THE POTENTIAL ROLE OF SOME LOWER LIMB PARAMETERS IN STATURE ESTIMATION

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ABSTRACT

Background: establishing a person's identity is known as personal identification. In human–induced and natural disasters, personal identification becomes necessary. Forensic anthropology is a subfield of physical anthropology that collaborates with other academic fields to better understand crime and its investigation. Anthropometry may be used to identify an individual's biological profile, including age, sex, ethnicity, and stature. **Objectives:** the aim of the present study was to analyze percutaneous and radiographic measurements of some different bones of the lower limb (tibia and foot) and their relationship to stature via the use of statistical analysis in an Egyptian sample, in Menoufia governorate. **Methods:** the study was conducted on an Egyptian sample, in Menoufia governorate. Each parameter (tibial length, foot length and foot width) was measured by two methods, percutaneously and radiologically. **Results:** this study was conducted on 387 Egyptian participants. The age of the participants included in this study ranged from 21 to 40 years old. There were significant positive correlations between stature and percutaneous and radiological measures of the left lower limb in the studied participants. A single linear regression formula obtained from percutaneous and radiological tibial length showed the least standard error of estimate. The accuracy of multiple regression equations obtained from percutaneous and radiological measures of left lower limb parameters was 62% and 58% respectively. **Conclusion:** tibial length was the most significant parameter predicting stature (with the least standard error of estimate (see) and the highest value of the pearson correlation coefficient. A single parameter could significantly be used for stature estimation. For stature prediction, using multiple regression equations is more accurate than simple regression equations.
Key words: foot length, foot width, stature, tibial length.

INTRODUCTION

Identification is the most important issue in forensic practice. The forensic anthropologist had difficulties while examining the skeletal remains. Stature determination from a variety of skeletal remains and body parts is one of the goals of the medicolegal investigation. Stature may be accurately estimated by using a variety of skeletal remains and body components, since they show a positive and linear association with stature **(Krishan et al., 2012)**.

In forensic investigations, stature estimation is mostly done using two methods: mathematical and anatomical. The direct reconstruction of stature using the anatomical technique entails measurement and summation of the lengths of many adjacent skeletal parts extending from the cranium to the foot.

When estimating the stature of victims of natural catastrophes, where bodies are occasionally unidentified, and this technique has shown to be more accurate. Regression equations based on the relationship between the measured stature and specific skeletal parts are used in the mathematical procedure. Since long bones are the components, most strongly connected with overall stature, long bone regression equations yield the most accurate predictions **(Dayal et al., 2008)**.

The current study aimed to analyse percutaneous and radiographic measurements of some lower limb parameters (tibia and foot bones) and their relationship to stature via the use of statistical analysis in an Egyptian sample, in Menoufia governorate.

MATERIAL AND METHODS

The present work was a cross-sectional study on a cluster random sample of attendants of out-patient's clinics at Menoufia university hospitals, where among 27 out-patient's clinics, internal medicine and dermatology clinics were chosen randomly to recruit the sample population. The age of the patients included in this study ranged from 21 to 40 years old. The lower limit was 21 years (the age of skeletal maturity), and the upper limit was 40 years, after which the stature starts to decline. The time of measurements was fixed at daytime light (from 10 am – 2 pm) to avoid any diurnal variation **(Kamal and Yadav, 2016)**. All the parameters were measured independently on the left side of each participant in a well-illuminated place by the same examiner to avoid interpersonal error **(Krishan et al., 2010)**.

The number of studied participants was 387 (180 males and 207 females) after excluding the non-responders (the response rate was 90%). They were selected from the two chosen clinics from the 1st of January 2021 to 31st of December 2022.

Inclusion criteria include healthy Egyptian individuals free from any apparent skeletal deformity.

Exclusion criteria include any apparent limb or vertebral column deformities, history of pathological, traumatic fractures or amputation of the lower limb and non-responders.

Ethical considerations:

Approval for this study was obtained by the Ethical Committee of the Faculty of Medicine, Menoufia University with number (19519FORE20). Written informed consent was obtained from each participant after explanation of the method of examination and the purpose of the study.

Measurements:

Stature was measured with a stadiometer while the subject was standing uprightly, barefooted, with straight back, hands by the side and registered to the nearest 0.1 centimetre. It was estimated as the distance from the highest point on the head (vertex) to the heel. The head of each subject was maintained in the Frankfort horizontal plane (eye ear plane) by supporting his/her chin **(Salama, 2013)**.

All percutaneous parameters were measured by anthropometric measuring tape:

Tibia percutaneous length is the distance between the tibiale; the highest point on the medial border of the medial condyle of the tibia to the spherion; the most prominent point on the medial malleolus. The participant sat facing the examiner with the left ankle relaxing on the right knee, so that the tibial medial side was exposed upwards and is easier to access **(Elhosary et al., 2018)**.

Foot length: is the distance from the most prominent part of the heel to the most distal point of the longest toe, either the second or the first **(Salama, 2013)**.

Foot width: was measured as the distance between the point of the anterior epiphyses of the first metatarsal and the joint of the anterior epiphyses of the fifth metatarsal (between the two most prominent points of the medial and lateral sides of the foot, respectively) **(Ghaleb et al., 2019)**.

All included subjects were examined by a conventional X-ray machine (Schimadzu, Japan) for standard left leg in antero-posterior views as well as the left foot in dorsi-plantar and lateral views. The studied parameters were measured on the X-ray machine:

Tibial length was measured from the highest point on the medial border of the medial condyle to the distal point of the medial malleolus **(Açıkgöz et al., 2021)**.

Foot length was the bony distance from the most posterior point of the calcaneus to the distal point of the most distal phalanx **(Gwani et al., 2017)**.

The foot width was measured as the distance between the most prominent point on the head of the first metatarsal bone to the most prominent point on the head of the 5th metatarsal bone **(fig. 1,2) (Shelton et al., 2019)**.

Sample size was calculated using the following formula:

$$n \geq \frac{NZ^2_{1-\alpha/2}p(1-p)}{d^2(N-1)+Z^2_{1-\alpha/2}p(1-p)}$$

Here:
n: Sample size
Z1-α /2 = standard normal variation at 5% type 1 error (P<0.05) = 1.96
p = Expected proportion of abnormality = 0.5
d = Absolute error or precision= 0.05

The total sample is 383 persons, to be rounded to 390 persons. Three participants were missed with a response rate of 99.23%.

Statistics analysis:

Analysis of the collected data was done using SPSS version 22. Descriptive statistics used were percentage (%), mean (X), standard deviation (SD) and range. Analytic statistics included student's t-test, Pearson's correlation coefficient, linear regression and multiple analysis and equations. For interpretation of the significance of the results, significance was considered at P< 0.05 and high significance was considered at P values < 0.001.

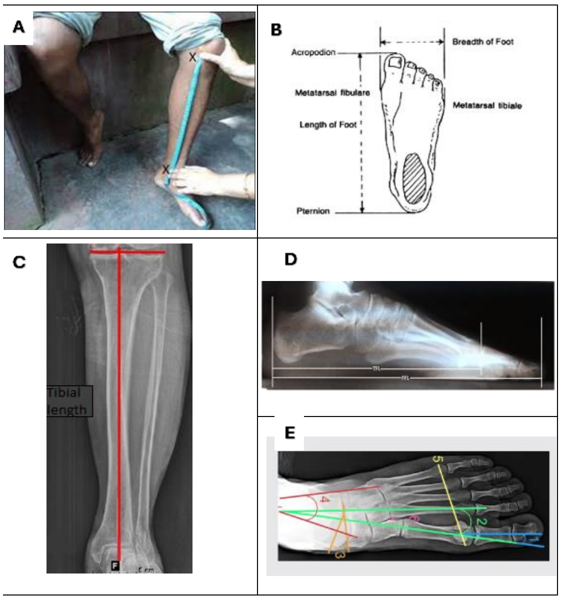


Figure (1): Methods of measurements: percutaneous measurements; (A): tibial length (Moitra, 2019), (B) foot length and width (Kamal and Yadav, 2016), radiological measurements; (C): the red line (tibial length) (Oh et al., 2020), (D): FFL (full foot length) (Gwani et al., 2017), (E): 5 = the yellow line (foot width) (Shelton et al., 2019).

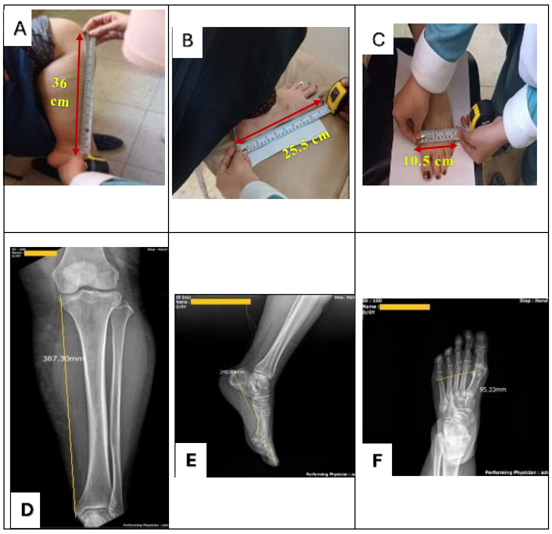


Figure (2): Percutaneous measured parameters on the left lower limb of a female volunteer, 38 years old, (A): tibial length, (B): foot length, (C): foot width, radiological measured parameters (D): tibial length, (E): foot length, (F): foot width

RESULTS

The total number of studied participants was 387 (180 males and 207 females). The mean stature of the included participants was 166.24±9.15 cm. In the male sample, the mean stature was 173.87±5.88 cm, while in females it was 159.60±5.63 cm. The stature of males was significantly higher than in females. The current research revealed significantly higher mean values for all percutaneous and radiological measures in males than in females where the P value was <0.001 **(Table 1)**.

Table (1): Stature, percutaneous and radiological measures of different parameters of the studied participants (N=387)

Measures (cm)	All participants (N=387)		Male (N=180)		Female (N=207)		t-test	p-value
	Mean	SD	Mean	SD	Mean	SD		
Stature	166.24	9.15	173.87	5.88	159.60	5.63	24.36	**<0.001*** **
Percutaneous measures								
Tibia length	38.31	2.73	39.83	2.28	36.99	2.37	11.96	**<0.001*** **
Foot length	25.63	1.90	26.78	1.51	24.63	1.61	13.45	**<0.001*** **
Foot width	11.15	1.52	11.41	1.59	10.92	1.43	3.22	**0.001** **
Radiological measures								
Tibia length	41.40	2.93	43.28	2.22	39.77	2.47	14.61	**<0.001*** **
Foot length	24.19	1.83	25.12	1.62	23.39	1.61	10.49	**<0.001*** **
Foot width	9.31	0.90	9.62	0.83	9.04	0.87	6.60	**<0.001*** **

Cm: centimeter; SD: standard deviation; **P-value <0.05 significant, ***P-value < 0.001 high significance.

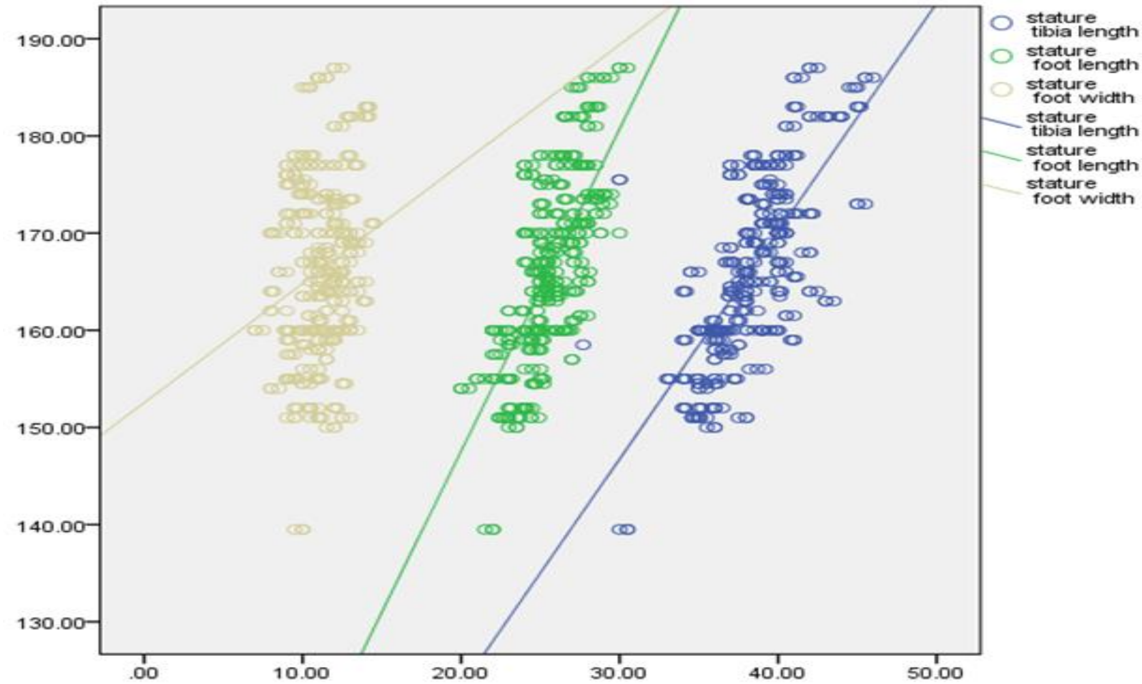
Regarding the Pearson correlation, the results showed that there was a strong positive, statistically significant correlation between stature, tibial length, and foot length, either measured percutaneously or radiologically. Radiological foot width showed a moderate positive correlation, while when measured percutaneously, it showed weekly positive correlation **(Table 2), (Graph 1, 2)**.

Table (2): Pearson Correlation between stature with percutaneous and radiological measures of different parameters in the studied participants (N=387)

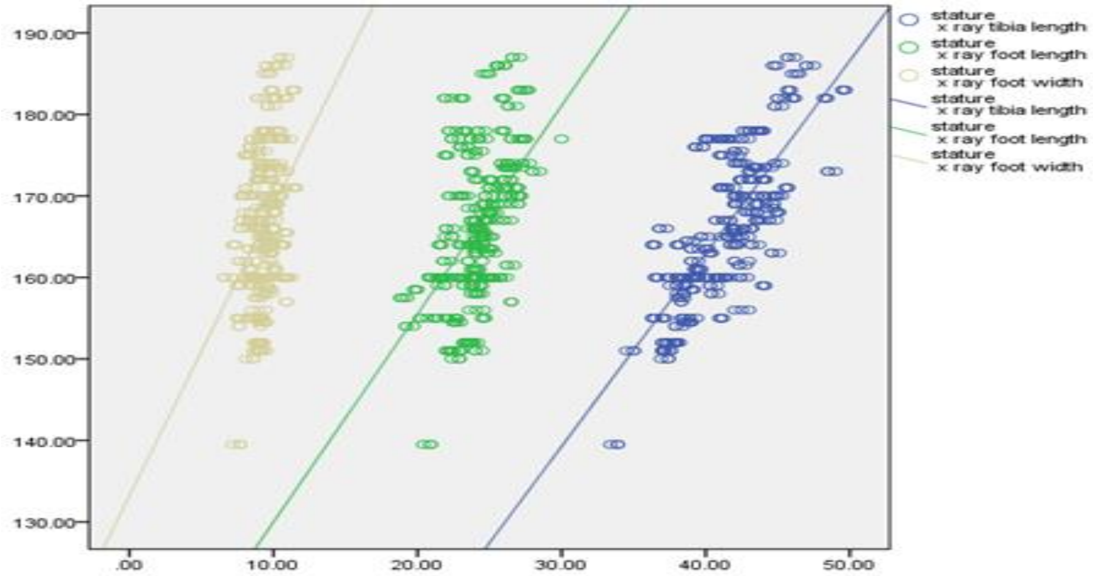
Measures	All participants (N=387)		Male (N=180)		Female (N=207)	
	r	p-value	r	p-value	r	p-value
Percutaneous measures						
Tibial length	0.70	**<0.001*****	0.50	**<0.001*****	0.59	**<0.001*****
Foot length	0.69	**<0.001*****	0.39	**<0.001*****	0.55	**<0.001*****
Foot width	0.20	**<0.001*****	0.03	0.667	0.21	**0.001****
Radiological measures						
Tibial length	0.76	**<0.001*****	0.45	**<0.001*****	0.69	**<0.001*****
Foot length	0.51	**<0.001*****	0.10	0.184	0.41	**<0.001*****
Foot width	0.35	**<0.001*****	0.18	**0.015****	0.16	**0.023****

r: Pearson correlation. 0.10 - 0.29 “weak”; 0.30 - 0.49 “moderate”; ≥ 0.50 “strong”

**P-value <0.05 significant, ***P-value < 0.001 high significance.



Graph (1): Scatter plot for positive correlation between stature with percutaneous measures of the lower limb in the studied participants.



Graph (2): Scatter plot for positive correlation between stature with radiological measures of the lower limb in the studied participants**.**

Regarding simple linear regression analysis, all percutaneous and radiological measures significantly predicted the stature. A simple linear regression equation using tibial length showed the least standard error of estimate (SEE) for all studied participants (SEE= 0.122 and 0.104 in percutaneous and radiological methods respectively),

male sample (SEE= 0.167 and 0.177 in percutaneous and radiological methods respectively), and female sample (SEE= 0.115 in both percutaneous and radiological methods) **(Table 3)**

Table (3): Simple linear regression analysis and regression equations for stature estimation from percutaneous and radiological measures of different parameters in the studied participants (N=387)

Measures	All participants (N=387)			Male (N=180)		Female (N=207)	
	p-value	**Regression equation**	**SEE**	**Regression equation**	**SEE**	**Regression equation**	**SEE**
Percutaneous measures							
Tibial length (TL)	**<0.001*****	**S=76.406+2.345xTL**	0.122	**S=122.499+1.290xTL**	0.167	**S=107.832+1.400xTL**	0.115
Foot length (FL)	**<0.001*****	**S=81.235+3.316xFL**	0.204	**S=132.890+1.530xFL**	0.268	**S=112.306+1.920xFL**	0.204
Foot width (FW)	**<0.001*****	**S=152.537+1.229xFW**	0.300	**S=172.500+0.120xFW**	0.278	**S=150.084+0.872xFW**	0.269
Radiological measures							
Tibial length (TL)	**<0.001*****	**S=68.267+2.366xTL**	0.104	**S=122.219+1.193xTL**	0.177	**S=96.632+1.583xTL**	0.115
Foot length (FL)	**<0.001*****	**S=104.429+2.555xFL**	0.219	**S=164.808+0.361xFL**	0.271	**S=126.402+1.419xFL**	0.223
Foot width (FW)	**<0.001*****	**S=133.175+3.551xFW**	0.487	**S=161.585+1.277xFW**	0.521	**S=150.355+1.022xFW**	0.447

SEE: standard error of estimate; S: stature; regression equation: Y=a+ bx, Y is the dependent variable (stature); X is the explanatory independent variable (measured variables); b is the slope of the regression line; a is the intercept (the value of y when x=0). **P-value <0.05 significant, ***P-value < 0.001 high significance.

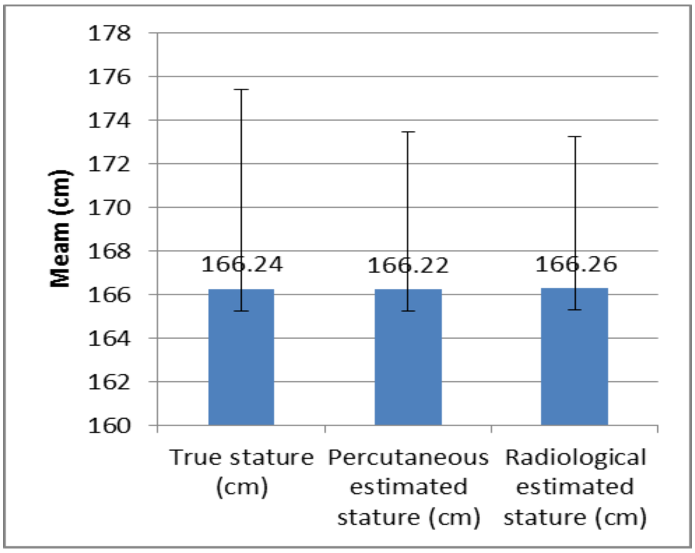
The multiple regression equation for stature estimation from percutaneous measures of the left lower limb parameters in the included volunteers was calculated as (S=55.940+1.572xTL+2.222xFL-0.619xFW). The accuracy of this model (R^2) was 62%. While (S= 63.879+2.203xTL+0.289xFL+0.449xFW) was the regression equation for stature prediction from radiological measures of the left lower limb parameters in the studied participants with an accuracy of 58% **(Table 4)**.

Table (4): Multiple linear regression analysis and regression equations for stature estimation from percutaneous and radiological measures of the left lower limb parameters in the studied participants (N =387)

Measures	R^2	constant	B	SEE	t	p-value
Percutaneous measures						
Tibial length (TL)	0.623	55.940	1.572	0.128	12.251	**<0.001*****
Foot length (FL)			2.222	0.190	11.691	**<0.001*****
Foot width (FW)			-0.619	0.204	3.029	**0.003****
Regression equation						
S=55.940+1.572xTL+2.222xFL-0.619xFW						
Radiological measures						
Tibial length (TL)	0.580	63.879	2.203	0.132	16.732	**<0.001*****
Foot length (FL)			0.289	0.223	1.296	**<0.001*****
Foot width (FW)			0.449	0.391	1.150	0.251
Regression equation						
S=63.879+2.203xTL+0.289xFL+0.449xFW						

R^2: R square; B: regression coefficient; SEE: standard error of estimate; regression equation: $Y=a+b_1x_1+b_2x_2+\ldots+b_nx_n$, Y is the dependent variable (stature); X is the explanatory independent variable (measured variables); b is the slope of the regression line; a is the intercept (the value of y when x=0). **P-value <0.05 significant, ***P-value < 0.001 high significance.

There was no significant difference between measured stature and stature estimated by multiple linear regression equations for percutaneous or radiological measures of the left lower limb parameters in the studied participants (p>0.05). Percutaneous or radiological estimation didn't differ significantly for the prediction of measured stature in the studied participants. The mean measured stature was 166.24±9.15 cm, while the percutaneous estimated stature was 166.22±7.22 cm and the radiological estimated stature was 166.26±6.97 cm **(Graph 3**



Graph (3): Mean ± SD of measured stature and stature estimated by multiple linear regression equations for percutaneous and radiological measures for the lower limb bones in the studied participants.

Regarding the mean value of percutaneous tibial length in relation to the measured stature in the overall sample, it represented 23.05% ± 1.17, the minimum percent was 17.09% and the maximum was 26.69%.

The mean percentage of tibial length of males was 22.91% ± 1.13 with a range from 17.09% to 26.30%. Tibial length represented about 23.17% ± 1.20 of the measured stature in females, and this value ranged from 17.48% to 26.69% **(Table 5)**.

Table (5): Percutaneous tibial length percent in relation to stature in all studied participants (N=387), males (N=180), and females (N=207)

	Minimum	Maximum	Mean	SD
All participants (N=387)				
Tibia length percent	17.09%	26.69%	23.05%	1.17
Males (N=180)				
Tibia length percent	17.09%	26.30%	22.91%	1.13
Females (N=207)				
Tibia length percent	17.48%	26.69%	23.17%	1.20

SD: standard deviation.

DISCUSSION

The importance of stature assessment in human identification has piqued the interest of forensic experts **(Moorthy et al., 2014)**. Stature estimation is an essential indicator of life expectancy, nutritional quality, and overall health. Also, stature is used to diagnose genetic illnesses **(Joerg and Blum, 2012)**.

Based on the concept that there is a known correlation between height and different bodily sections, such as the head, trunk, upper and lower extremities, estimation, or prediction of stature may be done using human skeletal remains **(Gheat et al., 2020)**.

The mean stature of the included participants was 166.24±9.15 cm. In males, the mean stature was 173.87±5.88 cm, while in females it was 159.60±5.63 cm. Nearer values were demonstrated by various Egyptian studies as **Moustafa (2017**), who found that the mean stature of males and females was 175.2 ± 6.2 cm and 161.2 ± 5.8 cm respectively. **Foad et al. (2018)** found that the mean stature of their studied participants was 169.35 ± 0.55 cm. **Gheat et al. (2020)** demonstrated that the mean stature of the studied sample in their study was 168.2 ± 9.1 cm. While higher values were recorded in Turkey with a mean stature of 175.51± 9.43 cm by **Duyar and Pelin (2010)**. Shorter mean stature was observed in the Indian population with a mean stature of 164.7±7.96 cm **(Pandey et al., 2017)**. Racial diversity may be the cause of differences in the mean values between this research and others **(Madden et al., 2012)**.

This study recorded that the mean stature of males was 173.87±5.88 cm; while that of females was 159.60±5.63 cm. Similar Egyptian studies found that males were significantly taller than females **(Issa et al., 2016; Ghaleb et al. 2019; Saleh and Abdel Wahed, 2023)**.

Also, a cross-sectional study conducted in Pakistan stated that the mean stature of male students was 171.70 ± 8.05 cm and was significantly higher than that of females (157.30 ± 8.22 cm) **(Gul et al., 2020)**.

Regarding percutaneous and radiological measures of different parameters, there were significantly higher mean values for all percutaneous and radiological measures in males than for females.

The difference in height between men and women can be attributed to a combination of genetics, hormones, and evolutionary factors. During puberty, both men and women experience a growth spurt due to the release of growth hormones. However, boys typically go through puberty later than girls, allowing them more time to grow taller. The increased levels of testosterone during puberty in boys also contribute to the growth of bones and muscle mass, leading to increased height **(Perkins et al., 2016)**.

The percutaneous length of bones and their relation to stature was studied in several previous research **Kuppast (2011); Pal and Datta (2014); Ragavan and Chandran (2015); Shah et al., (2015) and Girgis et al., (2024)**.

Concerning tibial length in the present work, the mean percutaneous length of tibia in the studied volunteers was 38.31±2.73 cm. The mean tibial length of males and females was 39.83±2.28 cm and 36.99±2.37 cm respectively.

Similar figures were recorded in the Indian study by **Mehta et al. (2015)**, which demonstrated that the mean left tibial length was 37±2.88 cm, and **Verma et al. (2020)** demonstrated that the mean tibial length was 37.58±3.7 cm on the studied Indian sample, while shorter values for the Egyptian (mean female tibial length 34.93±2.27 cm and mean male tibial length 37.76±2.67 cm) and Bengali population (mean female tibial length 34.22±2.74 cm and mean male tibial length 37.42±2.37cm) were observed by **Elhosary et al. (2018)**.

Human populations vary in stature and body measures due to ethnic and regional variations in body proportions **(Zaher et al., 2011)**. Egypt is a large nation with a diverse population that is divided into subgroups based on their ethnicity and culture. Body dimensions may vary between ethnic and geographic groups, and as a result, they may differ in how they correlate with stature **(Moustafa, 2017)**.

According to the parameters that were measured radiologically in the lower limb, the mean tibial length of overall participants was 41.40± 2.93 cm, while 43.28±2.22 cm and 39.77±2.47 cm were the mean radiologically measured tibial length of males and females respectively. Shorter values were observed by **Açıkgöz et al. (2021)**, who found in their radiological study on the Turkish population that the mean left tibial length in males was 39.54±1.88 cm; while in females it was 35.74±2.12 cm.

Genetic and environmental variables, including diet and climate, may be responsible for the difference in stature observed in various human populations **(Habib and Kamal, 2010)**. There may be some variation in the population's bone size and shape due to lifestyle choices influenced by environmental factors. This is the primary justification for doing research using certain equations for stature estimation in a population representative of the population **(Nor et al., 2013)**.

In studying the correlation between stature with all studied parameters, tibial length had the highest value of the Pearson correlation coefficient, so it was the best parameter to predict stature either percutaneously or radiologically measured (r = 0.70, 0.76 respectively), where the P value was <0.001 for all studied participants, male and female samples.

The results of the present study agree with **El-Meligy et al. (2006) and Mehta et al. (2015)**, who concluded that the correlation coefficient (r) values between the tibial length and stature of all included groups were highly significant. Also, **Lemtur et al. (2017)** stated that tibial length shows better correlation than ulna length in both sexes.

Petrovecki et al. (2007) found that all correlation coefficients between long bones (humerus, ulna, radius, femur, tibia, and fibula) and stature were significant.

On studying the percutaneous length of the foot, the foot length ranged from 20.00 cm to 30.50 cm and the mean foot length was 25.63±1.90 cm. In males, the mean foot length was 26.78±1.51cm and in females it was 24.63±1.61 cm. The results of this study agree with **Ghaleb et al. (2019)**, who observed similar values in Egyptian adults in greater Cairo (26.52±1.80 cm in males and 25.39±1.52 cm in females.

Regarding the radiologically measured foot length, the mean value of overall volunteers was 24.19±1.83 cm. The mean value of males was 25.12±1.62 cm and that of females was 23.39±1.61 cm. Similar values were revealed in a study in Nigeria, where full foot length was measured directly on radiographs by a plastic ruler and a sharp pencil and revealed that the mean foot length was 24.66±1.53 cm **(Gwani et al., 2017)**. Another radiological study on the Korean population using a 3D scanner, recorded nearer values where the mean foot length in males was 25.2±1.2 cm while that of females was 23.1±1.0 cm **(Jee et al., 2017)**.

The second-best predictor in the lower limb was foot length with a strong correlation coefficient (r = 0.69), and a highly significant P value (<0.001). This agrees with **Gwani et al. (2017)** as regards radiological foot parameters, where the results revealed that full foot length had a significant correlation with stature.

Verma et al. (2020), in their study, concluded that the correlation coefficient was highest between stature and foot length, followed by that between stature and hand length and then between stature and tibia length.

In the present work, the mean percutaneous foot width was 11.15±1.52 cm (for all subjects) in male and female volunteers; the mean values were 11.41±1.59 cm and 10.92±1.43 cm respectively. Similar values were observed in the Egyptian population by **Ghaleb et al. (2019)**, where the mean foot width in females was 10.27±0.80 cm and in males it was

10.99±1.14 cm, while shorter values were recorded in the Kori population in India, where the mean foot width in females was 8.62±0.5 cm and in males was 9.6±0.56 cm **(Kamal and Yadav, 2016)**.

Regarding radiological measures, the mean foot width of males was 9.62±0.83 cm and that of females was 9.04±0.87 cm. In study based on a 3D scanner by **Jee et al. (2017)**, similar figures were confirmed as the mean foot width for males was 9.9±0.5 cm and for females 9.2±0.5 cm.

Foot width was the least parameter to estimate stature, either percutaneously or radiologically measured with a weak correlation coefficient (r = 0.20, 0.35 respectively). This is in agreement with **Ghaleb et al. (2019)** which found that foot width had the lowest value in Spearman's correlation of the percutaneously measured parameters.

Ozden et al. (2005) reported a non-significant correlation between stature and foot width. Additionally, the study by **Sen and Ghosh (2008)** stated that foot length had the highest reliability and accuracy in stature estimation of an unknown subject. It can be concluded that dependence on bony prominence is more accurate than skin crease.

Concerning simple linear regression equations for stature determination by different measured parameters, this work revealed that all percutaneous and radiological measures predicted stature in the studied sample with a highly significant P value. So, a simple linear regression equation using a single parameter could significantly be used for stature estimation. A simple regression equation using tibial length and foot length showed the least SEE.

In studies conducted in African countries (Sudan, and Ghana), the best prediction measurements were provided from the length of the foot, ulna, and tibia in the equations of these research **(Ahmed, 2013; Abledu et al., 2016)**.

Percutaneously measured tibial length could be used for stature estimation in the studied sample by the simple regression equation (S=76.406+2.345xTL), in the male sample by (S=122.499+1.290xTL), and in the female sample by (S=107.832+1.400xTL), with SEE = 0.122, 0.167, 0.115 respectively, which was the lowest SEE of overall measured parameters.

Regression formulas based on the main long bones are usually thought to be more accurate than those that use other bones, including the hand and foot bones or the skull. The femur and tibia, which are the longest bones and account for the largest percentage of height, are also more accurate than the humerus and ulna **(Dayal et al., 2008)**.

The usefulness of regression equations is generally assessed based on their standard error of estimate (SEE), which is a good parameter of the relation between real and estimated values **(Ozaslan et al., 2012)**.

Elhosary et al. (2018) illustrated that the male regression equation for stature estimation by tibial length was (S = 94.080+2.145 x TL ±3.57), and the female regression equation for stature estimation by tibial length was (S = 76.617+2.375x TL±3.89) with a higher SEE than the present work.

In a study conducted by **Lemtur et al. (2017)** on 100 healthy Indian medical students, the regression equation that could estimate stature in males by percutaneous tibial length was (S = 101.85+1.81xTL ±3.73), while the regression equation could estimate stature in females was (S = 77.86 +2.36xTL ±2.94) with higher SEE value in both sex than in the current study.

The calculated regression equations of the studied sample that predicted stature from radiologically measured tibial length were (S=68.267+2.366xTL ± 0.104) for all volunteers, (S=122.219+1.193xTL ± 0.177) for male volunteers, and (S=96.632+1.583xTL ± 0.115) for female volunteers.

Açıkgöz et al. (2021) found in their study that the regression equations for stature determination by radiological measurement of left maximum tibial length (LMTL) were as follows: S = 93.056 + 2.035 x LMTL ± 3.62 for males and S = 71.720 + 2.509 x LMTL ± 3.89 for females. Finally, S = 65.946 + 2.701 x LMTL ± 3.95 was the equation that could predict stature for all samples.

Foot lengths that were percutaneously measured could be used for stature estimation in the studied subjects using the regression equation (S=81.235+3.316xFL) (with SEE 0.204) and in males, could estimate stature by the regression equation (S=132.890+1.530xFL) (with SEE 0.268). The regression formula (S=112.306+1.920xFL) (with SEE 0.204) was the model that could estimate stature in females using foot length.

Kamal and Yadav (2016), in their study on the Kori population in India, found that the regression equation for stature estimation by foot length was (S=85.2+2.88xFL) in females (with SEE 0.43) and (S=66.0+3.90x FL) in males (with SEE 0.49). Also, **Jee et al. (2017)** in their study illustrated that prediction accuracy was the highest when the regression equation involved foot length with the lowest SEE.

By using X-ray in this study, foot length could estimate stature by the regression equations (S=104.429+2.555xFL) in all volunteers, (S=164.808+0.361xFL) in male volunteers, and (S=126.402+1.419xFL) was the equation of radiological foot length for females. The SEE was 0.219, 0.271, and 0.223 for all volunteers, male volunteers, and females respectively.

Gwani et al. (2017) stated that stature could be estimated by radiologically measuring foot length through the following equations (99.56+2.70xFL for males), (62.30+4.15x FL for females), and (70.89+3.81x FL for all subjects). But with a higher SEE than that in the present work, which was 4.33, 5.37, and 4.83 for male, female, and overall subjects.

The present study revealed that the regression equation of percutaneous foot width for the estimation of all subjects' stature was (S=152.537+1.229xFW) (with SEE 0.300), while the equation for estimation of male stature was (S=172.500+0.120xFW) (with SEE 0.278), and for estimation of females was (S=150.084+0.872xFW) (with SEE 0.269).

The study of **Kamal and Yadav (2016)** found that stature could be estimated by foot breadth through the equations S=109.8+4.78xFB in females and S=120.2+4.63xFB in males. But with lower SEE than the present study (with SEE 0.007 in males, with SEE 0.034 in females).

According to the present work, radiological foot width could be used to predict stature in the overall sample by using the equation (S=133.175+3.551xFW), for female sample by (S=150.355+1.022xFW), and for male stature by (S=161.585+1.277xFW). The SEE of these equations was 0.487, 0.521, and 0.447 for the whole sample, male and female samples respectively.

Jee et al. (2017), in their study using a 3D scanner for the measurement of different foot dimensions, stated that foot width could be used to estimate stature by the following regression equations (S=99.4+7.090xFB in males, S=135.3+2.646xFB in females) with SEE 5.525 and 5.217 in males and females respectively which was higher than SEE in the present work.

The population's racial and ethnic diversity, diet, genetics, sex, landscape, age, and activity level all have an impact on stature. Consequently, a model that works for one population may not work for another **(Galofré-Vilà et al., 2018)**.

All the mentioned formulae of other researchers are specific to their studied populations. Therefore, their application to other populations might cause incorrect results **(Elseidy and Zanaty, 2014)**.

One of the indicators of a model's goodness of fit provided by the statistics is known as R2. The larger the R2, the better the regression model fits observations **(Davide et al., 2021)**. In the current research, multiple linear regression equations using different percutaneous and radiological measurements were significant in stature estimation in the sample studied with high accuracy (R2 ≈ 62% and 58% respectively), which is more than that of single regression equations. So, predicting stature using multiple regression equations is more accurate than simple regression equations. This was previously confirmed in numerous research (**Pelin et al., 2005; Dayal et al., 2008; Saleh and Abdel Wahed, 2023)**.

The regression equation that could estimate stature in the studied subjects by using percutaneous measures of left lower limb parameters was (S=55.940+1.572xTL+2.222xFL-0.619xFW) and radiologically was (S=63.879+2.203xTL+0.289xFL+0.449XFW). **Abledu et al. (2016)** documented that lower extremity measurements could provide better results compared to those of the upper extremity. The femur and tibia, which are the long bones that account for most of human stature, are the most reliable for stature prediction **(Dayal et al., 2008)**.

In the current work, there was no statistically significant difference between radiological and percutaneous measured variables for the prediction of stature. Radiography provides a reliable method of obtaining accurate measurements of the length of long bones. There has been an increased use of virtual imaging modalities in forensic science, especially in autopsies that provide non-invasive examination of deceased individuals. The benefits of imaging modalities were also recognized in forensic anthropology and studying different skeletal remains, giving rise to virtual forensic anthropology **(Mamabolo et al., 2020)**.

In the present study, the tibial length/stature ratio in overall volunteers was 23.05% ± 1.17, while in males it was 22.91% ± 1.13 and in females, it was 23.17% ± 1.20. Nearer figures were observed by **Duyar and Pelin (2003)**, who demonstrated in their study on Turkish males that the tibia length/stature ratio was 22.31% ± 0.75. The ratio of tibial length to body height has been seen to differ between populations and even individuals **(Trivedi, 2022)**.

CONCLUSION

Measurements of the lower limbs in adult Egyptians can be used to reasonably predict stature. By studying simple regression analysis and Pearson correlation, tibial length was the most significant parameter to predict stature (with the least standard error of estimate (SEE) and the highest value of the Pearson correlation coefficient). A simple linear regression formula using one parameter could significantly be used for stature estimation, but using multiple regression equations is more accurate.

RECOMMENDATIONS:

- More research is needed to confirm the derived equations. Also, more research is needed to validate the derived equations in a larger sample of Egyptians and to test the equations' validity in other age groups.
- Since all the study's participants were from the governorate of Menoufia, we also advise expanding the research to include governorates and other regions of Egypt.
- Research on other populations is also recommended to confirm whether it could be equally applicable elsewhere.
- Software programs and digital anthropometry can provide better and more accurate results.
- Simple linear and multiple regression equations obtained can be used for stature determination in Egyptian people accurately within an acceptable standard error of estimate. This will be beneficial in medico-legal investigations and in anthropometry.
- More research is needed to study the relation between stature and other body parts such as the humerus, ulna, and hand.

CONFLICT OF INTEREST:
No competing interests.
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الدور المحتمل لبعض قياسات الطرف السفلي في تقدير طول القامة

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الملخص العربي:

المقدمة: يُعرف تحديد هوية الشخص بالاستعراف الشخصي. وفي كلا من الكوارث الطبيعية والغير طبيعية ، يصبح تحديد الهوية الشخصية أمرا ضروريًا. يعد علم الأنثروبولوجيا الجنائية أحد فروع علم الأنثروبولوجيا الفيزيائية الذي يتعاون مع مجالات أكاديمية أخرى لفهم الجريمة والتحقيق فيها بشكل أفضل. ويمكن استخدام قياسات الجسم لتحديد الملف البيولوجي للفرد، بما في ذلك العمر والجنس والعرق وطول القامة.

الأهداف: هدفت الدراسة الحالية إلى تحليل القياسات المأخوذة فوق الجلد ومن صور الأشعة لبعض العظام المختلفة في الطرف السفلي (القصبة والقدم) وعلاقتها بطول القامة من خلال استخدام التحليل الإحصائي في عينة من المصريين بمحافظة المنوفية.

الطريقة: أجريت الدراسة على عينة من المصريين بمحافظة المنوفية، وتم قياس كل من طول القصبة، طول القدم، وعرض القدم بطريقتين: عن طريق القياسات المأخوذة فوق الجلد ومن صور الأشعة.

النتائج: أجريت هذه الدراسة على 387 مشاركًا مصريًا. تراوحت أعمار المشاركين في هذه الدراسة من 21 إلى 40 عامًا. وتبين وجود علاقة ذات دلالة احصائية بين طول القامة والقياسات الجلدية والشعاعية للطرف السفلي الأيسر لدى المشاركين في الدراسة. وبدراسة الانحدار الخطي البسيط ومعادلة الانحدار لتقدير طول القامة أوضحت الدراسة الحالية أن المعادلة الخطية البسيطة لتقدير طول القامة المعتمدة على طول عظمة القصبة مثلت أقل خطأ معياري تقليدي، فلذلك يمكن بواسطتها تقدير طول القامة بدقة. وكانت دقة معادلات الانحدار المتعدد التي تم الحصول عليها من القياسات المأخوذة فوق الجلد ومن صور الأشعة لقياسات الطرف السفلي الأيسر 62٪ و58٪ على التوالي.

الاستنتاج: يعد طول عظمة القصبة أفضل قياس لتقدير طول القامة (مع أقل خطأ معياري للتقدير وأعلى قيمة لمعامل الارتباط). ويمكن تقدير طول القامة عن طريق المعادلة الخطية البسيطة لأي من القياسات المدروسة. أما بالنسبة لتقدير طول القامة عن طريق استخدام معادلات الانحدار المتعددة فإنها يعطي نتائج أكثر دقة من استخدام معادلات الانحدار البسيطة.