Stature estimation from tibia percutaneous length: New equations derived from a Mediterranean population

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A~~BSTRACT~~bstract

Stature is a fundamental anthropometric character to trace the biological profile of a person. In some cases, when dismembered or mutilated bodies are discovered in a forensic context, it is essential to estimate stature from single districts of the body. Nevertheless, to date and worldwide, there are only few population-specific studies on stature estimation from leg length and none of them concerns modern populations in southern Europe. We attempted to fill this gap, focusing on the estimation of stature from the length of the tibia in a Mediterranean population (Italians). We carried out the current study on a sample of 374 Italian university students of both sexes (age range: 19.9~~-~~–34.4). Both, actual stature and percutaneous length of tibia were measured and new equations were developed for stature estimation. We tested separate regression equations for each sex, as well as an equation for remains, whose sex is unknown. To assess their reliability, the equations were tested on a holdout sample of 30 individuals from the same population. Moreover, results of new specific linear regression equations were compared to others from the literature. We demonstrated that the newly proposed formulae (for males and combined sexes) and the ones by Olivier (for females) provided the most reliable estimations of stature for southern Europeans.

Keywords: Stature estimation; Tibia length; Italy; Forensic ~~A~~anthropology

~~1.~~1 Introduction

Stature, defined as the distance between the point *vertex* and the point *planta* of a subject stretched vertically to the fullest extent and with the head held in the Frankfurt horizontal plane [1, 2], is a fundamental parameter of the individual biological profile and is commonly used for personal identification. In the forensic context, it is essential to derive this parameter both for living persons [2–4] and for cadavers [5, 6]. Given its importance for human identification, estimation of the stature is commonly carried out also on mutilated segments of human body. In this case, stature is often calculated from the measurements of long bones of the limbs with linear regression equations, assuming a linear relationship between the dimensions of long bones and living stature. Researchers have previously proposed regression formulae to evaluate stature from various anatomical parts *(*e.g. [7–10]). Comparisons with equations that consider the long bones lengths of upper limb have demonstrated that those of the lower limb give a better estimation of stature [11]. The most widely applied regression equations for estimation of stature [12–14] were developed from data collected from non-Europeans. Given the difference in body proportions among populations, other formulae have been proposed for modern Europeans [9, 15–18]. However, their usefulness for Mediterranean populations is questionable, as they have not been specifically developed for these populations or because there is a lack of sample representativeness. The same formulae were also largely applied on archaeo-anthropological remains. A debate is ongoing, if they are appropriate for stature estimation in past populations [19, 20]. In addition to genetic differences, environmental factors may affect the statural values of a population, as a worldwide study has recently shown [21]. This evidence highlighted the need for specific formulae for each population or ethnic group.

The aim of this study was to develop new linear regression equations from tibial percutaneous lengths measured in a sample of young Italian adults to obtain the most reliable stature estimation for current populations of southern Europe.

~~2.~~2 Materials and ~~M~~methods

The study involved a sample of 374 students (219 males and 155 females) attending the University of Ferrara (North-Eastern Italy). Ages ranged from 19.9 to 34.9 years for males, with a mean age of 22.4 years and standard deviation equal to 2.7 years. The range for females was 19.9 to 28.9 years, with a mean age of 22.4 years and standard deviation of 2.2 years. The recruitment was carried out advertising during tutorials. Students interested in participating in this study received from the researchers full information about the study and the necessary requirements. Since the reference population consisted only of young adults, exclusion criteria were age ≥ 35 and the presence of clinical conditions that may affect stature, i.e., endocrine, or genetic diseases. Written informed consent was provided by all participants. The Ethics Committee for Biomedical Research of Ferrara University has approved the experimental protocol.

~~2.1.~~2.1 Measurements

Anthropometric measurements were acquired by trained operators and according to standardized procedures [1]. Stature and leg length were measured to the nearest 0.1 cm using a stadiometer (Magnimeter, Raven Equipment Ltd., UK) and a large sliding caliper (GPM, SiberHegner Ltd., Switzerland), respectively. Stature (*vertex-planta*) was measured barefoot, adjusting the head of the participants according to the Frankfurt's plane and applying a slight force to mastoid processes to reach the maximum height. The maximum percutaneous length of the left tibia was measured on the subject sitting with his/her left leg crossed to the right (Fig. 1) between the most proximal landmark of medial condylar margin and the most distal one of the medial malleolus margin [22 (Need to be subsituted with reference [23])].

Fig. 1 Anthropometric measurement of percutaneous tibia length.

alt-text: Fig. 1

~~2.2.~~2.2 Statistical analyses

Before processing the data, we randomly selected a subsample of 30 subjects (15 males and 15 females) (holdout sample) for comparative purposes. Their anthropometric data were excluded from the database used to develop the linear regression equations. The other 344 subjects were identified as the study group (204 males and 140 females). Regression formulae for young adults were developed for each sex separately, as well as for a mixed sample consisting of the same group of females ($N = 140$) and an equivalent number of males ($N = 140$) randomly selected among the 204 subjects of the male sample (combined sex sample). Correlation coefficient (r), R^2, standard error of estimate (SEE) were computed.

The independent *t*-test was used to test the difference in stature and tibial length between the two sexes.

To assess the reliability of our regression equations, as well as of those obtained from previous studies, the formulae derived from the study group were applied to the holdout sample and the estimated stature was compared with the actual stature of the subjects. The regression equation from combined sex sample was applied to the whole holdout sample of 30 subjects. We positively selected regression formulae from previous studies if they considered a comparable measurement of tibial length (total length of tibia) and if they were obtained from samples composed of European subjects of both sexes. Three regression formulae were selected with these criteria [15, 17, 18]. These equations are based on measurements taken from cadavers (Pearson [15], Olivier [17]), living populations (Olivier [17]) or skeletal material (Sjøvold [18]). By using them, we tested their applicability to a sample of South Europeans in comparison to our equations.

We compared the actual stature of the holdout sample with the stature estimated using each equation selected from the literature and our new equation separately by using Wilcoxon matched pairs test. In this case, a non-parametric test is suitable due to the low sample size of the holdout sample (15 subjects of each sex). Furthermore, we computed on the same holdout sample, for comparative purposes, mean and median absolute errors for stature estimations and percent prediction error (PPE) as = 100 x [(regression estimate – measured stature)/measured stature].

Statistical analysis was performed using Statistica for Windows (version 11.0, StatSoft srl, Tulsa, OK).

3.3 Results

Descriptive statistics of the study group are shown in Table 1. The statistical difference observed between sexes was tested using the *t*-test for independent groups. A statistically significant sexual dimorphism was observed in both anthropometric measurements with an average difference between males and females of 13.3 cm in stature and 3.1 cm in tibia length.

Table 1 Descriptive statistics of the study group. Included are mean-value and standard deviation for different measurements in both sexes. The *p*-value indicates the differences between sexes.

alt-text: Table 1

Variables[a]	Males (*n* = 219)		Females (*n* = 155)		*p* value
	Mean	SD	Mean	SD	
Stature, cm	178.2	7.0	164.9	6.8	<0.001[a]
Tibial length, cm	40.2	2.9	37.1	2.7	<0.001[a]

[a] Statistical analysis performed using *t*-test.

Regression equations developed for males, females and the combined sample are shown in Table 2. Correlations between variables (tibia length and stature) were statistically significant for both sexes as well as for combined sexes. Low *p*-values indicate that the given equations are able to model stature from tibial length with confidence both considering males and females separately and combined. According to R^2, the tibia length explains 47% of the variation in the stature of males, 56% in females, and 62% in combined sexes. The standard error of estimate (SEE), which refers to the error that may arise in stature estimation, shows lower values in females than in males or in combined sexes. Figure 2 shows the scatter plot of stature on tibia length with regression line drawn in males, females and combined sexes. The results reported in Table 2 underline that all three correlations were positive and that males' measurements showed greater variability compared to those of females, who showed the lower SEE. As expected, the regression equation performed for combined sexes showed the greatest variability, with the higher SEE.

Table 2 Correlation coefficient and regression equations for the estimation of stature in males, females and combined sexes.

alt-text: Table 2

Parameter	Males	Females	Combined
	(*n* = 204)	(*n* = 140)	(*n* = 280)
Linear regression equation	Y = 111.39 + 1.663 * X	Y = 94.45 + 1.899 * X	Y = 80.01 + 2.366 * X
SEE	5.01	4.62	6.01
r	0.686	0.747	0.785
R^2	0.471	0.568	0.616
p value	<0.001	<0.001	<0.001

SEE: standard error of estimate; Y: stature (cm); X: tibia length (cm).

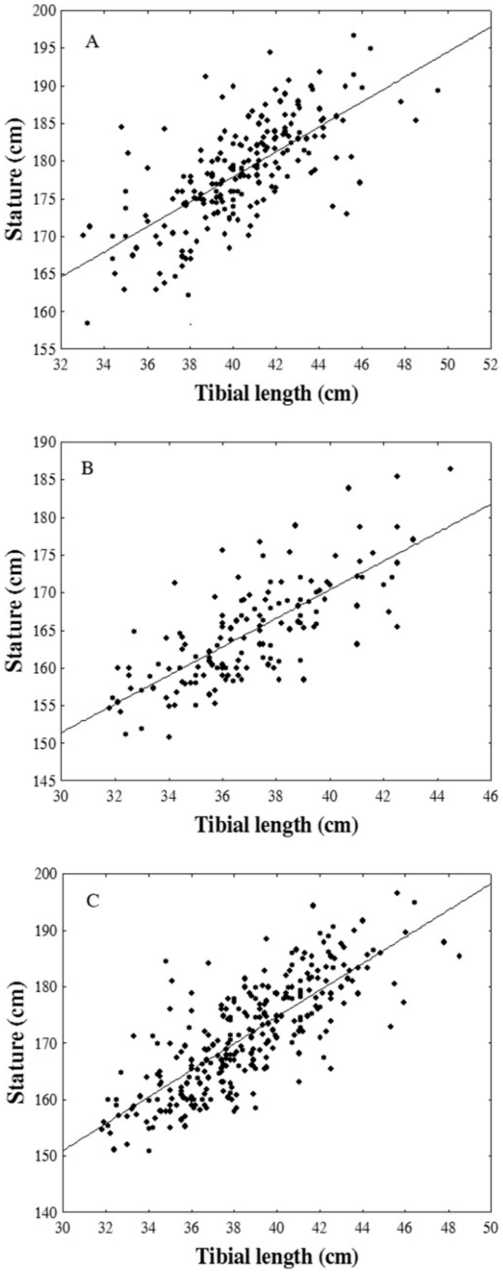

Fig. 2 Scatter plots illustrating the association between living stature and tibia length in males (A), females (B) and combined sample (C).

alt-text: Fig. 2

The comparison, performed on the holdout sample from the same population between stature estimated with the developed equations and its actual value, did not show any statistical difference (Table 3).

Table 3 Descriptive statistics (medians and range) of the actual stature of the holdout sample and of the estimated stature after the application of the regression equations.

alt-text: Table 3

Sex	*n*	Actual stature	Current study	1 vs 2	Pearson [15]	1 vs 3	Olivier [17]	1 vs 4	Sjøvold [18]	1 vs 5
		1	2		3		4		5	
		Median (range)	Median (Range)	*p*	Median (Range)	*p*	Median (Range)	*p*	Median (Range)	*p*
Males	15	174.6 (163.8–180.0)	175.0 (163.6–178.6)	0.721	169.6 (153.4–175.8)	0.004	171.1 (153.4–177.8)	0.114	174.3 (153.8–182.1)	0.386
Females	15	168.6 (161.0–178.5)	167.8 (159.6–174.4)	0.114	165.6 (155.4–173.7)	0.005	169.3 (159.3–177.2)	0.752	165.7 (162.5–186.1)	0.005
Unknown	30	169.9 (161.0–180.0)	171.5 (154.3–179.6)	0.390	–	–	–	–	175.7 (153.8–186.1)	0.263

The mean and median absolute error values obtained (Table 4) are in agreement with the results of the SEE from Table 2. Although females demonstrated lower absolute error and variability (SD) than males, both sexes show a good agreement between actual and estimated stature with median absolute difference ≤ 2 cm, on average. As expected, values of mean and median absolute errors and variability (SD) resulted higher in combined sexes than in males and females separately (median absolute difference > 3 cm). PPE resulted higher in females and combined sexes in comparison to males.. For 80% of the females we found an absolute error lower than 2.5 cm when comparing the estimate against the actual stature, and for 50% the absolute error laid between 0.8 and 2 cm. Among males, for 70% of them the absolute error was lower than 2 cm, and for 40% the absolute error was between 0.2 and 1.5 cm. When testing the equation for combined sexes, the absolute error was lower than 2 cm only in the 45% of cases.

Table 4 Absolute error after application of regression equations to a holdout sample.

alt-text: Table 4

Sex	*n*	Current study			Pearson [15]			Olivier [17]			Sjøvold [18] – *Caucasians*		
		Mean abs error	Median abs error	Mean PPE	Mean abs error	Median abs error	Mean PPE	Mean abs error	Median abs error	Mean PPE	Mean abs error	Median abs error	Mean PPE
Males	15	2.54	2.00	0.080	5.88	6.69	–3.383	4.85	5.10	–2.619	3.62	3.27	0.951
Females	15	1.99	1.79	–0.704	3.65	4.63	–2.176	1.45	1.02	0.051	5.99	3.27	3.551
Unknown	30	3.64	3.23	–0.798	–	–	–	–	–	–	4.80	3.74	1.300

The results obtained applying other regression equations from the literature based on tibia length to the same holdout sample are also given in Table 3 4. Pearson's equations [15] performed the most poorly, underestimating the stature ~~more than~~ ≥(Please, substitute with >)3% in males and 2% in females according to PPE. Moreover, the estimated statures were statistically different from actual statures (Table 3). For males and combined sexes, the best performance was based on the newly proposed equations (PPE <0.1% in males and < 1% in combined sexes). Only for females, the equations proposed by Olivier et al. [17] tended to perform a little better than the others especially on the basis of PPE. Mean and median absolute errors were lower than 2 cm in stature estimated using both Olivier's and new formulae (Table 4). No statistical differences resulted between estimated and actual statures applying Sjøvold's formulas [18], except for female stature (overestimated ~~more than~~ ≥(Please, substitute with >)3%) (Table 3).

~~4.~~4 Discussion

Identification of unknown human remains represents a primary purpose ~~of~~ in forensic investigations. To reach this goal might be particularly difficult when only scattered parts of a body are recovered. In this case, it is necessary to collect all the elements useful to trace individual's biological profile [22]. In addition to sex, ~~and~~ age at death [[24–27], etc.], ethnic group, pathological signals and special identification marks, the individual's stature in life is considered one of the fundamental characters for generic identification by allowing the biological profile to be traced. Stature, as well as all the others biological characters, may help in narrowing down the list of suspects, before using other more specific analyses, such as genetic and dental investigation or fingerprints for specific identification. Together with the other biological parameters, stature is therefore of great importance in forensic science [22, 28], both during the investigation phase and for the debate in court.

Our study examined the reliability of employing the length of the tibia as a predictive character of the subject's stature. In particular, we developed linear regression equations from a sample of a Mediterranean population. Many studies have been carried out to suggest regression equations for the estimation of stature from the long bones of ancient or recent skeletal materials (e.g. [7, 20, 29]). Yet, only few studies proposed new equations based on percutaneous anthropometric measures acquired on living individuals [8, 30, 31] or obtained by application of computed tomography [32–35]. Moreover, only few of them was specific for southern European populations. It is well known that the measurements of lower limb bones especially femur and tibia are more reliable in predicting the stature than those of upper limb [12, 36–38]. Femur length seems to provide the best stature estimation [12, 36, 37], albeit its measurement on living subjects provides some methodological limitations that need to be considered. In particular, it is not possible to obtain on the living a measure equivalent to the maximum length of the femur measured on the skeleton (caput-condylar length) with anthropometric techniques, since the femur head is impossible to reach. Maximum trochanter length (trochanter-condylar length) can be used as an alternative for estimating femur length, but this measurement is very rough due to the difficulty in determining the correct upper landmark (*trochanterion* or *epitrochanter*). Percutaneous length of fibula was also considered for stature estimation [31]. Though, in living people, leg length measured between the landmarks of the tibia is, in any case, more easily to determine.

Following the anthropometric rules generally employed in Europe [1], we collected measurements on the left side of the body. Other studies in the literature reported measurements made on the right side only [7, 39], or on both sides [31, 32]. In the last case, no statistical difference was observed for stature estimation obtained from the left or the right long bones [31, 32].

Literature often refers to stature estimates based on non-contemporaneous skeletal remains. Nevertheless, over time, numerous changes have been documented for stature [21, 37] and lengths of the limbs [40] in recent human populations. Therefore, if equations need to be applicable in a forensic context, the data on which they were developed on should preferably be from contemporaneous populations.

In addition to diachronic modifications, there are also synchronic changes based on ethnicity: the sizes of individuals from southern Europe differ, on average, from those of other European populations, the former being shorter than people living in Central and Northern Europe [21]. This affects proportions of body segments, making consequently inappropriate or doubtful the application of equations developed on other populations to estimate the stature among southern European subjects.

The equations here proposed were developed from a large sample of young living adults, and should be therefore used on subjects younger than 40 years, to make the decline of stature after this age [41] negligible. In older subjects, stature estimation obtained with the regression equations will mirror the stature of the subjects before its decrease with aging. In this case, the value obtained can be adjusted by subtracting an appropriate age corrective factor – possibly evaluated on the same population through a longitudinal study [42, 43]. The newly proposed equations are able to predict stature from tibial length, as demonstrated by the lower *p*-values obtained performing the regression analysis. However, the variance in individual stature is not completely explained by the length of the tibia. These results were expected and depend on the other factors involved. Human height is the synthetic measurement of different body segments and each of them influences the body height differently in relation to the specific body proportions of each individual [44, 45]. One of the factors that need to be taken into consideration when talking about body proportions is the difference between sexes [45]. Starting from the different Y intercept values in the equations developed for the two sexes, regressions coefficients show that the stature changes of 1.899 cm when tibia length changes of one unit in females, while in males the expected change in stature is 1.663 cm with a change of one unit in tibial length. Based on sitting height/stature ratio, women have shorter lower limbs than men for the same stature [46]. Furthermore, women have shorter legs than men, unlike the thigh which tends to be longer [47]. Similar results are reported by Sah et al. [10].

When tested on the holdout sample from the same population, the equations we developed performed better than other commonly used equations, at least for males and mixed sexes. For females, it is worth to mention that good results were obtained as well applying Olivier's equations [17]. Conversely, and despite their wide use, Pearson's equations [15] produced stature estimates that markedly differed from the actual ones and underestimated the height of both sexes. Finally, the equations proposed by Sjøvold for Caucasians [18], obtained combining both sexes, showed high mean absolute errors with a significant overestimation of the stature, especially in females. When applied to males or mixed sexes, although without any statistical difference, they performed worse than the new equations (the mean absolute errors were ~~more than~~ > (Please, replace with >1)1 cm higher than ours). Despite the slightly higher absolute mean standard error of stature estimation by our equations in female sex compared to Olivier's [17] (the difference was only 0.5), the newly developed set of equations works better in estimating stature ~~for~~ from the tibia than those taken from literature.

In conclusion, the proposed regression equations can be used for stature estimation of unidentified mutilated or decomposed human bodies in a forensic context in case the provenience from South Europe can be alleged. Future research should investigate the applicability of these equations to other samples of European populations.

Uncited reference

[23]

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Declarations of interest

None.

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Highlights

- Tibia percutaneous length is highly correlated with stature.
- New regression equations for stature estimation from tibial length have been developed.
- The new formulae provide a reliable estimation of stature for southern Europeans.

Queries and Answers

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