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Stature Estimation from Fragmentary Femora: A Revision of the Steele Method

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ABSTRACT: The skeletal remains presented to forensic anthropologists are often fragmentary. Previously described methods of estimating stature from segments of long bones have not proved satisfactory because of the difficulty involved in identifying the precise anatomical landmarks by which they are defined. This study represents an assessment of the feasibility of stature estimation from fragmentary femora. A sample of 200 males and females, blacks and whites (total sample = 800), was obtained from the Terry Collection. New regression equations for the estimation of maximum femur length and stature from three well-defined and easy-to-measure segments of the femur are presented. This technique represents an improvement over methods currently in use for estimating stature from femur fragments; the location of the anatomical landmarks and the accuracy of the prediction are enhanced. The applicability of these formulae to a modern forensic sample is addressed with regard to secular trends in stature increase and changes in body segment proportions.

KEYWORDS: physical anthropology, human identification, musculoskeletal system, fragmentary femora, secular trend, stature estimation

The estimation of stature from various skeletal elements has been an area of critical interest to physical anthropologists for nearly 100 years [*1*]. Past studies concerning stature estimation have been based on groups as racially and geographically diverse as the Chinese [*2*], British and East Africans [*3*], Mesoamericans [*4*], and South African blacks [*5,6*]. These papers presented data and statistical formulae for the determination of stature based on various long bone lengths. The formulae most often employed in the United States are those provided by Trotter and Gleser [*7–10*] and Trotter [*11*] for whites and blacks. All of these studies have demonstrated that there is a high correlation between the length of any whole, long limb bone and stature; the highest single correlation is usually with the femur.

Forensic anthropologists are often confronted with fragmentary remains, while the estimation of stature by conventional formulae is dependent upon whole limb bones. The estimation of living stature from long bones is based upon the principle that the various long limb bones correlate positively with stature. Since this is true, the parts of

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each individual long bone should also be related to stature even though they may not correlate as highly as the length of the whole bone. Stature estimation from fragmentary long bones has been attempted by Muller [*12*], Steele and McKern [*13*], and Steele [*14*]. In practice, these methods are problematic to apply because of the difficulty in identifying the exact location of necessary anatomical landmarks. Steele [*14*] himself recognized this problem when he stated:

> Another landmark not used in the present study, but used previously by the author and Dr. McKern, involves the humerus alone. The landmark in question is the point of greatest narrowing at the middle of the diaphysis. Although this narrowing can be related to a point, posterolaterally in the radial groove where the lateral supracondylar ridge becomes indistinct (on a level with the distal termination of the surface for m. deltoideus), in practice the point proved impossible to locate with sufficient constancy to give useful results (p. 87).

Most practicing physical anthropologists have also experienced difficulties in locating many of the other anatomical landmarks used to predict stature from fragmentary long bones. Indeed, many do not use either the Steele and McKern [*13*] or the Steele [*14*] formulae and hence do not attempt to estimate stature when no whole long limb bones are present because of this very difficulty. However, since skeletal remains are often fragmentary, it would be useful to devise a more reliable technique for stature estimation from smaller segments of long bones.

Objective

The objective of this study is to assess the feasibility of stature estimation using small fragments of the femur. As described above, the Steele and McKern [*13*] and Steele [*14*] methods are plagued by the difficulty of identifying the anatomical landmarks which define the various segments of the limb bones upon which estimations are calculated. The present approach seeks to avoid this pitfall by using standard, clearly defined measurements taken on the distal, proximal, and midshaft regions of the bone. Many of these measurements are already familiar to physical anthropologists, who regularly use them for comparative population studies or, in some cases, the determination of gender. It is also hoped that, if one presents data and provides equations for the estimation of stature from small segments of all areas of the bone, any recovered section might be used to estimate stature. It will normally be the case that smaller segments of bone will exhibit weaker relationships to stature than larger segments. Because the emphasis of this study is on smaller segments, the equations generated are therefore expected to offer a lower prediction accuracy for both maximum femur length and stature. However, when small segments alone are available, this approach will offer the best opportunity for the estimation of stature. The relationship of these dimensions to maximum femur length and stature has never been systematically examined.

The femur was selected as the initial skeletal element to be analyzed because, in addition to its high correlation with stature, it is (along with the feet) one of the bones most frequently recovered from Air Force crash sites. It is a large, durable bone protected by both large amounts of soft tissue and the seat and harness mechanisms of the aircraft.

Methodology

The sample measured was obtained from the Terry anatomical collection housed at the Smithsonian Institution's National Museum of Natural History in Washington, DC. The skeletons in the Terry collection are from cadavers dissected at the Washington University School of Medicine, St. Louis, Missouri, for which records contain reasonably accurate data for age, sex, race, and cadaver stature of the individuals. A sample of approximately 200 males and 200 females from blacks and whites (yielding a total sample of 800 individuals) was obtained. To be included in the sample, an individual must have race and sex recorded on the morgue record. Only femora exhibiting no gross pathological changes of the distal, proximal, or midshaft regions were included in the study. Left femora were measured whenever possible, though right femora were substituted if breakage or pathological conditions precluded the use of the left. Preference for inclusion in the sample was given to individuals for whom age and cadaver stature was also recorded. With few exceptions, photographs of the cadavers were examined in order to be certain that the stature was recorded when the body was placed vertically with the feet in natural plantar position.

The measurements used are defined in Table 1 and illustrated in Fig. 1. All seven measurements are standard and defined in Martin [*15*]. The definition of No. 7 was modified from a midshaft diameter to a minimum transverse shaft diameter in order to avoid the necessity of locating a midpoint on a fragment. All the measurements can be recorded with ease. Maximum femur length was measured on an osteometric board; all other measurements were obtained with sliding calipers. All measurements were taken by one of us (T. Simmons).

Data were entered on an IBM-compatible PC using dBase III-plus. Analysis of the data was carried out using the SAS package on the University of Tennessee's Vax cluster. Equations for the prediction of stature were generated in two ways. First, stature estimation was performed by the usual method of regressing stature onto bone measurements. Second, because the Terry collection records do not always list the cadaver stature of the individual, maximum femur length was also regressed onto bone measurements. By determining the maximum femur length of an individual from a fragment, one may then estimate the stature also, though the standard error of the estimate will be increased [*14*]. It is also, therefore, preferable to estimate stature directly from a fragment rather than estimating femur length as an intermediate step.

Results

Age, Stature, and Maximum Femoral Length

Stature, femur length, and age of the present sample are compared with other samples which have been used in stature estimation in Table 2. The means and standard deviations for age, stature, and maximum femur length are quite close to those presented by Trotter and Gleser [*9*] for the Terry Collection. They differ, however, from those presented by Steele [*14*], presumably because of that author's small sample size and his elimination of older individuals (those over age 70) from his study. Jantz and Moore-Jansen [*16*]

TABLE 1—*Measurements used for estimating stature from femoral fragments.*

Martin No.	Measurement
1	maximum femoral length (FML)
18	vertical diameter of femoral head (VHD)
15	vertical diameter of femoral neck (VND)
13	upper breadth of femur (VHA)
7	transverse diameter of midshaft (minimum) (WSD)
...	bicondylar breadth (BCB)
21	epicondylar breadth (FDL)
25	lateral condyle height (LCH)
26	medial condyle height (MCH)

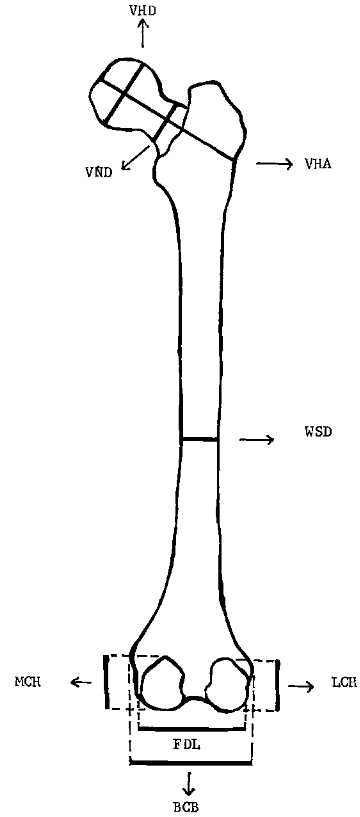

FIG. 1—*Schematic representation of measurements used for estimating stature from femoral fragments.*

have shown that the Terry Collection differs from the contemporary white and black population, with present-day populations exhibiting significantly longer femora. Table 2 also shows that Terry Collection heights are considerably below Trotter and Gleser's [*10*] Korean war dead and modern forensic science cases. For this reason, the use of the formulae to estimate maximum femur length may be more useful than those estimating stature directly due to this secular trend in stature increase.

In addition to the above noted secular trend for increased stature, difference in body proportions over several generations have been noted for Japanese medical students by Ohyama et al. [*17*]. They report that while the mean standing height of the Japanese students increased over three decades (1960s to 1980s), the mean leg length for these individuals remained constant. This indicates another potential difficulty in applying formulae for stature estimation which are derived from the Terry Collection sample. We do not mean to imply that the femur is not still the long bone which correlates most highly with stature; rather, we must simply caution again that modern forensic samples do not correlate precisely with earlier U.S. populations of individuals and that the exact differences between the two are as yet undetermined.

Summary of Fragment Measurements

Table 3 presents the means and standard deviations for each of the segments measured. Correlations for these measurements with femur length and cadaver stature are given in

TABLE 2—*Means and standard deviations of age (in years), stature[a] (in centimetres), and femur length (FXL) (in centimetres), of various samples compared with present sample.*

	N	Age	SD	Stature	SD	FXL	SD
			WHITE MALES				
Terry[b]	200	58.73	13.88	167.75	7.59	45.64	2.68
Terry [9]	255	61.66	12.55	167.89	7.34	45.66	2.45
Terry [14]	61	52.97	4.98	168.44	4.98	46.24	3.06
War dead [9]	545	23.14	4.31	173.90	6.63	47.29	2.36
War dead [10]	1265	...	...	174.39	6.55	47.17	2.30
Modern [16]	113	37.26	17.08	176.07	8.06	47.18	2.54
			BLACK MALES				
Terry[b]	203	47.33	16.77	170.18	7.97	47.47	2.93
Terry [9]	360	49.46	15.51	170.23	7.81	47.42	2.97
Terry [14]	42	43.25	13.21	172.02	7.84	47.92	3.28
War dead [9]	54	25.07	4.98	172.11	6.14	48.34	2.26
War dead [10]	191	...	...	173.86	6.65	48.41	2.48
Modern [16]	29	37.45	21.52	179.15	6.68	48.24	2.81
			WHITE FEMALES				
Terry[b]	201	63.19	15.59	157.07	7.76	42.71	2.36
Terry [9]	63	63.93	16.07	158.18	7.51	42.96	2.53
Terry [14]	52	63.35	17.02	157.62	7.96	42.69	2.71
Modern [16]	89	37.14	21.52	165.54	5.94	43.72	2.02
			BLACK FEMALES				
Terry[b]	199	48.11	18.44	159.04	6.63	43.99	2.41
Terry [9]	177	47.21	17.65	158.39	6.53	43.71	2.39
Terry [14]	57	39.58	15.52	159.88	6.22	43.96	2.30
Modern [16]	24	34.37	19.73	165.00	10.80	45.52	3.23

[a]Terry collection stature = cadaver stature − 2.5 cm. All others are stature obtained during life.
[b]Present study.

Table 4. The correlations show the strength of association between the segment measurements, stature and femur length. At the outset we had expected that proximal femur breadth (VHA) would be the best predictor, and that is borne out by the correlations in males; in females, however, several other measurements are more highly correlated. In general, correlations rarely exceed 0.65.

TABLE 3—*Means and standard deviations of the Terry collection segments (in centimetres), by race and sex.*

	W Males		B Males		W Females		B Females	
Variable	X	SD	X	SD	X	SD	X	SD
VHA	99.10	5.87	98.99	5.77	88.24	5.18	88.98	5.24
VHD	48.27	3.17	47.65	2.69	42.54	2.50	41.95	2.35
VND	33.09	3.05	31.16	2.60	29.27	2.62	27.17	2.48
WSD	28.26	2.16	28.05	2.21	25.10	2.13	25.18	2.03
LCH	41.35	2.91	42.33	3.00	36.30	2.53	37.05	2.34
MCH	40.92	3.01	41.94	3.22	37.22	2.90	37.75	2.70
BCB	77.81	4.30	77.71	4.57	68.44	3.75	67.74	3.94
FDL	83.42	4.47	83.00	4.22	74.57	3.54	73.94	3.95

TABLE 4—*Correlations of femur segments with maximum femur length and stature by race and sex.*

	W Males		B Males		W Females		B Females	
Variable	Ht	FML	Ht	FML	Ht	FML	Ht	FML
VHA	0.587	0.606	0.564	0.592	0.526	0.632	0.432	0.513
VHD	0.462	0.526	0.499	0.454	0.406	0.596	0.540	0.585
VND	0.312	0.384	0.393	0.315	0.409	0.409	0.461	0.422
WSD	0.386	0.281	0.251	0.276	0.428	0.295	0.367	0.277
LCH	0.557	0.571	0.503	0.452	0.677	0.665	0.571	0.585
MCH	0.417	0.459	0.391	0.404	0.595	0.518	0.470	0.403
BCB	0.512	0.541	0.509	0.440	0.294	0.445	0.220	0.345
FDL	0.493	0.521	0.560	0.465	0.428	0.537	0.329	0.415

Comparison with Steele's Results

The goal of this study was to attempt stature estimation from fragments which would equal or exceed Steele's in accuracy but would use standard measurements. This question can be examined by comparing the segment correlation with those from Steele that are more or less comparable. Steele's Segment 1 is measured from the proximal point on the head of the femur to the midpoint of the greater trochanter. It is comparable to our VHA in the size and location of the fragment.

Table 5 gives the correlations of our VHA and Steele's Segment 1 with stature and maximum femur length. For stature, our correlations exceed Steele's in three of the four groups and is only slightly lower in white males. For femur length, Steele's correlations are higher in three of the four groups. All 16 of the correlation coefficients are similar, indicating approximately equal predictive efficiency.

Steele's Segment 4 is comparable to our medial condyle height (MCH). His correlations with height and femur length exceed ours in four cases while ours exceed his in four cases. However, our lateral condyle height (LCH) yields consistently higher correlations than MCH in our data (see Table 4). Comparing LCH to Steele's Segment 4 shows our correlations to exceed his in seven of eight comparisons. It is evident that lateral condyle height has the higher correlation with stature and femur length and is to be preferred as the predictor variable when both condyles are present.

In this section, the statistical constants for estimating height and femur length from various fragments are presented. Only those equations which offer the best predictive capability and seem useful in forensic work will be presented.

The three variables showing the highest and most consistent correlations with maximum femur length and stature are VHA, vertical diameter of the femur head (VHD), and

TABLE 5—*Correlations of upper femur breadth (VHA) and Steele's Segment 1 with height and femur length.*

	Steele's Segment 1		VHA	
	Height	Femur Length	Height	Femur Length
White males	0.602	0.651	0.588	0.607
White females	0.498	0.623	0.526	0.632
Black males	0.472	0.606	0.564	0.593
Black females	0.431	0.543	0.432	0.514

posterior height of the fibular condyle (LCH). They are defined and measured as follows [15]:

> Martin No. 13: Upper Breadth of the Femur (along the axis of the femoral neck) (Upper epiphyseal length). Distance of the furthest (most medial) point on the head to the terminis of the neck axis on the lateral side of the bone. Spreading calipers (note: our measurement of this variable was taken with sliding calipers). The neck axis (axis of the anterior surface of the neck) is marked with a black pen according to visual approximation on the anterior surface of the neck so that the neck and head are divided in half as closely as possible (note: this usually results in the caliper points resting superiorly just above the fovea capitus, and inferiorly just below the final extent of the greater trochanter).
>
> Martin No. 18: Vertical diameter of the femoral head. Straightline distance from the most superior to the most inferior points on the head. Both points lie in a plane defined by holding the fovea capitus toward the measurer and positioning the neck axis on the horizontal. Sliding caliper.
>
> Martin No. 25: Posterior height of the fibular (lateral) condyle. Projected distance from the most superior to the most inferior point on the fibular (lateral) condyle. Sliding caliper.

Table 6 presents the slopes, intercepts, and standard errors of estimates for each race/sex group for stature and femur length using the variable VHA, VHD, and LCH as predictor variables. These are the constants of traditional regression equations. Thus, to estimate stature for a white male using VHA, one takes the slope times VHA and adds the intercept. The standard error of estimate then provides an indication of the likely range within which the true stature is likely to fall. For example, a VHA dimension of 95 cm for a white male would be used to estimate stature as follows:

$$\text{stature} = 0.78 \times 95 + 6.10 = 163.74 \pm 6.10$$

The average ages for all groups in this study are similar to those presented by Trotter and Gleser [9] in their work with the Terry Collection. In addition to concern regarding the secular trend in stature increase discussed above, Trotter and Gleser [7] addressed the issue of the effects of aging on stature. The correction of stature for age-related

TABLE 6—*Regression constants for estimating stature and femur length from various femur fragments, in centimetres.*

	Height			Femur Length		
	Slope	Intercept	S.E.	Slope	Intercept	S.E.
		PREDICTOR VARIABLE: VHA				
White males	0.78	89.64	6.10	0.29	14.81	2.10
White females	0.73	91.54	6.67	0.21	21.50	2.10
Black males	0.79	91.70	6.60	0.32	13.64	2.30
Black females	0.59	107.10	6.00	0.25	21.90	2.04
		PREDICTOR VARIABLE: LCH				
White males	1.47	107.09	6.24	0.54	20.86	2.18
Black males	1.34	113.23	6.91	0.46	25.44	2.59
White females	1.94	86.10	5.77	0.42	24.96	2.09
Black females	1.59	100.07	5.47	0.56	20.80	2.03
		PREDICTOR VARIABLE: VHD				
White males	1.11	113.89	6.77	0.43	23.57	2.32
Black males	1.51	97.82	6.92	0.54	19.45	2.56
White females	1.35	99.22	7.16	0.47	20.22	2.06
Black females	1.59	92.43	5.59	0.58	17.12	1.99

effects is given by Trotter and Gleser [*9*], who suggest that this formula be applied to all individuals over the age of 35 for whom stature is to be estimated.

Discussion

The method of femur length and stature estimation presented here has several advantages over previous attempts. First, the anatomical landmarks by which these measurements are standard, well defined, and easy to locate. Many of them are already in standard usage for the determination of sex or are standard measurements taken for comparative purposes on post cranial material. Second, the standard errors of estimates were equal to or better than those presented by Steele [*14*] for some of his smaller segments. And third, because the sample size used in this study is approximately four times that used by Steele [*14*], the regression equations are more accurately estimated.

Perhaps the most significant comparison of the technique presented in this study with that of Steele [*14*] concerns the standard errors of estimate. For comparable segments, such as those involving the proximal end (VHA) or the distal end (LCH), the standard errors of estimate provided by this study are uniformly lower than Steele's. That in turn indicates that the stature estimates are more accurate. To some extent this results from higher standard deviations for femur length and height in Steele's sample. This is apparently a consequence of Steele's smaller sample size.

The results of this study have demonstrated the feasibility of estimating stature and femur length from small fragments using standard measurements. It is becoming increasingly clear that the Terry collection skeletons were drawn from a population considerably smaller than contemporary Americans. Therefore, these results should be viewed more as indicative of the feasibility of the technique than as providing formulae applicable for forensic science work on contemporary people.

Conclusions

The technique for the estimation of stature from fragments of the femur presented in this paper represents an improvement over methods currently in use. In summary, the results of this study provide a statistically valid technique for the estimation of stature from fragmentary femora. Most important, the new equations presented herein are based on anatomical landmarks which are well defined and easy to locate and which thus constitute a definite improvement in the accuracy of the stature prediction. It is desirable to develop formulae using skeletons from contemporary populations, if possible. It is also possible that certain other bones likely to survive air crashes because of protection, such as the bones of the foot, calcaneous and metatarsals in particular, would lend themselves to stature estimation. Future research should be directed along these lines.

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