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TECHNICAL NOTE

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Stature Estimation Based on Dimensions of the Bony Pelvis and Proximal Femur*

ABSTRACT: Pelin et al. recently showed that sacral height measured on lateral magnetic resonance images can be used with moderate accuracy to reconstruct stature in males. In most forensic anthropological cases, however, sacral dimensions must be obtained from dry bones. In this study, the relationship between stature and sacral height, hip height, and femur head diameter measured on dry bone was evaluated for American Blacks and Whites of both sexes ($n = 247$). There are significant correlation between stature and these three dimensions, but the results suggest that none of the dimensions predict stature with the accuracy needed to be useful in forensic anthropological investigations.

KEYWORDS: forensic science, forensic anthropology, stature, sacrum, femur

The accurate estimation of stature helps to establish an individual's identity in medicolegal investigations involving skeletal remains. In most forensic anthropological investigations, stature is estimated using the combined dimensions of bones responsible for living stature (1,2) or using regression equations based on complete long bone length measurements (3–5). However, in some mass disaster, burn, and skeletal cases these methods cannot be applied because intact long bones are not available. As a result, anthropologists have developed methods for reconstructing stature based on measurements of other complete bones, such as the cranium (6), clavicles (7), scapulae (8,9), metacarpals (10,11), hand phalanges (12), vertebrae (13,14), tarsals (15,16) and metatarsals (17), or segments of long bones (18–22). Many of these bones, however, are frequently carried off by animals in skeletal cases (23) and are not recovered in mass disaster and burn cases (13). Furthermore, in methods based on fragments, the bone length is estimated and then the estimated bone length is used to estimate stature (18,19), which can compound any error.

In a recent article in this journal, Pelin et al. (13) investigated the use of sacral and coccygeal vertebral dimensions recorded from lateral magnetic resonance (MR) images to predict living stature in males. Their results showed that sacral dimensions may be used with moderate reliability to estimate stature (standard error 64–73 mm), but their method has not been applied to dry skeletons. As Pelin et al (13) note, it is necessary to test the method on dry bone and, if necessary, develop new regression equations.

In this study, the statistical correlation between living stature and sacral height (SH) taken on dry bone, a standard osteological measurement (24), is evaluated. Pelin et al. (13) used individual sacral segment measurements in addition to living SH in their analyses. While these measurements are relatively easy to measure with accuracy and precision from MR images (13), they are difficult to measure on dry bone with precision. Furthermore, Pelin et al. (13) found that SH and the sum of vertebral dimensions were more accurate predictors of stature than individual vertebral measurements. As a result, individual segment heights were not used in this study. This study was expanded, however, by using both males and females and two ancestral groups (American Whites and Blacks) and including coxa (hip) height (HH) and femur head diameter (HD). The coxa and femur head are often preserved in skeletonized, mutilated, and burned human remains that have an intact sacrum, and measurements of these bones are commonly collected by anthropologists (24). Therefore, we wanted to compare the accuracy of regression equations for estimating stature using HH and HD to equations based on SH. In addition to examining the correlation between stature and dimensions of the pelvic region, sex and ancestry differences were examined, and regression equations were developed for each group that can be used by forensic anthropologists to estimate stature. The advantages and limitations of using measurements of the pelvic region to estimate stature in medicolegal cases where more commonly used bones are not preserved or recovered are then discussed.

Materials and Methods

Anterior length of the sacrum SH, HH, and HD (Fig. 1) were obtained from the Forensic Data Bank (FDB) (24,25) for American Black and White males and females with known forensic or cadaver stature, age, and ancestry (Table 1). Forensic stature is the stature recorded on driver's licenses, medical records, and other documents, while cadaver stature is the height measured directly from a corpse. Individuals used in the study range in age from 17 to 89 years (Table 1). Left femora and coxae were preferentially used, but right bones were used if measurements of the left were not available. All dimensions were recorded to the nearest millimeter.

Statistical analyses were performed using SAS 9.0 statistical software (26). Linear least squared regression, which provides statistics on the strength of the relationship between two or more variables, was used to derive equations for stature estimation for each variable and to compare groups. Multiple regression equations were also derived using a maximum *r*-square (R^2) improvement (MAXR) stepwise method. The accuracy of the regression

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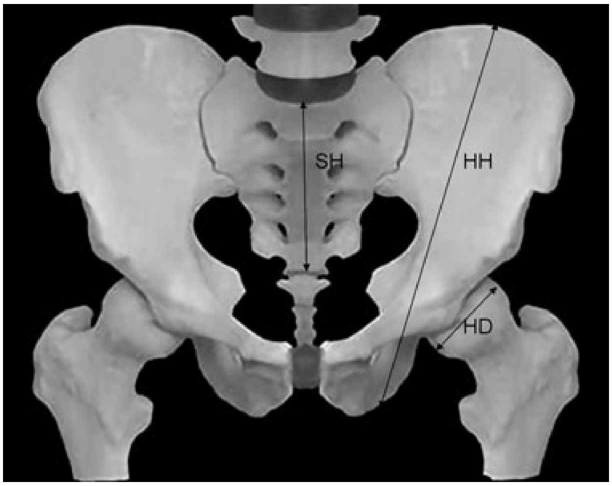

FIG. 1—*Measurements of the pelvic region—sacral height (SH), hip height (HH), and femur vertical head diameter (HD).*

TABLE 1—*Sample characteristics and descriptive statistics.*

Variable	Statistic	White Males	Black Males	White Females	Black Females
Stature*	*n*	92	57	60	38
	Mean	1768.0	1758.6	1635.5	1633.7
	SD	77.3	77.6	77.3	79.1
	Range	1570–2050	1550–1930	1370–1800	1420–1820
Sacral height (SH)*‡	*n*	92	57	60	38
	Mean	109.7	102.9	108.1	102.4
	SD	12.1	11.5	11.1	11.9
	Range	74–147	76–142	79–134	80–121
Hip height (HH)*‡§	*n*	92	57	60	38
	Mean	221.8	210.3	203.3	188.4
	SD	11.1	14.6	7.7	12.4
	Range	199–255	159–238	174–225	161–215
Femur head diameter (HD)*‡§	*n*	92	57	60	38
	Mean	48.3	47.4	42.5	41.7
	SD	2.4	2.5	2.0	2.2
	Range	43–55	42–53	39–47	35–46
Age†	*n*	92	57	60	38
	Mean	43.5	35.8	36.4	30.0
	SD	15.4	13.4	18.0	9.3
	Range	19–77	18–73	17–89	17–65

*In mm.
†In years.
‡Significant (≤0.05) ancestry differences.
§Significant sex differences.

equations was evaluated using the mean square error (MSE). Heterogeneity in regression coefficients among groups were evaluated using analysis of covariance.

Results

Summary statistics for stature, age, and the three pelvic region dimensions are presented in Table 1 by sex and ancestry. Table 2 shows the regression equations and corresponding statistics for each variable as well as the multivariate models. All measures show a statistically significant ($p \leq 0.05$) positive correlation with stature, except SH in White females (Table 2, Figs. 2–4). For males, HH exhibits the strongest correlation with stature and the smallest MSE. Sacral height is the weakest predictor of stature for Black males and HD is the weakest for White males. Among females, HD had the highest correlation with stature and the lowest MSE values followed by HH and then SH. In general, sacral height is a poorer predictor of stature than either HH or HD.

Pelvic region dimensions appear to correlate better with stature in American Blacks than in Whites (Table 2). For both males and females, the MSE values were lower for American Black than White regression equations. The MSE is also lower for females than males, suggesting that the estimation of stature from the pelvic region is more reliable for females than males. However, while there are significant sex and ancestry differences in the variables (Table 1), the slope of the regression lines do not differ significantly by sex or ancestry. This suggests the differences among groups are primarily due to sampling.

Multivariate equations outperformed univariate models for all groups. A MAXR procedure was used to find the best two- and three-variable equations (Table 2). The best two-variable models include HH and HD for all groups, except White males. The addition of the third variable does not increase R^2 except in Black females.

Discussion and Conclusions

Sacral height measured on dry bone in this study had higher MSE scores and generally lower correlations with stature compared to SH measured from MR images of males by Pelin et al. (13). The correlation (r) between sacral height measured from lateral MR images and stature reported by Pelin et al. (13) was 0.432. In this study, the correlations between SH and stature ranged from 0.13 to 0.46 (Table 2). There are several possible reasons for the differences between the results of this study and the one by Pelin et al. (13) besides the method used to measure SH. These include interobserver error and differences in sample size, mean age of the sample, ancestry, selection criteria, and methods used to obtain known stature.

In the study by Pelin et al. (13), SH was measured on lateral MR images by a single observer, while the FDB contains measurements from multiple observers. Interobserver error has the potential to increase noise (variation) in the data. While Pelin et al. (13) found that interobserver error for SH was generally low, it is possible that the differences in the correlation and MSE in this study compared to one by Pelin et al. (1) are due to noise created by interobserver error.

Sample characteristics may also explain some of the differences between the two studies. Pelin et al. (13) used a total of 42 living males of presumed Turkish descent with a mean age of 62 years. The male sample used in this study was considerably larger (98 White and 58 Black males), which may account for the greater range of variation in stature and SH and decreased accuracy of stature estimation. The mean age for males in this study was also more than 20 years younger (Table 1) than the sample used by Pelin et al. (13). Loss of stature begins around 30 years of age, but it is unknown how age-related decreases in stature would affect estimations based on sacral height. Since differences in the accuracy of estimating stature from SH were observed between American Blacks and Whites in this study, it is highly plausible that some of the differences in our results compared to Pelin et al. (13) are due to population differences. American Black and White males (Table 1) are on average taller than the Turkish males (mean = 1710 mm), but American Black males have a nearly 7 mm shorter average SH (102.9 mm) compared to American White (110.0 mm) and Turkish males (109.5 mm).

The selection criteria for inclusion of individuals also differed between the Pelin et al. (13) and present study. Pelin et al. (13) selected individuals with five sacral segments and no evidence of

TABLE 2—*Regression equations and statistics for estimating stature.*

Group*	Variable*	Regression Equation	DF†	*p*-value	*r*	MSE‡
WM	SH	1498.12 + 2.461 * SH	90	0.0001	0.39	71.69
	HH	1044.73 + 3.262 * HH	90	<0.0001	0.47	68.63
	HD	1367.96 + 8.277 * HD	90	0.0118	0.26	75.02
	SH, HH	994.57 + 1.659 * SH + 2.668 * HH	89	<0.0001	0.53	66.29
	SH, HH, HD	994.21 + 1.659 * SH + 2.665 * HH + 0.0170 * HD	88	<0.0001	0.53	66.67
BM	SH	1437.73 + 3.117 * SH	55	0.0003	0.46	69.55
	HH	954.69 + 3.822 * HH	55	<0.0001	0.72	54.49
	HD	1013.60 + 15.733 * HD	55	<0.0001	0.51	67.26
	HH, HD	842.28 + 3.384 * HH + 4.320 * HD	54	<0.0001	0.73	54.24
	SH, HH, HD	853.55 + 0.411 * SH + 3.273 * HH + 3.680 * HD	53	<0.0001	0.73	54.62
WF	SH	1540.03 + 0.883 * SH	58	0.3355	0.13	77.33
	HH	927.84 + 3.480 * HH	58	0.0064	0.35	73.07
	HD	990.51 + 15.176 * HD	58	0.0024	0.38	71.94
	HH, HD	650.25 + 2.394 * HH + 11.727 * HD	57	0.0019	0.44	70.42
	SH, HH, HD	943.63 – 0.210 * SH + 0.683 * HH + 13.58 * HD	56	0.0059	0.44	71.03
BF	SH	1336.75 + 2.898 * HH	36	0.0060	0.44	72.13
	HH	919.68 + 3.789 * HH	36	<0.0001	0.59	64.48
	HD	586.802 + 25.130 * HD	36	<0.0001	0.71	56.55
	HH, HD	449.27 + 1.991 * HH + 19.43 * HD	35	<0.0001	0.76	53.05
	SH, HH, HD	441.16 + 1.048 * SH + 1.752 * HH + 18.124 * HD	34	<0.0001	0.77	52.48

*WM, White Male; BM, Black Male; WF, White Female; BF, Black Female; SH, Sacral Height; HH, Hip Height; HD, Femur Head Diameter.
†Degrees of freedom.
‡Mean squared error, which can be used to develop confidence intervals.

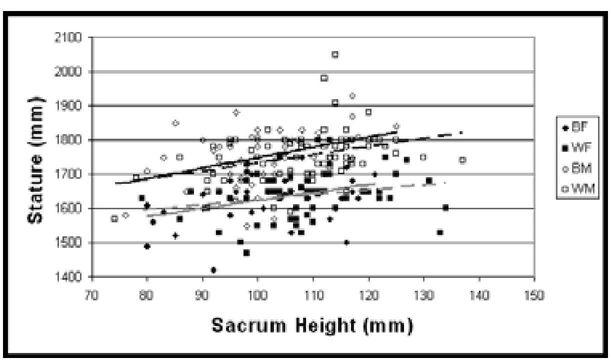

FIG. 2—*Relationship between sacrum height and stature. Regression lines are solid for males, dashed for females, black for American Blacks, and grey for American Whites. BF, Black females; BM, Black males; WF, White females; WM, White males. See Table 1 for sample sizes. The slope of the regression lines do not differ significantly by sex or ancestry.*

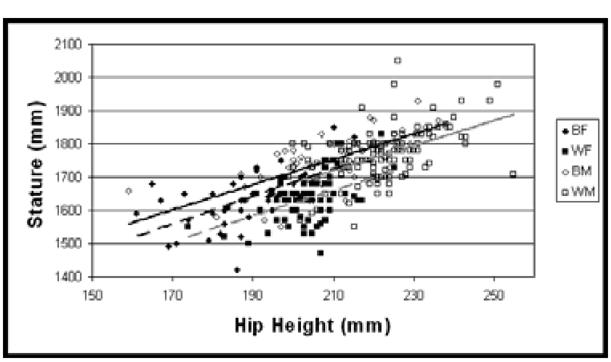

FIG. 3—*Relationship between hip height and stature. Regression lines are solid for males, dashed for females, black for American Blacks, and grey for American Whites. BF, Black females; BM, Black males; WF, White females; WM, White males. See Table 1 for sample sizes. The slope of the regression lines do not differ significantly by sex or ancestry.*

lumbosacral transitional anomalies. These criteria were not used in the current study, but lumbosacral transitional anomalies generally only occur in about 7% of the American population (27).

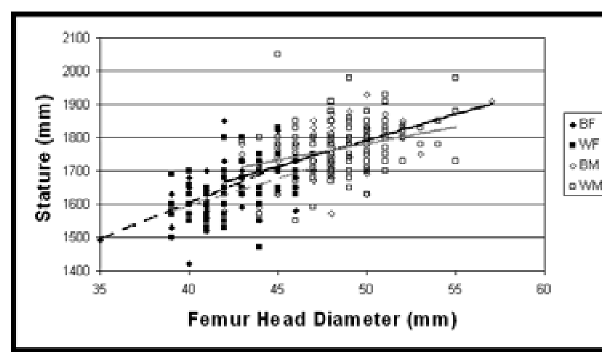

FIG. 4—*Relationship between femur head diameter and stature. Regression lines are solid for males, dashed for females, black for American Blacks, and grey for American Whites. BF, Black females; BM, Black males; WF, White females; WM, White males. See Table 1 for sample sizes. The slope of the regression lines do not differ significantly by sex or ancestry.*

Individuals with four or six sacral segments, while probably few in number, would have added variation to the data.

Finally, the method for determining "known" stature also differed. In this study, both forensic and cadaver stature were used as "known" statures, while Pelin et al. (13) used living stature. Forensic stature is often greater than measured stature (28). Willey and Falsetti (28) found that the statures recorded on the driver's licenses of college students were about half an inch greater for males and a quarter inch greater for females than measured living stature. In some cases, measured stature was greater than the stature on the driver's license probably because the individual failed to update the driver's license information after growth (28,29). However, the greatest problem with forensic stature is not its accuracy but its precision (29), which can increase the confidence interval for stature estimation and the slope of the regression line (28,29). There are numerous possible reasons for the imprecision of forensic stature, including failure to update driver's license stature after growth (28,29) and greater overestimation of stature by shorter individuals than taller individuals (30). With cadaver stature, interobserver error

TABLE 3—*Summary of results from selected previous studies.*

Bone	Reference	*r*	Error (mm)
Sacrum (height)	(13)	0.43	66
Sacral segments	(13)	0.12–0.43	66–73
Cranium	(6)	0.32–0.53	66–80
Metacarpals	(10)	0.49–0.84	55–81
Metacarpals	(11)	0.56–0.83	47–60
Vertebrae	(14)	0.18–0.64	53–68
Talus and calcaneous	(15)	0.72–0.82	41–62
Calcaneous	(16)	0.27–0.65	47–58
Metatarsals	(17)	0.58–0.89	40–76

and differences in methods used by observers are the most serious problems. Both can introduce noise into the data.

The accuracy of stature estimation based on measurements of the pelvic region was found to differ by sex and ancestry, although not significantly. The correlation between stature and HH, SH, and HD was greater in American Blacks than Whites, and greater in females than males (Table 2). Homogeneity in slopes among groups suggest that the differences between ancestral and sex groups are primarily due to sampling. However, it is possible that sex and ancestry differences in the relationship between pelvic region dimensions and stature have some influence. Blacks, on average, have shorter sacra and hips relative to stature (Figs. 2 and 3), and females generally have longer sacra and hips relative to stature than males.

Dimensions of the pelvic region (sacral height, hip height, and femur vertical head diameter) measured on dry bone correlate significantly with stature, but the error in the prediction is probably too great for equations based on these dimensions to be of use to forensic anthropologists in estimating stature. The 95% confidence interval for a stature prediction using equations for White males, for example, ranges from 265 to 300 mm. However, the confidence interval based on the mean and standard deviation is 309 mm. This suggests that the predicted stature would not be accurate enough to be of any help in the identification of an unknown individual. Sacral height, as well as HH and HD, are also poorer predictors of stature when compared to many of the other alternative bones examined by previous authors (Table 3). As a result, it seems that while sacral height can be used to estimate stature, forensic anthropologists would be better served using dimensions of the metacarpals, metatarsals, and ankle bones when estimating stature in mutilated, burned, and skeletal cases.

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