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Estimation of Stature from Foot Anthropometry: A cross-sectional study among Bengali speaking Hindu Population of West Bengal

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ABSTRACT This study was conducted to understand the relationship between foot dimensions and stature and to formulate multiplication factors and regression equations for estimation of body stature from foot measurements for the purpose of forensic identification. It was conducted on 340 healthy male Bengali speaking Hindu postgraduate students (21-29 years of age) of West Bengal, India. Both simple and multiple regression analysis were used to provide regression equations separately. All the foot measurements showed positive correlation with stature; among them, foot length showed more positive correlation than foot breadth. Regression analysis concluded that stature estimation could be carried out from foot length more accurately within the reference population.

INTRODUCTION

Forensic anthropometry is such a special aspect of forensic anthropology that emerged for dealing with personal identification as well as criminal identification with the help of anthropometric techniques. Personal identification or criminal investigation is, now a day, much necessary since today's world is evidencing a lot of unwanted events on daily basis. These kind of unwanted events may be of naturally occurred or of man-made. Natural disasters like earthquake, landslide, tsunami etc. As well as man-made disasters like building collapse, stampedes, air crush, road accident, railway accident, mining accident, bomb explosion, fire explosion etc. can cause mutilation of human body. Even a murderer may mutilate the body into pieces to destroy all kinds of traces of identity regarding the dead body and also to simplify the settlement of the same. In these kinds of events, dismembered body parts may frequently be found at the site. Forensic anthropometry plays here a major role in identifying the dismembered body or body parts by formulating a tentative biological profile of the unknown remains. This biological profile broadly involves determination of stature, sex, age and ethnicity. Among these, stature estimation is considered to be the most important initial measure for personal identification in forensic investigation since stature is the complex expression of genetics and environment (Varu et al. 2015).

In forensic investigation, determination of one's biological profile is most important for personal identification and stature is the key element of biological profile of an individual. Stature can be estimated from different body dimensions even from impression of different body parts. However, measurements of long bones have widely been used for stature estimation but in comparison hand and foot dimension have rarely been used though hand and foot impression are usually found in most of the crime scenes, even in mass disaster cases, victims are often found shoe clad. Therefore, foot dimension can be an excellent clue for personal identification. Rutishauser (1968) was the first who exhibited that foot print as well as foot dimension is as reliable as long bones in stature estimation (Agarwal et al. 2015).

Stature can be estimated from body parts as well as skeletal remains by two different methods; one is anatomical method and another is

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mathematical method. In anatomical method, stature is determined by summing up the measurements of all such skeletal parts of a body that contribute to the total body height, with correlation factor for soft tissues. On the other hand, in mathematical method stature can be obtained from bone or body parts or impression of body parts by deriving regression formula or multiplication factor. This method is more useful than anatomical method in medico-legal investigation as dismembered body parts or hand or foot impression may often be found at the spot. However, since body proportion (limb-trunk) may vary population to population, regression formula or multiplication factor derived from one population cannot be used for other population, therefore, population specific regression formula and multiplication factor from different body parts are necessary for this purpose (Varu et al. 2015).

Stature reconstruction of an individual from different body dimensions plays a vital role for personal identification in medico-legal cases. Stature estimation by the measurements of various long bones has been attempted by several scholars with different degree of success (Meena et al. 2013). Researchers like Pearson (1899), Trotter and Glesser (1952) have derived their own formulas for calculating the stature from long bones. There are also some studies on stature estimation in Indian context conducted by Athwale et al. (1963), Patel et al. (1964), Joshi et al. (1964), Lal and Lala (1972), Kalte and Bansal (1974), Saxena (1984), Bhatnagaret al. (1984), Thakur and Rai (1987). Some recent studies, conducted by Babu et al. (2013), Moorthy and Zulkifly (2014), Agarwal et al. (2015), Varu et al. (2015), Hasan et al. (2017), Mudasir et al. (2017), Yadav and Pathak (2018), Singh et al. (2019), exhibited positive and significant correlation between different body dimensions with stature with different degree of success. A similar study, conducted by Patel et al. (2007), performed on 502 medical students (278 males and 224 females) between 17 to 22 years of age, stated that r-value between stature or body height and foot length was higher in female (r= 0.80) than male (0.65) though it showed strong and statistically significant relationship with stature in both the sexes. This study suggested that there has a strong bonding between stature and foot length and if any one of the measurements was previously known, the other could be calculated with great reliability using regression method. Another study, conducted by Sen and Ghosh (2008), established sex-specific and sex-independent regression equation for estimating stature from foot dimensions bilaterally with statistically significant correlation coefficient of stature with FL (r= 0.813) and FB (r=0.693) at 0.01 significant level. Meena et al. (2013) in a similar study on 250 female visitors (18 - 23 years) to Lady Hardinge Medical College and Asst. Hospital, New Delhi, found positive and statistically significant correlation coefficient of stature with foot length (r= 0.583) and with foot breadth (r= 0.379) at 0.01 level. This study illustrated both simple linear regression and multiple regression equations for estimating stature from foot length and foot breadth. It stated that although stature can be carried out from both the foot measurements, foot length has greater reliability on prediction of stature than foot breadth. Babu et al. (2013), in their study that conducted on 104 participants (54 males and 50 females) in Secunderabad within the age limit of 21 to 35 years, suggested that foot length among all the variables provided highest reliability and accuracy in estimating stature of an unknown individual. He found positive r-value between stature and FLL (0.585), stature and FLR (0.583) in case of male and found 0.653 and 0.660 in case of female FLL and FLR, respectively, which were statistically significant. Correspondingly, study conducted by Pandey et al. (2014) on 200 medical students (100 males and 100 females) of ages ranging 18 to 23 years of MGM Medical College, Navi Mumbai, India, exhibited that all the foot measurements of male showed statistically significant difference from those of female ($P< 0.001$). Bilateral asymmetry was not found in case of foot length of male. It exhibited that male stature was significantly correlated with both the foot lengths (right r-value= 0.451 and left r-value= 0.452, $P< 0.001$). Female stature showed similar result with both the foot lengths, where right r-value= 0.421 and left r-value= 0.506, $P< 0.001$. This study formulated both simple linear regression and multiple regression equations to estimate stature from foot measurements. Yadav and Pathak (2018) in a similar study executed among 200 medical students (100 males and 100 females

of 17- 21 years) of Teerthanker Mahaveer Medical College and Research Centre, Moradabad, Uttar Pradesh, India, found all the studied measurements having higher and statistically significant correlation coefficient (r) with stature among those leg length had the highest r-value (0.8847) and foot length had the least (r= 0.7664). Similarly, study conducted by Singh et al. (2019) on 226 Gorkha personnel of Indian Armed Forces of 18-48 years of age, described that leg length had strongest correlation (r= 0.816) with stature compared to other variables such as arm length, foot length, hand length. It was also stated that hand length had weakest correlation with stature (r-value= 0.544). It derived equations for estimating stature using simple linear and multiple regression models.

Unlike the above studies, Vardhan and Pandey (2016), in their study performed on 185 participants (92 males and 93 females) of 19-25 years of age, in the department of anatomy, Katihar Medical College & Hospital, Bihar, concluded that foot length in males (r for RFL= 0.37 and r for LFL= 0.34) and females (r for both FL= 0.47) showed medium correlation with stature. So foot length provided the medium reliability and accuracy in estimating stature.

Objectives

The primary objective of the study is to ascertain the relationship of foot measurements with stature and to estimate the individual's stature from the foot parameters. The other specific objectives are:

- To determine the correlation coefficient of stature with foot length and foot breadth to understand the proportional relationship of this body part that contributes in determining the total body height with stature.
- To compute multiplication factor and regression equation for stature estimation among Bengali speaking Hindu male students.

MATERIAL AND METHODS

A cross-sectional study was carried out (from December 2016 to January 2017) among randomly selected 340 healthy male postgraduate students of West Bengal State University, North 24 pgs, West Bengal, India. The participants were within the age group of 21-29 years. The participants were apparently free from any skeletal and other deformities. Thrice value of every measurement was taken at a time. All the measurements were taken during college hours between 11:00 AM and 4:00 PM. A verbal consent was taken from every participant before measurement.

Anthropometric measurements such as height (vertex to standing platform), foot length (linear distance from the most prominent projected point of the heel to the most distal point of the longest toe) and foot breadth (linear distance from the most prominent point on the medial aspect of the head of the first metatarsal to the most prominent point on the lateral aspect of the head of the fifth metatarsal) were taken independently from left foot and right foot of each individual and recorded to the nearest 0.1 centimetre. All the measurements were taken following standard procedures recommended by Lohman et al. (1988). All the measurements were recorded thrice and mean of the thrice value was considered for statistical analysis.

Anthropometric rod was used to measure vertical height or stature. Martin's sliding calliper was used for measuring foot breadth, whereas in case of foot length, rod compass was used.

Data was complied on a Microsoft Excel datasheet (MS Excel 2013) and then transferred to Statistical Package for Social Sciences (SPSS 16.0). The strength of the relationships between the parameters and stature was established using Pearson's correlation. The regression equations and multiplication factors were derived for stature estimation with following standard formula.

Regression equations for estimating stature were derived from the parameters of feet by using the standard formula:

$Y = a + bX$

Where, Y = Stature, a = Value of constant, b = regression coefficient, X = parameters (of feet).

Multiplication factors for estimating stature are derived from the parameters of feet by using the standard formula:

Multiplication factor = Stature/parameters (of feet)

RESULTS

Since each measurement has been taken thrice for more accuracy, values of each mea-

surement of every individual have been converted into a single value by calculating their mean and termed as "Height"(HT), "Foot Length Right"(FLR), "Foot Length Left"(FLL), "Foot Breadth Right"(FBR), "Foot Breadth Left"(FBL).

Results show the descriptive statistics of all the anthropometric variables in Table 1, which depicts that the height of the population is ranging from 145.23 cm to 182.40 cm and mean of Height with SD is 167.25± 6.19 cm. FLR and FLL show almost same value (mean± SD) of 24.94±1.54 cm and 24.92±1.53 cm, respectively. FBR and FBL also show little bilateral asymmetry with mean value = 9.99±0.61 cm and 10.01±0.63 cm respectively. Pearson correlation of stature with all the studied parameters has been shown in Table 2. The correlation coefficient of every variable with stature is found to be positive and statistically significant at the 0.01 level. But the study shows that both the-foot lengths have stronger correlation with stature than both the foot breadths. The 'r'-value of FLR and FLL show 0.629 and 0.644 respectively, whereas in case of foot breadth 'r'-value of FBR and FBL is 0.385and 0.397 respectively. Multiplication factor of the variables with stature with its range, mean value, SE and SD have been shown by Table 3. From the mean multiplication values, stature can be estimated by using following formula:

Stature = Mean multiplication factor of the variable* value of the variable

Table 2: Correlation of body stature with foot length and foot breadth

Foot variables	*Ht*
FLR	0.629**
FLL	0.644**
FBR	0.385**
FBL	0.397**

** Significant, p<0.01

MFFLR ranges between 5.41 and 7.99 with SE = 0.01, MFFLL ranges between 5.41 and 8.12 with SE = 0.01, MFFBR ranges between 14.59 and 20.73 with SE = 0.05, MFFBL ranges from 14.65 to 21.19 with SE = 0.05.Table 4 contains regression analysis of all the studied foot measurements as independent variables with body height as dependent variable and also contains t-value of all the foot variables and its scatter diagrams are shown by all the figures (Figs. 1-4). Regression analysis shows value of constant, regression coefficient and adjusted coefficient of determination. Here it is seen that adjusted R^2 showed the value trend similar to that of Pearson correlation. Foot Length Left has the maximum R^2 value of 0.414, which means it has a stronger relationship than other variables as seen in case of 'r-value'. From this table regression equation can also be derived using above-mentioned formula: Y=a+bX, where Y= Body height and X= foot anthropometry (foot length or foot breadth).

Table 1: Descriptive statistics of all the variables

Variables	*N*	*Min.*	*Max.*	*Mean*	*SE*	*SD*
Age (in year)	340	21	29	22.94	0.11	2.06
Ht (in cm)	340	145.23	182.40	167.25	0.33	6.19
FLR (in cm)	340	19.93	29.50	24.94	0.08	1.54
FLL (in cm)	340	19.53	29.50	24.92	0.08	1.53
FBR (in cm)	340	7.60	11.57	9.99	0.03	0.61
FBL (in cm)	340	7.43	11.73	10.01	0.03	0.63

Table 3: Multiplication Factor of foot parameters with stature

	N	*Min.*	*Max.*	*Mean MF*	*SE*	*SD*
MFFLR	340	5.41	7.99	6.72	0.01	0.33
MFFLL	340	5.41	8.12	6.72	0.01	0.32
MFFBR	340	14.59	20.73	16.77	0.05	0.99
MFFBL	340	14.65	21.19	16.75	0.05	1.00

** Multiplication Factor = Stature / parameter

Table 4: Regression coefficient between stature as dependent and feet anthropometry as independent variables

Independentvariables	*Constant (a)*	*b-value*	*Adjusted R^2*	*t-value*	*p-value*
FLR	104.267	2.526	0.394	14.870	0.001
FLL	102.546	2.596	0.414	15.495	0.001
FBR	128.682	3.858	0.145	7.660	0.001
FBL	128.196	3.902	0.155	7.941	0.001

Where, R^2 = coefficient of determination, b = regression coefficient, a = value of constant.

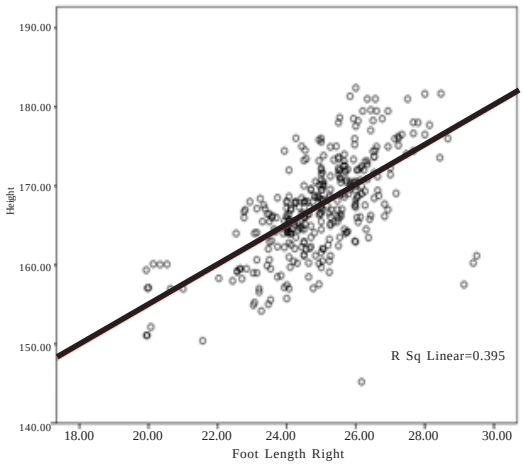
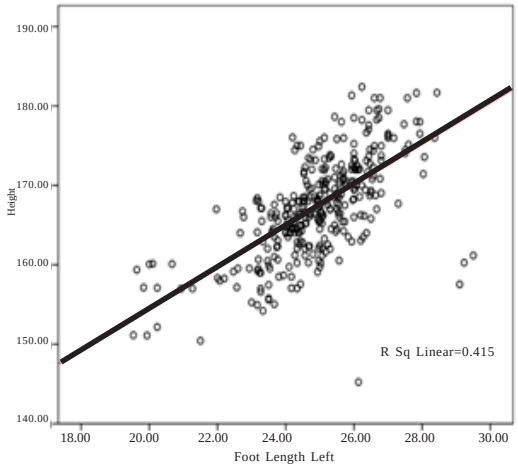


Fig. 1



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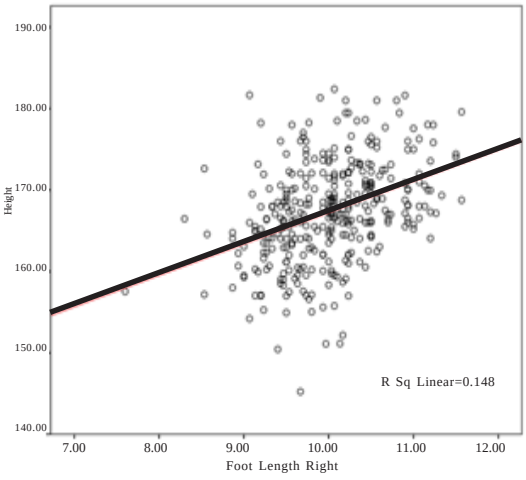

Fig. 3

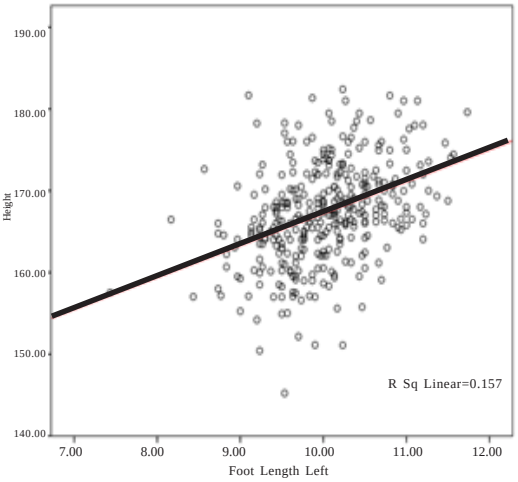

Fig. 4

Figs. 1-4. The figures contain scatter diagram of all the foot variables with body height like Fig. 1. Foot Length Right (FLR), Fig. 2. Foot Length Left (FLL), Fig. 3. Foot Breadth Right (FBR) and Fig. 4. Foot Breadth Left (FBL)

The estimated regression equations from the present study through simple regression analysis are:

- Y (Height) = 104.267+2.526*FLR
- Y (Height) = 128.682+3.858*FBR
- Y (Height) = 102.546+2.596*FLL
- Y (Height) = 128.196+3.902*FBLMultiple regression coefficient of body height as dependent with studied foot measurements as independent variables has been displayed in Table 5, to show multiple effect of length and breadth of a foot together on body height and to estimate the regression equation of height from foot length and foot breadth together. The equation is,

Y (Height) = $a+b_1X_1+b_2X_2$

Where b_1= b-value of length and b_2= b-value of breadth, on the other side X_1= foot length and X_2= foot breadth.

The estimated regression equations from the present study through multiple regression analysis are:

- Y (Height) =88.582 +(2.268*FLR)+ (2.210* FBR) (from right foot)
- Y (Height) = 88.366 +(2.323*FLL)+ (2.096* FBL) (from left foot)

DISCUSSION

Data obtained from one population cannot be used for another in estimation of stature for personal identification. That is why, the baseline data must be derived from the local population for the forensic use of its members.

The present study shows a greater statistically significant correlation of all the foot measurements with stature but both the foot lengths show higher correlation with stature than other foot variables. Several studies have also shown similar result, for example, Babu et al. (2013) found correlation coefficient between height and foot length positive and statistically significant which indicated that the foot length provided highest reliability in estimating stature of an unknown individual. Vardhan and Pandey (2016) found a medium correlation coefficient with stature and foot length from their study. They also concluded that there was a stronger correlation between stature and foot length found among females as compared to males, and there was no gross asymmetry on both sides. Krishan (2007) found that the correlation between stature and foot length was extremely high that suggested a close relationship among them. Patel et al. (2007) concluded that a fairly good result in estimation of height could be obtained using regression equation in either sex. Qamra et al. (1980) made a study on stature estimation from foot measurements and derived correlation coefficient of stature with foot breadth (Male 0.42 and Female 0.70) and foot length (Male 0.69 and Female 0.70). Sen et al. (2014) found higher correlation coefficient of stature with foot length over that of stature with foot breadth which indicated that foot length rather than foot breadth was more reliable in estimating stature. Pandey et al. (2014) concluded that simple linear regression and multiple regression analysis is quiet useful in stature estimation. It was also concluded that foot measurements even a single dimension of foot could better determine stature of an individual with reasonable accuracy and smaller standard error of mean.

In the present study, simple linear regression has derived equations for all the foot parameters bilaterally for stature estimation. The R^2 values are also showing a positive and greater regression correlation of the parameters with stature in the same line of Pearson correlation. Multiple regression equations from both the foot have also been derived, which involves both the dimensions of foot (length and breadth) to-

Table 5: Multiple regression coefficient of stature as dependent with length and breadth of foot as independent variables

Independentvariables	*Constant (a)*	*b-value*		*Adjusted R^2*
		Length	*Breadth*	
Right foot	88.582	2.268	2.210	0.437
Left foot	88.366	2.323	2.096	0.453

gether in a single equation. The present study also shows multiplication factor method for stature estimation from foot measurements with minimum SD and SE, which means this method is also relevant in this issue.

CONCLUSION

It has been concluded from the study that there is a strong correlation between stature and foot dimensions, and therefore, foot measurements can give better prediction of stature among the Bengali speaking Hindu population using regression method and multiplication factor method. As foot length has stronger correction with stature than foot breadth, it shows more reliability on estimating stature in the reference population than foot breadth.

RECOMMENDATIONS

As stature is an inherent character of an individual, though influenced by environment, can give better and reliable prediction in medico-legal issues within a regional population. Since lot of variation has been found in estimating stature from different body measurements, a vast account of studies on the same issue is required on different kinds of regional population from the different parts of the world which could be very useful in medico-legal aspects.

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REFERENCES

Agarwal S, Zaidi SHH, Agarwal SK 2015. Correlation of body height by foot length and knee height measurements in population of north India. *International Journal of Anatomy and Research*, 3(3): 1225-1229.

Athwale MC 1963. Estimation of height from length of forearm bones. A study of 100 Maharashtrian male adults of ages between 25 to 30 years. *American J Physical Anthropology*, 21: 105-112.

Babu RS, Deepika V, Potturi BR 2013. Estimation of stature from foot length. *International Journal of Pharmacy and Biological Sciences*, 3(3): 266-270.

Bhatnagar DP, Thapar SP, Batish MK 1984. Identification of personal height from the somatometry of the hand in Punjabi males. *For Sci Inter*, 24: 137-141.

Hasan KR, Ara S, Banna FAMH 2017. Correlation of Index Finger Length (2D) with height, weight and BMI in adult Bangladeshi male. *Journal of Enam Medical College*, 7(2): 90-94.

Joshi NB, Patel MP, Dongre AV 1964. Regression equation of height from ulna length. *Ind J Med Res*, 52: 1088-1091.

Kalte PM, Bansal PC 1974. Determination of regression formulae for reconstruction of stature from long bones of upper limbs in Maharashtrians and Marathwara region. *Journal of Anatomical Society (India)*, 23: 6-11.

Krishan K 2007. Anthropometry in forensic medicine and forensic science-'forensic anthropometry. *The Internet Journal of Forensic Science*, 2(1): 42-46.

Lal CS, Lala JK 1972. Estimation of stature from tibial and ulnar lengths in North Bihar. *Journal of Medical Association*, 58: 120-121.

Lohman T, Roche A, Martorell R 1988. *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Books.

Meena MC, Singh JP, Rani Y, Sharma GK 2013. Stature estimation from the dimensions of foot in females. *Antrocom Online Journal of Anthropology*, 9(2): 237-241.

Moorthy EN, Zulkifly NRB 2014. Regression analysis for stature determination from hand anthropometry of Malaysian Malays for forensic investigation. *Sri Lanka Journal of Forensic Medicine, Science & Law*, 5(2): 8-15.

Mudasir AK, Sheikh IB, Majid AK, Shaheen S 2017. Determination of stature from measurements of hand length and hand breadth: An anthropometric study of Kashmiri population. *International Journal of Anatomy and Research*, 5(2.3): 3968- 3875.

Pandey N, Roshan S, Kharate R, Sonawane M, Bhivate V, Ujwal NS 2014. Prediction of stature based on foot length. *Journal of Nobel Medical College*, 3(1): 66-70.

Patel MP, Joshi NB, Dongre AV 1964. Regression equation of height on tibial length. *Indian Journal of Medical Research*, 52: 531-534.

Patel SM, Shah V, Patel SV 2007. Estimation of height from measurements of foot length in Gujarat Region. *J Anat Soc India*, 56(1): 25-27.

Pearson K 1899. Mathematical contributions to the theory of evaluation on the reconstruction of the stature of prehistoric races. *Philosophical Transection of Royal Society, London*, 192: 167-244.

Qamra SR, Jit I, Deodhar SD 1980. A model for reconstruction of height from foot measurements in an adult population of Northwest India. *Indian Journal of Medical Research*, 71: 77-83.

Rutishauser IHE 1968. Prediction of height from foot length. *Archives of Disabled Child*, 43: 310-315.

Saxena SK 1984. A study of correlation and estimation of stature from hand length, hand breadth and sole length. *Anthropol Anz*, 42(4): 271-276.

Sen J, Ghosh S 2008. Estimation of stature from foot length and foot breadth among the Rajbanshi: An indigenous population of North Bengal. *Forensic Science International*, 181: 55.e1-55.e6.

Sen j, Kanchan T, Mondal N, Krishan K 2014. Estimation of stature from lengths of index and ring fingers in a North-eastern Indian population. *Journal of Forensic and Legal Medicine*, 22: 10-15.

Singh IL, Varte R, Rawat S 2019. Estimation of stature from different anthropometric measurements of Gorkha soldiers. *Defence Life Science Journal*, 4(1): 33-37.

Thakur SD, Rai KS 1987. Determination of stature from hand measurement. *Medicine Science and Law*, 78: 25-28.

Trotter M, Gleser GC 1952. Estimation of stature from long bones of American Whites and Negros. *American J Physical Anthropology*, 10: 463-514.

Vardhan H, Pandey NK 2016. Personal height of an individual person from measuring foot length. *International Journal of Medical and Health Research*, 2(8): 14-17.

Varu PR, Manvar PJ, Mangal HM, Kyada HC, Vadgama DK, Bhuva SD 2015. Determination of stature from hand dimensions. *The Journal of Medical Research*, 1(3): 104-107.

Yadav S, Pathak B 2018. Estimation of stature from the measurement of forearm, hand, leg, and foot dimensions in Uttar Pradesh region. *International Journal of Therapeutic Applications*, 35: 49-53.

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