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RESEARCH ARTICLE

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Estimating Height and Body Weight Using Foot Measurements

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Abstract

Objective: Determining the height and weight of the person is the most important factor in forensic cases in which the body integrity is impaired including natural disasters, traffic accidents, wars, murders and decomposition of the body. In this study, it was aimed to obtain linear and multiple regression models and formulas for determining height and weight from foot measurements.

Methods: The relationship between foot measurements and the height and weight of 180 adult individuals (90 males, 90 females) aged 20-65 years were analyzed retrospectively. Foot length and height, malleolar width, calcaneus length and height, 1-5. metatarsal length relationships with height were interpreted. Proximal metatarsal width, distal metatarsal width, 1-5. metatarsal distal end width, proximal end width and corpus width relations with a body weight were evaluated.

Results: For both feet in men, the correlations between height and foot length, height and 5th metatarsal length, and between weight and 2nd metatarsal distal end width were found to be significant. For both feet in women, correlation relationship between height and foot length, 1st metatarsal length, 3rd metatarsal length and in terms of body weight, the correlation relationship between the 1st metatarsal distal tip width, 3rd metatarsal corpus width, 4th metatarsal corpus width, and 5th metatarsal proximal tip width was found to be significant.

Conclusion: In the study, formulas for regression equations, height estimation and body weight were obtained from foot measurements. When the formulas have been developed are used according to gender, they show a deviation of 9-10 cm for height estimation and 11-14 kg for body weight estimation. When our formulas are evaluated by ignoring the gender difference, they show a deviation of less than 6 cm for height estimation and 8-9 kg for body weight. We believe that height and body weight from foot measurements could be predicted by the virtue of our formulas in similar populations. We think that our study results will be beneficial for forensic specialists, archaeologists, criminologists, and researchers who will conduct detailed research on this subject in estimating height and body weight from foot measurements in cases where body integrity cannot be preserved.

Key words: Metatarsal bones, Foot, Height estimate, Body weight estimate

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INTRODUCTION

In forensic investigations and archaeological researches, determining the age, gender, height and weight of an individual are important factors in the identification of an individual (1). It is not possible to determine the height and body weight of the person in cases such as natural disasters, traffic accidents, wars, murders and decomposition of the body in which the body integrity is impaired (2). Although the usability of long bones such as femur and tibia in estimation of height is reliable, their probability of being found in one piece is very low (3). Foot bones are suitable for evaluation due to their presence in both forensic and archaeological contexts, their small surface area, less exposure to taphonomic factors, and better protection by socks and shoes. Especially small bones such as metatarsal bones can often remain undeformed due to their resistance to postmortem changes (4). Height estimation studies were conducted on foot bones, hand bones, craniofacial bones, femur, tibia, fibula, humerus, ulna, sacrum, coccygeal vertebra, calcaneus and talus measurements in different populations (5-11). Studies on determining body weight in the literature are more limited (12-17). Although the data obtained in studies are specific to the relevant population, it is not correct to completely generalize fully to other populations. Estimation formulas for one population may not be reliable for other populations and ethnic groups. Therefore, regression analyzes for populations and ethnic groups should be performed and formulas should be presented (4). For this reason, it is important to obtain results specific to societies. In this study, it is aimed to examine the relationship between foot measurements, height and body weight, and to obtain linear and multiple regression formulas for estimating height and body weight from foot measurements and compare them with the literature.

METHODS

Research Group

Ethics committee approval was received for this study from the Health Sciences University Samsun Training and Research Hospital Non-Invasive Clinical Research Ethics Committee (07/07/2021, GOKA/2021/13/9). The study was conducted by retrospectively evaluating the bilateral foot radiographs of 180 adults (90 men, 90 women) aged 20-65 years. The inclusion criteria were to be male or female between the ages of 20-65, to have bilateral foot radiographs, and to not have any fractures or deformities in the foot bones. Individuals under the age of 20 and over the age of 65, with unilateral foot radiographs, with fractures or deformities in the foot bones and who did not have height and body weight information in the hospital registry were not included in the study.

In order to determine the sample size, a study titled 'Evaluation of Anthropometric Foot Anthropometric Measurements in Terms of Gender Detection and Height Estimation' was adopted; power and sample size analysis at α (alpha) =0.05 and a test power of 95% were determined as 81 people. A sample size of 180 people was determined in this study (18).

Simple random sampling method was used among patients who applied to the emergency department and orthopedics outpatient clinics of Terme State Hospital (Samsun, Turkey) and had bilateral foot radiography. The measurements were made by a single researcher at different times with an interval of 2 months, and the average results were studied.

Data Collection

The age, gender, height, body weight and background information of the patients were obtained from the hospital registry system.

Foot measurements evaluated by height

1. Foot length: It is the distance between the calcaneara, the rearmost point of tuber calcanei, and the acropodion, the tip of the longest toe.

2. Foot height: The distance from the sole of the foot to the highest point of the talus.

3. Malleolus width: The length between the most medial point of the malleolus mediale and the most lateral point of the malleolus lateralis.

4. Calcaneus length: The length between the most posterior point of the tuber calcanei and the calcaneocuboid joint.

5. Calcaneus height: Perpendicular length between the axis tangential to the calcaneus and the highest posterior point of the tuber calcanei, drawn from the lower posterior end of the tuber calcanei on the lower face of the calcaneus and tangential to the calcaneocuboid joint.

6. 1-5. metatarsal lengths: The length between the most distal point and the most proximal point of the 1-5. ossa metatarsi.

Foot measurements evaluated by body weight

1. Proximal metatarsal width: The length between the most medial point of the basis ossis metatarsale-1 and the lateral point of the basis ossis metatarsale-5.

2. Distal metatarsal width: Length between the most medial point of caput ossis metatarsale-1 and the most lateral point of caput ossis metatarsale-5.

3. 1-5. metatarsal distal end widths: The length between the most medial point and the most lateral point of the midline of the ossa metatarsi 1-5.

4. 1-5. metatars proximal end widths: The length between the most medial point and the most lateral point of the basis ossa metatarsi 1-5.

5. 1-5. metatarsal corpus widths: The length between the most medial point and the most lateral point of the midline of the ossa metatarsi 1-5.

Statistical analysis

IBM SPSS Statistics 22.0 (demo version). program was used for statistical analysis. The conformity of the parameters to the normal distribution was evaluated with the Shapiro Wilks Test and found to be appropriate. In addition to descriptive statistical methods (min, max, SD), Pearson Correlation Analysis was used to examine the relationships between parameters. Linear Regression Analysis (Backward method) was used for a multivariate analysis. Data analysis was performed at a 95% confidence interval and at a significance level of $p < 0.05$.

RESULTS

The mean age of the individuals in our study was 42.99±13.07 years. Their height varies between 149 and 185 cm, with an average height of 166.99±7.03 cm. The weights of individuals vary between 51 and 120 kg, with an average weight of 73.75±11,46 kg. The minimum, maximum, mean and standard deviation values of the measurements of both feet are given in Table 1.

Table 1. Minimum, maximum, mean and standard deviation values of right and left foot measurements (mm)

	Right		Left	
	Min-Max	Average±SD	Min-Max	Average±SD
1.MDEW	15.39-29.72	21.31±2.27	15.26-29.93	21.29±2.24
1.MPEW	16.13-28.42	22.32±2.38	16.1-28.44	22.25±2.37
1.MCW	8.89-18.76	14.39±1.74	9.2-18.21	14.35±1.69
1.ML	55.36-77.37	65.43±4.5	55.41-77.12	65.38±4.42
2.MDEW	8.32-16.06	12.17±1.49	8.27-15.92	12.13±1.45
2.MPEW	12.63-20.49	16.1±1.58	12.7-21.1	16.05±1.57
2.MCW	6.18-10.19	8.42±0.9	6.17-10.25	8.38±0.87
2.ML	59.8-81.49	70.87±4.86	59.9-81.4	70.78±4.75
3.MDEW	8.13-15.69	11.76±1.46	8.11-15.5	11.75±1.42
3.MPEW	11.22-23.71	16.94±2.02	11.15-23.6	16.89±1.99
3.MCW	5.02-9.99	7.33±0.84	5.11-9.78	7.32±0.8
3.ML	57.05-80.32	68.66±4.87	58.01-79.87	68.6±4.74
4.MDEW	6.61-14.99	10.8±1.66	6.82-14.9	10.76±1.61
4.MPEW	11.77-22.06	16.72±1.99	11.79-21.96	16.67±1.97
4.MCW	5.62-9.64	7.46±0.87	5.73-9.87	7.43±0.83
4.ML	58.95-80.48	68.6±4.57	59.03-79.57	68.52±4.51
5.MDEW	7.13-15.12	11.15±1.46	7.15-15.15	11.12±1.42
5.MPEW	13.21-23.92	18.56±2.28	12.94-23.85	18.51±2.25
5.MCW	5.94-10.6	7.97±0.95	5.89-10.54	7.95±0.94
5.ML	55.33-86.67	67.58±5.15	55.4-85.4	67.61±5.07
FL	225.32-301.12	261.13±17.28	225.46-301.25	261.08±17.2
MW	57.83-84.61	70.54±5.86	58.02-84.31	70.54±5.8
FH	70.3-104.56	84.48±6.12	71.16-104.4	84.5±6
PMW	57.11-99.2	72.64±7.56	57.2-99.67	72.58±7.51
DMW	65.91-105.36	87.67±7.16	66.89-103.88	87.67±7.08
CH	37.7-59.82	48.77±4.18	37.89-59.7	48.71±4.1
CL	67.89-97.36	81.06±6.45	68.15-97.2	81.02±6.4

MDEW: metatarsal distal end width, MPEW: metatarsal proximal end width, MCW: metatarsal corpus width, ML: metatarsal length, FL: foot length, MW: malleolar width, FH: foot height, PMW: proximal metatarsal width, DMW: distal metatarsal width, CH: calcaneal height, CL: calcaneal length

The correlation coefficients between height and right and left foot measurements of men, women, and the study group were evaluated with Pearson Correlation Analysis (Table 2). The highest correlation between height and foot measurements was found with the 5th metatarsal length in men, the 3rd metatarsal length in women, and the foot length in the study group.

Right and left foot measurements were evaluated by Multiple Regression Analysis (Table 3). The “R” value is the correlation coefficient that expresses the relationship between height and foot measurements in men, women and study groups. The “R2” value is the ratio of variations in height explained by foot measurements in all groups. Accordingly, the relationship between the change in height and right foot measurements was found to be 40.8% in men, 30.7% in women, and 59.6% in the study group. The relationship with left foot measurements was identified as 41.1% in men, 29.4% in women, and 59.9% in the study group.

Table 2. Correlations between height and study parameters

		Height (cm)					
		Men		Women		Study Group	
		r	p	r	p	r	p
Foot length	Right	0.559	0.000*	0.248	0.018*	0.696	0.000*
	Left	0.557	0.000*	0.253	0.016*	0.697	0.000*
Foot height	Right	0.326	0.002*	0.311	0.003*	0.611	0.000*
	Left	0.332	0.001*	0.316	0.002*	0.614	0.000*
Malleolar width	Right	0.350	0.001*	0.208	0.049*	0.654	0.000*
	Left	0.356	0.001*	0.210	0.047*	0.660	0.000*
Calcaneus height	Right	0.356	0.001*	0.255	0.015*	0.606	0.000*
	Left	0.352	0.001*	0.267	0.011*	0.609	0.000*
Calcaneus length	Right	0.457	0.000*	0.368	0.000*	0.688	0.000*
	Left	0.454	0.000*	0.367	0.000*	0.686	0.000*
1st metatarsal length	Right	0.420	0.000*	0.363	0.000*	0.605	0.000*
	Left	0.441	0.000*	0.370	0.000*	0.607	0.000*
2nd metatarsal length	Right	0.493	0.000*	0.316	0.002*	0.568	0.000*
	Left	0.511	0.000*	0.321	0.002*	0.574	0.000*
3rd metatarsal length	Right	0.463	0.000*	0.434	0.000*	0.618	0.000*
	Left	0.452	0.000*	0.413	0.000*	0.611	0.000*
4th metatarsal length	Right	0.535	0.000*	0.298	0.004*	0.608	0.000*
	Left	0.531	0.000*	0.292	0.005*	0.613	0.000*
5th metatarsal length	Right	0.604	0.000*	0.248	0.018*	0.657	0.000*
	Left	0.609	0.000*	0.246	0.019*	0.663	0.000*

Pearson Correlation Analysis, *p<0.05, r: correlation coefficient

Table 3. R, R2, adjusted R2 and standard error values of the estimation as a result of linear regression analysis of right and left foot measurements affecting height in men, women and the study group

	Gender	R	R^2	Adjusted R Square	SEE
Right	Men	0.639	0.408	0394	4.393
	Women	0.554	0.307	0.265	3.741
	Study group	0.772	0.596	0.587	4.515
Left	Men	0.641	0.411	0.397	4.383
	Women	0.542	0.294	0.252	3.776
	Study group	0.774	0.599	0.590	4.499

SEE: standard error of the estimate

Right and left foot measurements affecting height were evaluated with regression analysis. The relationship between height, foot length and 5th metatarsal length in both feet was significant in men ($p<0.05$). In women, the relationship between height and foot length, 1st metatarsal length and 3rd metatarsal length was found to be significant in both feet ($p<0.05$). Although the effects of foot height and calcaneal length parameters were close to statistical significance ($p>0.05$), they were not statistically significant, but these parameters remained in the estimation formula model. In the study group (men and women), the relationship between height and foot height, malleolar width, 3rd metatarsal length and 5th metatarsal length was found to be statistically significant in both feet ($p<0.05$) (Table 4).

According to the results of multiple regression analysis, our formulas for estimating the height of the right and left feet for men, women and the study group are in Table 5.

The correlation coefficients between body weight and right and left foot measurements of men, women, and the study group were evaluated with Pearson Correlation Analysis. The highest correlation between body weight and foot measurements was found with 2nd metatarsal distal end width in men and study group, and 1st metatarsal distal end width in women (Table 6).

Table 4. Regression analysis of right and left foot measurements affecting height

		Unstandardized Coefficients		Standardized Coefficients		
	Model	B	Std. Error	Beta	t	p
Men	(Constant)	104.804	9.446		11.095	0.000*
	RIGHT FL	0.117	0.046	0.281	2.525	0.013*
	RIGHT 5.ML	0.499	0.134	0.415	3.735	0.000*
	(Constant)	104.158	9.502		10.962	0.000*
	LEFT FL	0.114	0.047	0.270	2.425	0.017*
	LEFT 5.ML	0.523	0.136	0.427	3.841	0.000*
Women	(Constant)	119.360	9.898		12.060	0.000*
	RIGHT FL	-0.158	0.061	-0.441	-2.600	0.011*
	RIGHT FH	0.191	0.104	0.181	1.839	0.069
	RIGHT CL	0.233	0.120	0.251	1.951	0.054
	RIGHT 1.ML	0.401	0.171	0.343	2.339	0.022*
	RIGHT 3.ML	0.355	0.126	0.330	2.809	0.006*
	(Constant)	117.105	10.396		11.265	0.000*
	LEFT FL	-0.144	0.061	-0.401	-2.360	0.021*
	LEFT FH	0.198	0.108	0.180	1.832	0.070
	LEFT CL	0.236	0.119	0.253	1.974	0.052
	LEFT 1.ML	0.407	0.176	0.343	2.315	0.023*
	LEFT 3.ML	0.321	0.131	0.287	2.457	0.016*
Study group	(Constant)	80.458	5.567		14.453	0.000*
	RIGHT FH	0.251	0.073	0.218	3.421	0.001*
	RIGHT MW	0.342	0.078	0.285	4.377	0.000*
	RIGHT 3.ML	0.290	0.100	0.201	2.909	0.004*
	RIGHT 5.ML	0.315	0.100	0.231	3.145	0.002*
	(Constant)	79.171	5.669		13.965	0.000*
	LEFT FH	0.262	0.074	0.224	3.528	0.001*
	LEFT MW	0.359	0.078	0.297	4.587	0.000*
	LEFT 3.ML	0.265	0.103	0.179	2.567	0.011*
	LEFT 5.ML	0.328	0.104	0.237	3.156	0.002*

FL: foot length, ML: metatarsal length, FH: foot height, CL: calcaneal length, MW: malleolar width, *p<0.05

Table 5. Height estimation formulas for men, women and study groups

Right/ Left Foot	Men/ Women/ Study Group	Height Estimtion Formulas (cm)
Right	Men	104.804+0.117FL+0.499M5L±9.446
Left	Men	104.158+0.114FL+0.523M5L±9.502
Right	Women	119.360-0.158FL+0.191FH+ 0.233CL+0.401M1L+ 0.355M3L±9.898
Left	Women	117.106-0.144FL+0.198FH+0.236CL+0.407M1L+0.321M3L±10.396
Right	Study Group	80.458+0.251FH+0.342MW+0.290M3L+0.315M5L±5.567
Left	Study Group	79.171+0.262FH+0.359MW+0.265M3L+0.328M5L±5.669

FL: foot length, M5L: 5th metatarsal length, FH: foot height, CL: calcaneus lenght, M1L: 1st metatarsal lenght, M3L: 3rd metatarsal lengt, MW: malleolar width

Table 6. Correlations between weight and operating parameters

		Body Weight (kg)					
		Men		Women		Study group	
		r	p	r	p	r	p
Proximal metatarsal width	Right	0.092	0.391	0.175	0.098	0.268	0.000*
	Left	0.073	0.495	0.190	0.073	0.264	0.000*
Distal metatarsal width	Right	0.159	0.136	0.250	0.017*	0.301	0.000*
	Left	0.158	0.136	0.256	0.015*	0.307	0.000*
1st metatarsal distal end width	Right	0.224	0.034*	0.387	0.000*	0.386	0.000*
	Left	0.217	0.040*	0.392	0.000*	0.385	0.000*
1st metatarsal proximal end width	Right	0.199	0.060	0.240	0.023*	0.334	0.000*
	Left	0.199	0.061	0.228	0.031*	0.331	0.000*
1st metatarsal corpus width	Right	0.187	0.078	0.194	0.067	0.317	0.000*
	Left	0.197	0.062	0.196	0.064	0.323	0.000*
2nd metatarsal distal end width	Right	0.282	0.007*	0.351	0.001*	0.387	0.000*
	Left	0.287	0.006*	0.350	0.001*	0.389	0.000*
2nd metatarsal proximal end width	Right	0.139	0.191	0.194	0.066	0.270	0.000*
	Left	0.152	0.153	0.187	0.077	0.272	0.000*
2nd metatarsal corpus width	Right	0.09	0.400	0.218	0.039*	0.267	0.000*
	Left	0.115	0.280	0.222	0.036*	0.283	0.000*
3rd metatarsal distal end width	Right	0.153	0.149	0.196	0.064	0.255	0.001*
	Left	0.156	0.143	0.206	0.052	0.263	0.000*
3rd metatarsal proximal end width	Right	0.249	0.018*	0.011	0.916	0.255	0.001*
	Left	0.231	0.028*	-0.006	0.958	0.239	0.001*
3rd metatarsal corpus width	Right	0.142	0.180	0.303	0.004*	0.311	0.000*
	Left	0.137	0.197	0.306	0.003*	0.311	0.000*
4th metatarsal distal end width	Right	0.114	0.284	0.274	0.009*	0.285	0.000*
	Left	0.117	0.272	0.291	0.005*	0.293	0.000*
4th metatarsal proximal end width	Right	0.177	0.096	0.117	0.274	0.248	0.001*
	Left	0.15	0.160	0.112	0.291	0.230	0.002*
4th metatarsal corpus width	Right	0.02	0.849	0.104	0.329	0.180	0.015*
	Left	0.039	0.716	0.094	0.378	0.186	0.012*
5th metatarsal distal end width	Right	0.134	0.206	0.371	0.000*	0.313	0.000*
	Left	0.123	0.250	0.391	0.000*	0.320	0.000*
5th metatarsal proximal end width	Right	0.164	0.123	0.355	0.001*	0.296	0.000*
	Left	0.143	0.178	0.351	0.001*	0.283	0.000*
5th metatarsal corpus width	Right	-0.002	0.983	0.245	0.020*	0.222	0.003*
	Left	-0.005	0.961	0.26	0.013*	0.230	0.002*

Pearson Correlation Analysis, *p<0.05, r: correlation coefficient

In terms of body weight, the relationship between the width of the 2nd metatarsal distal end and body weight in both feet was statistically significant ($p<0.05$). The relationship between body weight and 1st metatarsal distal end width, 3-4. metatarsal corpus width and 5th metatarsal proximal end width was statistically significant ($p<0.05$) in both feet and in women. In the study group, the relationship between body weight and 1-2. metatarsal distal end width, 3-4. metatarsal corpus width and 5th metatarsal proximal end width was statistically significant ($p<0.05$) in both feet (Table 7).

Right and left foot measurements were evaluated by Multiple Regression Analysis (Table 8). The relationship between the change in body weight and the size of the right foot was 8% in men, 24.2% in women, and 23.2% in the study group. The relationship with left foot measurements was 8.3% in men, 28% in women and 22.7% in the study group.

According to the results of multiple regression analysis, our body weight estimation formulas that has been created for men, women and the study group in the right and left feet are in Table 9.

Table 7. Regression analysis of right and left foot measurements affecting body weight

		Unstandardized Coefficients		Standardized Coefficients		
	Model	B	Std. Error	Beta	t	p
Men	(Constant)	44.926	11.652		3.856	0.000*
	RIGHT 2.MDEW	2.509	0.908	0.282	2.762	0.007*
	(Constant)	43.346	11.991		3.615	0.000*
	LEFT 2.MDEW	2.643	0.939	0.287	2.816	0.006*
Women	(Constant)	17.010	13.398		2.970	0.048*
	RIGHT 1. MDEW	1.638	0.622	0.306	2.635	0.010*
	RIGHT 3.MCW	3.751	1.897	0.218	1.978	0.048*
	RIGHT 4.MCW	-3.753	1.762	-0.251	-2.130	0.036*
	RIGHT 5.MPEW	1.174	0.570	0.236	2.059	0.043*
	(Constant)	22.283	13.992		2.593	0.015*
	LEFT 1. MDEW	1.833	0.617	0.340	2.972	0.004*
	LEFT 3.MPEW	-1.162	0.613	-0.194	-1.897	0.061
	LEFT 3.MCW	5.050	1.997	0.282	2.528	0.013*
	LEFT 4.MCW	-3.725	1.803	-0.240	-2.066	0.042*
	LEFT 5.MPEW	1.187	0.573	0.232	2.070	0.042*
Study group	(Constant)	17.595	8.776		2.005	0.047*
	RIGHT 1. MDEW	1.087	0.453	0.215	2.402	0.017*
	RIGHT 2.MDEW	1.643	0.667	0.213	2.463	0.015*
	RIGHT 3.MCW	2.386	1.209	0.175	1.974	0.050*
	RIGHT 4.MCW	-2.632	1.204	-0.199	-2.186	0.030*
	RIGHT 5.MPEW	0.816	0.387	0.163	2.109	0.036*
	(Constant)	16.581	9.037		2.835	0.008*
	LEFT 1.MDEW	1.073	0.454	0.210	2.363	0.019*
	LEFT 2.MDEW	1.688	0.682	0.214	2.476	0.014*
	LEFT 3.MCW	2.518	1.301	0.176	1.935	0.055
	LEFT 4.MCW	-2.542	1.277	-0.184	-1.991	0.048*
	LEFT 5.MPEW	0.773	0.394	0.152	1.964	0.050*

MDEW: metatarsal distal end width, MCW: metatarsal corpus width, MPEW: metatarsal proximal end width, *p<0.05

Table 8. R, R2, adjusted R2 and standard error values of estimation as a result of linear regression analysis of right and left foot measurements affecting weight in men, women and the study group

	Gender	R	R^2	Adjusted R Square	SEE
Right	Men	0.282	0.080	0.069	11.523
	Women	0.492	0.242	0.207	8.944
	Study group	0.482	0.232	0.210	10.182
Left	Men	0.287	0.083	0.072	11.505
	Women	0.529	0.280	0.237	8.772
	Study group	0.477	0.227	0.205	10.214

SEE: standard error of the estimate

Table 9. Body weight estimation formulas for men, women and study groups

Right/Left Foot	Men/Women/Study Group	Body Weight Estimation Formulas (kg)
Right	Men	44.926+2.509M2DEW±11.652
Left	Men	43.346+11.991M2DEW±11.991
Right	Women	17.010+1.638M1DEW+3.751M3CW-3.753M4CW+1.174M5PEW±13.398
Left	Women	22.283+1.833M1DEW-1.162M3PEW+5.050M3KG-3.725M4CW+1.187M5PEW±13.992
Right	Study Group	17.595+1.087M1DEW+1.643M2DEW+2,386M3CW-2.632M4CW+0.816M5PEW±8.776
Left	Study Group	16.581+1.073M1DEW+1.688M2DEW+2.518M3CW-2.542M4CW+0.773M5PEW±9.037

M1DEW: 1st metatarsal distal end width, M2DEW: 2nd metatarsal distal end width, M3CW: 3rd metatarsal corpus width, M3PEW: 3rd metatarsal proximal end width, M4CW: 4th metatarsal corpus width, M5PEW: 5th metatarsal proximal end width

DISCUSSION

Determining the height and body weight of an individual in cases where body integrity is impaired is the most important factor in forensic cases (1). The small surface area of the foot bones and their ability to be evaluated due to their resistance to deformations are suitable for metric measurements. Estimation formulas created for one population may not be reliable for other populations, datas obtained in studies are specific to related and similar populations (4). During the comparison of the averages of height, body weight, foot length and foot width measurements in this study between other studies datas, differences were detected between the populations, and the mean measurement values were found to be significantly higher ($p<0.05$) in men than in women, similar to the literature (3,4,12,15).

As a result of multiple regression analysis, the correlation (R) between height and right foot measurements was found to be 0.554 in women and 0.639 in men. Correlation between height and left foot measurements was 0.542 and 0.641, respectively. R2 values showed that 30.7% of the foot measurements affecting height in women were caused by the right foot and 29.4% by the left foot measurements. Although these rates were higher in men, they were 40.8% and 41.1%, respectively. The remaining percentages depend on gender, age, population, hereditary and environmental factors (2). In the study group in which gender discrimination was ignored, the R value was 0.772 for right foot measurements and 0.774 for left foot measurements. R2 values showed 59.6% for right foot measurements and 59.9% for left foot measurements. We found that among the multiple regression equations which has been created for height estimation, the standard estimation error (SEE) rates were the least in the study group. While SEE was 9.44-10.39 cm in the formulas created for the male and female groups for height estimation, it was less than 6 cm in the study group. Apart from being specific to societies, these changes are due to differences in height and foot anatomy depending on nutrition, physical activity level, working conditions, climatic conditions and innate factors (2,18).

In a study investigating the relationship between height and foot length on the Indian population, the correlation coefficient between height and foot length was 0.63-0.92, and the correlation coefficient between height and foot width was between 0.41-0.54 (20). In our study, the correlation coefficients between height and foot length were found to be 0.24-0.69. In a study conducted in Turkey that evaluated the correlation between height and four different foot sizes: foot length, malleolar height, foot width and navicular height, the highest correlation coefficient was found to be foot length. In the results of their multiple regression analysis, they reported that SEE values were 9-10 cm in men and women, and below 4 cm in the study group (2). These values are quite similar to the SEE rates in our study. We also evaluated the correlation coefficients between height and 10 different foot measurements, and we have found that the highest correlation coefficient was with foot length in men and the study group, and with the 3rd metatarsal length in women.

In another study conducted in South Africa, 1-4. metatarsal length measurements, 5th metatarsal functional-physiological length measurements and height measurements were analyzed out of 226 skeletons of South African natives and European-South Africans (19). They reported that the highest correlation with stature was 0.73 in the 1st metatarsal length in South African women of European descent, and the lowest correlation was 0.44 in the 4th metatarsal length in South African native men. As a result of their multivariate equations, they obtained SEE in the range of 3.81–5.07 cm (19). In a study carried out in Turkey, formulas were developed to estimate height and gender from foot and shoe measurements with logistic regression analysis (21). The correlation coefficients between foot length and height are 0.579 to 0.614 for men and 0.490 to 0.500 for women. These values are higher than our correlation coefficients. In the study group of our study in which gender discrimination was excluded, the correlation coefficient between height and foot length was 0.696 and 0.697, which is higher. Their result of the regression formulas they created, the SEE rates were 31,410 cm for the right foot and 31,607 cm for the left foot (21), which are considerably higher than the SEE rates in our study.

When the correlations between body weight and foot measurements were evaluated in our study, the highest correlation was between the 2nd metatarsal distal end width in men and the study group, and 1st metatarsal distal end width in women. As a result of multiple regression analysis, the correlation (R) between body weight and right foot measurements was found to be 0.492 in women and 0.282 in men. Correlations between body weight and right and left foot measurements were 0.529 and 0.287, respectively. R2 values showed that 24.2% of the foot measurements affecting body weight in women were caused by the right foot and 28.0% by the left foot measurements. Although these rates were lower in men, they were 8.0% and 8.3% based on right and left foot measurements, respectively.

In a study evaluating the relationship between foot and footprint measurements and body weight. Researchers found that the measurements showing the highest correlation with body weight were between the surface measurements of the first and fifth metatarsal bone heads and the foot width they measured (R men: 0.555 and R women: 0.545). This is followed by heel width (R men: 0.523 and R women: 0.535). They reported 8,923-9,538 kg SEE rates in the estimation equations they created (13). Similar rates (8,776-9,037 kg SEE) were obtained in this study. In another study conducted in India, the correlation values between body weight and foot length (R men: 0.419-0.364, R women: 0.227-0.121) and the correlation between body weight and foot width (R men: 0.348-0.338, R women: 0.158- 0.138) was reported to be higher (14). In a study conducted in Malaysia there was a statistically significant relationship between body weight and foot width in both genders, and the correlation values (R) between them were reported as 0.094-0.121 in men and 0.103-0.180 in women (17). These correlation values are lower than those in our study. The study groups consisted of students between the ages of 17-20, therefore we think that the results cannot be generalized to large populations. In the study conducted in India, which estimated body weight from footprint measurements, they found correlations between 0.70 and 0.71 between body weight and distal metatarsal width in the right and left feet, respectively, and reported rates of 3.05-4.10 in their estimation equations (16). In another study conducted in UK, body weight estimations were made with the measurements of the 1st metatarsal bone (22). In their study, they reached 4.144 and 4.251 kg SEE values in the body weight estimation formulas they created using the 1st metatarsal dorsoplantar diameter and mediolateral diameter. These SEE rates are lower than the SEE values in our study (8,776-9,037 kg).

CONCLUSION

The accuracy of a regression equation in estimating height depends on the value of the standard estimation error. It is defined as a measure of the expected accuracy of a regression equation in estimating the height of an individual from the same population group from which the equation was originally derived. Regression equations derived from combinations of measures offer higher accuracy than univariate formulas. A high value for SEE means low accuracy and vice versa (5).

When the formulas we have developed are used according to gender, they show a deviation of 9-10 cm for height estimation and 11-14 kg for body weight estimation. When our formulas are evaluated by ignoring the gender difference, they show a deviation of less than 6 cm for height estimation and 8-9 kg for body weight. We believe that our formulas can predict height and body weight from foot measurements in similar populations.

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