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Original Research Article

Evaluation of upper extremity anthropometric measurements in terms of sex estimation

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ABSTRACT

Background: One of the most important and broadest areas of forensic medicine is identification. Among the various parameters used, the most important criterion for identification is to determine the sex of the individual concerned. The aim of the current study was to develop models to determine the sex of subjects in case of forensic situations in which anatomical remains and residues of the upper extremity have to be identified.

Methods: The research consisted of university students aged 18-25. Arm, forearm, upper extremity, hand, third finger and palmar length, hand width, wrist width, and wrist circumference measurements from 400 subjects were taken from the right and left upper extremities on the basis of anthropometric points. Models were than developed using logistic regression analysis.

Results: The developed models provided valid and reliable sex estimates with high and accuracy rates and low prediction errors.

Conclusions: The models are representative for the Turkish population in terms of identification. The study thesis can be regarded as an alternative method when economic or other difficulties are encountered in terms of DNA analysis.

Keywords: Anthropometry, Forensic medicine, Identification, Sex estimation, Upper extremity

INTRODUCTION

Body identification is one of the most important and broadest aspects of forensic medicine. The importance of identification and associated areas of forensic medicine is constantly growing due to natural disasters such as earthquakes, floods and fires, mass disasters such as plane, train and maritime accidents, wars, explosions and acts of terror and due to the heightened importance of security measures.[1,2] The identification of victims is of the greatest importance, but is particularly difficult in the case of criminal or suspicious deaths, especially in incidents involving hundreds, thousands or tens of thousands of mass deaths when the victims are fragmented, burned or made unrecognizable due to post-mortem changes.[1] Anthropometric methods are used if sex and stature cannot be estimated on the basis of primary anatomical structures.[3] Anthropometry, a multi-faceted technique for investigating sexual dimorphism, is a practical method with high predictivity and validity using discriminant and regression analyses.[4] Both skeletal collections and the external morphological characteristics of living subjects are used in the acquisition of community-specific anthropometric data.[3] Measurements of bodies and body parts and the sex relations in these vary considerably between different populations due to genetic and environmental factors. Data considered for use in sex differentiation therefore need to be population-specific.[5] Upper extremity anthropometric characteristics are important to the development of alternative methods in identity investigation in forensic sciences. Determination of the anatomical region and formations needing to be examined and evaluated for this purpose, the standardization of examination and measurement methodology and the conversion of the examination findings into mathematical models will assist practitioners in this field to estimate sex from available specimens.[1]

In order for identification to be possible, race, sex, age and height, regarded as the four major parameters of forensic anthropology, have to be estimated and a biological profile produced. This procedure makes it possible to narrow the pool in accident victims requiring matching and to produce more definitive markers, such as DNA, and it can be used for confirmation of final identification.[6] The most important criterion among the various parameters for identification is to determine the sex of the individual concerned. Since the individual's external and internal genitalia indicate sex directly, this may usually be regarded as a simple determination in forensic medicine. However, sex determination may be highly complicated and problematic in hermaphroditic, highly decomposed, fragmented or skeletonized cases. Nonetheless, recent studies have shown that sex estimation is possible with high probability from skeletal remains and different regions of the body.[7]

The purpose of this study was to show the relationship between upper extremity measurements and sex and to develop models to determine the sex of subjects in forensic situations from remaining anatomical parts and residues of the upper extremity for purposes of sex identification with high accuracy and reliability. Our findings will represent a specimen sample for individuals of Turkish birth in identification procedures.

DNA analysis is used in sex screening. However, such analysis for each body and body part in the wakes of mass disasters is a costly and time-consuming procedure, and more practical, low-cost and conventional methods are needed.[5] DNA analysis in cases of compromised body integrity involves high costs and requires a professional team, and is also a time-consuming process. In contrast, the alternative method described in the present study permits case identification with the application of models for which data have been developed in a more practical and economical manner. We therefore think that our technique can provide practicable information representative of Turkish society for forensic medicine, forensic anthropology and anatomy.

METHODS

400 volunteer's university students, 288 females and 112 males, aged 18-25, constituted the study group.

Subjects with function disorders in the measurement areas, or a history of upper extremity injury, any muscular disease, congenital disorder, deformity, fracture, amputation, movement restriction, systemic arthropathy, neurological disease, trauma or surgery were excluded from this study of healthy individuals. All the research groups in the study consisted of individuals born in Turkey.

Measurements

Right (R) and left (L) upper arm length (UAL_R, UAL_L), forearm length (FAL_R, FAL_L), upper extremity length (UEL_R, UEL_L), hand length (HL_R, HL_L), palmar length (PL_R, PL_L), third finger length (TFL_R, TFL_L), hand width (HW_R, HW_L), wrist width (WW_R, WW_L) and wrist circumference (WC_R, WC_L) measurements were evaluated in individuals from the research and control groups.

Anthropometric measurement points employed in the study

Stature: The distance between the sole of the foot and the vertex in an anatomical position.[8]

UAL_R and UAL_L: The distance between the olecranon and acromion with the elbow flexed at 90° and the shoulder fully adducted.[9,10]

FAL_R and FAL_L: The distance between the styloid process and olecranon with the elbow flexed at 90°.[6]

UEL_R and UEL_L: The distance between the acromion and the most distal part of the third finger.[11]

HL_R and HL_L: The distance between the most distal point of the third finger and the distal flexion line at the mid-point of the distance between the radial styloid process and ulnar styloid process.[7]

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.[12]

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.[13,14]

HW_R and HW_L: The distance between the distal ends of the ossae metacarpi II and V.[15-17]

WWR and WWL: The distance between the radial styloid process and ulnar styloid process.[6]

WC_R-WC_L: Measured around the wrist using a non-elastic tape measure.[18]

Anthropometric measurements of the right and left upper extremities in this study were performed using a Harpenden anthropometry set (Holtain Limited, UK), digital calipers with a 0-300mm measurement capacity sensitive to 0.01mm, a portable stadiometer for height measurements, a digital scale for weight and a non-elastic tape measure for wrist circumference. Hand measurements were performed with the thumb slightly abducted and the other fingers adducted with the palm facing upward. Three measurements were performed, and mean values were adopted. Measurements were based on anthropometric points in order to avoid potential measurement variations. Measurements were performed at the same time of day, in the same environment, using the same equipment and by the same individual.

Statistical analysis

Statistical analyses were performed on SPSS 21.0 software. The t-test was used to compare measurement values between the sexes, and models were developed using logistic regression analysis for sex prediction. Measurements exhibiting statistically significant differences between mean values between male and female groups were subjected to Pearson correlation analysis among themselves. Following correlation analysis, variables with correlation coefficients exceeding 0.70 based on variables' effects on one another were considered appropriate for the model and were subjected to logistic regression analysis. A threshold value of 0.50 was adopted during analysis within the logistic regression model established. Values smaller than 0.50 were evaluated as female, and values greater than 0.50 as male.

The independent variable in our logistic regression equations was the dichotomous-type sex variable. Women were determined as the reference group (coded with a 0 value) and men as the outcome group (coded with a 1 value). Hosmer and Lemeshow's Goodness of Fit test was used the general applicability to the data of the logistic regression models obtained. The stepwise technique was employed for multiple regression analysis. These values obtained from each model and corresponding to predictions produced by the model were compared with cross-classification tables. The statistical significance of the tables obtained was assessed using the Mc Nemar test. ROC analysis was also performed to compare the success rates of the logistic regression models obtained, and areas under the curve were calculated.[19] Statistical significance was set at $p<0.05$ for descriptive analyses and at $p>0.05$ for other analyses.

RESULTS

Descriptive statistics for study group shown in Table 1. Values obtained from upper right extremity measurements between males and females, upper arm length in males was 3.71cm, forearm length 4.1cm, upper extremity length 7.22cm, hand length 1.41cm, hand width 0.61cm, wrist width 0.28cm, wrist circumference 1.77cm, palmar length 0.81cm and third finger length 0.38cm greater compared to that in females.

Table 1: Descriptive statistics in terms of measurement parameters in study group.

Study 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
UAL$_R$	28.00	46.00	35.93 ± 2.98	UAL$_L$	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	UEU$_L$	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

SD: Standard Deviation; S: Stature; UAL: Upper 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; L: Left; R: Right

Based on values obtained from left upper extremities, upper arm length 3.5cm, forearm length 3.04cm, upper extremity length 7.28cm, hand length 1.4cm, hand width 0.62cm, wrist width 0.25cm, wrist circumference 1.72cm, palmar length 0.77cm and third finger length 0.36cm greater in males compared to that in females. Statistically significant differences were observed in all parameters between the male and female groups ($p<0.05$) with male measurements being higher than female (Table 2).

Analysis of Pearson correlation coefficients of the right and left upper extremity measurements for the male and female study groups revealed high and significant correlations ($p<0.01$) (Table 3).

We developed a six-item logistic regression model for sex prediction from three right upper extremity and three left upper extremity measurements. Due to the variation in remains in forensic medicine, models were developed for three separate conditions-including all upper extremity parameters (model 1), excluding upper extremity length (model 2) and hand measurements alone (model 3). The models for sex estimation from the right upper extremity are as follows (Table 4),

Table 2: Variations between mean measurements in the male and female study groups.

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

*p<0.05 significant. S: Stature; SD: Standard Deviation; t: t Statistics; UAL: Upper 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; L: Left; R: Right.

Table 3: Pearson correlation coefficients analysis of significant variables with each other.

Female				Male			
Right	**r**	**Left**	**r**	**Right**	**r**	**Left**	**r**
UAL_R-UEL_R	0.725	UAL_L-UEL_L	0.741	UAL_R-UEL_R	0.767	UAL_L-UEL_L	0.796
HL_R-HW_R	0.841	HL_L-HW_L	0.854	HL_R-HW_R	0.866	HL_L-HW_L	0.871
HL_R-WW_R	0.836	HL_L-WW_L	0.840	HL_R-WW_R	0.855	HL_L-WW_L	0.847
HL_R-PL_R	0.945	HL_L-PL_L	0.937	HL_R-PL_R	0.901	HL_L-PL_L	0.930
HL_R-TFL_R	0.923	HL_L-TFL_L	0.923	HL_R-TFL_R	0.928	HL_L-TFL_L	0.922
HW_R-WW_R	0.944	HW_L-WW_L	0.939	HW_R-WW_R	0.959	HW_L-WW_L	0.956
HW_R-PL_R	0.917	HW_L-PL_L	0.908	HW_R-PL_R	0.888	HW_L-PL_L	0.908
HW_R-TFL_R	0.921	HW_L-TFL_L	0.922	HW_R-TFL_R	0.919	HW_L-TFL_L	0.942
WW_R-PL_R	0.931	WW_L-PL_L	0.912	WW_R-PL_R	0.914	WW_L-PL_L	0.916
WW_R-TFL_R	0.931	WW_L-TFL_L	0.936	WW_R-TFL_R	0.920	WW_L-TFL_L	0.941
PL_R-TFL_R	0.948	PL_L-TFL_L	0.934	PL_R-TFL_R	0.878	PL_L-TFL_L	0.915

p<0.01; r: correlation coefficients

Table 4: Logistic regression formula coefficients of right upper extremity measurements.

Model		B	SD	WALD	DF	P	Exp (B)	%95 Exp (B)	
								Lower	**Upper**
1	TFL_R	-4.352	0.647	45.298	1	0.000	0.013	0.004	0.046
	HL_R	2.215	0.445	24.805	1	0.000	9.162	3.832	21.906
	HW_R	2.240	0.463	23.435	1	0.000	9.394	3.793	23.266
	UEL_R	0.413	0.065	40.232	1	0.000	1.510	1.330	1.716
	Constant	-56.566	5.953	90.298	1	0.000	0.000		
X^2=13.643 hosmer and lemeshow test p=0.092									
2 (Except for UEL_R)	TFL_R	-4.731	0.635	55.429	1	0.000	0.009	0.003	0.031
	HL_R	3.089	0.409	57.002	1	0.000	21.952	9.845	48.945
	HW_R	1.816	0.426	18.202	1	0.000	6.145	2.669	14.150
	UAL_R	0.382	0.077	24.446	1	0.000	1.465	1.259	1.705
	Constant	-48.480	5.032	92.833	1	0.000	0.000		
X^2=14.972 hosmer and lemeshow test p=0.092									
3 (Only hand measurements)	TFL_R	-4.519	0.649	48.434	1	0.000	0.011	0.003	0.039
	HL_R	3.538	0.402	77.294	1	0.000	34.386	15.627	75.664
	HW_R	2.443	0.550	19.766	1	0.000	11.511	3.920	33.798
	WW_R	-1.246	0.564	4.889	1	0.027	0.288	0.095	0.868
	Constant	-42.251	4.399	92.254	1	0.000	0.000		
X^2=11.075 hosmer and lemeshow test p=0.197									

B: Regression Coefficients; SD: Standard Deviation; DF: Degree of Freedom; Exp (B): Odds Ratio; Wald: Significance level of B coefficients in the logistic regression

Table 5: Logistic regression formula coefficients of left upper extremity measurements.

Model		B	SD	WALD	DF	P	Exp (B)	%95 exp (B)	
								Lower	Upper
1	TFL_L	-4.025	0.631	40.700	1	0.000	0.018	0.005	0.062
	HW_L	2.677	0.524	26.118	1	0.000	14.539	5.208	40.586
	HL_L	1.410	0.459	9.440	1	0.002	4.095	1.666	10.066
	UEL_L	0.551	0.086	41.351	1	0.000	1.736	1.467	2.053
	Constant	-58.495	6.249	87.615	1	0.000	0.000		
X^2=5.367 hosmer and lemeshow test p=0.718									
2 (except for UEL_L)	TFL_L	-4.682	0.628	55.609	1	0.000	0.009	0.003	0.032
	HW_L	2.738	0.546	25.192	1	0.000	15.456	5.306	45.024
	HL_L	3.976	0.558	50.725	1	0.000	53.297	17.846	159.177
	PL_L	-1.876	0.560	11.216	1	0.001	0.152	0.051	0.459
	UAL_L	0.376	0.084	20.139	1	0.000	1.457	1.236	1.717
	Constant	-52.286	5.533	89.298	1	0.000	0.000		
X^2=5.479 hosmer and lemeshow test p=0.705									
3 (only hand)	TFL_L	-4.896	0.601	66.389	1	0.000	0.007	0.002	0.024
	PL_L	-2.065	0.516	16.009	1	0.000	0.127	0.046	0.349
	HW_L	2.559	0.506	25.559	1	0.000	12.917	4.791	34.829
	HL_L	4.679	0.543	74.252	1	0.000	107.632	37.134	311.972
	Constant	-46.097	4.904	88.366	1	0.000	0.000		
X^2=7.994 hosmer and lemeshow test p=0.434									

B: Regression Coefficients; SD: Standard Deviation; DF: Degree of Freedom; Exp (B): Odds Ratio; Wald: Significance level of B coefficients in the logistic regression.

Table 6: Cross-classification table for right upper extremity in study group.

Models (right)	Estimated Groups	Real groups			P (Mc Nemar)
		(0:Female)	(1:Male)	Total	
Model 1_R	(0:Female)	273 (94.8%)	19 (17.0%)	292 (73.0%)	0.608*
	(1:Male)	15 (5.2%)	93 (83.0%)	108 (27.0%)	
	Total	288	112	400	
Model 2_R	(0: Female)	270 (93.8%)	23 (20.5%)	293 (73.3%)	0.533*
	(1: Male)	18 (6.2%)	89 (79.5%)	107 (26.7%)	
	Total	288	112	400	
Model 3_R	(0:Female)	271 (94.1%)	29 (25.9%)	300 (75.0%)	0.304*
	(1:Male)	17 (5.9%)	83 (74.1%)	100 (25.0%)	
	Total	288	112	400	

* p>0.05 significiant

Table 7: Cross-classification table for left upper extremity.

Models (left)	Estimated Groups	Real groups			P (Mc Nemar)
		(0:Female)	(1:Male)	Total	
Model 1_L	(0:Female)	274 (95.1%)	18 (16.1%)	292 (73.0%)	0.597*
	(1:Male)	14 (4.9%)	94 (83.9%)	108 (27.0%)	
	Total	288	112	400	
Model 2_L	(0:Female)	276 (95.8%)	21 (18.8%)	297 (74.2%)	0.263*
	(1:Male)	12 (4.2%)	91 (81.2%)	103 (25.8%)	
	Total	288	112	400	
Model 3_L	(0:Female)	273 (94.8%)	27 (24.1%)	100 (75.0%)	0.188*
	(1:Male)	15 (5.2%)	85 (75.9%)	300 (25.0%)	
	Total	288	112	400	

* p>0.05 significiant.

Sex (Model 1_R) = - 56.566+(-4.352×TFL_R)+(2.215×HL_R) +(2.240×HW_R)+(0.413×UEL_R),
Sex (Model 2_R)= -48.480+(-4.731×TFL_R)+(3.089×HL_R)+ (1.816×HW_R)+(0.382×UAL_R),
Sex (Model 3_R) = -42.251+(-4.519×TFL_R)+(3.538 ×HL_R) +(2.443×HW_R)+(-1.246×WW_R).

The models for sex estimation from the left upper extremity are as follows (Table 5),

Sex (Model 1_L) = -58.495+(-4.025×TFL_L)+(2.677×HW_L)+(1.410×HL_L)+(0.551×UEL_L),
Sex (Model 2_L) = -52.286+(-4.682×TFL_L)+(2.738×HW_L) +(3.976×HL_L)+(-1.876×PL_L)+(0.376×UAL_L),
Sex (Model 3_L) = -46.097+(-4.896×TFL_L)+(-2.065×PL_L) +(2.559×HW_L)+(4.679×HL_L).

Sex estimations obtained from right upper extremity measurements were quite close to the actual sex values, the highest success being achieved in model 1 with accurate classification (Table 6) of 94.8% in women and 83.0% in men (p=0.608). Sex estimations obtained from left upper extremity measurements were also quite close to the real sex values, the highest success being achieved in model 1 with accurate classification of 95.1% in women and 83.9% in men (p=0.597). The highest level of accurate classification in left-side measurements was observed in women in model 2, and this level was significant (95.8%, p=0.263) (Table 7). When the sex models were evaluated on the basis of the Youden index, with a high level of successful general classification, the most successful model in left upper extremity measurement was model 1 (Youden=0.790) which was also the most successful in right upper extremity measurements (Youden=0.778). Model 2 exhibited the highest accurate identification of women in left upper extremity measurements (Sens=0.958). Model 1 exhibited the highest level of accurate identification of men in left upper extremity measurements (Sel=0.839). Model 1, with the highest level of general success, also exhibited the highest sensitivity and selectivity in right-side measurements (Sens=0.948 and Sel=0.830). Examination of Youden index values revealed that the most successful obtained from left-side measurements exhibited better prediction than the most successful model from the right side (0.790>0.778) (Table 8).

The most successful of the models obtained for right-side measurements according to ROC analysis was model 1 (AUC: Area under curve, AUC_{Right} Model 1=0.889), and model 1 was also most successful for left-side measurements (AUC_{Left} Model 1=0.895). The most successful among all the models was model 1 for left-side measurements (AUC_{Left} Model 1=0.895) (Table 9).

Table 8: Indicators for models.

	Left measurements			**Right measurements**		
Indicators	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Sensitivity	0.951	0.958	0.948	0.948	0.938	0.941
Selectivity	0.839	0.812	0.759	0.830	0.795	0.741
Youden ındex	0.790	0.770	0.707	0.778	0.733	0.682

Table 9: ROC curves data statistics for right and left models.

Models	**AUC**	**SD**	p^a	**95% confidence ınterval**	
				Lower limit	**Upper limit**
Model 1_R	0.889	0.022	0.000	0.846	0.933
Model 2_R	0.866	0.024	0.000	0.819	0.913
Model 3_R	0.841	0.026	0.000	0.790	0.892
Model 1_L	0.895	0.022	0.000	0.853	0.938
Model 2_L	0.885	0.023	0.000	0.841	0.930
Model 3_L	0.853	0.025	0.000	0.804	0.903

DISCUSSION

Identification refers to determination based on characteristic features specific to a living or dead individual. Identification of living or dead subjects is necessary in the case of fragmented or seriously injured bodies, or of skeletonized and fragmented remains.[7] The growing incidences of mass disasters, such as conflicts, acts of terror and natural disasters, has created problems for investigators in terms of establishing identification from isolated upper extremity long bones. Great efforts have been made to identify remains in such disasters as the Turkish earthquake of 1999 and the terror attack on the World Trade Center in 2001.[20] Anthropometric techniques are a useful method in situations where sex estimation is not possible. Anthropometric measurements from the individual's dominant hand have been described as eliciting more objective results, and right-side measurements have been adopted in studies.[5] However, we evaluated both the right and left upper extremities in sex estimation in this study. We think it is necessary and useful for anthropometric measurements performed in consideration of the probability of both extremities being present in forensic cases and for models developed from these measurements to be considered from a broader perspective.

Our measurements comparing males and females were comparable to those of previous studies measuring common anthropometric parameters in the same or different populations.[5,9,12,18,21-25] These findings may lead to differentiation of the population. In this study, statistically significant differences were observed in all parameters between the male and female groups with male measurements being higher than female. These findings may be evaluated as resulting from adulthood commencing approximately 2years earlier in females and of epiphyseal fusion beginning and being completed earlier in females than in males.

Hand measurements provide quite accurate information concerning an individual's sex, age and height. The hand and wrist contain 45 separate ossification centers. The external surfaces and fusion points of these permit excellent evaluation of an individual's biological development. According to McKern, all the epiphyses in the fossa metacarpi and phalanx fusion at the ages of 14-19years in males and 13-17 in females. In addition to estimating age on the basis of ossification of hand bones, researchers have also begun predicting sex from these bones.[7] Karadayi et al. tested the relation between hand and wrist measurements and sex using discriminant function analysis.

They reported that on the basis of a single variable, the most reliable variable in sex differentiation was hand width at 83.4%, followed by wrist width at 82.9% and hand length at 79.3%. In discriminant functions where more than one variable was used, the most accurate binary model for sex differentiation was hand length and wrist width at 86.6%.[5] Another study reported accuracy of 77% in males and 80% in females when right hand length was used in sex differentiation, compared to 79% accuracy in males and 81% in females when left hand length values were used. Right hand width revealed sexual dimorphism with 80% accuracy in males and 83% accuracy in females and left-hand width with 81% accuracy in males and 82% accuracy in females. When hand length and hand width were compared, hand width emerged as the best, high-accuracy predictor of sex.[19] According to another study, right and left hand predict sex with 83% accuracy in males and 89% accuracy in females, right palmar length with 86% and 90% accuracy, left palmar length with 82% and 92% accuracy, right hand width 87% and 91% accuracy and left-hand width 89% and 92% accuracy, respectively.[10]

According to literature, ulnar length is the best parameter for indicating sexual dimorphism, followed, in descending order, by hand width, hand length and wrist width. Upper arm length was described as the least reliable parameter in sex differentiation. Ulnar length, the parameter exhibiting the highest sexual dimorphism, was able to predict sex with 88.5% accuracy in the study group and 90% in the control group, while hand width predicted sex with 85.5% accuracy in the study group and 82.5% in the control group. Upper arm length, exhibiting the lowest sexual dimorphism, predicted sex with 78.5% accuracy in the study group and 77.5% accuracy in the control group. When upper arm length was included in the model and a three-variable model consisting of ulnar length, wrist width and hand width was selected, sex was predicted with 89.5% accuracy in the study group and 87.5% accuracy in the control group. When two variables consisting of ulnar length and wrist width were selected in order to determine which three measurements were most effective when the upper arm was detached from the hand or missing, accuracy levels of 89% and 90% were obtained in the study and control groups, respectively. Sex was predicted with 85% accuracy using hand length and hand width together, but with 85.5% accuracy using hand width alone.

The authors concluded that ulnar length, wrist width and hand width provided better sex differentiation than upper arm length and hand length, and that forearm length provided better differentiation than the hand.[4] Chan Jee et al described maximum hand width and hand circumference as the parameters exhibiting the greatest variation between the sexes. On the basis of their results, sex was predicted with the greatest accuracy using maximum hand circumference (88.6% male and 89.6% female). Although hand width, hand circumference and hand thickness generally exhibited greater accuracy than hand length in sex prediction, the width and circumference of some finger joints also differed significantly among sex and age groups. It has therefore been suggested that hand dimensions such as hand length, palmar length, and hand width and maximum hand thickness are not affected by age group of sex and are therefore the parameters of choice for use in sex prediction in wide age groups.[13]

In our study, all the parameters were highly correlated with the right and left upper limb when evaluated according to sex. All models developed for sex prediction provided a high and reliable estimate of the study group. These results may be due to phalanx epiphyseal lines fusing at 14-19years in males and 13-17years in females and height reaching adults levels between early youth and the 20s.

Our study provides representative right and left extremity anthropometric measurements for the Turkish population and models developed from these measurements for purposes of sex estimation. The success levels of the models are discussed. The anthropometric measurements and models are also evaluated in terms of sexual dimorphism. The models developed provided reliable and accurate estimations with high correlation and accuracy levels and low prediction errors.

CONCLUSION

When factors that can lead to variations in upper extremity measurements, such as race, ethnicity, nutrition, climate and physical activity levels, are considered, although the models developed may vary between populations, they are representative for identification purposes for the Turkish population, and right and left side extremity measurements can also be used by populations giving similar findings to our own cases.

These practicable models that can be used for identification purposes by anatomists, forensic anthropologists, forensic pathologists, archeologists and forensic medicine investigators may be regarded as an alternative method under circumstances when difficulties are encountered in DNA analysis, for economic or other reasons, such as war and mass disasters.

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