Eurasian Journal of Anthropology Euras J Anthropol 3(1):1−9, 2012

Estimation of stature from the lengths of ulna and tibia: a cadaveric study based on group-specific regression equations

Osman Özgür Sargın[1], İzzet Duyar[2*], Sema Demirçin[3]

[1]*Department of Legal Medicine, Namık Kemal University, Tekirdağ, Turkey*
[2]*Department of Anthropology, Istanbul University, Istanbul, Turkey*
[3]*Department of Legal Medicine, Akdeniz University, Antalya, Turkey*

Received April 16, 2012
Accepted July 1, 2012

Abstract

Prediction of stature in forensic medicine and anthropology is one of the most important tools in forensic identification. This study is aimed at generating group–specific stature equations that produce the most accurate results. The study was conducted on 140 cadavers (78 males, 62 females) of ages ranging from 18 to 50 years. Ulna and tibia lengths of the cadavers, as well as body height, were measured using two different methods. Values of ulna and tibia were classified into three groups; long ulna/tibia, medium ulna/tibia, and short ulna/tibia, by using 15th and 85th percentile values as cut-off points, and then least square regression equations were generated for each group. The results of these bone length sensitive formulae are compared with the results obtained using the classical general formula. Comparisons highlight that group-specific formulae give more accurate results than those of general the formula making them better suited to estimation of stature versus than the general formula in forensic cases.

Keywords: *Forensic anthropology, forensic medicine, forensic identification, stature estimation, group-specific regression equations*

Introduction

Reconstruction of living stature plays a crucial role in determining the forensic identification. Stature is a particularly important aspect to determine when identifying cadavers that have lost their physical integrity or are decaying. Due to the significance of this feature, researchers and forensic practitioners have conducted numerous scientific studies geared at the estimation of stature. These studies have thus yielded two different estimation methods, the anatomical and the mathematical. The first of these is based on the addition of skeletal elements from the skull to the calca-

* Corresponding author: Department of Anthropology, Istanbul University, Beyazıt 34559, Istanbul, Turkey (**e-mail:** izduyar@yahoo.com)

ISSN: 2166-7411

neus (Fully, 1956; Raxter et al., 2006). The second method estimates living stature by considering the lengths of long bones, generally determined with the help of regression equations (Lundy, 1985).

The anatomical method has some limitations when it comes to those cadavers which have lost their physical integrity or have decayed. This being the case, experts tend to estimate stature using the mathematical method more. There are various techniques for applying the mathematical method. While some researchers simply consider the ratio of skeletal elements to the living stature, others prefer estimating stature via regression techniques (Feldesman et al., 1990; Konigsberg et al., 1998). Due to its practically, it has become the most common technique for estimating living stature. However, this method too has its limitations. The most important of these is that considerable deviations can be observed, particularly in short and tall people. When the stature for a shorter person is predicted through only one ("general") regression equation, the estimation might suggest that the subject is taller than she or he actually is. On the contrary, this procedure estimates tall people shorter than they actually are (Sjovold, 1990; Konigsberg et al., 1998; Duyar and Pelin, 2003).

In order to decrease the prediction errors mentioned above, some researchers recommended the use of a multi-formulae technique (stature group-specific equations) (Duyar and Pelin, 2003; Pelin and Duyar, 2003). The multi-formulae technique is based on generating a triple formula set rather than one formula from the reference group and/or sample. The reference group is divided into three sub-groups; short, medium and tall and specialized regression equations are developed for each subgroup. Developing three different regression formulae is also called "stature and/or long bones-sensitive" regression equations. The aim of this study is to develop long bone-sensitive equations using the least invasive methods from cadaver material.

Materials and Methods

The measurements in this study were obtained from 140 cadavers (78 males and 62 females) brought to the Antalya Group Chairmanship of the Council of forensic Medicine for corpse examination or autopsy between February 2007 and May 2008. The ages of the cadavers range between 18 and 50 years. Those under 18-years of age due to their incomplete bone development, and those over 50 were also excluded because of extreme decrease in body height resulting from aging and senility (Trotter and Gleser, 1951; Galloway et al., 1990; Giles, 1991; Chandler and Bock, 1991).

Stature values for the cadavers were measured with subjects on an autopsy table (length 2050 mm) using a steel ruler with the rigor mortis in place. The value for the distance between the top edge of the autopsy table and vertex and that between the bottom edge of the autopsy table and sole were measured in millimeters and were subtracted from the length of the table to obtain the stature of the cadaver. While measuring the cadaver stature, acromion, trochanterion and malleolus lateralis were kept on the same plane, in line with Krogman's (1962) proposal.

The lengths for left side ulna and tibia were taken with a 500 mm vernier caliper and without damaging the physical integrity of the corpses. The length of ulna was found by millimetrically measuring the distance between point of olecranon and the most distal point of the styloid eminentia with the elbow joint flexed to 90^0, and the length of tibia was found by millimetrically measuring the distance between the most proximal point of the medial condyle and the most distal point of the medial malleolus. The lengths of ulna and tibia were measured using two different techniques. The first involving percutaneous measuring, in which the distance between points determined in palpation was evaluated. In the second technique, green-tipped injection needles were pricked into the points determined by palpation, and then the distance between the points described above was measured (Figures 1 and 2).

Fig. 1: Measuring the length of ulna by needles

Fig. 2: Measuring the length of tibia by needles

All of the measurements taken for the ulnae and tibiae were recorded by the first writer. To insure reliability, the measurements of the first 13 males and 8 females were retaken by a forensic medicine expert of the Antalya Group Chairmanship of the Council of forensic Medicine. Intra-observer error was calculated by using these repeated measures (Table 1). Paired t-test values show that intra-observer error is low, particularly in tibia length.

Table 1: Intra-observer error of measurements (n = 21) and the results of paired *t*-test (in mm)

Difference	Mean	Std. Deviation	P
Ulna length 1 − Ulna length 2	0.810	3.043	0.237
Tibia length 1 − Tibia length 2	0.095	6.098	0.944

In this study, group-specific formulae for stature groups were developed, as well as a "general" formula for the whole sample. For the group specific-formulae, the sample was divided into three groups; short, medium, and tall, based in terms of their bone lengths. As in the classification of long bone lengths, 15th and 85th percentiles were used as cut-off points. Ulnae with a length of 223 mm or less were identified as short, 224-244 mm as medium, and 245 mm and above as long. Tibiae with a length of 313 mm or less were classified as short, 314-422 mm as medium, and 423 mm and above as long. The ordinary least square (OLS) linear regression technique was used both in generating the general formula and the long bones group-specific formulae.

The regression equations were constructed and tested by using the leave one out cross validation procedure. According to this procedure, the first individual was removed and regression equation was constructed depending on the remaining subjects and then the stature for the first individual was calculated. Later the second individual was removed and so on until all statures were estimated.

All the information about the cadavers and the measurement values were recorded to SPSS 13.0 package software and with which all statistical analysis were done. The paired *t*-test was used to assess the differences between the estimated and measured stature. *P* values <0.05 were considered significant.

This study was carried out upon the consent of Akdeniz University (Antalya, Turkey), the Faculty of Medicine Ethics Committee.

Results

Descriptive statistics (mean, minimum and maximum values, as well as the standard deviation) are given in Table 2. As expected, the mean values for males are higher than females.

Some previous studies have used percutaneous body measurements for determination of stature (e.g., Mohanty, 1998; Duyar and Pelin, 2003; Duyar et al., 2006; Agnihotri et al., 2009). This brings into question what the difference in accuracy is between percutaneous measurements and those measurements obtained without soft tissue. In this study, we address this question by comparing the percutaneous measurements with the measurements aided by green-tipped needles, which are assumed to be more reliable. The percutaneous ulna measurements were observed to give higher values. The difference between the mean values obtained by the two techniques is statistically significant (Table 3). On the other hand, no significant difference between the two techniques was found when accessing tibia length. Assessment was based on the more accurate measurements demarcated by the needles as the two techniques produced different results, especially in ulna.

It is well known that estimating stature from long bones shows a difference in terms of sex (Trotter and Gleser, 1952; Bermúdez et al., 1999; Mall et al., 2001). Because of this, regression formulae were generated separately for males and females (Table 4) using both general stature formulae and long bones-group-specific formulae.

Table 2: Descriptive statistics of the sample

	Minimum	Maximum	Mean	Std. Deviation
Females (n=62)				
Age (year)	18	50	32.1	
Body height (mm)	1437	1696	1573.0	56.65
Ulna length (mm)	207	253	233.5	10.14
Tibia length (mm)	277	381	332.2	18.33
Males (n=78)				
Age (year)	18	50	35.1	10.24
Body height (mm)	1556	1960	1704.2	66.02
Ulna length (mm)	232	314	262.6	13.43
Tibia length (mm)	319	458	369.0	22.94

Table 3: Comparison of the measurements taken by percutaneous and needle one (in mm)

	Percutaneous		Needled			
	Mean	SD	Mean	SD	Difference	P*
Females (n=62)						
Ulna length	235.2	10.31	233.5	10.14	1.69	.000
Tibia length	331.9	19.98	332.2	18.33	−.34	.649
Males (n=78)						
Ulna length	265.1	13.86	262.6	13.43	2.54	.000
Tibia length	370.2	23.83	369.0	22.94	1.23	.068

*Paired *t*-test

Table 4: Regression equations for body height estimation from the lengths of ulnae and tibiae

	Equation	R^2	F	P
Ulna, females (n=62)				
General	Stature = 3.776 Ulna + 691.25	0.457	50.56	0.000
Short	Stature = 3.508 Ulna + 750.10	0.243	2.89	0.123
Medium	Stature = 2.761 Ulna + 925.96	0.135	6.26	0.017
Long	Stature = 4.837 Ulna + 441.36	0.164	1.38	0.279
Ulna, males (n=78)				
General	Stature = 3.778 Ulna + 712.33	0.591	109.76	0.000
Short	Stature = 5.069 Ulna + 407.85	0.258	3.13	0.110
Medium	Stature = 3.618 Ulna + 752.17	0.297	22.85	0.000
Long	Stature = 5.649 Ulna + 181.67	0.814	39.40	0.000
Tibia, females (n=62)				
General	Stature = 2.129 Tibia + 865.60	0.475	54.24	0.000
Short	Stature = - 1.208 Tibia + 1881.07	0.098	0.872	0.378
Medium	Stature = 2.798 Tibia + 641.45	0.255	15.39	0.000
Long	Stature = 2.219 Tibia + 840.37	0.419	5.05	0.059
Tibia, males (n=78)				
General	Stature = 2.303 Tibia + 854.49	0.640	135.27	0.000
Short	Stature = 1.727 Tibia + 1063.14	0.361	5.65	0.039
Medium	Stature = 2.519 Tibia + 769.17	0.314	24.21	0.000
Long	Stature = 2.560 Tibia + 761.32	0.713	22.40	0.001

Stature estimation formulae specialized to the long bones were examined comparatively, first with the general formula obtained from our sample, and then with the general formulae which were derived from different samples and/or populations (Tables 5 and 6). The assessment mentioned was done by examining the difference between the measured stature values of corpses and their estimated values. As it can be seen in Table 5, the mean difference between the estimated and measured stature in female corpses is only 0.07 mm. However, when the values are predicted using the formulae of other researchers, it is observed that the mean difference between the measured and the estimated stature is −56.0 mm and 52.9 mm. When the data for the male corpses are examined, it can be seen that the lowest difference between the measured and the estimated stature again comes from the group-specific formula (the difference is 0.035 mm). The stature values predicted with the other formulae are different from the measured stature on average between −84.3 and 67.6 mm.

Table 5: Comparison of estimated and measured height from ulna in various populations

	Estimated height		Measured height		Difference	
	Mean	SD	Mean	SD	(mm)	P
Females (n=62)						
Ulna group specific	1572.9	56.65	1572. 95	56.65	0.071	0.989
Telkkä	1629.0	33.48	1572. 95	56.65	−56.04	0.000
Trotter-Gleser, Whites	1566.0	43.31	1572. 95	56.65	6.91	0.317
Trotter-Gleser, Blacks	1520.0	33.58	1572. 95	56.65	52.94	0.000
Ağrıtmış	1549.3	42.78	1572. 95	56.65	23.61	0.000
Sağır	1592.8	31.56	1572. 95	56.65	−19.83	0.000
Males (n=78)						
Ulna group-specific	1704.2	51.52	1704.23	66.02	0.035	0.994
Telkkä	1788.6	42.98	1704.23	66.02	−84.33	0.000
Trotter-Gleser, Whites	1735.2	50.50	1704.23	66.02	−30.94	0.000
Trotter-Gleser, Blacks	1661.5	42.98	1704.23	66.02	42.76	0.000
Trotter-Gleser, Mongoloids	1681.2	46.75	1704.23	66.02	23.01	0.000
Shitai	1636.6	42.18	1704.23	66.02	67.59	0.000
Ağrıtmış	1686.3	41.02	1704.23	66.02	17.90	0.000
Sağır	1716.1	44.46	1704.23	66.02	−11.87	0.016

Table 6: Comparison of estimated and measured stature from tibia in various populations

	Estimated height		Measured height		Difference	
	Mean	SD	Mean	SD	(mm)	P
Females (n=62)						
Tibia group specific	1573.0	41.92	1572. 95	56.65	−0.09	0.985
Telkkä	1566.5	34.83	1572. 95	56.65	6.48	0.221
Trotter-Gleser, Whites	1572.9	53.16	1572. 95	56.65	0.09	0.987
Trotter-Gleser, Blacks	1535.5	44.91	1572. 95	56.65	37.48	0.000
Dupertuis-Hadden	1586.6	48.30	1572. 95	56.65	−13.62	0.013
Pearson	1529.1	43.12	1572. 95	56.65	43.89	0.000
Sağır	1561.5	38.00	1572. 95	56.65	11.50	0.031
Günay	1551.4	34.83	1572. 95	56.65	21.58	0.000
Males (n=78)						
Tibia group specific	1704.2	53.70	1704.23	66.02	0.073	0.987
Telkkä	1704.5	48.17	1704.23	66.02	−0.269	0.953
Trotter-Gleser, Whites	1706.4	55.51	1704.23	66.02	−2.21	0.624
Trotter-Gleser, Blacks	1657.3	50.24	1704.23	66.02	46.90	0.000
Trotter-Gleser Mongoloids	1691.6	54.83	1704.23	66.02	12.60	0.006
Dupertuis-Hadden, Whites	1727.0	49.96	1704.23	66.02	−22.75	0.000
Dupertuis-Hadden, Blacks	1680.6	59.96	1704.23	66.02	23.66	0.000
Shitai	1646.0	69.05	1704.23	66.02	58.26	0.000
Sağır	1691.3	53.63	1704.23	66.02	12.89	0.005
Günay	1702.9	61.93	1704.23	66.02	1.33	0.773

When the tibia length derived stature formulae for females are examined, it can be noted that the group-specific formula produces a −0.09 mm mean difference while the other formulae give mean differences between −13.6 and 43.9 (Table 6). Trotter-Gleser's (1958) formula generated for American whites gave the same prediction error as in the group-specific formula we developed for females. Overall, the group-specific formula that has the smallest estimation error is that of male corpses. The stature estimated with the group-specific formula is 0.07 mm above the mean measured stature. The mean error range of the formulae proposed by other researchers suggests changes between −22.75 mm and 58.26 mm.

Discussion

In this study, both a general stature formula and group-specific formulae for long bones were generated for the determination of stature, and the results obtained from these two methods were evaluated. The comparisons show that group-specific formulae always give better results than the classical method. In the predictions in which the group-specific formulae for both ulnae and tibiae are used, the mean difference between the measured stature and the estimated stature is below 1 mm for our study group. The stature estimations done with the general formulae always give less inaccurate results than the group-specific formulae. Other researchers also verify that group-specific formulae do indeed give better results (Duyar and Pelin, 2003; Pelin and Duyar, 2003, Duyar et al., 2006; Duyar, 2007).

As pointed out in various studies, stature estimation derived from long bones may be influenced by some population-specific characteristics (e.g., Duyar and Pelin, 2010; Jantz et al., 2008; Kanchan et al., 2010), thus a regression equation developed for a population may have some restrictions when used in others. With this in mind, we cross checked the equations compared in our study for their viability to our sample, and consequently, the most applicable of these being derived from populations living in Turkey. While, for ulnae, Trotter-Gleser's (1958) equations rising from the American white population gave the most accurate result (6.9 mm) in females, Sağır's (2000) formula, developed from people in Turkey, gave the smallest estimation error (−11.9 mm) in males. When tibiae are being accessed, Trotter-Gleser's (1958) equation for American whites yielded the most accurate result (0.1 mm) in females while Günay et al.'s (1996) equation which they developed from the people in Turkey gave the smallest prediction error (1.3 mm) for males. In terms of estimating stature using ulnae, Telkkä's (1950) equation developed from the people in Finland (−56.0 mm) and Trotter-Gleser's equation for the African-American population gave the most erroneous results (52.9 mm) in females, and Telkkä's equation gave the least inaccurate result (−84.3 mm) for males. For tibiae, Pearson's (1899) equation for the French people (43.9 mm) and Trotter-Gleser's (1958) equation derived from African-Americans (37.5 mm) gave the most erroneous results in females whereas Shitai's (1983) equation from males in South China gave the most misleading result (58.3 mm) in males.

The fact that the equations developed from studies carried out in Turkey comparatively produce the smallest amount of error and the results of the group-specific formulae support the idea that general stature estimation formulae should be population-specific. Therefore, priority should be given to group-specific formulae when estimating stature in forensic cases, reducing the necessity of population-specific equations and enhancing accuracy.

Bibliography

Agnihotri AK, Kachhwaha S, Jowaheer V, Singh AP. (2009) Estimating stature from percutaneous length of tibia and ulna in Indo-Mauritian population. Forensic Sci Int 187:109.e1−109.e3.

Bermúdez OI, Becker EM, Tucker KL. (1999) Development of sex-specific equations for estimating stature of frail elderly Hispanics living in the northeastern United States. Am J Clin Nutr 69:992−998.

Chandler PJ, Bock RD. (1991) Age changes in adult stature: trend estimation from mixed longitudinal data. Ann Hum Biol 18:433−440.

Duyar İ. (2007) Stature-group-specific equations for stature estimation based on long bone lengths. Presented at the 7th Congress of the German Anthropological Association, 10−14 September 2007, Freiburg im Breisgau, Germany.

Duyar I, Pelin C. (2003) Body height estimation based on tibia length in different stature groups. Am J Phys Anthropol 122:23−27.

Duyar İ, Pelin C. (2010) Estimating body height from ulna length: need of a population-specific formula. Eurasian J Anthropol 1(1):11−17.

Duyar İ, Pelin C, Zagyapan R. (2006) A new method of stature estimation for forensic anthropological application. Anthropol Sci 114:23−27.

Feldesman MR, Kleckner JG, Lundy JK. (1990) Femur/stature ratio and estimates of stature in mid- and late-pleistocene fossil hominids. Am J Phys Anthropol 83:359−372.

Galloway A, Stini WA, Fox SC, Stein P. (1990) Stature loss among an older United States population and its relation to bone mineral status. Am J Phys Anthropol 83:467−476.

Giles E. (1991) Corrections for age in estimating older adults' stature from long bones. J Forensic Sci 36:898−901.

Günay Y, Şam B, Yavuz F, Kolusayın Ö, Çöloğlu S. (1996) Tibia uzunluğundan vücut boy uzunluğunun hesaplanması 1. Ulusal Biyolojik Antropoloji Sempozyumu; 1996 Oct 30–31; Ankara.

Jantz RL, Kimmerle EH, Baraybar JP. (2008) Sexing and stature estimation criteria for Balkan populations. J Forensic Sci 53:601−605.

Lundy JK. (1985) The mathematical versus anatomical methods of stature estimate from long bones. Am J Forensic Med Pathol 6:73−76.

Kanchan T, Menezes RG, Moudgil R, Kaur R, Kotian MS, Garg RK. (2010) Stature estimation from foot length using universal regression formula in a north Indian population. J Forensic Sci 55:163−166.

Konigsberg LW, Hens SM, Jantz LM, Jungers WL. (1998) Stature estimation and calibration: Bayesian and maximum likelihood perspectives in physical anthropology. Yrbk Phys Anthropol 41:62−92.

Krogman WM. (1962) The human skeleton in forensic medicine. Springfield, Illinois, USA: Charles C. Thomas.

Mall G, Hubig M, Büttner A, Kuznik J, Penning R, Graw M. (2001) Sex determination and estimation of stature from the long bones of the arm. Forensic Sci Int 117:23−30.

Mohanty NK. (1998) Prediction of height from percutaneous tibial length amongst Oriya population. Forensic Sci Int 98:137−141.

Pelin İC, Duyar İ. (2003) Estimating stature from tibia length: a comparison of methods. J Forensic Sci 48:708−712.

Pearson K. (1899) On the reconstruction of the stature of prehistoric races. Philos Trans R Soc [Serie A] 102:188−198.

Raxter MH, Auerbach BM, Ruff CB. (2006) Revision of the Fully technique for estimating statures. Am J Phys Anthropol 130:374−384.

Sağır M. (2000) Uzun kemik radyografilerinden boy formülü hesaplanması. Ph.D. Thesis. Ankara: Ankara University.

Sjovold T. (1990) Estimation of stature from long bones utilizing the line of organic correlation. Hum Evol 5:431−447.

Shitai M. (1983) Estimation of stature by long bones of Chinese male adults in south China. Acta Anthropol Sin 2:80−85.

Telkkä A. (1950) On the prediction of human stature from long bones. Acta Anatomica 9:103−117.

Trotter M, Gleser GC. (1951) The effect of ageing on stature. Am J Phys Anthropol 9:311−324.

Trotter M, Gleser GC. (1952) Estimation of stature from long bones of American whites and negroes. Am J Phys Anthropol 10:463−514.

Trotter M, Gleser GC. (1958) A re-evaluation of estimation of stature based on measurements of stature taken during life and of long bones after death. Am J Phys Anthropol 16:79−123.