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 lower and upper extremities deformities. 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 (56.6%) and females (50.0%). The left and right humeral lengths best-predicted sex for the male population with an accuracy of 78.0% and 77.8%, respectively, attributable to the larger sample size of the males than the females. Conclusion: There was a significantly strong positive correlation between the humeral length and height in males and females. The left humerus was a better predictor of height than the right humeral length best-predicted sex for the male population.

Keywords:
Forensic Anthropology
Height
Humerus
Ghana
Sex

ARTICLE INFO

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 lower and upper extremities deformities. 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 (56.6%) and females (50.0%). The left and right humeral lengths best-predicted sex for the male population with an accuracy of 78.0% and 77.8%, respectively, attributable to the larger sample size of the males than the females. Conclusion: There was a significantly strong positive correlation between the humeral length and height in males and females. The left humerus was a better predictor of height than the right humeral length best-predicted sex for the male population.

Introduction:
Humerus is a long bone that contributes significantly to the total height of the human body. It has been studied widely in different populations due to its numerous forensic, morphological, and anthropometric importance [1]. Humerus contributes significantly to the total height of an individual [2] and being sexually dimorphic. It is an easily palpable bone that can be measured in conditions where one's standing height cannot be readily determined. It is also a retrievable and preserved bone that is fragmented and decomposed bodies for identification [3]. Necessary in natural and man-made accidents [4-6].

Height and sex are features that play an essential role 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 also 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 easily estimated and identified respectively.

Previous studies report that sex and height are population-specific parameters, 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 for easy identification of victims. Armah et al. [10] preliminary data on estimating height and sex from the humeral length but with low sample size and hence low prediction accuracy. 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 deformities in the lower and upper extremities and Ghanaian by birth were included in the study. Individuals with deformities in the upper and lower extremities, amputees, and previous fractures...
were excluded from the study. People with suspected hormonal conditions such as childhood dwarfism, gigantism, and individuals who were obese and hence their bony landmarks could not be easily palpated were also excluded.

**Data Collection**

The Shahe's stature meter (Shanghai, China) was used to measure the participants' height in the Frankfurt plane. In contrast, the fibre-glass 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' head, and the value was read and recorded.

**Measurement of humeral length**: Percutaneous measurements of the right and left humeri were taken. The readings were taken twice to minimize 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.

**Statistics**

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

**RESULTS**

Table 1A: Descriptive statistics of Measured Indices of Participants

Table 1B: Independent t-test to see the existence of a mean difference between the means of the measured indices

The measured indices of both males and females are shown in Table 1A. A total of 286 individuals participated in the data collection for this study, with 167 (58.39%) males and 119 (41.61%) females. Table 1B 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. Both the left and right male humeri were significantly longer than the female (p < 0.001).

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

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

Table 3: Correlation between Body Height and left and right humeral length of the

**Study Participants**

The correlation between height, sex, and the pooled sample, bilateral humeral length of males, and height 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 sex-specific codes (Table 3).

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

A linear regression analysis was performed for males, females, and the pooled population to estimate height from humeral length. The Adjusted R² of the models derived for males was 56.6% for the left humerus and 54.0% for the right humerus, while that of the females was 50% for the left humerus and 47.4% for the right humerus. The model derived using the pooled population gave the highest adjusted R² of 59.8% and 57.6% for the left and right humerus, respectively (Table 4).

Table 5: Binary logistic formulae for sex determination

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 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, indicates a male, whereas a positive value is indicative of female (Table 5).

The left humeral length effectively 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.

**DISCUSSION**

**Height**

The development of the human skeleton is influenced by factors such as genetics, hormones, and nutrition [9,11]. These invariably affect the height of an individual. Oestrogen and testosterone play critical roles in the development of height 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 [9,11]. Males possess lower levels of oestrogen coupled with higher levels of testosterone. This enables the process of growth to continue in males even after that of females have ceased. This could account for the males being significantly taller than the females (p < 0.001) in this study. This finding is in agreement with the findings of other studies [2,3,12-15]. 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 important long bone. It has been studied widely in
different populations due to its numerous forensic, morphological, and anthropometric importance. 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 [14], Turkey [15], India [16], and Nepal [17]. 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 as compared to females could be due to hormonal differences as well as the frequent use of the hand in males for physical activities such as weeding, climbing and lifting heavy items causing the humeri to extend to accommodate the excessive force from these activities [8,18]. These findings agree with other studies [19,20]. In a study conducted by Armah et al. [8] in a Ghanaian population, humeral length was longer in males than in females. 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[19], 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 [21], Indian [2], Malaysian [22], Egyptian [23], and South African [24] populations.

**Height Estimation From Percutaneous Humeral Length Using Regression Analysis**

Several researchers have used humeral lengths among various populations to estimate stature using regression analysis. They have concluded that humeral lengths have a statistically significant (p < 0.001) positive correlation with stature [25-26]. The use of long bones for estimating height using regression equations has been shown to produce a positive correlation with a small standard error of estimation [8,17]. In the present study, the regression equation of the left humeral length estimated height in males (56.9%), females (50.5%), and the pooled population (59.8) (Table 4). Abimbola [27] in a study using 634 Nigerian participants, concluded that the humerus was the 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 predictor of height. Other research works reported similar results [28-29]. The regression models designed using the humerus are suitable specifically for a particular population [3]. Inaccurate height estimation could be obtained when these equations are applied to other populations [30].

**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, which can be attributed to the larger sample size of the males compared to the females. A study by Iscan et al. [31] 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**

From the current study, males were taller and had a significantly longer humeri than females. There was a strong positive and significant correlation between the humeral length and height in both males and females. The left humerus was a better predictor of height as compared to the right. Humeral length best predicted sex for the male population.

**Reference**


