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Linear Models for the Prediction of Radial Length from its Dimensions on Bones and Radiographs in Adult Nigerians

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ABSTRACT
Estimation of the stature from long bones and sex differences has valuable impact in various medico-legal investigations. Differences in stature and bone dimensions exist between populations as a result of genetic differences, isolation, differences in bio-cultural history, geographical climate and nutrition. This study investigated the relationship between landmark dimensions of the radius and its length using bones and radiograph samples in adult Nigerian population and determines the most reliable dimension for predicting the length of radius. The anatomically defined anthropometric measurements taken on the bone were maximum length of radius, sagittal diameter at mid-shaft, transverse diameter at mid-shaft, vertical radial head height, maximum head diameter, minimum head diameter, circumference of the radial head, circumference at the tuberosity, distal breadth. On the radiographs, the maximum length of radius, transverse diameter at mid-shaft, vertical radial head height, diameter at the tuberosity and distal breadth were taken. All the dimensions showed statistical significant positive correlation with the length of radius except the distal breadth. Males showed higher mean length compared to females. The most reliable dimension for predicting radial length was the vertical radial head height and the transverse diameter at mid-shaft. Regression equations were developed for estimating radial length from the highly correlated parameters.

Key words: Radius, Length, X-ray radiographs, Dimensions, Regression equations

INTRODUCTION
The length of long bones has been shown to correlate with stature and thus used for statural estimation by several researchers [1, 2, 3, 4, 5, 6, 7]. Estimation of the length of bones as a means of differentiating between two or more individuals has valuable impact in various medico-legal investigations and can be applied during mass calamities[8]. Increase in the incidence of terrorist attacks, natural and man-made disasters has resulted in increased availability of grossly mutilated, dismembered and skeletonized human remains. These have presented forensic anthropologist with the burden of partial identification by compiling a biological profile thereby narrowing the possibility of identifying the individual[9].

Sex specific differences in stature have been noted to exist between populations as a result of genetic differences, isolation, differences in bio-cultural practise, climate and nutrition[10, 11] hence, the need for population specific regression equations. This study was aimed at evaluating the relationship between the landmark dimensions and the length of the radius using bones and x-ray radiograph among Nigerians.

MATERIALS AND METHODS
Six hundred radii pooled from Anatomical Museums and X-ray radiographs from hospitals within the six geo-political zones (Northeast, Northwest, North-central, Southeast, Southwest and South-south) of Nigeria were utilized. All samples were assessed to eliminate obvious pathological damages or inabilities to locate and identify landmarks. Only firmly and fully ossified bones were included. Radiographs used were the ones that showed the entire length of the bone with sharp image in the anterior-posterior view and with no case of trauma.

On the bony samples, a digital vernier caliper calibrated to 0.1 mm was used for measuring small dimensions. An anthropometric board calibrated to 0.1 cm was used for taking full length measures and an anthropometric tape calibrated to 0.1 cm was used for taking circumferential measures. On the x-ray radiographs, a transparent ruler calibrated to 0.1 cm was used for all measurements taken. Bones collected were identified and separated into right and left. The radiographs were separated as either belonging to male or female and then into rights and left. To eliminate bias, the same measurements were verified from 30 randomly selected samples and technical error of measurements calculated. The landmarks used in the study were as follows.

Measurements on the Bone: Maximum length of radius (MLR) was measured from the most proximal end on the radial head to the tip of the styloid process.

i. Sagittal diameter at mid-shaft (SDM) or minimum mid-shaft diameter: was measured as the distance between the anterior and posterior surface of the mid-shaft.
ii. Transverse diameter at mid-shaft (TDM) or maximum mid-shaft diameter: was measured as the distance from the medial to the lateral surface of the mid-shaft.
iii. Vertical radial head height (VRHH) was measured as the height of the radial head measured directly above the radial tuberosity.
iv. Maximum head diameter (Max.HD) was measured as the largest diameter taken while rotating the digital caliper around the radial head.
v. Minimum head diameter (Min.HD) was measured as the smallest diameter taken while rotating the digital caliper around the radial head.
vi. Circumference of the radial head (CRH): was taken by placing the anthropometric tape measure around the radial head.
vii. Circumference at the tuberosity (CT) was taken by placing the anthropometric tape measure around the contour of the tuberosity.
viii. Distal breadth (DB) was measured from the most medial point of the ulnar notch to the most lateral point of the styloid process[12, 13, 14].

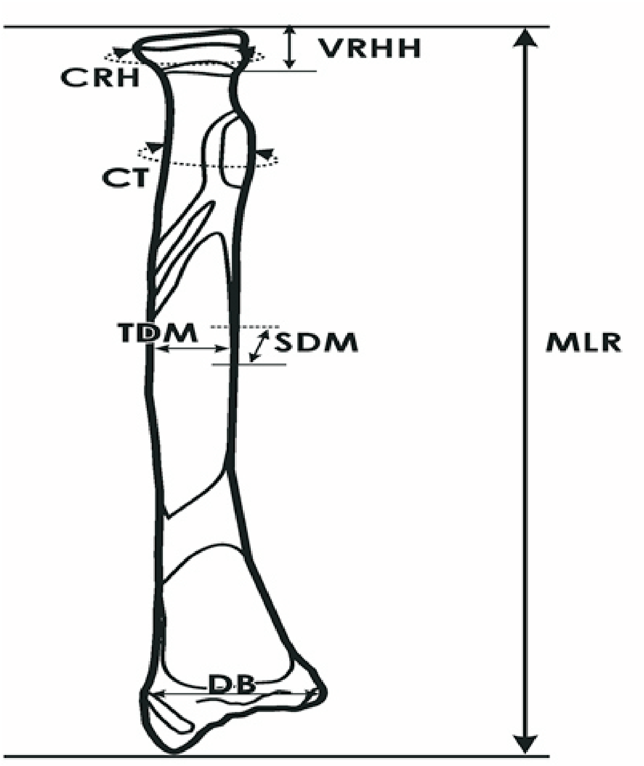

Figure 1: Diagram of the Radius

Measurements on the Radiographs:

i. Maximum length of radius (MLR) was measured from the most proximal end on the radial head to the tip of the styloid process.
ii. Transverse diameter at mid-shaft (TDM) or maximum mid-shaft diameter: was measured from the distance from the medial to the lateral surface of the mid-shaft.
iii. Vertical radial head height (VRHH) was taken as the height of the radial head measured directly above the radial tuberosity.
iv. Diameter at the tuberosity (DT) was measured as the distance from the medial to the lateral aspect of the tuberosity.
v. Distal breadth (DB) was measured from the most medial point of the ulnar notch to the most lateral point of the styloid process.

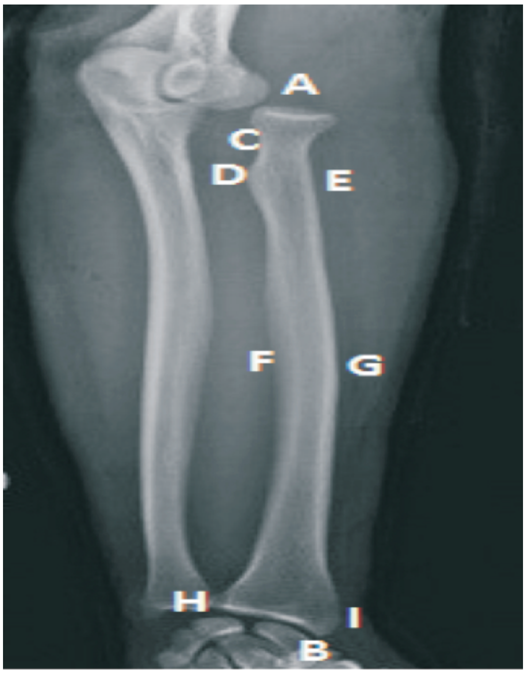

Figure 2: Radiograph image of forearm bones with landmarks indicated on the Radius. AB = Maximum length of radius (MLR), AC = Vertical radial head height (VRHH), DE = Diameter at the tuberosity (DT), FG = Transverse diameter at mid-shaft (TDM) and HI = Distal breadth (DB).

Statistical Analysis: To eliminate bias, the same measurements were verified from 30 randomly selected samples by two evaluators, the examiner and the recorder using the same unit and instrument and technical error of measurements were calculated. The intra- and inter- observer technical error of measurement (TEM) was calculated using [TEM = { $\sqrt{\sum D^2/2N}$}, where D = difference between the measurements, N = number of samples measured] and the coefficient of reliability was also calculated using [R = {1 - $(TEM)^2/SD^2$} where SD = standard deviation of all measurements] [15,16].

The mean, standard deviation, minimum, maximum and standard error were determined. Comparisons between the right and left variables were performed using student's t-test. Pearson's correlation coefficient was carried out to assess the relationship between the variables (independent variable, x) and length (ML – dependent variable, y). Regression analysis was undertaken to find the variables that relate to length and for estimating length using equations. Regression equations were derived to construct the length of each bone from the significant variables. Simple regression models at y = mx + c were derived, where 'c' is a constant, 'm' is the regression coefficient and the asterisk "*" denote significant values at $p<0.05$. After excluding highly correlated variables using a stepwise method, multivariate regression equations were derived and the most suitable parameter for predicting length was determined using the highly correlated variables. Analysis was done using SPSS (version 21) statistical package.

Ethical Clearance: Compliance with institutional rules with respect to human experimental research and ethics was strictly adhered to in the course of this study. Since bone specimens were selected from cadaveric skeletal collection pooled and stored for research and teaching purposes in the Department of Anatomy from Universities and radiographs from hospitals around Nigeria, written approval was obtained from the Human Research Ethics committee with reference number FCT/UATH/HREC/1085.

RESULTS

The technical error of measurement (TEM) for the bones and radiographs of radius are tabulated in Tables 1. The values of $R>0.95$ in all cases were regarded as reliable.

The mean length of radius using bones: the mean length for the right and left radius were 26.61 ± 1.68 cm and 26.14 ± 1.90 cm respectively. The mean length for the combined right and left variables using bones was 26.37 ± 1.81 cm. No significant difference in the mean length was observed between the right, left and the combined right and left variables. Pearson's correlation showed that all variables significantly correlated with the length of radius except the DB on the right side (Table 2).

The mean length of radius using x-ray radiographs: the mean length the right were 27.39 ± 1.35 cm for males and 25.82 ± 1.33 cm for females. For the left radius, the mean length was 27.39 ± 1.35 cm for males and 25.22 ± 1.56 cm for females. When the right and left variables were combined, the mean length was 27.22 ± 1.45 cm for males and 25.52 ± 1.49 cm for females. No significant difference was found in the mean length between the right, left and the combined parameters though males showed higher mean length than females in all categories. All variables correlated with the length of radius using Pearson's correlation (Table 4).

When all radial parameters from radiographs were combined irrespective of side or sex, the mean length was 26.42 ± 1.70 cm and all the variables correlated significantly with the length of radius (Table 6). Tables 3 and 5 shows summary of regression equations derived from Tables 2 and 4 respectively.

Table 1: Technical error for the measurement of radial parameters using bones and radiographs

		Intra-observer error				Inter-observer error			
S/N	Variables	TEM (b)	(r)	R(b)	(r)	TEM(b)	(r)	R (b)	(r)
1.	MLR	0.318	0.249	0.98	0.98	0.318	0.249	0.98	0.98
2.	VRHH	0.022	0.032	0.98	0.95	0.022	0.017	0.98	0.98
3.	MAX. HD	0.055	-	0.99	-	0.055	-	0.99	-
4.	MIN. HD	0.024	-	0.98	-	0.024	-	0.98	-
5.	CRH	0.158	-	0.98	-	0.158	-	0.98	-
6.	CT/DT	0.084	0.045	0.98	0.98	0.084	0.045	0.98	0.98
7.	SDM	0.024	-	0.99	-	0.024	-	0.99	-
8.	TDM	0.045	0.045	0.98	0.98	0.045	0.045	0.98	0.98
9.	DB	0.045	0.045	0.99	0.98	0.045	0.045	0.99	0.98

TEM = Technical error of measurement; R = coefficient of reliability, (b) = Bones, (r) = Radiographs, Number of bones

Table 2: Mean of the maximum length of radius and univariate analysis of the different parameters correlated with length of radius.

		Right N = 300				Left N= 300				Combined N = 600			
S/N	Variable	C	Mean ± SE	M	P-value	C	Mean ± SE	M	P-value	C	Mean ± SE	M	P-value
1.	MLR		26.61				26.14				26.37		
2.	VRHH	21.42	1.11 ± 0.01	4.67	0.000*	20.80	1.11 ± 0.01	4.82	0.000*	21.06	1.11 ± 0.01	4.79	0.000*
3.	MAX.HD	19.81	2.25 ± 0.01	3.03	0.000*	14.23	2.22 ± 0.01	5.38	0.000*	16.83	2.23 ± 0.01	4.28	0.000*
4.	MIN.HD	17.86	2.12 ± 0.01	4.13	0.000*	15.75	2.09 ± 0.01	4.97	0.000*	16.60	2.11 ± 0.01	4.64	0.000*
5.	CRH	19.45	7.07 ± 0.04	1.01	0.000*	10.86	6.92 ± 0.04	2.21	0.000*	14.85	6.99 ± 0.03	1.65	0.000*
6.	CT	18.93	4.93 ± 0.03	1.56	0.000*	14.39	4.93 ± 0.03	2.39	0.000*	16.54	4.93 ± 0.02	2.00	0.000*
7.	SDM	23.83	1.33 ± 0.01	2.09	0.000*	22.00	1.34 ± 0.01	3.09	0.000*	22.94	1.34 ± 0.01	2.57	0.000*
8.	TDM	21.67	1.34 ± 0.01	3.70	0.000*	20.13	1.32 ± 0.01	4.54	0.000*	20.85	1.33 ± 0.01	4.15	0.000*
9.	DB	26.37	3.34 ± 0.10	0.07	0.198	16.07	3.16 ± 0.02	3.19	0.000*	25.71	3.25 ± 0.05	0.21	0.000*

N = number of samples; C = regression constant; SE = standard error; M = coefficient of regression; * = significant at $p<0.05$ and Unit = cm.

Table 3: Summary of simple regression equations derived only from the correlated variables for estimating the length of radius were as follows:

S/N	Right	Left	Combined right and left
1.	L=21.418+4.668VRHH	L=20.798+4.817VRHH	L=21.055+4.790VRHH
2.	L=19.809+3.025Max.HD	L=14.228+5.375Max.HD	L=16.831+4.275Max.HD
3.	L=17.857+4.125Min.HD	L=15.748+4.969Min.HD	L=16.598+4.641Min.HD
4.	L=19.446+1.014CRH	L=10.859+2.209CRH	L=14.854+1.648CRH
5.	L=18.930+1.558CT	L=14.389+2.385CT	L=16.538+1.996CT
6.	L=23.831+2.087SDM	L=22.001+3.087SDM	L=22.939+2.571SDM
7.	L=21.670+3.699TDM	L=20.132+4.539TDM	L=20.853+4.153TDM
8.	-	L=16.073+3.189DB	L=25.707+0.205DB

Multivariate linear regression equations to identify the variables that best predict the length of radius were as follows:
Right = 7.636+5.126VRHH+5.968Max.HD
Left = 7.588+1.922Max.HD+2.056CRH
Combined = 8.241+2.237Max.HD+1.824CRH

Table 4: Mean of the maximum length of radius and univariate analysis of the different parameters of male and female radius from radiographs correlated with the length.

S/N	Variable	C	Mean ± SE	M	P-value	C	Mean ± SE	M	P-value	C	Mean ± SE	M	P-value
Males		Right	N = 158			Left	N= 158			Combined	N = 316		
1.	MLR		27.39				27.05				27.22		
2.	VRHH	23.94	1.13 ± 0.01	3.05	0.004*	24.65	1.15 ± 0.01	2.08	0.008*	24.63	1.14 ± 0.01	2.27	0.000*
3.	DT	26.41	2.58 ± 0.02	0.38	0.408	18.04	2.56 ± 0.02	3.52	0.000*	22.66	2.57 ± 0.01	1.77	0.000*
4.	TDM	24.47	1.40 ± 0.02	2.08	0.000*	23.52	1.40 ± 0.01	2.53	0.000*	24.02	1.40 ± 0.01	2.29	0.000*
5.	DB	27.43	3.51 ± 0.19	-0.01	0.799	17.89	3.29 ± 0.02	2.78	0.000*	27.11	3.40 ± 0.10	0.03	0.505
Females		Right	N = 142			Left	N= 142			Combined	N = 284		
1.	MLR		25.82				25.22				25.52		
2.	VRHH	23.36	1.10 ± 0.01	2.23	0.005*	20.62	1.07 ± 0.01	4.31	0.000*	21.69	1.09 ± 0.01	3.53	0.000*
3.	DT	19.12	2.44 ± 0.02	2.75	0.000*	16.97	2.43 ± 0.02	3.40	0.000*	17.97	2.43 ± 0.01	3.11	0.000*
4.	TDM	21.61	1.29 ± 0.01	3.25	0.000*	20.98	1.29 ± 0.02	3.29	0.000*	19.16	1.29 ± 0.01	3.31	0.000*
5.	DB	19.49	3.17 ± 0.02	1.99	0.000*	19.47	3.02 ± 0.03	1.90	0.000*	21.25	3.10 ± 0.02	2.05	0.000*

N = number of samples; C = regression constant; SE = standard error; M = coefficient of regression; * = significant at $p<0.05$ and Unit = cm.

Table 5: Summary of simple regression equations derived only from the correlated variables of the males and females radius for estimating length using radiographs was as follows:

S/N	MALES – Right	Left	Combined right and left
1.	L=23.935+3.050VRHH	L=24.652+2.083VRHH	L=24.630+2.268VRHH
2.	-	L=18.044+3.520DT	L=22.662+1.774DT
3.	L=24.470+2.079TDM	L=23.516+2.530TDM	L=24.018+2.286TDM
4.	-	L=17.893+2.782DB	-
	FEMALES		
1.	L=23.356+2.232VRHH	L=20.619+4.306VRHH	L=21.686+3.530VRHH
2.	L=19.119+2.750DT	L=16.972+3.395DT	L=17.966+3.105DT
3.	L=21.611+3.251TDM	L=20.983+3.294TDM	L=21.246+3.313TDM
4.	L=19.494+1.993DB	L=19.473+1.900DB	L=19.157+2.053DB

Multivariate linear regression equations to identify the variables that best predict the length of the males and females radius using radiographs were:

MALES Right = 22.449+2.111VRHH+1.816TDM
Left = 15.351+2.097DT+1.972DB
Combined = 20.375+1.641VRHH+1.038DT+1.645TDM

FEMALES Right = 16.364+1.417DT+1.715TDM+1.158DB
Left = 13.819+3.262VRHH+2.482DT+1.468TDM
Combined = 14.741+1.615VRHH+1.823DT+1.297TDM

Table 6: Mean of the maximum length of radius and univariate analysis of radius parameters irrespective of side or sex using radiographs.

S/N	Variables	C	Mean ± SE	M	P-value
1.	MLR	-	26.42	-	-
2.	VRHH	21.93	1.12 ± 0.01	4.02	0.000*
3.	DT	18.21	2.51 ± 0.01	3.28	0.000*
4.	TDM	21.38	1.35 ± 0.01	3.74	0.000*
5.	DB	25.85	3.26 ± 0.05	0.17	0.002*

Number of samples = 600; SD = standard deviation; C = regression constant; SE = standard error; M = coefficient of regression; * = significant at $p<0.05$ and Unit = cm.

Summary of simple regression equations derived only from the correlated parameters of the radius using radiographs irrespective of side or sex for estimating length were:

1. L=21.930+4.021VRHH
2. L=18.209+3.277DT
3. L=21.375+3.738TDM
4. L=25.848+0.174DB

Multivariate linear regression equations to identify the variables that best predict the length when all radiographs of radius were combined irrespective of sides or sex were: L=15.620+2.530VRHH+2.007DT+2.186TDM.

DISCUSSION

This work intends to provide forensic anthropologists and anatomist in general with a means of estimating the length of the radius through linear regression formulae from bones and x-ray radiographs among Nigerians.

In general, no significant difference in the mean length was found between the right and left radii. However, the males showed higher radial mean length compared to the females. These may be as a result of differences in pattern of physical activities; the males are exposed to a variable lifestyle compared to their female counterparts. It may also be a result of early attainment of adulthood of the female giving the male additional two or more years for further physical development[17, 18]. No significant difference was found between the mean length of the combined radiographs irrespective of sides or sex and the mean length from the combined bones. The present study agrees with the findings of Ibeabuchi *et al.*[5].

Ibeabuchi *et al.*[5] also noted that the maximum head diameter was the best predictor of radial length on the right side. The maximum head diameter and the vertical radial head height were the best predictors on the left side while the transverse diameter at mid-shaft and maximum head diameter were the best predictors of the length when the right and left radius parameters were combined. Our finding correspond with their work, only varying where we found the circumference at radial head (CRH) a better predictor of the length than transverse diameter at mid-shaft when the parameters were combined.

An Iranian population study reported the mean length of the radius according to age groups as being closely related between groups and found no significant difference in the mean length between the study groups[19]. However, gender difference was noted across the Iranian groups as in the present study. A remarkable difference in the mean length between males and females was reported by Mall *et al.*,[20] and Celbis and Agritmis,[21]. It is worthy of note that although the present study also showed a gender difference, higher mean length values in both sex were observed. This may be attributed to genetics, racial difference or difference in geographical location.

CONCLUSION

This study identified parameters from the bones and on its radiographs that correlate significantly with the length from which the length of the bone can be derived with relative accuracy. The best dimensions for estimating the length of radius were the vertical head height and the transverse diameter at mid-shaft. These findings is useful to obtain the length of the radius which can be employed in stature estimation in forensic case where difficulty exist in obtaining direct measurement such as in fragmented body remains among Nigerians.

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