Lower Limb And Foot Dimensions And Their Correlations With Body Height In Adult Population Of Aswan Governorate

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Abstract: Background: Estimation of an individual's stature is useful in lowering down the missing person's identity, besides sex, age and racial affiliation. This is essential when the body is found either dismembered, or even disintegrated. **Objective:** To construct a specific regression formula for estimating the stature using lower limb and foot dimensions in the Aswanian Egyptian population. **Subjects and Methods:** This cross sectional study included 1000 (500 males and 500 females) asymptomatic healthy adult students (18-22 years) from Aswan University. The parameters, measured to all subjects were body weight, stature, lower extremity length, leg length, foot length, and foot breadth, using standard measuring instruments. **Results:** The lower limb length, leg length, foot length and foot breadth were observed to have significant positive correlations with body height in both sexes, among the studied samples, as evidenced by Spearman's correlation coefficient. A paired t-test showed no significant difference between actual stature and estimated stature. **Conclusion:** It was found that lower limb and foot parameters can be used as predictors of stature in both sexes, for adult Aswanian Egyptian students. This data is important in human identification and may give a significant indicator from body remnants for unknown individual in a population.
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Introduction

Identification of skeletal remains and mutilated bodies is essential for both legal and humanitarian reasons. Stature or body height (BH) is an inherent characteristic that could be used to identify human, along with age, sex and racial affiliation.[1,2] The stature is a maximum distance from vertex to floor, maintaining the anatomical positionand Frankfort plane.[3] Estimation of stature is a vital parameter in developing a biological profile for identification of individuals in cases of natural and manmade disasters, and in crime investigations.[4] The estimated height narrows down the area of search for an investigator and the missing person's identity[5] and may provide a valuable indicator for an unknown individual in a population.[6] Apart from this, the estimated height is valuable when natural height measurement may be hindered by muscle weakness, joint or spinal deformity.[3] In humans, estimation of BH is also applied to check for normal or abnormal growth, especially in the young individuals.[4] There are two methods for estimation of stature namely, anatomical and mathematical methods.[7] Anatomical methods are used when a complete set of skeletal remains are found. The mathematical method is used in special cases, where a body is found dismembered or more than one set of bodies are found.[2] It is assumed that significant associations exist between the total stature and the individual body parts.[8] Many studies have been done to estimate the stature using different body parts, such as extremities, cephalofacial, vertebral column and arm span measurements in different countries.[9] Percutaneous measurements of upper and lower extremities, hands and feet were utilized in most studies to estimate height, based on either regression analysis or multiplication factor.[5,10] However, **Ahmed, (2013); Moshkdanian et al., (2014); Kamboj et al., (2018)[8,11,12]** emphasized that the lengths of lower limb and foot segments provided the reliability and accuracy in estimating stature with the use of regression equation and to measure sex differences. It is assumed that significant associations exist between the total stature and the individual body parts.[8] Many studies have been done to estimate the stature using different body parts, such as extremities, cephalofacial, vertebral column and arm span measurements in different countries.[9] Percutaneous measurements of upper and lower extremities, hands and feet were utilized in most studies to estimate height, based on either regression analysis or multiplication factor.[5,10]

Subjects and Methods

Study area

The study was carried out at Aswan governorate**,** a city on the Nile River, has been southern Egypt's strategic and commercial gateway since antiquity.

Figure 1: Map of Egypt showing the study area, Aswan governorate, south Egypt.

Sample collection: This cross sectional study included total 1000 (500 males and 500 females) asymptomatic, healthy adults of aswanian origin, residing in Aswan governorate. The subjects were students from Aswan University**,** between 18 to 22years of age. Before started the study, an informed consent was obtained from all participants and followed the procedure in accordance with the ethical standards approved by Research Ethic Committee in the faculty of Medicine of Aswan University. Subjects with any apparent lower limb or foot-related disease, orthopedic deformity, physical impairment, or disorders were excluded from the study.

Measurements and instruments:

The measurements were taken between 2 to 5 p.m. to eliminate the discrepancies due to the reported diurnal variations,[13] during the period from January 2018 until June 2018, on all subjects without head and footwear. The following measurements were performed to all subjects and were taken by the same observer. The measurements were repeated until concordant values were obtained. **Stature:** was measured by anthropometer joining the weighting machine. Each subject was asked to stand barefoot on the flat surface of the machine, according to the anatomical position and Frankfurt Plane, with eyes looking forward. Stature was measured in centimeter, as upright height from the vertex to the sole of the foot.[5] **Lower extremity Length:** a measuring tape (in centimeter) was typically used to measure the length of each lower extremity, by measuring the distance between the iliac crest and the floor. The cases were in a standing position, close to the wall without any rotation.[11]

Leg Length: a measuring tape (in centimeter) was typically used to measure the length of each leg, in a standing position, by measuring the distance between the lateral knee and the floor.[11] **Foot length:** using pelvimeter (in inches), foot length was measured on both sides, as the distance from the most posterior point of the heel to the most anterior point of the longest toe.[14] **Foot breadth:** using pelvimeter (in inches), foot breadth was measured as the distance between the medial-most of the first and lateral-most of the fifth metatarsal bone heads, for both sides.[14]

Statistical analysis: Data were analyzed with SPSS version 21. The normality of data was first tested with one-sample Kolmogorov-Smirnov test. Continuous variables were presented as mean ± SD (standard deviation) for parametric data. The variables in male and female groups were compared with Student t test while Pearson correlation was performed to correlate between continuous data (lower limb and foot dimensions) and body height. Significant variables on correlation for the males and females entered into linear regression model using the stepwise statistical technique to predict the most significant determinants and to control for possible interactions and confounding effects. Finally the estimated values of BH were compared with that of observed/actual values, using a paired t-test.

Level of significance: for all above mentioned statistical tests done, the threshold of significance is fixed at 5% level (p-value). Significant results when ($p \leq 0.05$) and highly significant when ($p \leq 0.001$).

Results

Descriptive statistics of stature measurements in males, females and the pooled overall sample are shown in Table 1. The mean stature in overall sample is 163.92 cm, in males is 169.97 cm and in female is 158.15 cm. The result showed that mean stature is found to be significantly higher in males than females (Table 1 & Fig.1). The descriptive statistics for the measurements of various lower limb parameters (lower limb length, leg length, foot length and foot breadth) in both left and right sides of males, females and the pooled sample are also shown in (Table 1 & Fig.1). The mean values of all lower limb and foot measurements are found to be significantly greater in males than in females, both in left and right extremities ($P < 0.001$) (Table 1 & Fig.1). The result reveals the nonexistence of significant bilateral asymmetry in both the genders (Table 1 & Fig.2).

Table (1): Shows descriptive statistics for height and lower limb and foot dimensions on both sides, in males, females and pooled overall sample.

Variables	Overall (n=1000)	Male (n=500)	Female (n=500)	p-value
Height (cm) Mean ± SD	163.92 ± 10.62	169.97±7.64	158.15±7.30	<0.001**
RT Lower limb length (cm) Mean ± SD	95.95± 6.561	99.89±4.49	92.00±5.89	<0.001**
LT Lower limb length (cm) Mean ± SD	95.95± 6.565	99.90±4.49	91.99±5.89	<0.001**
RT leg length (cm) Mean ± SD	50.32± 4.362	51.30±4.39	49.34±4.10	<0.001**
LT leg length (cm) Mean ± SD	50.39± 3.666	51.41±3.78	49.36±3.24	<0.001**
RT Foot length (cm) Mean ± SD	23.11 ± 1.879	24.16±1.45	22.02±1.65	<0.001**
LT Foot length (cm) Mean ± SD	23.11 ± 1.879	24.16±1.42	22.02±1.65	<0.001**
RT Foot breadth (cm) Mean ± SD	8.71 ± 1.259	9.49±1.19	7.89 ± 0.66	<0.001**
LT Foot breadth (cm) Mean ± SD	8.737 ± 1.24	9.55±1.16	7.92 ± 0.66	<0.001**

P value is between male and female ** p > 0.001

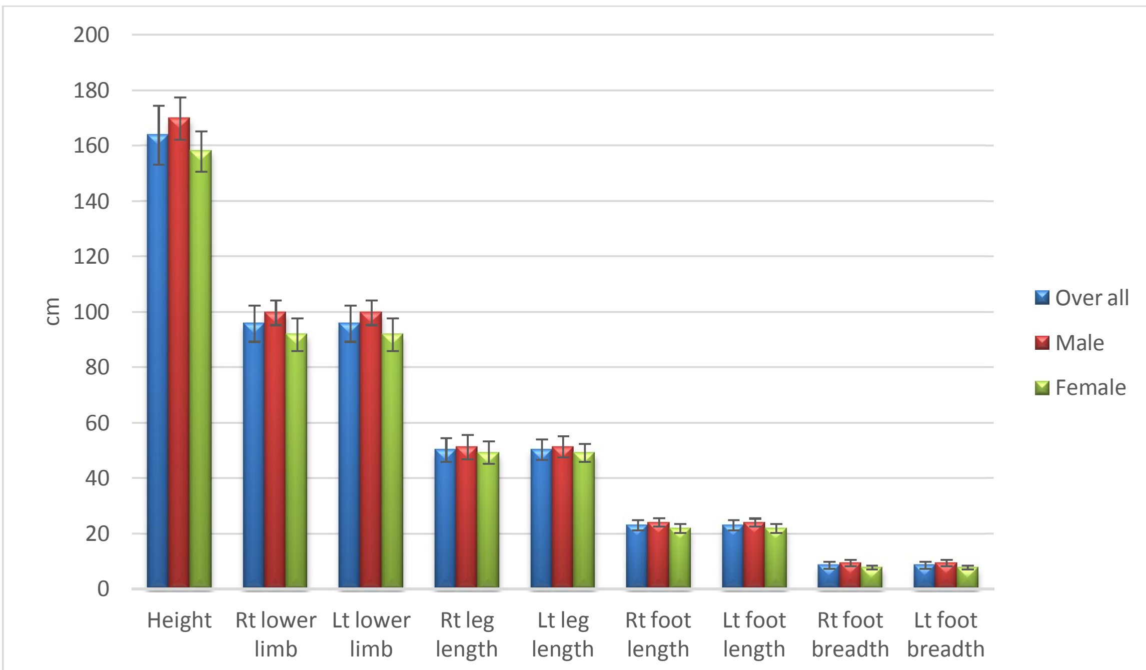

Fig.2: The mean values of height and lower limb and foot parameters in studied subjects of Aswan University.

The correlation analysis between body stature and the lower extremity parameters (lower limb length, leg length and foot length and breadth) on right and left sides have been performed for each sex (males & females) and presented in Table 2. The result shows statistically positive significant correlations (r) between body stature and all the lower limb and foot measurements in both sexes of the sample (* p > 0.05 & ** p > 0.001).

The lower limb length on both sides exhibits the maximum correlation in males (r= 0.681- 0.682) and females (r= 0.293) followed by leg length (r=0.497-0.500 in males and 0.210-0.222 in females), foot length (r=0.473- 0.490 in males and 0.137- 0.143 in females) (Table2). However, foot breadth showed the least correlation (r= 0.270- 0.228 in males and 0.112-0.123 in females) (Table2). The correlation coefficient values (r) of all measurements are found to be more in the males when compared with females **(Table 2).**

The foot length and breadth were found to be more significantly correlated with body height in males (p > 0.001) than in female (p > 0.05) on both sides **(Table 2).**

In addition, the relationship between the individual stature and lower limb length for overall sample was plotted and shown in Scatter graphs **(Figure 2).**

Table (2): shows the Pearson's correlation (r) between stature and Lower Limb and foot dimensions in male and female subjects.

Variable	Height (cm)	
	Male N= 500	Female N=500
	r	r
RT Lower limb (cm)	0.681**	0.293**
LT Lower limb (cm)	0.682**	0.293**
RT leg length (cm)	0.497**	0.210**
LT leg length (cm)	0.500**	0.222**
RT Foot length (cm)	0.473**	0.137*
LT Foot length (cm)	0.490**	0.143*
RT Foot breadth (cm)	0.270**	0.123*
LT Foot breadth (cm)	0.288**	0.112*

*** p > 0.05 & ** p > 0.001**

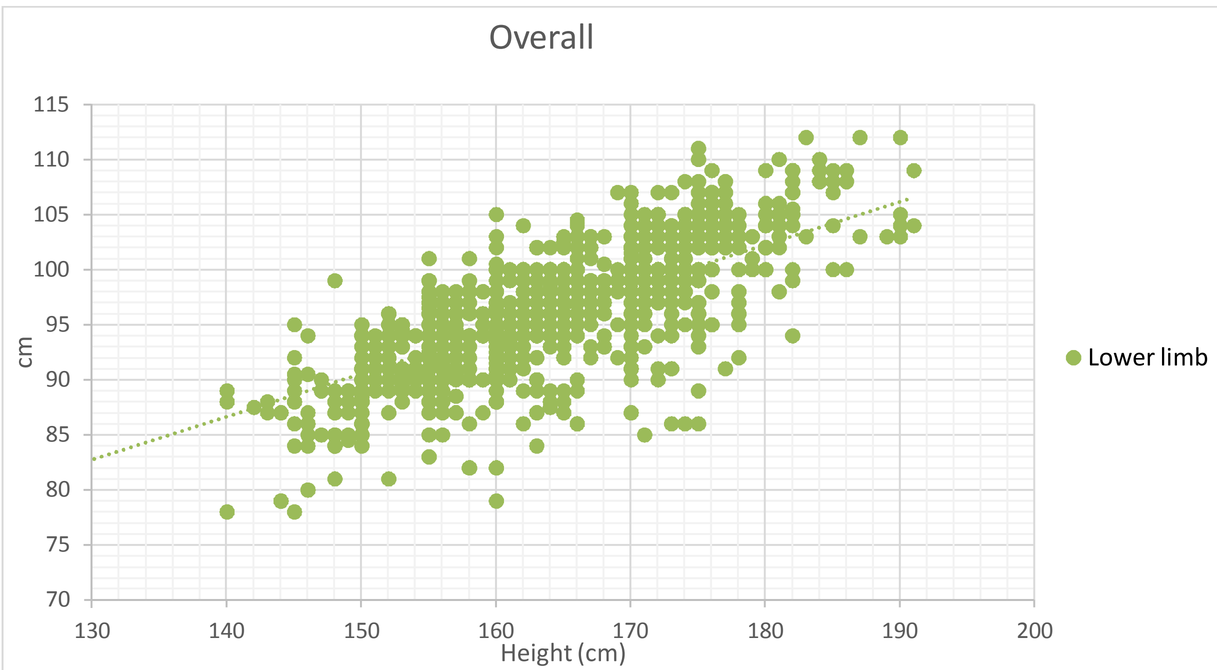

Figure (2) illustrate the scatter plots of Height vs. lower limb length for overall sample.

Linear regression analysis was determined for estimation of stature in males, females and combined sex overall sample (Table 3). Stature was estimated by using a regression formula; Y= C+ (B*X), where, Y (stature) = C (constant) + B (regression coefficient of an independent parameter) X.

Standard Error of Estimate (S.E.E) was estimated in this study (Table 3) for determination of the predictive accuracy of linear regression models for stature estimation from lower limb and foot dimensions. The result from this study emphasized that lower limb length appears to be the better predictor of stature, with P-value (<0.001) and least (S.E.E) in males, females and combined sex, followed by leg length, foot length and then foot breadth (table 3).

The best fitting regression line formula, in this study is derived from the lower limb length and the regression equation was calculated from (table 3), according to the formula (**y = c + b*x**), where;

y = estimated dependent variable score (**Body Height).**

c = constant
b = regression coefficient.
x = score on the independent variable

For Males: **Y = 54.30+ 1.158 x (Lower limb length),** that it showed the least standard error of estimate (**SEE=0.056**) (table 3) and high correlation coefficient (**r= 681-682**) (table 2).

For Females: **Y =113.68+ 0.480 x (Lower limb length),** with **(SEE= 0.07)** (table 3) and (**r= 0.293**) (table 2). The study exhibited that male parameters are more predictor of height in comparison to females with least S.E.E.

Table (3): Linear regression analysis for independent predictors of body height from Lower limb and Foot parameters.

	Overall sample				Males			Females			
parameter	B	Std. (S.E.E) Error	P-value	C Constant	B	P- value	C Constant	B	Std. (S.E.E) Error	P-value	C Constant
Rt Lower limb length	1.021	0.04	<0.001*	65.99	1.158	< 0.001*	54.30	0.480	0.07	< 0.001*	113.68
Lt Lower limb length	1.021	0.04	<0.001*	65.95	1.159	< 0.001*	54.20	0.481	0.07	< 0.001*	113.63
Rt leg length	1.155	0.08	<0.001*	105.70	1.007	< 0.001*	118.23	0.566	0.118	< 0.001*	129.88
Lt leg length	1.259	0.083	<0.001*	100.50	1.010	< 0.001*	118.02	0.664	0.131	< 0.001*	125.098
Rt foot length	2.790	0.165	<0.001*	100.03	2.411	< 0.001*	112.71	0.805	0.260	< 0.002*	140.12
Lt foot length	2.911	0.154	<0.001*	96.66	2.60	< 0.001*	107.13	0.837	0.260	< 0.001*	139.41
Rt foot breadth	4.102	0.233	<0.001*	128.16	1.720	< 0.001*	153.90	1.798	0.647	< 0.006*	143.63
Lt foot breadth	4.167	0.231	<0.001*	127.47	1.875	< 0.001*	152.03	1.599	0.638	< 0.01*	145.19

Table 4 showed that there was no significant difference (NS) between actual height and estimated height based on lower limb and foot measurements by paired t-test in this study. Thus, the equations formulated could be used to estimate stature.

Table (4): Shows descriptive statistics of mean values of actual and estimated height in the studied sample.

Variables	Overall (n=1000)	Male (n=500)	Female (n=500)	p-value
Actual height (cm) Mean ± SD	163.92 ± 10.62	169.97±7.64	158.15±7.30	<0.001**
Estimated height (cm) Mean ± SD	163.79± 6.69	167.82±4.58	159.76±6.01	<0.001**
P-value	0.62 NS	0.06 NS	0.08 NS	------

NS =non significance

Discussion

Stature with age, race and sex, these four parameters, are considered to construct the anthropometrical data that can approve the process of individual identification.[15,16] Identification appears to be a critical consideration in the forensic medicine, in cases of suicide, bomb blast, war, accident, earthquakes and crimes.[2,17,18,19] Dimensional relationship between whole body and body segments has been the scope of anatomists, scientists and anthropologists for many years. Furthermore, the correlation between body segments has been used to compare and variations between different ethnic groups and to relate them to life style and energy expenditure.[20,21] It is presumed that significant correlations occur between the total stature and different body parts[8,22] In this study, stature was assessed by using several parameters of lower limbs and foot to produce population-specific formula for the adult Aswanian students in south Egypt.

It is practical to use this mathematical method for stature estimation.[11] From independent t-test, in this study, stature and all the lower limb and foot measurements were significantly (p > 0.001) greater in males than in females. This result is in agreement with studies of **Ahmed (2013); Nor et al., (2013); Narde and Dongre (2013); Jervas et al., (2016); Abu Bakar et al., (2017).**[2,4,5,6,8] observed that males have greater mean value of stature as compared to females. In addition, **Ahmed (2013)**[8] showed that all variables of the lower limb (tibial length, foot length, and foot breadth) were significantly larger in males than in females and a significant positive correlation (p<0.001) was detected within the lower limb parts in Sudanese adults.

By Pearson's correlation of this study, parameters such as lower limb length, leg length, foot length and foot breadth were significantly correlated with stature in that sequence, both in males and females. This result was in agreement with results of **(Bavna & Nath, 2007; Nor et al., 2013; Abu Bakar et al., 2017)**[1,2,5] in Malaysian populations). The present study showed that lower limb length exhibited the maximum correlation (R= 0.682 in male & 0.293 in female), followed by Leg length (r=0.500 in male & 0.222 in female) with height. This is in accordance with that in **(Nor et al., 2013 & Abu Bakar et al., 2017)**[2,5] who stated that leg length; thigh length and foot length were strongly correlated with stature in that sequence.

The foot length (FL) and foot breadth (FB) parameters, in this study, had revealed significant correlations with stature, in agreement with **Sanli et al., (2005); Krishnan and Sharma (2007) & Nor et al., (2013).**[5,23,24] These parameters exhibited more significant correlation with stature in males (p > 0.001) than in females (p > 0.05), in the present study and the study of **Nor et al., (2013).**[5] We compare the correlation (r) between stature and foot measurements from previous studies and the present study in Table 5 as follow.

	Krishnan and Sharma (2007)		**Nor et al., (2013)**		**present study**	
Parameter	Male	Female	Male	Female	Male	Female
	Pearson correlation (r)					
FB	0.324	0.323	0.287	0.230	0.288	0.123
FL	0.741	0.734	0.598	0.394	0.490	0.143

The table showed the correlations of foot length and foot breadth with stature in the present study and as in **(Krishnan and Sharma, 2007 & Nor et al., 2013).**[5,24] Foot breadth and foot length correlation (r) values of this study were comparable in males with that in the previous studies (table 5). Female values were less comparable with the previous studies and showed lower correlation values (table 5). Nevertheless, foot length in males showed a good correlation (r= 0.490) in this study, although lower than in the previous studies (table 5). However, **Narde & Dongre (2013)**[6] demonstrated high correlation (r) values for foot length and breadth with stature in males (‘r’=0.970) and females (‘r’=0.986).

The prediction function was derived through linear regression for each of the measurement with body height for the overall people and for the males and females separately (table 3). Comparatively, the lower limb length appears to be the best predictor of stature in the current study and had provided maximum accuracy for stature estimation and the equation formed from it was observed to show the least standard error of estimate (SEE) for all groups (table 3) with good correlation value (r) with stature (table 2). This is followed by equations formed from leg length, foot length and foot breadth in that sequence. However, the food breadth in this study exhibited higher (SEE) and lower correlation (r) value with stature, especially in females (tables 2 & 3). **Krishan et al., (2010) & Moshkdanian et al., (2014)**[11,25] demonstrated higher accuracy and correlation of the total lower limb length with stature and their results emphasized that lower limb length can be a more logical predictor of stature for males in comparison with foot length. Comparatively, **Nor et al., (2013) & Abu Bakar et al., (2017)**[2,5] showed that leg length and foot length had good correlations with stature with least standard error of estimates. It was observed that the formula which gave the best fitting regression line was derived from the leg length that showed the least standard error of estimate (SEE= 4.20).[1,2] In accordance to the present result, **Bavna and Nath (2007 & 2008)**[1] observed that tibial length, among male Shia Muslims of Delhi provides the best estimate of stature and exhibits the overall maximum value of correlation with stature and least value of standard error of estimate (SEE). **Nor et al., (2013) & Abu Bakar et al., (2017)**[2,5] presumed that foot breadth which exhibits the maximum error of estimate and lowest value of (r), should be used only in the absence of the other measurements of the lower limb.

The regressions were cross-validated on the study sample, which showed no significant difference between actual stature and estimated stature values (table 4), based on lower limb measurements by paired t-test. Thus, the equations formulated could be used to estimate stature. This was in agreement with the findings in the literature.[5,24]

Conclusions:

The present study showed that the lower limb and foot measurements can be used for stature estimation in the adults of south Egypt, (Aswan government). The lower limb length, leg length, foot length and then foot breadth in that sequence are correlated with stature. Of the regressions, the equation based on total lower limb length gave the most accurate result with the least standard error of estimates. The equations formed in this study would be able to help identify human remains. It would be good to extend the study to include other parts of the skeletons and other areas in Egypt, for data compilation purposes in future. The study may extend to develop regression formulae and equations concerning relationships within the body parts to be applicable in forensics and reconstructive surgery.

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