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Estimation of Stature from the Vertebral Column in American Blacks

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ABSTRACT: Linear regression analysis was applied to data from 100 male and 100 female skeletons of American blacks from the Terry Anatomical Collection. To develop regression formulas for the estimation of stature using the vertebral column and portions thereof, the vertebral column was divided into contiguous sections containing from 1 to 23 vertebrae (C2 through L5). These bone-groups produced correlation coefficients ranging from 0.18 to 0.64, and the resulting regression formulas had standard errors ranging from 53.09 to 68.33 mm. The study shows that the vertebral column can be an aid in the estimation of stature, but the estimations are not as accurate as those made from the lengths of the long bones. Comparisons were made between the vertebral column proportions found in this study and those found by Fully and Pineau using white European males. Consideration was also given to the proper method for estimating stature when the vertebral column contains less than or more than the normal number of vertebrae.

KEYWORDS: physical anthropology, human identification, musculoskeletal system

Stature can be divided into two parts: the axial (head-trunk) length and the lower limb length [*1*]. A considerable amount of work has been done on the estimation of stature using the long bones of the body: the femur, tibia, fibula, humerus, radius, and ulna. On the other hand, very little has been done on the estimation of stature using the axial skeleton. The lack of such studies was mentioned by Pearson as early as 1898 [*2*]. Then, in 1929 in an editorial note following an article by Stevenson [*3*] on the estimation of stature of the Chinese, Pearson [*4*] made the following recommendation for the study of the vertebral column:

> If we consider the parts of the skeleton not taken into consideration, and which suggest selection, we naturally turn to the vertebral column as the most important. Of course the pelvic and cranial heights might present appreciable correlations, but the first subject for study seems to be the vertebral column. At present nobody knows the correlations between any individual vertebra and the total length of the column. It is quite possible that it might not be needful to use all the vertebrae, but that the correlation of stature with the heights of one or two vertebrae might be nearly as efficient as measuring the whole series. The investigation would be well worth while making, if the Chinese material extends to measurements on the vertebral column.

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Pearson's recommendation [4] went unnoticed, and the vertebral column has yet to be studied in this regard in the United States. In France, Fully and Pineau [5] presented a study that partially followed Pearson's recommendation. However, there is no indication that they were prompted by, or even aware of, his remarks.

The purpose of this research was to at least partially fill this void by developing regression formulas for the estimation of stature using the vertebrae of American blacks. Blacks were chosen for study because of the total lack of previous vertebral studies on this race and because of the availability of black specimens from the Terry Anatomical Collection now located in Washington, D.C.

Previous Studies Using the Vertebral Column

In 1894, Dwight [6] published a study in which he introduced a method for the estimation of stature using the spine. He dissected the spines of the cadavers of 56 males and 21 females and measured their straight-line lengths from the top of the atlas to the promontory of the sacrum. He then divided the spines, by sex, into groups according to total length and computed the average ratio of each group to the stature, thus establishing coefficients by which to multiply spines that fall into any of the groups to estimate stature. He found that, with only one exception, as the length of the spine increased, the coefficient decreased.

Using methods introduced by Topinard, Rollet, and Manouvrier, Dwight [6] computed estimated heights using the long bones and compared these to heights computed by his own methods. He used 20 males and 20 females for his comparison, although he had the spine measurements in only 17 cases for each sex. The results, when compared with the actual heights, revealed that for estimating the stature of males the Topinard method was the most accurate, with the Rollet, Manouvrier, and Dwight methods following in order of accuracy; Dwight's method was the most accurate for estimating female stature with the Manouvrier, Topinard, and Rollet methods following in order of accuracy. He thus established that the spine could be used as an indicator of stature. Unfortunately, this method does not readily lend itself to most forensic science cases because it requires a fresh, intact spine.

In 1960, Fully and Pineau [5] published a study that involved the vertebral column. Pearson [4] had commented in 1929 that the correlation between the individual vertebra and the length of the vertebral column was unknown and that research should be done in this area. He also suggested that a study be conducted to determine the correlation between the vertebrae and stature. Fully and Pineau [5] partially addressed these subjects in their research.

Using 164 skeletons of males who were between the ages of 18 and 65 years and who measured between 151 and 188 cm in height, Fully and Pineau [5] developed regression formulas for the estimation of the length of the column using certain groups of vertebrae. The skeletons used in this study were obtained from World War II concentration camps and consisted of French subjects (45%), Italians (27%), and other European nationalities (28%).

Fully and Pineau [5] measured each vertebra in its dry state, using the maximum height of the vertebral body. They used these measurements and their sums to develop regression formulas for the estimation of the length of the vertebral column using the following groups of vertebrae: (1) the first three thoracic; (2) the fifth, sixth, and seventh thoracic; (3) the last three thoracic; (4) the fifth, sixth, and seventh thoracic and the first three lumbar; and (5) the last three thoracic and the first three lumbar. In addition, they presented a table that gives the percentage of each of the vertebrae to the total length of the vertebral column.

Material and Methods

The skeletons of 100 black males and 100 black females from the Terry Anatomical Collection, which is located at the National Museum of Natural History, Smithsonian Institution, Washington, D.C., were used in this study. The Terry Collection consists of approximately 1600 skeletons obtained from dissecting-room cadavers at Washington University, St. Louis, Missouri, during the 51 years between 1914 and 1965 [*7*]. These cadavers were subjected to a series of anthropometric measurements prior to dissection, and records are available that give, among other information, the age, race, sex, and, in most cases, stature.

The technique used to measure the stature of the cadavers was explained by Terry in 1940 [*8*]. A special measuring panel, which reproduced characteristic features of standing posture, was constructed. The cadavers were carefully posed with "ankles bent, knees and hips extended, lumbar curve produced, shoulders squared and arms hanging at the sides, the face front and eye-ear plane horizontal." This was done to reproduce the living stature of the individual as opposed to the cadaver stature normally obtained in the supine position. In spite of these attempts, Trotter and Gleser [*9*] indicate that an average of 2.5 cm must be subtraced from the statures recorded for the Terry Collection in order to obtain living stature.

Trotter and Gleser [*10*] also pointed out that when using the Terry Collection in the estimation of stature, it is necessary to verify the recorded stature visually. Corrections were necessary since some of the subjects' feet were not placed flat on the baseboard of the measuring panel. It was possible to make corrections because a measuring rod was included in the photographs contained in the information folder for each cadaver.

Trotter and Gleser [*10*] reported an average decline in stature of 0.6 mm per year of age over 30. Because of these findings, an attempt was made to use only subjects between the ages of 23 and 40 years, inclusive. Unfortunately, after eliminating those skeletons for which stature had not been recorded, those for which measurements could not be corrected, and those with vertebrae unsuitable for study, it was necessary to extend the age limits of the female skeletons to obtain 100 that were satisfactory. For this reason, the males ranging in age from 23 to 40 years, while the females range from 19 to 50 years, inclusive. The average age of the males is 32.82 years; the average for the females is 34.34 years.

In order to compensate for the reduction in stature because of age, the statures of those cadavers over 30 years of age have been corrected by adding 0.6 mm to the recorded stature for each year of age over 30.[2]

The heights of the vertebrae were determined by measuring the maximum midline height of the vertebral bodies with sliding calipers (Fig. 1). Each vertebra was measured individually and bone-group lengths were subsequently determined by adding the individual heights of the appropriate vertebrae.

The first cervical vertebra was not used in this study because it has no body. Twenty-three bone-groups consist of the single vertebra C2 (second cervical) through L5 (fifth lumbar). The remaining bone-groups consist of the first 23 vertebrae taken two at a time (C2, C3; C3, C4; C4, C5; and so on), three at a time (C2, C3, C4; C3, C4, C5; C4, C5, C6; and so on), four at a time, and so forth until all 23 are taken together. Only continuous sections of the vertebral column are included, that is, combinations such as "C2, C3, C7" are not included. The 276 bone-groups developed by this method are referred to in this paper by their starting and ending vertebrae. For example, L2–L2 would represent the bone-group that consists of the single vertebra L2, while L2–L5 represents the bone-group consisting of the four vertebrae L2, L3, L4, and L5.

All measurements were made by the author, and a certain amount of bias was inadvertently introduced to the measurements. This bias was due to a tendency to report half-millimetres only when the height was very near to being exactly on a half-millimetre. This, however, should not substantially affect the outcome of this research because such bias should increase the standard deviations slightly without significantly affecting the means of the measurements. This bias does not affect the means of the bone-groups because it is self-eliminating when large numbers of measurmements are involved.

[2]Because the stature was originally recorded only to the nearest millimetre, the stature was increased by 0.6 mm per year truncated to the millimetre.

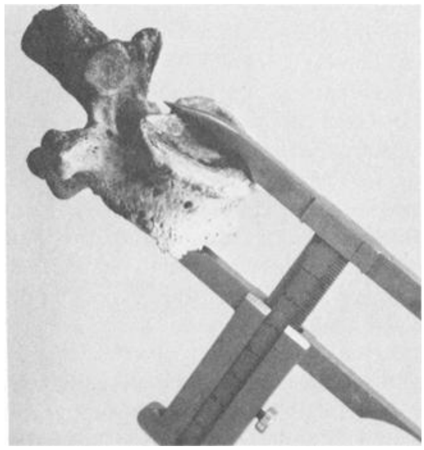

FIG. 1—*Technique for measuring midline height of vertebral bodies. (AFIP Negative 79-12382.)*

Statistical Analysis

The analysis of the data followed the linear regression method set forth by Pearson [*2*]. In order to use linear regression, it is necessary to make three assumptions: (1) that the material being studied is a sample (not necessarily random) from a large population; (2) that the stature and the bone heights are random variables from the population; and (3) that the relationship between the stature and the bone heights is linear.

The first of these assumptions is not a problem since the large population from which the sample came is the whole adult black population of the United States. The second assumption falls short of fulfillment because, as Terry himself [*8*] commented in 1940, a sample from the dissecting room is not representative of the general population because of long-term illness and malnutrition, in many cases, and dehydration of the body after death. Terry [*8*], however, went on to point out that, while the transverse body measurements are affected by these conditions, the longitudinal measurements remain unaffected. In a review of Trotter and Gleser's work [*9-11*] with the Terry Collection, nothing was found that would indicate the collection is not a random sample of the general population as far as the longitudinal measurements are concerned. The third assumption has no factual basis. When regression analysis is used it is necessary to assume a form for the regression line before beginning. The analysis indicates how well the assumed line fits the data but does not indicate whether another form of a line (such as quadratic or cubic) would better fit the data.

Results

After corrections are made for age, the mean statures of the cadavers are 1744.70 mm for the males and 1630.06 mm for the females. These means were compared with the mean statures obtained by Trotter and Gleser [*9*] from Terry Collection material and by various other researchers from sources other than the Terry Collection [*12*].

There was no statistically significant[3] difference between the mean statures found in this study and those found by Trotter and Gleser.[4]

[3]In this study, a difference is considered to be statistically significant when $P < 0.05$ with a two-tailed test. For the remainder of this paper the term "significant" refers to statistical significance.

[4]The mean statures found by Trotter and Gleser [*9*] were equivalent to living statures. Their means were converted to cadaver statures by adding 2.5 cm before any comparisons were made.

The mean stature of the females in this study was not significantly different from that reported for subjects from sources other than the Terry Collection.[5] The male mean was significantly different, although just barely.[6]

The coefficients of correlation[7] for single vertebrae varied from a low[8] of 0.18 to a high of 0.60 for the females. The males were less extreme in their variation with a low of 0.24 and a high of 0.58. The highest bone-group correlation was 0.62 for the males (in five different bone-groups) and 0.64 for the females (in six different bone-groups). Table 1 presents the regression formulas for these eleven bone-groups.

For the females, the coefficients of correlation continued to improve as the number of vertebrae in the bone-groups increased; the highest correlations appeared in groups containing 16, 17, 18, 19, 22, and 23 vertebrae. In contrast, while the males generally improved with greater numbers of vertebrae, the highest correlations were in groups of three, four, five, and six vertebrae and none of the bone-groups with eleven or more vertebrae had correlations as high as the single vertebrae L1 and L2.

The errors involved in stature estimations based on the bone-groups follow the same general pattern as the coefficients of correlation. The estimation equation for bone-group T12-L4 has the smallest standard error (54.72 mm) for the males. Bone-group C2-L4 has the smallest standard error (53.09 mm) for the females.

Fully and Pineau [5] provided a table showing the percentage of total vertebral column length that each vertebra represents as well as the cumulative percentages from the superior and the inferior ends of the column. Table 2 shows the values found by Fully and Pineau [5] along with the percentages found in the current study. The values found for the black males are almost identical to those found by Fully and Pineau [5] for white males. The black females disclose smaller percentages than the males in C2 through C4 and larger percentages in L2 through L5, being approximately equal to the males in the rest of the column. This indicates that the vertebral columns of the males are proportioned the same across these particular

TABLE 1—*Regression formulas (dimensions in millimetres).*

For black males with coefficients of correlation of 0.62						
Stature =	908.80 +	10.05 ×	(L1-L3)	±	55.06	
	892.29 +	7.80 ×	(T12-L3)	±	54.98	
	921.50 +	7.41 ×	(L1-L4)	±	54.87	
	900.38 +	6.16 ×	(T12-L4)	±	54.72	
	897.78 +	5.24 ×	(T11-L4)	±	54.94	
For black females with coefficients of correlation of 0.64						
Stature =	670.07 +	2.83 ×	(T1-L4)	±	53.42	
	663.69 +	2.74 ×	(C7-L4)	±	53.31	
	659.78 +	2.66 ×	(C6-L4)	±	53.37	
	657.72 +	2.58 ×	(C5-L4)	±	53.42	
	617.82 +	2.31 ×	(C2-L4)	±	53.09	
	621.11 +	2.17 ×	(C2-L5)	±	53.50	

[5]These subjects consisted of both living persons and cadavers. To maximize the size of the sample, the average stature of the living subjects was determined. This figure was converted to cadaver stature by adding 2.5 cm and was then averaged with the cadavers. This provided a sample of 2123 black females and 8471 black males.

[6]The mean was not significantly different if P was less than 0.045.

[7]The coefficient of correlation squared is equal to the percentage of variation in stature that is attributed to variation in the bone-group. Therefore the closer the correlation coefficient is to 1, the more accurate the estimation will be.

[8]This coefficient of correlation is not significantly different from a correlation of 0. All other coefficients of correlation found in this study differ significantly from 0.

TABLE 2—*Percentage of average vertebral height to vertebral column length.*

	Individual Percentage			Cumulative Percentage: From Superior End			Cumulative Percentage: From Inferior End		
	Fully and Pineau	Current Study		Fully and Pineau	Current Study		Fully and Pineau	Current Study	
Vertebra		Males	Females		Males	Females		Males	Females
C2	7.80	7.70	7.63	7.80	7.70	7.63	100.00	100.00	100.00
C3	2.89	2.81	2.69	10.59	10.51	10.33	92.20	92.30	92.37
C4	2.73	2.72	2.63	13.32	13.23	12.96	89.41	89.49	89.67
C5	2.66	2.64	2.61	15.98	15.87	15.57	86.68	86.78	87.04
C6	2.65	2.67	2.66	18.63	18.54	18.23	84.02	84.13	84.43
C7	2.95	2.94	2.91	21.58	21.47	21.14	81.37	81.46	81.77
T1	3.41	3.42	3.36	24.99	24.90	24.50	78.42	78.53	78.86
T2	3.61	3.70	3.62	28.59	28.60	28.12	75.01	75.10	75.50
T3	3.72	3.80	3.73	32.31	32.40	31.85	71.41	71.40	71.87
T4	3.83	3.83	3.79	36.14	36.23	35.64	67.69	67.60	68.15
T5	3.98	3.93	3.89	40.12	40.16	39.53	63.86	63.77	64.36
T6	4.10	4.07	4.01	44.22	44.23	43.54	59.88	59.84	60.47
T7	4.19	4.17	4.11	48.41	48.40	47.65	55.78	55.77	56.46
T8	4.24	4.26	4.21	52.65	52.66	51.87	51.59	51.60	52.35
T9	4.35	4.36	4.34	57.00	57.02	56.21	47.35	47.34	48.13
T10	4.61	4.61	4.59	61.61	61.63	60.80	43.00	42.98	43.79
T11	4.96	4.94	4.90	66.57	66.56	65.70	38.39	38.38	39.20
T12	5.23	5.28	5.27	71.80	71.84	70.97	33.43	33.44	34.30
L1	5.53	5.55	5.59	77.33	77.39	76.56	28.20	28.16	29.03
L2	5.62	5.60	5.77	82.95	83.00	82.32	22.67	22.61	23.44
L3	5.66	5.66	5.89	88.61	88.66	88.22	17.05	17.00	17.67
L4	5.63	5.63	5.87	94.24	94.29	94.09	11.39	11.35	11.78
L5	5.76	5.71	5.91	100.00	100.00	100.00	5.76	5.71	5.91

racial bounds, while the females are proportionally shorter in the cervical vertebrae and longer in the lumbar vertebrae than are the males. Similarly, Dwight [6] reported finding that the lumbar region was proportionally longer in females than in males.

Dwight [6] reported finding a few numerical anomalies (both less than and more than the normal number of vertebrae), although he was unable to provide any information as to how frequent these anomalies appeared. In the current study, anomalies were recorded when found but were not used in the data base for deriving the regression formulas. Among the males, approximately 5.6% had more than the normal number of vertebrae; four (3.2%) had an extra thoracic vertebra, and three (2.4%) had an extra lumbar vertebra. Approximately 2.4% had fewer than the normal number; two (1.6%) had only eleven thoracic vertebrae, and one (0.8%) had only four lumbar vertebrae.

Among the females in the current study, approximately 2.2% had more than the normal number of vertebrae; one (0.7%) had an extra thoracic vertebra, and two (1.5%) had an extra lumbar vertebra. Approximately 7.4% had fewer than the normal number; six (4.4%) had only eleven thoracic vertebrae, four (2.9%) had only four lumbar vertebrae, and one (0.7%) had only six cervical and eleven thoracic vertebrae.

With the data obtained from these abnormal vertebral columns, selected regression formulas were applied to determine the proper procedure for handling these anomalies.

With a normal vertebral column the procedure would be to use the regression formula with the smallest standard error for which the vertebrae were available. For example, if the vertebrae C2 through C5 and T7 through L5 were available from a black male, the formula for bone-group T12–L4 would be used to estimate stature.

With vertebral columns that were missing vertebrae or had extra vertebrae, it was found that the procedure would be the same as for normal vertebrae. If vertebrae are missing, the formula with the smallest standard error for which the vertebrae are available should be used. If there are extra vertebrae, the only difference in the standard procedure is to disregard the extra vertebra if it happens to be located within the chosen bone-group; that is, bone-group T10–L1 would contain T13, and the height of T13 would not be included in the height of the bone-group.

In the cases available for study, 72.7% of the estimates on males fell within one standard error when the above procedures were used, and 81.8% were within two standard errors. Of the four cases in which an extra vertebra fell within the bone-group with the least standard error, three resulted in better estimates when the extra vertebra was not included in the calculations.

For the females, 62.5% of the estimates were within one standard error when the above procedures were used, and 100% fell within two standard errors. Only one case was present in which an extra vertebra was included in the bone-group used for the estimations. In this case the regression formula provided a better estimate when the extra vertebra was not used in the calculations.

Discussion and Conclusions

In this study, the highest coefficient of correlation was 0.62 for the males and 0.64 for the females. This indicates that only 38% and 41% of the variation in stature was explained by the variation in length of the bone-group for the males and females, respectively.

In contrast to this, Trotter and Gleser [9] found correlations ranging from 0.712 to 0.861 for the males and from 0.633 to 0.848 for the females. This indicates that as much as 74% and 72% of the variation in statures are explained by the variation in long bone lengths for the males and females, respectively.

The greater the percentage of variation in stature that is attributable to the variation in bone-group length, the smaller the error in estimating stature. It would then be expected that the standard errors in the regression formaulas obtained from the vertebral column would be greater than the standard errors in the formulas obtained from the long bones. That is, indeed, what was found in this research.

The standard errors in the estimates vary from 67.89 to 54.72 mm for the males and from 68.33 to 53.09 mm for the females, when the vertebral regression formulas are used. These errors vary from 47.4 to 33.8 mm for the males and from 50.5 to 32.2 mm for the females when the long bone formulas are used [*9,13*].

The smallest of the standard errors in the estimations based on the vertebral column is significantly different from the standard errors based on the long bones with only three exceptions—equations based on the ulna and on the radius for the females and those based on the ulna for the males.

Based on these statistics, it can be concluded that the vertebral column can be a useful tool in the estimation of stature. It is not, however, as good a tool as are the long bones. If the long bones are available, they should be used for estimating stature.

Additional research needs to be conducted to determine the relationships between stature and vertebral bone-groups combined with the long bones. It would also be worthwhile to investigate the possibility of nonlinear relationships between stature and the vertebral bone-groups.

Summary

Linear regression analysis was applied to data from skeletons of 100 male and 100 female American blacks from the Terry Anatomical Collection to develop regression formulas for the estimation of stature using the vertebral column and portions thereof. The vertebral column was divided into contiguous sections containing from 1 to 23 vertebrae (C2 through L5).

These bone-groups produced regression formulas with correlation coefficients ranging from 0.18 to 0.64 and standard errors ranging from 53.09 to 68.33 mm. The study shows that the vertebral column can be an aid in the estimation of stature but that the estimations are not as accurate as those based on the lengths of the long bones.

Comparisons were made between the vertebral column proportions found in this study and those found by Fully and Pineau [*5*] for white European males.

Consideration was also given to the proper method for estimating stature when the vertebral column contains less than or more than the normal number of vertebrae.

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