serve as a better means for many forensic scientists to access their anthropometric data successfully in terms of sex determination.

Conclusions

This study has generated equations to effectively determine height in the study population. The equations can effectively determine the sex of males but may not be accurate in determining the sex of females. This study has also, added to the limited data on the use of percutaneous humeral length as a substitute for the determination of standing height and sex in the Ghanaian population, and it is a significant identification tool which can be employed in the field of forensic anthropometry.

CRediT authorship contribution statement

Thomas Diby: Writing – review & editing, Validation, Resources, Investigation, Data curation. **Joshua Tetteh:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Joseph Yorke:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Data curation. **Chrissie Stansie Abaidoo:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation. **James Nketsiah:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Formal analysis. **Juliet Robertson:** Writing – review & editing, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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