Original Research Article

Estimating Tibia Length: An Anatomical Landmarks Evaluation of Bones and X-ray Radiographs

Running head: Tibia Length Estimation Among Adults

Abstract

The ability to estimate the length of the bone is a major step towards estimating the stature of an individual in forensic investigation of mass fatalities where body parts are dismembered, scattered and mixed up. This is so because researchers have established that long bone length correlates with stature. Nine parameters of the tibia bone were measured using anthropometric board, anthropometric tape and digital caliper. Five of the nine parameters that could be read on anterior-posterior x-ray radiograph of the tibia measured using a transparent meter rule were used in this study. A total of 600 sample of N = 600, (300 right and 300 left bones) and (320 males: right = 160; left = 160; 280 females: right = 140; left 140 radiographs) obtained from Anatomy museums and hospitals in the six geo-political zones of Nigeria were used in this study. No significant difference ($p < 0.05$) in the mean value was found between measurements from the bones and those from the anteroposterior x-ray radiographs. The difference in mean for all variables were seen to be significantly ($p < 0.05$) higher for males compared to females. Results show that the tibia proximal breadth (TPB), medial-lateral diameter at mid-shaft (MLDM) and tibia distal breadth (TDB) were the best predictors of the length of tibia. Thus, in cases of mass fatalities as could happen in a plane crash or bomb blast, the estimate of the fragmented remains of the tibia, when compared with the estimate from an anti-mortem x-ray radiograph, may reveal the identity of the missing individual.

Key words: Estimation, Adults, Tibia, length, Regression

Introduction

Anthropometry is a systematic technique of measuring quantitatively the dimensions of the human body and the skeleton. Forensic anthropology, a sub-field of physical anthropology consists of the examination of skeletal animal remains, primarily for the purpose of identifying whether it belongs to human or not in a medico-legal setting (Bokariya, 2012). The biological profiles which include age, sex, race and stature are the primary distinguishing indicators in the process of identifying a missing person. Scientists have put in place diverse mean of identifying these attributes from skeletal remains. Stature estimation is more common with the use of the long bones since they relate directly with body height (Hasegawa *et al.,* 2009; NatthamonPureepatpong *et al*., 2012; Anitha *et al.* 2016; Spies *et al* 2019). Long bones that make up the greater proportion of stature like the femur and tibia are said to be more accurate than the other bones in estimating stature (Lundy and Feldesman, 1987). The ability to estimate the length of long bone from landmarks of their fractions has been reported by researchers (Celbis and Agritmis, 2006; Chibba and Bidmos, 2006; Ibeabuchi *et al*., 2017). It has been established that different regression formulae are required for different populations, for each different bone and also separately for each sex because variation in body proportions exists, making these formulae population and sex specific (Dupertuis and Hadden, 1951; Trotter and Gleser, 1952; Olivier *et al*., 1978; Lundy, 1983; Lundy and Feldesman, 1987). This study aims

to investigate if measurements from the x-ray radiographs can be used to estimate tibia length as those from the actual bone in the event of a disaster.

Materials and Method

Six hundred tibia pooled from Anatomical Museums and six hundred anteroposterior X-ray radiographs of tibia pooled from archived records in 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 ones that showed the entire length of the bone with sharp image in the anterior-posterior view and with no case of trauma were used.

On bony 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 measurements; while on the x-ray radiographs, a transparent ruler calibrated to 0.1 cm was used for all measurements. 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, using the same unit and instrument. The intra- and inter- observer technical error of measurement (TEM) of the anthropometric measurements 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] (Goto and Mascie-Taylor, 2007; Jaydip *et al.,* 2014). The landmarks used in the study were as follows:

Landmarks on bonny tibia (Fig. 1)

i. Maximum length of tibia (TML): was measured as the distance from the articular surface of the proximal end of tibia to the tip of the medial malleolus at the distal end.
ii. Tibia proximal breadth (TPB): was measured as the distance between the most projecting points on the medial and lateral condyles of the proximal articular region.
iii. Proximal shaft diameter (PSD): was measured as the maximum transverse distance of the proximal part of the shaft just inferior to the tibial tuberosity.
iv. Mid-shaft circumference (MSC): was measured as distance round the bone at the mid length of the bone.
v. Anterio-posterior diameter at mid-shaft (APDM): was measured as the anterior to posterior distance at the mid-shaft.
vi. Medio-lateral diameter at mid-shaft of tibia (MLDM): was measured as the distance from the medial aspect to the lateral aspect of tibia at the mid-shaft.
vii. Distal shaft diameter (DSD): was measured as the maximum transverse distance of the lower end of the shaft.
viii. Inferior articular surface length (IASL): was measured as the distance from the fibular notch to the articular facet of medial malleolus.
ix. Tibia distal breadth (TDB): was measured as the distance between the most projecting points on the medial and lateral surface of the distal articular region (Bass, 1995; Didia *et al*. 2009; Ugochukwu *et al*., 2016).

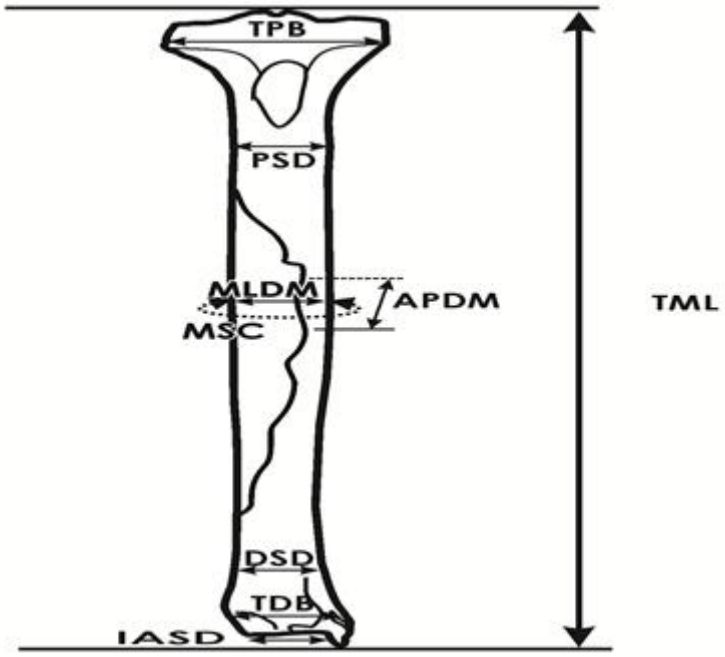

Figure 1: Diagram of the Tibia with landmarks indicated.

Measurements on the Radiograph of Tibia (Fig. 2)

i. Maximum length of tibia (MLT): was measured as the distance from the articular surface of the proximal end of tibia to the tip of the medial malleolus at the distal end.
ii. Proximal breadth of tibia (TPB): was measured as the distance between the most projecting points on the medial and lateral condyles of the proximal articular region.
iii. Medio-lateral diameter at mid-shaft of tibia (MLDM): was measured as the distance from the medial aspect to the lateral aspect of tibia at the mid-shaft.
iv. Inferior articular surface length (IASL): was measured as the distance from the fibular notch to the articular facet of medial malleolus.
v. Tibia distal breadth (TDB): was measured as the distance between the most projecting points on the medial and lateral surface of the distal articular region.

Statistical Analysis:

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 using equations. Regression equations were derived to construct the length of each bone from the significant variables. 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.

Figure 2: Radiograph image of the leg with landmarks indicated on Tibia.
AB = Maximum length of tibia (MLT), CD = Proximal breadth of tibia (TPB), EF = Medio-lateral diameter at mid-shaft of tibia (MLDM), GH = Inferior articular surface length (IASL) and HI = Tibia Distal Breadth (TDB).

Results

Technical error of measurement (TEM) with R>0.95 were regarded as reliable. Descriptive statistics were carried out to determine mean, standard deviation and standard error for the right and left sides, both right and left combined, then male and female (on radiographs) independently, then male and female combined. Student's t-test was applied and no significant difference were observed in the mean between right and left but the male showed higher mean values than female. The correlation coefficient between length (ML – dependent variable, y) and each of the measured variable (independent variable, x). Simple regression models at $y = mx + c$ were derived, where 'c' is a constant, 'm' is the regression coefficient and the asterisk "*" denotes significant values at $p<0.05$. To estimate the length of each bone from the dimensions measured, regression analysis was used to derive simple liner regression equations constructed using stepwise method. Multivariate linear regression equations to identify the dimension that best predict the length of each bone were then deduced. All measurements were taken in centimeters.

Eight variables were regressed against the maximum length of tibia (MLT). They were the tibia proximal breath (TPB), proximal shaft diameter (PSD), mid-shaft diameter (MSD), anterior posterior diameter at mid-shaft (APDM), medial-lateral diameter at mid-shaft (MLDM), distal shaft diameter (DSD), inferior articular surface diameter (IASD) and tibia distal breath (TDB). The technical error of measurement (TEM) for tibia and its radiographs, shown in Tables 1 and 4 had values of R>0.95 in all cases and were therefore regarded as reliable.

The mean length for the right tibia was 39.70 ± 2.75 cm with a range of 29.80 – 45.60 cm. The mean length for the left tibia was 39.74 ± 3.10 cm with a range of 28.40 – 45.60 cm. When both right and left variables were combined, the mean length was 39.72 ± 2.93 cm with a range of 28.40 – 45.60 cm. No significant difference in the mean length was found between the right and

the left tibia parameters (Table 2). All the variables were seen to correlate significantly ($p<0.05$) with the length of tibia (Table 3). With multivariate analysis, it was observed that the best predictors of the tibial length were TPB, MSC and MLDM for the right tibia. MSC and TDB were the best predictors of the length of the left tibia. When both right and left parameters were combined, MSC and TDB were found to be the best predictors of length.

Table 1: Technical error for the measurement of tibia parameters

S/N	Variables	Intra-observer error		Inter-observer error	
		TEM	R	TEM	R
1.	**TML**	0.473	0.98	0.455	0.98
2.	**TPB**	0.105	0.98	0.105	0.95
3.	**PSD**	0.071	0.98	0.063	0.99
4.	**MSC**	0.126	0.98	0.126	0.98
5.	**APDM**	0.055	0.98	0.055	0.98
6.	**MLDM**	0.055	0.98	0.055	0.98
7.	**DSD**	0.063	0.98	0.063	0.98
8.	**IASL**	0.032	0.99	0.032	0.99
9.	**TDB**	0.055	0.99	0.055	0.99

TEM = Technical error of measurement; R = coefficient of reliability

Table 2: Descriptive statistics of the mean and range of the different parameters of tibia

		Right N =300			Left N = 300			Combined N = 600
S/N	**Variable**	**Minimum**	**Maximum**	**Mean ± SD**	**Minimum**	**Maximum**	**Mean ± SD**	**Mean ± SD**
1.	**TML**	29.80	45.60	39.70 ± 2.75	28.40	45.60	39.74 ± 3.10	39.72 ± 2.93
2.	**TPB**	5.90	8.50	7.27 ± 0.51	2.80	8.70	7.42 ± 0.72	7.35 ± 0.63
3.	**PSD**	2.80	4.90	3.86 ± 0.39	2.60	4.80	3.73 ± 0.43	3.79 ± 0.42
4.	**MSC**	6.50	9.80	8.40 ± 0.65	6.30	9.80	8.42 ± 0.71	8.41 ± 0.68
5.	**APDM**	2.20	3.60	3.03 ± 0.30	1.70	3.90	3.08 ± 0.34	3.06 ± 0.32
6.	**MLDM**	1.50	3.10	2.24 ± 0.24	1.10	2.80	2.26 ± 0.28	2.25 ± 0.26
7.	**DSD**	2.60	4.80	3.64 ± 0.45	2.70	5.10	3.77 ± 0.62	3.71 ± 0.54
8.	**IASL**	2.30	3.90	3.07 ± 0.24	2.00	3.90	3.10 ± 0.32	3.09 ± 0.29
9.	**TDB**	3.20	5.00	4.31 ± 0.30	3.20	5.40	4.45 ± 0.43	4.38 ± 0.38

N = number of samples; SD = standard deviation; Unit = cm.

Table 3: Univariate analysis of the different parameters correlated with the length of tibia.

		Right N = 300				Left N= 300				Combined N = 600			
S/N	**Variable**	**C**	**SE**	**M**	**P-value**	**C**	**SE**	**M**	**P-value**	**C**	**SE**	**M**	**P-value**
1	**TPB**	13.77	0.03	3.56	0.000*	22.98	0.04	2.26	0.000*	20.17	0.03	2.66	0.000*
2	**PSD**	26.45	0.02	3.43	0.000*	30.14	0.03	2.58	0.000*	28.81	0.02	2.88	0.000*
3	**MSC**	21.54	0.04	2.16	0.000*	18.65	0.04	2.51	0.000*	19.97	0.03	2.88	0.000*
4	**APDM**	33.12	0.02	2.17	0.000*	27.35	0.02	4.02	0.000*	29.98	0.01	3.18	0.000*
5	**MLDM**	28.58	0.01	4.97	0.000*	27.21	0.02	5.54	0.000*	27.84	0.01	5.28	0.000*
6	**DSD**	34.63	0.03	1.39	0.000*	34.04	0.04	1.51	0.000*	34.33	0.02	1.45	0.000*
7	**IASL**	30.42	0.01	3.02	0.000*	30.07	0.02	3.12	0.000*	30.22	0.01	3.08	0.000*
8	**TDB**	16.68	0.02	5.34	0.000*	22.46	0.03	3.88	0.000*	21.29	0.02	4.21	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 4: Technical error for the measurement of tibia parameters using radiographs

S/N	Variables	Intra-observer error		Inter-observer error	
		TEM	R	TEM	R
1.	**TML**	0.513	0.98	0.511	0.98
2.	**TPB**	0.110	0.98	0.110	0.98
3.	**MLDM**	0.055	0.99	0.055	0.99
4.	**IASL**	0.032	0.98	0.032	0.98
5.	**TDB**	0.055	0.99	0.055	0.98

TEM = Technical error of measurement; R = coefficient of reliability.

Summary of simple regression equations derived only from the correlated variable for estimating the length of tibia were as follows:

Table 5 : Summary of simple regression equations derived only from the correlated variable

S/N	Right	Left	Combined right and left
1.	L=13.772+3.564TPB	L=22.984+2.259TPB	L=20.165+2.662TPB
2.	L=26.445+3.433PSD	L=30.138+2.576PSD	L=28.813+2.875PSD
3.	L=21.537+2.163MSC	L=18.652+2.505MSC	L=19.971+2.349MSC
4.	L=33.123+2.167APDM	L=27.354+4.022APDM	L=29.984+3.184APDM
5.	L=28.584+4.970MLDM	L=27.214+5.533MLDM	L=27.843+5.279MLDM
6.	L=34.626+1.392DSD	L=34.038+1.511DSD	L=34.331+1.453DSD
7.	L=30.415+3.021IASL	L=30.074+3.115IASL	L=30.219+4.207IASL
8.	L=16.680+5.339TDB	L=22.459+3.882TDB	L=21.285+4.207TDB

Multivariate linear regression equations to identify the variables that best predict the length of tibia were as follows:

Right = 9.410+2.838TPB+1.841MSC+1.988MLDM

Left = 15.289+1.666MSC+1.370TDB

Combined = 12.625+2.003MSC+1.739TDB

To estimate tibial length using x-ray radiographs, the variables measured were the maximum length of tibia (MLT), tibia proximal breadth (TPB), medial-lateral diameter at mid-shaft of tibia (MLDM), inferior articular surface length (IASL) and the tibia distal breadth (TDB). From the radiographs, it was found that the mean length for the male tibia was 40.73 ± 2.52 cm with a range of 32.10 – 45.60 cm for the right, 40.99 ± 2.73 cm with a range of 29.60 – 45.60 cm for the left and when right and left were combined, the mean length was 40.86 ± 2.63 cm with a range of 29.60 – 45.60 cm. No significant difference in the mean length was found between the right and the left parameters from radiographs (Table 6).

Pearson correlation showed that TPB, MLDM and TDB correlated significantly ($p<0.05$) with the length of tibia on right and left sides. When the right and the left were combined, all variables correlated significantly with the length of tibia (Table 7). Using multivariate analysis, it was observed that the best predictors of the length of tibia in male from radiographs were TPB, MLDM and TDB for the right side, TDB for left but when both sides were combined, TPB, MLDM and TDB were the best predictors of the length of tibia.

Table 6: Descriptive statistics of the mean and range of the different parameters of male tibia using radiographs.

		Right N =160			Left N = 160			Combined N = 320
S/N	**Variable**	**Minimum**	**Maximum**	**Mean ± SD**	**Minimum**	**Maximum**	**Mean ± SD**	**Mean ± SD**
1.	**MLT**	32.10	45.60	40.73 ± 2.52	29.60	45.60	40.99 ± 2.73	40.86 ± 2.63
2.	**TPB**	6.20	8.50	7.40 ± 0.47	2.80	8.70	7.57 ± 0.77	7.48 ± 0.64
3.	**MLDM**	1.50	3.10	2.27 ± 0.23	1.60	2.90	2.33 ± 0.25	2.30 ± 0.24
4.	**IASL**	2.40	3.50	3.10 ± 0.21	2.20	3.90	3.17 ± 0.28	3.13 ± 0.25
5.	**TDB**	3.50	4.90	4.39 ± 0.26	3.20	5.30	4.58 ± 0.37	4.48 ± 0.33

N = number of samples; SD = standard deviation; Unit = cm.

Table 7: Univariate analysis of the different parameters of male tibia using radiographs as correlated with the length.

		Right N = 160				Left N= 160				Combined N = 320			
S/N	**Variable**	**C**	**SE**	**M**	**P-value**	**C**	**SE**	**M**	**P-value**	**C**	**SE**	**M**	**P-value**
1	**TPB**	18.18	0.04	3.05	0.000*	32.28	0.06	1.15	0.000*	28.37	0.04	1.67	0.000*
2	**MLDM**	30.23	0.02	4.63	0.000*	32.96	0.02	3.45	0.000*	31.66	0.01	4.00	0.000*
3	**IASL**	38.45	0.02	0.74	0.437	36.17	0.02	1.52	0.051	36.83	0.01	1.29	0.029*
4	**TDB**	20.76	0.02	4.55	0.000*	27.65	0.03	2.92	0.000*	26.08	0.02	3.30	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 8: Descriptive statistics of the mean and range of the different parameters of female tibia from radiographs.

		Right N =140			Left N = 140			Combined N = 280
S/N	**Variable**	**Minimum**	**Maximum**	**Mean ± SD**	**Minimum**	**Maximum**	**Mean ± SD**	**Mean ± SD**
1.	TML	29.80	44.10	38.58 ± 2.56	29.60	43.70	38.34 ± 2.86	38.46 ± 2.71
2.	TPB	5.50	8.10	7.13 ± 0.51	5.60	8.40	7.23 ± 0.06	7.18 ± 0.64
3.	MLDM	1.50	3.10	2.21 ± 0.25	1.10	2.80	2.19 ± 0.03	2.20 ± 0.27
4.	IASL	2.20	3.90	3.04 ± 0.27	2.00	3.90	3.03 ± 0.03	3.04 ± 0.32
5.	TDB	3.20	5.00	4.23 ± 0.31	3.20	5.40	4.32 ± 0.04	4.28 ± 0.41

N = number of samples; SD = standard deviation; Unit = cm.

Table 9: Univariate analysis of the different parameters of the female tibia as correlated with the length using radiographs.

		Right N = 140				Left N= 140				Combined N = 280			
S/N	**Variable**	**C**	**SE**	**M**	**P-value**	**C**	**SE**	**M**	**P-value**	**C**	**SE**	**M**	**P-value**
1	**TPB**	14.06	0.04	3.44	0.000*	21.47	0.06	2.33	0.000*	19.34	0.04	2.67	0.000*
2	**MLDM**	29.16	0.02	4.27	0.000*	25.61	0.03	5.81	0.000*	27.05	0.02	5.19	0.000*
3	**IASL**	27.72	0.02	3.57	0.000*	28.86	0.03	3.13	0.000*	28.48	0.02	3.29	0.000*
4	**TDB**	17.95	0.03	4.88	0.000*	22.82	0.04	3.59	0.000*	21.87	0.02	3.88	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 10: Descriptive statistics of the mean and range of tibia parameters irrespective of sides or sex using radiographs.

S/N	Variables	Minimum (cm)	Maximum (cm)	Mean ± SD (cm)
1.	TML	29.60	45.60	39.74 ± 2.92
2.	TPB	2.80	8.70	7.34 ± 0.66
3.	MLDM	1.10	3.10	2.25 ± 0.26
4.	IASL	2.00	3.90	3.09 ± 0.29
5.	TDB	3.20	5.40	4.39 ± 0.38

Number of samples = 600; SD = standard deviation.

Table 11: Univariate analysis of the different parameters of tibia from radiographs irrespective of sides or sex.

S/N	Variables	C	SE	M	P-value
1.	**TPB**	21.843	0.027	2.438	0.000*
2.	**MLDM**	27.718	0.011	5.338	0.000*
3.	**IASL**	30.191	0.012	3.091	0.000*
4.	**TDB**	21.264	0.016	4.213	0.000*

Number of samples = 600; 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 variables of the male tibia for estimating length using radiographs were as follows:

Table 12: Summary of simple regression equations derived only from the correlated variables of the male tibia

S/N	Right	Left	Combined right and left
1.	L=18.183+3.047TPB	L=32.279+1.151TPB	L=28.368+1.669TPB
2.	L=30.229+4.631MLDM	L=32.958+3.448MLDM	L=31.660+4.003MLDM
3.	L=20.760+4.551TDB	L=27.653+2.916TDB	L=36.832+1.286IASL
4	-	-	L=26.084+3.297TDB

Multivariate linear regression equations to identify the variables that best predict the length of male tibia from radiographs were as follows:

Right = 20.078+2.350TPB+1.108MLDM+3.492TDB

Left = 25.998+2.017TDB

Combined = 25.925+1.046TPB+1.701MLDM+4.322TDB

The results from the radiographs of female showed that the mean length for the right was 38.58 ± 2.56 cm with a range of 29.80 – 44.10 cm and 38.34 ± 2.86 cm with a range of 29.60 – 43.70 cm for the left. When the right and left were combined, the mean length was 38.46 ± 2.71 cm with a range of 29.60 – 44.10 cm. Again, there was no significant difference in the mean length between the right and the left sides (Table 8). Pearson's correlation revealed that all variables correlated significantly ($p<0.05$) with the length of tibia (Table 9). Multivariate analysis revealed that the best predictors of female tibia length from the radiograph were TPB for the right side, MLDM and TDB for the left side. TPB, MLDM and TDB were seen to be the best predictors of tibial length when both sides were considered.

Summary of simple regression equations derived only from the correlated variables of the female tibia for estimating length from radiographs were as follows:

Table 13 Summary of simple regression equations derived only from the correlated variables of the female tibia

S/N	Right	Left	Combined right and left
1.	L=14.064+3.437TPB	L=21.472+2.334TPB	L=19.338+2.663TPB
2.	L=29.155+4.273MLDM	L=25.607+5.805MLDM	L=27.049+5.188MLDM
3.	L=27.720+3.568IASL	L=28.858+3.127IASL	L=28.481+3.285IASL
4.	L=17.947+4.878TDB	L=22.815+3.592TDB	L=21.868+3.880TDB

Multivariate linear regression equations to identify the variables that best predict the length of female tibia from radiographs were as follows:

Right = 14.064+3.437TPB

Left = 23.113+4.452MLDM+6.375TDB

Combined = 19.382+1.690TPB+1.876MLDM+2.658TDB

When all tibia parameters from radiographs were combined irrespective of sides or sex, the mean length was 39.74 ± 2.92 cm with a range of 29.60 – 45.60 cm (Table 10). All the variables were seen to correlate significantly with the length of tibia at $p<0.05$ level (Table 11). Multivariate analysis showed that TPB, MLDM and TDB were the best predictors of tibial length.

Summary of simple regression equations derived only from the correlated parameters of tibia for estimating length from radiographs were as follows:

1. L=21.843+2.438TPB
2. L=27.718+5.338MLDM
3. L=30.191+3.091IASL
4. L=21.264+4.213TDB.

Multivariate linear regression equation to identify the variable that best predicts the length of tibia form the parameters of the radiographs irrespective of sides or sex was:

L= 20.135+1.301TPB+1.941MLDM+4.357TD

Discussion

The ability to estimate the length of bones could be a lead way towards estimating stature and therefore identifying a missing person in a forensic investigation. This work provides forensic anthropologists and anatomist with a means of estimating the length of the tibia through linear regression formulae from fragmentary bones and x-ray radiographs among Nigerians.

The mean length of the tibia was 39.70 ± 2.75 cm for the right; 39.74 ± 3.10 cm for the left, and 39.72 ± 2.93 cm when the right and left parameters of the tibia were combined. The result showed no significant difference ($p<0.05$) in the mean length between the right and the left tibia, or between the combined tibial parameters and the separated right and left parameters. A study on a Nigerian population (Ugochukwo *et al.* 2016) reported a mean tibial length of 40.30 ± 4.32 cm for the right and 40.80 ± 3.91 cm for the left. Anitha *et al.,* (2016) also reported tibial mean length of 37.43 cm for the right and 37.50 cm for the left in a study of South Indian male subjects. These values correspond with the present work as the differences in mean length were of no significance. However, in a related study in the Nigerian population, the length of the tibia was measured in living subjects and the mean length for the male tibia was reported to be (46.66 cm) higher than the present study (Didia *et al*., 2009). The difference in the mean length may result from soft tissue interference.

Measurements from the radiographs show that the mean length for the right tibia in males was 40.73 ± 2.52 cm; 40.99 ± 2.73 cm for the left, and 40.86 ± 2.63 cm when the right and left parameters were combined. No significant difference in the mean length was found between the right and the left tibia from these radiographs. Also, the combined tibial parameters had no significant difference when compared to the separated right and left parameters. Thus, the length of the tibia from radiographs is not affected by the side from which the bone is taken from. Almost similar values were reported by Elhosary *et al.,* (2018) 37.76 ± 2.67cm for Egyptians males and 37.42 ± 2.37 cm for Bangali males respectively. Kavyashree *et al*., (2018) also reported the mean length of 38.52 for right and 38.56 cm for the left tibia respectively in their population. Contrary to these values, Anirban *et al*., (2013) reported a rather smaller value of 35.99 cm in males East Indian population. These variations in the mean length from different population group may be as a result of differences in genes or environmental factor.

The mean length for the right radiographs of female tibia was 38.58 ± 2.56 cm, 38.34 ± 2.86 cm for the left and 38.46 ± 2.71 cm when the right and left were combined. No significant differences were found in the mean length between the right and the left tibia, and when the combined parameter was compared to the separated right and left parameters. This indicates that the length of the tibia from female radiographs is also unaffected by the side from which the bone was derived. Elhosary *et al.,* (2018) reported the mean length of 34.93 ± 2.27 cm for Egyptian females and 34.22±2.74 cm for Bangali females respectively. Kavyashree, *et al.,* (2018) reported the mean length of female's tibia 33.96 cm for right and left 34. 03 cm. Anirban *et al*., (2013) reported 33.83 cm in females of East Indian population. The mean length is seen to vary with population indicative of the diversity in genetic materials. Didia *et al*., (2009) reported the mean length of 41.14 cm for the females. Didia *et al.,* (2009) values are rather high when compared to that of the present study. This may be as a result of soft tissues interference as compared to the present study which considered direct measurements on the bones and radiographs.

When all radiographs of tibia were combined irrespective of sides or sex, the mean length of tibia was 39.74 ± 2.92 cm. No significant difference in the mean length was found between the combined radiographs parameters and that of the actual bones 39.72 ± 2.93 cm. The best predictors of tibial length were TPB, MLDM and TDB. The results revealed that the mean length of tibia from the radiograph parameters were higher in the males than in the females. However, when the parameters were combined irrespective of sides or sex, the mean length showed no significant difference compared to that of the combined bone. Thus, the best predictor of the tibial length was TDB as indicated by all the sub-groups.

The tibia proximal breath (TPB), the mid-shaft circumference (MSC) and the medio-lateral diameter at mid-shaft (MLDM) were the best predictors of tibial length on the right using measurements from the bones while the MSC and tibia distal breadth (TDB) were the best predictors of tibial length on the left side and when the right and left bones were combined. The tibia proximal breadth (TPB), the medio-lateral diameter at mid-shaft (MLDM) and the tibia distal breadth (TDB) were the best parameters for predicting tibial length on the right side and when the right and left variables were combined but the TDB was the best variable for predicting tibial length for the left side using tibial measurements from the male radiographs. The tibia proximal breadth (TPB) was the best predictor of length on the right side from measurements of female tibial radiographs. The medio-lateral diameter at mid-shaft (MLDM) and the tibia distal breadth (TDB) were the best on the left side while TPB, MLDM and TDB were the best predictors of tibial length when the right and left variables were combined.

Conclusion

The present study shows that the estimate of the length of the tibia can be obtained from the measure of the proximal breadth of tibia, the medial-lateral diameter at the mid-shaft of tibia and the distal breadth of the bone with high level of accuracy. It also reveals that, when the measures derived from bones are compared to the estimate from the measures using an anti-morterm x-ray radiograph, the identity of an unknown person can be estimated. This study is recommended for tibia bone reconstruction in archeological, medico-legal as well as forensic cases.

Ethical Consideration:

Compliance with institutional rules with respect to human experimental research and ethics was strictly adhered to. Written approval was obtained from the Human Research Ethics committee with reference number FCT/UATH/HREC/1085.

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