Egyptian Journal of Forensic Sciences (2016) 6, 90–98

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Egyptian Journal of Forensic Sciences

journal homepage: http://www.journals.elsevier.com/egyptian-journal-of-forensic-sciences

ORIGINAL ARTICLE

Estimation of stature from hand dimensions in Bengalee population, West Bengal, India

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Received 5 December 2015; revised 10 March 2016; accepted 21 March 2016
Available online 11 April 2016

KEYWORDS

Anthropometry;
Hand dimensions;
Stature estimation;
Personal identification

Abstract: Stature estimation from decomposing bodies and incomplete skeletons particularly in personal identification is considered as one of the biggest aspects of forensic science. This issue has gained importance in recent times due to mass disasters like terrorist attacks, mass murders, transport accidents, floods and earthquakes. Thus, the present study was undertaken to set up a standard formulae to estimate stature from hand dimensions in the Bengalee population. Measurements of different hand dimensions and statures were taken from 1662 adult Bengalee women aged from 20 to 40 years following the standard technique and appropriate landmarks. There was no statistically significant bilateral variation of the measurements. The correlation coefficients between stature and all variables were positive and statistically significant ($p < 0.001$). The hand length and palm length showed a better correlation with stature than the other variables. Simple linear regression equations and multiple linear regression equation were formulated for stature estimation using the hand dimensions. The derived equations were applied to the control group and it was noted that the percentage difference between true stature of the control and the estimated stature ranged from 0.01% to 0.15%. The multiple linear regression equation was more reliable than the simple linear regression equations as a lower standard error of estimate and higher value of determination coefficient and multiple correlation coefficient. From the results of the present study, it may be concluded that hand dimensions can be successfully used for estimating stature of adult Bengalee women in forensic practice by enforcement agencies and forensic scientists.

1. Introduction

Personal identification is one of the main tasks of forensic research. Stature, age, sex, and ancestry helps in narrowing down the pool of the possible victim matches in the forensic investigation process and thus provide useful clues to the investigating agency in establishing the identification of the individuals. The relationship between different body

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Peer review under responsibility of The International Association of Law and Forensic Sciences (IALFS).

http://dx.doi.org/10.1016/j.ejfs.2016.03.001
2090-536X

dimensions can be utilized to solve crimes in the absence of complete evidence. This relationship can help a forensic scientist to calculate stature from mutilated and dismembered body parts in forensic examinations. Estimation of stature from the incomplete skeletal remains or from the mutilated or amputated limbs or parts of limbs or highly decomposed, fragmented human remains has obvious importance in personal identification in the events of murders, accidents or natural disasters considered as one of the biggest aspects of forensic science. Similarly, stature can be estimated from feet or footprints, imprints of the hand or from a shoe left at the scene of a crime. Anthropometric techniques have been used for stature and bone length estimation from unknown body parts and skeletal remains by anthropologists, medical scientists, and anatomists for over a hundred years.[1–3] This has been important in recent times due to natural disasters like cyclones, tsunamis, earthquakes, floods and man-made disasters like terror attacks, bomb blasts, mass accidents, wars, plane crashes etc. In such cases, the forensic pathologist is often opining about the identity of the deceased.

The relationship between body segments has been utilized to compare and highlight the differences between different ethnic groups and to narrate them to locomotor patterns, energy expenditure and lifestyle.[4] Stature is indeed a very important indicator of growth and development and is used in the clinical setting for nutrition and health research. Together with body weight, stature is an important parameter used to calculate basal energy expenditure, body mass index, basal metabolic rate, body composition, vital capacity and estimations of nutrient requirements.[5–8]

The relationship between body segments has been the focus of anatomists, anthropologists and scientists for many years. Prediction of the dimensions of different body segments is useful in many areas of modern science. Body proportions and the dimensions of different body segments, including the vertebral column, long bones of the limbs and the bones of the hand and foot have been used for stature estimation. However, the long bones of the limbs have been the most widely studied.[9–12] Different body parts can be used in the estimation of stature. Many studies have been conducted to estimate stature from various parts of the body like the trunk, vertebral column, limbs, long and short bones, hand, foot and hand and foot prints.[3,13–19] Many studies have shown the correlation of stature with body parts.[16,20–26] The Indian perspective of the problem of stature estimation has been studied by Krishan,[13]; Rastogi et al.[16]; Nagesh and Kumar,[17]; Khanapurkar and Radke,[20]; Chikhalkar et al.[21]; Jasuja and Sing,[22]; and Krishan and Sharma.[27]

The present study was undertaken to measure the stature, as well as the length and breadth of hand and to find out whether any correlation exists between the stature and hand dimensions. Consequently, a set linear regression formulae for estimation of stature from hand dimensions in the Bengalee population was made.

2. Materials and methods

2.1. Study design and sampling

This cross-sectional study was conducted on 1875 women selected from different villages of different districts of the West Bengal state, India. This study was a part of a research project assisted by the Rashtriya Vigyan Evam Sanchar Parishad (RVPSP), Department of Science and Technology, New Delhi, India. The eligibility criteria for recruitment of the participants included age range between 20–40 years, apparently healthy individuals with no physical deformity. The authors disqualified 27 orthopaedically challenged participants. Among the 1848 eligible, 186 participants were not interested in participating in the present study. Among the 1662 participants, 73 were excluded from the study due to missing or incomplete data. Thus, a final total of 1589 (85.98% of eligible) women participated in the present survey.

The two-stage sampling method was utilized. At first, a cluster sampling method was utilized to identify 20 clusters (villages) in each district e.g., East Midnapore, West Midnapore, Bankura, Purulia and Howrah of West Bengal, India. In the second stage, a systematic random sampling method was utilized to identify 20 households per cluster. All households in the cluster were listed and the number of the households was divided by the required number to get the sampling interval. The first household was chosen randomly using a lottery method and then subsequent households were selected by adding sampling interval to the random number. The selected participants were approached during field visits and the protocol of the study was explained verbally in the local language (Bengali). Written and signed consent was obtained from each participant. Before commencement of the study, ethical approval, and prior permission was obtained from the Institutional Ethics Committee and the study was carried out in accordance with the Helsinki declaration and with the ethical standards of the committee.

2.2. Measurement of body dimensions

Anthropometric measurements were taken from the participants following the standard technique and appropriate landmarks.[28,29] Weight was measured to the nearest 0.1 kg using a portable weighing machine (Libra, Libra Weighing Machine Limited, Bangkok, Thailand) and stature was measured to the nearest 0.1 cm using anthropometer (Hindustan Minerals, The Hindustan Mineral Products Co. Ltd., Kolkata, India). Hand length, palm length, hand breadth, maximum hand breadth and phalange lengths were taken to the nearest 0.1 cm using sliding caliper (Hindustan Minerals, The Hindustan Mineral Products Co. Ltd., Kolkata, India). The landmarks of different hand dimensions taken for measurements are shown in Fig. 1. Each participant was measured twice. When the two initial measures did not satisfy the 0.4 cm criterion, two additional measurements were taken and the mean of the closest records was used as the best estimate. All participants were wearing light clothes and were barefooted during measurements.

2.3. Statistical analysis

While conducting the present study, the technical error of the measurement (TEM) was taken into consideration. The technical error of measurement is an accuracy index for anthropometrical measurements and represents the measurement accuracy. It is the most common way to express the error margin in anthropometry. When performing repeating anthropo-

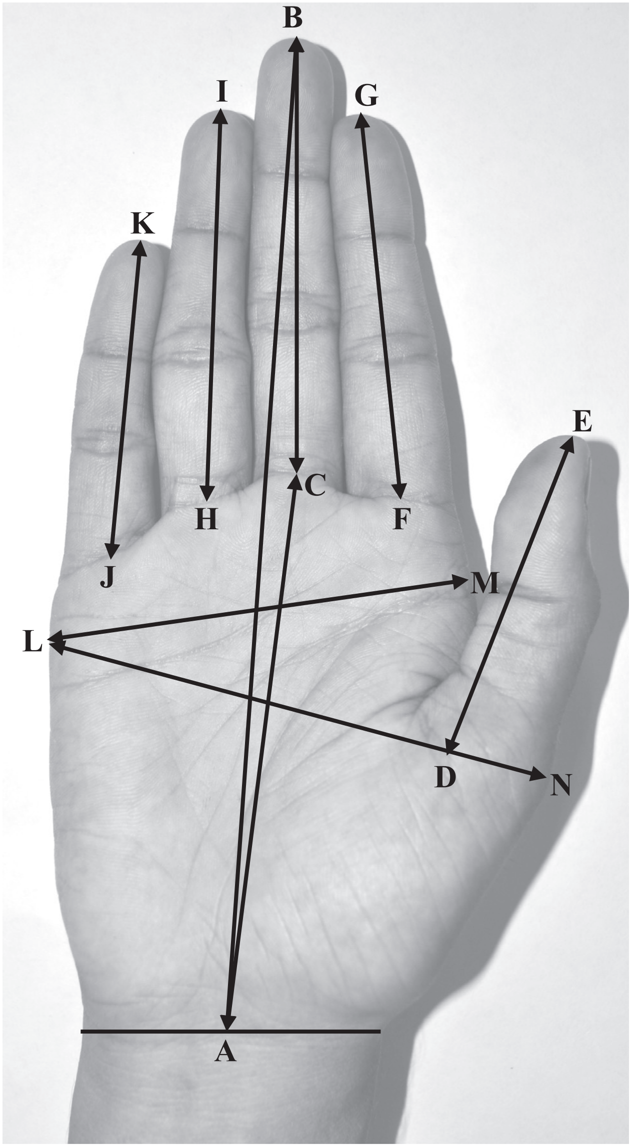

Figure 1 Human hand illustrating the landmarks of different hand dimensions. A to B: Hand length; A to C: Palm length; D to E: 1st digit length; F to G: 2nd digit length; C to B: 3rd digit length; H to I: 4th digit length; J to K: 5th digit length; L to M: Hand breadth; L to N: Max. hand breadth.

Table 1 Intra observer technical error of the measurement (TEM), relative TEM (%TEM) and percentage of coefficient of reliability (R) of different hand dimension.

Variable		TEM	%TEM	R
Stature		0.19	0.13	0.999
Hand length	R	0.077	0.508	0.988
	L	0.081	0.527	0.989
Palm length	R	0.050	0.575	0.988
	L	0.059	0.677	0.988
1st digit length	R	0.057	1.090	0.988
	L	0.052	0.987	0.988
2nd digit length	R	0.022	0.387	0.979
	L	0.035	0.606	0.982
3rd digit length	R	0.035	0.541	0.988
	L	0.045	0.684	0.98
4th digit length	R	0.047	0.799	0.989
	L	0.052	0.878	0.984
5th digit length	R	0.061	1.257	0.981
	L	0.061	1.272	0.979
Hand breadth	R	0.055	0.834	0.988
	L	0.055	0.838	0.988
Max hand breadth	R	0.065	0.828	0.988
	L	0.059	0.751	0.987

metrical measurements, the TEM index allows anthropometrics to verify the degree of accuracy. The lower the obtained TEM, the better the accuracy of the examiner in performing the anthropometrical measurement. To rule out the interobserver error, all the measurements were taken by one trained physical anthropologist. While collecting data, the instruments were regularly checked for their accuracy. Before begging data collection all measurements were taken from 20 women participants twice and technical error of measurement (TEM), the relative technical error of measurement (%TEM) and coefficient of reliability (R) was calculated.[30] In the present study, the %TEM for measurements was low and it was below the acceptable relative TEM. Acceptable relative TEM for intraobserver is 1.5% for anthropometric measures.[31] The reliability coefficient was also high (Table 1). The value of reliability coefficient ranged from 0 to 1. A coefficient of below 0 indicates "no reliability", >0 to <0.2 is slight reliability, 0.2 to <0.4 is fair reliability, 0.4 to <0.6 is moderate, 0.6 to <0.8 is substantial and 0.8–1.0 is almost perfect reliability. This indicated that the observer error for measurements in the present study was small and the measurements were reproducible without significant technical error. The Coefficient of Variation (% CV) of each measurement was also calculated. The % CV ranged from 2.95% to 8.89%, of which stature showed the lowest % CV, indicating good repeatability and reliability of stature measurements. A sample of 896 participants was randomly selected from the study participants and was identified as the study group. The other 693 participants formed the control group. When stature was analyzed in each group

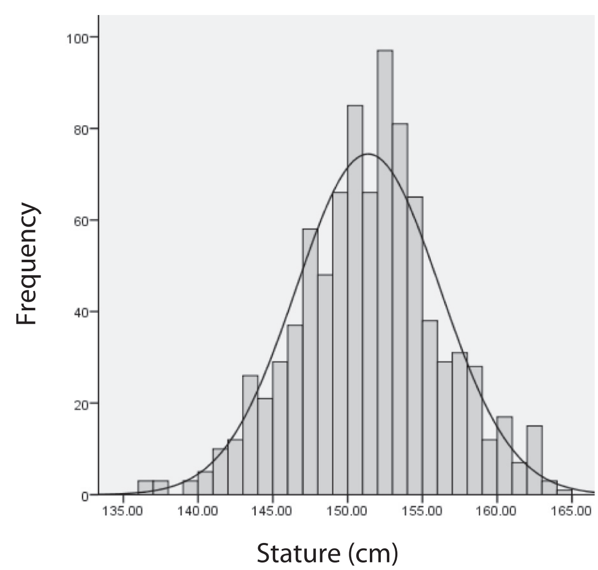

Figure 2 Distribution of participants in study group.

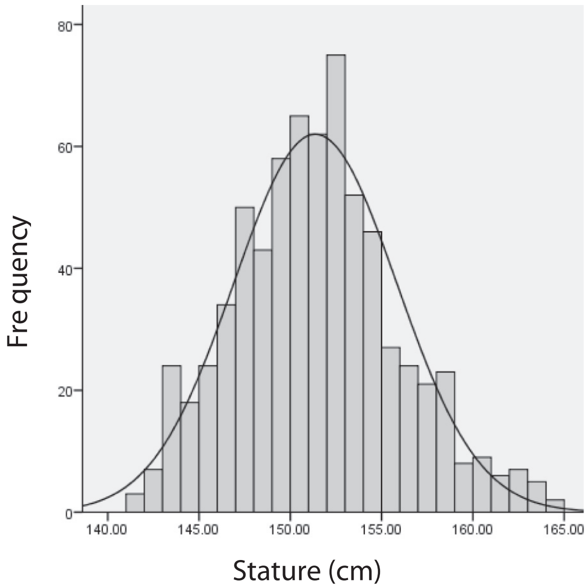

Figure 3 Distribution of participants in control group.

(study group and control group), Kolmogorov–Smirnov test was carried out to examine the normality distribution of data. The results of the present study stated that the stature of both groups was approximately normally distributed (Figs. 2 and 3). The coefficients of skewness and kurtosis were −0.051 and 0.153 for the study group, and 0.315 and −0.031 for the control group respectively. The Kolmogorov–Smirnov test of normality also confirmed these findings ($p < 0.001$ for both groups). The linear relation between the dependent variable (stature) and the explanatory variables (hand dimensions) was checked by establishing a scatter-plot matrix. The magnitude of the relationship between the dependent variable and explanatory variables was obtained by calculating the simple (Pearson) correlation. The simple linear regression equations and multiple linear regression equations with the explanatory variables were proposed as a statistical model to explain the total variation in stature, the dependent variable. The regression equations derived from the study group were applied in the control group to test the accuracy of the formulae. The data were analyzed using the statistical package of social science (SPSS 20.0) software. Statistical significance was set at $p < 0.05$.

3. Results

The physical characteristics of the participants have been shown in Table 2. The average age was 29.14 ± 8.08 years for the study group, and 29.41 ± 9.24 years for the control group. The average weight and stature of the participants were 47.53 ± 8.27 kg and 151.37 ± 4.8 cm for the study group, and 48.06 ± 8.03 kg and 151.36 ± 4.46 cm for the control group respectively. The results of the present study showed that there were no significant group differences in all variables by Student's t-test. Statistical analysis also indicated that there was no significant bilateral variation of the measurements.

The results of the scatter-plot matrix showed a linear relation between the dependent variable and the explanatory variables. From Table 3, it can be deduced that stature was significantly and positively correlated ($p < 0.001$) with all explanatory variables. Hand length and palm length showed higher correlation coefficient than that of the other hand dimensions indicating a strong relationship between the parameters.

Regression analysis was carried out to determine which hand dimensions best explained for variability in stature among women. The results of the present study did not show

Table 2 Descriptive statistics for stature and different hand dimension of women.

Variable		Study group (n = 896)		Control group (n = 693)	
		Mean ± SD	% CV	Mean ± SD	% CV
Weight		47.53 ± 8.27	17.40	48.06 ± 8.03	16.71
Stature		151.37 ± 4.8	3.17	151.36 ± 4.46	2.95
Hand length	R	16.3 ± 0.86	5.3	16.27 ± 0.81	4.97
	L	16.31 ± 0.85	5.22	16.27 ± 0.8	4.92
Palm length	R	9.14 ± 0.54	5.85	9.13 ± 0.49	5.40
	L	9.13 ± 0.54	5.93	9.12 ± 0.51	5.54
1st digit length	R	5.78 ± 0.47	8.19	5.77 ± 0.45	7.84
	L	5.8 ± 0.47	8.17	5.78 ± 0.46	7.93
2nd digit length	R	6.51 ± 0.47	7.28	6.47 ± 0.44	6.81
	L	6.52 ± 0.48	7.29	6.48 ± 0.44	6.86
3rd digit length	R	7.16 ± 0.47	6.55	7.13 ± 0.43	6.1
	L	7.18 ± 0.45	6.3	7.15 ± 0.42	5.85
4th digit length	R	6.65 ± 0.5	7.46	6.63 ± 0.46	6.93
	L	6.64 ± 0.5	7.45	6.62 ± 0.46	6.92
5th digit length	R	5.32 ± 0.48	8.89	5.29 ± 0.46	8.76
	L	5.32 ± 0.47	8.81	5.3 ± 0.45	8.52
Hand breadth	R	7.05 ± 0.49	7.02	7.04 ± 0.48	6.89
	L	7.03 ± 0.51	7.29	7.03 ± 0.5	7.16
Max hand breadth	R	8.55 ± 0.61	7.25	8.56 ± 0.63	7.41
	L	8.53 ± 0.63	7.43	8.53 ± 0.66	7.74

% CV: coefficient of variation.

Table 3 Correlation coefficient (R) between stature and different hand dimensions.

Variable	Right	Left
Hand length	0.683*	0.682*
Palm length	0.644*	0.642*
1st digit length	0.463*	0.454*
2nd digit length	0.50*	0.502*
3rd digit length	0.522*	0.516*
4th digit length	0.471*	0.488*
5th digit length	0.453*	0.44*
Hand breadth	0.53*	0.524*
Max hand breadth	0.452*	0.444*

* $p < 0.001$.

any significant bilateral variation in hand dimensions. Hence, the mean of the right and left hands together were used to derive regression equations from the hand dimensions. The simple linear regression equations for the estimation of stature from all explanatory variables were presented in Table 4. The table also showed a standard error of estimate (SEE) and determination coefficient (R^2). The SEE predicts the deviation of estimated stature from the true stature. A low value of SEE implies greater reliability in the estimated stature. In the present study, it ranged from 3.49 to 4.28 cm indicating good reliability in stature estimation. As the SEE values were minimal and the determination coefficients (R^2) was maximum for hand length and palm length compared to other variables, the hand length, and palm length can give the most accurate estimation of stature by linear regression analysis.

Table 5 presented the multiple linear regression equation for stature estimation from different explanatory variables (hand length, palm length, hand breadth and maximum hand breadth). It was observed that the multiple linear regression equation revealed the lower value of SEE as 3.433 cm and higher value of determination coefficient R^2 as 0.491 compared to the values given by the simple linear regression equations. Thus, it can be deduced that the multiple linear regression equation was the better indicator of stature estimation than simple linear regression equations.

Table 6 showed the comparison between estimated stature computed from the equations derived in the present study and true stature of the control group. There was no significant difference between the true stature and estimated stature by simple and multiple linear regression equations. The percentage difference between true stature and the estimated stature ranged from 0.01% to 0.15%.

Table 7 presented the comparison between the true stature of the control group with the estimated stature computed from the equations derived from other studies. It appears that the estimated stature has been overestimate than the true stature in the present study.

4. Discussion

Prediction of the stature of an individual is an important aspect of forensic examinations and anthropological studies. Stature provides important evidence in the forensic investigation process to the establishment of personal identification. Anthropologists have always been of particular interest to assess the stature of an individual from different dimensions of the body and bones. However, different parts of the body and stature differ between human populations.[32,33] From an Indian perspective, the problem of stature estimation has been studied by Krishan,[14] who predicted stature from cephalo-facial dimensions in the North Indian population, Rastogi et al.[16] estimated stature from hand anthropometry of North and South Indians, Chikhalkar et al.[21] estimated stature from long bones, hand and foot dimensions and Rani et al.[34] predicted stature from foot dimensions. India is a vast country with a large population and there are

Table 4 Linear regression formulae for stature estimation from different hand dimensions.

Variable	Regression model	SEE	R^2	R	p-Value
Hand length (HL)	3.88 * HL + 88.1	3.49	0.473	0.688	0.001
Palm length (PL)	5.86 * PL + 97.815	3.65	0.422	0.65	0.001
1st digit length (D1)	4.844 * D1 + 123.327	4.25	0.219	0.468	0.001
2nd digit length (D2)	5.237 * D2 + 117.251	4.14	0.259	0.509	0.001
3rd digit length (D3)	5.532 * D3 + 111.714	4.09	0.275	0.525	0.001
4th digit length (D4)	4.772 * D4 + 119.649	4.19	0.236	0.486	0.001
5th digit length (D5)	4.681 * D5 + 126.468	4.28	0.206	0.454	0.001
Hand breadth (HB)	5.183 * HB + 114.895	4.06	0.286	0.535	0.001
Max hand breadth (MHB)	3.553 * MHB + 121.047	4.28	0.206	0.454	0.001

SEE: standard error of estimate; R^2: determination coefficient; R: correlation coefficient.

Table 5 Multiple linear regression formula for stature estimation from hand dimensions.

	Regression model	SEE	R^2	R	p-Value
Hand length (HL), Palm length (PL), Hand breadth (HB), Max hand breadth (MHB)	86.259 + 2.382 * HL + 1.836 * PL + 0.56 * HB + 0.65 * MHB	3.433	0.491	0.705	0.001

SEE: standard error of estimate; R^2: determination coefficient; R: correlation coefficient.

Table 6 Percentage of difference (%) and mean difference between true stature and estimated stature in control group.

Variable			Mean ± SD	% diff.	Mean Diff. ± SD[*]
True stature			151.36 ± 4.46	–	–
Estimated stature	3.88 * Hand length + 88.1	R	151.21 ± 3.13	0.1	−0.15 ± 3.13
		L	151.23 ± 3.11	0.09	−0.13 ± 3.11
	5.86 * Palm length + 97.815	R	151.33 ± 2.89	0.02	−0.03 ± 2.89
		L	151.23 ± 2.96	0.08	−0.13 ± 2.96
	4.844 * 1st digit length + 123.327	R	151.28 ± 2.19	0.06	−0.08 ± 2.19
		L	151.32 ± 2.22	0.03	−0.04 ± 2.22
	5.237 * 2nd digit length + 117.251	R	151.14 ± 2.31	0.15	−0.22 ± 2.31
		L	151.21 ± 2.33	0.1	−0.15 ± 2.33
	5.532 * 3rd digit length + 111.714	R	151.18 ± 2.41	0.12	−0.18 ± 2.41
		L	151.29 ± 2.32	0.04	−0.07 ± 2.32
	4.772 * 4th digit length + 119.649	R	151.28 ± 2.19	0.05	−0.08 ± 2.19
		L	151.24 ± 2.19	0.08	−0.12 ± 2.19
	4.681 * 5th digit length + 126.468	R	151.23 ± 2.17	0.09	−0.13 ± 2.17
		L	151.28 ± 2.11	0.05	−0.08 ± 2.11
	5.183 * Hand breadth + 114.895	R	151.38 ± 2.51	0.01	0.02 ± 2.51
		L	151.31 ± 2.61	0.03	−0.05 ± 2.61
	3.553 * Max hand breadth + 121.047	R	151.44 ± 2.25	0.06	0.08 ± 2.25
		L	151.37 ± 2.35	0.0	0.01 ± 2.35
	86.259 + 2.382 * HL + 1.836 * PL + 0.56 * HB + 0.65 * MHB	R	151.27 ± 3.16	0.06	−0.09 ± 3.16
		L	151.23 ± 3.18	0.09	−0.13 ± 3.18

[*] Differences between estimated stature and true stature in control group.

multi-racial, multi-ethnic and multi-cultural sub-populations and they have their own variations. The body dimensions may be different in different parts of India. There may be inter-racial and inter-geographical differences in body dimensions and thus differ in their relation to stature. Stature estimation formulaes differ from one race to another. Dewangan et al.[35] measured a few hand dimensions from the north-eastern region of India, and compared these to central, eastern, southern and western regions of the country and reported that there were significant differences in hand dimensions between regions. Kar et al.[36] and Okunribido,[37] also pointed out that significant difference in anthropometry have existed compared to other nationalities. Sacngchaiya and Bunterngchit,[38] reported in their study that the variation in anthropometric dimensions existed between different populations. The difference in hand dimension of Nigerian females with foreign population has also been reported by Okunribido.[37] The similar finding also exists in four ethnic groups, Chinese, Japanese, Korean and Taiwanese.[39] Rastogi et al.[16]; Sanli et al.[24] and Zaher et al.[33] reported that the ethnic differences in body dimensions were affected by several factors such as heredity, economic development, socio-demographic status, environment, labor structure and type of work. However, body proportions vary not only with the ethnic and geographical origin but also with time context.[40] Another consideration is that body dimensions/proportions may change due to age, nutrition, environment, physical activity and living conditions.[20,24,25,41,42] These secular changes in body dimensions/proportions have implications for studies on stature estimation. A literature survey revealed that the stature estimation from body dimension among the Bengalee population is scanty. This lack of useful epidemiological data is the reason why we have attempted to investigate the relationship between hand dimensions with stature among the adult Bengalee women and to formulate standard equations to estimate stature from hand dimensions.

The present study showed that stature was significantly and positively correlated with all hand dimensions. Among the hand dimensions, the hand length and palm length showed the highest correlation with stature than the other dimensions. This study was consistent with previous studies that were undertaken by others on hand length.[16,21,23,27,43,44] This showed that the hand length was more useful in estimating stature than the hand breadth.

A Linear regression model was derived to estimate stature when a single dimension is available from the extremities. The reliability of stature estimation using regression equations is revealed by SEE which predicts the deviation of estimated stature from actual stature and is considered as a measure of the accuracy of the equations. In the present study, the SEE of the simple linear regression equations ranged from 3.49 to 4.28 cm. Actually, SEE obtained in the present study was lower than that reported previously by Ozaslan et al.[23] who studied the predictive role of hand and foot dimensions in stature estimation in Turkey, and reported SEE ranged from 6.03 to 6.39 cm for hand dimensions. Numan et al.[26] estimated stature from hand length and reported an SEE of 4.54 cm in Hausa, 4.96 cm in Igbo and 4.03 cm in Yoruba tribes in Nigeria. SEE of the present study was smaller than that achieved by Habib and Kamal,[45] who set models for stature estimation using of hand and phalange lengths in Egyptians with an SEE range from 5.3 to 7.27 cm. SEE of the present study was also smaller than that similar studies in different populations of India done by Rastogi et al.[16] who obtained an SEE of 4.11–5.97 cm for hand dimensions and Jasuja and Sing[22] reported SEE of 4.03 to 5.13 cm for hand and phalange length. Other researchers have stated similar figures for the standard error of estimation. For example, in a study on Turkish population, Sanli et al.[24] reported standard error of 3.49 cm for hand length.

In the present study, the multiple linear regression equation with stature as the dependent variable and hand length, palm

Table 7 Comparison between true stature and estimated stature derived from equations of hand length by earlier survey.

			Mean ± SD	% diff.	t
True stature			151.37 ± 6.24	–	–
Estimated stature	Khanapurkar and Radke[20]	R	152.6 ± 4.6	0.7	4.323*
	(Pune, India)	L	152.44 ± 4.56	0.71	4.448*
	Rastogi et al.[16]	R	155.42 ± 3.59	2.69	18.682*
	(South Indian)	L	155.58 ± 3.50	2.79	19.592*
	Rastogi et al.[16]	R	155.13 ± 3.72	2.49	17.108*
	(North Indian)	L	155.38 ± 3.54	2.66	18.588*
	Chikhalkar et al.[21]	R	160.25 ± 2.15	5.87	47.237*
	(Mumbai, India)	L	160.26 ± 2.13	5.88	47.378*
	Jasuja and Sing[22]	R	157.17 ± 1.3	3.84	32.941*
	(Patiala, India)	L	157.04 ± 1.33	3.75	32.146*
	Ozaslan et al.[23]	R	157.2 ± 2.26	3.86	30.739*
	(Turkey)	L	157.21 ± 2.24	3.87	30.859*
	Sanli et al.[24]	R	149.88 ± 3.02	0.98	7.223*
	(Turkey)	L	149.9 ± 3.0	0.97	7.16*
	Ilayperuma et al.[25]	R	152.65 ± 2.93	0.85	6.37*
	(Sri Lankan)	L	152.67 ± 2.9	0.86	6.467*
	Numan et al.[26]	R	150.05 ± 3.84	0.87	5.86*
	(Hausa tribe, Nigeria)	L	150.07 ± 3.8	0.85	5.786*
	Numan et al.[26]	R	163.07 ± 1.43	7.74	65.818*
	(Igbo tribe, Nigeria)	L	163.08 ± 1.42	7.74	65.915*
	Numan et al.[26]	R	155.36 ± 2.33	2.65	20.956*
	(Yoruba tribe, Nigeria)	L	155.38 ± 2.31	2.65	21.062*
	Hossain et al.[42]	R	151.76 ± 7.54	0.26	1.19
	(Bangladesh)	L	152.45 ± 7.5	0.72	3.283**

w.r.t. True stature
* $p < 0.001$.
** $p < 0.01$.

length, hand breadth and maximum hand breadth as explanatory variables was more reliable than the equations obtained from a single variable with a lower SEE, a higher value of determination coefficient (R^2) and multiple correlation coefficient (R). Thus only hand length or only hand breadth, as an explanatory variable, is not enough to explain the total variation in stature, the dependent variable. Thus, hand length, palm length, hand breadth and maximum hand breadth should be used together to estimate the total variation in stature. Rastogi et al.[16] reported that multiple regression equations gave better results in stature estimation for North and South Indians. Ozaslan et al.[23] formulated both single linear regression equations and multiple linear regression equations among Turkish from the hand and foot dimensions and reported that multiple linear regression formulas were the best estimation. Dayal et al.[46] reported that a higher accuracy was achieved in stature estimation when using more than one dimension in South African whites. This was consistent with Zaher et al.[33] who set multiple regression equations among the Egyptian population and reported that the multiple regression equation was more reliable than equations obtained from a single variable. Sen et al.[47] derived regression equations to estimate stature from lengths of the index and ring fingers in a northeastern Indian population and reported that the multiple regression equation was a better model than that of the simple linear regression equations. The determination coefficient (R^2) and correlation coefficient (R) values obtained in the present study were higher than those of Ozaslan et al.[23] and Zaher et al.[33] This indicated that the results obtained for R^2 and R give a better account of the variation in stature and a better model fit for the observed data.

Both single linear regression equations and multiple linear regression equation derived from the study group were applied to the control group in order to test the accuracy of the formulae. There was no significant difference between the true stature and estimated stature. The equations derived from other studies were applied in the control group. The estimated stature from hand dimensions from the equations developed for other populations was consistently higher than the true stature and estimated stature from equations developed in this study. Except equations developed by Sanli et al.[24] for Turkish and Numan et al.[26] for Hausa tribe, Nigeria showed a lower estimate of stature. The differences emphasize the usefulness of this study in estimation of stature from hand dimension in the Bengalee population.

From the results of the present study, it may be concluded that the hand dimensions can be successfully used for estimating stature of adult Bengalee women in forensic practice by enforcement agencies and forensic scientists. The present study also showed that the multiple regression equation was better than the single linear regression equations. Due to the multi-racial, multi-ethnic and multicultural diversity in India, each population group has a need of a separate study in this regard. The present study has provided the regression equations from hand dimensions that can be used for estimating stature of adult Bengalee women in West Bengal, India. These equations should not be used for other Indian population groups.

Author contributions

Conceived and designed the investigation: Amitava Pal and Prakash C. Dhara.

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Funding

This research work has been supported by Department of Science and Technology (RVPSP), New Delhi, India.

Conflict of interest

The authors have no conflicts of interest to declare.

Ethical approval

Necessary ethical approval was obtained from the university ethics committee.

Acknowledgments

The authors gratefully acknowledge the Department of Science and Technology, New Delhi, India for financial assistance. All of the authors wish to express their gratitude to the participants who volunteered for the present study.

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