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TECHNICAL NOTE

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A Test of Three Methods for Estimating Stature from Immature Skeletal Remains Using Long Bone Lengths*

ABSTRACT: In this study, the accuracy of three methods for stature estimation of children from long bone lengths was investigated. The sample utilized consists of nine identified immature skeletons (seven males and two females) of known cadaver length, aged between 1 and 14 years old. Results show that stature (cadaver length) is consistently underestimated by all three methods (from a minimum of 2.9 cm to a maximum of 19.3 cm). The femur/stature ratio provided the least accurate estimates of stature, and predictions were not significantly improved by the other two methods. Differences between true and estimated stature were also greatest when using the length of lower limb bones. Given that the study sample children grew in less than optimal environmental conditions, compared with the children that contributed to the development of the methods, they are stunted and have proportionally shorter legs. This suggests that stature estimation methods are not universally applicable and that environmental differences within a population (e.g., socioeconomic status differences) or differing levels of modernization and social and economic development between nations are an important source of variation in stature and body proportions of children. The fallibility of stature estimation methods, when they do not consider such variation, can be somewhat minimized if stature is estimated from the length of upper limb bones.

KEYWORDS: forensic science, stature, children, body proportions, environmental factors

In forensic cases, stature is seldom estimated from human remains when they are from a child. As Smith (1) points out, age is a key attribute for positive identification of children, whereas stature is less frequently critical. For this reason, long bone lengths are more likely to be used for estimating age rather than stature. However, in situations that involve commingling (or presumption of) of remains, such as multiple murders, mass disasters, or war crimes, estimating stature can be decisive in the identification of remains of children, particularly if they are of the same dental age. Snow and Luke (2) describe a case that can be illustrative of the importance of accurate stature estimates. In the summer of 1967, two girls disappeared from the Oklahoma City area. The girls were practically of the same age and stature estimation proved to be crucial to the identification, because it was fully consistent with one of the girls. The confidence intervals of the estimate had overlapped the two girls' stature and no reliable results could be obtained, thus precluding a positive identification. Because stature can play such an important role in the positive identification of a pre-existing child profile, it is essential to estimate it with accuracy. Even if a pre-existing profile is unlikely to exist, stature can represent an important means of establishing identity. In addition, because it may be of interest to estimate the body mass and stature of fossil or archeological specimens for comparison with modern children (3–7), the accuracy of current stature techniques is also important.

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The purpose of this technical note is to test the accuracy of three methods of stature estimation of children from long bone lengths. There are several methods with which to estimate stature of children and most rely on long bone lengths, although regression equations for stature based on second metacarpal length have also been proposed (8,9). The methods assessed in this study are the femur/stature ratio proposed by Feldesman (10) and the regression equations developed by Telkkä et al. (11) and Smith (1). These methods are all based on growth studies of living children where long bone lengths were obtained from radiographs. Although other stature estimation methods for children are available, they were considered unreliable techniques, either because stature has to be interpolated from tables (12–14) or because long bone lengths were obtained in living subjects from anthropometric landmarks (15–18). A sample of identified Portuguese child skeletons, which include cadaver length information from autopsy reports, provided the rare opportunity to investigate how closely stature estimated from each of these methods is from true stature. As far as the author is aware, this is the first study that has examined the accuracy of stature estimates from long bone lengths in children.

Materials and Methods

The materials studied consist of immature skeletons of known sex and age at death from the identified skeletal collection housed at the Bocage Museum in Lisbon, Portugal (19).

The source of the remains in this collection are unclaimed skeletons from the local cemeteries in Lisbon (see Ref. [19] for more details) and most of the individuals represent the middle to low social class of the city of Lisbon, as inferred from the origin of the remains and from the occupations of the males (19). In the collection, from a total of 127 immature skeletons under 16 years of age, 23 were found to be autopsied at a local hospital in Lisbon and at the National Institute of Legal Medicine, also in Lisbon. As standard measurements, such as cadaver length, are routinely collected by the medical examiner from the corpse during autopsy, a measure of living stature could potentially be available for these 23 children. However, we were only allowed access to the autopsy records of those children (n = 11) examined at the National Institute of Legal Medicine, in Lisbon. Out of these cases, one could not be located in the archives and in another the autopsy file had not recorded cadaver length. Therefore, the sample was comprised of the remains of nine immature individuals of known cadaver length, of whom two were females and the remaining were males. Individuals' dates of death fall between 1956 and 1972, and their ages vary from 1 to 14 years old. Because the growth status of these children at the time of their death is essential to assess the reliability of the stature estimation methods utilized, it is important to note that all, except two, lie below the 10th percentile of height-for-age of the WHO growth reference. This is an indication that the study sample children are stunted and a confirmation of their relative low socioeconomic status. Although this is a small sample, due to the dearth or inexistence of immature skeletal remains of known living height, it represents an important and rare test case to examine the accuracy of some of the most common techniques to estimate stature from long bone lengths of children.

Cadaver length was recorded by the medical examiners at the time of autopsy with the cadaver in supine position as the length from vertex to heels measured with a spreading caliper. Cadaver length was recorded in centimeters and in this study it was considered an approximate measure or proxy for living standing stature. Long bone lengths were measured on the curated specimens after they became available to the Bocage Museum, several years after death, burial and exhumation, and later curation of the remains by the Museum (see Ref. [19] for more details). Long bone measurements in Smith's (1) and Feldesman's (10) regression equations are of diaphyseal length. Diaphyseal (inter-metaphyseal) length of humerus, radius, ulna, femur, tibia, and fibula were measured as maximum lengths, parallel to the long axis of the bone, between proximal and distal ends, not including epiphyses. Only left bones were measured using an osteometric board and recorded to the nearest whole millimeter. Although the sample includes older children (13 and 14 years old), their long bones showed unfused epiphysis and, therefore, only the inter-metaphyseal length was obtained from these individuals. Two additional lengths were obtained from the femur and tibia, as described by Telkkä et al. (11), to conform to their respective regression formulas. The femur measurement was obtained as the maximum oblique length between the proximal metaphyseal end and the medial surface of the distal metaphysis, whereas the tibial length was measured as the maximum oblique distance between the lateral metaphyseal surface of the proximal end and the medial metaphyseal surface of the distal end. The other long bone measurements illustrated by Telkkä et al. (11) appear to be equivalent to maximum inter-metaphyseal lengths as measured here.

In all three methods examined, stature was measured from living subjects and long bone lengths were also obtained from the living but on radiographs. Compared with these methods, long bone lengths in this study were obtained from dry material and stature was established from cadaver length. Relative to living wet bone, dry bone tends to suffer a certain amount of shrinkage (20–23) and because there will be a certain amount of radiographic enlargement (24–27), dry and living long bones in radiographs will also differ in overall size. Additionally, stature as measured on the cadaver tends to overestimate stature measured on a living standing subject (21,28–30). Yet, these factors may tend to cancel one another in this study, as a correction factor would have to be added to long bone lengths and another correction factor subtracted from cadaver length. Regardless of whether one can assume or not that these factors will successfully cancel off each other, correcting dry to wet living radiographic long bone lengths and cadaver to living stature was considered relatively ineffective and minor relative to the various potential sources of error in an actual forensic case. Not only do different researchers disagree on the amount of adjustment required to convert cadaver to living stature, but the actual stature of a certain person may vary significantly during the day. For example, Trotter and Gleser (21) have shown that, in adults, cadaver stature is on average 2.5 cm greater than is living height, but this only applies to stature measured on hanging cadavers. Dupertius and Hadden (30), on the other side, conclude that any difference between living stature and supine cadaver length is insufficient to warrant special consideration. Even if we assume that there is a certain amount of stretching when measuring stature on a cadaver, a maximum mean daytime loss of stature of up to 2.81 cm has been observed in living adult subjects (31). Proportional amounts of shrinkage have also been reported in children's daytime stature variation (32–34). Another major source of error in a forensic case is that stature estimates will most likely be compared with a reported stature, rather than a true measured stature (35,36). This is probably the most important source of error in forensic cases, as reported stature tends to be greater than measured stature. Although there is no information on the accuracy of reported stature in children, available data for adults suggests that dissimilarities between reported and measured stature are also likely to occur in children. For example, overestimation of measured stature by reported stature in adults varies from approximately 1 cm (37) to 2.5 cm or more (35,38), which amounts to about as much as the adjustment required to converting cadaver to living stature. Discrepancy between measured and reported stature is particularly problematic for children, as there are usually no official records of reported stature in children, such as records of height in driver's licenses, identification or national citizenship cards. Even if there were such official records, they would tend to be unrealistic as the height of a child changes rapidly over time and is taken at the time the document is being issued and not at the time or prior to death. However, in such a situation it would not be difficult to project the stature from the time it was taken to the time of death or disappearance, but this would entail a certain amount of error and it would still be a projected rather than a measured stature. In an actual forensic case, measures of stature in children are, therefore, dependent on stature reported by parents or peers. Although measured stature can be obtained from measurements routinely made by the family pediatrician (2), it may have also been obtained several months or years before death. Additionally, in developing countries or in the lower classes, such information can be simply inexistent due to limited access to medical care. Although there are various potential sources of error, when estimating stature of children (or of adults) in an actual forensic case, we can still aspire to the best approximation and this is what is under examination here.

For each individual in the sample a stature estimate was obtained from each long bone and the respective 95% confidence interval was also calculated according to the specific methods. The ratio proposed by Feldesman (10) only allows stature to be estimated from femur length and no 95% confidence interval can be calculated from it. When using this method, only children between the ages of 8 and 18 were considered as it only applies to them. Similarly, the regression equations devised by Smith (1) only allows stature to be estimated in 3- to 10-year-olds. Different regression equations were applied to estimate the stature of children between the ages of 1 and 9 and children between 10 and 15 when using the technique described by Telkkä et al. (11). All three methods provide sex-specific regression equations but only Feldesman (10) and Smith (1) provide equations for when sex cannot be determined. Simple differences between cadaver length and estimated stature were calculated to assess how closely estimates obtained from the three methods and from the different long bones are from true stature. Because some individuals did not preserve all the long bones, stature estimates reflect the preservation status of the sample.

Results and Discussion

Individual stature estimates obtained from each of the three methods are shown in Tables 1–3. Results are presented by individual long bone and include cadaver length. Table 4 shows the differences between stature estimates obtained from the three different methods and cadaver length. In Table 4 results are also presented by individual specimen and illustrate simple differences between true and estimated stature, in the case of estimates obtained from Feldesman's (10) method, or mean differences between true and estimated stature calculated from all four long bones, when estimates are obtained from Smith's (1) and Telkkä et al. (11) regression equations. In addition, mean differences between true and estimated stature were broken down in Table 4 by mean differences between true and estimated stature obtained from the upper limb bones and mean differences between true and estimated stature obtained from the lower limb bones.

Results show that all three methods consistently underestimate stature as measured by cadaver length. This is particularly true for the femur/stature ratio (10), which tends to underestimate stature by around 19 cm. The regression equations developed by Smith (1) provide the smallest mean difference between true and estimated stature (−4 cm). Telkkä et al. (11) regression equations underestimate true stature by an amount that is between the two other methods (−6 cm). Differences between true and estimated stature are so significant that in some instances the estimated stature is almost at or at the upper limit of the confidence interval provided by each method. In only two cases was estimated stature found to be close to true stature. They are specimen #1534-A, a 1-year-old boy, and specimen #1533, a 7-year-old boy. However, the closeness of estimated and true stature was only obtained with one method and not with all methods. For example, estimated stature of specimen #1533 is close to true stature when Smith's (1) method is used, but not when Telkkä et al. (11) regression equations are employed. Unfortunately because of the small sample size not a lot of weight can be placed on the results, particularly as most of the subjects are between 7 and 14 years of age, and comments regarding children under 7 years of age must be made with caution. Nevertheless, an interesting pattern seems to arise where all three methods consistently underestimate stature.

TABLE 1—*Estimates of stature according to the femur/stature ratio (Ref. [10]) for when sex is known and when sex is unknown.*

Specimen	Age	Sex	Cadaver Length (cm)	Stature (sex specific) (cm)	Stature (unknown sex)
629	10.92	F	128	104.8	105.1
753-A	13.92	F	140	111.7	111.2
1180	8.92	M	122	109.3	108.7
574	9.75	M	124	110.8	110.2
1564	14.17	M	138	119.4	120.2

TABLE 2—*Estimates of stature according to the equations provided by Telkkä et al. (11) for the length of the humerus, radius, ulna, femur, tibia, and fibula.*

Specimen	Age	Sex	Cadaver Length	H	95% CI	R	95% CI	U	95% CI	Fe	95% CI	T	95% CI	Fi	95% CI
629	10.92	F	128	119.1	107.9–130.3	118.4	109.2–127.6	122.7	113.3–132.1	121.5	111.1–131.9	125.7	112.4–130.0	120.8	110.4–131.2
753-A	13.92	F	140	–	–	130.7	121.4–139.9	133.2	123.8–142.6	128.7	118.3–139.0	129.5	116.1–142.8	129.7	119.3–140.0
1534-A	1.17	M	69	69.9	64.0–75.8	69.6	63.1–76.0	68.2	62.1–74.3	69.3	61.3–77.4	71.3	64.9–77.8	70.9	64.8–77.0
1471	2.17	M	95	84.9	79.0–90.8	88.1	81.6–94.5	89.6	83.6–95.7	83.9	75.9–92.0	86.8	80.3–93.2	86.3	80.2–92.4
1533	7.08	M	115	113.6	107.7–119.4	114.2	107.8–120.7	115.3	109.2–121.3	110.1	102.0–118.1	109.1	102.6–115.5	109.6	103.5–115.6
570	7.75	M	123	–	–	–	–	–	–	111.8	103.8–119.9	114.5	108.1–121.0	114.3	108.3–120.4
1180	8.92	M	122	–	–	–	–	–	–	114.3	106.3–122.4	115.6	109.1–122.0	114.7	108.6–120.8
574	9.75	M	124	116.7	108.4–124.9	121.7	112.7–130.7	123.5	115.1–132.0	118.9	108.5–129.3	121.7	108.0–135.4	121.7	108.2–135.3
1564	14.17	M	138	129.9	121.7–138.2	131.8	122.8–140.8	132.1	123.7–140.6	132.7	122.3–143.1	131.1	117.4–144.8	128.6	115.0–142.1

H, stature obtained from humerus length; R, stature obtained from radius length; U, stature obtained from ulna length; Fe, stature obtained from femur length; T, stature obtained from tibia length; Fi, stature obtained from fibula length; 95% CI, 95% confidence interval. Cadaver length and stature values are in centimeters.

TABLE 3—*Estimates of stature according to the equations provided by Smith (1) for the length of the humerus, radius, ulna, femur, tibia, fibula, and femur + tibia.*

Specimen	Age	Sex	Cadaver Length	H	95% CI	R	95% CI	U	95% CI	Fe	95% CI	T	95% CI	Fi	95% CI	Fe + T	95% CI
Regression equations for children of unknown sex																	
629	10.92	F	128	120.2	114.3–126.1	116.0	109.8–122.1	119.3	113.6–125.0	119.5	114.7–124.3	119.9	115.5–124.3	118.0	113.6–122.4	119.7	115.8–123.5
1533	7.08	M	115	117.4	111.5–123.3	116.6	110.4–122.8	116.9	111.2–122.6	115.1	110.3–199.9	111.1	106.7–115.5	111.8	107.5–116.2	113.3	109.4–117.1
570	7.75	M	123	–	–	–	–	–	–	117.2	112.3–122.0	116.7	112.3–121.1	116.9	112.5–121.3	116.9	113.1–120.8
1180	8.92	M	122	–	–	–	–	–	–	120.1	115.3–124.9	117.8	113.4–122.2	117.3	112.9–121.7	119.0	115.2–122.9
574	9.75	M	124	122.1	116.2–128.0	122.8	116.6–129.0	123.4	117.7–129.1	122.4	115.3–127.2	120.3	113.4–124.6	120.9	112.9–125.3	121.4	115.2–125.3
Sex-specific regression equations																	
629	10.92	F	128	120.4	113.7–127.0	116.8	110.4–123.1	120.0	114.2–125.7	119.8	115.3–124.2	119.9	114.9–125.0	118.0	112.8–123.3	119.8	115.7–123.9
1533	7.08	M	115	117.2	112.5–122.0	115.5	110.2–120.9	116.1	110.9–121.3	114.9	107.8–122.0	111.0	107.6–114.4	111.7	108.7–114.7	113.1	109.6–116.5
570	7.75	M	123	–	–	–	–	116.9	109.8–124.0	116.7	113.3–120.1	116.8	113.8–119.8	116.8	113.3–120.2	116.9	109.8–124.0
1180	8.92	M	122	–	–	–	–	119.8	112.6–126.9	117.8	114.4–121.2	117.2	114.2–120.2	118.8	115.4–122.3	119.8	112.6–126.9
574	9.75	M	124	121.9	117.2–126.6	121.8	116.4–127.1	122.6	117.4–127.8	122.0	114.9–129.2	120.3	116.9–123.7	120.8	117.8–123.8	121.3	117.8–124.7

H, stature obtained from humerus length; R, stature obtained from radius length; U, stature obtained from ulna length; Fe, stature obtained from femur length; T, stature obtained from tibia length; Fi, stature obtained from fibula length; Fe + T, stature obtained from femur + tibia length; 95% CI, 95% confidence interval. Cadaver length and stature values are in centimeters.

TABLE 4—*Individual and mean differences between estimated and true stature for the three methods examined.*

					Telkkä et al. (sex specific)			Smith (sex specific)			Smith (unknown sex)		
Specimen	Age	Sex	Feldesman (sex specific)	Feldesman (unknown sex)	Mean	Upper Limb	Lower Limb	Mean	Upper Limb	Lower Limb	Mean	Upper Limb	Lower Limb
629	10.92	F	−23.2	−22.9	−6.7	−7.9	−5.4	−8.9	−9.0	−8.8	−9.2	−9.5	−8.9
753-A	13.92	F	−28.3	−28.8	−9.7	−8.1	−10.7	–	–	–	–	–	–
1534-A	1.17	M	–	–	0.9	0.2	1.5	–	–	–	–	–	–
1471	2.17	M	–	–	−8.4	−7.5	−9.3	–	–	–	–	–	–
1533	7.08	M	–	–	−3.0	−0.6	−5.4	−0.6	−1.3	−2.5	−0.2	2.0	−2.3
570	7.75	M	–	–	−9.4	–	−9.4	−6.2	–	−6.2	−6.1	–	−6.1
1180	8.92	M	−12.7	−13.3	−7.1	–	−7.1	−3.8	–	−3.8	−3.6	–	−3.6
574	9.75	M	−13.2	−13.8	−3.3	−3.4	−3.2	−2.4	−1.9	−2.9	−2.0	−1.2	−2.8
1564	14.17	M	−18.6	−17.8	−7.0	−6.7	−7.2	–	–	–	–	–	–
		Mean	−19.2	−19.3	−6.0	−4.9	−6.2	−4.4	−3.2	−4.8	−4.2	−2.9	−4.7

Results obtained using the equations provided by Telkkä et al. (11) and Smith (1) are broken down by mean difference between estimated stature obtained from all long bones and true stature (Mean), by mean difference between estimated stature obtained from upper limb bones and true stature (Upper limb) and by mean difference between estimated stature obtained from lower limb bones and true stature (Lower limb); differences are in centimeters.

Using cadaver length as a proxy for true standing stature is, probably, an unlikely cause for the results in this study. Even if stature was measured in the cadaver as if it was considerably stretched, this would hardly explain differences of up to 28 cm between cadaver length and estimated stature. Uncorrected regression formula for radiographic magnification of long bone lengths in Telkkä et al. (11) study may also be of some concern, but this would also be an unlikely explanation for such large differences between cadaver length and estimated stature. In addition, stature is consistently underestimated using all three methods, suggesting that the explanation may lie in the study sample itself. Inaccuracy of methods are, instead, likely to derive from differences in relative proportions of long bone length to body height between the children that contributed to the development of each method and the study sample children. The results suggest that the Lisbon children have proportionally shorter limb bones to stature than what would be expected from their stature estimates. In this respect, it is interesting to note that the regression equations devised by Smith (1) and Telkkä et al. (11) are least accurate when estimating stature from lower limb bones, compared with upper limb bones. This means that the Lisbon children have particularly shorter legs relative to stature.

Longitudinal studies have shown that leg length is the most important component responsible for the rapid growth of stature during childhood and adolescence (39–41). Leg length during childhood and adolescence grows very rapidly and contributes more to the variability in stature than trunk size that grows very slowly. Being the fastest growing segment, the legs are more sensitive to environmental conditions and deficits in stature result in proportionately shorter legs (41). In general, a relatively long leg implies a rapid growth and the influence of positive environmental factors during childhood and adolescence. Conversely, relatively short legs imply a slow growth and the influence of negative environmental factors during childhood and adolescence. Considerable evidence has accumulated to support the assertion that most of the deficit in stature of children who have grown in poor environmental circumstances derives from a reduction in leg length. For example, Buschang et al. (42) have found that statural growth differences between mild-to-moderate Mexican and North American schoolchildren are accounted for by diminished growth rates of leg length. Other studies showed that secular increases in height are to a greater extent the results of increased leg length rather than increased trunk height (43). Frisancho et al. (44) have also emphasized the impact of the environment on body proportions, in a study which has found that leg length of Mexican-Americans aged 2 to 17 years old was significantly associated with socioeconomic status. Individuals from the poorer families had significantly shorter legs, but equal trunk length, compared with boys and girls from the better-off families. Similarly, Bogin and co-workers (45–47) have shown that Maya children in Guatemala have significantly shorter legs in proportion to trunk than do Maya-American children, who have body proportions more similar to American children. Although the Maya-Americans are of low socioeconomic status for the United States, they live in much more favorable conditions for growth and development than Maya children in Guatemala and hence the difference in body proportions.

Data presented here and in previous studies (48,49) have shown that the study sample children are of low socioeconomic status and grew in poor environmental conditions, almost 50 years ago. As a consequence, they are stunted and have proportionally shorter legs relative to the Denver growth study children, who served as source for Feldesman's (10) and Smith's (1) stature estimation techniques. Comparatively, the children sampled for the Denver study are from families whose socioeconomic status is characterized as middle-to-upper-middle class (50). In addition to using Denver growth study data, Feldesman (10) also included two other samples, one from the Harvard School of Public Health Study and the other from British school children, which include a disproportionate number of higher social class children (51). Although there is no background information on the Finish sample utilized by Telkkä et al. (11), it is also likely that it too derives from a high socioeconomic segment. In addition to differing social status, the level of social and economic development and standard of living in the United States and Finland in the 1950s and 1960s was considerably higher than that in Portugal during the same period of time. Therefore, the short stature and short legs of the Lisbon children are not only an expression of their low socioeconomic status, but also of the overall poorer environmental conditions provided by the society in which they grew, namely in terms of access to adequate nutrition and health care.

It is unlikely that a genetic explanation can account for differences in body proportions between the study sample and the children that contributed to the development of each stature estimation method. In a growth study carried out between 1993 and 2001, Varela-Silva (52) show that relative leg length or trunk height does not differ significantly between Portuguese and American children, when using the NHANES II growth reference. Although the study sample children show altered body proportions 50 years ago, they are only a few of generations older and this is too little time for any important genetic change to take place. The rapid change in height which occurred in the last 30 years, because of improvements in social and economic conditions in Portugal (53), is instead, the likely explanation for this alteration in body proportions of Portuguese children.

Given that relatively shorter legs are associated with lower socioeconomic, nutritional, or health status (42–47,54), it is no surprise that stature, as a whole, is underestimated in most children and using most of the bone lengths, particularly the lower limb bones. This differential growth of the legs relative to the trunk in poor environmental circumstances, explains why mean difference between true and estimated stature, obtained from Smith's and Telkkä et al. regression formulas, is smaller when using any of the upper limb bones than when using the femur, tibia, or fibula. Because stunted children tend to have proportionally shorter legs, the femur/stature ratio in these children is also distorted and that is why Feldesman's (10) method was also not accurate. These results suggest that using the length of upper limb bones is slightly more reliable in stature estimation because it is less sensitive to environmental variations. Because there will be more variation in length and relative proportions of the lower limb bones due to differences in nutritional, health or socioeconomic status, and also to secular change effects, the upper limb will provide more stable estimates across these different factors that affect the quality of stature estimations.

It is interesting to note that all three methods are least accurate in girls, where differences between estimated and true stature are greatest. In a previous study (48), it was shown that females seem to be more affected in their development by environmental conditions than males in the Lisbon sample, which was attributed to preferential care towards males or neglect towards females in the growth period. However, given that the female sample size is made of only two individuals, it may just reflect random variation in such a small sample.

Socioeconomic status differences within populations and differing levels of modernization and socioeconomic development between populations are probably the most important factors explaining variations in growth status that can impact negatively on accuracy of stature estimation methods. The methods examined here have their origins in growth studies of well-nourished, well-cared-for children from either North America or Northern Europe and, as such, represent optimal rather than average or modal growth rates and cannot generate universally applicable methods. They represent neither the poorer children of their own societies, nor the underprivileged children of the developing nations. It has been shown that skeletal maturational delays related to socioeconomic differences between populations will make standards developed on the well-off children inapplicable to children of developing nations, as their skeletal ages will tend to underestimate true chronological age (55,56). The same rationale applies for stature estimation of poor children, which will be consistently underestimated when using standards based on healthy privileged children. This is particularly problematic, as most child remains that end up in forensic pathology or anthropology laboratories are of lower socioeconomic status.

The amount of error associated with stature predictions obtained in this study, suggests that such inaccuracy can result in misidentification of cases. However, this problem can be minimized if the investigator is aware of the potential effects of socioeconomic status on the application of these formulas. When there is a pre-existing profile or a strong presumption of identity, the socioeconomic status of the child would be of vital importance in the interpretation of stature estimates obtained from long bone lengths. Even when there is no a priori presumption of identification, when there is more than one presumptive child or when there is commingling of child remains of the same dental age, stature estimates can still provide vital information for establishing identity.

Conclusion

This study confirms the concerns of Smith (1), who cautions not to extrapolate the stature estimates widely beyond the population from which the regression equations derive and to the effects of nutrition on height and long bone proportions. This applies to cases when stature has to be estimated from a child that does not derive from a population or nation at the same level of modernization or of social and economic development of the population which contributed to the development of the method, or from a child that, despite belonging to that same population, is of lower socioeconomic status. This study also suggests that any assumptions of stability of relationship between long bone lengths and stature in modern populations are questionable and that similar assumptions when estimating the stature of archeological or fossil specimens are likely to be untenable. This is mainly because, depending on the health or nutritional status of a given child, the relative proportions of the lower limb compared with the trunk or stature will vary. The lower limb is more susceptible to variations in environmental circumstances and, therefore, preference should be given to estimates based on upper limb bones, when the socioeconomic background of the child cannot be determined. Overall, in a forensic case with a strong presumption of identity, the socioeconomic status of the child can be of crucial importance in interpreting stature estimates.

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