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Estimating body height from ulna length: need of a population-specific formula

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Abstract

In forensic work, it is important to be able to estimate body height from a variety of bones. It is well known that estimates based on upper limb long bone measurements are highly accurate. This report describes an equation devised for height estimation in the Turkish population based on ulna length, and compares the results with ulna-based formulae developed for several other populations. Anthropometric measurements were recorded for 254 healthy male subjects aged 18-45 years. The subjects were randomly divided into equal-sized study and control groups. A population-specific formula for height was created based on ulna length of the subjects in the study group. This formula and 14 other formulae reported in the literature were applied to the control group and the mean estimation errors were statistically compared. Analyses indicated that the population-specific equation gave the most accurate results. In addition, the formula devised by Trotter and Gleser for Mongoloids yielded more reliable results than other formulae. The Trotter-Gleser formulae for whites are the ones most frequently used in Turkey today; however, these equations do not yield reliable height estimates for our population.

Keywords: *Forensic anthropology, stature estimation, ulna length*

Introduction

Calculating stature from bones is an important element of forensic science. Of all the mathematical methods used, regression formulae based on long-bone measurements yield the most accurate results. Estimates based on long bones of the lower limb are the most precise, but those based on upper limb long bone measurements are also reliable. The ulna is a long bone that is often used for body height estimation. A number of authors have investigated stature estimation based on measurements of the ulna and other bones of the upper limb (Rao et al., 1989; Badkur and Nath, 1990; Mall et al., 2001).

Several authors have offered regression equations based on long bones (Breitinger, 1937; Telkkä, 1950; Trotter and Gleser, 1958; Muñoz et al., 2001); however

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it is well known that formulae that apply to one population do not always give accurate results for other populations. Pearson first reported this in 1899, stating that a regression formula derived for one population should only be applied to other groups with caution. In 1929, Stevenson confirmed the existence of inter-populational differences with respect to stature estimation (Lundy, 1985). Most studies since that time have stressed that regression formula for stature estimation should be population-specific (Krogman and İşcan, 1986).

The formulae derived by Trotter and Gleser (1958) are the ones most frequently used for stature estimation. In Turkey, the Trotter-Gleser formula for whites has been most widely used for forensic and anthropological studies; however, the accuracy of this formula for the Turkish population has not been evaluated in detail. This article presents a new regression formula based on ulna length for stature estimation in the Turkish population. Results using this formula were compared to those generated with other ulna-length-based formulae previously derived for different populations.

Subjects and methods

The study involved 254 randomly selected healthy males aged 18-45 years (mean age 23.10 ± 4.72 years, SD). The subjects originated from several cities in Turkey, but all were living in Ankara at the time of the study. Each subject was randomly assigned to either the study group (n = 127) or the control group (n = 127). There was a Gaussian distribution for stature in both groups (Figures 1 and 2). Kolmogorov-Smirnov tests verified the normality of the distribution of height in the study group (Z = 0.595, P = 0.871) and control group (Z = 0.640, P = 0.808).

Each subject's body height and forearm (ulna) length were measured using a Martin-type anthropometer. For height measurement, the subject stood in bare feet with his back to the anthropometer. The head was adjusted so that the Frankfurt plane was horizontal, and was then tilted slightly upwards by applying gentle force to the mastoid processes and zygomatic bones (Cameron et al., 1981). For ulna length, the subject's elbow was flexed to 90° with fingers extended in the direction of the long axis of the forearm, and the distance between the most proximal point of the olecranon and the tip of the styloid process of the ulna was measured (Martin et al., 1988). All measurements were recorded to the nearest millimeter. The means for age, stature and ulna length in the study and control groups are listed in Table 1. There were statistically no significant differences between the groups with respect to these parameters.

Table 1: Comparison of the general characteristics of the study and control groups

	Study group (n = 127)		Control group (n = 127)			
	Mean	SD	Mean	SD	F	Sig.
Age (years)	22.96	4.84	23.24	4.62	0.219	0.640
Body height (mm)	1755.07	94.25	1752.28	94.51	0.560	0.814
Ulna length (mm)	275.49	18.12	275.37	18.21	0.003	0.959

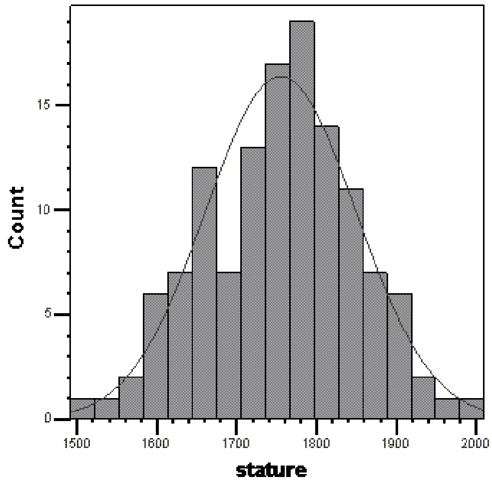

Figure 1: Distribution of the stature in study group.

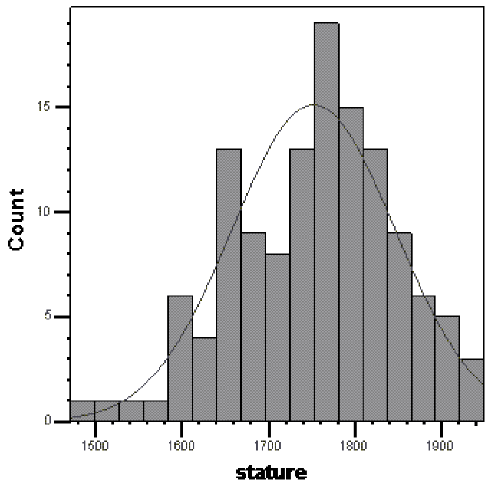

Figure 2: Distribution of the stature in control group.

The scatterplots showing the relationship between the ulna length and stature both in the study and control groups take place in Figures 3 and 4. We derived the following linear regression equation for height estimation (in millimeters) using the measurement data from the study group:

$$\text{Stature} = 3.958 * \text{ulna length} + 664.72 \pm 83.28$$

The statistical details of the equation were given in Table 2.

Table 2: Regression equation for stature estimation from ulna length

	Unstandardized coefficients B	Std. error	Standardized coefficients Beta	t	Sig.
Constant	664.721	83.283		7.981	0.000
Ulna	3.958	0.302	0.761	13.120	0.000

Dependent variable: stature

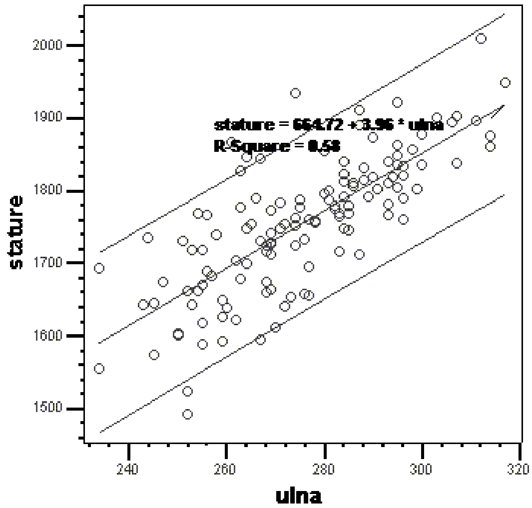

Figure 3: Scatterplot (with 95% confidence interval) for ulna length and stature in study group.

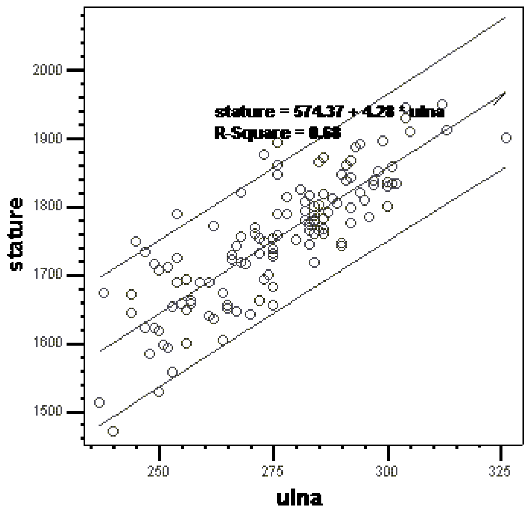

Figure 4: Scatterplot (with 95% confidence interval) for ulna length and stature in control group.

This new formula was applied to each control subject, and the mean height for the group was calculated. The mean height estimated by our new formula was compared with the mean of the true heights in the group. In addition, 14 other different equations for estimating stature from ulna length were also applied to the control group, and the mean height for each set was calculated. The accuracy of the 15 formulae was evaluated using the paired t-test. All statistical analysis was done using the software SPSS 11.5.

Results

The means and standard deviations for the subjects' heights calculated with our new formula and with the other 14 equations are listed in Table 3. The differences between true and estimated height with the 15 formulae and the statistical analysis of these differences are shown in Table 4. The new formula provided the closest estimation of true height, with a mean overestimation of +0.27 cm. The formula by Sağır yielded the next most accurate result (+1.30 cm), followed by the Trotter-Gleser formula for Mongoloids and the Allbrook formula for the British population, respectively. The estimation error for the later two formulae was close to 2 cm below true height. The Lundy formula for South Africans gave the least accurate results, with a mean underestimation of 20.71 cm.

Statistical analysis with the paired t-test revealed that the estimates from all except our new formula were significantly different from true height ($p<0.001$ for all), whereas the new formula was very accurate ($P = 0.577$).

Table 3: Estimated stature in the control group using the 15 different regression formulae (n=127)

Author/Source	Population	Mean	Std. Deviation
Actual stature	Turkish	175.28	9.45
This study	Turkish	175.49	7.24
Sağır (2000)	Turkish	176.54	6.05
Trotter-Gleser (1958)	Mongoloids	173.31	6.36
Allbrook (Krogman and İşcan, 1986)	British	173.23	5.60
Trotter-Gleser (1958)	Mexicans	172.62	6.51
Trotter-Gleser (1958)	Whites	179.12	6.88
Trotter-Gleser (1958)	Blacks	170.91	5.85
Trotter-Gleser (1958)	Puerto Ricans	170.84	6.04
Shitai (Krogman and İşcan, 1986)	South Chinese	168.34	5.74
Badkur and Nath (1990)	Indians	167.74	2.54
Allbrook (Krogman and İşcan, 1986)	Nilo-Hamit	167.74	5.96
Munoz et al. (2001)	Spanish	186.97	6.04
Allbrook (Krogman and İşcan, 1986)	Nilotic	162.06	6.57
Allbrook (Krogman and İşcan, 1986)	Bantu	161.55	5.93
Lundy (Krogman and İşcan, 1986)	South Africans	154.52	5.38

Table 4: Paired t-test results for comparisons of differences between true height and the heights estimated by the 15 formulae investigated

Estimated –True Height	Population	Mean*	Std. Deviation	t	Sig. (2-tailed)
Our formula – True height	Turkish	0.27	5.39	0.56	0.577
Sağır – True height	Turkish	1.30	5.63	2.63	0.010
Trotter-Gleser – True height	Mongoloids	-1.92	5.54	-3.91	0.000
Allbrook – True height	British	-2.00	5.79	-3.89	0.000
Trotter-Gleser – True height	Mexicans	-2.61	5.51	-5.34	0.000
Trotter-Gleser – True height	Whites	3.89	5.44	8.07	0.000
Trotter-Gleser – True height	Blacks	-4.31	5.70	-8.53	0.000
Trotter-Gleser – True height	Puerto Ricans	-4.39	5.64	-8.78	0.000
Shitai – True height	South Chinese	-6.89	5.74	-13.53	0.000
Badkur-Nath – True height	Indians	-7.49	7.50	-11.25	0.000
Allbrook – True height	Nilo-Hamit	-7.49	5.66	-14.91	0.000
Munoz – True height	Spanish	11.74	5.64	23.47	0.000
Allbrook – True height	Nilotic	-13.17	5.50	-27.01	0.000
Allbrook – True height	Bantu	-13.67	5.67	-27.16	0.000
Lundy – True height	South Africans	-20.71	5.88	-39.72	0.000

* Negative values indicate underestimates, and positive values indicate overestimates.

Discussion

Height-estimation formulae based on ulna length show similar levels of accuracy to calculations based on the length of other upper limb long bones. This is supported by the standard errors of the estimations reported in several studies. For example, the standard errors of estimations from formulae that Trotter and Gleser (1958) devised for several ethnic groups (whites, blacks, Mongoloids and Mexicans) based on humerus, radius, and ulna length were quite similar (approximately ±4-4.8 cm). On the other hand, the range in estimation error for the Trotter-Gleser equations based on long bones of the lower limb is 3.0-4.0 cm. Though estimates of body height based on lower limb long bones are more accurate, the results from formulae based on upper limb long bones are only slightly less precise. In this study, we developed a new ulna-based height estimation formula. We chose this bone because, compared to other bones of the upper limb, it is easier to get a more accurate measure of ulna length in living subjects.

Authors have underlined the need for population-specific stature estimation formulae for more than 100 years. The main reason for this is that the ratios of various body parts to stature differ from one population to another. In addition to ethnic differences, secular trends (Meadows and Jantz, 1995) and even environmental factors, such as socioeconomic and nutritional status, can influence body proportions (Malina, 1991; Duyar, 1997). Our findings in this study of Turkish males also support the need for population-specific formulae. When we used equations based on other populations to estimate stature in our subjects, the lowest underestimation was 20.71 cm and the highest overestimation was 11.74 cm. In contrast, the new population-specific formula that we devised yielded a mean overestimation of 0.27 cm, and this difference from true height was not statistically significant. We also found that another Turkish population-specific equation created by Sağır (2000) showed good accuracy for stature estimation in our subjects. This formula resulted in a mean overestimation of 1.3 cm. Although the Sağır equation was not as accurate as our new formula, it outperformed all the other population-based formulae we tested.

In a previous study, we emphasized the importance of population-specific formulae for height estimation from tibia length (Pelin and Duyar, 2002, 2003). In that report, the mean error with a newly derived equation specific for the Turkish population was only +0.1 cm. We found that another Turkish-population-specific formula by Sağır resulted in 0.06 cm overestimation. When we tested all the other tibia-based height estimation formulae published in the literature, an error range of -0.65 to +18.94 cm was found, excluding the Trotter-Gleser formula for Mongoloids (-0.01 cm).

Over the years, various authors' stature formulae have been used in forensic cases and anthropological studies in Turkey. The first anthropological studies conducted in our country employed the Pearson formula, and the Trotter-Gleser equation for whites has been most widely used in recent years. However, in the present study, we calculated a mean height overestimation of approximately 4 cm with this formula, in comparison to mean underestimation of approximately 2 cm with the Trotter-Gleser equation for Mongoloids. The above-mentioned previous report on stature estimation from tibia length also noted that estimates from the Trotter-Gleser formula for Mongoloids were more accurate (+0.01 cm) than those for the Trotter-Gleser formula for whites (mean overestimation of 3.14 cm) (Pelin and Duyar, 2002, 2003). Our present study and this investigation of tibia-based equations indicate that, for estimating height in Turkish subjects, the Trotter-Gleser formula for Mongoloids is more accurate than the Trotter-Gleser formula for whites.

In conclusion, this study shows that the Trotter–Gleser formula for whites, which is currently widely used for forensic studies in our country, is not accurate for the Turkish population. We stress that formulae used for estimating stature based on long bones should be population-specific.

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