Reconstruction of Stature from Long Bone Lengths

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INTRODUCTION

Dwight (1894) suggested two methods for estimation of stature from skeletal remains, i.e. Anatomical and Mathematical. The anatomical method involves in simply arranging the bones together, in reproducing the curves of the spine, in making respective allowance for the soft parts and measuring the total length. This method is workable when a complete skeleton is available. The mathematical method on the other hand is based on the relationship of individual long bone to the height of an individual and is workable even is a single long bone is available for examination. This method may be used either by computing Multiplication Factor (M.F.) or by formulating regression formulae.

Due to the obvious disadvantage of using anatomical method where complete skeleton is required, Fully (1956) implemented certain modifications for its easy workability. He computed percentage contribution of each vertebra to the total height of the column. Thus using these values for missing vertebra and measuring the remaining, the height of the vertebral column is derived by a simple proportionality equation. Besides this Fully employed following cranial and post cranial measurements for the purpose of stature estimation:

1. Basion - bregma height,
2. First sacral segment height,
3. Oblique length of femur,
4. Tibial length, and
5. Tarsal height.

After obtaining these measurements and adding the total height of the vertebral column one may obtain skeletal height, which can be used in the following regression equation to obtain living stature or ante mortem height.

Living stature=0.98(total skeletal height) 14.63±2.05 cm

Fully further suggested addition of a correction factor (CF) to the stature thus obtained:

Estimated stature up to 153.5 cm add10 cm to the result,

Estimated stature between 153.6 and 165.4 cm add 10.5 cm to the result,

Estimated stature above 165.5 cm adds 11.5 cm to the result.

The main advantage of Fully's method over the Dwight's is that one need not articulate the complete skeleton as described by Dwight. Sceondly, this method is applicable universally to males and females of any population around the world.

Despite Fully's (1956) attempt to make the anatomical method workable even if a couple of vertebrae are missing as well as highlighting its universal applicability and greater accuracy in the predicted stature, the mathematical method gained more popularity with its obvious advantage that it is more convenient in use as it requires only length of the recovered long bone. The bone length may be entered into respective regression formulae or multiplied with the specific multiplication factor to obtain the estimated height. Somehow this method was in use even before Dwight could name it. Beddoes (1887) made the first attempt to estimate stature from femoral length of 'Older Races of England' for either sex. Subsequently Rollet (1888) published the earliest formal tables for determining stature using all the six long bones of the upper and the lower limbs of 50 male and 50 female French cadavers ranging in age from 24 to 99 years.

Manouvrier (1892) reexamined Rollet's data by excluding 26 males and 25 females above the age of 60 years and based his prediction tables on 24 males and 25 females. He also suggested that the length of trunk declines by about 3 cm of their maximum stature due the effect of old age. The major difference between the approaches of Rollet and Manouvrier is that the latter determined the average stature of individuals who possessed the same length of a given long bone while the former determined the average length of a given long bone from individuals with identical stature. Manouvrier further suggested that while determining the stature from dried bones, 2mm to be added to the bone length for cartilage loss and subsequently 2 cm should be added to the corresponding stature to convert the cadaver stature to the living stature,

Pearson (1899), after Dwight had named the two methods of stature reconstruction, using Rollet's data developed regression equations for prediction of stature from long bone lengths. He restricted his study to four bones only, i.e. humerus, radius, femur and tibia.

His approach to stature estimation was based on regression theory, which involves the calculation of standard deviations for the series of long bones and of coefficients of correlations between the different bone lengths and stature. Pearson not only changed the prevailing approach to the stature estimation providing a more truly "mathematical method" but he departed in other ways from previous practices. He emphasized that the extension of the regression formulae from one local race to another must be made with great caution.

Stevenson (1929) computed regression formulae for Chinese and compared them with the Pearsons formulae. He observed that there is statistical improbability of the order of several millions to one that the formulae of one race would provide a satisfactory prediction of stature of an individual belonging to another group.

Subsequently several researchers formulated population and sex specific regression formulae using single bone or a combination of different long bones belonging to the upper and the lower limbs (Mendes Correa, 1932; Breitinger, 1937; Tellka, 1950; Dupertuis and Hadden, 1951; Trotter and Gleser, 1952, 1958; Fuji, 1958; Wells, 1959; Genoves, 1967; Kolte and Bansal, 1974; Oliver et al 1978; Yung-Hao et al, 1979; Cerny and Komenda, 1982; Shitai, 1983; Boldson, 1984; Badkar, 1985; Kodagoda and Jayasinghe,1988).

The alternative mathematical approach of stature estimation, i.e the use of multiplication factor (MF), was first advocated by Pan (1924) who formulated MFs for all the six long bones by simply computing the proportion of the said bone to the stature.

Multiplication Factor (MF) = Stature / Bone length. The average MF could be used be to estimate the stature.

This approach was subsequently used by various researchers (Nat, 1931; Siddique and Shah, 1944; Singh and Sohal, 1952; Kate and Majumdar, 1976; Badkur, 1985; Banerjee et al.1994) on different Indian skeletal populations. Like the regression formulae, these MFs are also population and sex specific and should not be used interchangeably (Nath, 1996).

In connection with the use of regression formulae and MFs for estimation of stature Eliakis et al. (1966) are of the opinion that it is necessary to make regression equations or prediction tables for every race and its sub races. While Medows and Jants (1995) observed that secular increase in the lower limb bone length is accompanied by relatively longer tibiae and suggested that the secular changes in proportion might render stature estimation formulae based on late 19th and 20th century samples inappropriate for modern forensic cases. Thus it is essential to keep on revising these means of stature reconstruction from time to time to meet the requirements of the present.

Out of the two methods of stature reconstruction, it is observed that the mathematical one is based on the relative proportion of bone lengths to height but it does not take into account the varying proportions of trunk length to total stature. The anatomical method on the other hand by including spine length when measuring skeletal height addresses this source of variation and thus provides greater accuracy in the estimated height.

Secondly the correction factor, which is added to the skeletal height while using anatomical method, compensates for the thickness of the soft tissues at the scalp, soles and cartilages of the joints. There is no evidence that these soft tissues differ from one population to another and thus we get a single equation irrespective of sexes for all the population groups.

The anatomical method also provides a possibility to regress individual long bones against skeletal samples lacking living stature or cadaver lengths. These equations only require addition of Fully's correction factor for the soft tissues to obtain estimated stature. One major drawback of this method is that it requires nearly complete skeleton for its implementation. Thus the first choice of the investigator is to employ the modified anatomical method provided that the skeleton is sufficiently complete. But in its absence one has to rely on the mathematical method.

In the present study an attempt has been made to formulate sex specific regression equations for estimation of stature using all the six long bones of the upper and the lower limbs.

MATERIAL AND METHODS

To accomplish the aims of the present study all the six long bones, i.e. humerus, radius, ulna, femur, tibia and fibula, belonging to the right and the left sides of 82 male and 62 female skeletons were measured. This provided a total of 1728 bones (984 male and 744 female). Each bone was measured for maximum length in accordance with the standard technique (Martin and Saller, 1959) and the documented stature was recorded for all the 144 skeletons (82 male and 62 female).

Data were subjected to statistical analysis for assessing bilateral and sex differences in the length of all the bones as well as stature. Bone lengths were subsequently correlated with the stature for formulation of sex specific regression equations for estimation of stature from these long bones.

RESULTS AND DISCUSSION

Table 1 presents the mean values and standard deviation for the right and the left side bones of male and female skeletons to observe the bilateral variations, if any. It is evident from the table that except femur, all the bones of the right side are longer than the left ones for both the sexes. The apparent variations observed in the length of these long bones reveal non-significant bilateral differences for both the sexes. Thus the sides (right and left) have been pooled to assess the sex differences.

Table 2 exhibits the mean values and standard deviation for the right, left and pooled (right and left) maximum lengths of all the six long bones of male and female skeletons. It is clear from the table that the male bones are sufficiently longer than the female ones and the sex differences, as assessed through t- test are highly significant ($p<0.001$) for all the bones as well as for stature.

Table 3 lists the values of correlation constant between stature and all the six long bones for both males and females. It is noticed that the female bones exhibit greater correlation with the stature than the males except for tibia. It is also observed that for both the sexes femur exhibits the highest correlation followed by tibia and fibula in case of lower limb bones while in case of upper limb bones humerus exhibits greater value of correlation with stature while ulna exhibits the least for both sexes.

Table 4 represents linear regression equations for the estimation of stature for both the sexes. It is also observed that the lower extremity bones exhibit both higher correlation and low standard error of estimate (SEE) for both the sexes. The three bones of the upper extremity exhibit relatively low correlation and greater SEE.

Table 5 presents multiple regression equa-

Table 1: Bilateral differences in different Bone lengths

Bone	*Sex*	*Right*		*Left*		*Value of*
		Mean (mm)	*S.D*	*Mean (mm)*	*S.D*	*t*
Hum	Male	313.8	11.3	312.8	16.4	0.401
	Female	301.8	17.9	299.9	17.3	0.601
Rad	Male	246.5	12.1	244.3	12.6	1.122
	Female	234.2	13.0	232.8	13.5	0.592
Ulna	Male	439.2	13.2	263.7	13.8	0.889
	Female	252.4	13.4	251.4	13.4	0.428
Fem	Male	439.2	21.5	440.0	20.9	0.254
	Female	418.6	23.5	419.4	24.2	0.199
Tib	Male	377.5	12.2	377.4	17.1	0.105
	Female	355.1	19.2	354.6	19.6	0.134
Fib	Male	364.4	15.5	364.0	15.8	0.179
	Female	344.5	19.0	345.4	19.0	0.269

Table 2: Sex differences in Different long bone lengths and stature

Bone	*Male Mean (mm)*	*S.D.*	*Female Mean (mm)*	*S.D.*	*Value of t*
Hum	312.73	16.36	299.95	17.32	4.526*
Rad	245.45	12.44	233.52	13.35	7.813*
Ulna	264.68	13.56	251.92	13.45	7.936*
Fem	439.63	21.21	419.06	23.88	7.718*
Tib	377.54	17.16	354.86	19.48	10.476*
Fib	364.22	15.65	344.91	19.05	9.186*
Stature	1661.2	35.47	1542.9	40.20	26.516*

*Significant at 1% level

HUM = Humerus; RAD = Radius; FEM = Femur; TIB = Tibia; FIB = Fibula

Table 3: Correlation between bone lengths and stature

Bone	*Value of r*	
	Male	*Female*
Humerus	0.655	0.776
Radius	0.501	0.738
Ulna	0.522	0.715
Femur	0.893	0.911
Tibia	0.851	0.843
Fibula	0.814	0.846

tions for the estimation of stature from different combinations of long bones among the males .The value of the multiple correlation varies from a minimum of 0.523 to a maximum of 0.974 with different combinations of the bone lengths .The SEE on the other hand works out to be as low as 8.31 mm when the length of the femur and tibia is combined to estimate stature and the highest SEE is observed as 30.97 mm in a combination of lengths of radius and ulna. However in most of the multiple regression equations the SEE is sufficiently low as compared to the one observed in case of linear regression equations for the males.

Table 6 lists multiple regression equations for estimation of stature from different combinations of long bones among females. It is observed that the value of multiple correlation enhances to 0.975 with the combination of all the six long bones while the least value is observed as 0.739 in an equation where the lengths of radius and ulna are combined to estimate stature. The SEE reduces to 9.26 mm in an equation with the highest value of multiple correlations. However for most of the equations the value of SEE is sufficiently low in comparison to the one observed with the linear regression equations.

DISCUSSION

It is evident from the analysis of results that

Table 4: Regression equations for estimation of stature from male and female bones

S. No.	*Sex*	*Regression Equations*	*±SEE*	*Value of r*
1.	Male	1209.15 +1.44 (HUM)	± 27.38	0.655
2.	Male	1305.15 +1.45(RAD)	±30.42	0.501
3.	Male	1294.55 +1.39(ULNA)	±30.91	0.522
4.	Male	994.11 +1.52(FEM)	±16.30	0.893
5.	Male	987.62 +1.78(TIB)	±19.00	0.851
6.	Male	976.92 +1.88(FIB)	±20.85	0.814
7.	Female	1010.48 +1.77 (HUM)	±25.58	0.776
8.	Female	1023.34 +2.22(RAD)	±27.36	0.738
9.	Female	1003.06 +2.14(ULNA)	±28.28	0.715
10.	Female	900.42 +1.53(FEM)	±16.73	0.911
11.	Female	923.06 +1.75(TIB)	±21.64	0.843
12.	Female	926.29 +1.79(FIB)	±21.59	0.846

Table 5: Multiple regression equations for estimation of stature among males

S. No.	*Multiple Regression Equations*	*±SEE*	*Value of r*
1.	S=832.58 –0.01(HUM)-0.03(RAD)-0.04(ULNA)+1.01(FEM)+0.99(TIB)+0.08(FIB)	±8.38	0.974
2.	S=832.78 – 0.01(HUM)-0.06(RAD)-0.02(ULNA)+1.04(FEM)+1.03(TIB)	±8.47	0.973
3.	S=828.95-0.01(HUM)-0.08(RAD)+1.02(FEM)+1.00(TIB)+0.09(FIB)	±8.44	0.974
4.	S=835.11-0.02(HUM)-0.04(RAD)+1.03(FEM)+1.03(TIB)	±8.37	0.973
5.	S=891.22+0.17(HUM)-0.23(RAD)+1.03(FEM)+0.83(FIB)	±13.48	0.930
6.	S=830.25+1.01(FEM)+1.02(TIB)	±8.33	0.973
7.	S=883.82+1.08(FEM)+1.02(FIB)	±13.62	0.927
8.	S=1146.92+0.92(HUM+RAD)	±27.29	0.658
9.	S=1161.47+0.86(HUM+ULNA)	±27.43	0.653
10.	S=1274.08+0.75(RAD+ULNA)	±30.97	0.523
11.	S=830.25+1.02(FEM+TIB)	±8.31	0.973
12.	S=875.17+0.98(FEM+FIB)	±13.69	0.926
13.	S=897.24+0.99 (TIB+FIB)	±16.85	0.887

Table-6: Multiple regression equations for estimation of stature among females

S.No.	*Multiple Regression Equations*	*±SEE*	*Value of r*
1.	S=774.90 –0.31(HUM)+0.34(RAD)- 0.27(ULNA) +0.99(FEM)+0.50(TIB)+0.50(FIB)	±9.26	0.975
2.	S=775.48 – 0.02(HUM)+0.34(RAD)-0.14(ULNA)+1.04(FEM)+0.82(TIB)	±9.98	0.970
3.	S=768.770-04(HUM)+0.11(RAD)+1.00(FEM)+0.51 (TIB) (0.47(FIB)	±9.31	0.974
4.	S=772.20-0.12(HUM)-0.21(RAD)+1.01(FEM)+0.86(TIB)	±9.96	0.970
5.	S=784.64+0.05(HUM)-0.03(ULNA)+1.04(FEM)+0.92(FIB)	±10.17	0.969
6.	S=780.99+1.06(FEM)+1.02(TIB)	±10.06	0.969
7.	S=784.30+1.05(FEM)+1.02(FIB)	±10.10	0.969
8.	S=941.82+1.12(HUM+RAD)	±23.71	0.811
9.	S=923.06+1.12(HUM+ULNA)	±24.00	0.806
10.	S=995.95+1.13(RAD+ULNA)	±27.34	0.739
11.	S=778.52+0.99(FEM+TIB)	±10.12	0.968
12.	S=782.39+1.00(FEM+FIB)	±10.12	0.968
13.	S=894.25+0.93 (TIB+FIB)	±20.28	0.866

the females despite having smaller bone dimensions than the males exhibit greater correlation with stature except for tibia where males exhibit a greater correlation with stature. The relationship between stature and the lower limb bones is of relatively greater significance in comparison to the upper limb bones for both the sexes as has been reported by almost all the earlier researchers the world over. Secondly, the lower limb bones directly contribute to stature while the upper limb bones do not and for prediction of stature using any one of the lower limb bones would provide a more reliable estimate. This fact has been substantiated by the high correlation between femur, tibia and fibula with stature coupled with low SEE as compared to the upper limb bones for both the sexes. Thus one may use femur length to have the best estimate of stature followed by tibial and fibular lengths for males and females. The upper limb bones may be used only in the absence of the lower limb bones for this purpose.

The accuracy in the predicted stature is sufficiently enhanced on using multiple regression equations .The combination of more than one bones not only increases the correlation values but reduces the SEE as well. As observed form table 4 that the femur length which has a correlation of 0.893 and 0.911, respectively for males and females the SEE works out to be 16.30 mm and 16.73 mm. On using the multiple regression equation the correlation values enhances to 0.974 and 0.975 for males and females while the SEE reduces by nearly 50 percent and works out to be 8.31 and 9.26 mm, respectively for males and females. This reduction in the SEE and enhancement in the degree of correlation suggests that the estimated stature using the multiple regression equations would be in close agreement with actual stature.

However it may not be always possible to use the best multiple regression equation as it depends upon the availability of all the long bones .In alternative situation one requires at least femur and tibia to achieve such an accuracy. In the absence of these any long bone may be used as all the bones exhibit a correlation above 0.5 with stature but then the SEE enhances.

In connection with the formulation of regression formulae Trotter (1970) emphasized that the accurate estimates of stature are derived from a sample of the population with same sex, race, geographical area and time period. In other words the regression formulae are both population and sex specific and should not be used interchangeably (Stevenson, 1929; Keen, 1953, 1955; Wells, 1959; Allbrook, 1961; Lund, 1983; and Nath, 1996)

Thus depending the availability of bones recovered from the scene of crime a forensic expert can achieve his target with sufficient reliability by selecting the appropriate bone from the recovered skeletal material and then measuring the length to enter it in the respective regression formulae to get the skeletal height which can be converted in to living stature using Fully's correction factor.

KEY WORDS Regression Formulae. Reconstruction. Stature. Bone Length.

ABSTRACT An attempt has been made in the present study to formulate regression formulae for reconstruction of stature using all the six long bones, i.e.humerus, radius, ulna, femur, tibia and fibula, belonging to 82 male and 62 female documented skeletons from Bhopal, Madhya Pradesh. A total of 1728 long bones (984 male

and 744 female) were measured for maximum length in accordance with the standard measurement technique. The stature was obtained for each skeleton from the documented records. Analysis revealed that the bilateral differences were non significant for either sex thus the sides were pooled for further analysis which revealed highly significant sex differences in bone lengths and documented stature (($p<0.001$). It is further observed that all the three lower limb bones exhibit high correlation with stature and a relatively low standard error of estimate for both the sexes as compared to the three bones of the upper limb. Femur provides the best estimate of stature among all the six long bones for either sex as it exhibits the least SEE and the highest correlation with stature. However a combination of all the six long bones further enhances the value of correlation as well as reduces the SEE which provides a more accurate estimate of stature for both males and females

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