J Forensic Sci, May 2007, Vol. 52, No. 3
doi:10.1111/j.1556-4029.2007.00428.x
Available online at: www.blackwell-synergy.com

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Stature Estimation of 3–10-Year-Old Children from Long Bone Lengths

ABSTRACT: Estimation of stature in adult forensic cases with available long bones of the limbs is routine, but such estimation is less common in subadult cases. Long bones from subadult cases are often used to estimate age, but in some instances stature may be helpful or even critical for identification. Few published regression equations exist for consultation in such cases. Data from the longitudinal growth study conducted by the Child Research Council in Denver in the mid-1900s are utilized to produce dual-sex and single-sex regression equations for the six long bones of the limbs (humerus, radius, ulna, femur, tibia, and fibula) and for the combined femur+tibia length. All measurements are from radiographs and are of diaphyseal length. Examples show that similar results can be obtained using a two-step process of "ballpark" estimation from published tables of the Denver data, but these new regressions allow a one-step standard error estimate for the means. Regressions are further compared with those previously published by Finnish researchers, which are generally broadly comparable. More routine stature estimation in subadult cases is encouraged both as an aid to possible identification and as a test of the available regression equations.

KEYWORDS: forensic science, forensic anthropology, height, prediction, skeletal, subadult

Forensic reports based on skeletal remains of adults commonly include an estimate of stature. If the remains are from a child, however, this potentially helpful characteristic is generally omitted. Whereas long bones are commonly used for adult stature estimation, when long bones appear in a forensic case involving a child, they are more likely to be used for estimating age rather than stature. As noted by Kondo et al. (1) (p. 458), "Contrary to abundant references for estimating adult stature from limb bone lengths . . . those for immature specimens are very limited" (2–5). (For more information on adult stature estimation, see (6–8).)

This situation is understandable. For a child, age is a critical identifying variable, and stature is less often a key factor leading toward a positive identification. In some cases, however, such as those involving commingling of remains or victims of war or mass disasters, stature estimation will be important. For example, in the Oklahoma case with two missing girls of similar age reported by Snow and Luke (9), stature estimation based on a femoral fragment proved to be critical in the final identification of one of the girls. In a more recent case, Warren et al. (10) (p. 469) state that, "Stature estimates, based on humerus length, were also important" for individual identification, along with the state of ossification centers.

The *Bibliography for the Forensic Application of Anthropology* (11) lists three sources (12–14) under the category of stature estimation for subadults, along with one case report (15). Eleven sources are provided for age estimation of subadults using long bone growth. The cited Maresh sources (16,17) are based on data from the Child Research Council longitudinal growth study in Denver; another source from this research group (18) provides lengths of long bones relative to height that can be used for stature estimation. It is possible to predict approximate stature using tables based on the Harvard growth study (19) that provide stature, tibia length, and femur length for boys and girls from 8 to 18 years of age, or using a table in Pritchett (20) providing stature, humerus length, radius length, and ulna length from ages 7 to 15 for girls and ages 7 to 17 for boys based on a study of the Denver data. One can also use a simple femur–stature ratio developed by Feldesman (21). If enough skeletal material is available, it is possible simply to "add up the parts" to estimate stature (1).

Attallah and Marshall (12,22) used anthropometric and photogrammetric limb segment lengths from the longitudinal data obtained by the Institute of Child Health, University of London, to estimate stature as well as chronological age. Similarly, if a reasonable proxy for anthropometric knee height ("the distance from the posterior surface of the thigh, just proximal to the patella, to the sole of the foot when the knee is bent at a 90° angle") can be made, the equations of Chumlea et al. (23) (p. 1386) may be of help. For anthropometrically determined tibia length, Zorab and colleagues (24,25) provide regression equations for 11–15-year-old girls and boys, and for tibia and ulna lengths, Lal and Lala (26) give proportions for males and females from 12 to 21 years of age. More recently, Gauld et al. (27) have developed height prediction equations using ulna length and age; Miller and Koreska (28) provide an anthropometric height prediction equation from ulna length alone.

Using radiographic data, Virtama et al. (29) provide regression equations for all six long bones of the limbs for 10–15-year-old males and females. Himes et al. (13) present regression equations for stature from Guatemalan children based on second metacarpal length (see also Kimura (30) for a similar study of Japanese children). These authors comment in the introduction to their article that, except for equations based on the growth of Finnish children (14,31,32),

> one must interpolate from tables of age-specific means or percentiles of long bone lengths and stature . . . Also available are age-specific percentiles of long limb bone lengths expressed as a percentage of stature for Denver children . . . However, the errors of estimation arising from interpolation from these tables are undetermined and probably rather large (p. 452).

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Received 14 Aug. 2005; and in revised form 7 Jan., 28 Mar. and 2 Dec. 2006; accepted 24 Dec. 2006; published 13 April 2007.

The purpose of this paper is to utilize a subset of the Denver data to create regression equations in order to eliminate the need for such interpolation and to compare the results with those obtained from "ballpark" estimation using the tables in Maresh (18) and with those obtained from the Finnish regressions.

Methods

Records of 67 subjects (31 boys and 36 girls) from the Denver growth study were selected for analysis. The age range covered is 3–10 years. Hansman (33) (p. 105) states that, "In general subjects were measured supine to 2 years of age and in the erect position for subsequent years." Therefore, by age three it is reasonable to assume that all or almost all measurements would be of standing height. Measurements of diaphyseal length were recorded through age 12; starting at age 10, lengths including epiphyses were recorded (18). Thus, in order to utilize a consistent measurement of length from these records, age could not extend beyond 12 years. In forensic cases involving subadults, sex is often unknown. While childhood growth for these girls and boys is similar (34), girls have an earlier adolescent spurt, with the peak velocity of leg bones preceding that of arm bones (35). The tibia velocity is likely to peak especially early, even before age 10 in some girls. Therefore, age 10 was selected as the maximum age for analysis.

Three sets of regression equations were calculated. (An additional fourth set was calculated as a methodological test; see below.) The main set is for cases in which the sex is unknown, which is the most likely forensic scenario. For these regressions, sexes are combined. The other two sets of regression equations are for females and males separately. These regressions were calculated for two reasons. First, in certain cases the sex of the child may be known (e.g., through DNA analysis) or suspected. Second, separate regression equations are helpful for comparison with those of earlier authors.

Measurements are of diaphyseal length, "the greatest possible length of the shaft, taken along the long axis of the bone from epiphysial line to epiphysial line" (16) (p. 228). It should be noted that the Denver dataset includes many relatives (see pedigrees in (36)). While the data used here eliminated same-sex relatives, some opposite-sex relatives are included. Further, it is important to note that the long bone lengths were measured from radiographs without correction for magnification, and thus will vary somewhat from lengths measured on dry bones.

In the interest of simplicity, standard linear least-squares regressions of long bone lengths versus stature were generated. There has been considerable discussion in the anthropological literature regarding the appropriate methods of regression to use for different analyses. The regressions used here are an example of what Konigsberg et al. (37) refer to as "inverse calibration," with stature regressed on long bone length. This is a Bayesian approach that assumes that the stature distribution of the reference sample is appropriate for the test case; in choosing inverse calibration as the method of choice, one is assuming that the test case is drawn from a stature distribution similar to that of the calibration sample. If the target stature is too far from the reference mean, as it might be in an archeological or paleoanthropological case, inverse calibration performs poorly. In the language of Konigsberg et al. (37), one should be interpolating, not extrapolating beyond the reference data.

Statistics were performed using Excel. Over the age span used, long bone growth approaches linearity, with small quadratic terms for polynomial models (34), ensuring that linear regressions will yield reasonable estimates of stature from long bone lengths. It is predicted that leg bone lengths will be more highly predictive of stature than will arm bone lengths. As leg bone lengths are generally preferred to those from arm bones in height estimation, and as previous work (34) indicates that the correlation of the size of the femur and tibia for boys may not be as high as for other bone combinations, a combined femur+tibia regression has been calculated in addition to the single-bone versus height regressions.

Results and Discussion

Combined-sex regressions are given in Table 1 and shown in Figs. 1–7. F values from ANOVA tests indicate highly significant results for all regressions; t-statistics for intercepts and slopes likewise display high significance in all cases. Correlations between bone length and stature are very high for all the bones. These high correlations result in part from the fact that both bone length and height are correlated with age. r^2 values are marginally higher for the lower limb bones than for the upper limb bones, but the difference is minor. Standard errors (SE) are likewise similar across limbs but are a little lower for leg bones. As expected, the best result is obtained using the femur+tibia combination.

Sample sizes (N) and means and variances of the long bone lengths for each regression are given in Table 1 and subsequent regression tables following the recommendation of Giles and Klepinger (38) to report such information so that confidence intervals can be adjusted for a single predicted value. However, for these regressions such adjusted values will not change substantially compared with those calculated as the estimate ± 2 SE. The magnitude of the SE should be duly appreciated. For example, it can be seen in Table 1 that the SE for height predicted from the length of the femur is *c.* 2.5 cm. Thus, the full 95% confidence interval covers a range of about 10 cm. In addition, in these regressions it is assumed that the variance of y does not change as x changes; there is a single SE estimate. However, as is evident in the figures, this is not the case. There is a tendency for the variance in height to increase with longer bone lengths (at greater ages). There is thus a corresponding tendency for the SE to be

TABLE 1—*Regression equations for children of unknown sex.*

	Equation	SE (cm)	r^2	N	Mean(x) (mm)	Variance(x)	SE and CI, Intercept	SE and CI, Slope
Humerus	0.4658(x)+27.053	3.00	0.96	762	200.74	884.720	0.742; 25.596–28.510	0.0037; 0.4586–0.4730
Radius	0.6229(x)+27.500	3.16	0.95	762	149.40	492.144	0.781; 25.966–29.033	0.0052; 0.6128–0.6331
Ulna	0.5898(x)+23.742	2.91	0.96	761	164.12	553.453	0.744; 22.281–25.204	0.0045; 0.5810–0.5986
Femur	0.2928(x)+36.923	2.46	0.97	758	285.68	2267.811	0.544; 35.854–37.992	0.0019; 0.2891–0.2965
Tibia	0.3519(x)+38.614	2.24	0.98	762	232.85	1581.956	0.483; 37.666–39.562	0.0020; 0.3479–0.3560
Fibula	0.3620(x)+37.273	2.24	0.98	762	230.11	1495.755	0.490; 36.312–38.234	0.0021; 0.3578–0.3661
Femur+tibia	0.1612(x)+36.981	1.97	0.98	758	518.57	7567.602	0.432; 36.133–37.829	0.0008; 0.1596–0.1628

SE, standard error; CI, confidence interval.

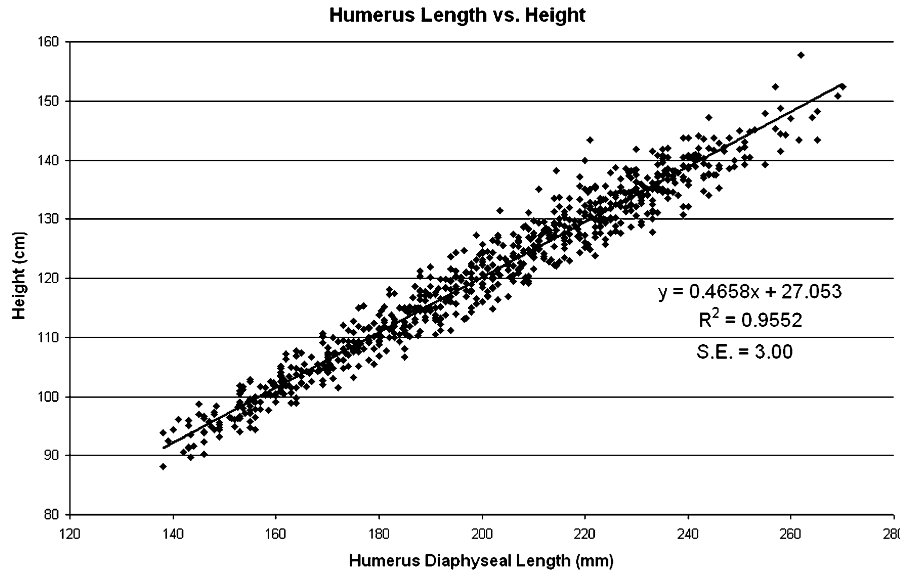

FIG. 1—*Regression of height on diaphyseal length of the humerus for 67 children (36 girls and 31 boys) aged 3–10 years. N = 762 data points.*

overestimated at short bone lengths and underestimated at long bone lengths. For young children, the full ± 2 SE range produces a height range that is not especially helpful.

Technically, it should be recognized that while the sample size of points is very large (up to 762 data points), the large Ns derive from 67 individual children who were repeatedly measured, and whose data thus form longitudinal series of points. Four children have long bone measurements for only two ages, and three have measurements deriving from three measurement occasions; the remaining children have data for more than three ages. Each association of a particular length and a particular stature is independent, but these measures derive from a series of children growing through time. Had all the measurements come from different children, the ranges and SEs would probably be larger, but to an unknown degree.

In order to assess the effect on the error estimates of repeated sampling of the same children, a semi-random strategy of data sampling was used for an alternate series of combined-sex analyses. First, the random number generator in Excel was utilized to help rank order ID numbers six separate times, once for each single-bone analysis, so as to scramble their order. Next, for each analysis, sequential passes were made through the data file, selecting data in order by age for the scrambled ID numbers, skipping IDs with missing data (i.e., age 3 bone length and stature for the first ID in the list with these data, age 3.5 bone length and stature for the next ID in the list with these data, etc.). Each child's data were sampled once only, with IDs skipped due to missing data on earlier passes tried again on subsequent passes until 60 children had contributed data. At that point, there were four data points for each half-year age. The remaining seven IDs were then examined, with the remaining data points chosen nonrandomly so as to balance the age distribution as nearly as possible. For example, some children had data for only ages 9 years and above, and so some data from younger ages were preferentially chosen.

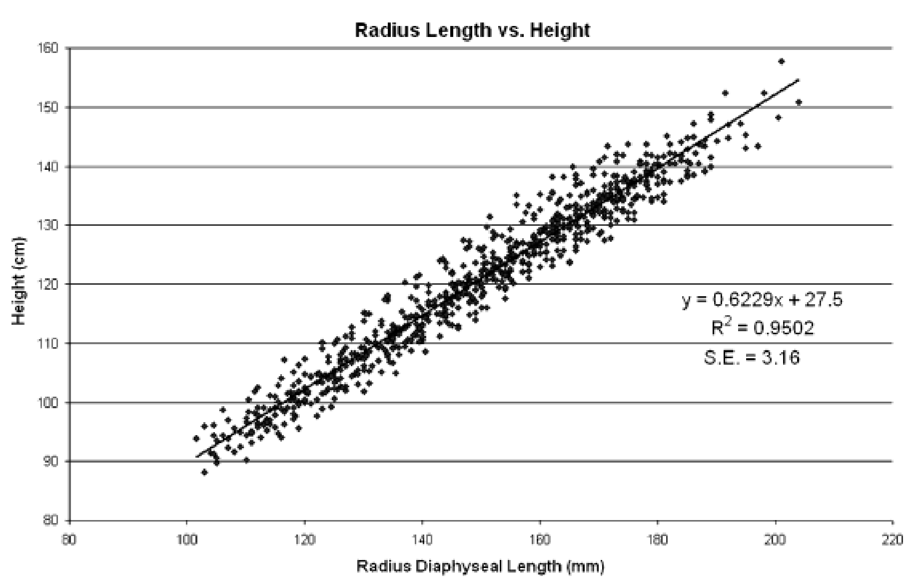

FIG. 2—*Regression of height on diaphyseal length of the radius for 67 children (36 girls and 31 boys) aged 3–10 years. N = 762 data points.*

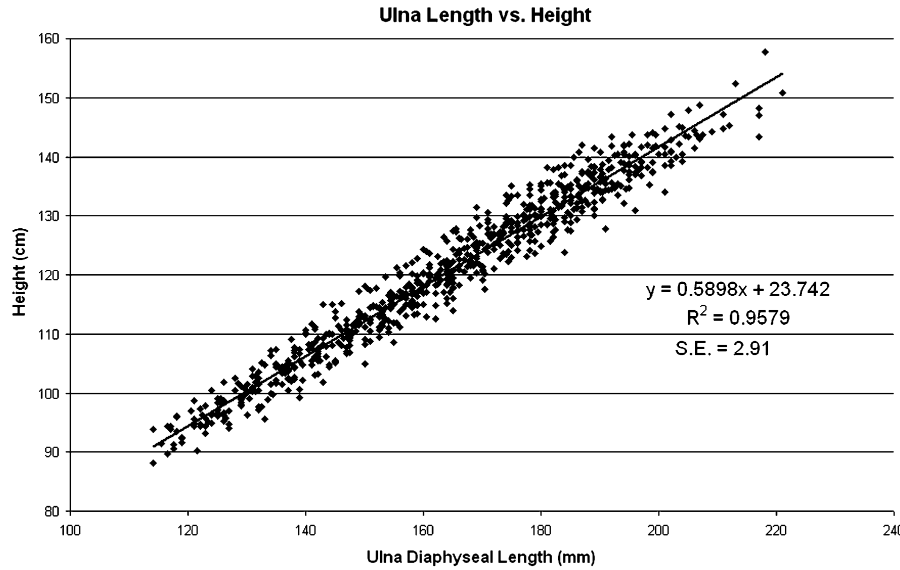

FIG. 3—*Regression of height on diaphyseal length of the ulna for 67 children (36 girls and 31 boys) aged 3–10 years. N = 761 data points.*

The results of these analyses are presented in Table 2. Surprisingly, in four of six cases, the SEs for the predicted statures *decrease*. In the remaining two cases, for the tibia and the fibula, the SE increases are slight. Therefore, use of repeated measurements throughout growth for these children does not have the effect of inappropriately depressing the SEs of the height estimates.

The means for bone lengths in Tables 1 and 2 are close, but the variances are in each case higher for the analyses in Table 2, likely due to the final seven nonrandom selections across the available age span, constrained by missing data (ages). While one might be tempted to prefer the equations in Table 2 for reasons of statistical independence and the added benefit of the height estimate SE reductions, an examination of the SEs and confidence intervals for the regression line slopes and intercepts indicates that the regressions in Table 1, generated from the full dataset, are the better ones. The regression lines presented in Table 1 are considerably more narrowly constrained. Therefore, regressions based on the full dataset (or its subdivision by sex) are recommended and are utilized throughout the remainder of this paper.

A semi-random strategy was utilized to provide better balance across ages and to avoid a further decline in sample size due to missing data. Error ranges based on a smaller sample or one with unbalanced ages might be larger than those in Table 2. Another issue to consider is the distinction between predicting "biological" stature and "forensic" stature (39). The regressions assume that a child's true, biological stature is known. The childhood equivalent of a forensic stature for an adult (e.g., from a driver's license) might be the stature listed on a child's ID card or pediatric medical chart, neither of which is likely to have been measured as precisely as the statures of children in the Denver study. For the Denver children, it is reasonable to expect that statures and long bone lengths were not only measured precisely (i.e., with low measurement error) but also that the strong relationship between long bone lengths and stature allows a reasonably accurate (i.e.,

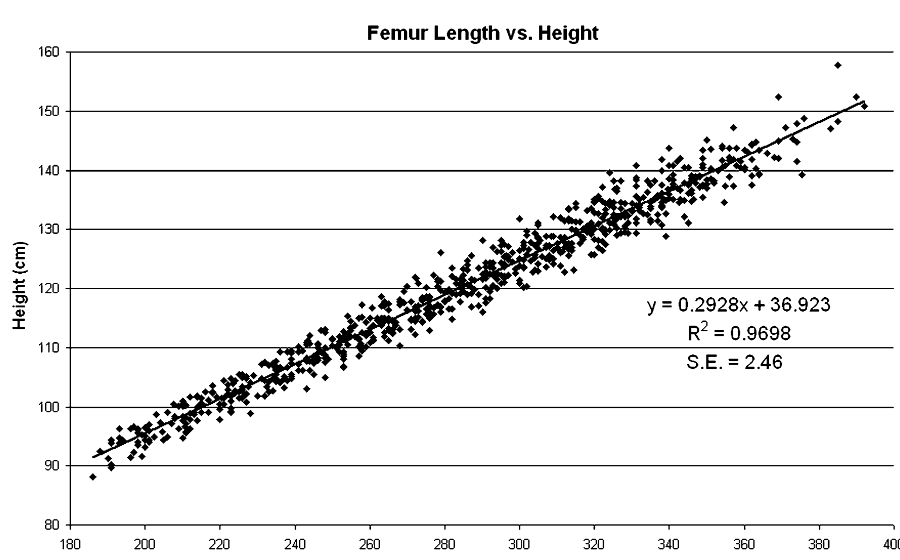

FIG. 4—*Regression of height on diaphyseal length of the femur for 67 children (36 girls and 31 boys) aged 3–10 years. N = 758 data points.*

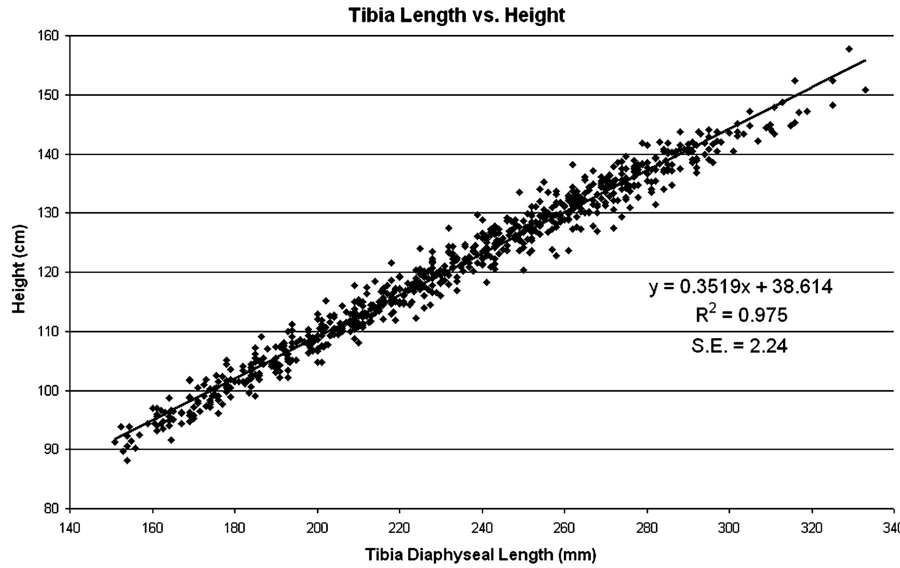

FIG. 5—*Regression of height on diaphyseal length of the tibia for 67 children (36 girls and 31 boys) aged 3–10 years. N = 762 data points.*

near the true target, on average) estimation of biological stature, even if the variation in the relationship between bone lengths and stature does not allow a narrow prediction interval for an individual case. When the regressions are applied to modern forensic cases, it should be possible to maintain a similar degree of precision, assuming that landmarks on long bones can be measured as precisely as those on radiographs, but there may be a loss of accuracy with respect to the match to the recorded or recollected statures if there is some bias in the forensic statures or in the adjustment for radiographic magnification. These potential limitations should be recognized.

Tables 3 and 4 present the single-sex regressions. As with the combined-sex regressions, *F* values and *t*-statistics show very strong significance in all cases, and as expected for children of this age range, for each bone these regressions are similar across sexes and similar to the combined-sex regressions. For the arm bones, all the regression equations are statistically equivalent, judging by the ranges of the confidence intervals for the intercepts and slopes. However, although the equations for girls and boys are statistically not significantly different, boys tend to have relatively longer forearms (34,40,41). The slopes of the regression lines are identical (for the ulna) or nearly so (for the radius) but the intercepts are estimated as being slightly higher in girls, producing parallel or nearly parallel regression lines. Due to the longer forearms of boys, using the sex-specific regressions will yield a slightly lower stature for boys for the same radius or ulna length. In contrast, the sex-specific regressions for the humerus are trivially different, but the one for the boys has a smaller SE.

The femur+tibia regressions are all statistically equivalent. For each of the individual leg bones, there are some statistically significant differences. For the fibula, the regression equation for females has an intercept beyond the confidence interval for the equation for the males, and the slope for the female equation is

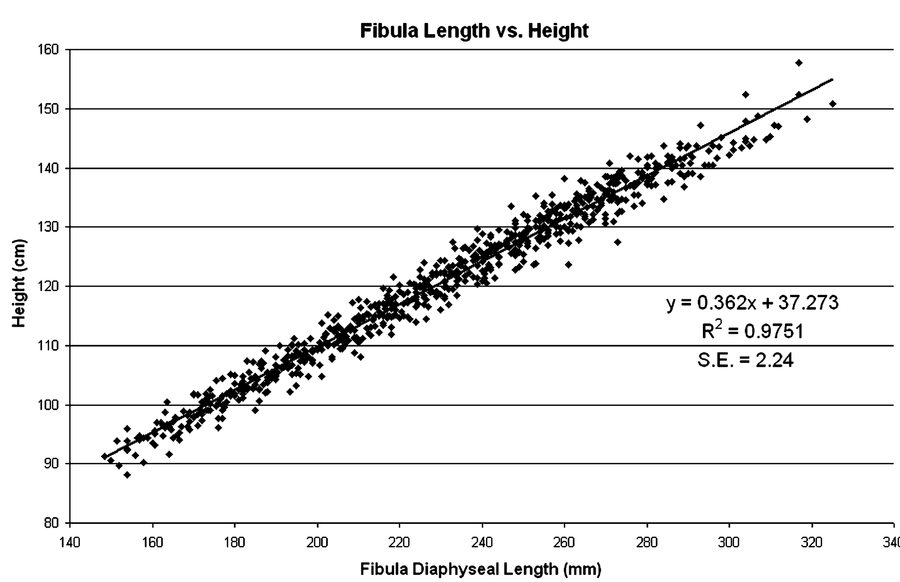

FIG. 6—*Regression of height on diaphyseal length of the fibula for 67 children (36 girls and 31 boys) aged 3–10 years. N = 762 data points.*

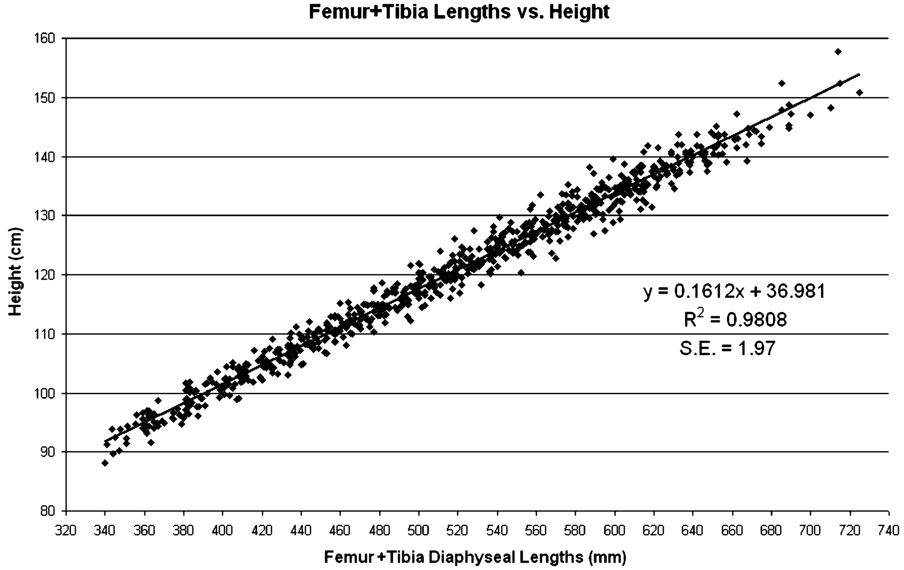

FIG. 7—*Regression of height on the summed diaphyseal lengths of the femur and tibia for 67 children (36 girls and 31 boys) aged 3–10 years. N = 758 data points.*

just barely outside the confidence interval for the slope of the male equation, but this is not a practically important difference. As for the humerus, however, if the sex is known to be male, the equation for males may be preferred due to its smaller SE.

For the tibia, the slopes and intercepts for the three equations are statistically different. (The combined-sex equation has a slope and an intercept within the female confidence intervals but beyond the male ranges.) Although the sex difference is small, at the extremes it becomes substantial enough that use of the sex-specific equations is warranted, especially given the SE difference.

Similarly, for the femur, except at lengths around 240 mm, use of the sex-specific equations is recommended when possible. For the slopes and the intercepts, the male and female equations are statistically different; for the slope, the combined-sex equation is statistically different from that of the boys and that of the girls.

Comparison of results from different studies is rendered difficult due to differences in measurement technique, e.g., anthropometric versus radiographic, use of diaphyseal lengths only or lengths including epiphyses, and adjustment or lack thereof for varying magnification in radiographic studies. The closest comparisons can be made with Maresh (18) for the Denver data and with Telkkä et al. (31) and Virtama et al. (29), who examined radiographs of Finnish children and measured diaphyseal lengths. The data from these studies were not adjusted for magnification.

For purposes of comparison, three lengths were chosen for each long bone. The middle length ("medium") in each case was close to the mean length from Table 1, rounded to the nearest cm. The smaller ("short") and larger ("long") lengths selected were equidistant from the middle length and were chosen so as to be toward the edges of the distribution but not the most extreme values. Long bone values for the comparisons are as follows:

	Short (mm)	Medium (mm)	Long (mm)
Humerus	150	200	250
Radius	110	150	190
Ulna	120	160	200
Femur	220	290	360
Tibia	170	230	290
Fibula	170	230	290

Predicted statures for these lengths for the sex-specific regressions from this paper are presented in Table 5.

Using a two-step process with the Maresh (18) tables to obtain height estimates works surprisingly well (Table 5). First, tables of long bone length for age were used to select ages for which the long bone lengths were the closest to the example lengths. (In one case, the "short" ulna length for boys, the length was precisely intermediate between two half-year ages; in that one instance only was proportional (0.5) interpolation carried out.) Next, separate tables from Maresh (18) provided relative bone lengths by age that could be used, with algebraic substitution, to calculate an estimated stature. In all cases, the "ballpark" estimates from the Maresh (18) tables are within ± 1 SE of the estimates from the regressions calculated here; the largest absolute difference (1.9 cm) is for the "short" ulna length for girls. Using the regressions, however, is easier and avoids having to use two separate

TABLE 2—*Alternate regression equations for children of unknown sex (N = 67).*

	Equation	SE (cm)	r^2	Mean(x) (mm)	Variance(x)	SE and CI, Intercept	SE and CI, Slope
Humerus	$0.4602(x)+28.038$	2.87	0.96	200.25	981.995	2.281; 23.483–32.592	0.0113; 0.4378–0.4827
Radius	$0.5834(x)+32.829$	2.78	0.96	148.98	567.481	2.164; 28.507–37.151	0.0143; 0.5547–0.6120
Ulna	$0.5765(x)+25.747$	2.76	0.96	163.00	598.939	2.284; 21.186–30.308	0.0139; 0.5488–0.6041
Femur	$0.3048(x)+33.561$	2.39	0.98	282.75	2412.753	1.715; 30.136–36.986	0.0060; 0.2929–0.3167
Tibia	$0.3462(x)+39.512$	2.30	0.97	230.38	1640.879	1.634; 36.249–42.775	0.0070; 0.3323–0.3602
Fibula	$0.3478(x)+40.104$	2.31	0.98	228.25	1818.094	1.545; 37.019–43.190	0.0067; 0.3345–0.3611

SE, standard error; CI, confidence interval.

TABLE 3—*Regression equations for girls.*

	Equation	SE (cm)	r^2	*N*	Mean(*x*) (mm)	Variance(*x*)	SE and CI, Intercept	SE and CI, Slope
Humerus	0.4668(*x*)+27.006	3.40	0.94	423	201.12	890.286	1.128; 24.789–29.223	0.0055; 0.4559–0.4777
Radius	0.6269(*x*)+27.747	3.23	0.95	423	148.59	496.595	1.059; 25.666–29.829	0.0070; 0.6130–0.6408
Ulna	0.5906(*x*)+24.276	2.94	0.96	423	163.59	564.562	0.995; 22.320–26.232	0.0060; 0.5788–0.6025
Femur	0.2984(*x*)+35.609	2.26	0.98	421	285.66	2256.204	0.671; 34.290–36.928	0.0023; 0.2939–0.3030
Tibia	0.3475(*x*)+39.641	2.57	0.97	423	233.83	1647.717	0.732; 38.203–41.079	0.0031; 0.3414–0.3536
Fibula	0.3600(*x*)+37.768	2.68	0.97	423	230.92	1531.105	0.780; 36.236–39.301	0.0033; 0.3534–0.3665
Femur+tibia	0.1616(*x*)+36.914	2.10	0.98	421	519.39	7718.414	0.615; 35.706–38.122	0.0012; 0.1593–0.1639

SE, standard error; CI, confidence interval.

error ranges on the estimates if one desires more than a rough mean value.

A broader comparison can be made with the regressions based on Finnish data. In one paper (31), regressions for children 1–9 years of age are presented; in another (29), regressions are given for children from 10 to 15 years of age (see also 14). For the "short" and "medium" examples, the former regressions were used, while for the "long" examples both were tried (Table 5). It should be noted that for the 1–9 year olds, the Finnish regression equations for the femur are not linear; the natural logarithm (ln) is used for the stated "log" in those equations. Consistent with the Finnish data, for the Denver children the growth of the femur shows a greater departure from a quadratic model than does the growth of the humerus, radius, and tibia (34). Comparisons of the 1–9-year-old Finnish regressions for bones other than the femur with those presented here show that the slopes of the Finnish regression equations are outside the Denver confidence intervals for the slopes except for the radius in girls and the ulna in boys; the Finnish equation intercepts are beyond the Denver confidence intervals with the exception of the ulna in both sexes, the humerus in boys, and the tibia in girls.

In all cases, the SEs of the Finnish equations are larger than those presented here, but a similar pattern of generally larger errors for the girls' equations (age 1–9 years) is apparent. However, for the Finnish equations SEs are on average higher for the leg bones, whereas for the present equations they are lower for the leg bones, with the exception of the femur for boys. This difference, as well as some of the height estimate differences, may be partially attributable to the difference in measurement technique. Although the Finnish researchers reported that maximum diaphyseal lengths were measured (31), their Fig. 1 appears to indicate that the measurements were not always taken along the long axis of the shaft, as were those of Maresh (16). While for the arm bones and the fibula the depicted measurement technique appears similar to that of Maresh, for the femur and especially for the tibia, the measurement line is tilted with respect to the shaft's axis.

In all cases, the Finnish measurements for 1–9 year olds are smaller, which might in part stem from differences in radiographic magnification. The focal length in the Finnish study is reported as 110 cm, while Maresh (16) lists that for the Denver study as 228.6 cm. Therefore, due to the shorter focal length, the Finnish children's bones will have been magnified more, meaning that the true bone lengths will be shorter and will therefore be associated with a shorter height.

Ten of the Finnish girls' estimated mean heights using the 1–9-year-old equations exceed −1 SE of the regression means presented here for the new equations (Table 5), as do ten of the boys' estimated mean heights. For girls, the "medium" femur estimate exceeds −2 SEs, and the "long" one exceeds −4 SEs. Using the equations for 10+ year olds, however, results in fewer large differences for the "long" bones. Likewise, while for males the example "long" bones have three of six estimates exceeding −2 SEs, using the 10+ formulas reduces this to two beyond ±1 SE.

It must be remembered that none of these figures have been adjusted for magnification, and this inevitably adds variation beyond the stated SEs. There are several possible approaches to this problem. One is to calculate an average adjustment for the magnification. Based on experiments, Maresh (18) (p. 162) states that magnification/distortion is estimated as "1 to 1.5 percent with the bone in contact with the cassette and as much as 2 to 3 percent with the bone in a simulated body position with respect to the cassette surface." Feldesman (21), following Green et al. (42), suggests up to 6% magnification for the femur at a distance of 6 feet; he adjusted femur lengths below 45 cm by the factor 0.968 for the 7.5 foot tube-film distance (16) used in the Denver study. For the "long" femur example here, this would reduce the 360 mm radiographic length to 348.48 mm.

Secondly, one could attempt to simulate the *in vivo* radiographic technique of Maresh, using the 7.5 foot tube-film distance and placing the bone off the cassette at a distance approximating the fleshy thickness (assuming defleshed bones), perhaps utilizing foam blocks. For this to work well, however, experimentation would be necessary, and this would be at best an approximation.

Another option would be to calculate a stature initially ignoring the magnification factor, judging it to be minor relative to the myriad potential sources of error in a forensic case. As recovered

TABLE 4—*Regression equations for boys.*

	Equation	SE (cm)	r^2	*N*	Mean(*x*) (mm)	Variance(*x*)	SE and CI, Intercept	SE and CI, Slope
Humerus	0.4644(*x*)+27.151	2.41	0.97	339	200.27	879.985	0.894; 25.392–28.910	0.0044; 0.4557–0.4730
Radius	0.6218(*x*)+26.623	2.75	0.96	339	150.41	486.182	1.033; 24.591–28.655	0.0068; 0.6084–0.6352
Ulna	0.5906(*x*)+22.777	2.66	0.96	338	164.79	540.380	1.038; 20.735–24.819	0.0062; 0.5784–0.6029
Femur	0.2860(*x*)+38.536	2.63	0.96	337	285.71	2289.067	0.868; 36.828–40.243	0.0030; 0.2801–0.2919
Tibia	0.3581(*x*)+37.213	1.73	0.98	339	231.62	1501.803	0.570; 36.092–38.334	0.0024; 0.3533–0.3628
Fibula	0.3645(*x*)+36.643	1.53	0.99	339	229.10	1454.194	0.507; 35.646–37.640	0.0022; 0.3602–0.3688
Femur+tibia	0.1606(*x*)+37.099	1.77	0.98	337	517.56	7399.744	0.590; 35.939–38.258	0.0011; 0.1584–0.1628

SE, standard error; CI, confidence interval.

TABLE 5—*Stature estimation comparisons (girls/boys, cm).*

	"Short"	"Medium"	"Long"	SE
Sex-specific regressions, this study				
Humerus	97.026/96.811	120.366/120.031	143.706/143.251	3.40/2.41
Radius	96.706/95.021	121.782/119.893	146.858/144.765	3.23/2.75
Ulna	95.148/93.649	118.772/117.273	142.396/140.897	2.94/2.66
Femur	101.257/101.456	122.145/121.476	143.033/141.496	2.26/2.63
Tibia	98.716/98.090	119.566/119.576	140.416/141.062	2.57/1.73
Fibula	98.968/98.608	120.568/120.478	142.168/142.348	2.68/1.53
Ballpark estimations from Maresh (1970)				
Humerus	95.5/97.0	119.5/120.8	143.2/143.8	
Radius	95.7/94.0	121.6/120.5	146.6/145.8	
Ulna	93.2/93.1	118.3/117.5	141.3/141.7	
Femur	100.0/100.5	121.5/122.1	142.8/143.1	
Tibia	97.0/97.2	120.2/120.4	140.3/141.1	
Fibula	97.9/97.9	120.0/121.3	142.9/143.1	
Telkkä et al. (1962), Ages 1–9 years				
Humerus	94.40/94.15*	115.70*/116.20*	137.00*/138.25**	4.9/3.0
Radius	95.03/93.18	120.35/118.70	145.67/144.22	3.5/3.3
Ulna	93.48/92.62	116.44/116.46	139.40*/140.30	5.1/3.1
Femur	97.12*/97.93*	115.48**/115.84**	132.86***/132.80***	4.1/4.1
Tibia	96.18/96.71	116.22*/117.29*	136.26*/137.87*	5.2/3.3
Fibula	97.05/97.24	117.15*/117.76*	137.25*/138.28**	5.0/3.1
Virtama et al. (1962), Ages 10–15 years				
Humerus			139.65*/139.25*	5.7/4.2
Radius			146.45/143.74	4.7/4.6
Ulna			142.60/141.30	4.8/4.3
Femur			145.82*/144.28*	5.3/5.3
Tibia			142.80/141.15	6.8/7.0
Fibula			143.68/142.91	5.3/6.9

*Exceeds ± 1 SE of means for sex-specific regressions, this study.
**Exceeds ± 2 SE of means for sex-specific regressions, this study.
***Exceeds ± 3 SE of means for sex-specific regressions, this study.
SE, standard error.

bones will rarely be in pristine condition, full diaphyseal lengths themselves may need some estimation, and this error may well be greater than that stemming from radiographic distortion. While one might wish to avoid summation of errors, the "true" magnification adjustment in a given case will be difficult to estimate precisely. In the forensic context, the change in estimate due to magnification may often not be critical to identification. However, if heights are unadjusted, this should be noted, and a comment made that the expected height will most likely be slightly higher than the mean calculated from the regression equation. If diaphyses are complete, the adjustment factor of Feldesman (21) is recommended pending further research. Until these regressions and the necessary adjustments for radiographic magnification have been experimentally verified, due caution should be exercised in their use in a legal context.

Conclusions

It is proposed that the regression equations presented here will simplify the task of stature estimation for subadults in forensic casework. While utilizing a subset of the data of Maresh (18) and producing mean estimates comparable to those obtained by a two-step process using her tables, these regression equations are both faster to use and provide one SE figure for the means. Using examples, it is further shown that height estimates obtained from these equations are on the whole generally broadly comparable to those obtained using the Finnish equations of Telkkä and colleagues (29,31).

As always, it is best not to extrapolate these results widely beyond the population from which they derive. Both the Denver and the Finnish data derive from populations that would be considered "Caucasian" in a forensic context. Children from different populations may have genotypically differing average proportions that would affect the stature estimates. Environmental differences such as nutrition can affect proportions as well, as is witnessed by the leg length secular trend among the Japanese (see (43)).

Age is more commonly estimated from children's long bone lengths in forensic casework than is stature. However, in cases of war or mass disasters, stature may be a critical parameter for subadult identification. In some cases, a stature estimate may prove particularly useful in conjunction with an age estimate. If a child has been malnourished, height may be stunted for age while the child may retain more nearly normal long-bone proportions for height. A height estimate that does not match a dental or skeletal age estimate is itself a clue for identification. In addition, stature estimation in cases in which this parameter is merely confirmatory and/or in which an antemortem height can be verified will act as a check on the accuracy of the available regressions from the Denver and the Finnish samples for both ethnically similar and more distinct groups. Therefore, stature estimation in subadult forensic cases is to be encouraged.

Acknowledgments

The subjects, their families, and the original researchers of the Denver longitudinal study are thanked for their dedication to the growth study over many years. Dr. Peter Buschang provided xeroxed data sheets from the Denver study, and Dr. Dana Austin offered encouragement and helpful suggestions and references. Thoughtful comments from the anonymous reviewers improved the discussion of the results.

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