Original article:

Estimation of stature from radius length in living adult Bengali males

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Abstract:

Introduction: Estimation of stature from length of long bones is of practical importance and has to be population specific. Work on estimation of stature in living subjects from radius length is limited. We attempted to develop a predictive equation for stature from radius length.

Methodology: Stature and length of radius were measured in 510 healthy adult Bengali men aged between 21-50 years. Scatter plots were constructed with regression lines to correlate height with length of left radius (LR) and right radius (RR), measurements being in centimeters. Multiple linear regression was applied to develop a predictive equation for stature based on age and radius lengths. Its validity was tested by predicting stature in 30 additional randomly selected subjects and comparing estimated height with actual height.

Result: Height showed strong correlation with length of left ($r = 0.971$, $p < 0.001$) and right ($r = 0.974$, $p < 0.001$) radius. The gender specific equation for prediction of stature was: Height = 23.9695 + 1.3848 X LR + 4.0723 X RR – 0.01678 X Age; the equation having a standard error of estimate (SEE) of 1.69 cm. If age was omitted, the equation was: Height = 23.5517 + 1.3932 X LR + 4.0571 X RR; with SEE of 1.70 cm. Strong agreement between observed and estimated heights in the holdout sample of 30 individuals was indicated by intraclass correlation coefficient of 0.978.

Conclusion: Using these equations it is possible to predict stature in adult Bengali males from radius length. Applicability to other situations remains to be explored.

Key words: Stature estimation, Radius

Introduction

Stature implies the natural height of an individual in an upright position i.e. the distance from crown to heel. It is strongly influenced by genetic factors, health and nutrition and by growth and development in infancy, childhood and adolescence. Stature is important in characterization of genetic disorders, in sports and defense studies, ergonomics, study of evolution and comparative anatomy of humans and primates and prehistoric ancestors. Stature, or its estimation from partial skeletal remains, is also of value in personal identification, as is often required in forensic and medicolegal practice.

Stature can be estimated by employing either the anatomical or the mathematical method. The anatomical method estimates total skeletal height and is based on the summed height of skeletal elements that contributes to stature. To calculate the living stature of an individual using the anatomical method, correction factors that compensate for soft tissue need to be added.[1-3] The main disadvantage, however, is that a nearly complete skeleton is needed. The mathematical method makes use of one or more bone lengths to estimate the stature of an individual. This method employs bone length and stature tables based on regression formulas to estimate the skeletal height or living stature. Even a single bone can be used to estimate stature by this method.Various research workers have estimated stature from measurements of different parts of the body e.g. foot length, foot breadth, length of superior extremity, length of inferior extremity and different bones of the body.[4-7] Stature varies with ethnicity, age, sex and heredity. Telkka opined that each racial group needs a separate formula for estimation of stature.[8]

Most research work regarding stature estimation has been done with cadavers. However, cadavers differ in various ways from living subjects – most of them are aged, they might have suffered from chronic debilitating disease, and they may have lain in an abnormal posture so that bringing back to normal position is difficult. Hence, accurate stature estimation using measurements taken from cadavers may not be possible. The radius is a forearm bone whose upper end (head) and lower end (styloid process) are both subcutaneous, making it easy to measure the length of the radius in living subjects. Only limited work has been done to estimate stature from the length of radius and none is documented for ethnic Bengali population. Keeping all these in mind, in the present study, an attempt was made to find out a valid formula for the estimation of stature of living Bengali males (age group= 21-50 years) from the percutaneous length of radius using the mathematical method.

Materials and Methods

This descriptive study was conducted between May 2010 to April 2011 in a tertiary care teaching hospital that mainly serves the population of Kolkata and neighboring districts. The study protocol and informed consent documents were approved by the institutional ethics committee.

Adult male subjects, aged between 21-50 years, were recruited provided their mother tongue was Bengali and they were permanent residents of West Bengal. Those with any visible deformity of spine or limb bones, history of forearm bone fracture, long-term corticosteroid use, thyroid disorder or generalized bone disorder during childhood or adolescence, were excluded. Purposive sampling was done from male relatives accompanying patients presenting to medical or surgical out-patient departments. About 10% of the subjects recruited were volunteers from medical college faculty, undergraduate and postgraduate students. The target sample size was 500 subjects, to be subdivided into a model cohort of 470 subjects and a test cohort of 30 subjects selected by simple random sampling (using a computer generated random number list) from these 500. The aim was to develop a predictive regression equation for stature from radius length measurements in the subjects belonging to the model cohort. The predicted stature in the 30 subjects serving as the test cohort was then to be compared with their actual stature to determine the validity of the regression equation.

Stature was measured as the distance from crown to heel in standing erect posture with a calibrated anthropometer. Radius length was measured, using spreading calipers, as the distance between the most prominent and palpable part of the radial head to the styloid process. Lengths of left and right radius were taken separately. All measurements were taken between 11:00 AM to 3:00 PM to eliminate any discrepancies due to diurnal variation. Each measurement was actually taken thrice and the average of the three readings recorded in centimeters.

Statistical analysis: Data were summarized by usual descriptive statistics, namely mean, standard deviation (SD) and 95% confidence interval (CI) of the mean. Paired numerical variables were compared between groups by Student's paired samples t test. Scatter plots were drawn to depict association between stature and bone length, and the strength of association expressed by Pearson's correlation coefficient (*r*). Multiple linear regression analysis was done using left and right radius length and age as the predictors. The standard error of estimate (SEE) of the regression equation was calculated as the standard deviation of the residuals. The male gender specific regression equation was then applied to predict stature of individual subjects in the test cohort. The predicted stature and the actual measured stature were compared for agreement by calculating the intraclass correlation coefficient (ICC) and drawing a Bland-Altman plot. $P < 0.05$ was considered statistically significant. Statistica version 6 [Tulsa, Oklahoma: Stat Soft Inc., 2001] and MedCalc version 11.6 [Mariakerke, Belgium: MedCalc Software, 2011] were used for statistical analysis.

Table 1. Descriptive statistics of study variables (n = 510)

	Range	Mean ± SD	95% confidence interval of mean
Age (year)	21.0 – 50.0	35.4 ± 8.57	34.6 – 36.1
Height (cm)	145.0 – 184.0	164.2 ± 7.50	163.6 – 164.9
Left radius length (cm)	22.0 – 29.0	25.7 ± 1.34	25.6 – 25.9
Right radius length (cm)	22.2 – 29.2	25.8 ± 1.34	25.7 – 26.0

Table 2. Parameters of the multiple regression model used in developing a predictive equation for stature on the basis of age and radius lengths (n = 510)

Independent variable	Regression coefficient	Standard error	t	P
(Constant)	23.9695			
Age	– 0.01678	0.008770	– 1.913	0.056
Left radius length	1.3848	0.4992	2.774	0.006
Right radius length	4.0723	0.5004	8.138	< 0.001

[Coefficient of determination (R^2) for this model was 0.949 and the Standard error of estimate (standard deviation of the residuals) was 1.69 cm.]

Table 3. Parameters of the simplified (age excluded) multiple regression model used in developing a predictive equation for stature on the basis of radius lengths (n = 510)

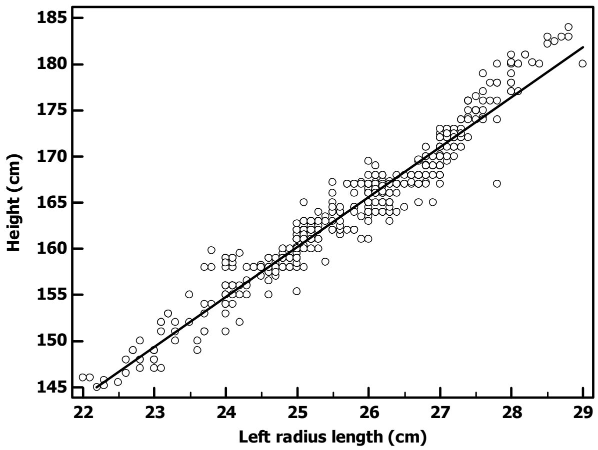
Independent variable	Regression coefficient	Standard error	t	P
(Constant)	23.5517			
Left radius length	1.3932	0.5005	2.784	0.006
Right radius length	4.0571	0.5017	8.087	< 0.001

[Coefficient of determination (R^2) for this model was 0.949 and the Standard error of estimate (standard deviation of the residuals) was 1.70 cm.]

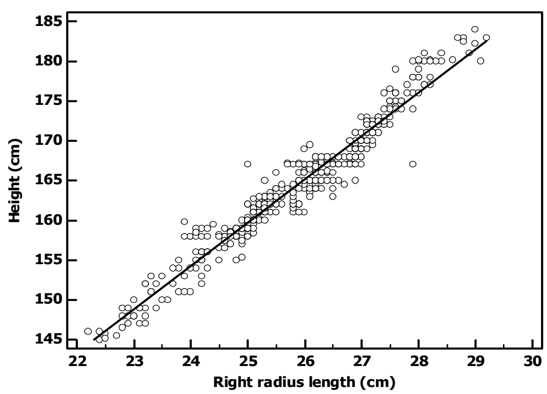
Table 4. Table to ascertain stature of healthy adult Bengali men using radius length

Radius length (cm)*	Age 25 ± 5 years	Age 35 ± 5 years	Age 45 ± 5 years
21.0	138.1	138.0	137.8
21.5	140.9	140.7	140.5
22.0	143.6	143.4	143.3
22.5	146.3	146.2	146.0
23.0	149.1	148.9	148.7
23.5	151.8	151.6	151.5
24.0	154.5	154.4	154.2
24.5	157.2	157.1	156.9
25.0	160.0	159.8	159.6
25.5	162.7	162.5	162.4
26.0	165.4	165.2	165.1
26.5	168.2	168.0	167.8
27.0	170.9	170.7	170.6
27.5	173.6	173.5	173.3
28.0	176.3	176.2	176.0
28.5	179.1	178.9	178.7
29.0	181.8	181.6	181.5
29.5	184.5	184.4	184.2
30.0	187.3	187.1	186.9

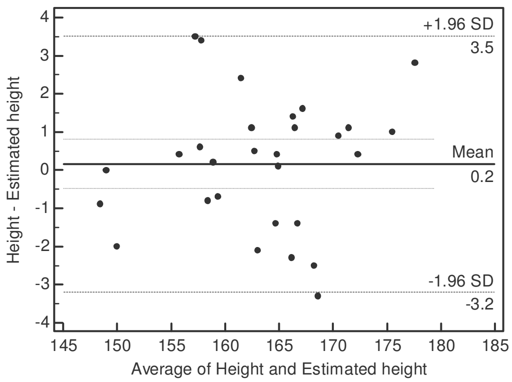
[* Assuming radius length to be equal for the two sides. Height values (cm) have been derived from the multiple linear regression equation (including age and radius lengths as predictors) presented in the text.]



[Figure 1. Scatter plot depicting association between height and left radius length for 510 adult Bengali men.]



[Figure 2. Scatter plot depicting association between height and right radius length for 510 adult Bengali men.]



[Figure 3. Bland-Altman plot showing agreement between actual height and estimated height (predicted from multiple linear regression) in the test cohort of 30 subjects.]

Results

Although the recruitment target was 500 subjects, complete data was eventually available from 540 subjects. Thirty of these subjects were separated as the test cohort by simple random sampling. The rest 510 comprised the model cohort. The data from this model cohort of 510 subjects is summarized in Table 1. The mean length of left radius and right radius did not show statistically significant difference ($p = 0.257$).

Scatter plots were drawn to study the association between height (in Y-axis) and length of left or right radius (in X-axis) in the whole cohort (Figures 1 and 2). As the association was clearly linear, simple linear regression equation and Pearson's correlation coefficient (r) were estimated for individual scatter plots and these data are presented in the figures. The correlation coefficients were statistically significant ($p < 0.001$). In Figure 1 the equation of the regression line for left radius is $Y = 24.8284 + 5.4158 X$ and the r value is 0.971 (95% CI 0.965 to 0.975) with $p < 0.001$.The SEE is 1.80 cm. In Figure 2 the equation of the regression line for right radius is $Y = 23.5635 + 5.4448 X$ and r is 0.974 (95% CI 0.969 to 0.978) with $p < 0.001$. The SEE is 1.71 cm.

The model cohort was further divided into three subgroups according to age – 21-30 years, 31-40 years and 41-50 years (n = 170 each). The study variables showed no statistically significant difference between these subgroups. Subgroup specific scatter plots were also constructed and r values calculated. These were very similar to values obtained for the whole of the model cohort. The subgroup specific data have not been shown. Multiple linear regression was used to develop a predictive equation for stature based on age and left and right radius lengths. The regression model parameters are depicted in Table 2. The model quality was good with coefficient of determination R^2 value of 0.949. This indicated that nearly 95% of the variability in stature was explained by the three predictors selected. The SEE was 1.69 cm.

The final regression equation for stature was:

$$\text{Height} = 23.9695 + 1.3848 \times LR + 4.0723 \times RR - 0.01678 \times \text{Age}$$

where age is in years and height, left radius length (LR) and right radius length (RR) are in cm.

This equation was applied to predicting the stature in the 30 subjects who comprised the test cohort. The extent of agreement between actual stature and estimated stature has been depicted graphically by a Bland-Altman plot in Figure 3. The ICC value for these two sets of figures was 0.978 (95% CI 0.963 – 0.987), indicating strong agreement.

If age was excluded from the model, the regression equation for stature was:

Height = 23.5517 + 1.3932 X LR + 4.0571 X RR

where height, left radius length (LR) and right radius length (RR) are in cm.

The model parameters are depicted in Table 3. This simplified model also had R^2 value of 0.949 and SEE of 1.70 cm, and showed similar strong agreement with observed height when used to predict stature in the test cohort. Table 4 presents a listing of values from which stature can be determined at a glance for adult Bengali men.

Discussion

Ever since Pearson[4] estimated height from limb-bones, many regression equations have been developed for stature estimation. Methods of measurement and bones used to obtain the regression equations of previous investigators are different from one another.[8-10] However, many researchers have cautioned that formulas used to estimate stature should be specifically derived for each different population.[10-13]Several studies on stature estimation have been done in India too. Athawale[14] derived regression formula for estimation of stature from length of long bones in Maharastrian males and showed that using the formula given by Western workers involves an error of 5-8%. His regression formula was: Stature = 59.2923 cm + 4.1442 X average length of right and left radius in cm ± 3.66 cm. Sarojini Devi et al[15] computed correlation coefficient (r = 0.619 for male and 0.584 for female) and regression equations for estimation of stature by using upper arm length among living population of Maring tribes of Pallel area, Chandel district, Manipur.

The present study included 510 males between 21-50 years from Kolkata and neighboring districts of West Bengal. The age restriction was made since ossification of radius is usually complete by 20 years of age and beyond 50 years the possibility of degenerative changes affecting stature increases. The mean height was 164.2 cm with range between 145 – 184 cm. These values conform well with the work of Basu, who, in 1963, conducted anthropometry of the Kayasthas, a prominent ethnic subsection of the Bengali population.[16]

The positive linear relationship between stature and the lengths of left and right radius showed strong correlation as is evident from the scatter plots. In fact the correlation coefficient exceeded 0.97 for both left and right radius. The associated p values were also < 0.001, indicating that the association observed in the sample also holds true for the underlying population. Thus, it is quite acceptable to use the radius for indirect stature estimation. Many researchers[3,17,18] have shown that regression formulas using combination of bone lengths show better accuracy in predicting total skeletal height than those using single bone. Keeping this in mind, the present study attempted to develop a predictive equation for stature based on age, length of left radius and length of right radius. Although the strong positive correlation observed in the whole cohort also held true for age band-wise (decadal) subgroups, multiple regression equations were not constructed for individual age bands since age was not a major predictor in this situation. The quality of regression equations is assessed on the basis of their SEE which is calculated as the standard deviation of the residuals. In this study the SEE was 1.69 cm. Other studies with radius in different populations show comparable or higher SEE. Some documented values are 4.24 – 5.05 cm in the study by Trotter and Gleser,[5] 3.66 cm by Athawale,[14] 3.58 cm by Dayal et al[18] and 5.63 cm by Mahakkanukrauh et al.[19] The low values of SEE provided enough statistical justification for stature prediction in the present study.

The predictive equations when tested on the test cohort of 30 randomly selected males, provided stature values in strong agreement with directly measured stature. Thus the equation derived from our study can safely be used in Bengali male population to predict stature. Further work is underway to derive similar predictive equation for adult Bengali female population. It also remains to be explored whether the equations would be successful in predicting stature from cadaveric bone length and predicting stature in healthy subjects over 50 years of age.

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