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Estimation of Adult Stature from Fragmentary Tibias

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ABSTRACT: Linear-regression equations derived from measurements of tibial condyles from 100 individuals in the Hamann-Todd Collection retrodicted known stature with a level of confidence comparable to many of the existing stature-estimation techniques. Statures of an independent control group were estimated with similar success. The strong linear relationship that exists between the length of the tibia and the size of the condyles allows adult stature (of American whites and blacks) to be estimated from the proximal tibia. Since complete tibial length is not required, this technique could prove useful in forensic science and archaeological cases where less-than-intact elements are recovered.

KEYWORDS: physical anthropology, stature estimation, tibia, osteology

Estimation of human stature by mathematical methods has a long history in physical anthropology [*1*]. Today, probably the most common techniques used by forensic anthropologists, archaeologists, and others who need to calculate stature from skeletal remains, are those developed by Trotter and Gleser in a series of articles [*2–5*] and by Genovés [*6*]. Other techniques (for example, [*7–9*]) are used less frequently but are based on the same logical, general principle—a linear relation exists between bone length and body height.

A drawback to mathematical techniques of estimating stature has always been limited applicability to fragmentary remains. With a few exceptions, most of these techniques require substantial portions of the skeleton, or at least one intact limb bone, to accurately estimate height. Yet archaeological specimens commonly are recovered with no intact, or even reparable, long bones. The same is true in many forensic-science cases. Steele and McKern [*10,11*] attempted to overcome this handicap by devising a technique that uses measurements of long-bone segments rather than intact elements. Unfortunately, the effectiveness of this method in less-skilled hands is limited, since it may be "difficult to locate the necessary anatomical landmarks" required [*12*, p. 28]. (See Simmons, Jantz, and Bass [*13*] for a "revision" of this technique that is applicable to fragmentary femurs.)

The technique presented in this paper was devised for use on less-than-complete tibias from which no reliable measurements of length can be obtained (and is an offshoot of a study on the applicability of the proximal tibia to sex estimation [*14*]). Since the required measurements are taken from the tibial condyles, the requisite landmarks may be easier to locate than those required by the Steele and McKern technique.

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Materials

A total of 116 left tibias from the Hamann-Todd Collection at the Cleveland Museum of Natural History were measured. The tibias were selected from 58 males and 58 females, distributed equally by race (black or white). No tibias with obvious or suspected pathologies (for example, arthritis) were used.

The 116 tibias were divided into two samples. Sample 1 (n = 100) was used to formulate the regression equations employed in this study, and Sample 2 was employed as an independent test of the equations' accuracy. Sample 2 consists of 8 males and 8 females distributed equally by race. Neither sample controlled for age (Table 1).

Statures for individuals represented by the selected tibias were taken from the Hamann-Todd files (see Todd and Lindala [*15*] for information on how statures were measured). These figures represent stature at time of death. Although corrections for the difference between stature during life and that measured in the morgue were not made, Dupertuis and Hadden [*16*] had concluded earlier that the statures assembled for the Hamann-Todd cadavers were equivalent to living statures. Furthermore, since stature estimates generated from single bones, such as the tibia, probably will most closely reflect maximum stature attained during life rather than stature that results from age-related changes, it was necessary to correct reported statures for age before analysis. This was done using

TABLE 1—*Sample 1 statistics.*

Category	Age	Stature (cm)[a]	Measurement (mm)				
			BB	MCW	MCL	LCW	LCL
Means							
Total sample	42	168.4	71.97	31.27	45.65	32.23	39.62
White male	48	171.8	75.78	33.39	47.93	33.93	42.36
Black male	36	177.2	77.62	33.80	48.81	35.19	42.98
Black female	37	161.9	66.61	29.03	42.76	29.94	36.28
White female	48	162.4	67.85	28.84	43.09	29.87	36.87
Male	42	174.5	76.70	33.60	48.37	34.56	42.67
Female	42	162.2	67.23	28.94	42.93	29.90	36.58
White	48	167.1	71.81	31.12	45.51	31.90	39.61
Black	37	169.6	72.12	31.42	45.79	32.56	39.64
Standard deviations							
Total sample	17	8.9	5.63	3.15	4.19	3.06	4.31
White male	13	6.6	3.36	2.41	3.95	2.48	3.64
Black male	17	6.0	2.75	2.06	2.96	1.73	2.89
Black female	16	5.0	2.36	1.82	2.14	1.17	2.25
White female	17	7.1	3.25	2.20	3.47	2.18	3.32
Male	17	6.8	3.18	2.23	3.48	2.21	3.27
Female	18	6.1	2.88	2.00	2.86	1.74	2.82
White	16	8.2	5.17	3.24	4.42	3.09	4.42
Black	17	9.5	6.11	3.08	3.98	3.03	4.25
Ranges							
Total sample	16–81	144.4–189.0	60–83	26–39	37–55	25–38	32–52
White male	25–81	158.0–185.4	67–83	29–39	38–55	29–37	36–52
Black male	18–62	166.4–189.0	70–82	31–38	42–53	31–38	36–49
Black female	16–71	171.6–150.5	62–71	26–34	39–47	28–32	32–40
White female	19–78	144.4–177.2	60–79	26–35	37–54	25–36	32–47
Male	18–81	158.0–189.0	67–83	29–39	38–55	29–38	36–52
Female	16–78	144.4–177.2	60–79	26–35	37–54	25–36	32–47
White	19–81	144.4–185.4	60–83	26–39	37–55	25–38	32–52
Black	16–71	150.5–189.0	62–82	26–38	39–53	28–38	32–49

[a]Corrected for age.

the protocol determined by Trotter and Gleser [*2*]. (Note that Galloway [*17*] cites slightly different age-related stature corrections.)

Methods

Eight measurements of the proximal end of each tibia were taken to the nearest 0.1 mm using a vernier sliding caliper. One day later, 20 (20%) of the Sample 1 tibias were remeasured, and the pool of measurements was culled to five, each having an intraobserver error of 3.5% or less. This level was selected arbitrarily as it proved to be a natural separation point. The five measurements retained are described below. Martin [*18*] may be consulted for clarification. Note that these are the same measurements that can be used for sex identification [*14*].

1. Biarticular breadth (BB): Maximum breadth of the proximal articular surface of the tibia as measured from the lateral edge of the lateral condyle to the medial edge of the medial condyle. This is not the maximum breadth of the proximal tibia (cf. [*18*]), but rather the maximum breadth of the articular surface. The calipers should be placed only on the articular surface edges of condyles.
2. Medial condyle articular width (MCW): Maximum transverse width of the medial condyle as measured from lateral to medial edges. The surface of the condyle generally is circumscribed by a slight rim, and points of the caliper should be placed on this rim.
3. Medial condyle articular length (MCL): Similar but perpendicular to width. Measurement should record maximum length from the anterior edge of the medial condyle to the posterior margin.
4. Lateral condyle articular width (LCW): Similar to width measurement made on the medial condyle but made on the lateral condyle.
5. Lateral condyle articular length (LCL): Maximum length of the lateral condyle as measured in a manner similar to that for MCL.

Following measurement, simple and multiple linear-regression equations were formulated using the SYSTAT statistical package (version 3.2; [*19*]) on a Macintosh SE computer. Selected equations are listed in Table 2 along with the corresponding standard errors for each equation. (Note Giles and Klepinger's [*20*] words of caution concerning the use of standard errors in linear-regression estimates.) To use the equations, the designated measurement (in mm) is multiplied by the appropriate coefficient, and the corresponding constant is added to the product. The final value is the estimated adult stature in cm.

Results and Discussion

Estimation of adult stature using the proximal tibia is possible due to a linear relation that holds between stature and dimensions of the proximal end of the tibia (for example, Fig. 1, biarticular breadth shown, $r = 0.82$).

To be of value, the stature formulas presented here must not simply estimate adult stature; rather they must do so with a level of confidence comparable to existing techniques. For example, standard errors for complete bones in the Trotter and Gleser series range from 2.99 to 5.05 cm; for the Genovés equations the range is 2.61 to 3.82 cm; and for the Steele and Mckern equations for use on fragmentary remains the range is 3.71 to 6.01 cm. By comparison, the equations selected for inclusion in Table 2 have standard errors ranging from 3.69 to 5.92 cm. The percentage of Sample-2 tibias whose estimated statures fall within these standard errors ranges from 50 to 100% (Table 2). (Obviously, the small number of Sample-2 individuals will necessitate further studies to adequately evaluate the techniques' accuracy.)

TABLE 2—*Equations for the estimation of adult stature (in cm) from the proximal tibia.*

Equation	Standard error (+/−)	Sample 2	
		n	Accuracy (%)[a]
White Male			
1.031 (MCL) + 122.38	5.24	4	75
1.149 (MCW) + 0.992 (MCL) + 85.87	4.51	4	75
0.867 (MCL) + 0.606 (LCL) + 104.56	4.88	4	75
0.947 (MCW) + 0.911 (MCL) + 0.325 (LCL) + 82.73	4.48	4	75
Black Male			
1.313 (BB) + 75.36	4.88	4	100
1.115 (MCL) + 122.80	5.11	4	100
1.14 (LCL) + 128.26	5.11	4	75
0.836 (MCL) + 0.853 (LCL) + 99.79	4.62	4	100
Black or White Male			
1.145 (MCL) + 119.14	5.56	8	75
1.054 (LCL) + 129.55	5.92	8	88
0.924 (MCL) + 0.742 (LCL) + 98.17	5.11	8	88
0.966 (MCW) + 1.012 (MCL) + 93.12	5.19	8	75
0.641 (BB) + 0.806 (MCL) + 0.352 (LCL) + 71.39	4.95	8	88
0.621 (MCW) + 0.896 (MCL) + 0.549 (LCL) + 86.86	5.01	8	75
White Female			
1.64 (MCL) + 91.77	4.29	4	50
1.642 (LCL) + 101.89	4.62	4	75
1.66 (BB) + 50.27	4.71	4	75
1.062 (MCL) + 0.854 (LCL) + 85.19	3.86	4	50
1.032 (LCW) + 1.149 (LCL) + 89.22	4.41	4	75
0.950 (MCL) + 0.578 (LCW) + 0.661 (LCL) + 79.84	3.84	4	50
Black Female			
1.318 (MCL) + 105.82	4.35	4	75
0.905 (LCL) + 129.05	4.62	4	75
1.142 (MCW) + 128.78	4.64	4	50
1.374 (MCL) + 0.962 (LCL) + 68.44	3.77	4	50
0.742 (MCW) + 1.089 (MCL) + 94.02	4.24	4	75
0.613 (MCW) + 1.182 (MCL) + 0.916 (LCL) + 60.50	3.69	4	75
Black or White Female			
1.556 (MCL) + 95.53	4.25	8	63
1.393 (LCL) + 111.18	4.63	8	88
1.134 (MCL) + 0.842 (LCL) + 82.75	3.73	8	63
Black or White Male or Female			
1.085 (MCL) + 0.904 (LCL) + 83.01	4.47	16	69
0.296 (BB) + 0.261 (MCW) + 0.894 (MCL) + 0.562 (LCL) + 75.87	4.34	16	69

[a]Number of control individuals whose estimated stature falls within one standard error.

Analysis of residuals suggests that the equations presented here have a slight tendency to underestimate stature. Furthermore, estimates greater than 175 cm and less than 160 cm tend to produce larger residuals than estimates that fall between those values. Both trends are weak, however, and the overall pattern of residual values is random.

Conclusions

The technique presented here must be employed with a full awareness of the restrictions that confine it. Not only were the equations generated from a small sample (in comparison

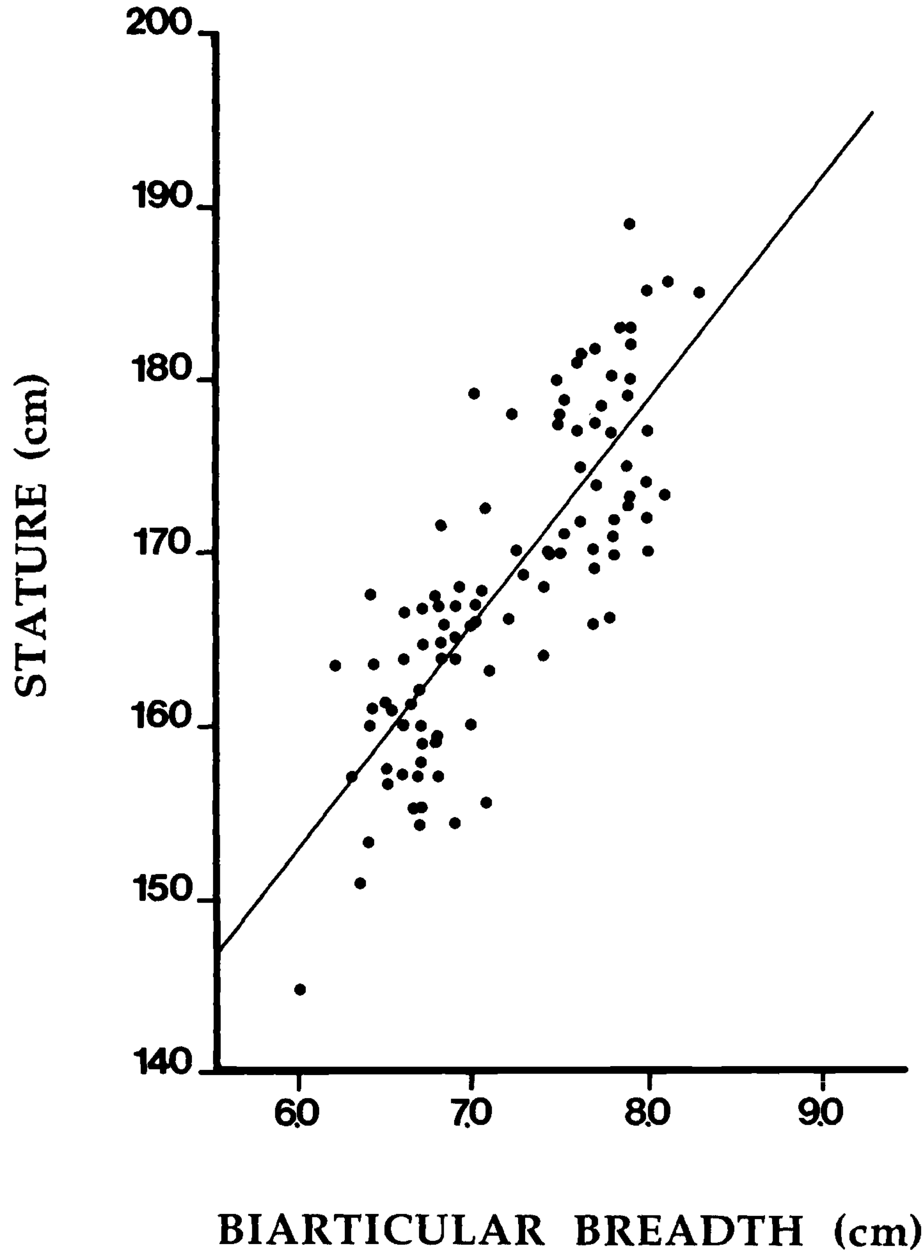

FIG. 1—*Linear relation between age-corrected adult stature and biarticular breadth of the tibia. (Points represent all Sample-1 tibias without segregation by sex or race.)*

to that of Trotter and Gleser, for example) of morgue specimens, but ethnically the sample was restricted to American blacks and whites. Therefore, until demonstrated otherwise, these equations should be considered population specific. Further, despite a level of precision comparable to existing, better-established methods, the technique presented here is offered only as a supplement for these methods. Whenever possible, stature estimates should always be made using the most-reliable technique on the most-reliable element, that is, from intact long bones. Adult stature should not be estimated from the proximal tibia unless there is no other viable option. With these caveats clearly stated, the proximal tibia is useful for estimating stature in archaeological and forensic-science cases where no intact elements are recovered.

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