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Estimation of stature from arm span, arm length and tibial length among Bengalee children aged 3-11 years

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ABSTRACT:

Background: *Estimation of human stature has significant bearings on assessment of growth, nutritional status and personal identification. Often the prediction of stature from bone remains or body parts of children is complicated by the ongoing growth. Despite these disadvantages, a situation may arise where estimation of a child's stature becomes important. In such a situation equations derived for adults cannot be applicable.* ***Materials and Methods:*** *The present cross-sectional study was conducted among 240 children (boys: 116; girls: 124) aged between 3 to 11 years and belonging to the Bengali Hindu Caste Population from Naxalbari, District Darjeeling, West Bengal, India. Standard procedures were followed to record stature, arm span, arm length and tibial length. Intra- and inter- observer technical errors of the measurement (TEM) were calculated. One way analysis of variance (ANOVA), correlation, linear regression and stepwise regression were used to analyze the data.* ***Result:*** *The boys had higher mean age, mean stature, mean arm span, mean arm length and tibial length than girls. However, using ANOVA, the sex difference were not significant ($p>0.05$). Stature was observed to be positively and significantly correlated with all the anthropometric variables among both sexes. When stepwise regression was used, it was observed that the correlation coefficient (R) and the coefficient of determination (R^2) increased with inclusion of arm length and tibial length with arm span as the predictor. The addition of age as a variable further increased the predictive accuracy of the model. Predictive accuracies of the equations were higher among girls than boys.* ***Conclusion:*** *The present study has observed strong associations of stature with age, arm span, arm length and tibia length. The strength of prediction in general increased with the increasing number of parameters and from using linear to stepwise multiple regressions. Addition of age as a variable influenced the predictive accuracy of the model which becomes helpful for stature estimation among the children when the age is known.*

Keywords: *Stature, arm span, arm length, tibial length, Bengalee Hindu Caste Population, correlation, regression*

INTRODUCTION

Anthropometry is a commonly used technique for measurement and quantification of proportions of the human body. It may be defined as the single most portable, universally applicable, inexpensive and non-invasive technique for assessing size, proportions and composition of the human body. This technique has often been viewed as a traditional and perhaps the basic tool of biological anthropology and has a long tradition of indispensible use in the same.

Stature is an important variable of assessing body size. Estimation of stature has significant bearings on assessment of growth, nutritional status, calculating body surface area and predicting pulmonary function (Gauld and Rakhir 2004). Measurement of stature is also important for determination of basic energy requirement, standardization and measures of physical capacity (Jalzem and Gledhill 1993).

Identification of human remains recovered from disasters or crime scenes is important for both legal and humanitarian reason. In the process of personal identification, estimation of stature is used along with age, sex and ethnicity to construct the biological profile of the individual in question. Estimation of stature has also an important role to play in identification of decomposed or mutilated bodies (Singh et al. 2012). Assessment of stature is also closely associated with predication and standardization of physiological parameters such as lung volumes, muscle strength, glomerular filtration, basal metabolic rate and for adjustment of drug dosage in humans (WHO 1995; Mohanty et al. 2001; Chhabra 2008). Human stature reaches its maximum at the age of 21 to 25 years, after which it starts to decline by about 2.5 cm every 25 years (Krishan et al. 2012). Along with the effect of aging, decline in stature also takes place due to certain conditions like famine.

The prediction of stature from bone remains or body parts of children remains complicated by the ongoing process of growth. However, knowledge of sex and age may provide additional help. Smith (2007) has emphasized the usefulness of estimating a child's stature when the age is known. Often it may happen that the anthropologist may be presented with a situation where estimation of stature of a child remains becomes important. In such a situation adult equation cannot be used.

Studies have consistently estimated stature from other body parts (e.g., Kulkarni and Patki 1989; Radoinova et al. 2002; Kanchan et al. 2008; Rastogi et al. 2009; Krishan et al. 2013; Geetha et al. 2015). A number of studies have utilized measurements of the lower extremity such as tibial length, femur length, foot length, foot breadth, fibular length, sole length, knee stature to predict stature (e.g., Saxena 1984; Kulkarni and Patki 1989; Singh and Phookan 1993; Radoinova et al. 2002; Ozer et al. 2007; Singh et al. 2012; Kanchan et al. 2013). Some studies using measurements of the upper extremity such as humeral length, arm length, arm span, hand length, hand breadth and metacarpal length for estimating the same are also present (e.g., Kimura 1992a, 1992b; Radoinova et al. 2002; Singh et al. 2012; Ibegbu et al. 2014, 2015). Studies have also used skull and its parts, and dental dimensions as predictors of stature. Here the studies of Sarangi et al. (1981), Chiba and Terazawa (1998), Kalia et al. (2008); Rao et al. (2009), Agnihotri et al. (2011), Cui and Zhang (2013) and Gonzalez-Colmenares et al. (2015) are mentionable. A number of studies have utilized impressions or prints of foot, soles of shoes and even position of clothing on image of camera footage to estimate stature (e.g., Giles and Vallandigham 1991; Ramstrand et al. 2011; Reel et al. 2012; Pawar and Pawar 2012; Hemy et al. 2013; Scoleri et al. 2014). Although all the studies mentioned above were on adults, some studies had been using these variables among children. Here the studies of Rutishauser (1968), Kimura (1992a; 1992b), (Smith 2007), Krishan et al. (2011) and Ibegbu et al. (2014; 2015) may be cited.

All the studies on stature estimation cited above are based on the principles of correlation and associations. The method of ratio is another best alternative for stature estimation. Feldesman (1992) has published a significant paper on femur-stature ratio. There is more emphasis on the population specific studies as ethnicity, geography and environment may influence body proportions. Moreover, stature predicted using regression equations always comes in a range (Lundy 1986).

A need for population specific studies on stature estimations has long been emphasized (Telkka 1950). This is primarily due to the racial and ethnic variations present in different regions of the world. This need led to several studies being initiated to obtain regression models for predicting stature from body dimensions among different populations, as evident from the studies mentioned earlier. Contemporary India is composed of a large number of ethnic and indigenous elements exhibiting enormous amounts of ethnic and genetic diversity (Beiteille

1998; Majumder 1998). The country is a vast country with varied geographical conditions where stature is observed to vary with ethnicity, sex and geographical locations. Thus, there exists a need for developing regression models for the estimation of stature from different body parts in various ethnic and population groups. A number of studies have been undertaken in this regard (e.g., Krishan and Sharma 2007; Rastogi et al. 2009; Krishan et al. 2011, 2013; Kanchan et al. 2013; Geetha et al. 2015).

The northern part of the state of West Bengal, India is popularly known as North Bengal and comprises of six districts. The district of Darjeeling is one of them and is made up of the Eastern Himalayan hills and the Terai foot hills. This north most district of West Bengal shares borders with Nepal in the west, state of Sikkim in the north, Kingdom of Bhutan in the north-east and the district of Jalpaiguri in the east. The number of indigenous, tribal and caste population makes the district highly heterogeneous. The Rajbanshi, Dhimal, Mech, Toto, Lepcha, Rabha and Limbu (Limboo) are some of the East Asian tribal inhabitants of the district (Datta Banik 2011). The major non-tribal populations are the Bengali Caste, Nepali Caste and Bengali Muslim. Studies on stature estimation among the populations of North Bengal are practically nonexistent. In fact, a detailed literature search using "Pubmed" has shown that such studies are relatively scarce among the populations of this region. Here the studies of Sen and Ghosh (2008), Datta Banik (2011) and Sen et al (2010; 2014; 2015) are mentionable.

The afore-mentioned studies done among the populations of North Bengal have utilized data from adult individuals. There are no studies that have used data from children. Given the importance of stature for assessment of growth, nutritional status and personal identification, the present study assesses the relationship between stature, arm span, arm length and tibial length among children belonging to the Bengalee Hindu Caste Population (BHCP) of the region.

MATERIALS AND METHODS

The present cross-sectional study was conducted on school children (aged 3-11 years) belonging to the heterogeneous Bengali Hindu Caste Population (BHCP), nature of which has been described elsewhere (Mondal and Sen 2010). All the children were the residents of Naxalbari block of the district of Darjeeling located in North Bengal. The data was collected from three schools located in the block. The children were selected using a multistage stratified random sampling method. Initially children belonging to the age group of 3-11 years were singled out. Then those children belonging to the BHCP were identified based on their birth records and school information. A total of 264 children belonging to the BHCP (boys: 126; girls: 138) were approached to take part in the study. Twenty four of them (boys: 10; girls: 14) were subsequently excluded from the study as either their dates of birth were not available in the school records or they did not belong to the age group or population selected. The final sample size consisted of 240 children (boys: 116; girls: 124).

The study was conducted during the months of August and September 2014. Permissions for the study were taken from the local Panchayat (a village level governing authority) prior to data collection. An informed consent was obtained from either parent of the children. Necessary approvals and clearances were obtained from the University of North Bengal. The study was conducted in accordance with the ethical guidelines for human experiments as laid down in the Helsinki Declaration of 2000 (Touitou et al. 2004).

Anthropometric measurements of stature, arm span and arm length were recorded following the standard procedures as outlined by Weiner and Lourie (1981). Tibial length was recorded following the method of Marfell-Jones (2006). Stature, arm length and tibial length were measured using a standard anthropometer to the nearest 0.10 cm. Arm span were measured using a flexible tape. Specially for measuring arm length and tibial length 1st and 2nd segments of anthropometer (rod compass) were used. All the measurements were recorded in minimum clothes and bare feet from the left side of the subject.

Stature was measured with the anthropometer rod to the nearest 0.10 cm. The child was made to stand on a flat surface with the both heels together. The head was kept stretched upward to the fullest extent in the Frankfurt horizontal plane. The horizontal arm of the anthropometer was brought down lightly to touch the vertex in the mid-sagittal plane of the subject. Arm span measurement were taken from the tip of the middle finger of one arm to the tip middle finger of other arm (dactylion to dactylion) with arm outstretched at right angles to the body, on a level concrete floor with upper backs, buttocks and heels against the wall. Arm length was taken from the tip of humerus (acromion) bone to tip of the middle finger (dactylion) of left arm while the subject is standing erect in the Frankfort position with arms hanging down wards lateral to the body. Tibial length was measured from the knee joint (tibiale mediale) to the ankle joint (sphyrion tibiale) of the left leg while subjects sits on a stool and crosses the left ankle over the right knee to present the medial surface of left leg horizontally.

Intra-observer and inter-observer technical errors of the measurements (TEM) were calculated using a standard procedure (Ulijaszek and Kerr 1999). The TEM was calculated using the following equation:

$TEM=\sqrt{(\Sigma D^2/2N)}$, D=difference between the measurements, N=number of individuals.

The co-efficient of reliability (R) was subsequently calculated from TEM using the following equation:

$R=\{1-(TEM)^2/SD^2\}$, SD= standard deviation of the measurements.

For calculating TEM stature, arm span, arm length and tibial length were recorded from 50 children other than those selected for the study by both the authors. Very high values of R (>0.966) were obtained for TEM and these values were observed to be within acceptable limits (R=0.95) as proposed by Ulijaszek and Kerr (1999). Hence, the measurements recorded are considered to be reliable and reproducible. Subsequently all the measurements for the present study were recorded by one of the authors (BD).

The measurements recorded were statistically analyzed using SPSS 17.0. The analysis included means, standard deviation and ranges. Analysis of sex difference in stature, arm span, arm length and tibial length was done using one-way analysis of variance (ANOVA). Correlation analysis between these variables was done to assess their associations with stature. Linear and stepwise multiple regression was done to estimate stature from arm span, arm length and tibial length. The p values of <0.01 and <0.05 were considered to be statistically significant.

RESULTS

Statistical constants

The means, standard deviations and ranges of stature, arm span, arm length and tibial length of the boys (n=116) and girls (n=124) in the present study are shown in Tables 1 and 2. The boys had a mean age of 7.04 years, mean stature of 116.80 cm, mean arm span of 116.30 cm, mean arm length of 50.08 cm and mean tibial length of 25.57 cm. For girls mean age was 6.89 years, mean stature was 114.77 cm, mean arm span was 113.56 cm, mean arm length was 48.48 cm and mean tibial length was 25.11 cm. The mean arm span, arm length and tibial length for Bengali boys of the present study were higher than girls.

It was also observed that among boys, arm span varied from 92.64% to 108.50% of stature, arm length varied from 38.87% to 77.80% of stature and tibial length varied from 19.76% to 37.85% with respect to stature. Among girls, arm span varied from 93.14% to 112.07% of stature, arm length varied from 38.58% to 45.13% of stature and tibial length varied from 19.28% to 30.76% with respect to stature.

Sex differences in stature, arm span, arm length and tibial length

The sex differences in stature, arm span, arm length and tibial length were analyzed using ANOVA. It was observed that the F-ratios were statistically not significant in case of all four variables ($p>0.05$). The detailed analysis is shown in Table 3.

Correlation between the variables

Stature was observed to be positively and significantly correlated with age ($r = +0.886$, $p<0.01$), arm span ($r = + 0.978$, $p<0.01$), arm length ($r = + 0.828$, $p<0.01$) and tibial length ($r = + 0.856$, $p<0.01$) among boys. Similarly it was significantly correlated with age ($r = + 0.829$, $p<0.01$), arm span ($r = +0.972$, $p<0.01$), arm length ($r = + 0.970$, $p<0.01$) and tibial length ($r = + 0.937$, $p<0.01$) among girls. Associations of age, arm span, arm length and tibial length with stature were therefore strong among both boys and girls. The overall sex combined correlations also exhibited a similar pattern. The overall sex combined correlations between stature and age ($r = + 0.855$, $p<0.01$), stature and arm span ($r = + 0.975$, $p<0.01$), stature and arm length ($r = + 0.894$, $p<0.01$), stature and tibial length ($r = + 0.890$, $p<0.01$) were all statistically significant.

Linear regression model for prediction of stature

A linear regression equation was fitted to predict stature from arm span, arm length and tibial length. Stature was taken as the dependent variable and age, arm span, arm length and tibial length as the independent variables.

The regression equations derived for both boys and girls are shown in Table 4. In all the cases, the regression coefficients were observed to be statistically significant ($p<0.05$). The predictive accuracy of stature estimation was higher among girls than boys. When regression equations were derived for prediction of stature in all the children taken together irrespective of sex, the predictive accuracy of predicting stature fell between the predictive accuracy of boys and girls. In other words, predictive accuracy of unknown subjects was greater than that of boys and lesser than that of girls (Table 4). The Standard Error of Estimate (SEE) for arm span as predictor was least among boys (2.532) followed by the unknown sample (2.809) and girls (2.861). A smallest SEE for arm length as predictor was observed among girls (2.902). Overall arm span appeared to be the best predictors for stature and followed by arm length. Tibial length also appeared to be a relatively good predictor of stature.

Step-wise multiple regression of stature on arm span, arm length and tibial length

The step-wise multiple regression equations for stature on arm span, arm length, and tibial length among the children are depicted in Table 5. In all cases, regression coefficients were statistically significant ($p<0.05$). It was observed that the correlation coefficient (R) and the coefficient of determination (R^2) increased with the inclusions of arm length and tibial length with arm span as predictors in the equation. The coefficients of determination were highest for the 2nd equation for girls followed by the equation for boys and then the unknown sample.

Using step-wise multiple regression equation after considering age as factor has produced one equation each for boys and girls and two for the unknown sample (Table 6). Among these best fit equations, the equation for girls with a R^2 value of 0.965 and SEE of 2.259 was stronger than the other best fit equations for stature prediction (Table 6). Out of two best fit equations for unknown category with age as additional variable 2nd equation with R^2 of 0.962 and SEE of 2.374 is relatively accurate equations for stature prediction.

DISCUSSION

Age and sex along with stature constitute the important criteria for establishing the identity of the remains of the human body (Rastogi et al. 2009). This is because every human body part has a more or less constant relationship with stature (Kerley 1977). It has also been opined that stature estimation can provide a valuable idea about an individual’s identity (Kanchan et al 2008). Humans across the globe show a lot of ethnic variations as a result of which there is a need for population specific studies on stature estimations (Telkka 1950). Subsequently a large quantum of studies have been initiated to obtain regression equations for predicting stature from body dimensions among different populations (e.g., Zeybek et al. 2008; Akhlaghi et al. 2012; Domjanic et al. 2015; Jee and Yun 2015).

The mean differences stature, arm span, arm length and tibial length between the Bengalee boys and girls of the present study were statistically not significant ($p>0.05$). However, studies have reported significant sex differences with respect to stature and hand length (e.g., Ibegbu et al. 2015). In their study among Malawain children, Zverev and Chisi (2005) showed that stature and arm span among differed significantly between sexes. It has been later opined that these differences may be attributed to ethnicity (Yabanci et al. 2010) or geography.

A number of studies have assessed the relationship between stature, arm span, arm length, tibial length, knee stature, sitting stature both among adults (Aggarwal et al. 2000; Mohanty et al. 2001; Bjelica et al. 2012), elderly (Shahar and Pooy 2003; Fatmah 2009, 2010) and among children (Yousafzai 2003; Neyestani et al. 2009; Yabanci et al. 2010). Majority of these studies have observed that the correlation between stature and arm span was stronger than with any other parameter. The present study has also reported similar findings as the correlation coefficients between stature and arm span were 0.978 (boys) and 0.972 (girls). Datta Banik (2011) also reported a similar correlation (boys: 0.97; girls: 0.93) between stature and arm span for Dhimal individuals from North Bengal. A higher correlation has been reported for Malawain boys (0.983) and girls (0.986) by Zverev and Chisi (2005). A study on Turkish children by Yabanci et al. (2010) reported relatively lower correlations which ranged from 0.85 to 0.92. This study also reported range of correlation between stature and age from 0.35 to 0.74. The correlation between stature and age in the present study was 0.89 for boys and 0.83 for girls which was higher that reported by Yanabci et al. (2010). Tibial length also has shown to be strongly associated with stature in the present study. However the non-existence of other studies reporting the correlation between stature and tibial length among children deprived further comparisons.

The study of Yousafzai (2003) reported the best stature predictor to be arm span followed by those models containing arm length and then tibial length. In the present study, the linear equation model with arm span as predictor exhibited highest coefficient of determination followed by tibial length and arm length among boys. The trend was arm span, arm length and tibial length for girls and the unknown sample.

Step-wise multiple regression equation model and equations considering age as additional variable had higher prediction accuracy than linear regression equations in the present study. Similar results have been reported by Sen and Ghosh (2008) and Sen et al (2014) on Rajbanshi adults of North Bengal. Presence of arm length and tibial length along with arm span showed increased predictive strength in the step-wise regression. Out of two best fit equations for girls and unknown sample, the 2nd equation was more accurate than the first. Similarly presence of age as additional factors along with arm span, arm length and tibial length increased the predictive accuracy of equations. Regression equation model for girls remained more accurate than that of boys. Among the equations for unknown, the 2nd equation was more accurate.

The strength of tibial length as predictor of stature increased from linear equation to step-wise multiple linear equation and then in equations with age as an additional factor. Some studies reported tibial length to be a weaker predictor of stature than arm length (Yousafzai 2003; Neyestani et al. 2009; Yabanci et al. 2010) which is also true for the present study. However, the studies cited did not use step-wise multiple regression analysis.

CONCLUSION

The present study has documented strong associations of stature with age, arm span, arm length and tibial length. The sex differences with respect these parameters are not significant. The strength of prediction in general increased with the increasing number of parameter and from linear to stepwise multiple regressions. Addition of age as a variable has also influence the predictive accuracy of the equations which is helpful for the stature estimation among juvenile if the age is known.

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Table 1. Mean, standard deviation and range of age, stature, arm span, arm length and tibia length of the boys (n=116)

Variable	Minimum	Maximum	Mean	Std. Deviation
Age	3.73	12.68	7.04	1.87
Stature	90.00	152.00	116.80	12.13
Arm span	89.60	151.00	116.31	12.77
Arm length	37.30	82.70	50.08	6.78
Tibial length	17.80	50.80	25.57	4.08

All measurements are in centimeter excluding age which is in years

Table 2. Mean, standard deviation and range of stature, arm span, arm length and tibial length of the girls (n=124)

Variable	Minimum	Maximum	Mean	Std. Deviation
Age	3.45	12.73	6.89	1.97
Stature	85.60	145.00	114.77	11.95
Arm span	87.10	149.00	113.56	12.46
Arm length	35.40	64.00	48.48	5.89
Tibial length	18.10	34.00	25.11	3.34

All measurements are in centimeter excluding age which is in years

Table 3. Sex difference in the variables among the children using ANOVA.

Variable	f- value	d.f.	Level of significance
Age	0.365	238	p>0.05
Stature	1.709	238	p>0.05
Armspan	2.837	238	p>0.05
Arm length	3.779	238	p>0.05
Tibial length	0.916	238	p>0.05

Table 4. Linear regression equation in stature (cm) estimation from arm span, arm length and tibial length among the children.

Gender	Variable	Equation	R	R^2	SEE
Boys (n=116)	Arm span	8.758 + (0.929) Arm span	0.978	0.957	2.532
	Arm length	42.675 + (1.480) Arm length	0.828	0.685	6.837
	Tibial length	51.711 + (2.546) Tibial length	0.856	0.732	6.308
Girls (n=124)	Arm span	8.882 + (0.932) Arm span	0.972	0.945	2.809
	Arm length	19.303 + (1.969) Arm length	0.970	0.941	2.902
	Tibial length	30.621 + (3.351) Tibial length	0.937	0.878	4.185
Unknown (n=240)	Arm span	9.082 + (0.928) Arm span	0.975	0.951	2.681
	Arm length	32.426 + (1.692) Arm length	0.894	0.800	5.403
	Tibial length	42.585 + (2.888) Tibial length	0.890	0.792	5.508

Table 5. Step-wise multiple regression equation in stature (cm) estimation from arm span, arm length and tibial length among the children.

Gender	Equation	R	R^2	SEE
Boys (n=116)	10.539 + (0.846) Arm span + (0.309) Tibial length	0.980	0.960	2.451
Girls (n=124)	11.777 + (0.679) Arm span + (1.032) Tibial length	0.979	0.958	2.454
	13.282 + (0.463) Arm span + (0.760) Tibial length + (0.614) Arm length	0.981	0.963	2.339
Unknown (n=240)	11.224 + (0.796) Arm span + (0.518) Tibial length	0.978	0.957	2.517
	11.600 + (0.719) Arm span + (0.498) Tibial length + (0.180) Arm length	0.979	0.959	2.469

Table 6. Step-wise multiple linear regression equation in stature (cm) estimation from arm span, arm length and tibial length among the children adding age as a variable.

Gender	Equation	R	R^2	SEE
Boys (n=116)	15.824 + (0.760) Arm span + (0.309) Tibial length + 0.663 age	0.981	0.962	2.390
Girls (n=124)	17.000 + (0.442) Arm span + (0.699) Tibial length + (0.541) Arm length + 0.552 age	0.983	0.965	2.259
Unknown (n=240)	16.568 + (0.714) Arm span + (0.481) Tibial length + 0.719 age	0.980	0.961	2.406
	16.491 + (0.657) Arm span + (0.467) Tibial length + (0.148) Arm length + 0.667 age	0.981	0.962	2.374