Anatomy Section

Estimation of Stature from Upper Extremity Anthropometric Measurements

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ABSTRACT

Introduction: Stature is one of the most important biological profiles for identification procedures. However, major difficulties are experienced in the identification of fragmented bodies in mass deaths. Anthropometric methods have been utilised as a reliable way to quickly establish the identification of victims using only a few parts of the body.

Aim: To develop models for stature estimation in forensic situations in which anatomical components and remnants of the upper extremity require identification.

Materials and Methods: The study population consisted of aged 18-25 years (200 female, 200 male). Participants were selected from the Karadeniz Technical University, Turkey by stratified randomisation method according to sex. Measurements were taken from the upper extremities of all subjects on the basis of anthropometric points. The relationship between stature and upper extremity parameters was performed using Pearson correlation coefficient. Models were developed from using linear regression analysis.

Results: A statistically significant difference was observed between the male and female groups ($p < 0.05$), with male measurements being higher than those of females. All body dimensions positively correlated with stature. The strongest correlations with stature were observed for upper extremity length for all groups and for both right (research: r=0.861; males: r=0.675; females: r=0.768) and left sides (research: r=0.868; r=males: 0.716; r=females: 0.758, $p < 0.01$). Developed models elicited valid and reliable stature estimates with high accuracy rates ($p < 0.001$). The accuracy of stature estimation models ranged from ±3.538 to ±4.958 cm.

Conclusion: The study suggested that estimation of stature can be made possible using various dimensions of the upper extremities. One must consider differences between populations in order to apply functions as such to others. This study provides new forensic standards for stature estimation from the upper extremity measurements of Turkish adults.

INTRODUCTION

Identification is one of the main tasks of forensic analysis and refers to the determination of the identity of a living or deceased individual based on certain characteristic features [1,2]. Stature is one of the most important biological profiles in forensic sciences [3]. It exhibits racial variations in different populations and is also affected by genetic and environmental factors, nutrition, sex, age and physical activity [3-6]. Estimation of stature from fragmented skeletal remains, mutilated or amputated limbs or severely decomposed and dispersed human body parts is of very great importance in terms of victim identification in the case of murder, accidents or natural disasters and represents one of the major aspects of forensic science [1].

Anthropologists, anatomists and other medical specialists have employed anthropometric techniques to estimate stature and bone length from unidentified body parts for more than a century [1,7]. Various studies have been published on estimating the stature from skeletal remains [8,9]. Two methods of stature estimation have been established, the mathematical method and the anatomical method [10]. The anatomical method requires the existence of an entire skeleton and the addition of correction factors to compensate for soft tissues. The mathematical method requires a single bone or body parts and makes use of regression formulas or multiplication factors to elicit stature estimates based on correlation of individual bone measurements to statures observed in living populations [4,10]. An entire skeleton or long bone may be unavailable when bodies are dismembered or mutilated during conflicts and mass disasters, or as the result of criminal actions. One practical alternative is therefore, the development of standard calculations employing different parts of the human skeleton [3,4].

Numerous studies have been carried out for identifiying individuals and estimating stature from various parts of the body such as the upper and lower extremities [1,3-5,10-18]. Various linear regression equations have developed in these studies and these formulas give positive results with high correlation and accurate prediction for stature estimation. Stature in humans reaches adult levels between early youth and the 20s. In women, this generally occurs around mid-youth, while in men it takes place toward late youth [19]. A study from Turkey reported no significant difference between the sexes in terms of 10-year increases in stature, citing figures of 0.96 cm in males and 0.92 cm in females [20]. Studies from Europe and North America show that stature increases by up to approximately 1 cm every 10 years [21].

In studies on stature estimation using extremities, it was shown that there are racial and ethnic variations between stature and upper extremity [4,5,14,16]. Since racial, ethnic and nutritional factors play important roles in human growth and development, different formulas have to be applied for different population [22]. Hence, a study on Turkish population was required. The aim of the current study was to reveal the association between upper extremity measurements and the individual's stature, and then to develop models to determine stature with high accuracy and reliability in forensic situations in which anatomical parts and remains need to be identified in the Turkish adults.

MATERIALS AND METHODS

Sample

This cross-sectional study consisted of high school students from the Karadeniz Technical University (KTU), Trabzon, Turkey. Turkey consists of seven geographical regions. There are various ethnic

groups (average 23) in the minority in Turkey (Kurd, Circassian, Azeri, Laz, Armenian, Gagavuz, Arab, Tatar etc.,) This study was conducted only on people of Turks ethnicity who constitute 71% of the population according to 2008 data (United States Centre for World Mission-USCWM). KTU accepts students from all geographic regions of Turkey regardless of ethnic orgin and socio-economic status.

Sample size was predicted using 80% power at the 5% level of significance in accordance with standard statistical protocol. The total number of students who were enrolled in the courses during the 2016-2017 and 2017-2018 academic years of the university was determined as 861. Approximately 70% of this number is made up of female students (252 males, 609 females). Because of the fact that the students who were enrolled in the study are composed of mostly females, stratified randomisation method was used according to sex with 1:1 ratio. 400 volunteer individuals, 200 male and 200 female, aged 18-25 years, were included in the research group.

Subjects with function disorders in the measurement areas, a history of upper extremity injury, any muscular disease, congenital disorder, deformity, fracture, amputation, movement restriction, systemic arthropathy, neurological disease, trauma or surgery and individuals without Turkish ethnicity were excluded from this study. Ethical approval was obtained from the University Ethics Committee and the research was carried out in accordance with the declaration of Helsinki (protocol no: 24237859-508; approval no: 2016/87). All subjects signed an informed consent form.

Measurements

All upper limb measurements were taken from the right (R) and left (L) sides. The anthropometric measurement points for the measurements in the study are given in the following sections.

Stature (S): Stature was measured from the vertex to the floor in the anatomical position and the Frankfurt plane using a portable stadiometer (SECA 213).

Arm length (AL_R and AL_L): The distance between the olecranon and acromion with the elbow flexed at 90 degrees and the shoulder fully adducted [Table/Fig-1a] [6,11].

Forearm length (FAL_R and FAL_L): The distance between the radial styloid process and olecranon with the elbow flexed at 90 degrees [Table/Fig-1b] [4].

Upper extremity length (UEL_R and UEL_L): The distance between the acromion and the most distal part of the third finger [Table/Fig-1c] [22].

[Table/Fig-1]: Upper limb measurements: (a) arm length; (b) forearm length; (c) upper extremity length.

Hand length (HL_R and HL_L): The distance between the most distal point of the third finger and the mid-point of inter-styloid (mid-point of the distance between the radial styloid process and ulnar styloid process) line [Table/Fig-2a] [2]. Hand measurements were performed with the thumb slightly abducted and the other fingers adducted with the palm facing upward.
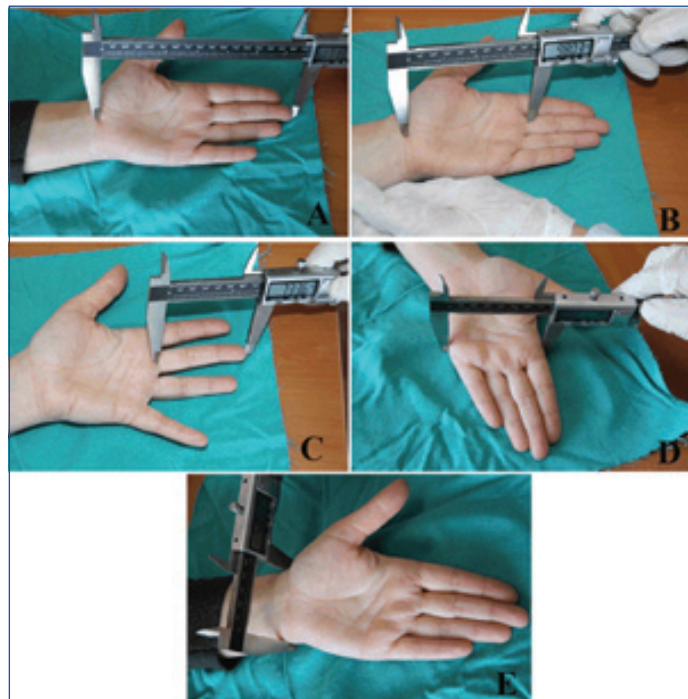
Palmar length (PL_R and PL_L): The distance between the transverse flexion line of the wrist joint and the flexion line at the most proximal point of the third finger [Table/Fig-2b) [7].

Third finger length (TFL_R and TFL_L): The distance between the most distal point and the proximal flexion line at the base of the third finger on the palmar surface [Table/Fig-2c] [23].

Hand width (HW_R and HW_L): The distance between the distal ends of the ossae metacarpi II and V [Table/Fig-2d] [14,16].

Wrist width (WW_R and WW_L): The distance between the radial styloid process and ulnar styloid process [Table/Fig-2e] [4].

Wrist circumference (WC_R and WC_L): Wrist circumference was measured around the wrist using a non-elastic tape measure.

[Table/Fig-2]: Hand measurements: (a) hand length; (b) palmar length; (c) third finger length; (d) hand width; (e) wrist width.

Anthropometric measurements were taken using the standard technique and appropriate landmarks [24]. Arm, forearm and upper extremity lengths were measured using a Harpenden anthropometry set (Holtain Limited, UK). Hand measurements were taken using digital calipers with a 0-300 mm measurement capacity sensitive to ±0.01 mm. Stature was measured to the nearest 0.1 cm in bare feet with the subjects standing upright against a stadiometer. Measurements were performed at the same time of day (1 PM-3 PM) to prevent diurnal variation and all measurements were taken by the same individual in order to avoid personal bias.

STATISTICAL ANALYSIS

Statistical analyses were performed on SPSS 21.0 software. Normal distribution and homogeneity of variance were assessed. The t-test was used to compare measurement values between the sexes. Relations between stature and right and left extremity measurements were determined using Pearson Correlation Analysis with 95% confidence interval. Models were developed using linear regression analysis. The stepwise method was used for multiple regression analysis. The multiple regression models were derived as Y (stature)=a (constant)+b1 (regression coefficient of the first variable) X1 (first variable)+b2 (regression coefficient of the second variable) X2 (second variable)+…bn (regression coefficient for the nth variables) Xn (nth variable)±Standard Error Estimation (SEE). The accuracy of these equations was demonstrated by the SEE. Lower SEE values indicated higher accuracy [4,25]. Models were developed for two separate conditions in the present study, one

including all upper extremity parameters and the other involving hand measurements alone.

Before beginning data collection, stature and the upper extremity measurements of a sample of 40 volunteers (20 males, 20 females, using stratified randomisation method according to sex) were measured on two separate days and each participant was measured twice. The absolute Technical Error of Measurement (TEM) was initially calculated using the following equation: where, D represents the difference between two successive measurements, and N represents the number of individuals. The relative Technical Error of Measurement (rTEM) was calculated from two successive set of measurements by dividing the TEM for a given variable by the grand mean of that variable and multiplying the result by 100.

$$TEM = \sqrt{\frac{\Sigma D^2}{2N}}$$

The coefficient of Reliability (R) was calculated. In addition to these measurements, the Coefficient of Variation (CV) was calculated with the following formula: where $\overline{X}$ is the average of measurements and SD is the standard deviation. The CV expresses sample variability relative to the mean of the sample.

$$CV = \frac{SD \times 100}{\overline{X}}$$

Intra-observer measurement error and reliability were calculated to be within acceptable limits for all measurements (R >0.9; rTEM <5%). [Table/Fig-3,4] show the results of precision and reliability analysis of anthropometric measurements found statistically significant at multiple regression analyses.

	a	b	d²	TEM	rTEM (%)	R*	p-value
S	162.69±9.36	163.41±9.3	0.72±0.33	0.56	0.34	0.996	<0.001
UEL$_R$	75.2±5.18	75.68±5.20	0.48±0.27	0.39	0.52	0.994	<0.001
UEL$_L$	74.78±5.13	75.3±5.14	0.53±0.24	0.41	0.54	0.994	<0.001
AL$_R$	36.18±2.90	36.67±2.94	0.5±0.31	0.41	1.13	0.980	<0.001
AL$_L$	35.96±2.68	36.51±2.70	0.55±0.20	0.41	1.14	0.977	<0.001
FAL$_R$	26.74±2.22	27.09±2.31	0.36±0.29	0.32	1.20	0.980	<0.001
FAL$_L$	26.66±2.16	27.05±2.17	0.38±0.25	0.33	1.21	0.977	<0.001
HL$_R$	17.59±1.42	17.98±1.45	0.4±0.18	0.31	1.72	0.955	<0.001
HL$_L$	17.48±1.45	17.85±1.48	0.37±0.16	0.28	1.59	0.963	<0.001
HW$_R$	7.58±0.91	7.89±0.92	0.31±0.10	0.23	2.93	0.938	<0.001
HW$_L$	7.52±0.88	7.85±0.94	0.33±0.11	0.24	3.18	0.928	<0.001
PL$_R$	10.02±1.05	10.31±1.03	0.29±0.14	0.23	2.25	0.952	<0.001
PL$_L$	10.01±1.05	10.37±1.12	0.37±0.21	0.30	2.92	0.925	<0.001
WC$_R$	15.96±1.39	16.52±1.42	0.56±0,13	0.40	2.49	0.917	<0.001
WC$_L$	15.94±1.37	16.43±1.37	0.49±0.20	0.37	2.30	0.926	<0.001
WW$_R$	5.16±0.87	5.37±0.87	0.21±0.11	0.17	3.21	0.962	<0.001
WW$_L$	5.14±0.87	5.41±0.87	0.27±0.16	0.22	4.23	0.934	<0.001
TFL$_R$	7.41±0.99	7.53±1.00	0.12±0.08	0.10	1.40	0.989	<0.001
TFL$_L$	7.4±0.92	7.52±0.93	0.12±0.07	0.10	1.29	0.989	<0.001

[Table/Fig-3]: Anthropometric measurements, TEM, rTEM and R values.
n=40; a: Average of the first measurement; b: Average of the second measurement; d: Difference between the average; TEM: Technical error measurement; rTEM: Relative technical error of measurement; R*: Coefficient of reliability; p: Statistical significance level of R; R: Right; L: Left; S: stature; UEL: Upper extremity length; AL: Arm length; FAL: Forearm length; HL: Hand length; HW: Hand width; PL: Palmar length; WC: Wrist circumference; WW: Wrist width; TFL: Third finger length

RESULTS

Descriptive statistical analysis findings for the right and left upper extremities in the research group are shown in [Table/Fig-5]. T-test results for all measurements in male and female groups are shown in [Table/Fig-6]. A statistically significant difference was observed between the male and female groups (p<0.05), with male measurements being higher than those of females.

Variables	$\overline{X}$	SD	CV
Stature	163.05	9.33	5.72
UEL$_R$	75.44	5.19	6.88
UEL$_L$	75.04	5.13	6.84
AL$_R$	36.42	2.92	8.01
AL$_L$	36.24	2.69	7.42
FAL$_R$	26.92	2.26	8.41
FAL$_L$	26.85	2.17	8.07
HL$_R$	17.78	1.44	8.09
HL$_L$	17.67	1.46	8.29
HW$_R$	7.74	0.91	11.78
HW$_L$	7.69	0.91	11.83
PL$_R$	10.16	1.04	10.24
PL$_L$	10.19	1.09	10.68
WC$_R$	16.24	1.40	8.63
WC$_L$	16.18	1.37	8.45
WW$_R$	5.27	0.87	16.49
WW$_L$	5.27	0.87	16.43
TFL$_R$	7.47	0.99	13.30
TFL$_L$	7.46	0.92	12.38

[Table/Fig-4]: Average, standard deviation and coefficient of variation.
n=40; $\overline{X}$: average; SD: Standard deviation; CV: Coefficient of variation; R: Right; L: Left; S: Stature; UEL: Upper extremity length; AL: Arm length; FAL: Forearm length; HL: Hand length; HW: Hand width; PL: Palmar length; WC: Wrist circumference; WW: Wrist width; TFL: Third finger length

Research Group (n=400)							
	Min	Max	Mean±SD		Min	Max	Mean±SD
AGE	18	25	19.37±1.48	S	143.00	187.00	163.15±8.46
AL$_R$	28.00	46.00	35.93±2.98	AL$_L$	29.00	45.00	35.78±2.80
FAL$_R$	22.00	36.00	26.64±2.19	FAL$_L$	22.00	37.00	26.59±2.13
UEL$_R$	56.00	88.00	74.90±4.92	UEL$_L$	55.00	87.00	74.56±4.84
HL$_R$	13.06	21.21	17.30±1.51	HL$_L$	13.30	21.07	17.26±1.48
HW$_R$	4.06	10.88	7.35±1.23	HW$_L$	4.30	10.97	7.29±1.20
WW$_R$	2.30	8.30	4.97±1.16	WW$_L$	2.32	8.15	4.95±1.13
WC$_R$	13.00	20.00	15.81±1.25	WC$_L$	11.16	20.50	15.77±1.27
PL$_R$	6.59	14.04	9.78±1.27	PL$_L$	6.69	13.07	9.74±1.26
TFL$_R$	4.18	10.79	7.22±1.23	TFL$_L$	4.10	10.65	7.17±1.23

[Table/Fig-5]: Research group (n=400) descriptive statistics for all measurements (cm).
SD: Standard deviation; R: Right; L: Left; S: Stature; AL: Arm length; FAL: Forearm length; UEL: Upper extremity length; HL: Hand length; HW: Hand width; WW: Wrist width; WC: Wrist circumference; PL: Palmar length; TFL: Third finger length

[Table/Fig-7] illustrates the correlation coefficients between stature and right upper extremity measurements, and [Table/Fig-8] illustrates the correlation coefficients between stature and left upper extremity measurements for the research and male-female groups. Statistically significant correlations were observed in all parameters in all groups (p<0.05). Comparison of correlations (r) between stature and upper extremity parameters in different populations are presented in [Table/Fig-9].

Models developed from the right upper extremity measurements for stature estimation are presented in [Table/Fig-10], and models for left upper extremity measurements are shown in [Table/Fig-11]. The research, male and female groups were evaluated as a whole, and the increases in coefficient of determination (R^2) produced by all variables added to the model were found significant (p<0.001).

Right hand regression equations for the research, male and female groups are shown in [Table/Fig-12], and left hand regression equations are shown in [Table/Fig-13]. The research, male and female groups were evaluated as a whole, and the increases in the coefficient of determination produced by all variables added to the model were found significant (p<0.001).

	Female (n=200) Mean±SD	Male (n=200) Mean±SD	t	p
AGE	19.34±01.47	19.45±1.51	-0.662	0.508
S	159.35±5.80	172.92±6.06	-20.738	<0.001*
AL_R	34.89±2.29	38.60±2.90	-12.125	<0.001*
FAL_R	25.71±1.43	29.01±2.02	-15.764	<0.001*
UEL_R	72.88±3.68	80.10±3.78	-17.467	<0.001*
HL_R	16.90±1.37	18.31±1.39	-9.173	<0.001*
HW_R	7.18±1.21	7.79±1.16	-4.559	<0.001*
WW_R	4.89±1.15	5.17±1.15	-2.149	0.032*
WC_R	15.31±0.92	17.08±1.07	-16.406	<0.001*
PL_R	9.55±1.22	10.36±1.23	-5.908	<0.001*
TFL_R	7.11±1.20	7.49±1.26	-2.756	0.006*
AL_L	34.80±2.15	38.30±2.72	-12.177	<0.001*
FAL_L	25.74±1.48	28.78±1.98	-14.720	<0.001*
UEL_L	72.53±3.61	79.81±3.46	-18.315	<0.001*
HL_L	16.86±1.35	18.26±1.33	-9.293	<0.001*
HW_L	7.12±1.19	7.74±1.12	-4.751	<0.001*
WW_L	4.88±1.13	5.13±1.13	-1.996	0.047*
WC_L	15.28±0.91	17.00±1.23	-13.376	<0.001*
PL_L	9.52±1.23	10.29±1.17	-5.635	0.000*
TFL_L	7.07±1.21	7.43±1.25	-2.645	0.008*

[Table/Fig-6]: Analysis of differences between mean measurements in the male and female groups.
*p<0.05 significiant; S: Stature; R: Right; L: Left; t: t statistics; AL: Arm length; FAL: Forearm length; UEL: Upper extremity length; HL: Hand length; HW: Hand width; WW: Wrist width; WC: Wrist circumference; PL: Palmar length; TFL: Third finger length

	Research group (n=400)		Female (n=200)		Male (n=200)	
	r	p	r	p	r	p
AL_R	0.717	<0.001**	0.575	<0.001**	0.497	<0.001**
FAL_R	0.753	<0.001**	0.549	<0.001**	0.486	<0.001**
UEL_R	0.861	<0.001**	0.768	<0.001**	0.675	<0.001**
HL_R	0.501	<0.001**	0.309	<0.001**	0.339	<0.001**
HW_R	0.480	<0.001**	0.260	<0.001**	0.248	0.038*
WW_R	0.320	<0.001**	0.314	<0.001**	0.317	<0.001**
WC_R	0.626	<0.001**	0.572	<0.001**	0.675	<0.001**
PL_R	0.301	<0.001**	0.310	<0.001**	0.303	<0.001**
TFL_R	0.200	<0.001**	0.225	<0.001**	0.223	0.018*

[Table/Fig-7]: Correlations between stature and right upper extremity measurements.
**p<0.01, *p<0.05 significiant; r: Correlation coefficient

	Research group (n=400)		Female (n=200)		Male (n=200)	
	r	p	r	p	r	p
AL_L	0.724	<0.001**	0.574	<0.001**	0.534	<0.001**
FAL_L	0.734	<0.001**	0.538	<0.001**	0.473	<0.001**
UEL_L	0.868	<0.001**	0.758	<0.001**	0.716	<0.001**
HL_L	0.505	<0.001**	0.307	<0.001**	0.350	<0.001**
HW_L	0.469	<0.001**	0.258	<0.001**	0.231	<0.001**
WW_L	0.318	<0.001**	0.317	<0.001**	0.312	<0.001**
WC_L	0.608	<0.001**	0.545	<0.001**	0.321	0.001**
PL_L	0.293	<0.001**	0.304	<0.001**	0.221	0.019*
TFL_{SOL}	0.181	<0.001**	0.231	<0.001**	0.219	<0.001**

[Table/Fig-8]: Correlations between stature and left upper extremity measurements.
**p<0.01, *p<0.05 significiant; r: Correlation coefficient

	Sex	Turkey	Sudanese	Central India	Southern Nigeria	Turkey	Iranian	North India	Nigeria	Australian
		Present study	Ahmed AA [4]	Shende MR et al., [22]	Oladunni E [10]	Özaslan A et al., [28]	Akhlaghi M et al., [13]	Chandra A et al., [23]	Ugbem LP et al., [16]	Howley D et al., [27]
UEL_R	Male	0.675	0.698	0.416	-	0.450	0.635	-	-	-
	Female	0.768	0.643	0.367	-	0.660	0.735	-	-	-
	Combine	0.861	-	0.540	-	-	0.832	-	-	-
UEL_L	Male	0.716	-	-	-	-	-	-	-	-
	Female	0.758	-	-	-	-	-	-	-	-
	Combine	0.868	-	-	-	-	-	-	-	-
AL_R	Male	0.497	-	-	0.142	-	0.602	-	-	-
	Female	0.575	-	-	0.214	-	0.669	-	-	-
	Combine	0.717	-	-	-	-	0.759	0.565	0.206	-
AL_L	Male	0.534	-	-	-	-	-	-	-	-
	Female	0.574	-	-	-	-	-	-	-	-
	Combine	0.724	-	-	-	-	-	-	-	-
FAL_R	Male	0.486	0.725	-	0.390	-	0.354	-	-	0.748
	Female	0.549	0.722	-	0.481	-	0.299	-	-	0.780
	Combine	0.753	-	-	-	-	0.580	-	0.543	0.886
FAL_L	Male	0.473	-	-	-	-	-	-	-	0.740
	Female	0.538	-	-	-	-	-	-	-	0.778
	Combine	0.734	-	-	-	-	-	-	-	0.887
HL_R	Male	0.339	0.602	-	-	0.530	0.696	-	-	0.647
	Female	0.309	0.615	-	-	0.350	0.724	-	-	0.719
	Combine	0.501	-	-	-	-	0.816	0.598	0.609	0.949
HL_L	Male	0.350	-	-	-	-	-	-	-	0.686
	Female	0.307	-	-	-	-	-	-	-	0.865
	Combine	0.505	-	-	-	-	-	-	-	0.748
HW_R	Male	0.248	0.358	-	-	0.140	0.310	-	-	0.505
	Female	0.260	0.431	-	-	0.290	0.509	-	-	0.433
	Combine	0.480	-	-	-	-	0.736	0.460	0.583	0.743

Parameter	Sex										
HW$_L$	Male	0.231	-	-	-	-	-	-	-	-	0.592
	Female	0.258	-	-	-	-	-	-	-	-	0.535
	Combine	0.469	-	-	-	-	-	-	-	-	0.785
PL$_R$	Male	0.303	-	-	-	-	-	-	-	-	0.540
	Female	0.310	-	-	-	-	-	-	-	-	0.569
	Combine	0.301	-	-	-	-	-	-	-	-	0.777
PL$_L$	Male	0.221	-	-	-	-	-	-	-	-	0.505
	Female	0.304	-	-	-	-	-	-	-	-	0.620
	Combine	0.293	-	-	-	-	-	-	-	-	0.783
WC$_R$	Male	0.675	-	-	-	-	-	-	-	-	-
	Female	0.572	-	-	-	-	-	-	-	-	-
	Combine	0.626	-	-	-	-	-	-	-	-	-
WC$_L$	Male	0.321	-	-	-	-	-	-	-	-	-
	Female	0.545	-	-	-	-	-	-	-	-	-
	Combine	0.608	-	-	-	-	-	-	-	-	-
WW$_R$	Male	0.317	0.522	-	-	0.180	-	-	-	-	-
	Female	0.314	0.327	-	-	0.140	-	-	-	-	-
	Combine	0.320	-	-	-	-	-	-	-	-	-
WW$_L$	Male	0.312	-	-	-	-	-	-	-	-	-
	Female	0.317	-	-	-	-	-	-	-	-	-
	Combine	0.318	-	-	-	-	-	-	-	-	-
TF$_R$	Male	0.223	-	-	-	-	-	0.674	-	-	-
	Female	0.225	-	-	-	-	-	0.644	-	-	-
	Combine	0.200	-	-	-	-	-	0.759	0.480	-	-
TF$_L$	Male	0.219	-	-	-	-	-	-	-	-	-
	Female	0.231	-	-	-	-	-	-	-	-	-
	Combine	0.181	-	-	-	-	-	-	-	-	-

[Table/Fig-9]: Comparison of correlations (r) between stature and upper extremity parameters in different populations.
R: Right; L: Left; S: Stature; UEL: Upper extremity length; AL: Arm length; FAL: Forearm length; HL: Hand length; HW: Hand width; PL: Palmar length; WC: Wrist circumference; WW: Wrist width; TFL: Third finger length

Group	±SEE	R	R^2	Adj R^2	F	VIF	p
RG	±3.909	0.888	0.788	0.787	492.069	UELR: 2.187 FALR: 2.444 WCR: 1.715	<0.001
Male	±4.385	0.697	0.486	0.477	51.626	UELR: 1.317 FALR: 1.317	<0.001
Female	±3.580	0.789	0.622	0.620	234.720	UELR: 1.359 FALR: 1.359	<0.001

Regression Equations

$S=45.441+(1.084×UEL_R)+(0.814×FAL_R)+(0.938×WC_R)$
$SM=81.447+(0.921×UEL_R)+(0.610×FAL_R)$
$SF=61.620+(1.042×UEL_R)+(0.848×FAL_R)$

[Table/Fig-10]: Models for all right upper extremity measurements.
S: Stature; RG: Research group; M: Male; F: Female; SEE: Standard error estimation; R: Coefficient of reliability; R^2: Coefficient of determination; Adj R^2: Adjusted r-squared; VIF: Variance inflation factor; F: F statistics

Group	±SEE	R	R^2	Adj R^2	F	VIF	p
RG	±3.975	0.884	0.781	0.780	471.663	UEL$_L$: 2.342 FAL$_L$: 2.469 WC$_L$: 1.674	<0.001
Male	±3.721	0.716	0.592	0.589	116.006	UEL$_L$: 1.000 FAL$_L$: 1.000	<0.001
Female	±3.538	0.797	0.635	0.628	98.067	UEL$_L$: 2.583 FAL$_L$: 1.600 WC$_L$: 1.196 WW$_L$: 5.979 HL$_L$: 7.177	<0.001

Regression Equations

$S=44.912+(1.197×UEL_L)+(0.620×FAL_L)+(0.792×WC_L)$
$S_M=65.529+(1.075×UEL_L)+(0.616×FAL_L)$
$S_F=56.365+(0.813×UEL_L)+(0.411×FAL_L)+(0.939×WC_L)+(2.257×WW_L)+(1.784×HL_L)$

[Table/Fig-11]: Models for all left upper extremity measurements.
S: Stature; RG: Research group; M: Male; F: Female; SEE: Standard error estimation; R: Coefficient of reliability; R^2: Coefficient of determination; Adj R^2: Adjusted r-squared; VIF: Variance Inflation Factor; F: F statistics.

Group	±SEE	R	R^2	Adj R^2	F	VIF	p
RG	±4.707	0.827	0.684	0.682	285.893	WC$_R$: 1.279 HL$_R$: 3.490 WW$_R$: 3.021	<0.001
Male	±4.897	0.605	0.425	0.348	20.737	WC$_R$: 1.215 HL$_R$: 3.982 WW$_R$: 3.718	<0.001
Female	±4.245	0.686	0.471	0.465	84.232	HL$_R$: 3.338 WW$_R$: 3.325 WC$_R$: 1.012	<0.001

Regression Equations

$S=55.760+(2.539×WC_R)+(5.598×HL_R)+(-5.951×WW_R)$
$S_M=96.068+(1.306×WC_R)+(4.254×HL_R)+(-4.517×WW_R)$
$S_F=78.379+(4.726×HL_R)+(-5.051×WW_R)+(1.685×WC_R)$

[Table/Fig-12]: Models for right hand measurements.
S: Stature; RG: Research group; M: Male; F: Female; SEE: Standard error estimation; R: Coefficient of reliability; R^2: Coefficient of determination; Adj R^2: Adjusted r-squared; VIF: Variance inflation factor; F: F statistics

DISCUSSION

The results of the current study demonstrate that the statures and recorded upper extremity measurements of males are significantly larger than those of females. Our comparison, findings between males and females were similar to those of previous studies in which anthropometric measurements were performed in the same and different populations [3,4,10,12-14,16-18]. These findings may be attributed to stature in males being greater than in females for genetic reasons, due to puberty in females starting and ending approximately two years earlier than in males.

The correlation coefficients between stature and right and left upper extremity measurements in this study were highly significantly and positively correlated in the research and male-female groups, indicating that linear regression equations for the estimation of stature can be derived from upper extremity measurements. The

Group	±SEE	R	R²	Adj R²	F	VIF	p
RG	±4.812	0.791	0.625	0.621	208.137	HL_L: 1.964 WW_L: 1.537 TFL_L: 2.080 PL_L: 1.036	<0.001
Male	±4.958	0.591	0.470	0.431	19.346	HL_L: 4.258 HW_L: 3.144 WC_L: 1.132	<0.001
Female	±4.124	0.709	0.502	0.495	90.655	WC_L: 1.050 HL_L: 3.551 WW_L: 5.077 PL_L: 4.875	<0.001
Regression Equations							
$S=62.608+(10.121 \times HL_L)+(-2.494 \times WW_L)+(-4.592 \times TFL_L)+(-2.961 \times PL_L)$ $S_M=104.276+(4.665 \times HL_L)+(-4.671 \times HW_L)+(1.152 \times WC_L)$ $S_F=73.605+(1.660 \times WC_L)+(6.031 \times HL_L)+(-4.416 \times WW_L)+(-2.279 \times PL_L)$							

[Table/Fig-13]: Models for left hand measurements.
S: Stature; RG: Research group; M: Male; F: Female; SEE: Standard error estimation; R: Coefficient of reliability; R²: Coefficient of determination; Adj R²: Adjusted r-squared; VIF: Variance inflation factor; F: F statistics.

highest correlation with stature in the research, female and male groups was observed in the right upper extremity length (r=0.861, r=0.768, and r=0.675, respectively) and left upper extremity length (r=0.868, r=0.758 and r=0.716, respectively) (p<0.01). Our findings were rather higher than the results of Shende MR et al., study [22], and were similar to those reported by Akhlaghi M et al., study for right sides in Iranian population [13]. After upper extremity length, the highest correlations were observed in right and left forearm lengths (r=0.753, r=0.734) in both groups; in right and left arm lengths (r=0.575, r=0.574) in females; and in right and left arm lengths (r=0.497, r=0.534, respectively) in males [Table/Fig-7,8] in the current study. In Özaslan A et al., study, the highest values were associated with upper extremity length (62%) and forearm length (38%) for males and upper extremity length (64%) and arm length (43%) for females in Turkish subjects [26]. The correlation between stature and arm length in the present study was higher than that reported for studied North Indian [23] and Nigeran [16] subjects, but is lower than Iranian [13] subjects. When the right forearm length is evaluated, the correlation coefficient was greater than that reported for studied Nigeran [10,16] and Iranian [13] populations, but is lower for Sudanese [18] and Australian (Howley) populations. The correlation values of left forearm length were lower than Australian subjects in Howley D et al., study for research, male and female groups [27].

In the present study, arm length exhibited a higher correlation coefficient than hand length, and the lowest correlations in the research group were in right third finger length (r=0.200) and left third finger length (r=0.181). The lowest correlations among female subjects were in right third finger length (r=0.225) and left third finger length (r=0.231). In the male group, the lowest correlation were in right third finger length (r=0.223) and left third finger length (r=0.219) [Table/Fig-7,8]. The correlation of the third finger length was found to be quite low in contrast to the Iranian [13] and North Indian population [23]. Ugbem LP et al., reported significant correlations between stature and arm length, forearm length, hand length and hand width in Nigerian subjects, again in agreement with our results [16]. In contrast to our study, they reported the highest degree of correlation with hand length, while the lowest degree of correlation was with arm length. The correlation coefficients between stature and the hand length, hand width and wrist width were lower than Sudanese subjects [18]. Comparison of correlation coefficients between stature and upper extremity parameters in different populations are shown in [Table/Fig-9]. It can be seen clearly that, although all upper extremity parameters were significantly correlated with stature in both our current study and previous studies, the strongest and weakest correlations varied between populations. These variational findings may be the result of variables such as genetic background, nutrition, climate

and physical activity levels between populations, or the number of samples included in the study.

Considering the probability of both extremities being present in forensic cases, right and left upper extremity measurements were evaluated together in stature estimation in the current study. In case of multiple fleshed body parts being recovered for analysis, the model with the lowest SEE should be chosen because this will produce the most accurate stature estimate [27]. Ahmed AA estimated stature from upper extremity measurements and reported a SEE: ±3.54-±5.85 for both sexes in Sudanese population [18]. In Navid S et al., study, stature and upper extremity length were correlated in all cases (±SEE=7.16, R²=0.513) and in the male group (SEE=±4.52, R²=0.398) on the basis of linear regression equations developed for stature estimation in Iranian population [6]. Özaslan A et al., reported SEE ranged from ±6.03 to ±6.9 cm for hand dimensions [28] and Şanlı SG et al., reported SEE ±3.49 cm for hand length in Turkish population [29]. Ilayperuma I et al., developed model using hand length values in Sri Lankan adults (SEE: ±3.493 in males, ±3.625 in females) [17]. In the current study, the best regression equations were determined in the research group for the right upper extremity (SEE: ±3.909, R²: 0.788), and for the left upper extremity (SEE: ±3.975, R²: 0.781) [Table/Fig-10,11]. The best regression equations were determined in research group for the right hand (SEE: ±4.707, R²: 0.684), and for left hand (SEE: ±4.812, R²: 0.625). These results show that the right upper extremity and right hand elicited a better estimate than the left upper extremity and left hand [Table/Fig-12,13]. The accuracy of stature estimation models for all ranged from ±3.538 to ±4.958 cm in the current study. SEE obtained in the present study was lower than that reported previously studies [6,18,27,28].

LIMITATION

In spite of the efforts made to increase the sample size, the final sample was smaller than desired. Turkish adults would necessitate a larger sample with adequate geographical and social heterogeneity or a national examination that evaluates all population. Equations are specific to the Turkish population and these should not be used for other populations. The models achieved in this study were based on adult sample and are not applicable for juveniles.

CONCLUSION

The results of present study demonstrate strong relationship between the upper extremity components and stature. All models developed in this study provided valid and reliable stature estimations with high correlation and accuracy levels and low estimation error. The stature estimation formulas have a 3-4 cm deviation. The models in this study can be used for forensic identification purposes in the Turkish adults. Right and left upper extremity measurements can also be used for populations with similar anthropometric characteristics to those of our cases.

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