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Forensic Anthropology Population Data

Predicting adult stature from metatarsal length in a Portuguese population[☆]

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ABSTRACT

Stature can be considered one of the ‘‘big four’’ parameters to be ascertained within the biological profile in cases of forensic anthropology. However, the most reliable available methods for stature estimation require the preservation of the long bones, but since this is very often not the case, the development of alternative methods, based on distinct bones, is mandatory. Therefore, in the present work the reliability of the first two metatarsal bones in reconstructing stature is tested. The data consist of length measurements taken from the first two metatarsals removed from documented cadavers of known stature. The sample for this study consists of 220 metatarsals, namely 110 first metatarsals and 110 second metatarsals collected during the autopsies carried out in the National Institute of Legal Medicine in Portugal.

The aim was to propose regression equations for the Portuguese population and test the formulae proposed by other authors to determine adult stature using metatarsal bones. We found that when estimating stature from measurement of the metatarsals, the best correlation was that obtained from the relationship with the maximum length of the 2nd metatarsal. The corresponding regression equation is as follows: $S = 790.041 + 11.689M2$.

1. Introduction

In forensic anthropology, the determination of adult living stature is one of the four key factors in assessing the biological profile, which is determinant for positive identification of skeletal remains. During the past century, several studies have estimated height based on long bone measurements, namely those conducted by Manouvrier [1], Olivier and Tissier [2,3], Trotter and Gleser [4–6] and Mendonça [7]. Estimation of stature from the different dimensions has considerable forensic value, not only for the identification of skeletal remains, but also in developing descriptions of suspects from evidence at the scene of the crime and in corroborating height estimates from witnesses [8–10].

A number of studies have tried to document the relationship between stature, foot length, hand length, shoeprint length for different human populations utilizing linear and multiple regression statistical equations [11–19]. Stature has even been estimated from soft tissue measurements [20]. It has been noted that sex, weight, ethnicity and even regionality clearly affect the various relationships proposed to provide a priori estimations of unknowns [8–15,21]. This has given rise to a recent increase in publications using a similar methodology to study different populations [15,17,21–23] and which have even based stature estimation on immature skeletal remains [24].

Although long bones, such as the femur and tibia, are the most reliable for the estimation of stature, in practice they are quite likely to be fragmented in such a way that precludes any accurate assessment [25]. On the other hand, small bones such as those of the foot are more likely to be preserved, and for this reason, it is crucial to develop reliable methods to determine adult stature from foot bones. As mentioned above, several studies have been made on both hand and foot bones [11–13,26–33], and of these metatarsals seem to be appropriate. The regression equations developed by Byers et al. [26] have been applied in forensic contexts since 1989, and because there is always some type of specificity associated with these equations, i.e., dependence on the reference series from which they were derived, it is essential to obtain an up-to-date population sample from the corresponding country [7,8,34].

To verify whether metatarsal lengths can be used to infer adult stature, we have sought the most appropriate parameters from adult cadavers of known stature in order to obtain accurate regression equations for use in forensic contexts.

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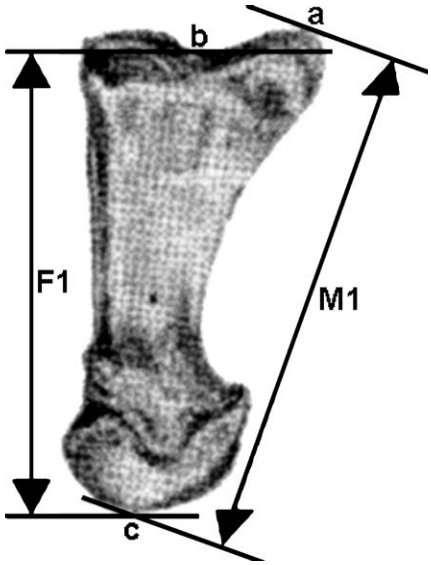

Fig. 1. Physiological ($F1$) and maximum length ($M1$) of 1st metatarsal.

2. Materials and methods

The present research is based on a study of 110 cadavers autopsied in 2001 at the National Institute of Legal Medicine of Portugal. The individuals, 20 females and 90 males, were all Caucasoid Portuguese, and all bodies with skeletal deformities, pathologies or fractures on the left lower extremities that could preclude accurate measurements were excluded. In other words, the absence of degenerative alterations and/or other pathologies affecting foot bones was verified.

Another important selection criterion was age at death: only individuals aged from 20 to 75 years were included in the study.

The real stature of the individuals was taken as the distance from the vertex to the plantar face of the heel and this was measured during autopsy with a sliding calliper (cadaveric stature, CS).

When previous height records were available, these were compared with CS, and no statistically significant differences were found between these two values [35].

The foot bones measured were the first and the second metatarsals of the left side. Bones were removed from the cadaver usually after autopsy. After forcing the foot in an extension movement, an incision in inverted L of lateral opening was made, placing the horizontal branch at the level of the previous line of tarsus and the vertical branch following the medial edge of the foot. After batting the skin and the subcutaneous tissues, the tendons, ligaments and muscles were cut in order to give access to the intended bones, which were then disarticulated and removed.

The elimination of the cartilage was not easy. To verify its thickness, the cartilage was completely removed from some metatarsals and the bones measured with and without it. As the differences were not statistically significant, bones were measured with cartilage.

All measurements were taken with a calliper and registered in millimetres.

2.1. Description of the measurements

$F1$ – Physiological length of 1st metatarsal – The distance between the deepest point of the proximal articular surface and the most distal point of the head (Fig. 1).

$M1$ – Maximum length of 1st metatarsal – The distance between the tip of the tuberosity and the most distal point of the head (Fig. 1).

$F2$ – Physiological length of 2nd metatarsal – The distance between the deepest point of the proximal articular surface and the most distal point of the head (Fig. 2).

$M2$ – Maximum length of 2nd metatarsal – The distance between the proximal tip and the most distal point of the head (Fig. 2).

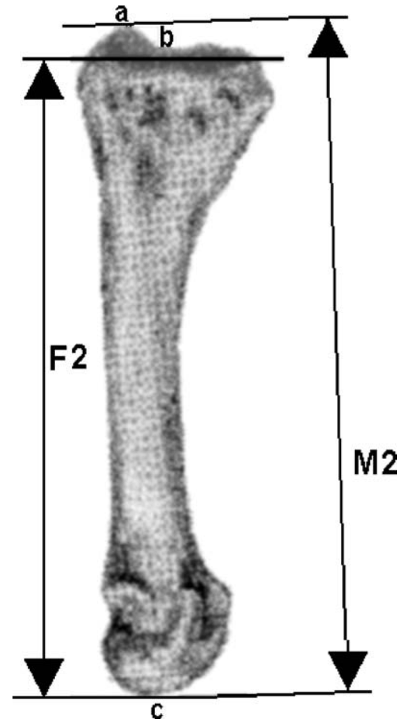

Fig. 2. Physiological ($F2$) and maximum length ($M2$) of 2nd metatarsal.

Statistical analysis of data and related graphs were carried out using the SPSS statistical program (SPSS® 15.0 for Windows). The conditions for the applicability of the regression model, such as index of normality, variance of homogeneity and the control of the colinearity were verified.

3. Results

The average age of men ($n = 90$) was 46.20 ± 12.28 years, whereas for women ($n = 20$) was 45.37 ± 11.29 years. Descriptive statistics of all measurements for each group are shown in Table 1.

The coefficients of correlation between the metatarsal lengths and the true stature were always positive and statistically significant. The correlation value was higher for the entire sample, labelled as “Unknown sex” (males and females), where the coefficient was always higher than 0.7 and lower than 0.8. When the sample was separated by sex the correlations were slightly lower (Tables 2–4).

Whatever the procedure, the highest correlation with stature was $M2$, maximum length of 2nd metatarsal. The corresponding regression equation is as follows: $S = 790.294 \pm 11.69M2$.

When comparing the means obtained with this formula with the true values of stature (measured during autopsy), using a paired-sampled t-test, no significant differences were found ($t = 0.007$; d.f. (degrees of freedom) = 107; $p = 0.995$).

However, because of its shape and constitution, the 1st metatarsal tends to be better preserved than the 2nd, so stature

Table 1
Descriptive statistics of all measurements (mm) for each group.

	Female ($n = 20$)				Male ($n = 90$)			
	Minimum	Maximum	Mean	S.D.	Minimum	Maximum	Mean	S.D.
Stature	1500	1770	1619	61.9	1480	1950	1704	71.6
$F1$	53	69	58	3.7	52	72	63	3.7
$F2$	64	79	69	4.3	71	94	75	4.7
$M1$	57	71	62	3.4	58	77	68	3.7
$M2$	66	82	72	4.4	74	97	77	4.8

Table 2
Regression formulae for males (in mm).[a].

Formula	*N*	*R*	Adj R^2	S.E.
$S = 963.949 + 11.678F1$	90	0.611	0.366	57.0
$S = 834.630 + 11.563F2$	88	0.761	0.574	47.2
$S = 865.335 + 12.317M1$	90	0.641	0.404	55.3
$S = 817.849 + 11.374M2$	88	0.762	0.575	47.1

[a] Stature (*S*), physiological length of 1st metatarsal (*F*1), physiological length of 2nd metatarsal (*F*2), maximum length of 1st metatarsal (*M*1), maximum length of 2nd metatarsal (*M*2), in mm. S.E.: standard error; *R*: correlation coefficient; Adj R^2: adjusted determination coefficient.

Table 3
Regression formulae from females (in mm).[a].

Formula	*N*	*R*	Adj R^2	S.E.
$S = 919.146 + 12.006F1$	20	0.728	0.504	43.5
$S = 957.350 + 9.488F2$	20	0.674	0.423	47.0
$S = 871.260 + 11.970M1$	20	0.675	0.426	46.9
$S = 961.592 + 9.117M2$	20	0.663	0.408	47.6

[a] Stature (*S*), physiological length of 1st metatarsal (*F*1), physiological length of 2nd metatarsal (*F*2), maximum length of 1st metatarsal (*M*1), maximum length of 2nd metatarsal (*M*2), in mm. SE: standard error; *R*: correlation coefficient; Adj R^2: adjusted determination coefficient.

Table 4
Regression formulae for unknown sex (in mm).[a].

Formula	*N*	*R*	Adj R^2	S.E.
$S = 887.530 + 12.826F1$	110	0.702	0.489	55.2
$S = 798.894 + 11.990F2$	108	0.792	0.624	47.6
$S = 816.157 + 13.007M1$	110	0.721	0.515	53.7
$S = 790.041 + 11.689M2$	108	0.793	0.626	47.5

[a] Stature (*S*), physiological length of 1st metatarsal (*F*1), physiological length of 2nd metatarsal (*F*2), maximum length of 1st metatarsal (*M*1), maximum length of 2nd metatarsal (*M*2), in mm. S.E.: standard error; *R*: correlation coefficient; Adj R^2: adjusted determination coefficient.

estimation can still be made with confidence when the former bone is the only one available.

To test whether this formula performed better than others, we applied it to both single and multiple measurements, and no significant differences in the correlation coefficients were detected. However, *R* figures do not increase when a combination of the four measures is used.

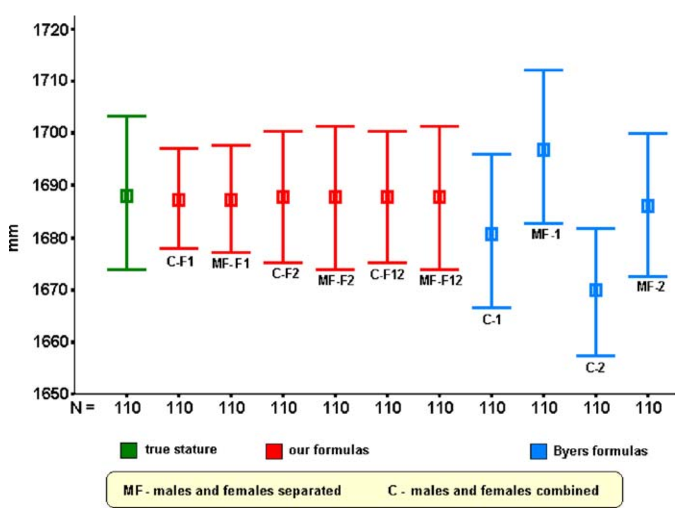

Fig. 3. Predicted values of stature with Byers' formula and ours (*Y*-axis = stature, *X*-axis = *N*).

Table 5
Estimation of stature from the skeletal collection of the anthropological museum of the University of Coimbra according to different formulae.[a].

Formula	*N*	Mean stature (cm)	S.D.
Trotter and Gleser [6]	60	161.26	8.10
Byers et al. (Met1) [8]	60	159.42	7.65
Byers et al. (Met2) [8]	60	159.94	7.29
*F*1	60	161.04	5.31
*F*2	60	161.38	5.41
*M*1	60	161.68	5.87
*M*2	60	161.97	5.65

[a] Physiological length of 1st metatarsal (*F*1), physiological length of 2nd metatarsal (*F*2), maximum length of 1st metatarsal (*M*1), maximum length of 2nd metatarsal (*M*2), in mm. S.D.: standard deviation.

The second phase of the analysis was to test the applicability and reliability of Byers' formulae [26] and to compare their performance with ours. For this purpose, the same combination of measurements used in Byers' formulae was tested with the equations obtained, and compared to our own R^2 values, which were mainly slightly higher. Furthermore, the stature results obtained with those formulae applied to our sample were compared with the true stature.

Stature variation comparison can be seen in Fig. 3, where Byers' formulae give both higher and lower results.

To validate the formulae we used the Identified Skeletal Collection of the Museum of Anthropology of Coimbra University (of unknown stature). We estimated the stature of 60 skeletons using the 4 formulas obtained from our samples and compared the results with those obtained using the formulas published by Trotter and Gleser [6] for the femur and Byers et al. [26]. Values close to those of Trotter and Gleser were obtained with any of our formulae, there being no significant difference.

However, the differences between the estimates of Byers et al. with those of Trotter and Gleser were statistically significant ($p < 0.006$). The results are shown in Table 5.

4. Discussion and conclusion

Considering that metatarsal bones are indeed some of the most well preserved and complete bones in cases of forensic anthropology, the results here obtained can be considered a positive contribution in assessing the biological profile given that it was possible to construct anthropometric regression equations for stature estimation from our data. Linear models for the prediction of stature from foot and boot dimensions have proved to be the quickest and most useful mathematical model [10].

It has been reported in the literature that the dimensions of hands and feet can provide good reliability in estimating stature in forensic examinations, with foot length being the most accurate guide with *R* values close to those presented in this paper [14], but some facts need to be taken into consideration. It is known that body weight has a strong and positive correlation with the various measurements of footprints, so that an extra weight of 20 kg significantly affects stature estimation [21], but this limitation does not appear in estimation based on metatarsal length.

Byers et al. [26] showed moderate relationships with correlation coefficients that ranged between 0.59 and 0.89, Bidmos reported slightly lower values [16]. A similar value to Byers was obtained in this present study. The correlations found here are significant, with some values very close to 0.8, and therefore, the analysis proceeded with confidence. The correlations figures in Tables 1–3 are approximately the same magnitude for stature estimated from fragmentary long bones [36–38], living stature from anthropometric soft tissue measurements [20] or from foot dimensions [33,39] and are even better than those obtained from foot length, and much better than those from foot breadth [8].

As might be expected, in most cases the stature estimation equations given in recent studies are more precise than those previously available and regional studies are very much needed as racial and ethnic variations arise in different regions [16,33,40]. When the results from Byers' equations were compared to ours, the statistical results show that ours were more accurate. This could be due to the so-called specificity of regression equations in relation to the series on the base from which they were developed. In fact, our formulae were obtained from a reference population of present day individuals with known stature and, above all, they were calculated from cadavers with known stature.

Although our formulae seem more appropriate to estimate stature, Byers' and Bidmos' formula should not be rejected because they could be useful when specific formulae for a specific population are unknown or not available. However, to improve accuracy formula have been obtained and tested in a skeletal collection with known stature. Furthermore, and taking into account that one of the problems of our sample was the low number of females, an increase in the size of the female sample and a subsequent analysis according to sex, should be performed.

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