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Modification of the Trotter and Gleser Female Stature Estimation Formulae

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ABSTRACT: Stature-estimation formulae in common use are those of Trotter and Gleser. Their formulae for females are based on Terry collection skeletons. These skeletons are from people who died in the early 1900s. Because there has been considerable change in body size since then, it is possible that the Trotter and Gleser formulae are inappropriate for modern forensic-science application. The Trotter and Gleser female formulae are tested using data from the Forensic Data Bank at the University of Tennessee. For whites, the femur and tibia yield stature estimates differing from one another by about 3 cm. Using femur and tibia lengths from modern forensic cases and modern height data from anthropometric surveys, new regression intercepts are calculated for Trotter and Gleser's female formulae. The new intercepts improve the performance of the formulae on modern individuals. The Trotter and Gleser formulae for black females require no adjustment. Both blacks and whites have experienced a secular increase in bone length, but whites have experienced a change in proportions as well.

KEYWORDS: physical anthropology, female-stature estimation, Trotter and Gleser formulae, femur length, tibia length

The formulae of Trotter and Gleser are the most widely used means of estimating stature. In their 1952 work, male equations were estimated from WWII casualties and female equations were derived from the Terry collection [*1*]. Later, they were able to re-evaluate the male equations using Korean War dead [*2*], but no comparable sample of females is available. The female stature formulae in common use today are still derived from the Terry collection [*3*]. Secular changes in bone length and body height have been well documented [*4,5*]. These secular changes raise the possibility that the Terry-derived female-stature estimation formulae provide unreliable estimates of stature.

What is required is a modern sample of females with height measured during life and long bones after death. Even though no such ideal sample exists, it is still possible to estimate certain regression parameters using readily available modern data. In this article, data from the Forensic Anthropology Data Bank at the University of Tennessee are used to evaluate the secular changes in tibia and femur length, to evaluate the applicability of Terry-based regression formulae to modern females, and to revise the existing female formulae to provide better estimates of stature from lower limb bone length.

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Methods and Materials

The Forensic Anthropology Data Bank contains the following information relevant to the goals defined above: long bone lengths, age, race, sex, and stature [5]. Only cases positively identified for race and sex, and when necessary, age, were used. Stature comes from a variety of sources, including driver's licenses, missing persons reports, medical records, or information obtained from relatives. In some cases it was measured after death.

The first step was to compare long bone lengths from modern forensic cases to those used by Trotter and Gleser. Then, the Trotter-Gleser formulae are used to estimate stature from long bone lengths. These estimates (YHAT) are compared to the living statures (LIVSTAT) recorded in the forensic data bank. When only a cadaver stature was available, it was converted to LIVSTAT by subtracting 2 cm. All living statures were adjusted for age changes using Galloway [6]. Data available for these tests are shown in Table 1.

The familiar regression equation for stature estimation is:

$$Y = bX + a$$

where X = bone lengths, Y = stature, b = slope of regression line and a = Y intercept. The regression coefficient b is estimated from a sample by least squares, and the Y intercept a is calculated from sample means as:

$$a = \overline{Y} - b\overline{X}$$

It has been argued that regression coefficients do not exhibit significant variation among populations within racial groups [7]. Acceptance of this position allows use of the regression coefficients estimated from the Terry samples [1]. New intercepts, if required, can be estimated using independent estimates of bone length and stature.

Results

Table 2 shows mean femur and tibia lengths, their standard deviations and a test of difference between the modern and Terry samples. It is evident that Terry females are significantly shorter in all lengths in both whites and blacks. In blacks the modern vs. Terry difference is about the same for both bones. However, in whites, one sees that the tibia difference is more than twice that of the femur. This in turn implies the existence of a change in proportions in whites, the tibia being relatively longer in modern individuals.

Mean stature for several samples of modern females is shown in Table 3. This is not an exhaustive survey, but should provide a good indication of height variation. The values cluster rather closely around a grand mean of 163.03. Both military samples contain small proportions of nonwhites, but there is no suggestion that an important black-white stature difference exists. Therefore 163 cm is taken as the modern stature mean for both races.

TABLE 1—*Numbers of femora and tibiae available for analysis.*

	Whites	Blacks
Total femora	84	26
Total tibiae	79	19
Femora with ht.	38	15
Tibiae with ht.	34	11

TABLE 2—*Means and standard deviations of female femur and tibia lengths for modern whites and blacks from the forensic data bank compared to Terry Whites and Black.*

		Modern			Terry				
Group	Bone	N	Mean	S.D.	N	Mean	S.D.	diff	t
Whites	Femur	84	438.32	20.94	63	429.59	25.31	8.73	2.23*
Whites	Tibia	82	357.81	20.83	63	340.29	21.51	17.52	4.93*
Blacks	Femur	26	453.85	30.01	177	437.71	23.91	16.14	2.62*
Blacks	Tibia	19	371.31	26.23	177	354.15	21.35	17.16	2.76*

*$P < 0.05$.
**$P < 0.01$.

TABLE 3—*Means and standard deviations of height for various female samples.*

Population	N	Mean	S.D.
U.S. Army [*8*]	1331	162.96	6.52
U.S. Air Force [*9*]	1901	162.10	6.00
U.T. students [*10*]	244	163.74	5.81
Fels mothers [*11*]	99	164.50	5.70
Oakland Blacks [*12*]	1929	162.80	5.93
Oakland Whites [*12*]	5467	163.40	6.22
Weighted mean	10 971	163.03	
Forensic cases[a]	54	165.44	8.58
Terry Whites [*13*][b]	63	160.69	—
Terry Blacks [*13*][b]	177	159.91	—

[a]Present study. Stature adjusted for aging as described in [*6*].
[b]Stature adjusted for cadaver length and aging as described in [*13*].

Also included in Table 3 are mean statures for Terry collection whites and blacks and modern forensic cases. The shorter stature of Terry females compared to modern samples is readily apparent. It is also evident that the forensic mean is higher than means for measured height. This is quite likely a reflection of the well-known overstatement of height [*10,11*].

Table 4 gives the results of applying the Trotter and Gleser [*1*] stature equations for whites to modern forensic-science cases. It shows that the femur and tibia provide quite different mean estimated heights, the tibia estimating height over 3 cm greater than the femur. The standard deviation of the difference between LIVSTAT and YHAT is the error of estimate. It is considerably larger than the error in the original formulae. This is to be expected, since errors of estimate increase when regressions are applied to different samples. In addition, the estimation error will reflect inaccuracies inherent in the forensic statures. Comparing the estimates with statures reported for forensic cases shows that the femur yields estimates about 2.4 cm less than reported stature, while the tibia yields estimates about 0.6 cm greater than reported stature.

Having shown that Trotter and Gleser formulae for whites yield inconsistent estimates, the femur and tibia lengths from modern forensic cases and the estimate of stature obtained from anthropometric surveys are next used to obtain new intercepts for their formulae. For white femur and tibia the intercepts are:

$$\text{Femur: } a = 163 - 2.47 * 438.32 = 54.74$$

$$\text{Tibia: } a = 163 - 2.90 * 357.81 = 59.24$$

TABLE 4—*Comparison of living stature with estimated stature for whites using the Trotter & Gleser '52 formulae.*

	Femur	Tibia
N	38	34
Mean LIVSTAT	166.22	166.40
Mean estimated Ht(YHAT)	163.81	167.04
Mean LIVSTAT-YHAT	2.41	−0.64
Stand. Dev. LIVSTAT-YHAT	3.97	4.42
Min LIVSTAT-YHAT	−7.04	−10.45
Max LIVSTAT-YHAT	9.67	8.86

Incorporating these intercepts into the Trotter and Gleser formulae yields the following:

$$\text{Femur: Stature} = 2.47 * \text{Fem} + 54.74 \pm 3.72$$

$$\text{Tibia: Stature} = 2.90 * \text{Tib} + 59.24 \pm 3.66$$

These new intercepts adjust Trotter and Gleser's femur intercept upward by 0.6 cm and the tibia intercept downward by over 2 cm.

Estimated heights and associated statistics using the revised intercepts are shown in Table 5. Now, the femur and tibia produce similar estimated heights. The discrepancy between LIVSTAT and estimated stature is now consistent for both tibia and femur, ranging from 1.7 to 1.8 cm respectively. The reason for this discrepancy will be addressed in the discussion.

Table 6 shows the application of Trotter and Gleser's black female formulae to the modern forensic cases. As in whites, the femur underestimates LIVSTAT by over 1.7

TABLE 5—*Comparison of living stature with estimated stature for whites using the Trotter & Gleser '52 formulae with new intercepts.*

	Femur	Tibia
N	38	34
Mean LIVSTAT	166.22	166.40
Mean estimated Ht (YHAT)	164.45	164.74
Mean LIVSTAT-YHAT	1.77	1.66
Stand. Dev. LIVSTAT-YHAT	3.97	4.42
Min LIVSTAT-YHAT	−7.68	−8.16
Max LIVSTAT-YHAT	9.03	11.15

TABLE 6—*Comparison of living stature with estimated stature for blacks using the Trotter & Gleser '52 formulae.*

	Femur	Tibia
N	15	11
Mean LIVSTAT	164.35	164.65
Mean estimated Ht (YHAT)	162.85	165.15
Mean LIVSTAT-YHAT	1.50	−0.50
Stand. Dev. LIVSTAT-YHAT	3.83	5.23
Min LIVSTAT-YHAT	−5.08	−9.28
Max LIVSTAT-YHAT	6.34	8.96

cm, but the tibia overestimates LIVSTAT by only 0.57 cm. Using the modern femur and tibia lengths and measured stature to re-estimate the intercepts yields the following:

$$\text{Femur: Stature} = 2.28 * \text{Fem} + 59.52$$

$$\text{Tibia: Stature} = 2.45 * \text{Tib} + 72.01$$

These intercepts are virtually identical to those given by Trotter and Gleser [*1*] for black females. Consequently, it is not necessary to use revised estimates of intercepts for black females; Trotter and Gleser's formulae may be used as originally presented.

Discussion

The results presented above raise several important points bearing on problems in estimating living stature from long bone lengths. The first point concerns the nature of secular trend. The secular increase in height has been repeatedly demonstrated, both skeletally [*4,5*] and from measurements on the living [*14*]. The long bone lengths of modern forensic-science cases compared to Terry collection means are in agreement with previous findings on this point. As far as I am aware, however, a change in femur-tibia proportion has not been previously noted. Trotter and Gleser [2] reported the tibia as the only bone showing a significant difference between WWII and Korean war dead. They attributed the difference to different technicians having measured the two series rather than a biological change. These results make it more difficult to dismiss the difference as technical variation. At present, however, one can only speculate about what underlying biological causes may be responsible for the secular change in femur-tibia proportions.

Equally interesting is the apparent absence of a change in femur-tibia proportions in blacks. Even though modern blacks exhibit a secular increase in long bone length compared to Terry blacks, the increase is isometric. For this reason the intercepts originally presented by Trotter and Gleser based on the Terry collection remain valid. The sample of blacks is admittedly small so the above conclusions must remain tentative.

The second point concerns the manner in which stature is attributed to individuals. Trotter and Gleser in their 1952 study measured stature systematically from cadavers. In their later work they used military records, again a systematic source of height. In the sample of modern forensic-science cases no such systematic source of stature is available. From the 54 individuals possessing an estimate of height, six were measured after death. The remaining estimates came from such various sources as driver's license, missing-persons reports, relatives, and medical records. Such sources of height information are notoriously inaccurate [*15*]. Willey and Falsetti [*10*] found that height as it appears on driver's licenses overstates measured height by 0.57 cm in a female sample drawn from the University of Tennessee community. Mothers in the Fels research sample overstated their own heights by an average of 1 cm, and their husband's heights by 1.3 cm [*11*]. This tendency to overestimate height presumably applies to the various estimates of living stature available from the forensic records. That mean reported height of forensic cases exceeds average predicted height by about 0.7 cm can most easily be explained by a systematic over reporting of height in forensic cases. It is apparent that when one estimates stature from long bones as part of the preliminary identification process, the wide latitude in reported stature to which the estimate will be compared must be borne in mind.

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