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Humeral Length Estimation: Retrospective Radiological and Anthropometric Investigation

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Abstract

Researchers have made it possible to estimate the length of bones from their fragments in recent times; therefore, the stature can be estimated from the length of the bones so derived. The length of long bones has been the major means through which stature estimates were made. This study aimed to compare the length estimates of the humerus from anatomical landmarks (variables) on the bone and x-ray radiographs of humerus in adult Nigerians. 600 bones and 600 radiographs obtained from Anatomy museums and hospitals in the six geo-political zones of Nigeria were measured. The variables were regressed against the maximum length of humerus and all correlated positively. No significant difference in the mean value was found between bones and radiographs from these measurements. The differences in mean for all variables were seen to be significantly higher for males compared to females with the best predictor of length being the bi-epicondylar width. This finding is useful to anatomist, forensic anthropologist, archeologist and medico-legal cases for the identification of unknown body remains.

Keywords: Humerus; Radiographs; Regression; Length

Introduction

Estimating the human body height is generally based on two distinct standardized methods: the anatomical method, which often requires the presence of a complete skeleton, or the mathematical method, which on the other hand requires a complete bone and utilizes a set of regression formulae with or without multiplication factors to estimate the stature based on the correlation of individual measurements from annotated landmarks on bones [1]. Reports have established that a linear relationship exists between body height and various human body parts and also between body height and human bones [2-8]. The accuracy of estimating body height is higher when undamaged long bones of known sex and ethnic identity are available [9]. Equations based on measurements of long bones in the limbs using the Trotter and Gleser, (1958) [10] formulae are the most widely used amongst anatomists, anthropologists and forensic scientists. These formulae allow for standard error of estimate of approximately 3 to 5 cm for living stature [9].

However, a complete skeleton or an intact long bone may not be available when bodies are grossly dismembered or mutilated in wars, mass fatalities, and crimes. Therefore, the need to proffer a more practical and achievable alternative is to develop new standards that utilize different parts of the human skeletal remains. The estimation of length from the fragmentary remains found in a forensic or archeological investigation is an important step towards the identification of the deceased [11,12]. Forensic investigators have been faced with different fragmentary body parts due to increased natural and man-made disasters [10]. It is therefore important to put in place different means of identifying the individual where such occur.

Genetic differences between populations have made the use of same monogram for different populations erroneous [13]. Forensic anthropologists have put forward means to estimate the biological profiles of age, sex, race and stature from bones [14]. This study investigated the possibility of humeral length estimates using radiologic and anthropometric landmarks.

Materials and Methods

Six hundred humeri 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. As inclusion criteria, 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 carefully selected and only the samples that showed the entire length of the bone with clear image in the anterior-posterior view and without trauma were used.

On the samples, a digital vernier caliper calibrated to 0.1 mm was used for measuring small dimension; 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; while on the x-ray radiographs, a transparent ruler calibrated to 0.1 cm was used for all measurements taken. Bones collected were sex pooled but identified and separated into right and left.

Radiograph samples were separated as either belonging to male or female and then into rights and left. All samples were marked to avoid mix up and repetition. Only antero-posterior radiographs of this bone were used, hence only landmarks that were readable on these radiographs were measured. 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 landmarks used in the study were as follows:

Measurements from Humerus (Figure 1)

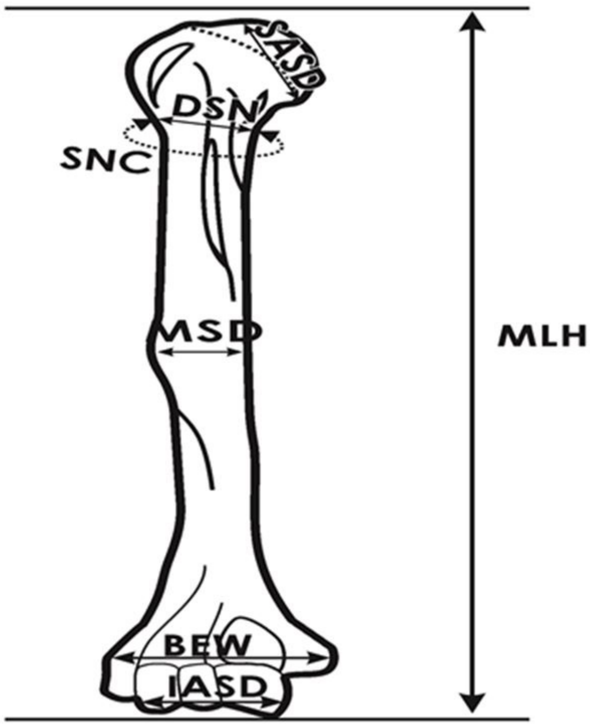


Figure 1: Diagram of the Humerus. Source: Computed by researcher

i. The maximum length of the humerus (MHL) was measured from the most proximal point on the head of the humerus to the most distal point on the trochlea.

ii. The vertical diameter of the superior articular surface (SASD) was measured as the maximum distance between two points on the head of the humerus, in the plane of the tip of greater tuberosity.

iii. Surgical neck circumference (SNC): was measured as the distance round the surgical neck of the humerus.

iv. Diameter of surgical neck (DSN): was measured as the maximum distance between two points on the surgical neck of the humerus, in the plane of the tip of greater tuberosity.

v. Mid shaft diameter (MSD): was measured as the transverse diameter at the level of the deltoid tuberosity.

vi. Olecranon vertical diameter (OVD): was measured as the distance between the most distal point and the most proximal point along the edge of the fossa olecrani.

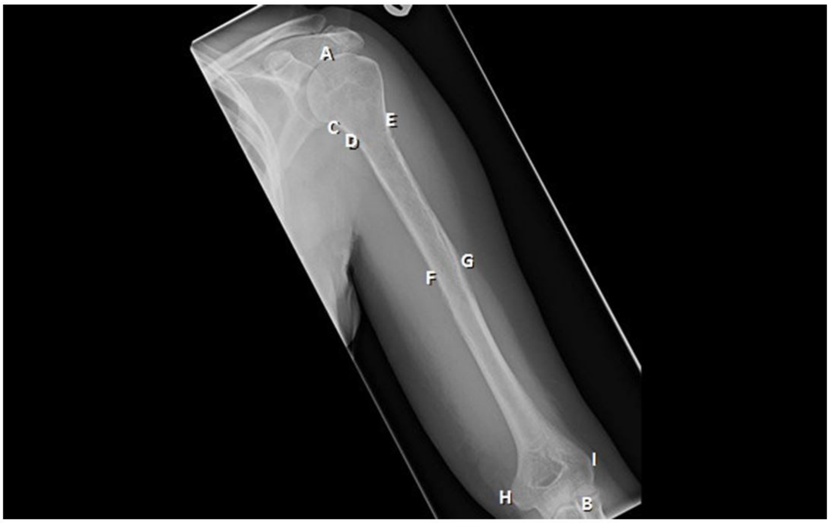
vii. Olecranon transverse diameter (OTD): was measured as the distance between the most medial point and the most lateral point along the edge of the fossa olecrani.

viii. The inferior articular surface diameter (IASD): was measured as the maximum combined width of the trochlea and the capitulum at the anterior surface.

ix. Transverse trochlea diameter (TTD): was measured as the distance between the medial and lateral ends of the trochlea.

x. The biepicondylar width (BEW): was measured as the maximum distance between the medial and the lateral epicondyles [15,16].

Measurements on the X-ray Radiograph of Humerus (Figure 2)



AB = Maximum length of humerus (MLH); AC = Superior articular surface diameter (SASD); DE = Diameter of surgical neck (DSN); FE = Mid-shaft diameter (MSD) and HI = Biepicondylar width (BEW)
Figure 2: Radiograph image of the Humerus. Source: Computed by researcher

i. The maximum length of the humerus (MLH): was measured as the straight distance from the proximal point on the head of the humerus to the most distal point on the trochlea.

ii. The diameter of the superior articular surface (SASD): was measured as the maximum distance between two points on the head of the humerus, in the plane of the tip of greater tuberosity.

iii. Diameter of surgical neck (DSN): was measured as the maximum distance between two points on the surgical neck of the humerus, in the plane of the tip of greater tuberosity.

iv. Mid shaft diameter (MSD): was measured as the transverse diameter at the level of the deltoid tuberosity.

v. The biepicondylar width (BEW): was measured as the maximum distance between the medial and the lateral epicondyles.

Statistical Analysis

The intra- and inter- observer technical error of measurement (TEM) of the anthropometric readings were calculated using [TEM = {√∑D2/2N}, where D = difference between the measurements, N = number of samples measured] and the coefficient of reliability was also calculated using [R = {1 - (TEM)2/SD2} where SD = standard deviation of all measurements], values of R ≥ 0.95 were regarded as reliable [17,18]. 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 and length. Regression analysis was undertaken to find the variables that relate to length and for estimating length from the significant variables using equations. After excluding highly correlated variables using a stepwise method, multivariate regression equations were derived and the most suitable variable for predicting length was determined using the highly correlated variables. Analysis was done using SPSS (version 21) statistical package and values at $p < 0.05$ were regarded as significant.

Ethical Clearance

Compliance with institutional rules with respect to human experimental research and ethics were strictly adhered to in the course of this study. Written approval was obtained from the Human Research Ethics Committee, University of Abuja Teaching Hospital with reference number FCT/UATH/HREC/1085.

Results

Table 1 show the technical error of measurements (TEM) for the bones and radiographs of humerus. The values of R > 0.95 were regarded as significant. The mean length of the right humerus was 32.73 ± 1.94 cm; the mean for left humerus was 32.80 ± 2.32 cm and the combined right and left humeri had the mean length of 32.77 ± 2.14 cm. No significant difference in the mean length was found between the right, left and the combined humeri from bones. All the variables correlated with the length of the humerus except the mid-shaft diameter and olecranon vertical diameter on the left (Table 2).

		Intra-observer error				Inter-observer error			
S/N	Variable	TEM (b)	(r)	R (b)	(r)	TEM (b)	(r)	R (b)	(r)
1.	MLH	0.30	0.318	0.98	0.98	0.30	0.318	0.98	0.98
2.	SASD	0.08	0.077	0.98	0.98	0.08	0.077	0.98	0.98
3.	SNC	0.13	-	0.98	-	0.13	-	0.98	-
4.	DSN	0.07	0.055	0.98	0.98	0.07	0.055	0.98	0.98
5.	MSD	0.03	0.032	0.99	0.98	0.03	0.032	0.99	0.98
6.	OVD	0.05	-	0.98	-	0.05	-	0.98	-
7.	OTD	0.06	-	0.98	-	0.06	-	0.98	-
8.	IASD	0.08	-	0.98	-	0.08	-	0.98	-
9.	TTD	0.05	-	0.98	-	0.05	-	0.98	-
10.	BEW	0.10	0.114	0.98	0.98	0.10	0.114	0.98	0.98

TEM = Technical error of measurement; R = Coefficient of reliability; (b) = Bones; (r) = Radiographs; Number of samples used = 30

Table 1: Technical Error from the Measurement of Humeral parameters using bones and radiographs

		Right N = 300					Left N = 300					Combined N = 600				
S/N	Variab	C	SE	Mean ± SD	M	P-value	C	SE	Mean ± SD	M	P-value	C	SE	Mean ± SD	M	P-value
	MLH			32.73 ± 1.94					32.81± 2.32					32.77±2.14		
1.	SASD	17.52	0.02	4.23 ± 0.33	3.59	0.000*	27.58	0.03	4.15 ± 1.26	1.26	0.000*	24.18	0.02	4.19 ± 0.40	2.05	0.000*
2.	SNC	24.44	0.04	7.90 ± 0.75	1.05	0.000*	21.27	0.04	8.11 ± 0.71	1.42	0.000*	23.10	0.03	8.00 ± 0.73	1.21	0.000*
3.	DSN	30.67	0.02	2.64 ± 0.42	0.78	0.003*	31.35	0.03	2.67 ± 0.51	0.55	0.037*	31.06	0.02	2.66 ± 0.47	0.64	0.001*
4.	MSD	28.86	0.02	2.06 ± 0.32	1.88	0.000*	31.47	0.02	2.01 ± 0.38	0.66	0.059	30.42	0.01	2.04 ± 0.35	1.16	0.000*
5.	OVD	31.10	0.02	1.81 ± 0.31	0.90	0.013*	31.99	0.02	1.77 ± 0.38	0.46	0.188	31.65	0.01	1.79 ± 0.35	0.62	0.013*
6.	OTD	29.74	0.02	2.53 ± 0.36	1.18	0.000*	30.81	0.03	2.51 ± 0.47	0.80	0.006*	30.40	0.01	2.52 ± 0.42	0.94	0.000*
7.	IASD	25.01	0.02	3.81 ± 0.41	2.03	0.000*	28.55	0.03	3.89 ± 1.80	1.12	0.000*	26.94	0.02	3.80± 0.43	1.54	0.000*
8.	TTD	32.10	0.02	2.24 ± 0.35	0.73	0.022*	31.10	0.02	2.25 ± 0.39	0.76	0.028*	31.10	0.15	2.25± 0.37	0.75	0.001*
9	BEW	23.35	0.03	5.89 ± 0.56	1.59	0.000*	23.92	0.03	5.84 ± 0.55	1.52	0.000*	23.67	0.02	5.87 ± 0.55	1.55	0.000*

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

Table 2: Descriptive statistics and univariate analysis of the different parameters correlated with length of humerus

Multivariate linear regression equations to identify the parameters that best predict the length of humerus were derived as follows:

Right = 15.697+2.594SASD+0.892MSD+0.684BEW

Left = 14.609+1.817SNC+1.103OTD+1.525BEW

Combined = 15.660+1.364SNC+1.414OTD+1.404BEW

Using x-ray radiographs, the mean length of the male right humerus was 33.65 ± 1.81cm and 31.67 ± 1.58 cm for females. The mean length for the males left humerus was 33.63 ± 1.93 cm and 31.68 ± 1.70 cm for females. When right and left were combined, the mean length was 33.64 ± 1.87 cm for males and 31.67 ± 1.64 cm for females. No significant difference in the mean length was found between the right, left and combined humeri though males showed higher humeral mean length compared to their female counterparts (Figure 3).

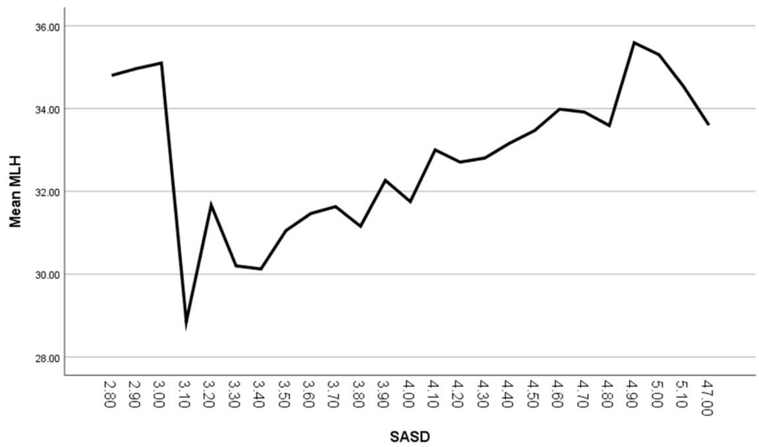


Figure 3: Line graph of Maximum length of humerus (MLH) against Superior articular surface diameter (SASD)

In both males and females on the right, all variables correlated with the length of humerus except the diameter at surgical neck. On the left, only the biepicondyle width correlated with the length in males. In females, all variables correlated with the length except the diameter at surgical neck. When the right and left variables were combined, the diameter at mid-shaft and the biepicondyle width correlated with the length of humerus in males while all the variables correlated with the length of humerus in females (Table 3) (Figure 4).

		Male right, N = 162					Male left, N = 162					Combined N = 324				
S/N	Variab	C	SE	Mean ± SD	M	P-value	C	SE	Mean ± SD	M	P-value	C	SE	Mean ± SD	M	P-value
	MLH			33.65± 1.81					33.63± 1.93					33.64± 1.87		
1.	SASD	21.18	0.03	4.34 ± 0.32	2.88	0.000*	33.57	0.27	4.45 ± 3.40	0.01	0.748	33.46	0.13	4.39 ± 2.41	0.04	0.356
2.	DSN	33.11	0.03	2.72 ± 0.41	0.20	0.578	32.88	0.05	2.67 ± 0.57	0.28	0.290	32.96	0.03	2.69 ± 0.50	0.25	0.227
3.	MSD	30.01	0.02	2.12 ± 0.29	1.71	0.000*	33.20	0.03	2.01 ± 0.43	0.22	0.544	32.24	0.02	2.06 ± 0.37	0.68	0.016*
4.	BEW	27.60	0.05	6.03 ± 0.57	1.00	0.000*	28.01	0.04	5.95 ± 0.56	0.95	0.000*	27.83	0.03	5.99 ± 0.57	0.97	0.000*
		Female Right, N = 138					Female Left, N = 138					Combined N = 276				
	MLH			31.67± 1.58					31.68± 1.70					31.67±1.64		
1.	SASD	18.18	0.03	4.10 ± 0.31	3.29	0.000*	25.70	0.03	4.10 ± 0.40	1.46	0.000*	22.86	0.02	4.10± 0.36	2.15	0.000*
2.	DSN	30.35	0.04	2.55 ± 0.42	0.52	0.111	29.99	0.04	2.67 ± 0.43	0.63	0.060	30.20	0.03	2.61 ± 0.43	0.57	0.014*
3.	MSD	29.77	0.03	1.99 ± 0.33	0.96	0.018*	29.49	0.03	2.01 ± 0.32	1.09	0.017*	29.64	0.02	2.00 ± 0.32	1.02	0.001*
4.	BEW	22.44	0.04	5.72 ± 0.50	1.61	0.000*	24.23	0.04	5.73 ± 0.51	1.30	0.000*	23.36	0.03	5.72 ± 0.50	1.45	0.000*

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

Table 3: Descriptive statistics and univariate analysis of the different parameters correlated with the length of male/female humerus using radiographs

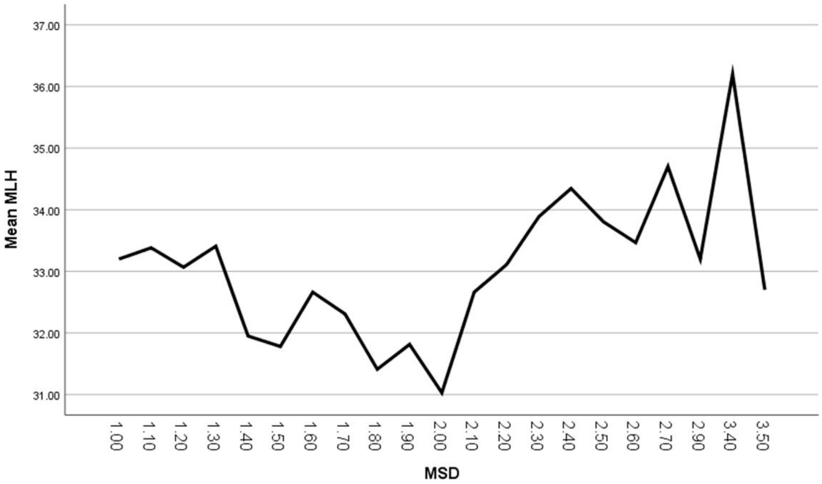


Figure 4: Line graph of Maximum length of humerus (MLH) against Mid-shaft diameter (MSD)

Multivariate linear regression equations to identify the parameters that best predict the length of male humerus using radiographs were as follows:

Right = 19.667+2.674SASD+1.126MSD

Left = 28.009+0.946BEW

Combined = 27.699+1.122BEW

Multivariate linear regression equations to identify the parameters that best predict the length of female humerus using radiographs were as follows:

Right = 17.331+2.747SASD+0.537BEW

Left = 23.999+1.051BEW

Combined = 21.668+1.402SASD+0.744BEW

When all data obtained from radiographs were combined irrespective of side or sex, the mean length of humerus was 32.74 ± 2.02 cm and all the measured variables correlated with the length of humerus (Table 4) (Figure 5). Multivariate linear regression equation to identify the parameter that best predict the length of humerus when all the radiographs were combined irrespective of sides or sex was: L= 23.258+0.654MSD+1.968BEW

S/N	Variables	Min.	Max.	Mean ± SD	C	SE	M	P-value
1.	MLH	26.20	43.00	32.74 ± 2.02	-	-	-	-
2.	SASD	2.80	47.00	4.26 ± 1.79	32.22	0.07	0.12	0.008*
3.	DSN	1.20	3.80	2.66 ± 0.47	31.26	0.02	0.55	0.002*
4.	MSD	1.00	3.50	2.04 ± 0.35	30.59	0.01	1.05	0.000*
5.	BEW	4.20	8.10	5.87 ± 0.55	23.80	0.02	1.52	0.000*

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

Table 4: Descriptive statistics and univariate analysis of humeral parameters using radiographs irrespective of side or sex

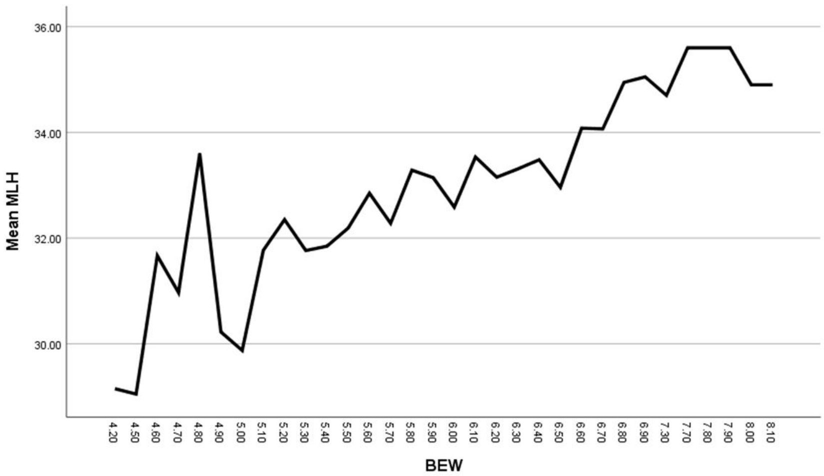


Figure 5: Line graph of Maximum length of humerus (MLH) against Biepicondylar width (BEW)

Discussion

This finding is in agreement with the report of Esomonu *et al,* (2013) [15] of northern Nigerian population. A study of the Munich and Cologne populations reported a similar humeral mean length in both males and females and also indicates a gender difference [12]. However, a Southern Nigerian population study [19] and a study of Maharashtra population [20] reported a lower humeral mean length.

The variables that best predict the length of the humerus from bones on the right side were the superior articular surface diameter, the mid-shaft diameter and the biepicondyler width. The surgical neck circumference, the olecranon transverse diameter and the biepicondyler width were the best predictors on the left side and when the right and left were combined. However, Esomonu *et al,* (2013) [15] reported the best predictor of humeral length was the anatomical neck circumference on the right and when the humeral variables from the right and left were combined. But on the left, the anatomical neck circumfrence and the distance between the proximal edge of the fossa olecrani and the most distal point of trochlea humeri were the best predictors of humeral length. Although the surgical neck circumference was found to be a significant parameter for estimating humeral length, the present study found the biepicondylar width (BEW) to be a better predictor of humeral length (Table 5).

References	Population	Unit (cm)	Unit (cm)	Unit (cm)	Best parameter for predicting length of humerus
Mall et al. (2001)	Munich and Cologne	Males 33.40 cm	Females 30.70 cm	Nil	Nil
Ebeye (2013)	Southern Nigerian	Males 31.12 cm	Females 28.81 cm	Nil	Nil
Esomonu et al., (2013).	Northern Nigerian	Right bones 31.4 cm	Left bones 31.3 cm	Combined right and left bones 31.3 cm	Nil
Borkar, (2014)	Maharashtra Males	Right 30.98 cm	Left 30.92 cm	Nil	Nil
	Females	28.27 cm	28.12 cm		
This study	Nigerians Bones	Right 32.73 cm	Left 32.80 cm	Combined right and left 32.77 cm	BEW
	Males radiographs	Right 33.65 cm	Left 33.63 cm	Combined right and left 33.64 cm	BEW
	Females radiographs	Right 31.67 cm	Left 31.68 cm	Combined right and left 31.67 cm	BEW
	All Radiographs Samples	males, females, Right and left		32.74 cm	BEW

Table 5: Mean humeral length in different populations

Conclusion

These findings reveal strong correlations between the various parameters taken from the bones and x-ray radiographs and the length of humerus. In forensic cases where a fragment of the bone is found, comparing the results of its estimate with that from an anti-mortem x-ray radiograph may reveal the likely identity of the individual. Therefore, this finding can be applicable for the identification of unknown body remains.

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