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TECHNICAL NOTE

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Stature Reconstruction Using Fragmentary Femora in South Africans of European Descent

ABSTRACT: It is well documented that the intact femur has the highest correlation with stature and as such has been widely used in the derivation of regression equations for stature estimation. As intact femur is not always present for analyses in forensic cases, it has become necessary to derive regression equations for the estimation of stature from fragments of this bone. Few studies have presented regression equations for stature estimation from fragments of the femur. Because these equations are population specific, it was the aim of this study to derive similar equations for estimation of stature and maximum length of femur from measurements of the femur of South Africans of European descent. A sample of 50 male and 50 female complete skeletons were obtained from the Raymond A. Dart Collection of Human Skeletons. Total skeletal height for each of the skeletons was calculated using the Fully's method. Six variables were measured on each femur which included the vertical neck diameter, upper breadth of femur, epicondylar breadth, bicondylar breadth, lateral condyle length, and medial condyle length. Regression equations for the estimation of stature are presented. The range of standard error of estimate for these equations (3.71–5.31) was slightly higher than those obtained for intact long bones (2.13–3.79). It is therefore suggested that in the absence of intact femur, regression equations derived from the present study can provide a reliable estimate of adult stature.

KEYWORDS: forensic science, stature, fragmentary femur, South Africa, forensic anthropology

There has been a lot of interest in the estimation of stature from different elements of the human skeleton since the 19th century when Pearson first derived regression equations for stature estimation (1). This method of stature estimation is based on the relationship between lengths of long bones and stature and is often referred to as the mathematical method (2). The other method of stature estimation involves the use of the entire skeleton by summing up appropriate measurements from the skull to the foot (2). This method was first suggested by Fully (3) and is sometimes called the anatomical method. The advantages and disadvantages of these methods have been discussed in a previous study (2).

Most studies conducted on stature estimation using the mathematical method revolve around the use of intact long bones of the upper and lower extremities (4–13). Measurements of the skull (14,15) and postcranial elements (16–21) have also been used in the formulation of regression equations for stature estimation. These equations are population and sex specific. The femur has been shown to be the most useful because it has the highest correlation with stature (1,22). Unfortunately, the femur is sometimes found in different states of fragmentation which therefore renders the equations derived from the intact bone inappropriate especially in forensic cases. This has necessitated the derivation of regression equations from fragments of the femur.

Steele and McKern (23) conducted one of the earliest studies on stature estimation from fragments of long bones. They identified landmarks on the humerus, femur, and tibia of Americans from which these bones were divided into segments (23). The percentage proportion of each segment to the maximum length of the long bone was then calculated. Stature was subsequently estimated from the calculated maximum length of the long bone using previously derived appropriate regression equations (23). Similar studies were carried out in India by Mysorekar et al. (24,25). In 1990, Simmons et al. (26) suggested the use of standard measurements of the femur in the estimation of stature and maximum length of femur (MAXL) because of the difficulty in easily reproducing measurements of segments of the femur as suggested by Steele and McKern (23). Subsequently, standard tibial measurements were used for stature estimation in Americans (27), Guatemalans (28), and South Africans of European descent (29) with different degrees of success. As no previous study has been conducted on the usefulness of femoral measurements in stature estimation in South Africans of European descent, it is the aim of this study to derive regression equations for estimation of stature and maximum length of the femur (MAXL) in this population group.

Materials and Methods

The samples used in this study were obtained from the Raymond A. Dart Collection of Human Skeletons housed in the School of Anatomical Sciences, University of the Witwatersrand, Johannesburg, South Africa. The sample consisted of 50 male and 50 female complete skeletons of South Africans of European descent. These skeletal remains represent an admixture of individuals who are descendants of migrants from the Netherlands, the U.K., France, Germany, and other European countries (30). The following inclusion criteria were used in the selection of skeletons for this study: (i) presence of all skeletal elements that constitute stature; (ii) documented ages at death which ranged between 29 and 75 years; and (iii) absence of pathologies and excessive osteophytic lipping. These skeletons belong to individuals that died between 1957 and 1998.

Skeletons were selected using the simple random sampling technique. For each selected skeleton, total skeletal height (TSH) was

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TABLE 1—*Definition of measurements.*

Measurements	Abbreviation	Definition
Maximum length of femur	MAXL	The linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle.
Upper epicondylar length	UEpL	The linear measurement between the most superior point on the fovea capitis of the femur and the inferior aspect of the greater trochanter.
Vertical neck diameter	VND	The minimum linear distance between the superior and inferior points on the neck of the femur.
Epicondylar breadth	EpB	The linear distance between the medial border of the medial condyle and the lateral border of the lateral condyle.
Bicondylar breadth	BCB	The linear distance between the medial and the lateral epicondyles of the femur.
Medial condylar length	MCL	The linear distance between the most anterior and the most posterior points on the medial condyle.
Lateral condylar length	LCL	The linear distance on the lateral condyle measured in an anteroposterior direction.

estimated using the Fully's method (3). These measurements included: (i) basi-bregmatic height of the skull; (ii) maximum heights of vertebrae (C2-S1); (iii) physiological length of the femur, (iv) lateral condylomalleolar length of the tibia; and (v) articulated height of the talus and calcaneus.

In addition, seven measurements as described by Bräuer (31) were taken on each left femur (Table 1). All femoral measurements were taken using a vernier caliper except MAXL and bicondylar breadth which were measured on an osteometric board. Statistical analyses were carried out on each group (male and female) separately using the 'STATISTIX' program (32). Means and standard deviations for TSH and all femoral measurements were obtained for each group. Regression analyses were then performed in stages. First, TSH was regressed on individual and various combinations of measurements of the femur. Second, MAXL was also regressed against each of the six femoral measurements. From these analyses, the correlation coefficient (*r*), standard error of estimate (SEE), regression coefficient, and constant were obtained. Regression equations were formulated from coefficients and constants.

Results

Mean ages were 58 and 62 years for males and females, respectively. Males presented with statistically significant higher mean values compared to females with regard to TSH and all measurements of the femur (Table 2). The degree of association (correlation) between measurements of segments of the femur, MAXL and TSH are presented in Table 3. Generally, a moderate-to-strong correlation was observed.

In males, all measured variables on the femur showed significant positive correlation with TSH. Upper epicondylar length (0.661) displayed the highest correlation with TSH for an individual measurement while epicondylar breadth (0.525) showed the lowest correlation. A lower degree of correlation was obtained between MAXL and femoral measurements. This ranged between 0.400 for epicondylar breadth and 0.610 for upper epicondylar length (Table 3). In females, a strong positive correlation was observed between measurements of the femur and stature. Lateral condyle length (0.785) presented with the highest correlation while vertical neck diameter and upper epicondylar length (0.562) showed the least correlation (Table 3). A similar pattern of correlation was obtained between MAXL and its measurements (Table 3).

Table 4 shows regression equations that can be used in the estimation of stature from femoral measurements. These equations are arranged in descending order of SEE and increasing order of correlation. Only the best equations with reasonable application are presented. In males, functions 1 and 2 were derived from the lateral condyle length and upper epicondylar length because they both showed the highest correlation for an individual measurement (Table 4). The other functions, formed from various combinations of measurements of femur, presented with lower SEE (4.80–4.89) and higher correlation coefficient (0.73–0.75). Regression equations for females are also presented in Table 4. The highest correlation for an individual measurement was obtained for bicondylar breadth and lateral condylar length. The degree of correlation between TSH and different combinations of measurements ranged from 0.82 to 0.83. Equations for predicting TSH in females (Table 4) also presented with better accuracy as shown from the range of SEE (3.71–3.95).

In the estimation of MAXL from measurements of its parts, regression equations for males showed moderate correlation between femoral measurements and MAXL (Table 5). In the female sample, moderate-to-high correlation was obtained. This ranged between 0.78 and 0.83 (Table 5). The SEE obtained for

TABLE 2—*Descriptive statistics.*

	Males			Females				
Measurements	*n*	Mean	SD	*n*	Mean	SD	*F* statistic	*p*-value
TSH/cm	50	157.44	6.99	50	147.60	6.28	54.76	0.000
MAXL	50	465.22	27.56	50	433.80	22.18	39.43	0.000
BCB	50	80.68	4.18	50	72.22	3.91	109.22	0.000
UEpL	50	99.90	5.63	50	90.12	5.56	76.29	0.000
VND	49	33.99	2.70	50	29.92	2.77	54.76	0.000
MCL	50	65.33	3.70	50	59.54	3.19	70.32	0.000
LCL	50	65.18	3.53	50	60.30	3.47	48.61	0.000
EpB	48	75.99	3.35	44	67.37	4.11	122.21	0.000

TSH, total skeletal height; MAXL, maximum length of femur; BCB, bicondylar breadth; UEpL, upper epicondylar length; VND, vertical neck diameter; MCL, medial condyle length; LCL, lateral condyle length; EpB, epicondylar breadth.

TABLE 3—*Correlations of measurements of fragments of femur with maximum length of femur and stature.*

	Males		Females	
Variable	TSH	MAXL	TSH	MAXL
BCB	0.609	0.459	0.782	0.781
UEpL	0.661	0.610	0.562	0.623
VND	0.585	0.478	0.562	0.544
MCL	0.582	0.426	0.729	0.724
LCL	0.659	0.537	0.785	0.753
EpB	0.525	0.400	0.705	0.722

BCB, bicondylar breadth; UEpL, upper epicondylar length; VND, vertical neck diameter; MCL, medial condyle length; LCL, lateral condyle length; EpB, epicondylar breadth.

TABLE 4—*Equations for stature estimation (cm), correlation, and standard error of estimate (SEE) from fragments of femur.*

	Equations	Correlation	SEE
	Male		
1	1.31(LCL) + 72.32	0.66	5.31
2	0.82(UEpL) + 75.64	0.66	5.31
3	0.50(UEpL) + 0.80(LCL) + 55.63	0.73	4.89
4	0.53(UEpL) + 0.58(VND) + 0.58(LCL) − 0.22(EpB) + 63.68	0.74	4.81
5	0.49(UEpL) + 0.54(VND) + 0.53(LCL) + 55.93	0.75	4.80
6	0.55(UEpL) + 0.56(VND) + 0.41(LCL) + 0.41(BCB) − 0.49(EpB) + 61.07	0.75	4.80
	Female		
1	1.26(BCB) + 56.96	0.78	3.95
2	1.42(LCL) + 61.88	0.78	3.93
3	1.21(LCL) + 0.38(EpB) + 48.83	0.82	3.78
4	0.67(BCB) + 0.79(LCL) + 52.00	0.82	3.71
5	0.37(BCB) + 1.03(LCL) + 0.17(EpB) + 47.07	0.83	3.78
6	0.40(BCB) − 0.21(VND) + 1.07(LCL) + 0.23(EpB) + 45.43	0.83	3.81

TABLE 5—*Equations for estimation of maximum length of femur (cm), correlation, and standard error of estimate (SEE) from fragments of femur.*

	Equations	Correlation	SEE
	Male		
1	0.30(UEpL) + 16.73	0.61	2.21
2	0.25(UEpL) + 0.21(VND) − 0.06(EpB) + 18.31	0.62	2.17
3	0.23(UEpL) − 0.04(BCB) + 0.22(VND) − 0.16(MCL) + 0.24(LCL) − 0.05(EpB) + 17.81	0.64	2.21
4	0.22(UEpL) + 0.16(VND) − 0.01(BCB) + 0.13(LCL) + 12.61	0.65	2.20
5	0.25(UEpL) + 0.21(VND) + 14.20	0.65	2.17
6	0.22(UEpL) + 0.19(VND) + 0.02(BCB) + 0.24(LCL) − 0.19(MCL) + 12.73	0.66	2.19
	Female		
1	0.44(BCB) + 11.42	0.78	1.40
2	0.33(BCB) + 0.11(UEpL) + 9.95	0.80	1.36
3	0.29(BCB) + 0.21(LCL) + 10.10	0.80	1.36
4	0.22(BCB) + 0.09(UEpL) + 0.17(LCL) + 9.14	0.81	1.33
5	0.26(BCB) + 0.11(UEpL) − 0.14(VND) + 0.18(LCL) + 7.81	0.82	1.33
6	0.22(BCB) + 0.11(UEpL) − 0.14(VND) + 0.20(LCL) + 0.06(EpB) + 6.26	0.83	1.37

maximum femoral length estimation from its fragments ranged from 2.17–2.21 cm for males and 1.33–1.40 cm in females.

Discussion

The results of the descriptive statistics showed that males presented with statistically significant higher mean value of TSH than females (Table 2). It can therefore be inferred that males are generally taller than females which is in support of previous studies on stature estimation in South Africa (6,7,15,20,21,29). Males also showed higher mean values compared to females for all femoral measurements thereby confirming sexual dimorphism of femoral dimensions as reported in an earlier study by Steyn and İşcan (30).

According to Steele and McKern (23), Müller made the first attempt in estimating the maximum length of a long bone from measurements of its sections. Müller divided the humerus, radius, and tibia into sections from which percentage contribution of each section to the maximum length of the long bone was obtained (23). Steele and McKern (23) criticized the exclusion of femur from Müller's selection because the femur is regarded as the singular bone with one of the highest correlations with stature. They (23) replaced the radius with the femur in their study but used the method of delineating a long bone into sections as suggested by Müller.

In an attempt to derive equations for stature estimation using fragments of femur from a sample of a more recent skeletal collection, Simmons et al. (26) reported a difficulty in reproducing the measurements as suggested by Steele and McKern (23). As a result, Simmons et al. (26) used eight standard measurements of the femur namely: (i) vertical diameter of femoral head; (ii) vertical diameter of femoral neck; (iii) upper breadth of femur; (iv) transverse diameter of midshaft; (v) bicondylar breadth; (vi) epicondylar breadth; (vii) lateral condylar height; and (viii) medial condylar height, in the estimation of stature of Americans. Four of the above mentioned measurements were used in the present study because of the ease with which they could be reproduced. In addition to these, two other measurements namely medial and lateral condylar lengths were selected because of their high coefficient of reproducibility.

All measurements used in this study showed positive correlation with MAXL and stature (Tables 4 and 5). Females consistently showed higher correlation coefficients compared to males which is in support of previous studies (e.g., 6, 7, 20, 21, 29). This could be caused by less variability in females compared to males as shown in the value of standard deviation for TSH and most femoral measurements. The range of correlation between femoral measurements and TSH in males (0.66–0.75) is slightly lower than that obtained for the female sample (0.78–0.83). This result is expected as measurements of fragments of the femur are small in dimension as compared with TSH. Therefore, the degree of correlation between these fragments and TSH in general should be moderate.

Measurements of the distal end of the femur consistently showed the best correlation with stature and MAXL in females (Tables 4 and 5). However, the upper epicondylar length, one of the measurements on the proximal aspect of the femur, showed the highest correlation with MAXL and stature in males (Tables 4 and 5). The lateral condylar length showed the second highest correlation for stature and MAXL in males. In general, measurements of the distal end of the femur displayed the highest correlation with stature and MAXL in this study which is contrary to the observation made by Simmons et al. (26). In the latter study (26), the upper epicondylar length, a proximal femora measurement consistently showed the best correlation with stature and MAXL in both sexes.

The correlation coefficients of comparable measurements of femur in the present study and those of Simmons et al. (26) with MAXL and stature are presented in Table 6. The general trend reveals that measurements in this study showed a higher correlation compared with corresponding measurements of Simmons et al. (26) in both sexes indicating that measurements in this study have a higher predictive efficiency compared to those used by Simmons et al. (26). The moderate-to-high degree of correlations obtained in the present study confirms the usefulness of fragments of femur in the estimation of stature in South Africans of European descent. Practitioners of forensic anthropology in South Africa will therefore find the regression equations presented in this study useful when intact long bones are not present for analysis.

The accuracy of each regression equation derived in this study was assessed using the obtained SEE. Regression equations for stature estimation in males presented with slightly higher SEE compared to those obtained for females (Table 4). Similar results were obtained for range of SEE for regression equations for estimation of MAXL from its fragments (Table 5). While this is in support of previous observation made by Chibba and Bidmos (29), it contradicts that made by Simmons et al. (26) whereby similar range of SEE were obtained for both sexes.

Table 7 shows a comparison of the range of SEE from some selected previous studies with that from the present study. The range of SEE from the present study is lower than that obtained for intact calcanei, metatarsals, metacarpals, and fragmentary tibiae. This suggests that regression equations derived from the present study using fragments of femur are more accurate in the estimation of stature compared to those derived in earlier studies using the calcaneus, metatarsals, metacarpals, and fragments of long bones of the lower extremity.

Conclusion

Regression equations were derived for estimation of stature and MAXL from measurements of fragments of the femur. Females showed higher correlation between measured variables and both stature and MAXL compared to males. This allowed for formulation of more accurate regression equations for females compared to males. The accuracy of the equations in this study is lower than that obtained for intact long bones but higher than that for other skeletal elements like metatarsals, metacarpals, intact calcaneus, and fragments of tibia. Therefore, intact long bones should be used in the estimation of stature when they are available for forensic analysis. However, in the absence of intact long bones, equations presented in this study can offer a reasonable estimate of stature.

TABLE 6—*Comparison of correlation coeffcients from Simmons et al. (26) and present study.*

	Male				Female			
	Simmons et al. (26)		Present Study		Simmons et al. (26)		Present Study	
	MAXL	Stature	MAXL	Stature	MAXL	Stature	MAXL	Stature
UEpL (VHA)	0.606	0.587	0.610	0.661	0.632	0.526	0.623	0.562
VND	0.384	0.312	0.478	0.585	0.409	0.409	0.544	0.562
BCB	0.541	0.512	0.459	0.609	0.445	0.294	0.781	0.782
EpB (FDL)	0.521	0.493	0.400	0.525	0.537	0.428	0.722	0.705

UEpL, upper epicondylar length; VND, vertical neck diameter; BCB, bicondylar breadth; EpB, epicondylar breadth.

TABLE 7 —*Comparison of standard errors of estimate for stature by different authors.*

Investigator	Skeletal Elements	SEE
Lundy and Feldesman (6)	Long bones of upper and lower limbs	1.8–5.3
Dayal (7)	Long bones of upper and lower limbs	1.8–5.5
Trotter and Gleser (4)	Long bones of upper and lower limbs	3.0–5.1
Present study	Fragments of femur	3.7–5.3
Bidmos and Asala (20)	Calcaneus	4.0–5.9
Holland (18)	Calcaneus	4.1–6.3
Bidmos (21)	Calcaneus	4.2–5.4
Byers et al. (16)	Metatarsals	4.0–7.6
Meadows and Jantz (17)	Metacarpals	5.1–5.7
Chibba and Bidmos (29)	Fragments of tibia	5.2–6.7
Simmons et al. (26)	Fragments of femur	5.5–7.2

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