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Estimation of Femoral Length Through Fragmentary Bone Dimensions

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ABSTRACT Bone fragments have often been neglected by most researchers assuming no relevant information can be obtained from such remains. The present study aims at formulating means of reconstruction of femoral length from fragmentary measurements pertaining to multiple dimensions of the femur unlike earlier studies where a single (linear or transverse) dimension is used. A total of 288 femora, belonging to 82 male and 62 female documented skeletons have been measured for fifteen linear, transverse, sagittal and circumferential measurements along with maximum length. All the skeletons belonged to the residents of Madhya Pradesh, India. Analysis of data reveals non-significant bilateral differences in all the fragmentary dimensions of the femur, but the sex differences are highly significant at the $P<.01$ level. Thus, the sexes have been dealt with separately for computation of linear and multilinear regression formulae. Shaft length shows the highest correlation with the femoral length and proves to be the best single predictor of bone length for either sex. This is followed by the upper epiphyseal breadth for males and bicondylar breadth for females. Ten out of fifteen fragmentary measurements contribute to formulate four multiple regression equations for both sexes. The equation based on two linear, one transverse and a circumferential measurements proves to be the best indicator of femoral length.

INTRODUCTION

The stature of an individual is a descriptive characteristic which after death can contribute immensely to identification. But this characteristic is not as important as, for example, age, sex and race. When a dead body has become skeletonised and the anatomical relationship of individual bones is lost, a single intact long limb bone can help in estimation of stature as there exists a relatively high correlation between limb bone length and stature (Steele, 1970). But what should be done if only fragments of limb bones have survived as a consequence of mass disaster?

A solution to such problems was suggested by Gertrude Muller way back in 1935, who provided a scientific basis for the estimation of bone lengths through their fragments. For this purpose Muller examined the humerus, radius and tibia and identified several landmarks on these bones to measure certain linear segment lengths and calculated the mean per cent total length of these segments to estimate bone lengths. Bone lengths, thus estimated can then be used to reconstruct stature using appropriate regression formulae. However, such statural estimates would normally have higher standard deviations than the ones based on intact bones (El-Najjar and McWilliams, 1972).

Subsequently, Steele and McKern (1969) realized the value of Muller's technique in estimating total lengths of broken or fragmentary bones and employed the least squares method of factor analysis to formulate sex specific regression equation for each segment and for combination of certain segments of the femur, tibia and humerus. They used the femur instead of radius on the premise that the femur, besides being the longest bone of the body, is more closely related to stature than do the radius. Steele (1970) went a step further and used these segment lengths for direct estimation of stature, thereby reducing the standard deviation and established sex and race specific standards for American Whites and Blacks.

In a recent study Simmons et al. (1990) have revised the technique for estimation of stature from fragmentary femora by incorporating eight linear and transverse measurements. Their prediction equations are based on distinct anatomical landmarks which are easy to locate and thus constitute a definite improvement in the accuracy of stature reconstruction in comparison to Steele's (1970) method.

In India, Chandra et al. (1966) used four linear segment lengths and one transverse dimension (bicondylar breadth) of 200 femora to estimate femoral length using Mullers method (1935).

Mysorekar et al. (1980, 1982, 1984) used one-to-two linear dimensions of upper and/or lower ends of femur, radius, humerus, ulna and tibia to formulate regression equations for estimation of respective bone lengths (incidently their articles are entitled as estimation of stature from parts of bones but they provide formulae for estimation of bone length only and not stature). Chandra and Nath (1984, 1985), on the other hand, used a single transverse dimension of the humerus and femur to compute a multiplication factor (MF) for the reconstruction of bone lengths. Rao et al. (1989a, b) used linear segment lengths of upper extremity bones to reconstruct their respective lengths following Muller's (1935) method. Gupta and Nath (1996, 1997a, b) used linear segment lengths of femur, tibia, fibula, humerus and radius to reconstruct respective bone lengths from their fragmentary dimensions.

Departing from the tradition of considering either linear segment lengths or a transverse dimension, Badkur and Nath (1989, 1990 a) used a set of linear, transverse, sagittal and circumferential dimensions of the humerus and ulna to formulate linear as well as multilinear regression equations for estimation bone length and stature. Badkur and Nath (1990 b) and Nath and Badkur (1990) using a similar set of fragmentary measurements on the radius formulated regression formulae for the reconstruction of bone length and stature respectively. Nath and Badkur (1995) and Nath et al. (1995) used multiple dimensions of femur and formulated regression equations for prediction of stature directly from bone fragments.

In the present study, an attempt has been made to formulate sex-specific linear and multilinear regression formulae for the estimation of femoral length using a total of fifteen fragmentary measurements pertaining to linear, transverse, sagittal and circumferential dimensions of the femur.

MATERIAL AND METHODS

Data for the present study is comprised of 288 femora of both sides, belonging to 82 male and 62 female skeletons assigned to the Medicolegal Institute, Bhopal, Madhya Pradesh, for forensic examinations. All the skeletons belonged to residents of Madhya Pradesh in India. The skeletons were well documented for sex and stature, and ranged in age from 20 to 35 years. The documented records provided information with regard to place of residence but not their actual socio-economic status.

A total of 16 linear, transverse, sagittal and circumferential measurements were obtained on well macerated right and left femora with cartilage removed after sufficient time to assure complete drying of the bones. Details of the measurements have been described elsewhere (Nath and Badkur, 1995 and Nath et al., 1995). All the measurements, including the maximum length were taken by one of the author (P.B.) following the standard measurement techniques (Table 1; Fig. 1) recommended by Martin and Saller (1959) and Bass (1971).

Table 1: List of measurements used for estimating bone length from femoral fragments

Fig. I	*Measurements*
a-c	Head height (HH)
c-c$_1$	Neck height (NH)
b-d$_1$	Trochanteric height (TH)
d-e	Shaft length (SL)
e-h	Height of medial condyle (HMC)
f-g	Height of patellar surface (HPS)
a-h	Maximum length (ML)
	Upper epiphyseal breadth (UEB)
i-i$_1$	Upper shaft diameter (USD)
j-j$_1$	Mid-shaft diameter (MSD)
k-k$_1$	Lower shaft diameter (LSD)
l-l$_1$	Bicondylar breadth (BB)
	Sagittal diameter at the midele (SDM)
	Upper shaft circumference (USC)
	Mid-shaft circumference (MSC)
	Lower shaft circumference (LSC)

RESULTS

Preliminary examination of the data reveals greater dimensions of left side bones over the right ones among males and a reverse trend among female bones. Despite certain minute variations, the bilateral differences are statistically non-significant for both the sexes. Owing to non-significant bilateral variation in all the 16 measurements, the sides have, thus, been pooled to determine the sex differences.

Table 2 displays the pooled mean values of the 16 femoral measurements along with their respective standard errors. Male femora exhibit larger dimensions for all measurements and the differential trands as assessed through the t-test, reveal highly significant sex difference for all the measurements at the $p < .01$ level of significance,

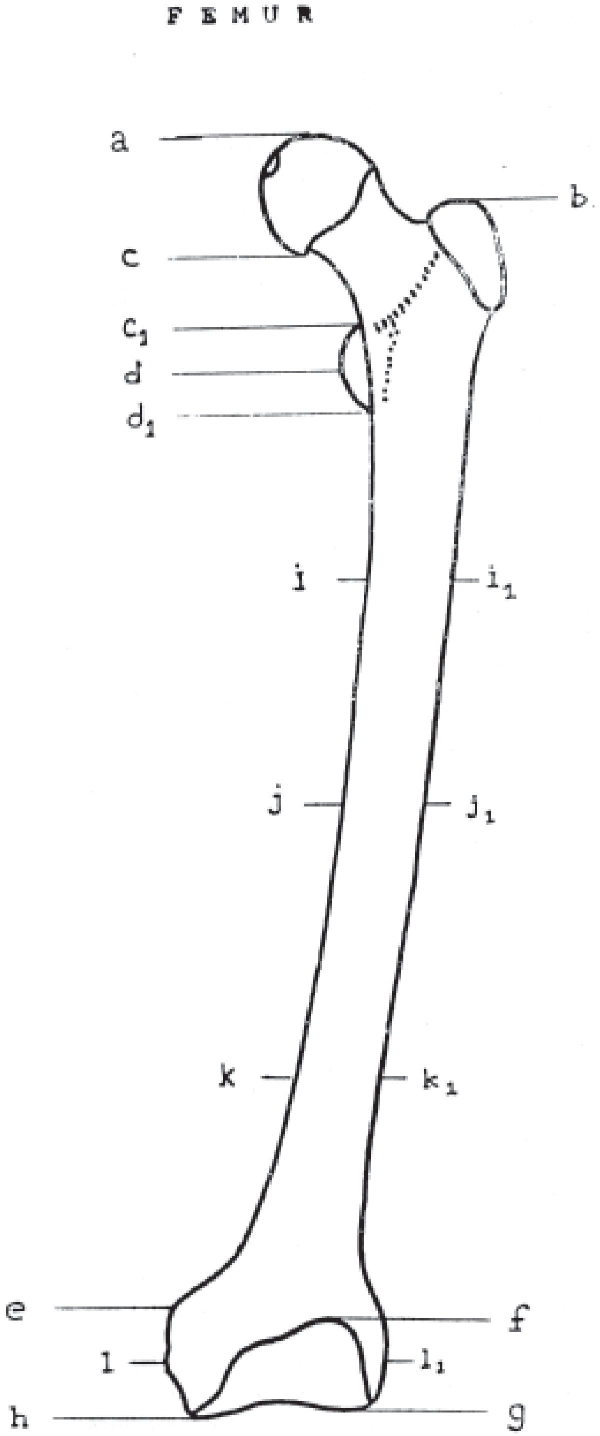

Fig. 1. Details of landmarks on femur

except for mid-shaft diameter (MSD) where the sex differences are significant at the $p < .05$ level. As a consequence of the highly significant sex differences, the sexes have been dealt with separately for computation of regression formulae for the reconstruction of femoral length from fragmentary bone measurements after ascertaining the linearity of the relationship.

Reconstruction of Femoral Length from Its Fragmentary Measurements

On subjecting the data to regression analysis, different linear and multilinear regression equations have been formulated for the prediction of femoral length from its fragments. Table 3 exhibits 15 regression equations each for males and females based on linear, transverse, sagittal and circumferential measurements. The correlation coefficient (r) ranges between .916 and .318 for males and between .931 and .395 for females. The relationship of these fragmentary measurements with femoral length is variable for both the sexes, for example, bicondylar breadth (BB) exhibits a sufficiently high correlation among females ($r = .771$) as against males ($r = .539$). Similarly USD among males exhibits a much higher correlation ($r = .513$) with femoral length than among females ($r = .400$).

Table 3 further reveals that the following 7 fragmentary measurements -SL, BB, HH, TH, HMC, SDM and NH- out of a total of 15 exhibit much higher correlations with femoral length among females, while the remaining 8 measurements exhibit a relatively higher correlation with bone length among males.

Table 4 presents four multilinear regression equations each for males and females incorporating 10 out of 15 fragmentary measurements. A combination of four fragmentary measurements TH, SL, MSC and MSD works out to be the best predictor of femoral length for both sexes as the value of multiple correlation (R) enhances to a maximum of .965 for males and .967 for females, in contrast to the values of linear correlation (Table 3). While a combination of 3 fragmentary measurements yield R between .737 and .669 for males and from .748 to .731 for females (Table 4).

DISCUSSION

Krogman and Iscan (1986) while delineating

Table 2: Sex differences in different fragmentary measures and maximum length of femora

S.No.	*Measurements*	*Male (N = 164)*		*Female (N = 124)*		*Value of*
		$\overline{X}$ *(mm)*	*S.E*	$\overline{X}$ *(mm)*	*S.E*	*'t'*
1.	Head height (HH)	40.8	0.27	38.9	0.28	4.66**
2.	Neck height (NH)	26.1	0.39	22.3	0.39	6.52**
3.	Trochanteric height (TH)	59.2	0.41	55.1	0.46	6.66**
4.	Shaft length (SL)	324.5	1.28	312.1	1.65	6.06**
5.	Height of medial condyle (HMC)	43.1	0.23	40.5	0.27	7.50**
6.	Height of patellar surface (HPS)	35.9	0.21	33.8	0.22	6.83**
7.	Maximum length (ML)	439.6	1.65	419.1	2.15	7.72**
8.	Upper epiphyseal breadth (UEB)	85.6	0.51	80.9	0.59	5.94**
9.	Upper shaft diameter (USD)	27.3	0.18	26.5	0.21	7.73**
10.	Mid-shaft diameter (MSD)	24.9	0.15	24.3	0.19	2.51*
11.	Lower shaft diameter (LSD)	29.0	0.24	27.3	0.24	4.78**
12.	Bicondylar breadth (BB)	76.1	0.37	71.9	0.46	7.13**
13.	Sagittal diameter at the middle (SDM)	26.7	0.18	24.8	0.26	6.06**
14.	Upper shaft circumference (USC)	82.9	0.43	79.4	0.55	5.06**
15.	Mid-shaft circumference (MSC)	82.8	0.43	78.7	0.58	5.83**
16.	Lower shaft circumference (LSC)	91.2	0.60	85.4	0.68	6.42**

** Significant at the $p < .01$ level, * Significant at the $p < .05$ level

Table 3: Linear regression equations for estimation of femoral length from its fragmentary measurements

	Regression Equations	*Correlation Coefficient*
Males		
1.	54.63 + 1.19 (SL) + 8.56 mm	.916
2.	250.70 + 2.21 (UEB) + 15.53 mm	.686
3.	220.97 + 2.64 (MSC) + 15.53 mm	.685
4.	270.50 + 1.85 (LSC) + 15.80 mm	.672
5.	230.16 + 2.53 (USC) + 15.99 mm	.662
6.	259.83 + 5.01 (HPS) + 16.49 mm	.654
7.	285.21 + 3.79 (HH) + 16.80 mm	.616
8.	295.74 + 2.43 (TH) + 16.94 mm	.607
9.	257.01 + 4.24 (HMC) + 17.48 mm	.573
10.	293.63 + 5.86 (MSD) + 17.71 mm	.557
11.	256.63 + 2.41 (BB) + 17.92 mm	.539
12.	318.97 + 4.44 (USD) + 18.31 mm	.513
13.	310.24 + 4.83 (SDM) + 18.31 mm	.513
14.	350.68 + 3.07 (LSD) + 18.85 mm	.468
15.	404.86 + 1.34 (NH) + 20.22 mm	.318
Females		
1.	41.06 + 1.21 (SL) + 8.81 mm	.931
2.	180.25 + 3.32 (BB) + 16.95 mm	.771
3.	222.09 + 2.50 (MSC) + 17.63 mm	.682
4.	284.06 + 5.44 (SDM) + 18.01 mm	.664
5.	221.71 + 5.07 (HH) + 18.02 mm	.664
6.	219.34 + 2.52 (USC) + 18.21 mm	.665
7.	215.81 + 6.02 (HPS) + 18.55 mm	.638
8.	233.56 + 2.29 (UEB) + 18.72 mm	.630
9.	260.78 + 2.87 (TH) + 19.09 mm	.610
10.	257.75 + 1.89 (LSC) + 19.33 mm	.597
11.	228.27 + 4.71 (HMC) + 19.44 mm	.591
12.	297.71 + 4.99 (MSD) + 21.26 mm	.471
13	369.26 + 2.23 (NH) + 21.94 mm	.413
14.	311.14 + 4.07 (USD) + 22.08 mm	.400
15.	322.38 + 3.54 (LSD) + 22.14 mm	.395

different studies carried out by eminent scholars the world over on stature estimation from long bones, commented that the broken or burnt bone fragments recovered from the crime scene, air crash or train mishap should be measured and subjected to estimation of respective bone length at the first oportunity. Stature can be estimated subsequently by employing statural formulae for the concerned bone to the bone length estimates. The initial part of their suggestion was neglected by most researchers. As a result only a few studies are available on this aspect wherein Muller (1939), Steele and McKern (1969), Steele (1970), Mysorkar et al. (1980, 1982, 1984), Rao et al. (1989a, b) and Gupta and Nath (1996, 1997a, b) used linear segment lengths for estimation of bone length and stature. Chandra et al. (1966) and Simmons et al. (1990) incorporated linear and transverse diemnsions of femur to estimate bone length and stature respectively. Chandra and Nath (1984, 1985) used a single transverse measurement to estimate bone length, while Badkur and Nath (1989, 1990a, b) Nath and Badkur (1990, 1995) and Nath et al. (1995) used multiple dimension (linear, transverse, sagittal and circumferential) to estimate both bone length as well as stature.

The approach followed in the present study is not only different from the intitial studies of Muller (1939) and Steele and Mckern (1969) for the purpose of reconstructing femoral length from fragmentary masurements (as both these studies

Table 4: Multilinear regression equations for estimation of femoral length from its fragmentary measurements

	Multilinear Regression Equations		*Multiple Correlation Coefficient*
Males			
1.	23.32 + 1.12 (TH) + 1.00 (SL) + 0.29 (MSC) + 0.10 (MSD)	± 5.62 mm	.965
2.	225.42 + 1.63 (HH) + 1.06 (NH) + 1.40 (UEB)	± 14.51 mm	.737
3.	198.81 + 2.10 (MSC) + 0.50 (MSD) + 0.71 (BB) +	± 15.38 mm	.697
4.	214.89 + 1.58 (HMC) + 3.27 (HPS) + 0.51 (BB)	± 15.96 mm	.669
Females			
1.	18.94 + 1.15 (TH) + 1.00 (SL) + 0.57 (MSC) - 0.81 (MSD)	± 6.26 mm	.967
2.	144.34 + 1.58 (MSC) - 0.39 (MSD) + 2.22 (BB)	± 15.09 mm	.784
3.	157.03 - 0.15 (HMC) + 2.71 (HPS) + 2.46 (BB)	± 16.37 mm	.739
4.	193.24 + 2.98 (HH) + 1.39 (NH) + 0.98 (UEB)	± 16.59 mm	.731

incorporated only linear bone segments for this purpose) but also differe from those of Chandra et al. (1966) and Simmons et al. (1990) who used transverse dimensions along with the linear ones to estimate bone length and stature from fragmentary measurements, while the present study incorporates multiple femoral dimensions.

Owing to the highly significant sex differences (Table 2) in all the measurements, the sexes have been treated separately for computing regression formulae for the estimation of bone length. Considering the linear regression equations the best estimates of femoral length are obtained using SL ($r = .916$), UEB ($r = 686$), MSC ($r = .658$) and SDM ($r = .513$) respectively with linear, transverse, circumferential and sagittal femur measurements among males. This sequence remains unaltered for females except for the replacement of the transverse measurement UEB by BB (Table 3). In view of the relatively higher values of r for SL, BB and SDM with femoral length among females and that of UEB and MSC among males, the accuracy in predicted femoral length would be greater for females than males.

The degree of accuracy in estimated femoral length is enhanced through multilinear regression equations. The multiple correlation (R), incorporating two linear (TH and SL), one circumferential (MSC) and a transverse (MSD) measurement increses to .965 (Table 4) as against .916 (Table 3) with a single fragmentary linear (SL) measurement for males. The value of R increases to .967 (Table 4) with the same combination of four measurements among females from .931 (Table 3) with a single linear measurement (SL).

The value of multiple correlation is greater for females than males in three out of four multilinear regression equations (Table 4). This is indicative of the fact that the accuracy in predicted femoral length using multilinear regression equations would be greater among females than males.

Out of a total of fifteen measurements considered in the present study the following five bone dimensions LSC, USC (circumferential), USD, LSD (transverse), and SDM (sagittal) do not contribute in the formation of multilinear regression equation despite the fact that they individually exhibit a relatively high correlation with femoral length (Table 3).

Different linear and multilinear regression equations formulated and presented in this study are specifically derived for Indians belonging to Madhya Pradesh. These equations would enable us to reconstruct femoral length in all those instances where skeletal remains of femur are identified from the recovered skeletal material. It is essential for an expert to first identify the sex of the recovered skeletal material before entering the measured dimensions of the segments in respective linear or multilinear regression formulae, available for both the sexes to reconstruct bone length. The bone length, thus, estimated could be used subsequently for estimation of stature either by entering the estimated femoral length into the statural formulae available for the same population (Trotter, 1970) or by using fresh regression formulae (Nath and Badkur, 1995 and Nath et al., 1996) from the fragmentary measurements of femur for reconstruction of stature.

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