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Testing Anatomical Methods for Stature Estimation on Individuals from the W. M. Bass Donated Skeletal Collection

ABSTRACT: This study compared eight versions of the anatomical method for stature estimation on a white male sample (n = 34) from the W. M. Bass Donated Skeletal Collection. The aim was to evaluate errors in the estimates and to discuss how useful the methods are in forensic context. The average error estimating living stature was less than 1 cm for six of the methods. The correlations between the estimates were high (r = 0.982–0.999). In practice, differences between the versions as well as those between long bone-based equations and anatomical methods were small. Anatomical method is nevertheless more accurate than long bone regressions when individuals with atypical body proportions are examined.

KEYWORDS: forensic science, forensic anthropology, stature, anatomical method, cadaver length, reported stature

There are various ways to estimate the stature of an individual from skeletal remains. Regression equations for long bones are most often used, but the anatomical method of measuring the entire skeleton may also be used. Lundy (1) has discussed the advantages and disadvantages of both approaches. In general, the anatomical method takes into account the individual and population-based differences in body proportions which appear mainly in trunk height and long bone lengths. Thus, the anatomical technique is preferred for archaeological materials in which the regression equations based on modern samples may not work. In forensic context, appropriate regression equations are available, but the population the individual represents might not be known or the body proportions of the individual in question may differ from the typical proportions. Individual variations in trunk height and long bone lengths can be retained in the estimated stature when the anatomical method is applied.

Maijanen and Niskanen (2) compared seven anatomical techniques using an archaeological sample from Westerhus, Sweden. The estimated average stature for males ranged from 167.6 to 172.7 cm depending on the method. The Westerhus material could not be used to test the accuracy of the methods, because in the medieval archaeological material true statures of the individuals could not be known. Therefore, the goal of the current study was to utilize a sample with documented statures to test the methods. The sample was from the W. M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville (UTK). Eight anatomical techniques of stature estimation were compared to evaluate the accuracy of the methods and their applicability in forensic anthropology.

Five of the chosen techniques are taken from literature: Fully's (3) method with anterior vertebral heights, Formicola's (4) version of Fully and Pineau's (5) method, Raxter et al.'s (6) two regression equations for the anatomical method and Niskanen and Junno's (7) method. In addition, three alternative vertebral heights (see Materials and Methods) were applied to Fully's (3) method to study their applicability. This was necessary, because Fully (3) did not clearly state how he measured maximum vertebral heights and other researchers have interpreted the measurement in different ways (4,8). The most commonly used vertebral measurement has been the anterior midline height, which has been found to underestimate stature (6,9,10). Based on the underestimation, it has been suggested that Fully's (3) soft tissue factor, which is added to the total skeletal length to obtain the stature estimate, is incorrect (6,9,10). Four different vertebral heights were used in the current study to examine if the underestimation in Fully's (3) method is due to a wrong interpretation of the vertebral measurement.

One of the major issues of the study of stature estimation methods is the accuracy and reliability of the documented statures. Usually, documented statures that are used as the base for regression equations are cadaver lengths, living or reported statures. In the W. M. Bass Donated Skeletal Collection documented statures include both cadaver length and reported stature. The cadaver length is measured from the dead body usually by medical examiners. The reported stature is the stature reported by the individual or his/her family member and usually it is based on a recent or an old measurement or on pure visual estimation.

Most of the cadaver lengths used in the current study are taken by medical examiners, but some of them have been taken at the Anthropological Research Facility at UTK. Cadaver statures are subject to interobserver error, since there have been numerous researchers measuring individuals in varying conditions throughout the years. Terry (11,12) also noted that the cadaver length measured in supine position on a table is greater than the length measured in a standing position on an upright table. It is assumed that the cadaver lengths in this case have been measured in supine position.

In general, stature estimation methods aim at estimating living stature. Nevertheless, changes in the human body and thus stature after death are not entirely understood. It is assumed that the loss of muscle tone changes the normal positions of body parts and especially flattens the curves of the vertebral column (12). The factors that are used to correct cadaver length to represent living

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stature, range from 0 to 2.5 cm (13–16). As the range shows, there are uncertainties regarding the factor and whether it is constant regardless of age, sex, and the stature itself (6,17). The most widely used method for correcting the cadaver length has been Trotter and Gleser's (16) method in which they subtracted 2.5 cm from the cadaver length to arrive at the living stature. This correction was based on data from the Terry collection cadavers and military data on living statures.

There are also numerous studies on the reliability of reported statures (18–25). Reported statures have been found to be somewhat biased. Usually people tend to over-report their stature, at least by rounding it to the next greater even digit. For example, Willey and Falsetti (22) noted that heights reported in male driver's licenses were on average 1.3 cm greater than the actual measured height. Giles and Hutchinson (26) found the average overestimation to be 2.5 cm for males in their study. Some studies (19,25) have demonstrated that the statures reported by relatives are on average greater overestimates than self-reported ones.

These issues with cadaver lengths and reported statures were taken into account when the estimates in the current study were compared with documented statures. Even though some bias is expected in the documented statures in the W. M. Bass Donated Skeletal Collection, the advantage of using the collection is that it has not been used to develop any of the tested methods and thus, it is an independent sample.

Materials and Methods

This study was limited to white males (n = 38), because individuals from other groups (females in general or black males) are fewer in the collection. Individuals chosen for the study were under 59 years old and had a documented stature and no injuries or pathological conditions affecting stature. These individuals had preferably both or at least one measurable femur, tibia, and ankle. In addition, cranium and vertebral column with maximum of three missing vertebrae were needed for the study. Extensive osteophytic growth, and fused or compressed vertebrae were the main reasons why individuals were excluded from the sample. Individuals with surgical plates or screws in the long bones were also left out of the study. Individuals over 59 years of age were not included because of the loss of stature with increasing age. The average age for the sample was 45 (ranging from 27 to 59 years of age).

In this study, eight versions of the anatomical method were compared. First of all, Fully's (3) method was used as it is most often applied (8,27) (FullyANT from now on). This method computes skeletal height from basion-bregma height (BBH), height of C2, summed anterior midline heights of vertebrae C3-L5 (ANT), anterior height of the first sacral segment (S1ANT), physiological length of the femur (FEM2), length of the tibia (TIB1), and articulated talo-calcaneal height in anatomical position (TCA). Other vertebral heights (maximum midline [FullyMAX], posterior midline [FullyPOST], and maximum anywhere anterior to pedicles [FullyXAP]), were also applied to this method. Maximum midline height (MAX) in this study is usually either the posterior or the anterior height depending on whichever is greater. Posterior midline height (POST) is not usually used for Fully's (3) method but here it was tested as well. The maximum height anywhere anterior to pedicles (XAP) is a new measurement introduced by Raxter et al. (6). In addition to skeletal length, Fully (3) gave three categories for soft tissue correction based on the skeletal length: 10 cm added to skeletal lengths equal to or under 153.5 cm, 10.5 cm to skeletal lengths between 153.6 and 165.4 cm, and 11.5 cm to skeletal lengths equal to or over 165.5 cm. Fully's (3) method is based on living statures and bone measurements of males, mainly Frenchmen, buried in a cemetery of a World War II concentration camp at Mauthausen.

Raxter et al. (6) revised Fully's (3) method by transforming the addition of the skeletal elements and the soft tissue factor into a regression equation based on data from the Terry Collection. Their material includes black people and white people, males and females. Raxter et al.'s (6) Equation 1 includes both the soft tissue and age correction. The skeletal height is calculated from BBH, maximum height of C2, maximum height of C3-L5 anywhere anterior to pedicles (XAP), maximum height of the first sacral segment (S1MAX), FEM2, TIB1, and TCA. To estimate living stature with known age, the Equation 1 is: $1.009 \times$ skeletal height $- 0.0426 \times$ age + 12.1. If the age is unknown, the Equation 2 is: $0.996 \times$ skeletal height + 11.7 (6). Both equations were used in this study, even though Raxter et al. (28) noted their equation without age factor is likely to underestimate the stature of younger individuals.

Formicola (4) used a version of the anatomical method by Fully and Pineau (5) in which the soft tissue factor is 10.8 cm regardless of the skeletal length. Basically, the measurements are the same as in Lundy's (8) interpretation of Fully's (3) method except that Formicola (4) used the maximum midline height of the vertebrae (29), and the talo-calcaneal height (TCH) is articulated but not measured in anatomical position. Formicola's (4) interpretation is used, since Fully and Pineau (5) do not clearly describe those measurements.

Niskanen and Junno (7) introduced a version of the anatomical method that includes the least number of measurements of these methods. This is the first time the method based on bone measurements and literature is applied to a sample with known statures. The method includes the following measurements: BBH, summed posterior heights of T1-L5, FEM2, and TIB1. The TCH and the first sacral segment are substituted by a sex-specific addition (males 14.0 cm of which ankle is 7.0 cm and height from promontory to the top of the acetabular roof is 6.5 cm). This addition also includes an estimate of the scalp. The vertebral column height is converted into promontory-basion length of a living individual by multiplying the summed posterior heights of T1-L5 by 1.503. In addition, the summed femoral and tibial dry bone lengths are converted into living bone lengths by multiplying them by 1.015.

Measurements used in this study and their abbreviations are in Table 1. For femur, tibia, and ankle height, the average of left and right sides was used unless one side was unavailable, in which case the existing measurement was used alone. Four measurements were taken from each of the vertebrae, except for a single measurement of the axis (C2). Proper measurements required the vertebrae to be in good condition. If there was extensive lipping distorting the vertebral heights, the individual was excluded from the sample. Usually exclusion from the sample involved the anterior height whereas the posterior height could be measured. There were cases with a breakage of the posterior rim at midline caused by Schmorl's nodules, but the height could be easily estimated from the intact rim.

Slightly compressed vertebrae were measured but they were later reconstructed to the probable maximum height. The missing vertebral measurements were reconstructed by using sex- and population-specific regression equations based on the overall data collected on this material. The equations were computed from the next superior and inferior vertebra. If the vertebra had other measurements, they were used in the regression; thus if the anterior height was not measurable but the posterior height was, the posterior height with the superior and inferior anterior heights were used in the regression. Individuals with extra vertebrae (one with L6)

TABLE 1—*Measurements, abbreviations, and references.*

Measurements
Basion-bregma height (BBH) (30)
Height of the C2 including dens (3,8)
Anterior height at midline (total height of the column ANTC2L5) (8)
Posterior height at midline (total height of the column POSTC2L5, or POSTT1L5) (31)
Maximum height at midline (total height of the column MAXC2L5) (29)
Maximum height anywhere anterior to the pedicles (total height of the column XAPC2L5) (6)
Anterior height of the first segment of sacrum at promontory (S1ANT) (8)
Maximum height of the first segment of sacrum (S1MAX) (6)
Height from promontory to the top of the roof of acetabulum (PROheight) (6)
Maximum length of femur (FEM1) (32)
Bicondylar length of femur (FEM2) (32)
Maximum length of tibia without tubercles but including malleolus (TIB1) (32)
Biomechanical length of tibia (TIB2X) (mean of lateral and medial [TIB2] articular lengths) (33)
Maximum length of fibula (FIB1) (32)
Articulated height of talus and calcaneus (TCH) (4)
Articulated height of talus and calcaneus in anatomical position (TCA) (6)

were included in the study, and the height of the extra vertebra was calculated into the total spine length (34).

There were also two cases in which the maximum height of the first sacral segment could not be determined. In these cases, the anterior midline height was used as a substitute for the missing measurement. Other elements were not reconstructed. Measurements were taken with spreading and sliding calipers and osteometric board. All statistical analyses were performed with SPSS 15.0 (SPSS Inc., Chicago, IL).

Evaluation of the Reliability of the Documented Statures

This current sample included cadaver lengths and reported statures. Because both types of statures include potential error, neither was preferred and both were included in the study. In order to exclude noticeably incorrect documented statures from the sample and to examine if the groups could be pooled together, both stature groups were tested by studying the soft tissue estimates (documented stature—skeletal length) and comparing the documented stature to estimates calculated using modified Trotter and Gleser's (35) regression equations. The skeletal length chosen for this purpose was different from the versions used in the anatomical methods under study. This skeletal length included the following measurements: BBH, maximum height of the C2 including dens, C3-L5 posterior midline heights, promontory-acetabular height, bicondylar length of femur, average physiological lengths of the tibia measured both from lateral and medial articular surface midpoints, and ankle height. The major difference in this skeletal height compared with other versions is the inclusion of the promontory-acetabular height instead of the first sacral segment and the physiological length of the tibia instead of the tibial length including medial malleolus. These measurements reflect clearly the elements contributing directly to the stature as is presented in Raxter et al.'s (6) Table 4. However, the skeletal length used for this purpose could have been any of the above mentioned, because the intention was to exclude outliers, not to find the correct soft tissue estimate.

Another method to evaluate the reliability of the documented statures was to calculate stature estimates using a modification of Trotter and Gleser's (35) regression equations for femur and fibula. Their least squares regression (LSQ) equations were modified into reduced major axis (RMA) equations according to Hens et al. (36). RMA regression was chosen over LSQ, because LSQ tends to underestimate tall statures and overestimate short ones (36,37). The mean value of the estimates from femur and fibula was used. Fibula was preferred to tibia because of the uncertainties in tibia measurement (38) in the original study. A clear difference between a regression-based estimate and a documented stature was considered to indicate possible problems in the documented stature and such individuals were excluded from the sample.

The soft tissue estimates showed that the cadaver statures are more variable than the reported statures. The average soft tissue estimate in the reported group was 11.7 cm (SD 1.9) and 9.8 cm in the cadaver group (SD 3.4). Based on the soft tissue estimate and a clear difference (10 cm) between the documented stature and the regression equation-based estimate, three individuals were excluded from the cadaver sample. From the reported sample one outlier was excluded. After these exclusions, the sample included 34 individuals: 22 with cadaver lengths and 16 with reported statures, including four individuals with both statures (Table 2). The difference in the average soft tissue estimate between the two stature groups was not significant (t-test $p > 0.9$). Even though the stature and the skeletal height in the reported group were bigger than in the cadaver group the skeletal height/stature-ratios were almost equal and indicated that the groups could be combined. The final combined sample included 34 individuals: 22 cadaver lengths and 12 reported statures (four individuals with both types of the documented statures available were included in the cadaver group based on the more probable soft tissue estimate).

The data from the National Health and Nutrition Examination Survey (NHANES) 1999–2002 (39) shows the same average height, 177.9 cm, for white males as in the current sample with combined documented statures without adjusting to living stature. The NHANES data concerns males born in 1940–1960 and is thus contemporaneous with most of the individuals in the current sample. This suggests that the used documented statures are not necessarily greatly inflated or, if they are, the average living height in this sample is clearly lower than in white American males in general. The skeletal height/stature-ratios suggest equal bias in statures in cadaver and reported groups.

Results

The descriptive statistics of the sample are shown in Table 3. When the documented stature groups were compared with each other, the statures were used without any corrections. The uncorrected statures were used to calculate the errors in the estimated statures, but, in addition, the documented statures were corrected in three ways. The corrections were made to adjust statures to the likely living stature, because the methods used aim at living stature. First, the widely used 2.5 cm for correcting the cadaver length into living stature (16) was subtracted from the cadaver lengths, but the reported statures were left uncorrected. Second, the reported statures in the sample were corrected using Rowland's (21) regression

TABLE 2—*Mean and SD for cadaver lengths and reported statures.*

	Cadaver (n = 22)	Reported (n = 16)
Stature (uncorrected)	176.68 (7.13)	177.55 (7.72)
Skeletal length*	164.78 (7.44)	165.63 (7.11)
Soft tissue†	11.90 (2.84)	11.92 (2.33)
(SKL/Stature) × 100	93.26	93.28

*Skeletal length (SKL) = BBH + POSTC2L5 + PROheight + FEM2 + TIB2X + TCA.

†Soft tissue = documented stature − skeletal length.

TABLE 3—*Descriptive statistics in cm for the combined sample* (n = *34).*

	Mean	Range	SD
Stature	177.85	164.00–188.00	6.59
BBH	14.14	13.10–15.10	0.51
ANTC2L5	50.38	44.56–54.93	2.21
POSTC2L5	52.68	45.59–56.08	2.42
MAXC2L5	53.46	46.82–57.21	2.39
XAPC2L5	52.14	45.51–56.50	2.45
POSTT1L5	41.03	35.65–43.82	1.94
S1ANT	3.49	2.97–4.03	0.23
S1MAX	3.58	2.99–4.03	0.25
PROheight	6.85	5.31–7.75	0.58
FEM1	47.75	42.20–52.20	2.31
FEM2	47.37	41.75–51.55	2.30
TIB1	39.41	33.35–44.40	2.30
TIB2X	37.58	31.93–42.60	2.21
FIB1	39.13	33.50–44.70	2.32
TCA	7.37	5.65–8.20	0.56
TCH	6.40	5.17–7.05	0.39
Skeletal length*	165.98	147.55–177.74	6.90
Soft tissue†	11.87	7.89–18.09	2.42
T&G RMA‡	176.83	160.06–191.74	6.89

*Skeletal length = BBH + POSTC2L5 + PROheight + FEM2 + TIB2X + TCA.

†Soft tissue = documented stature − skeletal length.

‡T&G RMA = RMA-modifications fem1 = 2.84488 × fem1 + 40.767 and fib1 = 3.1801 × fib1 + 53.268 combined based on Trotter and Gleser (35) and age corrected (40).

equation to correct the reported statures into their probable actual height but the cadaver statures were not corrected. Rowland's (21) sex-specific equation is based on a comparison of measured and self-reported heights. The average correction for the reported heights in this sample was −1.6 cm, which is in accordance with the previously mentioned studies of the over-reported stature (22,26). Third, both cadaver and reported statures were corrected using their own correction factor and their average stature is referred to as a corrected living stature.

The average residuals (observed stature − estimated stature) are presented in Table 4. Only residuals without age correction are shown in the table, because the average age of the sample is 45 and the average correction is only 0.3 cm according to Giles (40). Comparing the estimated statures with the uncorrected documented statures, it is clear that all the methods underestimate stature, except the Niskanen and Junno (7) method, which overestimates statures on average by less than 1 mm. The underestimation was expected, because the methods provide living stature estimates. The corrections made to adjust the documented stature to living stature naturally decrease the underestimation. Correcting only the reported statures with Rowland's (21) equation results in bigger residuals than correcting only the cadaver lengths. This was expected, as the Rowland's (21) correction is on average smaller than cadaver correction and there are fewer reported statures than cadaver lengths in the sample. When corrected living stature is used residuals vary 0.03–2.75 cm. All methods underestimate corrected living stature, except the FullyMAX and Niskanen and Junno's (7) method.

Based on the residuals FullyANT clearly underestimates stature, as noted by earlier studies (6,9,10), and is the weakest of the methods applied. Another systematically weak method is FullyXAP. Niskanen and Junno's (7) method works well with uncorrected documented statures, but not when the suggested corrections for living stature (16,21) are used. FullyMAX, Raxter et al. (6) Equation 1, and FullyPOST give constantly better estimates than the other methods, no matter which correction is used. If the corrected living stature is considered to be the most reliable stature, all methods give average errors less than 1 cm, except Niskanen and Junno (7) and FullyANT (significantly different from 0, $p < 0.05$).

Table 5 shows residuals for the estimates calculated with Trotter's (41) and Ousley's (17) regression equations for lower limb bones. In general, these long bone-based estimates give smaller residuals with uncorrected stature than most of the anatomical methods. When the corrected living stature is used most of the regression equations overestimate stature and their average errors are larger than most of the average errors given by anatomical methods. Ousley's (17) equations are for estimating forensic stature (reported or driver's license) and thus, they were expected to show this pattern in the residuals. Trotter's (41) equations work better in estimating corrected living stature as they were supposed to.

Correlations between residuals and documented statures were studied to determine possible directional bias in the estimates. However, the correlations were not statistically significant to give preference to any of the methods. Correlation coefficients between the corrected living stature and the estimated stature are shown in Table 6. The coefficients vary between 0.918 and 0.938. The highest correlation is found with FullyPOST followed by FullyMAX and Formicola's (4) application, but the differences are small as is shown also in the correlations between different methods (r = 0.982–0.999). The estimated statures based on Trotter's (41) and Ousley's (17) equations give lower correlations than the

TABLE 4—*Residuals (observed − estimated stature) for anatomical methods using uncorrected and corrected statures.*

Uncorrected Stature†	Mean 177.9	Cadaver − 2.5 cm‡	Mean 176.2	Reported − Correction§	Mean 177.3	Corrected Living Stature¶	Mean 175.7
Niskanen & Junno	−0.03*	FullyMAX	0.08*	Niskanen & Junno	−0.59*	Raxter et al. (equation 1)	0.03*
FullyMAX	1.69	Raxter et al. (equation 1)	0.59*	FullyMAX	1.13	FullyPOST	0.32*
Raxter et al. (equation 1)	2.20	FullyPOST	0.88*	Raxter et al. (equation 1)	1.65	FullyMAX	−0.48*
FullyPOST	2.50	Formicola	1.18	FullyPOST	1.94	Formicola	0.62*
Formicola	2.79	Raxter et al. (equation 2)	1.19	Formicola	2.23	Raxter et al. (equation 2)	0.63*
Raxter et al. (equation 2)	2.81	FullyXAP	1.45	Raxter et al. (equation 2)	2.25	FullyXAP	0.90*
FullyXAP	3.07	Niskanen & Junno	−1.64	FullyXAP	2.51	Niskanen & Junno	−2.20
FullyANT	4.92	FullyANT	3.30	FullyANT	4.36	FullyANT	2.75

†Uncorrected documented statures.

‡Cadaver − 2.5 cm, uncorrected reported.

§Uncorrected cadaver, reported—Rowland's (21) correction.

¶Cadaver − 2.5 cm, reported—Rowland's (21) correction.

*Not significantly different from 0, $p > 0.05$, t-test.

TABLE 5—*Residuals (observed – estimated stature) for long bone regression equations.*

	Uncorrected Stature	Corrected Living Stature
Trotter Fem1, Tib1	1.26	−0.92*
Trotter Fem 1	2.81	0.63*
Trotter Fib1	1.21	−0.97*
Ousley Fem1, Tib1	−0.34*	−2.51
Ousley Fem1	0.54*	−1.64
Ousley Tib1	−0.82*	−2.99

*Not significantly different from 0, $p > 0.05$, *t*-test.

anatomical methods. Only the highest correlation ($r = 0.888$) for the long bone-based estimates, i.e. Trotter's (41) equation for femur, is shown in the table.

In order to demonstrate how the anatomical method takes body proportions into account, an example is presented here. The regression equations based on long bones will give the same stature estimate for individuals with the same bone length. Using only femur will ignore the contribution of tibia to the height and vice versa. If it is possible, combined femur and tibia lengths should be used. However, using the combined length of lower limb bones does not recognize the differences in the vertebral column lengths. In this sample, two individuals have almost the same combined length of femur (fem1) and tibia (tib1) (82.5 and 82.6 cm), but their documented cadaver statures differ by 6.5 cm (169 and 162.5 cm after adjusting to living stature). The vertebral column lengths show a difference of 5.8 cm (52.6 and 46.8 cm). Individuals will have almost identical estimates when regression equations are used. For example, using combined femur and tibia Trotter's (41) equation gives estimates of 170.5 and 170.7 cm and Ousley (17) 171.6 and 171.8 cm. The versions of the anatomical method retain the relative difference in the vertebral column length giving stature estimates that differ from each other by 7.3–8.8 cm (e.g. Raxter et al. [6] Equation 1 estimates 171.1 and 163.0 cm).

Discussion and Conclusions

The aim of this study was to compare eight versions of the anatomical method and their estimates in a single collection, the W. M. Bass Donated Skeletal Collection. In general, most of the methods underestimate documented stature, even when the stature is adjusted to living height. The corrected living stature is considered to give the most probable height for the sample, since the reported statures are expected to be somewhat inflated and the correction of 2.5 cm for cadaver length is commonly accepted. In addition, Raxter et al. (6) used 2.5 cm in their study, which is the only method utilized in the current study based on cadaver lengths.

Results on Fully's (3) method using anterior midline vertebral height (ANT) support the previous studies (6,9,10). It is clear that this version gives too short estimates and should not be used. Because of different interpretations on which vertebral height Fully (3) actually used in his study, other vertebral heights were tested. The vertebral measurement (XAP) introduced by Raxter et al. (6) does not perform well when used with Fully's (3) method, which was also noted by Raxter et al. (6). It could be concluded that very likely this is not the measurement Fully (3) used in his method even though Raxter et al. (6) found this measurement to be more accurate in their new application than the anterior midline height. Contrary to ANT or XAP, maximum midline height (MAX) seems to work well when applied to Fully's (3) method. Based on the residuals, it is one of the best methods used in this study, which gives a reason to consider that Fully (3) used maximum midline height in his study. The posterior midline height (POST) also gives good estimates, which is expected, because maximum height in the vertebrae was usually located in the posterior part in this sample.

Niskanen and Junno's (7) method was tested here for the first time against documented statures. It seems to work with uncorrected cadaver and reported statures, but overestimates the living statures. Even though the Niskanen and Junno (7) method itself requires modification, if living stature is the goal, the idea behind the method is worth considering. One of the advantages of this method is that it requires fewer measurements and is thus better suited for incomplete remains. It also utilizes posterior vertebral height, and thus most of the serious lipping and compression of vertebral body can be avoided.

The smallest errors with living stature estimates are shown by Raxter et al.'s (6) Equation 1, FullyMAX, and FullyPOST. The advantage of Raxter et al.'s (6) technique is that it has been created using both sexes and two populations (white and black), whereas Fully's (3) method was solely based on white males. If other than a white male sample was tested in this current study, Fully's (3) population-specific soft tissue correction factor could possibly cause more error, as was suggested by Bidmos (10). Raxter et al.'s (6) vertebral measurement (XAP) is however new and somewhat more difficult to locate than midline heights. This might hinder its wider use compared to other vertebral measurements. In the end, differences among the majority of the anatomical methods (residuals and correlations) are small and recommending only one method is not justified. These three above-mentioned versions work best in this sample, whereas the Niskanen and Junno (7) method and Fully-ANT are clearly weaker than other methods.

The current study used one sample limited to white males. Future research should include testing of the methods on larger, more diverse samples including females and other populations. The correction factors for adjusting documented stature to living stature might also include some bias. The skeletal height/uncorrected

TABLE 6—*Correlation coefficients between corrected living statures and estimated statures (without age correction).*

	Stature	Fully ANT	Fully MAX	Fully XAP	Fully POST	Formicola	Niskanen & Junno	Raxter (equation 1)	Raxter (equation 2)
FullyANT	0.924								
FullyMAX	0.935	0.996							
FullyXAP	0.927	0.997	0.996						
FullyPOST	0.938	0.994	0.999	0.994					
Formicola	0.934	0.994	0.997	0.994	0.997				
Niskanen & Junno	0.918	0.987	0.991	0.985	0.993	0.995			
Raxter (equation 1)	0.929	0.995	0.993	0.998	0.990	0.992	0.982		
Raxter (equation 2)	0.923	0.996	0.995	0.999	0.993	0.999	0.986	0.999	
TrotterFem	0.888	0.955	0.953	0.954	0.951	0.952	0.939	0.943	0.950

stature-ratio suggested that the correction factors might not be that different between cadaver and reported statures. Since other suggested factors (13–15) for cadaver length are smaller than Trotter and Gleser's (16) factor, the 2.5 cm should be considered the absolute maximum correction factor.

Despite the possible errors in the documented statures, the current study has shown the relative differences between the anatomical versions. The anatomical method, in general, seems to work better than the long bone-based equations applied in this study. However, in forensic context, the stature is usually estimated by using long bone equations. They require fewer measurements than the anatomical method and thus save time. One of the major reasons for using the long bone equations is that they require less complete skeleton than the anatomical method. The conditions of the remains will naturally direct which methods can be applied in each case, but the anatomical method could probably be used more often than it is applied at the moment. A review of forensic cases in New Mexico between 1974 and 2000 showed that 36% of the 598 cases had complete skeleton and another 36% had one or more major bones missing (42). This means that at least 36% would have been usable for the anatomical technique, and probably even more, if the cases missing nonessential elements for the method were included.

The greatest advantage of using the anatomical method is gained when it is applied to an individual with atypical body proportions. The differences in proportions will not be recognized by the long bone equations. This is also why the entire skeleton is useful in estimating stature of an individual with undetermined or mixed ancestry. The anatomical method can also point out deviations from the average height due to the differences in vertebral column length and thus be more helpful in identification process, because extreme heights, either tall or short, are the most useful for identification purposes (43). If the skeletal remains are complete enough, the anatomical method can provide a useful tool for stature estimation both in forensic anthropology and archaeology.

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