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Estimation of Stature from Metacarpal Lengths

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ABSTRACT: Formulae for the estimation of stature from metacarpal lengths are presented. Two samples of metacarpal specimens were employed in the analysis: one of 212 individuals from the Terry Collection, and one of 55 modern males, all of whom had measured statures. One measurement, the midline length, was taken on each metacarpal. Stature was regressed on the basis of the metacarpal length to derive equations for the Terry Collection individuals. Comparisons between the Terry Collection males and the modern sample showed the latter to have longer metacarpals and greater statures. The Terry equations were tested using the modern male sample. In spite of the differences noted, the Terry equations perform acceptably on modern individuals. The performance was slightly better for whites than for blacks. Since the female equations were not tested, they should be employed with greater caution.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, stature, metacarpals

In the study of modern human skeletal remains, stature estimates are usually based upon the long bone length. In the absence of measurable long bones, other skeletal elements, such as the clavicle [*1*], vertebrae [*2,3*], and metatarsals [*4*], have been employed. Only one attempt to use metacarpals is known to us: in that study, Musgrave and Harneja [*5*] used 166 living subjects of British extraction (120 males and 46 females). Since hands or hand bones are occasionally encountered in forensic science cases as the only available skeletal elements, the need for further information is evident.

Materials and Methods

The study included two samples, one from the Terry Collection, Smithsonian Institution, Washington, DC, and one of modern individuals from the Regional Forensic Center, Memphis, Tennessee. These two samples are dealt with separately, the modern sample being employed as a test sample.

Terry Collection Sample

The metacarpals of 212 individuals from the Terry Collection were included in the dry bone sample. All ten metacarpals were measured for 53 black males, 56 white males, 55 black females, and 48 white females. The majority of these individuals were chosen because they were used in a previous stature study [*6*], and femur length data were

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available. The age, sex, race, and stature were known for all specimens included in the sample.

The midline length (ML), defined as the length from the midline of the proximal articular surface to the midline of the distal articular surface [*7,8*], was measured on each metacarpal (Fig. 1). A Helios dial caliper was used to take the measurements, which were recorded to the nearest tenth of a millimetre. Stature was adjusted for cadaveral stature by subtracting 2 cm from each individual [*4,9*].

Methods similar to those used by Trotter and Gleser [*10*] were followed in determining age changes. First, stature was regressed onto the femur length and age to obtain the equation

$$\text{Stature} = b_0 + b_1\,(\text{femur}) + b_2\,(\text{age})$$

where b_0 is the intercept, b_1 is the slope, and b_2 is a partial regression coefficient that describes stature loss with age after controlling for femur length. It was used to estimate maximum stature:

$$\text{Maximum stature} = \text{stature} - b_2\,(\text{age} - 45)$$

Trotter and Gleser [*10*] used 30 as the age when stature decline begins, but Galloway [*11*] and Cline et al. [*12*] report that stature loss begins around 45 years of age. Therefore, we adjust individuals 45 and over to their maximum stature.

The general linear model procedure using the SAS package on the University of Tennessee's Vax cluster was used to estimate regression models for each bone:

$$\text{Maximum stature} = b_0 + b_1\,(\text{bone length}) + b_2\,(\text{group}) + b_3\,(\text{bone length} * \text{group})$$

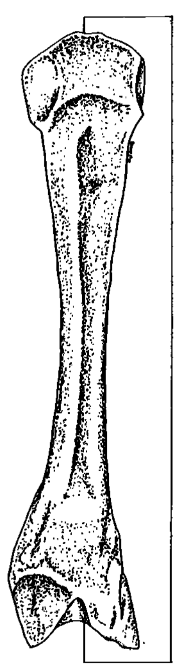

FIG. 1—*Drawing illustrating how the midline length is measured on a second metacarpal.*

The null hypothesis $b_3 = 0$ tests for slope variation among groups. If the null hypothesis is accepted, a common slope for all groups may be employed. In this case, the regression model

$$\text{Maximum stature} = b_0 + b_1 \text{ (group)} + b_2 \text{ (bone length)}$$

is appropriate. Stepwise regression was also performed to determine whether multiple bones improved the relationship between stature and bone length. All analyses were conducted on the left and right sides separately.

Modern Test Sample

A sample of modern Americans was employed as a test sample for the new equations as well as to test for possible changes in stature or bone length due to secular trend. This sample included both left- and right-hand wrist radiographs of 30 black and 25 white males examined at the Regional Forensic Center in Memphis, Tennessee, between May and November 1989. The age, race, sex, and stature were recorded, although the precise age was unavailable for 3 individuals. Stature was measured using an anthropometer from heel to crown while the body was in a supine position and recorded in centimetres to the nearest half centimetre. These statures were then adjusted for cadaveral statures by subtracting 2 cm.

The radiographs were made with the hand positioned palm up so that the dorsal surface was closer to the surface to minimize distortion, with a scale taped to the film cassette. The cone of the X-ray machine was approximately 76 cm from the film.

The metacarpal measurements taken on radiographs included the midline length as defined above. A Helios dial caliper was used to measure to the nearest tenth of a millimetre. The scale used on the radiographs was measured to test for parallax. Twenty diameters of the standard on radiographs were measured to the nearest thousandth of a millimetre, and a mean was determined. Two diameters were measured on the actual standard to the same accuracy and averaged. The actual standard mean was then subtracted from the radiographic standard mean to determine the required adjustment for the radiographic measurements. The correction, 0.24 mm, was subtracted from the measurements prior to further analysis.

For the modern sample we used Galloway's [*11*] age adjustment. Differences in the means between the Terry sample and the modern sample were tested for significance. The new equations were then used to estimate statures of the modern sample.

Results

Terry Collection

The aging coefficients found by least squares analysis are given in Table 1 and were used to adjust the recorded stature to the maximum stature for individuals 45 years or older. The maximum statures are used for the remaining analyses. Summary statistics are given by groups in Table 2.

The strength of the relationship between metacarpal length and stature is reflected in the correlation coefficients for each of the five measurements for both the left and right sides, and these are given in Table 3.

Test results for slope differences were not significant. The equations for stature estimations are given in Table 4. Since slopes exhibit no significant variation, a common slope and standard error of estimate may be applied to all groups. To estimate stature, one multiplies the metacarpal length times the slope corresponding to the metacarpal

TABLE 1—*Age adjustment formulae for the Terry Collection.*[a]

Race	Sex	Formula
White	Male	max stature = stature + 0.098 80 (age over 45)
White	Female	max stature = stature + 0.182 94 (age over 45)
Black	Male	max stature = stature + 0.047 94 (age over 45)
Black	Female	max stature = stature + 0.060 65 (age over 45)

[a]Results in centimetres.

and adds the appropriate intercept. (The following illustrates how the formulae are used to estimate stature, employing the third left metacarpal of a black male with a midline length of 73mm.)

$$\text{Stature} = (73\text{ mm})\,(1.298) + 80.28 \pm 5.19$$

$$\text{Stature} = 165.03\text{ cm} \pm 5.19$$

The stepwise analysis yielded no significant improvement in stature estimation.

TABLE 2—*Summary statistics for the Terry Collection.*

		Whites		Blacks	
Variable		Mean	SD[a]	Mean	SD
		MALES[b]			
Age, years		57.82	14.43	45.77	16.32
Stature, cm		169.13	7.47	171.36	7.41
Left, mm	M1	46.12	2.98	49.30	2.85
	M2	66.47	4.08	71.15	4.08
	M3	64.89	3.75	70.16	4.21
	M4	58.09	3.73	62.30	4.01
	M5	53.46	3.37	57.34	3.57
Right, mm	M1	46.62	3.06	49.54	3.11
	M2	66.33	4.02	71.20	4.01
	M3	65.02	3.68	70.19	4.15
	M4	57.89	3.61	62.20	3.66
	M5	53.01	3.13	57.22	3.54
		FEMALES[c]			
Age, years		64.33	15.91	42.04	17.77
Stature, cm		161.54	7.64	159.36	6.96
Left, mm	M1	43.01	2.95	44.22	2.66
	M2	62.28	4.11	65.58	3.98
	M3	60.65	4.20	64.38	4.01
	M4	54.18	3.78	57.08	3.70
	M5	49.73	3.36	52.03	3.17
Right, mm	M1	43.10	2.91	44.53	2.70
	M2	62.68	4.49	66.04	4.24
	M3	61.08	4.30	67.57	3.76
	M4	54.62	3.96	56.95	3.64
	M5	49.93	3.41	52.30	3.10

[a]SD = standard deviation.
[b]White males = 56; black males = 53.
[c]White females = 48; black females = 55.

TABLE 3—*Correlation coefficients for stature and bone length.*

	Whites		Blacks	
	Males	Females	Males	Females
Left M1	0.659	0.667	0.627	0.648
M2	0.809	0.788	0.676	0.613
M3	0.825	0.746	0.613	0.671
M4	0.816	0.711	0.599	0.677
M5	0.780	0.685	0.604	0.611
Right M1	0.641	0.704	0.654	0.668
M2	0.790	0.779	0.655	0.641
M3	0.785	0.710	0.572	0.698
M4	0.811	0.724	0.615	0.614
M5	0.704	0.640	0.591	0.634

Modern Sample

Summary statistics are given for white and black males in Table 5. Table 6 shows the differences between the means of the Terry Collection and modern samples. This difference divided by its standard error provides a test of significance. In all comparisons, except left *M*1, the differences are negative, denoting greater values in the modern sample. Only differences in the white sample are consistently significant at the 0.05 level or below. In whites, Metacarpals 2 through 5 exhibit greater differences than the first metacarpal, while in blacks this pattern does not emerge.

Table 7 gives the results of applying the Terry stature formulae to the modern test sample. The mean residuals are calculated as $\Sigma(Y_i - \hat{Y}_i)/N$ and provide an indication of systematic bias. Whites show a distinctive pattern: the first metacarpal yields a pattern of overestimation of stature, while the systematic bias for Metacarpals 2 through 5 is small. In blacks, the systematic bias is more variable: the first metacarpal yields systematic overestimation, while Metacarpals 2 through 5 yield systematic underestimation.

The standard error columns in Table 7 show what percentage of the test cases yield predictions within one, two, and three standard errors of maximum stature. The equations for whites perform slightly better than those for blacks. In whites, 60% or more of the

TABLE 4—*Equations for stature estimation for the Terry Collection, in centimetres.*

		b_0 (Intercept)				
		Whites		Blacks		
	b_1 (Slope)	Males	Females	Males	Females	SE[a]
Left M1	1.674	91.89	89.52	88.81	85.33	5.57
M2	1.311	81.96	79.86	78.05	73.36	5.10
M3	1.298	84.90	82.81	80.28	75.79	5.19
M4	1.355	90.41	88.11	86.93	82.01	5.27
M5	1.468	90.64	88.52	87.17	82.97	5.47
Right M1	1.659	91.77	90.02	89.15	85.45	5.52
M2	1.261	85.51	82.52	81.60	76.11	5.15
M3	1.279	85.98	83.44	81.61	76.80	5.36
M4	1.375	89.54	86.44	85.44	81.07	5.33
M5	1.433	93.16	89.95	89.35	84.41	5.67

[a]SE = standard error of the mean.

TABLE 5—*Summary statistics for modern males.*

Variable	Whites[a] Mean	Whites[a] SD	Blacks[b] Mean	Blacks[b] SD
Age, years	46.29	21.51	42.21	14.94
Stature, cm	169.13	7.47	172.45	6.57
Left, mm M1	47.37	2.66	49.26	3.72
M2	70.18	2.79	72.55	4.10
M3	68.06	3.22	71.02	3.95
M4	61.94	3.22	63.60	4.17
M5	56.36	2.63	58.73	4.17
Right, mm M1	47.86	2.52	49.63	4.59
M2	70.15	2.31	72.83	4.17
M3	67.73	2.24	71.65	4.27
M4	60.95	2.28	64.18	4.07
M5	56.03	2.54	58.52	4.15

[a]Whites: left, 24 individuals; right, 25.
[b]Blacks: left, 30 individuals; right, 29.

predicted statures fall within ±1 standard error of the maximum stature. In blacks, this value is 50% or less. In blacks, however, all predicted values fall within ±2 standard errors of the maximum stature. These figures show that application of the Terry formulae to modern individuals will predict stature within ±1 standard error 50% or more, and only rarely will the prediction be off by 3 or more standard errors.

Discussion and Conclusions

The purpose of this study is to provide another means for the estimation of stature when long bones are unavailable. It utilizes American whites and blacks so the stature formulae should be more appropriate for the American population than those of Musgrave

TABLE 6—*Differences between Terry and modern sample means and the ratio of differences to standard errors, in centimetres.*

Variable		Whites[a] Differences	Whites[a] Differences/SE	Blacks[b] Differences	Blacks[b] Differences/SE
Stature		−4.18	−2.59*	−1.10	−0.10
Left	M1	−1.25	−1.85	0.04	0.05
	M2	−3.71	−4.71**	−1.41	−1.50
	M3	−3.17	−4.28**	−0.86	−0.81
	M4	−3.46	−4.20**	−1.30	−1.42
	M5	−2.90	−4.14**	−1.39	−1.53
Right	M1	−1.23	−1.90	−0.09	−0.10
	M2	−3.82	−5.40**	−1.63	−1.72
	M3	−2.71	−4.07**	−1.46	−1.49
	M4	−3.06	−4.61**	−1.98	−2.18*
	M5	−3.02	−4.59**	−1.32	−1.45

[a]Whites: left, 24 individuals; right, 25.
[b]Blacks: left, 30 individuals; right, 29.
[c]Probabilities:
*$P < 0.05$.
**$P < 0.01$.

TABLE 7—*Results of the modern test sample using new equations.*

Variable	Residual Mean	Proportion Correct ±1 SE	±2 SE	±3 SE
		WHITES		
Left ($N = 24$)				
M1	−2.38	0.625	0.333	0.042
M2	+0.39	0.667	0.333	...
M3	−0.34	0.708	0.292	...
M4	+0.24	0.750	0.208	0.042
M5	−0.20	0.667	0.333	–
Right ($N = 25$)				
M1	−2.15	0.720	0.160	0.120
M2	+0.66	0.640	0.320	0.040
M3	−0.69	0.760	0.240	...
M4	+0.03	0.880	0.080	0.040
M5	+0.14	0.720	0.280	...
		BLACKS		
Left ($N = 30$)				
M1	−1.18	0.500	0.500	...
M2	+0.71	0.433	0.567	...
M3	+0.01	0.533	0.467	...
M4	+0.65	0.467	0.533	...
M5	+0.93	0.300	0.700	...
Right ($N = 29$)				
M1	−1.02	0.448	0.552	...
M2	+0.92	0.552	0.448	...
M3	+0.73	0.552	0.448	...
M4	+1.17	0.552	0.448	...
M5	+0.72	0.448	0.552	...

and Harneja [*5*]. Further, the sample sizes are greater and the correlations of stature with metacarpal length slightly higher than those reported by Musgrave and Harneja for the male sample. Our correlations range from 0.565 to 0.828, theirs from 0.53 to 0.67. Consequently, our standard errors of estimate are lower, ranging from 4.68 to 5.96 cm; those of Musgrave and Harneja range from 5.49 to 6.30 cm. In the female sample, our correlations range from 0.61 to 0.79, theirs from 0.61 to 0.84. However, their female samples are quite small with 20 for the left side, and 26 for the right side. The differences between their left and right sides are explained through the two different samples, while our female sample includes the left and right sides from the same individuals. The standard errors of estimate are lower, ranging from 4.68 to 5.96 for our sample of females; those of Musgrave and Harneja range from 4.71 to 8.15.

Comparison of our metacarpal-stature correlations with those of Steele [*13*] and Simmons et al. [*6*] clearly shows the metacarpal relationships to be stronger than those for long bone fragments. Stature estimation equations from long bone fragments possess correspondingly higher standard errors of estimate. Therefore, stature estimates from metacarpals are to be preferred to those based on long bone fragments.

Terry Collection data have been used extensively to establish identification standards [*14,15*]. Rarely have these standards been systematically tested on modern people. Differences between the Terry long bone dimensions and those of modern cases have been documented, and Terry-based standards have been shown to be biased in certain instances [*16*]. Our comparisons show that the Terry and modern samples also differ in metacarpal lengths, yet our modern sample was predicted by the Terry equations with relatively small bias, especially when using Metacarpals 2 through 5.

The equations for females have not been tested; they should be used with caution. The equations for males, however, indicate that, whenever possible, in the absence of intact long limb bones, metacarpals can be reliably employed for the estimation of stature. In particular, Metacarpals 2 through 5 should be used instead of the first metacarpal.

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