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ORIGINAL ARTICLE

Estimation of stature using fragmentary femora in indigenous South Africans

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Abstract Intact long bones of the upper and lower extremities have been used in the derivation of regression equations for the estimation of stature in different population groups. These bones are sometimes presented to forensic anthropologists in different states of fragmentation thereby making the derived equations unusable. This has necessitated the need to assess the usefulness of measurements of fragments of long bones (e.g., femur) in the estimation of stature. While few studies have reported such equations, which are population and sex specific, it was the aim of this study to derive equations based on measurements of commonly preserved fragments of the femur for the indigenous South African population group. A total of 100 complete skeletons, equally distributed by sex, were obtained from the Raymond A. Dart collection of human skeletons. Stature was estimated for each of the skeleton using the Fully's method (Fully in Ann Med Leg 35:266–273, 1956). Regression equation for the estimation of stature and maximum length of the femur were derived from six measurements of the femur. The standard error of estimate for regression equations for stature estimation (3.72–4.38) was slightly higher than that presented for intact femur. This study confirms the usefulness of fragments of the femur of indigenous South Africans in the estimation of stature.

Keywords Stature · Fragmentary femur · South Africa · Forensic anthropology

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Introduction

The estimation of stature and body size is of great interest to forensic and physical anthropologists. A detailed account of the different methods of stature estimation and body size from bones using various techniques is well documented in previous studies by Lundy [1], Krogman and İşcan [2], and Porter [3]. In 1899, Pearson developed arguably the most used statistical theorems in stature reconstruction termed regression analysis [2]. This theory was used in the derivation of population and sex-specific regression equations for the estimation of stature [2, 3]. Subsequently, there has been a lot of interest to derive similar equations using intact long bones of the upper and lower limbs in Americans [4,5], British and East Africans [6], South Africans [7, 8, 9], Portuguese [10], Germans [11], Bulgarians [12], and Turks [13] among others. Attempts were also made to formulate regression equations using measurements of the skull [14, 15] and other postcranial elements [16–21]. From the results of all these studies, the femur in the intact state is one of the bones with the highest correlation with stature. It has also been shown to yield the best accuracy in the estimation of stature for any individual skeletal element [22].

However, the femur is not always recovered intact in forensic and archaeological cases thereby rendering the equations derived from the whole bone inappropriate for analysis. This has necessitated the derivation of regression equations from fragments of the femur. Steele and McKern [23] made the first attempt at estimating stature from fragments of the femur using five landmarks from which four segments were delineated. They [23] derived regression equations for the estimation of maximum length of the femur from each of the segments and combinations of these segments using prehistoric American femora obtained from three different sites in Mississippi. Similar equations were also presented for the estimation of maximum length of the humerus and tibia from different segments of these bones.

The method of estimating maximum length of the femur from its segments was revised by Simmons et al. [24] because the techniques for delineating segments of this bone as suggested by Steele and McKern [23] were not easily reproducible. Simmons et al. [24] used seven standard measurements of femur obtained from the Terry Collection in the derivation of equations for estimation of maximum length of femur and stature. Studies have also been conducted on the usefulness of fragments of the upper end of the radius and the lower end of the femur [25], segments of the ulna and tibia [26], and fragments of tibia [27, 28] in the estimation of stature with different degrees of success.

Because no studies have yet been conducted on the estimation of stature from fragments of the femur in South Africa, this study aimed to derive regression equations for estimation of the maximum length of the femur and stature from fragments of the femur.

Materials and methods

Materials

Two sets of samples were used in this study. The calibration sample (sample A) consisted of 100 (50 male and 50 female) complete skeletons of indigenous South Africans (ISAs). This sample was used in the derivation of regression equations for estimation of the maximum length of femur and stature. The test sample (sample B) of 20 complete skeletons, equally distributed by sex, was used in the assessment of the reliability of the derived regression equations. These skeletal elements 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 ISA population group consisted of various tribes including Zulu, Xhosa, Tswana, Sotho, Pedi, Venda, etc, but for the purpose of this study, samples were obtained mainly from the Zulu, Xosa, Sotho, and Tswana tribes, as they constitute the majority of the skeletons of the ISA population group in the Raymond A. Dart Collection. These four chiefdoms were treated as a single homogeneous group because previous studies have shown that no statistically significant intertribal differences exist in the metrical analyses of skulls [29] and postcranial skeletons [1].

The ages of individuals whose skeletons form the samples used in this study ranged between 46 and 75 years. Period of death for these skeletons ranged between 1975 and 2000. Complete skeletons comprised of a complete skull, vertebrae, femur, tibia, talus, and calcaneus were used. Specimens with missing elements including calvaria, broken edges, and those with excessive osteophytic lippings were excluded from this study.

Methods

A simple random sampling technique was used in the selection of skeletal materials because it gives all specimens an equal opportunity of being chosen. Fully's [30] method was used in the calculation of total skeletal height (TSH). This became necessary, as previous studies have shown that documented cadaver lengths in the Raymond A. Dart Collection are not reliable [1, 31]. The following measurements as described by Fully [30] and Bräuer [32] were taken on each complete skeleton:

1. Basi-bregmatic height of the skull using a spreading caliper
2. Maximum heights of vertebrae (C2–S1) using a sliding caliper
3. Physiological length of the femur using an osteometric board
4. Lateral condylomalleolar length of the tibia using an osteometric board
5. Articulated height of the talus and calcaneus using an osteometric board

The sum total of these measurements gives an estimate of TSH. In addition to the abovementioned, seven other measurements were taken on each left femur. They are as described below following the instructions of Bräuer [33]:

1. Maximum length of femur: the linear distance between the most superior part of the head of the femur and the most inferior part of the medial condyle
2. Upper epicondylar length (UEpL) or upper breadth of femur (VHA): the linear measurement between the most superior point on the fovea capitis of the femur to the inferior aspect of the greater trochanter
3. Vertical neck diameter (VND): the minimum linear distance between the superior and inferior points on the neck of the femur
4. Epicondylar breadth (EpB): the linear distance between the medial border of the medial condyle and the lateral border of the lateral condyle
5. Bicondylar breadth (BCB): the linear distance between the medial and the lateral epicondyles of the femur
6. Medial condyle length (MCL): the linear distance between the most anterior and the most posterior points on the medial condyle
7. Lateral condyle length (LCL): the linear distance on the lateral condyle measured in an anteroposterior direction

Table 1 Descriptive statistics

	Males			Females			F statistic	p value
Measurements	Number	Mean	Standard deviation	Number	Mean	Standard deviation		
TSH	50	153.21	5.53	50	143.12	6.95	64.56	0.0000
MaxL	50	454.60	21.38	50	428.60	25.37	30.69	0.0000
BCB	50	78.72	4.05	50	69.96	5.04	91.79	0.0000
UEpL	50	95.32	5.96	50	85.74	6.59	58.16	0.0000
VND	50	32.31	2.44	50	28.20	2.52	68.65	0.0000
MCL	50	64.55	3.75	50	57.86	3.62	82.37	0.0000
LCL	50	64.73	3.58	50	59.86	4.41	36.75	0.0000
EpB	50	74.93	4.61	50	66.60	4.96	75.66	0.0000

All femoral measurements are in mm.
TSH Total skeletal height in cm, *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

The maximum length and BCB were measured on an osteometric board, while the rest of the measurements were taken using a vernier caliper.

Lin's [33] concordance coefficient of reproducibility was used in the assessment of the reliability of the measuring technique used in this study, and ten complete skeletons were used for this purpose. After establishing that the measuring technique was adequate, data were collected and placed into excel spreadsheets, and statistical analysis was carried out on the male and female groups separately using the "Statistix" program.

Descriptive statistics including means and standard deviations were obtained for both sexes. Normality of distribution of data for both sexes was also verified by comparing the histograms of each femoral measurement with the normal distribution curve. Thereafter, univariate and multivariate regression analyses were performed. Firstly, TSH was regressed on individual measurements and combinations of measurements of the femur. Secondly, the maximum length of the femur was regressed against individual measurements and combinations of measurements of the femur. From these analyses, the correlation coefficient (r), unstandardized coefficient, constant, and standard error of estimate (SEE) were obtained. Regression equations were formulated from these coefficients and constants.

Femoral measurements from each of the specimens in the test sample were substituted separately for males and females into appropriate regression equations derived in this study for estimation of (a) maximum length of the femur and (b) stature. To assess the reliability of each regression equation in the estimation of stature, the number of specimens with calculated TSH (using Fully's method) falling within 1 and 2 standard errors of estimation of the estimated skeletal height (using derived regression equation from the present study) is expressed as a percentage of the total number of specimens in the tested sample. A similar procedure was also performed for regression equations derived for estimation of maximum length of the femur.

Results

The means and standard deviations of femoral measurements and TSH are presented in Table 1. Males consistently showed significantly ($p<0.001$) higher mean values for all the measurements compared with females. The mean ages for males and females were 41.8 and 46.5 years, respectively.

All measurements of the femur showed a positive correlation with TSH. The MCL showed the highest correlation (0.74) with TSH (Table 2) in the male sample while the other measurements displayed moderate correlation with TSH (Table 2). However, all femoral dimensions in the female sample displayed high correlation with TSH (Table 2).

Table 3 shows equations that can be used in the estimation of TSH from measurements of the femur. The equations are arranged in increasing order of correlation and decreasing order of SEE. The range of correlation coefficient (0.62–0.76) for the equations in males is lower than that obtained for females (0.80–0.85), while the range of SEE in males (3.72–4.36) compares well with that obtained for females (3.82–4.18). The addition to and subtraction of SEE from the final estimate provides a range for TSH. As an illustration, a male individual with LCL of 60 mm will have a TSH of (see Eq. 1 in Table 3):

$$\begin{aligned} \text{TSH} &= [(0.96 \times 60) + 90.86] \pm 4.36 \text{ cm} \\ &= (57.6 + 90.86 \pm 4.36 \text{ cm}) \\ &= 148.46 \pm 4.36 \text{ cm} \end{aligned}$$

Table 2 Correlations of femoral measurements with stature and maximum length of femur

Measurements	Males		Females	
	TSH	MaxL	TSH	MaxL
BCB	0.559	0.529	0.816	0.720
UEpL	0.608	0.653	0.785	0.799
VND	0.542	0.517	0.731	0.681
MCL	0.744	0.711	0.735	0.619
LCL	0.623	0.626	0.769	0.696
EpB	0.523	0.560	0.803	0.746

BCB Bicondylar breadth, *UEpL* upper epicondylar length, *VND* vertical neck diameter, *MCL* medial condyle length, *LCL* lateral condyle length, *EpB* epicondylar breadth

Addition of a soft tissue factor of 10.0 cm for a skeletal height of less than or equal to 153.5 cm as suggested by Fully [30] gives a living stature estimate of:

$$\mathrm{ELS} = 158.46 \pm 4.36$$

Therefore, the estimated living stature of the individual will range between 154.10 and 162.82 cm.

Males showed a moderate correlation between individual femoral variables and maximum length of the femur, while a higher degree of correlation was obtained in the female sample (Table 2). Regression equations that can be used in the estimation of maximum length of the femur from various combinations of femoral variables are presented in Table 4. Equations derived for female samples presented with a higher correlation (0.80–0.83) compared with that obtained for the male sample (0.63–0.75). The SEE obtained for the estimation of maximum length of the femur from its fragments ranged from 1.46 to 1.69 cm for males and 1.48 to 1.54 cm in females.

The result of the accuracy of derived regression equations for estimation of maximum length of the femur and TSH at 1 and 2 standard errors of estimate are shown in Tables 3 and 4. In general, a higher degree of accuracy was obtained in both sexes at 2 SEE.

Discussion

In an attempt to derive equations for stature estimation using fragments of femur, Simmons et al. [24] reported a difficulty in reproducing the measurements as suggested by Steele and McKern [23]. As a result, Simmons et al. [24] used eight standard measurements of the femur in the estimation of the stature of Americans. In the present study, four of the measurements were used because of the high coefficient of reproducibility that was obtained. These are: VND, VHA or UEpL, BCB, and EpB. In addition to these, two other measurements namely, medial and lateral condylar lengths, were selected because they have been shown to be sexually dimorphic in ISAs [34] and also because of their high coefficient of reproducibility.

Each of these six measurements showed statistically significant sex differences. This indicates that fragments of the femur are sexually dimorphic in this population group, which is in support of earlier observations made by Asala et al. [34]. A comparison of the mean measurements from the present study with those obtained by Asala et al. [34] showed no statistically significant difference. The result of this comparison can be explained based on the fact that the

Table 3 Equations for stature estimation (in cm), correlation, and standard error of estimate from fragments of femur

	Equations	Correlation	SEE	Accuracy(%)	
				1 SEE	2 SEE
Male					
1	0.96(LCL)+90.86	0.62	4.36	80.0	100.0
2	1.10(MCL)+82.47	0.74	3.73	70.0	100.0
3	0.93(MCL)+0.14(UEpL)+79.42	0.75	3.72	100.0	100.0
4	1.24(MCL)−0.17(BCB)+86.22	0.75	3.75	100.0	100.0
5	1.02(MCL)+0.19(UEpL)−0.16(EpB)+81.04	0.76	3.73	100.0	100.0
6	1.10(MCL)+0.16(UEpL)−0.21(BCB)+83.78	0.76	3.73	90.0	100.0
Female					
1	1.13(EpB)+68.19	0.80	4.18	70.0	100.0
2	1.13(BCB)+64.42	0.82	4.06	50.0	100.0
3	0.73(EpB)+0.59(LCL)+59.62	0.84	3.87	60.0	90.0
4	0.73(BCB)+0.36(UEpL)+61.08	0.84	3.88	60.0	100.0
5	0.55(EpB)+0.53(LCL)+0.53(VND)+59.62	0.85	3.82	70.0	100.0

Fully's soft tissue correction factors: TSH≤153.5 cm, add 10 cm; between 153.6 and 165.4 cm, add 10.5 cm; and ≥165.5 cm, add 11.5 cm
For example, a male with MCL of dimemsion 70 mm will give TSH=(1.10×70)+82.47=77+82.47=159.47 cm
Living stature will therefore be 159.47+10.5 cm±SEE=169.97 cm±3.73

Table 4 Equations for estimation of maximum length of femur (in mm), correlation, and standard error of estimate from fragments of femur

	Equations	Correlation	SEE	Accuracy(%)	
				1 SEE	2 SEE
Male					
1	0.37(LCL)+21.23	0.63	1.69	90.0	100.0
2	0.41(MCL)+19.32	0.71	1.52	70.0	100.0
3	0.47(MCL)−0.01(BCB)+20.88	0.72	1.53	70.0	100.0
4	0.29(MCL)+0.11(UEpL)+17.04	0.74	1.47	70.0	100.0
5	0.12(UEpL)+0.36(MCL)−0.10(BCB)+19.14	0.75	1.46	70.0	100.0
6	0.12(UEpL)−0.10(BCB)+0.37(MCL)−0.01(LCL)+19.21	0.75	1.48	70.0	100.0
Female					
1	0.31(UEpL)+16.46	0.80	1.54	80.0	90.0
2	0.24(UEpL)+0.11(EpB)+15.33	0.81	1.53	80.0	90.0
3	0.24(UEpL)+0.25(VND)+15.03	0.82	1.48	80.0	100.0
4	0.26(UEpL)−0.06(MCL)+0.28(VND)+16.14	0.82	1.49	80.0	100.0
5	0.23(UEpL)−0.17(MCL)+0.28(VND)+0.15(LCL)+16.70	0.83	1.48	80.0	100.0
6	0.04(EpB)+0.15(LCL)+0.26(VND)+0.21(UEpL)−0.19(MCL)+16.63	0.83	1.50	80.0	100.0

two studies used recently acquired skeletal materials from the same population group. The two studies differ in that Asala et al. [34] used a larger sample size and did not include the Tswana tribe.

All femoral measurements used in this study showed positive correlation with maximum length of the femur and stature (Table 2). Females consistently showed higher correlation coefficients compared to males. This is consistent with observations made from previous studies [20, 21, 28]. Because femoral measurements are small in dimension compared to stature, one would expect that the degree of correlation is lower compared to that for the maximum length of the femur. However, most measurements of the femur showed a higher degree of correlation for stature compared with the maximum length of the femur in both sexes (Table 2). This observation is not unusual and has been reported in earlier studies by Simmons et al. [24] and Chibba and Bidmos [28] using the femur and tibia, respectively, in which higher correlation coefficients were obtained between measurements of these bones and stature compared to that between the maximum length of these bones and measurements of their fragments.

Measurements of the distal end of the femur consistently showed the best correlation with stature and maximum length of the femur. In males, the medial and lateral condyle lengths showed the highest correlation with stature, while the BCB displayed the highest correlation in females (Table 2). However, the UEpL, one of the measurements on the proximal aspect of the femur, showed the highest correlation with the maximum length of the femur in females and also displayed the second best correlation in males (Table 2). The general trend in this study whereby measurements of the distal end of the femur displayed the highest correlation with stature and maximum length of femur differs from the observation made by Simmons et al. [24]. In the latter study [24], the UEpL, a proximal femora measurement, consistently showed the best correlation with stature and maximum length of femur in both sexes.

Table 5 shows the correlation coefficients of comparable measurements of the femur in the present study and those of Simmons et al. [24] with the maximum length of the femur and stature. For three out of the four measurements, the correlation reported in this study was higher than that of Simmons et al. [24] in males. However, all female measure-

Table 5 Comparison of correlation coefficients from Simmons et al. and the present study

	Male				Female			
	Simmons et al.		Present study		Simmons et al.		Present study	
	MaxL	Stature	MaxL	Stature	MaxL	Stature	MaxL	Stature
UEpL (VHA)	0.592	0.564	0.653	0.608	0.513	0.432	0.799	0.785
VND	0.315	0.393	0.517	0.542	0.422	0.461	0.681	0.731
BCB	0.440	0.509	0.529	0.559	0.345	0.220	0.720	0.816
EpB (FDL)	0.465	0.560	0.560	0.523	0.415	0.329	0.746	0.803

ments in this study showed a higher correlation compared with the corresponding measurements of Simmons et al. [24]. This indicates that the measured variables in this study have a higher predictive efficiency compared to those used by Simmons et al. [24]. The moderate to high correlations obtained in this study confirm the usefulness of fragments of femur of the ISA population group in the estimation of stature and maximum length of the femur. Regression equations derived from these measurements will therefore be of great assistance to forensic and physical anthropologists in South Africa in the estimation of stature.

Conclusions

Measurements of the proximal and distal ends of the femur of the ISA population group have been shown to be sexually dimorphic in a previous study by Asala et al. [34]. In the present study, these measurements showed a moderate to high positive correlation with stature. The MCL and BCB, both being distal end measurements, showed the highest correlation in both males and females. The MCL also showed the highest correlation with maximum length of femur in males, while UEpL, a proximal measurement, displayed the best correlation in the female sample. Correlation coefficients for comparable measurements in this study are higher than those presented by Simmons et al. [23] for African Americans, thereby showing a higher predictive efficiency of measurements used in this study. Regression equations for stature estimation and maximum length of femur using various combinations of measurements of the femur in both sexes are presented. The range of SEE for regression equations for estimation of stature in males and females is higher than that presented for intact femurs by Lundy and Feldesman [8] and lower than that obtained for intact metatarsals [16], metacarpals [17], calcanei [20, 21], and fragmentary tibiae [27, 28]. In the absence of intact femur, therefore, regression equations derived in this study are more reliable in the estimation of stature compared with the aforementioned skeletal elements i.e., metatarsals, metacarpals, calcanei, and fragmentary tibiae.

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