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TECHNICAL NOTE

ANTHROPOLOGY

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The Effect of Vertebral Numerical Variation on Anatomical Stature Estimates

ABSTRACT: Most humans possess 24 presacral vertebrae composed of seven cervicals, 12 thoracics, and five lumbars. However, variation from this standard pattern exists. The purpose of this study was to test the effect of congenital vertebral numerical variation on anatomical stature estimates and to recommend appropriate procedures when such variation occurs. Our sample consists of 41 individuals with unusual vertebral count patterns and known cadaveric statures from the Smithsonian's Terry Collection. Raxter et al. published a revised Fully anatomical technique in 2006 and we used this to estimate living stature. Based on our results, we recommend using the standard anatomical technique to reconstruct stature, regardless of vertebral pattern. However, when an individual possesses six sacral segments together with a normal number of presacral vertebrae, we recommend the addition of a slight correction factor of 1.3 cm or 0.8% of estimated stature.

KEYWORDS: forensic science, forensic anthropology, stature estimation, anatomical method, skeletal measurement, vertebrae

Human vertebral columns typically consist of seven cervical, 12 thoracic, and five lumbar vertebrae, totaling 24 presacral vertebrae, along with five fused sacral vertebrae (1–3). Variation in vertebral counts does occur, however, both in the total number of vertebral segments and their distribution between different vertebral regions (2,4). Numerical variations are typically due to segmental border shifting, which results in vertebrae at transitional zones assuming the characteristics of the region above or below the border (cephalad or caudad), consequently increasing or decreasing the quantity of that particular vertebral type (2). Incidence of nonmodal vertebral numerical patterns varies among populations (5,6) and ranges from 2% to 24% (7,8). Occurrence may be due to developmental irregularities (2) such as that related to an abnormal number of somites (2) and mutations of Hox, Pax, and POU genes (9,10). Variation has then generally been attributed to genetic influence and considered to be determined early in the embryological stage (3).

Fully's (11) technique for estimating living stature involves measurement of skeletal elements from the skull through the foot, including the maximum heights of the presacral vertebrae (except C1) and S1. However, Fully did not address the issue of vertebral numerical variation and its possible effect on stature estimation. Lundy (1) analyzed adult male and female South African Blacks from the Raymond A. Dart Collection. He found no statistically significant differences in mean skeletal heights between individuals with varying and standard vertebral counts, and recommended the inclusion of all presacral vertebrae measures in the calculation of stature using Fully's (11) anatomical method. However, Lundy (1) only examined varying total vertebral counts and did not address the possible effects of varying vertebral count patterns. He also did not address sacral segments. Lundy (12) used the Fully (11) technique to estimate stature from the skeletal remains of a Vietnam War naval aviator, which was compared with antemortem stature records. The remains possessed a sacralized sixth lumbar vertebra "with S1 in the position of second sacral segment" (p. 1046, 12). Lundy (12) recommended that in this situation both sacral segments should be included in stature measurement if they are situated above the superior margin of the acetabulum when the pelvis is reconstructed in anatomical position. However, this recommendation is based on only a single individual. The purpose of this study was to test the effect of vertebral numerical variation on anatomical stature estimates and to recommend appropriate measurement procedures.

Materials and Methods

The sample consisted of 22 Black males, nine White males, eight Black females, and two White females ($n = 41$), all adults of known age, ancestry, sex, and cadaveric stature from the Robert J. Terry Collection at the National Museum of Natural History, Smithsonian Institution (13). All the individuals possessed congenital vertebral numerical variation in the sacral, lumbar, and/or thoracic regions. Ages ranged from 20 to 95 years, with a mean age of 45 years. Sample selection was based on availability of cadaver statures, presence of all the elements required to employ a recently revised Fully technique (14), as well as lack of significant pathology (i.e., osteoarthritis, fractures, vertebral wedging, or vertebral collapse) that would impede proper measurement. Sample selection was also aided by Carl Sensing's notes (Sensing was a former lab technician to R.J. Terry and M. Trotter). For comparison, we also included 115 individuals from our 2006 paper (14) that all possessed the standard vertebral numerical count of seven cervical, 12 thoracic, five lumbar, and five sacral vertebrae (the original sample consists of 119 individuals; however, four had unusual vertebral patterns, thus the sample used here was reduced to 115).

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Segments were determined to be thoracic when they possessed a costal facet for articulation with a movable rib, either unilaterally or bilaterally (3). Vertebral elements were determined to be lumbar segments by the absence of costal facets for articulation with a movable rib, neither unilaterally nor bilaterally (3). Designation of a first sacral segment was determined by the presence of auricular surfaces, complete bilateral articulation with the ilia, presence of sacral foramen, sacral canal, and a kidney-shaped body (15). All first sacral segments were completely fused to the second sacral segments.

Living statures were derived from known cadaveric statures (cadaver stature-2.5 cm) following Trotter and Gleser's (16) recommendation. Skeletal stature was calculated using a revised Fully anatomical method and converted to living stature as previously described (14): Living Stature = 1.009 × Skeletal height − 0.0426 × age + 12.1 (dimensions in cm). Mean directional differences between Fully estimated statures (FES) and living statures (LS) were calculated for each of the vertebral count patterns represented in the sample by subtracting LS from FES, so that a positive directional difference indicates a relatively larger FES than LS, and vice versa. In addition, the absolute values of these differences were calculated as a measure of random error. Medians rather than means are reported for absolute differences because of the skewed distribution of these data (17). For individuals with six sacral segments, FES was calculated including only S1, and both S1 and S2 heights. Two-way ANOVA was performed on the total pooled sample to assess the effect of sex and ancestry on calculated errors. All statistics were carried out using Microsoft Excel XP and SPSS 16.0.

Results and Discussion

Table 1 presents average differences between FES and LS for each of the vertebral count patterns represented in our sample, excluding the cervical vertebrae since all the individuals in our sample possessed a standard count for this region. We also show comparable statistics for individuals with normal vertebral count patterns, derived from our previous study (14). The largest numbers of anomalies in the sample are individuals that possess an additional sacral, lumbar, or thoracic vertebra, but otherwise normal numbers of other vertebrae. Overall variant patterns, measuring all presacral vertebrae plus S1 produces stature estimates within 0.4 cm (directional error) or 1.3 cm (absolute error) of living stature, on average. These errors are slightly larger than, but similar to those in the normal sample (Table 1). Two-way ANOVA results for our total variant sample (FES including S1 only) show no significant effect of ancestry or sex on directional and absolute errors ($p \geq 0.07$), matching previous results for individuals with normal counts of vertebrae (14). Thus, when using the Fully anatomical method, we concur with Lundy (1) and recommend the measurement of all presacral vertebrae and S1, regardless of variation in presacral vertebral numerical count.

However, some slight modification of this recommendation may be warranted for individuals with six sacral vertebrae but a normal number of presacral vertebrae. Including only S1 here produces an underestimation of stature of 1.3 cm, while including both S1 and S2 produces an overestimation of 1.6 cm, i.e., the directional (and absolute) errors are close to equivalent (Table 1). As Lundy (12) noted, the relative position of S1 and S2 in individuals with six sacral vertebrae may affect decisions on whether to include one or both in stature estimates. To further explore this issue, we calculated the distance between the inferior margin of S1 and the superior margin of the acetabulum for our sample, measured with the pelvis reconstructed in anatomical position. We found a greater distance from S1 to the acetabular roof for individuals with six sacral segments (4.5 cm) compared to individuals possessing four or five sacral segments (3.2 cm). For individuals with four or five sacral segments, the distance is 6.3% of total presacral vertebral length, while for individuals with six sacrals it is 9.3%. Independent sample *t*-test results showed statistically significant differences for both the raw distances and proportions between individuals possessing four or five sacral segments and six sacral segments ($p \leq 0.05$). Thus, possessing six sacral segments appears to lead to a somewhat taller pelvis on average. Therefore, when an individual possesses the standard presacral vertebral count of 24, but possesses six sacral segments, we recommend that living stature estimates calculated using the standard anatomical method, including only S1, be increased by 1.3 cm or multiplied by 1.008.

In conclusion, based on our analysis of 41 individuals with atypical vertebral count patterns, we recommend using the standard (modified Fully technique) anatomical method (14), including measurement of all presacral vertebrae (except C1) plus the first sacral segment, to reconstruct stature, regardless of vertebral pattern. However, when an individual possesses six sacral segments together with a normal number of presacral vertebrae, we recommend the addition of a slight correction factor (1.3 cm or 0.8% of estimated stature).

TABLE 1—*Mean directional and median absolute differences (cm) for each vertebral count pattern.*

Number of Vertebrae				FES-LS (Including S1 only)		FES-LS (Including S1 and S2)	
Thoracic	Lumbar	Sacral	N	Directional	Absolute	Directional	Absolute
11	6	5	2	1.86	2.72		
12	5	4	2	0.26	0.52		
12	5	6	11	−1.26	1.22	1.63	1.67
12	6	5	11	1.31	1.69		
13	4	6	1	0.64	0.64	3.54	3.54
13	5	4	1	−0.05	0.05		
13	5	5	13	0.69	1.82		
Pooled			41	0.35	1.22		
Normal pattern (12:5:5)			115*	−0.02	1.12		

*Sample derived from Raxter et al., 2006.

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