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Research Article

Prediction of Stature using Percutaneous long bones of the Upper and Lower limbs among Asante and Ewe Ethnic Groups in Ghana

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Abstract

Introduction: Sophisticated technological advancements for the identification of people are readily available in developed countries. Meanwhile, relatively less expensive algorithms in physical anthropometry could be employed for such identification purposes. Although such evaluations have been done in some countries, due to interpopulation variations, such relations should be ethnic-and sex-specific.

Aim: Therefore, the present study sought to assess the relationship between the long bones of the upper and lower limbs among two ethnic groups in Ghana for stature estimation.

Methodology: Using a purposive non-random sampling technique, participants made up of 140 Asantes and 102 Ewes aged 20 to 25 years were recruited after an ethical approval was obtained from the Committee on Human Research, Publication and Ethics, KNUST.

Results: For the same sex, there was no statistically significant difference between Asantes and Ewes concerning height. The most useful parameters for stature estimation among the Asante males were left fibular and tibial lengths, with those of the females being left ulnar, fibular, and radial lengths. However, for the Ewe males, the most significant parameters for height estimation were right fibular and humeral lengths, whereas for the Ewe females, being right tibial and humeral lengths.

Conclusion: Findings of the study are useful for the identification of humans with dismembered body parts involved in various disasters, such as automobile accidents. The database and formulae derived would be useful for stature estimation needed in biological profiling and other assessments of bedridden patients.

More Information

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Keywords: Percutaneous; Anthropometry; Ethnicity; Stature

Introduction

It has been reported that human identification of unknown remains is commonly done using long bones. This is because, employing various anthropometric algorithms, the stature of the deceased could be estimated from the remains of the skeletal parts of the body [1]. The alternative means of doing this is to employ percutaneous measurement of bones [2].

Moreover, anthropometric means of predicting stature and sex are more practical and cost-effective compared to DNA analysis [3]. Apart from sex, age, and race, stature plays a significant role in the identification of people [4]. Particularly for people with disproportionate growth problems, myopathy, skeletal dysplasia, or stature loss during spinal surgeries, predictions of stature using measurements of body parts are often helpful [5]. Furthermore, regression models developed for height estimation utilizing long bones frequently have significantly lower standard errors of estimates. Long bones are therefore more accurate at measuring stature [6,7].

According to Dumitri, et al. [8], external variables that can alter bone formation include diet, exercise, and psychosocial factors. The nature of the occupation or task one is involved in, lifestyle, particularly due to the influence of civilisation, may be impactful on body parts, including the limbs [1].

In predicaments that result in mutilated body parts, medicolegal experts are challenged to help identify the victims [9,10]. The events of natural calamities continue to increase now and then, with mutilated body parts frequently encountered [11]. In Ghana, reports show that there are increased natural disasters and road traffic accidents resulting in multiple casualties [12]. The identification is usually resolved using tested formulae which are specific to one population and therefore cannot be applied to another population since variations exist owing to diet, environment, and lifestyle [13].

With the increasing number of medicolegal cases, comprehensive knowledge of the modern human populations in the Ghanaian society has become urgent so that the correct interpretation of unknown persons from contemporary forensic applications can be provided. Therefore, there is an utmost need to obtain ethnic-specific identification formulae for the assessment of the relationship between long bones of the limbs and height. Thus, the current study sought to analyze and bring out the association between percutaneous lengths of the limbs among the Asante and Ewe ethnic groups in Ghana using a percutaneous approach for stature estimation.

Materials and methods

Study design and ethical issues

This study employed a cross-sectional design to recruit participants aged 20 – 25 years. Ethical approval was obtained from the Committee on Human Research, Publication and Ethics, School of Medical Sciences, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana (Reference Number: CHRPE/AP/129/20). All procedures performed on the participants were done by the ethical standards outlined in the 1964 and subsequent modifications of the Declaration of Helsinki. Informed consent was also sought from each study participant before relevant data were collected confidentially. A non-probability purposive sampling technique was employed to recruit (both parents and grandparents from the ethnic group of interest) Ewe and Asante participants. The study was made up of 140 Asantes [71(50.7%) males and 69(49.3%) females] and 102 Ewes [61(59.8%) males and 41(40.2%) females].

Inclusion criteria

Only consented participants from the aforementioned ethnic groups aged 20 - 25 years were recruited for the present study.

Exclusion criteria

Individuals with old or current fracture(s) of the upper or lower limb or other orthopaedic deformities (kyphosis, lordosis, scoliosis) that could affect the measurements of the long bones or stature were excluded. Also, individuals with metabolic or developmental disorders (dwarfism, gigantism) that could potentially affect the maximum dimensions of the bones or stature were excluded from the present study.

Measurements taken

For both sexes and ethnic groups, except the stature, each remaining parameter was taken bilaterally following the protocols suggested in the International Standards for Anthropometric Assessment published by the International Society for the Advancement of Kinanthropometry (ISAK).

Humeral length: Percutaneous distance from the lateral end of the clavicle to the lateral epicondyle of the humerus. This was done with the elbow bent at an angle of 90° and participants being in a sitting position and the arm fully adducted at the shoulder joint.

Ulnar length: It was measured as the distance from the tip of the olecranon process of the ulna to the head of the ulna. In other words, it is the displacement of the styloid process from the tip of the olecranon process with the elbow fully flexed (90°) and palm spread over the opposite shoulder.

Radial length: It was measured as the displacement from the radial head to the radial styloid process.

Femoral length: It was measured as the displacement from the greater trochanter to the lateral epicondyle of the femur.

Tibial length: It was measured as the distance from the medial-most superficial point on the upper border of the medial condyle of the tibia to the tip of the medial malleolus (Spherion) of the tibia. The angle between the flexor surface of the leg and the thigh was maintained at 90°. This was achieved by asking each participant to sit (as it is easier to access the tibia in this position) facing the observer with the ankle resting on the knee, so that the medial aspect of the tibia faced upwards.

Fibular length: It was measured as the distance from the fibular head to the lateral malleolus. Each participant was asked to sit in order to make the landmarks easily accessible and palpable.

Stature of the participants: It was taken using a stadiometer as the displacement from the vertex of the head to the floor with participants being barefooted, feet close together, body erect, and head positioned in the Frankfurt horizontal plane in accordance with the International Biological Programme [14]. The shoulders of each participant were relaxed, the back was made straight, the upper surface of the thighs was made horizontal, the feet were supported, and the back of the knee joint was cleared of any obstacle, and then the vertex of the head contacted firmly with the stadiometer before the value was recorded.

Precautions observed during measurements

To reduce both inter-observer and intra-observer rate of error and to ensure reproducibility, all measurements were taken twice by the same investigator. Long bone lengths and stature of all participants were taken at a specific time from 10.00 am to 2.00 pm. Most of the landmarks were highlighted on the skin using a marking pencil to increase accuracy.

Definition of key concepts

Percutaneous refers to that which takes place through the skin or with the skin present.

Anthropometry refers to the measurement of some areas of the human body.

Ethnicity refers to the fact of belonging to a population group or subgroup consisting of persons who share a common cultural background.

Stature refers to the natural height of an individual while standing in an upright position.

Statistical analysis

Data obtained from study participants were entered into Microsoft Office Excel Spreadsheet 2019 and analyzed using IBM SPSS version 26.0. For descriptive statistics, data were expressed in means together with standard deviation. An independent samples t-test was employed to assess sexual dimorphism in the study participants based on the parameters studied. The existence of bilateral asymmetry was assessed using a paired samples t-test. Statistically significant level for differences or otherwise was pegged at $p < 0.05$ (95% confidence level). Pearson's correlation coefficient (r) was used as the measure of strength and direction of the association between height and percutaneous bone lengths for both males and females of each ethnic group. The coefficient of determination (R^2), together with its adjusted value (adjusted R^2), was estimated to determine how much of the variance in the dependent variable could be explained by its relationship to the other variables. Using a stepwise approach, linear regression equations (both simple and multivariate) were derived as predictive models for stature using percutaneous long bone lengths.

Results

Intrasex variation among Asantes and Ewes

Differences between anthropometric parameters of both males and females of different ethnic groups: Using an independent samples t-test, some variations between Asante males and Ewe males, as well as Asante females and Ewe females, were observed (Table 1).

Bilateral differences between right and left measurements of Asante participants stratified by sex using a paired samples t-test

Bilateral asymmetry of ethnic-and sex-specific parameters of upper and lower limbs is shown in Tables 2,3.

Pearson's Correlation Between Height and Percutaneous Long Bone Lengths of Asante and Ewe Participants Stratified by Sex

Results of the Pearson's correlation between height and percutaneous bone lengths of both ethnic groups based on sex are summarised in Tables 4,5.

Linear regression analyses for height estimation using lengths of long bones

Regression Equations for Height Estimation Using Long Bone Lengths of Male Asantes and Ewes

Stepwise linear regression analysis was performed for height estimation for males using the percutaneous long bones of the upper and lower limbs (Table 6).

Regression Equations for Height Estimation Using Long Bone Lengths of Female Asantes and Ewes

Stepwise linear regression analysis was performed for height estimation for females using the lengths of percutaneous long bones of upper and lower limbs (Table 7).

Discussion

Population characteristics of study participants

The present study comprised 140 Asantes [71(50.7%) males and 69(49.3%) females] and 102 Ewes [61(59.8%) males and 41(40.2%) females]. The age range of the participants of the study was 20 – 25 years. This age range was appropriate because studies have shown that there is skeletal deformity with advancing age and thus a reduction in one's stature [15,16]. Also, it has been reported that the ossification of bones of the limbs is completed around age 20 – 25 years of postnatal life. Other findings reveal that, beyond the fifth decade of extrauterine life, degenerative alterations occur in articulations and cartilages [17], consequently affecting limb dimensions and height. For instance, because participants aged above 65 years were recruited for height estimation using fibular length, unlike the present study, which recorded a strong correlation coefficient between fibular length and height, Auyeung, et al. [18] recorded a moderate correlation among both males ($r = 0.574$) and females ($r = 0.559$).

In the present study, males were significantly taller than females among both Asantes and Ewes. This is in line with those reported by several investigators among different populations across the globe [19-23]. Similarly, Kavyashree, et al. [24] reported significantly greater mean height among males (170.88 cm) than females (158.87 cm). Banerjee, et al.

Table 1: Comparison of Anthropometric Parameters of Both Males and Females of Different Ethnic Groups.

	MALES [MEAN ± SD (cm)]				FEMALES [MEAN ± SD (cm)]			
	Asantes (N = 71)	Ewes (N = 61)	t	p	Asantes (N = 69)	Ewes (N = 41)	t	p
RHL	35.73 ± 0.98	35.63 ± 0.78	0.645	0.520	33.70 ± 1.49	33.14 ± 1.48	1.900	0.060
RUL	28.71 ± 1.24	29.36 ± 1.18	-3.083	0.002	26.47 ± 1.55	27.05 ± 1.16	-2.077	0.040
RRL	25.41 ± 1.59	26.27 ± 1.53	-3.189	0.002	23.05 ± 1.46	24.07 ± 1.37	-3.644	0.000
RFL	39.92 ± 1.70	39.52 ± 1.26	1.560	0.121	37.17 ± 1.47	38.32 ± 1.02	-4.828	0.000
RTL	38.17 ± 1.62	38.41 ± 1.05	-1.025	0.308	35.96 ± 1.64	37.28 ± 0.97	-5.303	0.000
RFibL	36.88 ± 1.33	37.23 ± 0.97	-1.688	0.094	34.85 ± 1.52	36.18 ± 0.99	-5.518	0.000
LHL	35.85 ± 1.03	35.84 ± 0.81	0.087	0.931	33.77 ± 1.60	33.31 ± 1.49	1.490	0.139
LUL	28.73 ± 1.29	29.53 ± 1.11	-3.843	0.000	26.56 ± 1.61	27.14 ± 1.24	-1.985	0.050
LRL	25.53 ± 1.61	26.46 ± 1.46	-3.444	0.001	23.04 ± 1.47	24.16 ± 1.53	-3.815	0.000
LFL	39.66 ± 1.73	39.29 ± 1.33	1.334	0.185	36.93 ± 1.51	38.11 ± 1.04	-4.424	0.000
LTL	37.85 ± 1.64	38.17 ± 1.18	-1.260	0.210	35.87 ± 1.63	36.98 ± 0.97	-4.479	0.000
LFibL	36.70 ± 1.51	37.04 ± 0.92	-1.580	0.117	34.67 ± 1.56	35.98 ± 1.04	-5.249	0.000

RHL = Right Humeral Length; RUL = Right Ulnar Length; RRL = Right Radial Length; RFL = Right Femoral length; RTL = Right Tibial Length; RFibL = Right Fibular Length; LHL = Left Humeral Length; LUL = Left Ulnar Length; LRL = Left Radial Length; LFL = Left Femoral length; LTL = Left Tibial Length; LFibL = Left Fibular length; N = Number of Participants; SD = Standard Deviation; cm = centimetre; t = test statistic; p = Statistical significance level

Table 2: Comparison of Right and Left Anthropometric Parameters of Asantes Stratified by Sex.

	MALES (N = 71)			FEMALES (N = 69)		
	df	t	p	df	t	p
RHL – LHL	70	-3.295	0.002	68	-1.169	0.246
RUL – LUL	70	-0.330	0.743	68	-1.493	0.140
RRL – LRL	70	-2.461	0.016	68	0.130	0.897
RFL – LFL	70	5.539	0.000	68	4.625	0.000
RTL – LTL	70	4.466	0.000	68	1.628	0.108
RFibL – LFibL	70	3.406	0.001	68	4.534	0.000

RHL = Right Humeral Length; RUL = Right Ulnar Length; RRL = Right Radial Length; RFL = Right Femoral length; RTL = Right Tibial Length; RFibL = Right Fibular length; LHL = Left Humeral Length; LUL = Left Ulnar Length; LRL = Left Radial Length; LFL = Left Femoral length; LTL = Left Tibial Length; LFibL = Left Fibular Length; N = Number of Participants; df = Degree of freedom; t = test statistic; p = Statistical significance level

Table 3: Comparison of Right and Left Anthropometric Parameters of Ewes Stratified by Sex.

	MALES (N = 61)			FEMALES (N = 41)		
	df	t	p	df	t	p
RHL – LHL	60	-6.876	0.000	40	-3.508	0.001
RUL – LUL	60	-4.555	0.000	40	-1.701	0.097
RRL – LRL	60	-4.117	0.000	40	-1.392	0.172
RFL – LFL	60	4.815	0.000	40	10.220	0.000
RTL – LTL	60	4.809	0.000	40	7.287	0.000
RFibL – LFibL	60	5.964	0.000	40	6.212	0.000

RHL = Right Humeral Length; RUL = Right Ulnar Length; RRL = Right Radial Length; RFL = Right Femoral length; RTL = Right Tibial Length; RFibL = Right Fibular length; LHL = Left Humeral Length; LUL = Left Ulnar Length; LRL = Left Radial Length; LFL = Left Femoral length; LTL = Left Tibial Length; LFibL = Left Fibular Length; N = Number of Participants; df = Degree of freedom; t = test statistic; p = Statistical significance level

Table 4: Pearson's Correlation Between Height and Long Bone Lengths of Asantes Stratified by Sex.

	MALES (N = 71)		FEMALES (N = 69)	
	HEIGHT		HEIGHT	
	r	p	r	p
RHL	0.700	0.000	0.748	0.000
RUL	0.614	0.000	0.743	0.000
RRL	0.459	0.000	0.589	0.000
RFL	0.516	0.000	0.701	0.000
RTL	0.763	0.000	0.754	0.000
RFibL	0.829	0.000	0.785	0.000
LHL	0.703	0.000	0.741	0.000
LUL	0.645	0.000	0.813	0.000
LRL	0.479	0.005	0.562	0.000
LFL	0.504	0.000	0.654	0.000
LTL	0.822	0.000	0.727	0.000
LFibL	0.831	0.000	0.788	0.000

RHL = Right Humeral Length; RUL = Right Ulnar Length; RRL = Right Radial Length; RFL = Right Femoral length; RTL = Right Tibial Length; RFibL = Right Fibular length; LHL = Left Humeral Length; LUL = Left Ulnar Length; LRL = Left Radial Length; LFL = Left Femoral length; LTL = Left Tibial length; LFibL = Left Fibular length; r = Pearson's correlation co-efficient; p = Statistical significance level

Table 5: Pearson's Correlation Between Height and Long Bone Lengths of Ewes Stratified by Sex.

	MALES (*n* = 61)		FEMALES (*n* = 41)	
	HEIGHT		HEIGHT	
	r	p	r	p
RHL	0.693	0.000	0.621	0.000
RUL	0.158	0.225	0.570	0.000
RRL	0.012	0.925	0.340	0.000
RFL	0.708	0.000	0.751	0.000
RTL	0.650	0.000	0.797	0.000
RFibL	0.753	0.000	0.759	0.000
LHL	0.702	0.000	0.588	0.000
LUL	0.117	0.370	0.513	0.000
LRL	0.040	0.762	0.329	0.036
LFL	0.723	0.000	0.724	0.000
LTL	0.693	0.000	0.723	0.000
LFibL	0.712	0.000	0.759	0.000

RHL = Right Humeral Length; RUL = Right Ulnar Length; RRL = Right Radial Length; RFL = Right Femoral length; RTL = Right Tibial Length; RFibL = Right Fibular length; LHL = Left Humeral Length; LUL = Left Ulnar Length; LRL = Left Radial Length; LFL = Left Femoral length; LTL = Left Tibial length; LFibL = Left Fibular length; r = Pearson's correlation co-efficient; p = Statistical significance level

Table 6: Linear Equations for Height Estimation Using Right Percutaneous Long Bone Lengths for The Males of Asantes and Ewes.

	MALES			
	EQUATION	R^2	ADJ.R^2	SEE
ASANTES	• H = 49.516 + 3.284 (RFibL)	0.688	0.683	2.9746
	• H = 64.138 + 2.902 (LFibL)	0.691	0.686	2.9610
	• H = 62.613 + 1.696 (LFibL) + 1.210 (LTL)	0.712	0.703	2.8785
EWES	• H = 9.103 + 4.314 (RFibL)	0.567	0.560	3.6968
	• H = -34.530 + 3.004 (RFibL) + 2.594 (RHL)	0.646	0.634	3.3712
	• H = 51.111 + 3.019 (LFL)	0.522	0.514	3.8834
	• H = -7.154 + 1.945 (LFL) + 2.803 (LHL)	0.623	0.610	3.4771

RHL = Right Humeral Length; RFL =Right Femoral Length; RFibL = Right Fibular Length; LHL =Left Humeral Length; LFL = Left Femoral Length; LTL =Left Tibial Length; LFibL =Left Fibular Length; ADJ. = Adjusted; H= Height; R^2 = Regression co-efficient of determination; SEE = Standard Error of Estimate

Table 7: Linear Equations for Height Estimation Using Right Percutaneous Long Bone Lengths of Asantes and Ewes.

	FEMALES			
	EQUATION	R^2	ADJ.R^2	SEE
ASANTES	• H = 39.767 + 3.432 (RFibL)	0.616	0.610	4.1405
	• H = 32.041 + 2.303 (RFibL) + 1.778 (RUL)	0.722	0.714	3.5485
	• H = 70.706 + 3.338 (LUL)	0.660	0.655	3.8933
	• H = 42.532 + 2.090 (LUL) + 1.769 (LFibL)	0.742	0.734	3.4190
	• H = 43.658 + 2.495 (LUL) + 1.990 (LFibL) - 0.849 (LRL)	0.757	0.746	3.3404
EWES	• H = 26.521 + 3.585 (RTL)	0.636	0.626	2.6779
	• H = 25.980 + 2.954 (RTL) + 0.725 (RHL)	0.676	0.659	2.5587
	• H = 45.451 + 3.189 (LFibL)	0.576	0.565	2.8904

RHL = Right Humeral Length; RUL = Right Ulnar Length; RFL =Right Femoral Length; RTL = Right Tibial Length; RFibL = Right Fibular Length; LUL =Left Ulnar Length; LRL = Left Radial Length; LFibL =Left Fibular Length; ADJ. = Adjusted; H= Height; R^2 = Regression co-efficient of determination; SEE = Standard Error of Estimate

[25] also had a significantly greater mean height for the male participants (164.05 cm) than the females (156.38 cm), which is in line with the present study. Although an individual's stature is impacted significantly by epigenetic factors such as nutritional status, growth rate, and physiological capacities, by and large, males are taller than females as a result of quite longer bone growth duration in the former than the latter [26]. This is perhaps due to the cessation of ossification of long bones of the limbs occurring earlier in females than in males [27]. Therefore, more precisely, males being taller than females could be directly linked to the early epiphyseal line formation in females as a result of high estradiol but low testosterone levels in females [28].

This is because oestrogens are known for enhancing the epiphyseal plate ageing process, causing the proliferative tendency of the plate chondrocytes to become exhausted, leading to the synostotic epiphyseal line formation. As a result, males have about two more years of osseous tissue growth than females [20]. However, there was no statistically significant difference between Asante males and Ewe males or Asante females and Ewe females in terms of height ($p > 0.05$). This could be as a result of the closeness in stature, which has been asserted by most Ghanaians, although according to Chawla, et al. [29], ethnic or racial affiliation affects one's height. This observation could be due to similar environmental conditions, common physical activities engaged in by study participants, genetic constitution, and nutritional states, which are essential in the growth and development of humans. All the participants of the present study were tertiary students residing in Kumasi as of the time of sampling. Being an inherent trait, stature forms one of the most relevant identifying features of humans [30]. This is because there are peculiarities in stature among different populations with respect to sex. Other studies have shown that the stature of an individual is considerably influenced by age, sex, physical activity, as well as the population [31,32].

Sexual dimorphism of the percutaneous bones of the upper and lower limbs of the study participants

The present study recorded significantly greater mean percutaneous upper and lower limb bone lengths for both the right and left sides of the body among the males than females for both ethnic groups. These results also correspond to the differences in the heights of the study participants. This is because it has been asserted that longer limbs are associated with taller people [33]. Regarding the ulnar length, the findings of the present study are in line with those by Paul, et al. [17], who recruited 500 participants aged 20 – 50 years, where males had a significantly longer ulna than females, although the upper limit of the age range differed significantly among the two studies. Another study by Itlapuram, et al. [34] among the students of Narayana Medical College, Nellore, Andhra Pradesh, males recorded significantly longer ulnae than females. Regarding the humeral length, the present study conforms with findings of Ismail, et al. [35] who reported sexual dimorphism in humeral lengths with males recording greater mean values than females among a Malaysian population. Also, in an Egyptian population, Ali and Abd Elbaky [36] reported significantly greater humeral length in males than females. Similarly, among South African Black indigenes, Whites, and Hybrid populations, males recorded significantly greater values than females [37]. Males recording significantly greater mean humeral lengths than females could also be attributed to how often the study's males are engaged in weeding and are involved in more physical activities using the upper limb than females at home and in school. More often, males actively engage in extracurricular activities such as playing football, volleyball, and tennis, among others. These activities could contribute to males having larger long bones than females. Additionally, in childhood, boys spend more time playing games that involve climbing, which may potentially extend their limbs and consequently lengthen their bones. Just like the current study, males had considerably longer mean femora than females [38]. It has been reported that males have larger lower limbs compared to females, and this has been largely attributed to differences in environmental responses, mechanical loading patterns, and hormonal differences [39]. To buttress this point, the literature has it that, the linear dimensions of especially the fibula in males are larger than that of females probably from the fact that, males have longer period of growth during puberty and therefore larger bones and musculature due to the influence of sex genes, sex steroid hormones and other hormones such as growth hormone and *insulin-like growth factor 1* alongside mechanical loading [40,41]. Moreover, it has been speculated that females have relatively shorter femora than males as a result of the former having broader pelves and thus greater bicondylar femoral angles [42]. In the present study, tibial lengths being greater in males than in females are in line with reports from other studies [24,43]. For fibular length, findings of the present study are in line with those reported by Auyeung, et al. [18] and Hishmat, et al. [44], where males recorded significantly greater fibular lengths than females. However, although males recorded greater fibular length than females, no sexual dimorphism was observed among a Pakistani population [45].

Estimation of height using percutaneous long bones of the limbs stratified by sex

In the present study, several differential regression models for height estimation for the Asante and Ewe participants were derived using lengths of long bones. Derivation of these formulae for various predictions is possible since there exist consistent biological relations between body parts and the entire body [46]. The most useful models for height estimation utilized fibular lengths. This was followed by ulnar lengths. This suggests that, based on head-to-head comparison, the lower limb percutaneous bones are cumulatively more useful than those of the upper limb. This contradicts a study carried out by Celbis and Agritmis [47] where it was opined that upper limb long bones are as useful as those of the lower limb for stature estimation of the living.

Where individuals have abnormal posture, their true height cannot be established. Therefore, the equations derived using the percutaneous long bones of both the upper and lower limbs can be applied conveniently for such applications. The equations are appropriate enough, as both simple and multiple linear regression equations were derived for each group. This means that the presence of only one of the long bones will not be a limitation to height estimation. According to Waghmare, et al. [48], a particular long bone measurement or a combination of such bones is a reflection of the height of an individual. As with the present study, some authors have reported the appropriateness in the use of long bones for stature prediction since they are often associated with low standard error of estimates [49,50]. In the present study, the adjusted coefficient of determination of equations obtained for multivariate ones was greater than that of the univariate ones. This means that multivariate equations are more useful than simple ones [46]. This is because, as evident in the present study, multiple regression shows reduced mean absolute percentage error of prediction [51].

According to Duyar and Pelin [52], for increased accuracy, regression equations should be population-specific. This is because factors including ethnicity, occupation, nutrition, and environment play significant roles in the overall development of humans. The staple food for Asantes is fufu (made using cassava) with varieties of soup, while Ewes enjoy more of Akple (made using maize) with okra soup. In both food items, some pounding or riding using the upper limb is needed with concomitant support of the lower limbs. Environmental conditions affect the type of work members of a particular community embark on. Both Asantes and Ewes belong to the tropical area of Ghana and are mainly involved in agricultural activities. Therefore, there is some kind of closeness between the two ethnic groups with respect to their daily activities. However, for increased accuracy through elimination of other confounding factors, in the present study, models derived were sex-and ethnic-specific.

Although it has been proposed that the best way to estimate the height of an individual is to use skeletal remains, percutaneous measurements of bones in the living can also serve as a surrogate means [2]. It has been shown that stature estimation using bones is quite difficult and cumbersome since it involves several activities, including cleaning and bone preparation. As a result, percutaneous measurements instead of direct bone measurements are often embraced and preferred by most forensic anthropologists since it is more advantageous [53]. That is why the present study considered the percutaneous approach, just like other studies [54,55]. Reconstruction of an individual's stature using body parts offers great anthropological merits when identifying even the dead. In addition, height estimation is useful during the stepwise identification of an unknown person since height is a useful feature essential to help narrow down the window of search of individuals [56]. Congruent with other study findings, other authors have reported reliable results in the use of long bones for height estimation [57,58].

Among the population of Jordan and a study carried out in Northern Ghana, humeral length was found to be a proxy useful for height estimation [2,59]. Shah, et al. [54] utilized a regression method to derive models for the estimation of height using arm length, which is almost the same as the percutaneous humeral length result of the present study. Additionally, the use of percutaneous humeral lengths or fragment measurements for height estimation has been reported by other investigators [36,60]. Stature predicted from measurements of body parts is very useful, especially among individuals with disproportionate growth disorder, myopathy, skeletal dysplasia, or stature loss during spinal column procedures [5]. This is because it has been shown that there is a steady height increase of a person, perhaps till adolescence, and then later declines due to backbone erosion occurring as one advances in age [17]. Therefore, in situations where some disease conditions or disabilities would not permit direct height measurement, the derived formulae would be suitable as proxy predictors of height. In the present study, among other parameters, right tibial length was useful for height estimation among Ewe females. This is in agreement with that by Kavyashree, et al. [24]. Similarly, a study carried out on 400 participants aged 17-24 years, it was found that tibial length explained 74% of height variation in males and 72% in females [61]. In the present study, linear regression models were derived for each ethnic group and sex so as to satisfy the proven concept of interpopulation variation in body proportions [62]. Regression equations derived for the prediction of height in the present study did not differ significantly from the actual measured height of the study participants, making the derived models very appropriate for stature estimation.

Conclusion

In both Asantes and Ewes, males were significantly taller and had greater anthropometric parameters than females. Within the same sex, there was no statistically significant difference between Asantes and Ewes concerning height. Ewe males had significantly greater ulnar and radial lengths than Asante males. Meanwhile, Ewe females had significantly greater ulnar, radial, femoral, tibial, and fibular lengths than Asante females.

Most of the percutaneous long bones were useful for height estimation in the present study for both ethnic groups. The most useful parameters for the Asante males were left fibular and tibial lengths, with those of the females being left ulnar, fibular, and radial lengths. For the Ewe males, the most significant parameters for height estimation were right fibular and humeral lengths, with the Ewe females being right tibial and humeral lengths.

The study has presented efficient anthropometric models for adequate identification of individuals by applying the appropriate corresponding model. Findings of the study are therefore useful for the biological profiling of humans with dismembered body parts involved in various disasters such as automobile accidents. The database and formulae derived would be useful for stature reconstruction needed for various assessments on bedridden patients.

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Data availability statement

Data used to support the study findings will be made available by the corresponding author upon request.

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