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TECHNICAL NOTE

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On the Non-equivalence of Documented Cadaver Lengths to Living Stature Estimates Based on Fully's Method on Bones in the Raymond A. Dart Collection

ABSTRACT: Regression equations for stature estimation have been derived from documented cadaver lengths available as part of the demographic information in the catalogue of skeletonised remains in different collections around the world. The Raymond A. Dart Collection is one such collection, but the reliability of documented cadaver lengths in it has been previously questioned. The aim of this study was to compare these lengths with estimated living stature using Fully's anatomical method. Living stature was estimated with this method from a total of 156 complete skeletons obtained from the Collection. These heights were then compared with the documented cadaver lengths. It was observed that the documented cadaver lengths were significantly higher than the estimated living stature using Fully's method.

KEYWORDS: forensic science, Raymond Dart Collection, Fully's method, documented cadaver lengths

Stature is one of the important characteristics necessary for establishing the identity of an individual in forensic and archaeological cases (1). It complements data on age, sex and population affinity in human identification and may vary in the same individual depending on the time of day when measured (2). Daily variation in stature (which may be regarded as normal if there is a decrease between 1cm and 2 cm) is due mainly to compression of the intervertebral discs by the weight of the body while in the sitting or upright position (2).

The heights of individuals available in recorded form as part of their anthropometric data are referred to as documented stature. Important sources of this include passports and travel documents, drivers' licenses, military records and hospital admission records. Documented stature from such sources is usually reported by the relatives of the individuals or by the individual themselves. Himes and Roche (3) observed that reported stature is often overestimated by individuals as well as their spouses, which could be erroneous. Measured stature, on the other hand, in the United States and United Kingdom can sometimes be obtained from health and nutrition survey, and from study of growth patterns (4) or anthropometric studies of recruits in the military or the police. This measured stature is usually taken under the direct supervision of a physical anthropologist or a physician and is more reliable.

In South Africa, sources of documented stature include the measured lengths of cadavers found in the catalogue of skeletonised remains that constitute the Raymond A. Dart Collection of Human Skeletons, housed in the School of Anatomical Sciences of the University of the Witwatersrand, Johannesburg. Most of these skeletons do not have recorded stature because measurements of the lengths of cadavers were started only about 30 years ago by Professor P. V. Tobias (personal communication) who has been studying growth changes and secular trends of stature through measurements of living stature especially among South African blacks (5–8).

In forensic practice, skeletal remains may be the only resource available for stature estimation. Different methods have been used, including: (i) the anatomical method (9,10–14), (ii) the mathematical method (1,15–19), and (iii) bone length: stature ratios (20). The use of the anatomical method in estimating stature involves the addition of the basibregmatic height of the skull, the height of the longitudinally assembled bones of the vertebral column in the absence of intervertebral discs, the length of the long bones of the lower limb and the talocalcaneal height.

The anatomical method as it is been presently used today was suggested by Fully (9). He measured appropriate dimensions of the skull, vertebrae, femur, tibia, talus and calcaneus. The sum of the measurements gave the total skeletal height (TSH). The method of Fully (9) has been used to estimate TSH and later was used to derive regression equations from the lengths of long bones of the upper and lower extremities for estimating the stature of adult South African blacks (10–11,13) and whites (21). Also, the Fully's method has been used to derive regression equations for stature estimation from nine measurements of the calcaneus of South African blacks (22) and whites (23). The advantage of Fully's method in the estimation of stature is that it takes into account all the components that constitute total skeletal stature. However, it is time consuming and complicated (14).

In order to account for the thickness of the scalp, the intervertebral discs and the soft tissue of the sole of the foot, a correction index devised by Fully (9) was added. For TSHs of 153.5 cm or less,

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10.0 cm was added, between 153.6 and 165.4 cm, 10.5 cm, and for skeletal heights of 165.5 cm and above, 11.5 cm was added. The resultant height is referred to as the estimated living stature (ELS_{Fully}).

Since TSH and ELS_{Fully} can be estimated from complete skeletons with documented cadaver lengths in the Raymond A. Dart Collection of Human skeletons, it is therefore the aim of this study to investigate whether a statistically significant difference exists between ELS_{Fully} and documented cadaver lengths.

Materials and Methods

Materials used in the present study were obtained from the Raymond A. Dart Collection of Human Skeletons, housed in the School of Anatomical Sciences of the University of the Witwatersrand, Johannesburg, which contains well over 4000 skeletons, mostly derived from cadavers of hospital patients. The stated or estimated age (from hospital records), sex, population affinity and documented cadaver lengths at the time of death are known. It is from this collection that 156 complete skeletons (78 whites and 78 blacks) equally distributed by sex were obtained by simple random technique. The ages of the individuals represented by the skeletons at the time of death ranged between 22 and 75 years.

In the Collection, different tribes or chiefdoms constitute the South African black population. These are Zulu (Natal Nguni), Xhosa (Cape Nguni), Pedi, Sotho, Tsonga, Tswana, Venda and a few other smaller groups. Previous studies have shown that there are no significant intertribal differences in the metrical and nonmetrical features of the skull (24), vertebral column (25) and limb bones (10) of the South African black population. Therefore, for the purpose of this study, the different tribes that constitute South African blacks were considered to belong to the same homogeneous group.

The South African white population consists of migrants from the Netherlands, United Kingdom, France, Germany and other European countries. The admixture of these groups over the years with local groups might have changed their genetic make-up so that they differ from European and American whites (26). The samples for the white population used in this study were drawn from the Collection. This consists of skeletal remains of individuals from the South African white group.

Only skeletons with skull including calotte (skull cap), cervical vertebra C2 to lumbar vertebra L5, sacrum, left femur, left tibia, left talus and left calcaneus were used. Bones with obvious pathological conditions such as fusion of vertebrae, fracture with or without malunion, presence of pins and plates, broken odontoid processes and excessive osteophytic lipping were excluded.

Each complete skeleton was then laid out on a table with the vertebrae arranged in sequence from the second cervical vertebra to the fifth and sometimes sixth lumbar vertebra. The variation in the number of the presacral vertebrae has been observed and documented for different populations (10,25,27–29). When extra vertebrae were present, the anterior body heights of these vertebrae were included in the calculation of total skeletal height as suggested by Lundy (10,28–29). On each complete skeleton the following measurements as described by Lundy (14) were taken:

- *Basibregmatic Height of the Cranium (BBH)*: This is the distance between bregma (the junction between the sagittal suture and coronal suture of the skull) or in cases of asymmetry, the point of intersection between the coronal suture and the median sagittal plane and the basion (most inferior part of the anterior margin of the foramen magnum) in the median plane. This was measured using a spreading caliper.
- *Maximum Body Height of the Vertebrae*: The distance between the most superior and the most inferior points on the body of each vertebra (usually found to be on the anterior aspect of the body was measured using a digital vernier caliper. However, in the case of C2 the tip of the odontoid process was taken to represent the most superior point. Although the odontoid process (lying posterior to the anterior arch of the atlas) does not directly contribute to stature, it is included in the measurement of the height of the axis, as it is taken to represent the body of the atlas. The distance between the midpoint of the sacral promontory and the midpoint of a horizontal line between the first and second sacral segments represents the height of the body of S1.
- *Bicondylar (Physiological) Length of the Femur (FEML)*: This is the distance between the most superior point on the head of the femur and an imaginary line that runs across the most inferior parts of the two condyles with the femur in a position that corresponds to the standing position. It was measured with an osteometric board.
- *Maximum (Condylomalleolar) Length of the Tibia (TIBL)*: The distance between the superior articular surfaces of the condyles and the tip of the medial malleolus represents the maximum length of the tibia. It was measured with an osteometric board.
- *Articulated Talocalcaneal Height (TCH)*: The talus and calcaneus of the left side were articulated and the height measured with the use of a mandibulometer.

All the measurements listed above were tested for repeatability using the concordance correlation coefficients of reproducibility (30) on a sample of 10 complete skeletons. The range of these coefficients were from 0.915–0.985 (Table 1), which are within internationally accepted standards (31).

ELS_{Fully} was obtained by adding the appropriate correction factor for soft tissue thickness as suggested by Fully (9). From the documented cadaver length, the estimated maximum living stature (ELS_{max}) was calculated by (i) subtracting 2.5 cm from the cadaver length as suggested by Trotter and Gleser (15) and (ii) compensating for stature decrease due to ageing observed in adults using formulae derived by Cline and co-workers (32). Descriptive statistics including mean and standard deviation were obtained for ELS_{max} and ELS_{Fully}. The paired Student's t-test was performed to ascertain whether a statistically significant difference existed between these two measurements.

TABLE 1—*Table of concordance correlation coefficients of reproducibilty (Pc) (Test-Retest System).*

Variable	Pc
BBH	0.991
C2	0.995
L5	0.986
S1	0.934
FEML	0.998
TIBL	0.990
TCH	0.935

BBH = Basibregmatic height, C2 = anterior body height of axis, L5 = anterior body height of fifth lumbar vertebra, S1 = anterior body height of first sacral vertebra, FEML = Physiological length of femur, TIBL = Condylomalleolar length of tibia, TCH = Articulated height of talus and calcaneus.

TABLE 2—*Descriptive statistics of documented height and estimated living stature for South African whites and blacks.*

	ELS_{max}		ELS_{Fully}					
	Mean	Sd	Mean	Sd	t-value	df	Sig (2 tailed)	*r*
Black male	166.63	5.10	162.58	5.60	6.052	38	0.000*	0.70**
Black female	161.39	8.21	152.94	6.93	6.583	38	0.000*	0.45**
White male	171.09	7.28	169.20	6.74	1.728	38	0.092	0.53**
White female	158.48	8.85	155.52	6.63	3.410	38	0.002*	0.79**

ELS_{max} = Estimated maximum living stature from cadaver length.
ELS_{Fully} = Estimated living stature using Fully's method.
r = correlation.
* Statistically significant at $p < 0.05$.
** Statistically significant at $p < 0.01$.

Results

Table 2 shows the descriptive statistics of estimated maximum living stature from documented cadaver lengths (ELS_{max}) and estimated living stature using Fully's method (ELS_{Fully}). The mean ELS_{max} for each of the four groups except the white male group was significantly higher than the corresponding mean value of ELS_{Fully}. The correlation between DCL and ELS was generally poor (Table 2). The highest correlation value was 0.79, obtained for the white female group, and the lowest was 0.45 (black female). The differences between ELS_{max} and ELS_{Fully} for the measured skeletons are presented in Figs. 1–4. A marked difference was observed. However, the difference in the white population group was less (Figs. 1 and 2) than in the black population group (Figs. 3 and 4).

Discussion

Previously, some anthropologists have shown that Fully's method for stature estimation, though tedious and time consuming is more reliable than regression equations (12,33). In the course of this study, it was observed that most of the measurements used in the estimation of TSH are easily reproducible (Table 1). However, some difficulties were encountered in the measurement of the anterior body height of the first sacral vertebra. These were due mainly to the faintness or sometimes complete absence of the horizontal line between the first sacral (S1) and second sacral (S2) vertebra. There has been doubt about the use of only the S1 vertebra in stature estimation using Fully's method. Some anthropologists have observed that the method underestimates living stature (personal communication with Professors Haffajee and Steyn). Perhaps other measurements from the sacrum such as anterior body heights of other sacral vertebrae might contribute to TSH. This is worth investigating.

The inclusion of the medial malleolus in the measurement of the condylomalleolar length of the tibia is also controversial. In deriving regression equations for stature estimation in American whites and blacks, Trotter and Gleser (15) omitted the medial malleolus in the course of measuring the length of the tibia making their tibia measurement 10 to 12 mm shorter than the actual measurement that includes the medial malleolus. The implication of this is that subsequent usage of Trotter and Gleser's formula resulted in overestimation of stature (34). In using Fully's method to estimate skeletal height and subsequently estimate living stature, the measurement of the length of tibia should include the medial malleolus. However, the question arises as to the relevance of the inclusion of the medial malleolus since it does not directly contribute towards stature.

Fully's soft tissue correction factors are widely used by anthropologists because they are believed to be non-population and non-sex specific (10–12). However, the general applicability of these factors is questionable. The marked differences observed in Figs. 3 and 4 between ELS_{max} and ELS_{Fully} in the black population groups compared to those in Figs. 1 and 2 might be due to the fact that the application of these correction factors worked better for the white

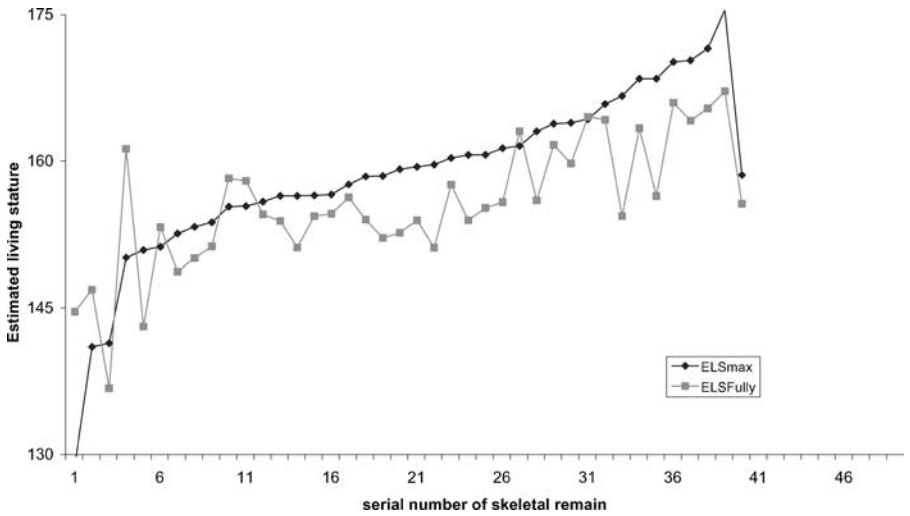

FIG. 1—*Comparison between estimated living statue (ELS_{Fully}) and documented cadaver lengths (ELS_{max}) for white females.*

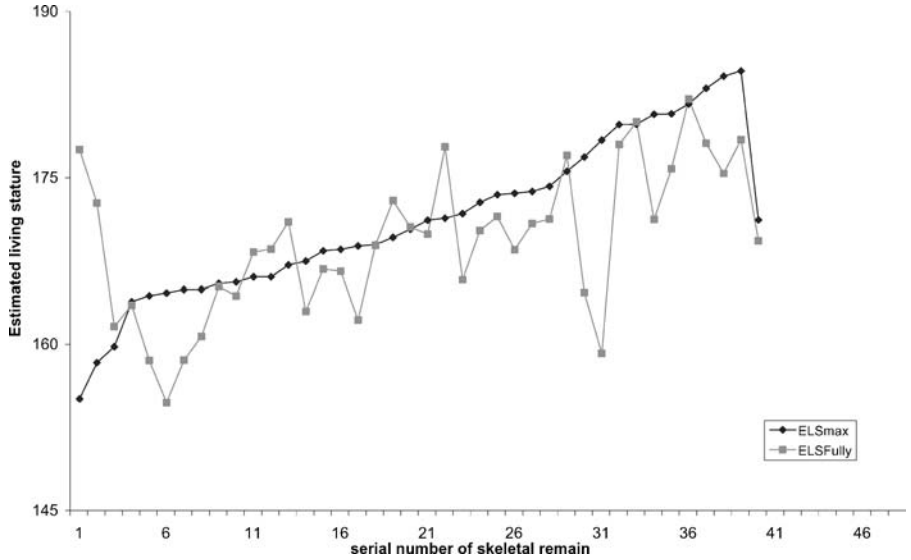

FIG. 2—*Comparison between estimated living statue (ELS_{Fully}) and documented cadaver lengths (ELS_{max}) for white males.*

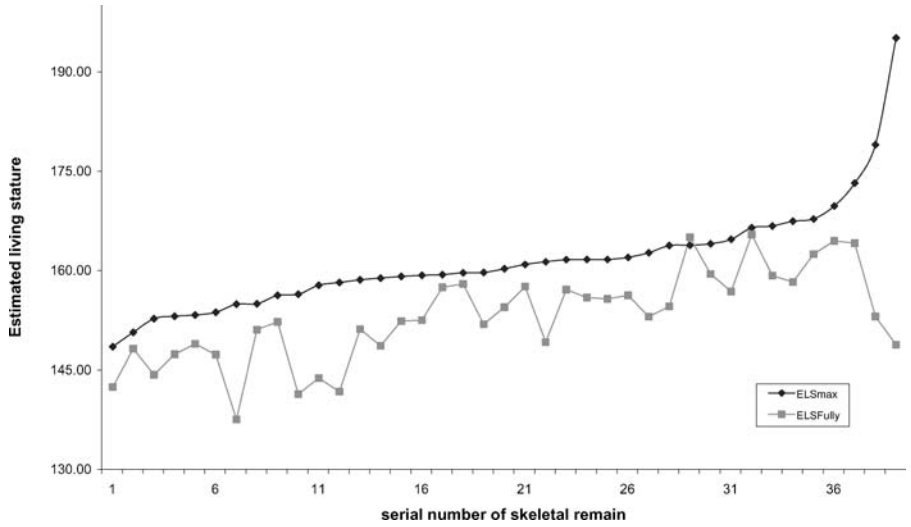

FIG. 3—*Comparison between estimated living statue (ELS_{Fully}) and documented cadaver lengths (ELS_{max}) for black females.*

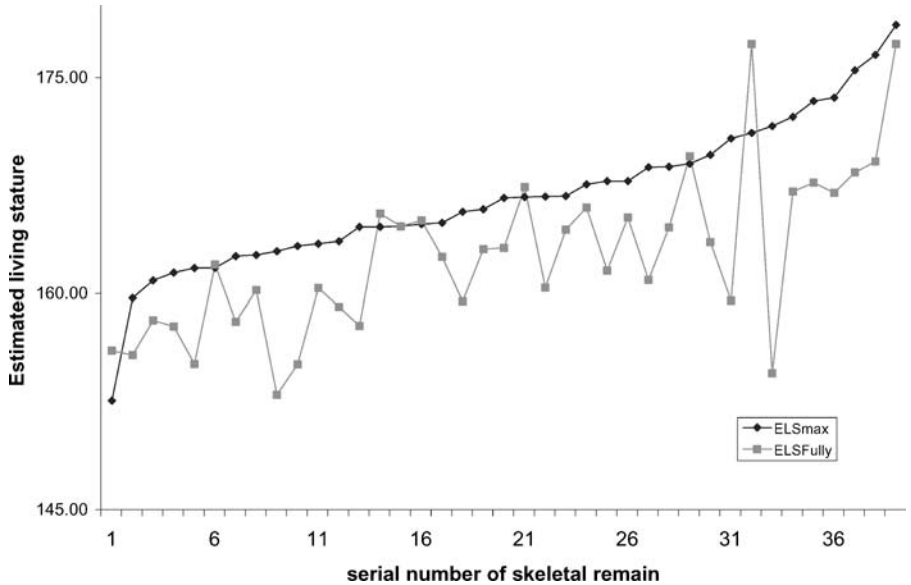

FIG. 4—*Comparison between estimated living statue (ELS_{Fully}) and documented cadaver lengths (ELS_{max}) for black males.*

samples. Since these factors were originally derived from French samples, to which the South African white population is possibly closer to genetically than to black South Africans, these correction factors may indeed be population specific.

Unfortunately, the documented cadaver lengths in the Raymond A. Dart Collection of Human Skeletons may be unreliable (10). A closer examination of the plots in Figs. 1–4 shows the existence of marked disagreements between ELS_{max} and ELS_{Fully}. The author assessed the way in which cadaver length measurements are taken today by technicians and some flaws were noted. The plantar surfaces of the feet, for example, were not made to touch the footplate provided for that purpose. The soles of the feet were not at right angles to the body, while the neck was often in an extended position. The figures on the measuring tape attached to the measuring instrument used were not clear. All these factors may have added error to the final measurement. There is no evidence to suggest that that these errors are generalised as there are instances in Figs. 1–4 in which agreements exist between ELS_{max} and ELS_{Fully}. It is possible that these cadaver length measurements were properly taken by more experienced technicians.

Since stature estimates obtained from the use of Fully's method (9) take into account "all" the components that constitute stature, they should be expected to give a more accurate estimate. However, this study has demonstrated possible limitations with regard to the application of Fully's (9) soft tissue correction factors to other population groups. This study has also, from most plots in Figs. 1–4, shown that Fully's method underestimates living stature. If soft tissue factors specific for South African population groups were derived, they would quite possibly improve the reliability of this method as well as the regression equations derived from Fully's method.

Conclusion

The documented cadaver lengths in the Raymond A. Dart Collection are significantly higher than the estimated living statures calculated using Fully's method. However, documented cadaver lengths in the Collection may not be totally accurate. When a complete skeleton is available for adult stature estimation, Fully's method is considered a reliable method since it takes into account the skeletal components that constitute stature. However, this method has its limitations and should be used with caution. The soft tissue correction factors derived by Fully (1956) seemed to work better for the white samples used in this study than for blacks, possibly due to population specificity. There is therefore a need to derive such factors for the different South African population groups.

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