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ORIGINAL ARTICLE

Estimation of Stature from Upper Limb Measurements by Regression Analysis in North -West Indian Population

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Abstract:

The estimation of a deceased stature, which is a part of the identification process, is crucial in cases where mutilated or dismembered bodies presented for postmortem examination. Nevertheless, stature differs by race and is determined by genetics, environment, climatic conditions, and geographic location. Therefore, the study was intended to estimate stature from upper limb parameters in the north-west Indian population, to see if there is a significant correlation between stature and various upper limb parameters, and to create regression equations for estimating stature from various upper limb parameters. Inclusion in the study group was restricted to subjects who were willing to participate and who provided written informed consent. Students with evident physical deformities were not included in the study. Using Pearson's correlation test, correlations between various parameters of the upper limb and height were determined. Gender-specific linear regression equations for estimating stature were developed by using upper limb measurements. Stepwise regression analysis was used to generate equations for multiple regressions based on a variety of parameter combinations. Using a paired T-test, there was no statistically significant difference observed between known and estimated stature for both the right and left sides in a mixed-gender and in both males and females ($p>0.05$). From the parameters, the upper limb length and hand length had shown strong positive correlations with stature in the north-west Indian population.

Keywords: Identification; Stature; Upper limb; Arm length; Hand length; Forearm length; Hand breadth.

Introduction:

The aim of conducting a post-mortem examination or autopsy is not merely dissecting the body to find out the cause of death, but also to determine the identity of the deceased in cases of decomposed, mutilated, fragmented and skeletonised bodies. Identification appears to be a critical consideration in forensic medicine as it helps in connecting the criminal to the crime. Along with sex, age, and race, stature is also considered one of the important parameters for identification.[1-3] It is common to find the fragments or peripheral parts of the body such as fingers, hands, feet, etc. in deaths from natural disasters like earthquakes, cyclones, floods, tsunamis, and man-made disasters like bomb blasts, terror attacks, mass accidents, wars, plane crashes, railway accidents etc. Stature estimation which is an integral part of identification is of paramount importance in such scenarios. Different parts of the body can be used for the estimation of stature.[4-9] Numerous studies have been conducted in different regions in the past to estimate the stature from various upper limb segments of the body. However, stature varies with race and is determined by a person's genetics, environment, climatic conditions and geographical location.[10] Therefore, the study was intended to estimate stature from upper limb parameters in the north-west Indian population, to see if there is a significant correlation between stature and various upper limb parameters, and to create regression equations for estimating stature from various upper limb parameters.

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Materials and Methods:

The cross-sectional study was conducted in a tertiary care centre of Southern Haryana. The study subjects comprise of medical students of more than 18 years of age who belongs to North-west region of India. The approval was obtained from Institutional Ethical Committee before the commencement of study. Only those students who voluntarily gave their informed consent were enrolled in the study. Those who had evident physical abnormalities were excluded. The following measurements were obtained and recorded in the proforma:

Stature: After making sure the individuals weren't wearing any kind of footwear or headwear, the stature was measured on stadiometer. Subjects were asked to stand tall on a stadiometer, with their feet axis parallel or slightly divergent, their heads balanced on their necks in the Frankfurt Horizontal Plane, and their hands hanging by their sides. The stadiometer's movable horizontal head piece was brought into touch with the subject's scalp to measure their height in centimetres.[11,12]

Upper Limb Length: Participants were instructed to stand tall with their weight spread evenly on their feet, their shoulders relaxed with arms at their sides. The distance from the acromion process to the tip of the longest finger was measured using a measuring tape and recorded in centimetres to the nearest decimal place.[12,13]

Arm Length: Participants were made to stand with the arm straight at the side of the body and the forearm bent to 90 degrees

Table 1. Descriptive statistics of age, stature and various upper limb dimensions.

Para-meter	Males (n=116)				Females (n=88)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Age	21.30	1.60	18	28	20.82	1.98	18	27
Stature	174.27	5.90	162	189	161.43	5.73	148	175
ULR	78.24	3.88	70.10	92	71.20	3.76	63	82.30
ULL	78.22	3.93	70.30	92	71.23	3.83	63	82.30
ALR	36.67	2.75	26.30	45.50	33.29	2.45	27	42
ALL	36.71	2.83	26.50	47	33.33	2.50	27	41
FLR	28.95	2.81	22.80	47	26.27	2.49	23	42.10
FLL	28.84	2.90	22.50	48	26.14	2.61	22	42
HLR	18.84	0.92	16.20	22	17.44	1.16	14	20
HLL	18.87	0.96	16.20	22	17.49	1.15	13.50	20.20
HBR	8.36	0.57	6.30	10	7.48	0.53	6.50	8.70
HBL	8.30	0.58l	6.30	10	7.43	0.56	6.40	8.70

ULR: Upper limb right; ULL: Upper limb left; ALR: Arm length right; ALL: Arm length left; FLR: Forearm length right; FLL: Forearm length left; HLR: Hand length right; HLL: Hand length left; HBR: Hand breadth right; HBL: hand breadth left.

Table 2. Pearson's correlation analysis between upper limb parameters and stature.

Parameter	Males		Females		Combined	
	R	p-value	R	p-value	R	p-value
ULR	0.635**	0.000	0.673**	0.000	0.822**	0.000
ULL	0.605**	0.000	0.658**	0.000	0.807**	0.000
ALR	0.382**	0.000	0.525**	0.000	0.647**	0.000
ALL	0.394**	0.000	0.537**	0.000	0.648**	0.000
FLR	0.489**	0.000	0.218*	0.042	0.559**	0.000
FLL	0.473**	0.000	0.222*	0.038	0.547**	0.000
HLR	0.512**	0.000	0.542**	0.000	0.707**	0.000
HLL	0.510**	0.000	0.495**	0.000	0.687**	0.000
HBR	0.318**	0.001	0.232*	0.030	0.606**	0.000
HBL	0.275**	0.003	0.229*	0.032	0.582**	0.000

* p-value <0.05; ** p-value <0.01

at the elbow joint. The distance from the acromion process to the olecranon process was measured using a measuring tape and recorded in centimetres to the nearest decimal place.[14,15]

Forearm length: With forearm flexed at 90 degrees at the elbow joint, the distance between the radial styloid process and olecranon was measured with a measuring tape and recorded in centimetres to the nearest decimal place.[13]

Hand Length: The hand length was measured by using Vernier callipers. The participants were instructed to place their hand on a hard horizontal surface in supine position with their fingers fully extended and adducted. In this position, the hand length was measured from the mid-point of the distal transverse crease of the wrist to the tip of longest finger.[16] Hand Breadth: The hand breadth was also measured by using Vernier callipers. With the hands placed supine on a flat hard horizontal surface with all the fingers extended and adducted, the hand breadth was measured as a distance between the radial side of the second metacarpophalangeal joint and the ulnar side of the fifth metacarpophalangeal joint.[17]

All measurements were recorded in centimetres to the nearest two decimal places on both right and left side of the body. The measurements were performed every day at the same time between 2:00 and 3:00 PM to minimise the inconsistencies caused by diurnal fluctuation. Also, the measurements were done by the same observer each day to eliminate any intra-observer

Table 3: Linear regression equations for stature (cm) estimation in male, female & combined.

Parameter	Equation	R	R2	SEE
Males				
ULR	98.578+0.967 ULR	0.63	0.40	4.57
ULL	103.263+0.928 ULL	0.60	0.36	4.72
ALR	144.207+0.820 ALR	0.38	0.14	5.47
ALL	144.123+0.821 ALL	0.39	0.15	5.45
FLR	144.558+1.026 FLR	0.48	0.23	5.17
FLL	146.467+0.964 FLL	0.47	0.22	5.22
HLR	112.223+3.292 HLR	0.51	0.26	5.09
HLL	114.824+3.150 HLL	0.51	0.26	5.09
HBR	146.990+3.262 HBR	0.31	0.10	5.62
HBL	151.279+2.769 HBL	0.27	0.07	5.70
Females				
ULR	88.455+1.025 ULLR	0.67	0.45	4.26
ULL	91.396+0.983 ULLL	0.65	0.43	4.33
ALR	120.489+1.230 ALR	0.52	0.27	4.90
ALL	120.393+1.231 ALL	0.53	0.28	4.86
FLR	148.273+0.501 FLR	0.21	0.04	5.62
FLL	148.723+0.486 FLL	0.22	0.04	5.61
HLR	114.623+2.684 HLR	0.54	0.29	4.84
HLL	118.503+2.454 HLL	0.49	0.24	5.00
HBR	142.773+2.493 HBR	0.23	0.05	5.60
HBL	144.165+2.323 HBL	0.22	0.05	5.60
Combined				
ULLR	65.645+1.371 ULLR	0.82	0.67	4.91
ULLL	68.099+1.338 ULLL	0.80	0.65	5.10
ALR	105.526+1.795 ALR	0.64	0.41	6.59
ALL	106.467+1.766 ALL	0.64	0.42	6.58
FLR	123.782+1.617 FLR	0.55	.031	7.17
FLL	126.278+1.534 FLL	0.54	0.30	7.23
HLR	79.073+4.916 HLR	0.70	0.50	6.11
HLL	81.972+4.747 HLL	0.68	0.47	6.28
HBR	109.670+7.398 HBR	0.60	0.36	6.87
HBL	113.451+6.973 HBL	0.58	0.33	7.03

error in an approach that may have occurred. Before proceeding with the data collection, a pilot study was conducted to assess the reliability and reproducibility of the numerous upper limb measures in question. The measurements of the upper limbs that were going to be employed in the study were obtained by the same observer on 10 different subjects over the course of two separate days. Both times, the measurements that were taken were essentially the same.

Statistical Evaluation: IBM SPSS Statistics Version 20.0 for Windows (Armonk, NY: IBM Corp) was utilised for statistical analysis of the data. A p-value 0.05 was considered as statistically significant. The Pearson's correlation test was applied in order to assess whether or not there was a relationship between the parameters of the upper limb and stature. Gender-specific linear regression models for the estimate of stature were established. Coefficient of correlation (R), coefficient of determination (R2), and standard error of estimation (SEE) were determined. Using stepwise regression analysis, the equations for multiple regressions were generated based on various parameter combinations. The paired t-test was employed to compare the known and estimated stature.

Result:

A total of 204 students participated in the study, which comprises of 116 males and 88 females. The mean age for males in this study

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Table 4. Multiple regression equations for stature (cm) estimation in male, females & combined.

Equation	R	R2	SEE
Males			
82.786+0.654 ULR-0.045 ALR+0.546 FLR+1.083 HLR+ 0.687 HBR	0.70	0.49	4.27
89.061+0.473 ALR+0.668 FLR+1.891 HLR+1.540 HBR	0.66	0.43	4.50
98.943+0.747 FLR+2.260 HLR+1.329 HBR	0.62	0.39	4.65
106.024+2.936 HLR+1.543 HBR	0.53	0.28	5.04
86.383+0.575 ULL-0.010 ALL+0.525 FLL+1.227 HLL+ 0.605 HBL	0.68	0.46	4.39
93.855+0.446 ALL+0.618 FLL+1.846 HLL+1.372 HBL	0.64	0.41	4.58
102.112+0.690 FLL+2.247 HLL+1.185 HBL	0.61	0.37	4.71
108.543+2.903 HLL+1.318HBL	0.52	0.27	5.06
Females			
81.288+0.665 ULR+0.460 ALR+0.006 FLR+1.180 HLR- 0.440 HBR	0.71	0.51	4.09
96.164+0.880 ALR+0.075 FLR+1.993 HLR-0.099 HBR	0.64	0.42	4.46
112.240+0.186 FLR+2.607 HLR-0.153 HBR	0.54	0.29	4.88
114.464+2.677 HLR+0.039 HBR	0.54	0.29	4.87
81.588+0.617 ULL+0.553 ALL-0.006 FLL+1.063 HLL- 0.129 HBL	0.71	0.50	4.15
95.259+0975 ALL+0.039 FLL+1.773 HLL+0.224 HBL	0.64	0.41	4.49
114.256+0.211 FLL+2.287 HLL+0.224 HBL	0.50	0.25	5.03
116.862+2.376 HLL+0.405 HBL	0.49	0.24	5.03
Combined			
54.768+0.820 ULR+0.227 ALR+0.387 FLR+1.254 HLR+ 1.332 HBR	0.85	0.72	4.56
60.662+0.885 ALR+0.538 FLR+2.306 HLR+2.490 HBR	0.81	0.66	5.01
68.899+0.726 FLR+3.159 HLR+2.762 HBR	0.77	0.59	5.50
73.030+3.730 HLR+3.468 HBR	0.74	0.55	5.80
56.369+0.770 ULL+0.275 ALL+0.380 FLL+1.258 HLL+ 1.420 HBL	0.84	0.70	4.71
62.821+0.909 ALL+0.499 FLL+2.186 HLL+2.538 HBL	0.80	0.65	5.12
71.289+0.709 FLL+3.027 HLL+2.838 HBL	0.76	0.57	5.65
75.034+3.634 HLL+3.441 HBL	0.72	0.52	5.95

was 21.30 years and 20.82 years for females. The descriptive statistics for age, stature, and various upper limb dimensions for both males and females is depicted in Table 1.

The Pearson's correlation in the combined group showed good correlations between upper limb parameters and stature, in which ULR exhibited the highest correlation (R=0.822) followed by ULL (0.807). All upper limb parameters showed a significant correlation with stature in both males and females. The Pearson's correlation between upper limb parameters and stature in males, females and a group consisting of both sexes is depicted in Table 2.

A summary of linear regressions in males, females and combined sexes is depicted in Table 3. By employing the linear regression equation, the stature can be approximated from the mutilated or fragmentary body remains by using the regression: y (stature) = b (constant) + a (regression coefficient of the independent parameter) x. The regression in a group consisting of both sexes showed that ULR and ULL have a coefficient of determination (R2) of 68% and 65% respectively. This means that approximately 68% of the variation was contributed by the parameters, while the remaining 32 % of the variation was due to random error (Table 3). The variance was subsequently reduced for rest of parameters. The regression-based on ULR and ULL in males, females and a group consisting of both sexes showed the lowest standard error of estimation (SEE) i.e., 4.57, 4.26, 4.91for ULR and 4.72, 4.33, 5.10 for ULL respectively, as compared to all other parameters (Table 3).

Table 5. Descriptive statistics of mean values of known stature and estimated stature in male, female & combined.

		N	Min	Max	Mean	SD
Known Stature	Male	116	162	189	174.27	5.90
	Female	88	148	175	161.43	5.73
	Combined Sex	204	148	189	168.73	8.63
Estimated Stature RT	Male	116	164.81	185.89	174.26	4.17
	Female	88	152.73	173.70	161.39	4.12
	Combined Sex	204	150.95	188.93	168.69	7.35
Estimated Stature LT	Male	116	163.93	185.66	174.31	4.05
	Female	88	154.35	172.43	161.45	4.07
	Combined Sex	204	152.10	189.42	168.74	7.26

Table 6. Paired T-test between known & estimated height.

		Mean	t	Sig
Estimated Stature RT	Male	0.003	0.009	0.993
	Female	0.037	0.089	0.929
	Combined Sex	0.041	0.130	0.896
Estimated Stature LT	Male	-0.045	-0.113	0.910
	Female	-0.020	-0.046	0.963
	Combined Sex	-0.008	-0.024	0.981

The regressions obtained by the multiple regression analysis for all five parameters by using various combinations for both left and right sides in males, females and a group consisting of both sexes have been depicted in Table 4. In the combined group, the multiple regressions showed lower SEE (4.56–5.95) than that in linear regressions (4.91–7.23) (Table 4). The regressions based on ULR, ALR, FLR, HLR and HBR showed the lowest SEE in both males and females (4.27 and 4.09 respectively) $p<0.01$ which was highly significant.

The mean difference between known stature and estimated stature was 0.01 cm on the right and -0.04 cm left side in males. The mean difference between known stature and estimated stature in both the sexes is depicted in Table 5.

There was no statistically significant difference between known stature and estimated stature by using paired t-test for both right and left side in a group consisting of both sexes, males and in females ($p>0.05$) (Table 6).

Discussion:

Estimation of stature is an important factor in the identification of comingled remains received during a forensic examination, which can be achieved by anatomical and mathematical examination. The body's physique is influenced by climatic, hereditary, nutritional and racial factors. Therefore, considering this, the study was undertaken to use various dimensions of upper limb from the living people in north-west population of India and correlate it with stature. In the present study, males surpassed females in stature as well as upper limb dimensions which are in concurrence with other studies.[8,9,18] The fact that males are taller than females explain this difference. The age of puberty being two years later in males as compared to females gives them additional time for growth.[8,18]

In the current study, strong positive correlation was observed between upper limb length on both right side (r=0.822) as well as left side (r=0.807) in combined group consisting of both sexes, while moderate degree of association observed between hand breadth and stature in males and females for both right and left

Table 7. Pearson's correlation comparison of various studies on different populations for arm length and forearm length.

Study	Population	Parameter											
		ALR			ALL			FLR			FLL		
		M	F	CS	M	F	CS	M	F	CS	M	F	CS
Present Study	North Indian	0.382	0.525	0.647	0.394	0.537	0.648	0.489	0.218	0.559	0.473	0.222	0.547
Uzun et al[13]	Turkish	0.497	0.575	0.717	0.534	0.574	0.724	0.486	0.549	0.753	0.473	o.538	0.734
Ahmed AA[1]	Sudanese	-	-	-	-	-	-	0.725	0.722	-	-	-	-
Akhlaghi et a[17]	Iranian	0.602	0.669	0.759	-	-	-	0.354	0.299	0.58	-	-	-
Howley et al[19]	Australian	-	-	-	-	-	-	0.748	0.78	0.886	0.74	0.778	0.887

Table 8. Pearson's correlation comparison of various studies on different populations for hand length and hand breadth.

Study	Population	Parameter											
		HLR			HLL			HBR			HBL		
		M	F	CS	M	F	CS	M	F	CS	M	F	CS
Present Study	North Indian	0.512	0.542	0.707	0.51	0.495	0.687	0.318	0.232	0.606	0.275	0.229	0.582
Krishan et al[18]	North Indian	0.599	0.686		0.609	0.677		0.514	0.503		0.537	0.403	
Uzun et al[13]	Turkish	0.339	0.309	0.501	0.35	0.307	0.505	0.248	0.26	0.48	0.312	0.317	0.318
Rastogi et al[8]	North Indian	0.659	0.717	-	0.664	0.694	-	0.504	0.46	-	0.44	0.473	-
Pal et al[2]	Bengalee	-	-	0.683	-	-	0.682	-	-	0.53	-	-	0.524
Ahmed AA[1]	Sudanese	0.602	0.615	-	-	-	-	0.353	0.431	-	-	-	-
Akhlaghi et al[7]	Iranian	0.696	0.724	0.816	-	-	-	0.31	0.509	0.736	-	-	-
Howley et al[19]	Australian	0.647	0.719	0.949	0.686	0.865	0.748	0.505	0.433	0.743	0.592	0.535	0.785

Table 9. Comparison of coefficient variance and standard error of estimate of various studies.

Study		Upper Limb parameter																	
		ULR			ULL			HLR			HLL			HBR			HBL		
		M	F	CS	M	F	CS	M	F	CS	M	F	CS	M	F	CS	M	F	CS
Present Study	R2	0.40	0.45	0.67	0.37	0.43	0.65	0.26	0.29	0.50	0.26	0.25	0.47	0.1	0.05	0.36	0.07	0.05	0.33
	SEE	4.58	4.26	4.91	4.72	4.34	5.10	5.1	4.84	6.11	5.1	5.01	6.28	5.62	5.61	6.87	5.70	5.61	7.03
Uzun et al[13]	R2	0.49	0.62	0.78	0.59	0.64	0.78	0.43	0.47	0.68	0.47	0.5	0.62	-	-	-	-	-	-
	SEE	4.39	3.58	3.90	3.72	3.54	3.97	4.9	4.25	4.70	4.96	4.12	4.81	-	-	-	-	-	-
Krishan et al[18]	R2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	SEE	-	-	-		-	-	5.22	3.78	-	5.17	3.82	-	5.6	4.5	-	5.5	4.76	-
Rastogi et al[8]	R2	-	-	-	-	-	-	0.43	0.51	-	0.44	0.48	-	0.25	0.21	-	0.19	0.22	-
	SEE	-	-	-	-	-	-	5.01	4.24	-	4.97	4.38	-	5.74	5.4	-	5.97	5.36	-
Pal et al[2]	R2	-	-	-	-	-	-	-	-	0.47	-	-	0.46	-	-	0.28	-	-	0.27
	SEE	-	-	-	-	-	-	-	-	4.25	-	-	3.49	-	-	3.95	-	-	4.06

side. (Table 2). Our results for upper limb length are consistent with studies conducted by Uzun et al.[13] on Turkish population (r=0.861 for right side and r=0.868 for left side) and by Akhlagi et al.[7] on Iranian population (r=0.832 for right side). The comparative analysis of correlation of arm length and forearm length of various studies on different populations is depicted in Table 7. It was observed from the results of various studies that arm length and forearm length exhibit a moderately strong correlation with stature like in studies done by Uzun et al.[13] and Shakya et al.[11]

Similarly, the hand length and hand breadth depicted moderately strong positive correlation with the stature in the current study as well as in the other study results also. The comparative analysis of correlation of hand length and hand breadth of various studies on different populations is depicted in Table 8.

A small standard error of estimate (SEE) in regression analysis depicts greater accuracy. The regression based on upper limb right side in males, females and combined group showed the lowest standard error of estimation (SEE) i.e., 4.57, 4.26 and 5.91 respectively, as compared to all other parameters (Table 3). Table 9 compares the coefficient of determination (R2) and the standard error of estimate for upper limb length, hand length and hand breadth of various studies on different populations.

The mean difference between the estimated stature and known stature was in the current study was 0.01 for right side and 0.04 cm for left side. The mean difference between known stature and estimated stature was in females for the right side was 0.04 cm and 0.02 cm on left side. No statistically significant difference (p-value >0.05) was observed between the known stature and estimated stature by using paired T-test for both right and left side in any of the group (Table 6). Therefore, the derived right and left side equations can be employed for estimation of stature. No statistically significant difference was observed between the known stature and estimated stature based on the various upper limb measurements by paired t- test in other studies as well.

Study limitations: Population migration and colonization can impact the regional groups. These factors were not taken in to account while categorization of the study subjects. The sample size in the present study was not enormous. Therefore, further studies on a larger sample size that represents the particular population after taking in account the confounding factors like migration etc. could be undertaken.

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Conclusion:

The present study has established a definite correlation between stature and five parameters individually, namely upper limb length, arm length, forearm length, hand length and hand breadth. Out of the six parameters studied, the upper limb length showed the highest degree of correlation and hand breadth showed the lowest degree of correlation. The regression equations formulated in this study provided valid and reliable stature estimations with high correlation and accuracy levels and the same can be used for the forensic identification purposes.

Conflict of Interest: None to declare.

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