Reconstruction of the Length of the Humerus from its Fragments

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Abstract

Introduction: Intact long bones recovered amongst human skeletal remains, are ideal to reconstruct the stature of unidentified individuals by formulating regression equations. In many forensic situations, long bones are often encountered in different fragmentary states due to decomposition and mutilation. This necessitates the reconstruction of the length of long bone from its fragmentary portions.

Method: Standard humeral measurements, the maximum length of the humerus, epicondylar breadth, vertical head diameter, transverse head diameter obtained from 96 humeri belonging to a contemporary Sri Lankan population were analyzed with the aim of generating regression equations to estimate the maximum length of the humerus from the measurements of its fragments.

Results: All measurements obtained from those showed a positive correlation with the length of the humerus. The regression models formulated to estimate the maximum humeral length using single variables showed a moderate degree of correlation (0.518-0.669). The vertical diameter of head was the best single variable to predict ($r = 0.669$, SEE=15.55) the maximum length of the humerus. The multiple regression models formulated using different combinations of variables showed stronger correlations (0.669 to 0.716) with lower error estimates (SEE=14.79–15.31).

Conclusion: The results may contribute to the estimation of the length of the humerus from its fragments, providing valuable information for the purpose of identification of unknown human remains from contemporary Sri Lankan population.

Keywords: Humerus, Fragments, Stature, Forensic anthropology

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Introduction

Establishment of the identity of unknown skeletal remains presents a major challenge in the field of forensic medicine and physical anthropology. Stature offers one of the important aspects of the identification of an individual.[1] Its estimation is an important initial step in developing the biological profile during any forensic investigation. A precise estimation of stature can be achieved when the entire skeleton is available.[2]

The skeletal material drawn from forensic and archaeological settings however, is rarely complete and undamaged. Hence, it is essential to establish techniques to estimate stature from skeletal elements that are likely to resist decay and be recovered.

It is widely agreed that strong correlations are present between the stature and dimensions of different skeletal components of the human body.[1] Based on this positive dimensional relationship of various skeletal components with stature, establishment of methods to estimate stature of unknown individuals has been a core focus for over a period of a century.

Previous studies have documented that a variety of bony elements can be used to estimate stature.[3-8] Intact long bones of the upper and lower extremities have been documented as more reliable in the estimation of stature.[9] Using the lengths of intact long bones regression equations have been generated to estimate stature in different population groups.[1,9-11] In most forensic circumstances the long bones are recovered in fragmentary states due to environmental effects, thus making the stature estimating equations derived from intact bones inappropriate for analysis. This justifies the development of formulae for reconstruction of the total length of the long bone from the measurements of its fragmentary portions. As stated by Steele and McKern,[6] Mu¨ller was the first to attempt a reconstruction of the length of long bones such as the radius, humerus and tibia from their fragments by deriving regression equations. Since then numerous studies have emerged utilizing measurements of fragments of various bones such as the femur, [6,12,13], tibia[8,14] radius,[15] humerus[16, 17] and the ulna[18] to predict the total length of the bone. Once the total length of a long bone is derived from a fragment, it is possible to calculate living stature of the individual using regression equations that are already formulated to calculate stature from the particular long bone.[6]

As evident from the earlier studies, osteometric standards vary between different population groups and also within a population group[1,19] due to diverse factors, including genetic, climatic, and nutritional status of the population, all of which are reported to have an effect on skeletal growth.[1] Thus, the need to establish population-specific standards in the analysis of skeletal remains has been underscored by contemporary researchers for better accuracy. It is important to acquire data from many skeletal components, especially the ones that are likely to withstand decay and be recovered in order to be able to assess stature in case only parts of corpses are found.[20]

An extensive search of the literature revealed that regression formulae for the estimation of the maximum length of the humerus from its fragments are not available for the contemporary population in Sri Lanka. Hence, the present study was carried out with the aim of establishing the correlation between the maximum length of the humerus and the measurements of its fragments, and to derive population specific regression models to estimate the maximum length of the humerus from its fragments in a contemporary Sri Lankan population.

Methodology

Approval from the institutional ethical committee was sought and obtained prior to data collection (ERC/FDS/UOP/1/2017/04). A total of 96 adult humeri (64 male and 32 female) were procured from the skeletal collection available in the Department of Basic Sciences, Faculty of Dental Sciences, University of Peradeniya, Sri Lanka. Any humerus that showed skeletal abnormality, signs of surgical procedures, or signs of healed fractures was excluded from the study. Measurements were obtained using an osteometric board and a digital vernier caliper (Mitutoyo, Japan) according to the standard procedures recommended in previous studies.[21]

Four measurements were obtained from each humerus.

Maximum length of humerus (MLH) - the direct distance from the most superior point on the head of the humerus to the most inferior point on the trochlea Transverse diameter of the head (TDH) - The horizontal distance between the lateral most points on the articular margin of the head.

Vertical diameter of head (VDH) - The direct distance between the most superior and inferior points on the border of the articular surface of the head taken at right angle to the transverse diameter. Epicondylar breadth of humerus (EBH) - The distance of the most laterally protruding point on the lateral epicondyle from the corresponding projection of the medial epicondyle.

To eliminate an inter-observer error all measurements were recorded by one investigator. To ensure the reliability of the measuring technique used in this study, Lin's concordance correlation coefficient of reproducibility (CCC) test was conducted before the commencement of the study by measuring ten humeri. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) software. Normality of distribution of data was verified using Kolmogorov-Smirnov test. Means, standard deviations, minimum and maximum values were generated for all measurements of the humerus. The relationship between the maximum length of a humerus and measurements of humeral fragments was assessed by Pearson's correlation coefficient.

Simple linear and multiple regression equations were computed for the estimation of the MLH from measurements of its fragments. The models with highest coefficient of determination (R2) and minimum standard error of the estimate (SEE) were selected as the best models to predict the MLH. An ANOVA was performed to verify the significance of the fitted model in predicting the MLH considering a p-value of < 0.05 as statistically significant.

Results

The results of the Kolmogorov-Smirnov test confirmed that the data are distributed normally (p > 0.05). Table 1 presents the mean, standard deviation, minimum and maximum values of all humeral measurements.

Table 01: Descriptive statistics for the measurements of the humerus (in mm)

Measurement	N	Minimum	Maximum	Mean	SD
MLH	96	243	348	303.76	20.81
TDH	96	32	44	38.67	3.30
VDH	96	33	48	40.59	3.58
EBH	95	48	65	54.97	4.57

Table 02: Pearson's correlations coefficients of measurements of fragments of humerus with MLH

Variable	Pearson's correlation coefficient	p-value
EBH	0.518**	< 0.001
VDH	0.669**	< 0.001
TDH	0.655**	< 0.001

**. Correlation is significant at 0.001 level (2-tailed).

All measurements of the fragments of humerus showed a positive correlation with MLH (Table 2}. The correlation coefficients ranged from 0.518 to 0.669. The VDH showed the highest correlation (0.669) with MLH (Table 2).

Table 3. Linear regression equations for the estimation of the MLH (in mm) using independent variables

Equation	R	R^2	Adjusted R^2	SEE	F-value	p-value
173.906+2.365*(EBH)	0.518	0.269	0.261	17.93	34.139	<0.001
146.133+3.883*(VDH)	0.669	0.447	0.441	15.55	76.053	<0.001
144.164+4.127*(TDH)	0.655	0.429	0.423	15.80	70.687	<0.001

Table 3 presents the linear regression equations that can be used in the estimation of MLH from independent measurements of fragments of humerus. The range of correlation coefficients for the equations varies between 0.518 and 0.669 while the SEE varies between 15.55and 17.93.

The regression model formulated using VDH presenting the highest correlation of 0.669 (with a SEE of 15.55) is the best estimator of MLH. The addition to and subtraction of SEE from the final estimate provides a range for MLH. Therefore, the maximum length of the humerus can be best estimated using VDH as shown below-

Maximum length of the humerus = 146.133+3.883 (VDH) ± 15.55

Regression equations that can be used to estimate the maximum length of the humerus incorporating different combinations of measurements of fragments of humerus are presented in Table 4. These equations resulted in stronger correlations (0.669 to 0.716) and accuracy rates than those established with single variables. The strongest correlation was observed for the regression model formulated using all three variables (TDH, VDH, and EBH) (p < 0.001) (Table 4). Therefore, the maximum length of the humerus can be best predicted by the following regression model using a combination of humeral fragments:

Maximum length of the humerus = 108.175+1.963*(TDH)+2.072 *(VDH)+0.647 *(EBH) ±14.79

Table 4. Multiple regression equations for the estimation of the MLH (in mm) using different combinations of measurements of fragments of humerus

Equation	R	R2	Adjusted R2	SEE	F - statistic	p - value
122.676+3.197*(VDH)+0.935 *(EBH)	0.687	0.47	0.46	15.31	41.17	< 0.001
122.133+2.358*(VDH)+ 2.222*(TD H)	0.709	0.50	0.49	14.83	46.99	< 0.001
118.289+1.102*(EBH)+ 3.357*(TDH)	0.678	0.46	0.45	15.49	39.16	< 0.001
108.175+1.963*(TDH)+2.072 *(VDH)+0.647 *(EBH)	0.716	0.51	0.49	14.79	31.89	< 0.001

Discussion

Previous studies have shown the usefulness of fragments of humerus in the estimation of its maximum length.[6,16,17,23–25] As humeri had not

before been analyzed in the Sri Lankan population for this purpose, the main aim of this study was to assess the reliability and accuracy of using measurements of humeral fragments to estimate the MLH. In spite of numerous studies available,[6-8, 12-18] the estimation of long bone lengths from fragmentary remains continues to be a demanding task as formulae derived for a particular population group cannot be applied to another due to genetic and other innumerable differences. As a result, a multitude of publications involving similar methodology based on the estimation of long bones lengths from fragmentary skeletal remains in different populations have arisen in recent times.
In the initial studies conducted for the purpose of reconstructing the length of the humerus, the researchers have utilized the measurements of linear segments of the humerus.[6,17] The approach followed in the present study is different. In this study in addition to the linear bone segments, transverse measurements were also utilized as in some recent studies.[23,25]

The maximum length of the humerus varied between 243.00 mm to 348.00 mm, with a mean of 303.86 mm in the present sample (Table 2). In a study conducted in a south Indian population [26] the mean humeral length was reported as 302.8 mm. In a study conducted in a north Indian population Devi et al.[23] observed the mean humeral length as 308.4 mm and 307.9 mm on the right and left side, respectively. The MLH described for Egyptians,[24] Brazilians[25] and the northern Thais[27] were 313.7 mm, 313.0 mm and 307.8 mm, respectively. Among different population groups the mean humeral length showed variation and it varied between 302 and 313 mm.

In the present investigation, the fragmentary measurements were acquired from the proximal and distal extremities of the humerus to assess their reliability in predicting MLH. All fragmentary measurements utilized in this study showed statistically significant positive correlations (R = 0.518 to 0.669) with MLH (Table 2), a result which is in agreement with previous studies.[23,24] Further, the study demonstrated the efficacy of fragments of the humerus in the estimation of its maximum length by generating regression equations.

The regression models formulated using single variables showed a moderately high degree of correlation with the MLH. When single variables were considered, the VDH emerged as the best predictor of the MLH. The VDH has been reported as the best single variable to predict the MLH in a south Indian (0.75)[26] and a Brazilian (0.71)[25] population. On the other hand, Devi et al.[23] reported that the best prediction of MLH was shown by the TDH on the right side (R=0.653) and upper epiphyseal breadth on the left side (R=0.540), emphasizing the need for population-specific standards.

Numerous studies[23,26] including the present one demonstrate that the regression equations formulated to predict the MLH using a combination of variables provide superior correlation with better accuracy rates (lower SEE). However, the combinations of variables giving better correlation varied among different population groups.[23,26] The best multivariate model to predict the MLH incorporated a combination of the vertical diameter of the superior articular surface and the transverse diameter of the inferior articular surface (R = 0.788, R2 = 6.20) in a south Indian population whereas in a north Indian population the combination of the upper epiphyseal breadth, lower epiphyseal breadth, transverse diameter of the head and the vertical diameter of the head formed the best model, with the multiple regression correlation increasing to a maximum of 0.716 on the right side and 0.575 on the left side. In the present study, the combination of the EHB, TDH and VDH provided the best multiple regression model to predict the humeral length, with a stronger correlation (R=0.716) emphasizing again the significance of establishing population specific standards.

In the present study, we analyzed the strength of the correlation between the maximum length of the humerus and its fragments. Correlation is the measure of the relationship between two variables. The moderate to high degree of positive correlations obtained in this study by simple and multiple regression analyses confirm the usefulness of fragments of the humerus in reconstructing the maximum length of humerus by formulating regression formulae.

Conclusion

In this study, the measurements obtained from the proximal and distal ends of humerus, demonstrated a moderately high degree of positive correlation with the MLH, substantiating the views expressed by previous researchers that the measurements of fragments of humerus may serve as reasonably good estimates of the MLH. Thus, in forensic analyses where only single variables are available, the MLH may be predicted with considerable accuracy by using the simple regression equations generated in this study. The multiple linear regression equations generated using a combination of fragmentary measurements enhanced the degree of accuracy in predicting the MLH. The multiple regression models presenting superior correlations (0.678 – 0.716) with lower error estimates (14.799 – 15.492) will be useful in estimating the MLH in medico-legal situations where several segments of a humerus are recovered.

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