Original Article

Regression equations for the estimation of radial length from its morphometry in South-West Nigerian population

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Abstract

Background to the Study: Where natural or man-made disasters present bone fragments as it occur in forensic cases, regression equations derived from measurement of these bones fragments have been used to determine the length of the intact long bone. This study reports on the morphometry of the radius and the estimation of its length using regression equations in a Nigerian population. **Methods:** The maximum length of the radius was measured using an osteometric board. The distal breadth, sagittal diameter at mid-shaft, transverse diameter at mid-shaft (TDM), vertical radial head height (VRHH), maximum head diameter (Max. HD), and minimum head diameter (Min. HD) were measured using digital vernier caliper while the circumference of the radial head and the circumference at the radial tuberosity were measured using an anthropometric tape. Pearson correlation and Persian regression were used to derive the liner regression equations for the measured parameters that showed a correlation with the length of the radius. **Result:** Estimation of the length of the radius from the measures of Max. HD, VRHH, and TDM were archived with relative accuracy. In deriving regression equations for the length of the radius of the right and left sides, irrespective of sides, the Max. HD and TDM were both significant in estimating the length of the radius; on the right side only the Max. HD exhibited significant correlation while on the left side, both the Max. HD and VRHH exhibited significant correlation. **Conclusion:** These findings may help in anthropometric, forensic, and archaeological investigation for the estimation of the stature of the remains of unknown bodies using regression equations and could serve as the basis of comparison for future studies in a Nigerian population.

Key words: Morphometry, Nigeria, radial length, regression

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BACKGROUND TO THE STUDY

Based on the principle that the dimensions of various long bones correlate positively with human stature (Simmons *et al*. 1990), forensic anthropologists are being able to employ multiple techniques to build the biological profile. When accidental or natural disasters occur with mass fatalities, victims' remains may be fragmented, scattered, and muddled together, making it difficult to build complete individual biological profiles. Pioneers of forensic estimation of stature from long bones including Pearson (1898), Dupertuis and Hadden (1951), Trotter and Gleser (1952) and Genovés (1967). Duyar and Pelin (2003) have suggested "estimations of stature are more accurate if different regression formulae are used for specific stature group." In a cadaveric study of the modern Thai's, Pureepatpong (2012) and found that the upper extremities present more accurate stature estimates than the lower extremities (except femur) in the males. On the other hand, femur, tibia, and fibula among the females presented more reliable stature estimates than the upper extremities. Marinkovic and Vilic (2012) studied the correlation between the lengths of the long bones of the forearm and the fibula with stature in a Serbian population and found that the length of long bones of the forearm and the leg are characterized by various degree of correlation with stature.

Population-specific linear regression formulae for stature estimation based on forearm bone length have been developed from several studies though with mixed results. Athawale (1963) used an Indian population to determine regression formulae for estimating stature from the forearm bones. His study indicates a more significant linear relationship between forearm length and stature than between either of the individual forearm bones and stature. However, a German study by Mall *et al*. (2001) found a weak and otherwise insignificant correlation between bones and living stature. However, Celbis and Agritmis (2006) found that the radius and ulna correlate strongly with stature in a modern Turkish population. Their study utilized recently deceased cadavers and concluded that linear regression formulae for males and females could be used to estimate living stature. Celbis and Agritmis (2006) study is important because it shows that measurement taken from the bones of cadavers might be just as useful as measurements taken from dried bones to estimate stature.

More frequently, bones presented in forensic cases are fragmented, which makes it difficult to estimate stature. Several studies have attempted to use bone fragments to estimate long bone length and thus, the living stature of an individual. A study by Steele and McKern (1969), using long bone fragments from prehistoric American population, measured the maximum lengths of the femur, humerus, and tibia and applied regression formulae to the bone lengths and found that utilizing specific segments of the humerus, femur, and tibia, they could estimate the corresponding long bone lengths and provide a reasonable estimate of living stature. Ivan *et al*. (2012) studied the morphometry of the distal radius and found that while the length of the radius correlates negatively with palmar tilt, it correlated positively with width of the distal radius.

Reports on the morphometric correlates of stature with individual long bone dimensions are rare in the scientific literature in the Nigerian population. A recent study by Esomonu *et al*. (2013) presented regression equations for estimation of the length of the humerus from its morphometry in a Nigerian population. In deriving the regression equations for the length of the humerus of the right and left sides, irrespective of sides, both the anatomical neck circumference (ANC) and the mid-shaft diameter were significant in estimating the maximum length of the humerus; on the right side, however, only the ANC exhibited significant correlation, while on the left side both the ANC and the most distal point of trochlea humeri exhibited significant correlation.

In the present cadaveric study, we characterized the morphometric dimensions of the radius bone in a South-West Nigerian population and derived regression equations for predicting the length of the bone using established morphometric protocols.

METHODS

Institutional Approval and Ethical Clearance

For this study, strict compliance with institutional rules regarding human experimental research was ensured. Since study specimens were selected from the cadaveric skeletal collection pooled and stored for research purposes in the Department of Anatomy, College of Medicine, University of Lagos, statutory written approval was obtained from the Departmental Research Ethics committee prior to the commencement of specimen collection and processing. Furthermore, as the study was developed in partial fulfillment of the requirement for the award of the degree of Masters of Science in Anatomy of the University of Lagos, ethical clearance was also obtained from the Research Grants and Experimentation Ethics Committee of the College of Medicine of the University of Lagos at the inception of the study (approval letter CM/COM/8/VOL.XI/2014).

Study Sample

A total of forty radius bones of unknown sex obtained from the anthropometric laboratory of the Department of Anatomy, University of Lagos were used in this study. These bones were pooled, with completely closed epiphyseal plates indicating that they belonged to adults. They were also identified as right or left bones separated and numbered to avoid repetition before measurements were taken. Measurements were taken directly on the bones using osteometric board for all length measures, anthropometric tape for all circumference measures, and digital vernier caliper calibrated to the nearest 0.01 mm for all other measures. Nine parameters were taken into consideration. As shown in the diagram, they include:

- Distal breadth (DB) is recorded from the most medial point of the ulnar notch to the most lateral point of the styloid process [Figure 1] (Knussman, 1980)
- Maximum length of the radius (MLR) is measured from the most proximal end on the radial head to the tip of the styloid process
- Sagittal diameter at mid-shaft (SDM) or minimum

MSD, is the distance between the anterior and posterior surface of the mid-shaft
- Transverse diameter at mid-shaft (TDM) or maximum MSD, is the distance from the medial to the lateral surface of the mid-shaft
- Vertical radial head height (VRHH) is the height of the radial head measured directly above the radial tuberosity
- Maximum head diameter (Max. HD) is the largest diameter taken while rotating the digital caliper around the radial head
- Minimum head diameter (Min. HD) is the smallest diameter taken while rotating the digital caliper around the radial head
- Circumference of the radial head is taken by placing the anthropometric tape measure around the radial head
- Circumference at the tuberosity (CT) is taken by placing the anthropometric tape measure around the contour of the tuberosity (Buikstra and Ubelaker, 1994).

All measurements were taken to the nearest centimeters [Plates 1-3 in the appendix]. Comparisons between right and left radii were performed for all the bony markers using Student's *t*-test. Analysis using Pearson correlation coefficient was carried out to assess the relationship between the markers and length. Regression analysis was also carried out to find the markers that were related to the length and for estimating the length using equations. Based on the regression analysis, regression equations were derived to construct the length of the radius bone from the significant bony markers. Multivariate regression equations were derived after excluding highly correlated markers using a stepwise method. Analysis was done using the Statistical Package for the Social sciences SPSS version 17.0 statistical package (Statistics Solutions,Inc.).

RESULTS

The results of this study are presented as descriptive statistics (mean ± SD), with their respective standard errors of estimate (SE) for the nine different anthropometric parameters for the right and left radii separately [Table 1] and the aggregated value for sex and side combined [Table 2]. All reported *P* values were >0.05 when the right and left radii were compared. The mean length of the right radius was 26.3 ± 1.6 cm while that of the left radius was 25.8 ± 1.9 mm [Table 1]. The mean

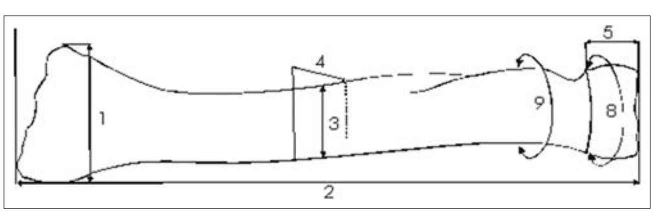

Figure 1: Measurement of the morphometry of radius

differences were not statistically significant. Except for the circumference of head of radius (CHR), all standard error estimates were well below 1.0.

Univariate regression analysis, which was employed for the calculation of the radial length from the three different humeral measurements, is presented in Table 3. The positive correlation with radial length were all significant except for the minimum height diameter (min.HD) for the left side and the circumference of the radial head (CHR) in both sides either separately and combined.

Table 4 presents the simple regression equations of the right, left and both sides of the radius, relating MLR with specific anatomical bony markers.

Multivariate linear regression equations to identify the dimension that best predicted the length of radius are given thus: Right = 20.537 + 2.758 Max. HD; Left = 17.760 + 2.648 Max. HD + 2.922VRHH; Both = 13.637 + 5.148 TDM + 2.288 Max. HD.

Figures 2-4 are linear regression scatter-plots for the anatomical bone mark dimensions with the best predictive values.

Table 1: Descriptive statistics of the right and left radius parameters

Variables	Left			Right			P
	Mean	SE	SD	Mean	SE	SD	
MLR	25.8048	0.41573	1.90512	26.3158	0.37691	1.64292	0.491
DB	3.2586	0.06993	0.32044	3.3242	0.06839	0.29811	0.518
SDM	1.1714	0.02859	0.13101	1.1295	0.03047	0.13282	0.350
TDM	1.4505	0.04148	0.19009	1.3968	0.4404	0.19198	0.219
VRHH	1.1495	0.04004	0.18351	1.1211	0.03274	0.14271	0.458
Maximum HD	2.2019	0.04977	0.22807	2.1579	0.07578	0.33033	0.274
Minimum HD	2.0857	0.04410	0.20210	2.0284	0.07724	0.33667	0.381
CHR	6.9000	0.15477	0.70922	6.9263	0.12327	0.53732	0.469
CT	4.9286	0.12250	0.56138	4.8368	0.11753	0.51230	0.289

MLR - Maximum length of radius, DB - Distal breadth, SDM - Sagittal diameter at mid-shaft, TDM - Transverse diameter at mid-shaft, VRHH - Vertical radial head height, HD - Head diameter, CHR - Circumference at the head of radius, CT - Circumference at the tuberosity, SE - Standard error, SD - Standard deviation

Table 2: Descriptive statistics of radius parameters of both right and left

Variables	Mean	SE	SD
MLR	26.0475	0.28168	1.78153
DB	3.2898	0.04868	0.30786
SDM	1.1515	0.02085	0.13188
TDM	1.4250	0.03012	0.19047
VRHH	1.1360	0.02592	0.16394
Maximum HD	2.1810	0.04403	0.27845
Minimum HD	2.0585	0.04304	0.27221
CHR	6.9125	0.9892	0.62560
CT	4.8850	0.08439	0.53376

MLR - Maximum length of radius, DB - Distal breadth, SDM - Sagittal diameter at mid-shaft, TDM - Transverse diameter at mid-shaft, VRHH - Vertical radial head height, HD - Head diameter, CHR - Circumference at the head of radius, CT - Circumference at the tuberosity, SE - Standard error, SD - Standard deviation

Table 3: Univariate analysis of the right, left, and both sides of the radius as correlated with the various bony markers

	Right				Left				Both			
Variables	**A**	**SE**	**B**	***P***	**A**	**SE**	**B**	***P***	**A**	**SE**	**B**	***P***
DB	12.231	0.769	2.852	0.001*	13.631	0.628	3.472	0.001*	12.889	0.691	2.241	0.001*
SDM	16.379	0.711	2.398	0.001*	13.680	0.712	2.761	0.001*	15.638	0.669	1.886	0.001*
TDM	18.106	0.687	2.126	0.001*	17.026	0.604	2.680	0.001*	17.990	0.604	1.737	0.001*
VRHH	20.733	0.433	2.844	0.001*	17.670	0.682	2.027	0.001*	19.061	0.566	1.668	0.001*
Maximum HD	20.537	0.557	2.785	0.001*	11.709	0.766	2.724	0.001*	17.481	0.614	1.801	0.001*
Minimum HD	20.798	0.627	2.019	0.000*	10.127	0.797	2.734	0.053*	17.929	0.603	1.759	0.001*
CHR	14.691	0.549	4.306	0.063	12.998	0.799	2.563	0.072	12.255	0.702	2.287	0.068
CT	17.266	0.584	3.072	0.001*	14.156	0.696	2.770	0.035*	15.817	0.645	2.072	0.001*

DB - Distal breadth, SDM - Sagittal diameter at mid-shaft, TDM - Transverse diameter at mid-shaft, VRHH - Vertical radial head height, HD - Head diameter, CHR - Circumference at the head of radius, CT - Circumference at the tuberosity, SE - Standard error, *$P<0.05$

Table 4: Simple regression equations of the right, left, and both sides of the radius, relating MLR with the bony markers

Right	Left	Both
12.231+2.852 DB	13.631+3.472 DB	12.889+2.241 DB
16.379+2.398 SDM	13.680+2.761 SDM	15.638+1.886 SDM
18.106+2.126 TDM	17.026+2.680 TDM	17.990+1.737 TDM
20.733+2.844 VRHH	17.670+2.027 VRHH	19.061+1.668 VRHH
20.537+2.758 maximum HD	11.709+2.724 maximum HD	17.481+1.801 maximum HD
20.798+2.019 minimum HD	14.156+2.770 CT	17.929+1.759 minimum HD
17.266+3.072 CT		15.817+2.072 CT

MLR - Maximum length of radius, DB - Distal breadth, SDM - Sagittal diameter at mid-shaft, TDM - Transverse diameter at mid-shaft, VRHH - Vertical radial head height, HD - Head diameter, CHR - Circumference at the head of radius, CT - Circumference at the tuberosity

DISCUSSION

Researchers have established that long bones correlate effectively with statures both in living and in cadaveric bodies. (Trotter and Gleser 1952, Ozaslan *et al*. 2003, Duyar and Pelin 2003, Hauser *et al*. 2005). The length of long bones has been estimated from bony markers. The length of the femur (Simmons *et al*. 1990), tibia (Chibba and Bidmos, 2006), humerus (Esomonu *et al*., 2013), femur, humerus and tibia (Steele and McKern, 1969), radius and ulna (Celbis and Agritmis, 2006) and radius (Holla *et al*., 1996) has been estimated using bony markers for application in fragmentary bony remains. Krishan and Ahilasha (2007)., Lundy and Feldesman (1987), and Trotter and Gleser (1952) agree that the use of regression formulae derived in a specific population can under or over-estimate stature when applied in another population. Therefore, all formulae used to estimate stature should be population-specific. Duyar and Pelin (2003) established that not only is there a need for different regression formulae between males, females, and different populations, but also that there is a possible need for different formulae between stature groupings. Thus, the present study provides regression formulae for stature estimation from fragmentary radii bones within the South-West Nigerian population, which is made up of a generous admixture of Nigerians drawn from several ethnic nationalities (NPC, 2006). The radii length estimates obtained using the formulae derived from the present study are the preliminary data formulae available for the Nigerian population as no literature exist for estimation of the Nigerian radius.

From the statistical analysis, the mean length of the right side is 26.3 ± 1.6 cm, and that of the left side is 25.8 ± 1.9 cm [Table 1]. When both sides were considered irrespective of sides, the mean was found to be 26.0 ± 1.8 cm [Table 2]. Thus, no statistically significant difference was found in mean between the right and left bony markers. Seven parameters on the right, left, and when both sides were considered irrespective of sides [Table 3] showed statistically significant correlation with the length of radius, leaving out only the circumference at the head of radius (CHR). When simple regression equation was carried out on the right, left, and on both sides to find the bony marker that could estimate the length of radius, it was seen that the same parameters showed significant correlations on the right and both sides. These include the DB of radius, the SDM, the TDM, the VRHH, the Max. HD, the Min. HD and CT of radius. On the left side, Min. HD did not correlate significantly with the length of the radius, but the other six parameters did [Table 4]. The correlation of DB with length of the radius agrees with the work of Ivan *et al*., (2012), where he reported that the distal diameter of the radius correlates well with the length of the bone. With multivariate analysis to determine which of the parameters correlate best, the Max. HD and VRHH correlate best, the Max. HD and VRHH correlate well on the left while on both sides the Max. HD and TDM correlate best.

CONCLUSION

The MLR can be estimated from a single fragment of the bone, whether at its proximal, middle or distal end using values of regression coefficient and intercept for known measurement of a significant marker. This research is a preliminary step in predicting the length of the radius and thus stature of an individual from bony markers of the radius bone in South-West Nigerian population. These

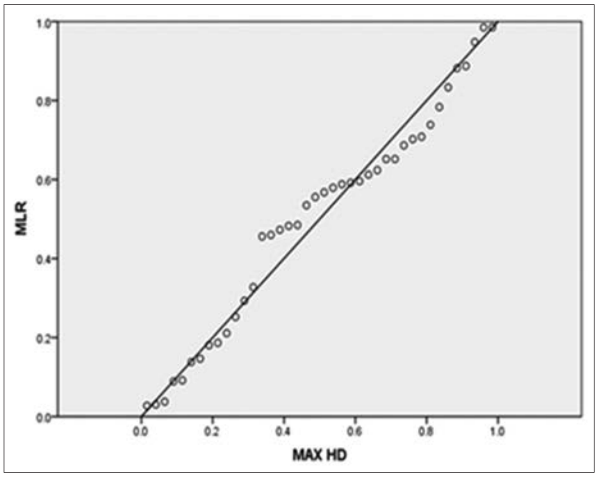

Figure 2: Scattered plot of maximum length of the radius against the maximum head diameter

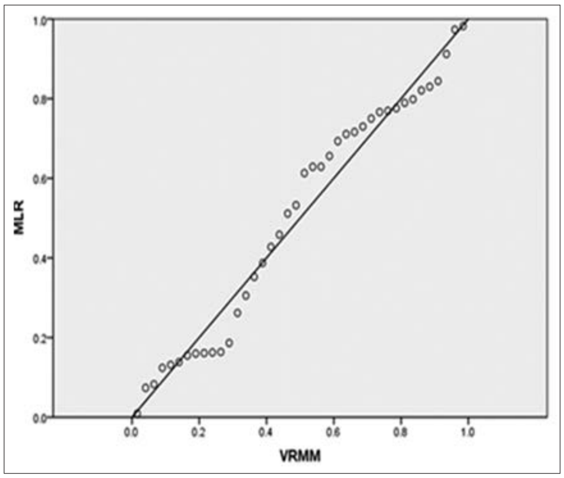

Figure 3: Scattered plot of maximum length of the radius against the maximum head height

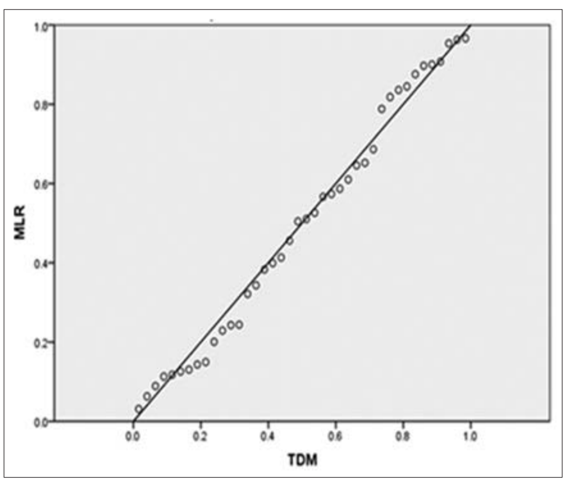

Figure 4: Scattered plot of maximum length of the radius against transverse diameter at mid-shaft

data are recommended to anthropologist, forensic experts, geneticist, and medical practitioners who may find it very useful and also serve as the basis of comparison for future studies on Nigerians.

APPENDIX

Plate 1: Measurement of maximum length of radius using a customized osteometric board

Plate 2: Measurement of maximum head diameter of the radius using a digital vernier caliper

Plate 3: Measurement of maximum distal breadth of radius using a digital vernier caliper

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