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Can stature estimation formulas derived from measurements of living people apply to cadavers?

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Abstract

In almost all of the studies that propose formulas for estimating stature from foot measurements of living people, it has been stated that the stature formulas obtained can be used on dismembered body parts and/or cadavers. No study was made to estimate the body height from the foot measurements of cadavers. In this study, it was tested whether stature estimation formulas developed from foot measurements of living individuals were successful in predicting the actual body height of cadavers. In this study, the three anthropometric measurements (stature, foot length, and foot breadth) were taken from total 136 cadavers (76 males and 60 females) aged between 18-50 years. Various stature estimation formulas based on foot dimensions of living people were applied to our cadaver sample. When the published formulas derived from Turkish and non-Turkish populations were applied on our sample, it was observed that the equations yielded overestimations, varied averagely between +2 to +9 cm and +6 to +12 cm, respectively. Therefore, recommended stature estimation formulas derived from the foot measurements based on living people should be used with caution when applying forensic cases.

Introduction

Human body parts and their traces (e.g. footprints, handprints, earprints etc.) can give crucial information for biological or forensic identification of victims, especially in case of disasters, aircraft accidents, fires or unsolved deaths. They contain clues about the person's biological profile such as sex, age, stature, and body weight. Stature or body height, which is an important component of biological profile, can be estimated from the lengths of limbs and foot and footprints. For this reason, there has been remarkable increase in studies proposing regression equations for estimating stature based on foot and footprints dimensions during the last two decades (e.g., Atamtürk and Duyar, 2008; Krishan et al., 2012; Agarwal et al., 2018; Kim et al., 2018; Singh et al., 2019; Venkatachalam and Felix, 2019).

In these studies, it can be seen that the regression equations with high success rate can be applied in case of identification of forensic cases (Jasuja et al., 1991; Giles and Vallandigham, 1991; Özaslan et al., 2012; Krishan and Sharma, 2007). Most of these studies focused on the producing the regression equations and technical details such as standard errors of the estimates (SEE) were discussed merely, and a few of them addressed the applicability and the problems arising during this procedure (Atamtürk and Duyar, 2008). In addition, in most of these studies, foot dimensions were measured while individuals were standing, and the regression equations developed from these measurements could be used to estimate the stature of the cadaver (Atamtürk and Duyar, 2008; Saxena, 1984; Krishan and Sharma, 2007; Kanchan et al., 2008; Singh et al., 2019). However, the applicability of these equations to the dead individual(s) or cadavers has not been tested.

It is well known that the values of many anthropometric measurements differ according to the position of the person when taking the measurement (Duyar, 2000). For example, the value of body height is different when the person is in a supine position, but is different if it taken while standing. Some authors indicated that there is a difference of about 2 cm between these two positions, emphasized that the measurement taken in supine position would be higher (Trotter and Gleser, 1952, 1958; De Mendonça, 2000). Paralell to this, footprints on hard ground were found to be about 10% smaller than the actual foot size (Atamtürk, 2003). However, it can be assumed that the foot measurements taken in the living individuals at standing position will be larger and this may cause deviations in the estimates.

In this study, the extent to which the stature estimation equations based on foot measurements of livings give accurate results in predicting the body height of cadavers will be examined. Thus, the accuracy rate of these equations was tested in forensic cases. Additionally, body height estimation equations were developed to be used only in cadavers based on the measurements on supine position taken in corpses.

Materials and methods

The study was conducted in the Antalya Group Chairmanship of the Council of Forensic Medicine, Antalya, Turkey. The material consists of 76 male and 60 female corpses, in the age group ranging from 18 to 50 years (mean age 35.13 years for males and 32.06 years for females). The distribution of the individuals by age groups is given in Table 1. The corpses under 18 years of age due to their incomplete bone development, and the corpses over 50 years of age were excluded from the study because of extreme shortening of their body height. While selecting these individuals, attention was paid to the fact that they were citizens of the Republic of Turkey, they did not have any physical deformities, and their body integrity was intact.

Table 1. Distribution of individuals by age groups

Age groups	Females	Males	Total
18-24	17	18	35
25-29	8	8	16
30-34	11	9	20
35-39	8	11	19
40-44	8	15	23
45-50	8	15	23
Total	60	76	136

Three anthropometric measurements were taken from the fresh corpses: cadaver stature, foot length, and foot breadth. Anthropometric measurements were taken before autopsy without rigor mortis. The measurements are taken as follows:

Cadaver stature: While the corpse laying on an autopsy table (length 2050 mm) in a supine postion and in full extension, the stature was measured using a steel ruler. The bodies were laid on the autopsy table in such a way that the anatomical points of acromion, trochanterion and malleolus lateralis were kept on the the same anatomic plan (Krogman, 1962). To obtain the cadaver stature, the distance between the upper edge of the autopsy table and the vertex plus the distance between the lower edge of the table and the lowest point of the heel were subtracted from the total length of the autopsy table (see Fig. 1).

Foot lenght was taken from the distance between the pternion (extreme point of the heel) and the akropodion (extreme point of longest toe) from the individual lying on the autopsy table (Martin and Saller, 1957; Olivier, 1969; Duyar, 2000).

Foot breadth (FB) was measured to the distance from the medial margin of the head of the first metatarsal bone (metatarsal tibiale) to the lateral margin of the head of the fifth metatarsal bone (metatarsal fibulare) (Martin and Saller, 1957; Olivier, 1969; Duyar, 2000).

All the calculations and statistical tests were performed using the SPSS 21 software programme for windows. One-way analysis of variance (ANOVA) test was used to compare the anthropometric measurements of the subjects. Paired *t*-test was used to assess the differences between the measured stature and the estimated ones based one the formulas gathered from the literature. For our sample, stepwise regression technique was performed while developing stature estimation equations from the foot measurements.

All the procedures used in the study were in accordance with the ethical standards of the Research Ethics Committee of School of Medicine, Akdeniz University, Antalya (ethical approval number and date is 120/ 12.02.2007).

Results and discussion

The descriptive statistics of stature, foot and foot breadth measurements of the male and female cadavers are given in Table 2. As expected, both stature and foot measurements are higher in males than in females, and these differences between sex groups are significant statistically ($P < 0.001$).

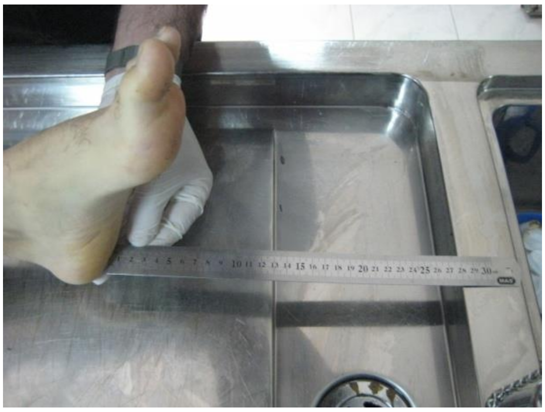

Figure 1. The measurements of cadaver stature on the autopsy table

In the literature, since there are no equations for estimating the stature from the foot measurements for cadavers, the stature estimation equations derived from the various living poeoples while the foot was bearing body weight were applied to our sample (Table 3). The first group of regression equations derived from the people living in Turkey. There are five studies in this group: Atamtürk and Duyar (2008), Turgut et al. (1998), Özden et al. (2000), Özaslan et al. (2012), and Şanlı et al. (2005). All of these studies were conducted in young adult or adult plus elderly groups.

In this study, stature estimation formulas developed from the foot measurements in various populations were also applied. Giles and Vallandigham (1991) proposed stature estimation equations based on the measurements taken from the adults living in the United States. Saxena (1984) developed a stature estimation equation based on Nigerian males in the age ranges of 20-30 years. Kanchan et al. (2008) produced the stature estimation equations from foot measurements of 100 males and 100 females, aged between 18-80 years in India. Krishan and Sharma (2007) generated stature estimation equations on 123 males and 123 females aged between 17-20 years in a North Indian population.

Stature estimation formulas compiled from the literature were applied to male and female cadavers in our sample (Table 4). The findings are given in Table 5. As can be seen here, most of the proposed formulas produced stature estimates that were statistically different from actual height. Only the average stature obtained from the two equations gave the body height estimates that were not statistically different from actual the stature (Özaslan et al., 2012; Özden et al., 2000). It is noteworthy that both of these two studies are conducted on the samples living in Turkey. It is clear that thre are remarbable differences between actual stature and estimated ones in all studies conducted in other populations, including some in Turkey.

Table 2. Descriptive statistics of the anthropometric measurements (in mm)

	Males		Females		Pooled		
	Mean (n=76)	SD	Mean (n=60)	SD	Mean (n=136)	SD	*F*-Statistics
Stature	1704.78	66.713	1572.63	57.572	1646.48	90.874	148.207*
Foot breadth	236.33	13.561	210.55	12.923	82.46	7.977	126.273*
Foot length	87.34	6.258	76.27	5.109	224.96	18.445	123.107*

*$P < 0.001$

Table 3. Stature estimation formulas proposed by various researchers

Reference	Sex (cm/mm)	Equation	SEE
Atamtürk and Duyar (2008)*	S1 = (4.211 * FL) + (4.981 * Sex) + 62.208		4.58
	S2 = (3.957 * FL) + (5.070 * Sex) + (-0.111 * Age) + 72.862		4.84
Turgut et al. (1998)	Male (cm)	S = 2.66 * FL + 105.21	--
	Female (cm)	S = 3.97 * FL + 66.36	--
Özden et al. (2000)	Male (cm)	S = 1.4 * FL + 137.5	6.60
	Female (cm)	S = 2.7 * FL + 99.1	5.40
Şanlı et al. (2005)	Male (mm)	S = 3.53 * FL + 822.66	4.30
	Female (mm)	S = 2.84 * FL + 932.09	3.55
Özaslan et al. (2012)	Male (mm)	S = 3.52 * FL+ 840.88	4.94
	Female (mm)	S = 2.96 * FL + 941.95	5.59
Saxena (1984)	Male (cm)	S = 3.96 * FL + 67.49	--
Giles and Vallandigham (1991)	Male (cm)	S = 3.447 * FL + 82.206	4.86
	Female (cm)	S = 3.614 * FL + 75.065	4.70
Krishan and Sharma (2007)	Male (cm)	S = 1.51* FL + 3.29 * FB + 99.59	3.02
	Female (cm)	S = 2.60 * FL + 2.11 * FB + 79.36	2.98
Kanchan et al. (2008)	Male (cm)	S = 2.82* FL + 93.269	3.88
	Female (cm)	S = 2.37 * FL +103.270	4.39

SEE: Standard error of the estimate.
FL: Foot length; FB: Foot breadth.
For sex; female = 0 and male = 1.

Table 4. Differences between the estimated and measured stature values (males, cm)

	Mean estimation	Mean difference	SS	t	P
Measured stature	170.48				
Atamtürk and Duyar (2008) S1	166.94	3.53	4.99	6.16	0.000*
Atamtürk and Duyar (2008) S2	166.72	3.75	5.36	6.12	0.000*
Turgut et al. (1998)	168.07	2.40	4.96	4.23	0.000*
Özden et al. (2000)	170.59	-0.10	5.55	-0.17	0.865
Şanlı et al. (2005)	165.78	4.69	4.87	8.41	0.000*
Özaslan et al. (2012)	167.28	3.20	4.87	5.74	0.000*
Giles and Vallandigham (1991)	163.67	6.80	4.86	12.20	0.000*
Saxena (1984)	161.45	4.93	4.93	15.97	0.000*
Krishan and Sharma (2007)	164.01	6.46	5.26	10.72	0.000*
Kanchan et al. (2008)	159.89	10.58	4.92	18.76	0.000*

* $P \leq 0.001$

Table 5. Differences between the estimated and measured stature values (females, cm)

	Mean estimation	Mean difference	SS	t	P
Measured stature	157.26				
Atamtürk and Duyar (2008) S1	151.08	6.18	5.74	8.35	0.000*
Atamtürk and Duyar (2008) S2	152.64	4.62	5.40	6.63	0.000*
Turgut et al. (1998)	149.95	7.31	5.59	10.13	0.000*
Özden et al. (2000)	155.95	1.31	5.11	1.99	0.051
Şanlı et al. (2005)	153.09	4.17	5.14	6.29	0.000*
Özaslan et al. (2012)	158.20	0.93	-0.93	-1.35	0.181
Giles and Vallandigham (1991)	151.16	6.10	5.41	8.74	0.000*
Krishan and Sharma (2007)	150.19	7.07	5.31	10.29	0.000*
Kanchan et al. (2008)	153.07	4.20	5.06	6.41	0.000*

* $P \leq 0.001$

It is known that different factors affect the anthropometric variability, particularly in body height (e.g. Duyar, 2022). In various studies have examined how and to what extent the variability of anthropometric measures is affected by many factors such as age, gender, nutrition, geography, and diseases (Trotter and Gleser, 1951; Maedows and Jantz, 1999; De Mendonça, 2000; Bogin, 2010; Duyar, 2010). Based on these studies, it can be said that the anthropometric parameters, including body proportions, have distinctive characteritics and this fact affect stature estimation procedures (Genoves, 1967; Sjøvold, 2000; Klepinger, 2006; Duyar and Pelin, 2010). For this reason, in this research, anthropometric measurements taken on cadavers were applied to equations derived from individuals living in different cities or regions of Turkey. As can be seen from Tables 6 and 7, all measurements of females and males in our sample, especially stature, has the lowest values and the difference is more pronounced among males.

The researchers emphasized that there was a marked difference between the stature of livings and cadavers (Trotter and Gleser, 1952, 1958; Trotter, 1970; De Mendonça, 2000; Cardoso et al., 2016). For instance, Trotter (1970) found that the cadavers were on average 2.35 cm taller compared with their living stature. Similarly, De Mendonça (2000) reported that an average 2 cm difference between the living stature and cadaver stature. Therefore, the authors (Trotter, 1970; De Mendonça, 2000) stated that a correction term should be applied for stature difference between livings and cadavers. From this point of view, it is expected that the measured stature of cadavers in our sample is about 2 cm longer than those of livings. However, different results were obtained in our study. The average stature of our sample is shorter than 2-4 cm when compared the other studies conducted in Turkey.

As expected, the equations of stature estimation yielded more accurate predictions, when we applied the formulas derived from Turkish population, 0-4 cm in males and 0-7 cm in females. On the other hand, the estimations errors increased considerably when we used the equations based on populations other than Turkish population. The latter group of equations produced mean difference ranged between 5-10 cm in males and 4-7 cm in females. In addition, considering that the stature of the cadavers will be nearly 2 cm longer in the literature, it can be said that the difference between the estimated and measured stature will increase up to +2-9 cm for Turkish samples and up to +6-12 cm for different populations.

Table 6. Anthropometric measurements obtained in male individuals in different studies

	Present study		Atamtürk and Duyar (2008)		Özden et al. (2000)		Özaslan et al. (2012)	
	Mean (n=76)	SD	Mean (n=253)	SD	Mean (n=294)	SD	Mean (n=224)	SD
Stature	1704.78	66.713	1723.7	7.33	1743.9	72.1	1724.4	68.65
Foot length	236.33	13.561	258.4	12.6	260.0	13.4	250.86	13.56
Foot breadth	87.34	6.258	99.5	4.8	94.1	9.9	93.69	7.43

Table 7. Anthropometric measurements obtained in females in different studies

	Present study		Atamtürk and Duyar (2008)		Şanlı et al. (2005)		Özden et al. (2000)		Özaslan et al. (2012)	
	Mean (n=60)	SD	Mean (n=263)	SD	Mean (n=80)	SD	Mean (n=275)	SD	Mean (n=132)	SD
Stature	1572.6	57.6	1573.9	65.3	1599.6	49.2	1609.4	63.1	1620.1	64.19
Foot length	210.6	12.9	234.5	10.7	234.8	12.1	232.6	10.7	228.9	10.7
Foot breadth	76.3	5.1	90.5	5.4	--	--	82.4	11.8	86.1	10.7

Table 8. Height estimation formulas obtained from foot measurements of cadavers

Model	Equation	SEE (cm)	Adjusted R^2
Model 1	3.96 FL. - 75.68	5.43	0.64
Model 2	2.85 FL. +5.87. Sex	5.03	0.70
Model 3	2.93 FL. + 6.02. Sex -0.13. Yaş +93.54	4.89	0.72

FL: Foot length
For sex; female = 1 and male = 2.

As far as we know, there is no study in the literature suggesting a formula for estimating stature from foot measurements to apply for cadavers. Our study revealed that stature estimation formulas developed from living populations predict the actual height with errors ranging from 2 to 12 cm. Therefore, in our study we generated stature estimation equations for cadavers and dead bodies (Table 8). Some authors state that body size, age and sex should be taken into consideration when estimating stature (Atamtürk and Duyar, 2008). For this reason, stepwise regression analysis was applied to create stature estimation formulas that are sensitive to age and sex from foot measurements in cadavers. Table 8 shows the three best-performing regression models. It can be said that these models will reduce the margin of error on the cadavers when the stature is to be estimated for the people living in Turkey.

Conclusion

Our research has revealed two conclusions. Firstly, when the equations of stature estimation based on foot measurements in the living individuals are applied to cadavers, the estimation errors increases considerably. Therefore, it is necessary to approach caution to forensic stature formulas from foot measurements. Secondly, our findings suggest that the correction factor for cadaver stature (approxiamately 2 cm) is not always applicable during the stature estimation procedure.

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