Original article:

"Estimation of the length of the tibia from dimensions of the distal articular surfaces of the tibia in adult Kenyans"

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ABSTRACT:

Introduction: The present study was planned to determine the utility of distal tibial dimensions in estimation of the length of the tibia in a Kenyan population.

Materials and methods: A total of 156 tibiae were obtained for the present study from the Department of Human Anatomy, University of Nairobi and the osteology collection of the National Museums of Kenya, Nairobi. Measurements were taken directly from the bone using a digital pair of vernier calipers (Sealey Professional Tools™). Morphometric data were analyzed and measurements were expressed in means ± standard deviation. For those dimensions that showed a linear association with the length of the tibia, Pearson's correlation test was carried out. Linear regression to derive equations for estimation of the length of the tibia was carried out.

Results: The height of the fibular incisura, breadth of the medial malleolus and the length and width of the tibial plafond displayed moderate linear association with the length of the tibia. The linear regression models generated for length estimation yielded low coefficients of determination.

Conclusion: Though, it is possible to estimate the length of the tibia from its distal dimensions, caution should be observed when using these dimensions because the estimates from the equations incorporating them have low accuracy.

INTRODUCTION

In forensic analysis, the estimation of the stature is key in identification of an individual (Wright and Vasquez, 2003). The stature of an individual can be estimated from long bones especially the tibia and the femur as these have direct correlation to the height of an individual (Brickley and McKinley, 2004). The tibia is ideal in this application as it resists erosion and keeps its anatomical shape for long even after burial (Krici and Ozan, 1999). Estimation of stature from the length of the tibia has so far employed techniques that require well preserved tibiae (Duyar and Pelin, 2003; Lin *et al*., 2004). This is problematic to the forensic analyst working with fragmentary skeletal remains (Wright and Vasquez, 2003). In such situations, the estimation of the length of a bone from its fragments is important.

Inter-individual differences in osteometric parameters, which include the length of these bones, have been attributed to hormonal differences, differential loading at joints as well as differences in muscle bulk (Burghardt *et al*., 2010). The long bones of the lower limb display these differences clearly and have thus been used in forensic analysis for stature estimation (Brickley and McKinley, 2004). Mechanical loading is especially high in the distal ends of long bones of the lower limb and as such they display significant inter-individual differences (Burghardt *et al*., 2010). Since the distal tibia bears body weight in a relatively small surface area during the stance phase of gait, it is subjected to high biomechanical strains that in turn affect bone modeling (Burghardt *et al*., 2010). It is therefore plausible to postulate significant differences in distal tibial dimensions. Such differences in the dimensions of the distal tibia have been reported for the fibular incisura (Yildrim *et al*., 2003; Sora *et al*., 2004; Kin *et al*., 2008) the medial malleolus and the tibial plafond (Fessy *et al*., 1997). The use of these dimensions in estimation of the length of the tibia from skeletal remains has however not been reported. Moreover, due to populational differences exhibited by osteometric dimensions, formulae derived for a particular population are not applicable to other populations (Wright and Vasquez, 2003; Krishan, 2007). There is therefore need to obtain this information for the Kenyan population as there is scarcity of such studies on the indigenous Kenyan population.

MATERIALS AND METHODS

A total of 156 tibiae, obtained from the department of Human Anatomy and the osteology collection at the National Museums of Kenya (Nairobi), were used in the current study. These included tibiae, of both sexes, with completely closed epiphyseal plates indicating they belonged to adults. Tibiae with chipped condyles, malleoli and incisural tubercles or those that exhibited any sign of previous fracture in life were not included in the study. Measurements were taken directly on the bone using an osteometric board and a digital pair of vernier calipers (Sealey Professional Tools ™, United Kingdom; accurate to 0.01 mm) by the same author (MM).

To minimize intra-observer errors, several measurements of the same dimension were done and an average of these measurements recorded. The length of the tibia was measured using an osteometric board. This length was defined as the vertical distance from the most superior point on the medial tibial condyle to the most inferior point on the medial malleolus (Jantz *et al*., 1995).

On the fibular incisura, the following measurements were taken: the width of the fibular incisura which is the distance between anterior and posterior tubercles 1 cm proximal to the tibial plafond; the depth of the FI, the distance from the deepest point of the FI to a line between tips of the anterior and posterior tubercles and the height of the FI which is the vertical distance between the tibial plafond and the point where the interosseous border of the tibia splits into anterior and posterior edges (Taser *et al*., 2009). The dimensions of the medial malleolus (MM) measured included its height; the distance from its base at the tibial plafond to its tip and the breadth; defined as its anteroposterior length (Fessy *et al*., 1997). The width of the tibial plafond (TP) which is the mediolateral dimension of the talar facet at the middle of the joint and the length of the TP ; the anteroposterior dimension of the talar facet at the middle of the joint were also measured (DeSilva, 2008).

The means and standard deviations of the width, height and depth of the FI, the height and breadth of the MM and the length and width of the tibial plafond TP were calculated using SPSS software (Version 17.0, Chicago, Illinois). For those dimensions that displayed linear associations with the length of the tibia, Pearson's correlation test was carried out to establish the strength of the association. Linear regression to derive equations for tibial length estimation was carried out. Tables are used to present the data.

RESULTS

The mean± standard deviations in the sample population (n=156) of the dimensions of the tibia measured are presented in the table below:

Measure	Minimum	Maximum	Mean	Standard Deviation
Length of the tibia (cm)	30.7	45.5	38.2	2.75
Width of the tibial plafond (mm)	21.7	35.4	26.55	2.18
Length of the tibial plafond (mm)	21.7	36.2	28.61	2.39
Height of the fibular incisura (mm)	21.2	43.8	32.35	4.14
Depth of the fibular incisura (mm)	1.8	6.4	3.44	0.87
Width of the fibular incisura (mm)	10.1	26.6	21.50	2.37
Height of the medial malleolus (mm)	9.3	19.5	14.19	1.89
Breadth of the medial malleolus (mm)	16.8	27.8	21.88	2.22

SCATTER PLOTS SHOWING THE ASSOCIATION BETWEEN THE LENGTH OF THE TIBIA AND DISTAL TIBIAL DIMENSIONS

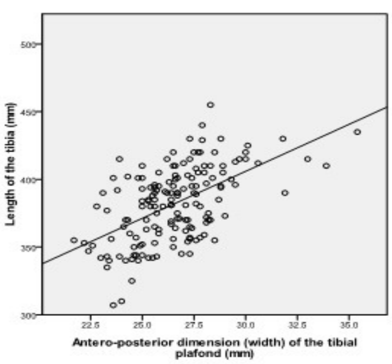

Figure 3: Scatter plot (length of the tibia against the width of the tibial plafond)

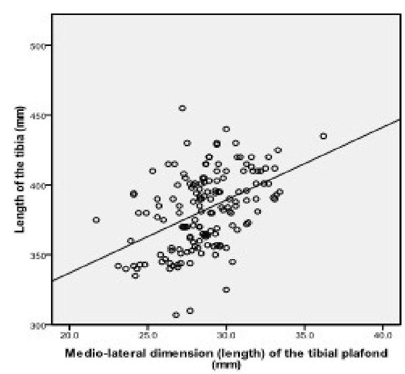

Figure 4: Scatter plot (length of the tibia against the length of the tibial plafond)

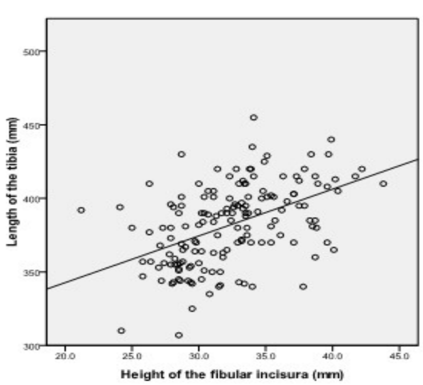

Figure 5: Scatter plot (length of the tibia against the height of the fibular incisura)

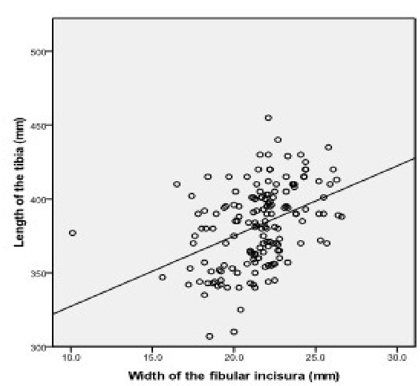

Figure 6: Scatter plot (length of the tibia against the width of the fibular incisura)

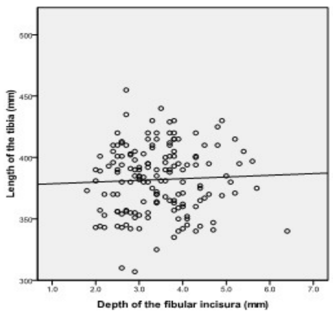

Figure 7: Scatter plot (length of the tibia against the depth of the fibular incisura)

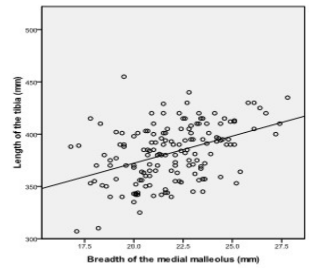

Figure 8: Scatter plot (length of the tibia against the breadth of the medial malleolus)

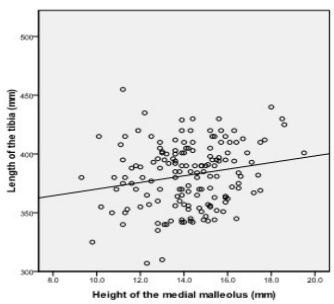

Figure 9: Scatter plot (length of the tibia against the height of the medial malleolus)

The length and the width of the tibial plafond, the height of the fibular incisura and the breadth of the medial malleolus displayed relatively strong linear association with the length of the tibia. Pearson correlation test to determine the strength of the linear associations between these distal tibial dimensions and the length of the tibia was carried out. The results are presented in the table below:

Table: Correlation between the length of the tibia and dimensions of the distal tibia

Length of tibia and:	Pearson's correlation	*p* value
Length of tibial plafond	0.454	<0.001
Width of the tibial plafond	0.551	<0.001
Height of fibular incisura	0.479	<0.001
Width of the fibular incisura	0.410	<0.001
Breadth of medial malleolus	0.419	<0.001

Models were generated to estimate the length of the tibia in millimeters from dimensions of the distal

The equations, correlation coefficients (r), coefficients of determination (R^2) and standard errors of the estimates (SEE) of each of the models are presented.

Equations for estimation of the right are presented below:

In these equations: WTP- Width of the tibial plafond; LTP- Length of the tibial plafond; HFI- Height of the fibular incisura; WFI- Width of the fibular incisura; BMM- Breadth of the medial malleolus.

Table: Linear regression models for estimation of the length of the right tibia from dimensions of the distal tibial articular surfaces.

Model	Equation	SEE	*r*	R^2
1	LT =215.50+WTP (6.23)	21.08	0.564	0.318
2	LT =159.77+WTP (5.11) + LTP (3.00)	20.12	0.621	0.386
3	LT=130.68+WTP (3.71) + LTP (3.20) + FIH (1.88)	18.86	0.683	0.467
4	LT=126.22+WTP(4.33)+LTP(3.87)+FIH(1.98)-WFI(1.62)	18.73	0.693	0.481
5	LT = 125.58+WTP (3.82) + LTP (3.75) + FIH (1.98)+ BMM (0.81) -WFI(1.59)	18.81	0.695	0.483

Equations for estimation of the left are:

Table: Linear regression models for estimation of the length of the left tibia from dimensions of the distal tibial articular surfaces.

Model	Equation	SEE	*r*	R^2
1	LT =171.34+WTP (7.98)	25.08	0.550	0.303
2	LT =156.78+WTP (6.40) + LTP (1.96)	25.00	0.563	0.317
3	LT=67.91+WTP (5.06) + LTP (2.63) + FIH (3.24)	21.29	0.715	0.512
4	LT=68.94+WTP(4.93)+LTP(2.44)+FIH(3.17)+WFI(0.47)	21.46	0.720	0.512
5	LT = 66.07+WTP (4.47) + LTP (2.283) + FIH (2.28)+ BMM (0.71) +WFI(0.64)	21.56	0.717	0.514

Equations for estimation of the length of the tibia for both the right and left tibiae are presented below:

Table: Linear regression models for estimation of the length of the left tibia from dimensions of the distal tibial articular surfaces.

Model	Equation	SEE	*r*	R^2
1	LT =176.99+WTP (7.49)	22.98	0.528	0.304
2	LT =159.66+WTP (5.45) + LTP (2.72)	22.36	0.588	0.337
3	LT=106.08+WTP (3.90) + LTP (3.17) + FIH (2.52)	20.04	0.691	0.478
4	LT=104.56+WTP(4.13)+LTP(3.44)+FIH(2.59)-WFI(0.66)	20.07	0.692	0.479
5	LT = 103.60+WTP (3.78) + LTP (3.34) + FIH (2.58)+ BMM (0.53) -WFI(0.60)	20.11	0.693	0.48

Among these models, model 3 is preferred because the inclusion of the width of the FI and the breadth of the MM in model 4 and 5 was not beneficial. The contribution of the width of the FI, indicated by the significance of its *t* statistic, to model 4 was not statistically significant (p=0.472). Similarly, the contribution of the width of the FI and the breadth MM to model 5 was not statistically significant (p = 0.520 and 0.594 for width of the FI and breadth of the MM respectively).

DISCUSSION

In forensic and archeological analysis of skeletal remains, estimation of stature of an individual is central as such data can be used in medico-legal cases to identify an individual and, in archeological studies, analysis of the nutritional status and general body size of the population (Udhaya *et al*., 2011). The tibia can be used in the estimation of stature as it displays significant inter-individual and sexual differences. The use of distal tibial dimensions, which are reported to display significant seual differences to estimate the length of the tibia is therefore useful in estimating the height of an individual. Pertinent to this is the fact that the systematic use of regression formulae derived in a specific population can under- or over-estimate stature when applied in another population (Krishan, 2007). Thus, authors have recommended that regression equations which are obtained in a certain population should not be applied to other populations (Wright and Vasquez, 2003; Krishan, 2007). In the current study, data was sex aggregated, though the greatest accuracy in estimating stature would be obtained when the sex was available (Scheuer, 2002). However, it has been noted that differences of the femur length were independent of sex. Therefore in our analysis both sexes were aggregated. Similar methods have been applied in the estimation of the length of the humerus (Udhaya *et al*., 2011).

In the estimation of the length of the long bone from its fragments, the use of accurately recognizable landmarks is mandatory (Krishan, 2007). Because of these reasons, the measures used to derive a regression equation to estimate the length of the long bones become limited (Udhaya *et al*., 2011). Usually, the transverse dimensions along the diaphysis are not appropriate for estimating the length because of their inability in defining the precise landmarks. Therefore, the only leftover location opts for measurements on the fragments of the proximal or distal diaphysis. Hence, for our present study, the dimensions of the distal segments of the tibia alone were selected. This is so because these dimensions are affected greatly by the modeling that results from intensive biomechanical loading at the ankle joint.

Several authors have derived linear regressions to estimate the maximum length of long bones from the measurement of its fragments in different populations (Mysorekar *et al*., 1980; Holland, 1996; Wright and Vasquez, 2003; Chibba and Bidmos, 2007; Salles *et al*., 2009). In our present study we also derived regression equations to measure the length of the tibia from dimensions of its distal articular facets, with right and left sides separately, in an indigenous Kenyan population, which has not yet reported.

The current study has demonstrated moderate correlations between the dimensions of the distal tibia and its length. The length of the tibia shows positive correlation with the width of the tibial plafond (r= 0.551), the breadth of the medial malleolus (r=0.419) and the height of the fibular incisura (r=0.479). These findings concur with and extend the findings by Taser *et al*., (2009) who demonstrated correlations between the length of the tibia and the dimensions of the fibular incisura (Taser *et al.*, 2009). Determination of the length of the tibia is important in the estimation of stature (Duyar and Pelin, 2003; Brickley and McKinley, 2004). Since these dimensions display positive correlation with the length of the tibia, they can be used in estimation of the length of the tibia. However, caution should be observed when they are used in this regard because the moderate positive correlations observed imply that their use in estimation of the length of the tibia would yield low accuracies. The equations derived for length estimation showed strong positive correlations and low coefficients of determination. This indicates that estimates obtained in their use would have lower accuracy compared to incorporating the distance between the tibial plateau and plafond, and other landmarks along the length of the shaft of the tibia used by previous workers (Mysorekar *et al*., 1984; Holland, 1996; Wright and Vasquez, 2003; Chibba and Bidmos, 2007). The equations derived in the current study may however be more be useful in analysis of more fragmentary tibiae. Though useful in this regard, these equations should be applied cautiously due to the low accuracy yielded.

CONCLUSION

Though it is possible to estimate the length of the tibia from the dimensions of the fibular incisura, tibial plafond and medial malleolus, caution should be applied in this regard as the equations incorporating these dimensions have low accuracies.

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