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Age Estimations from Diaphyseal Lengths: Two Months to Twelve Years

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Accurate identification of individuals by skeletal structures requires estimations of age, sex, race, and stature plus the presence or absence of such distinguishing features as healed or healing fractures (or other pathologies), restorative or reparative dental work, skeletal anomalies, and others. Correct identification, within limits, is maximized when the investigator has the remains of a complete adult skeleton. As skeletal parts diminish in number and as the age of the individual decreases, accuracy in identification also decreases. When found in combination, that is, with fragmentary skeletons of subadults, these features make for the least desirable situation if accurate individual identification is to be made or even attempted. Kerley [*1*] has recently reminded us of the inherent difficulties of determining sex, race, and stature in subadults even when complete remains are available. As the remains become more fragmentary these parameters become most difficult to evaluate.

Age determination, however, is usually the primary identifying characteristic in subadult material when remains are fairly complete, especially if the dental structures are reasonably intact. If dental development and eruption data are incomplete or missing, we can use information on epiphyseal appearance and closure. For the individual less than twelve years of age, however, this may be difficult since the major epiphyses have not usually begun to fuse to their diaphyses by this age [*2-4*] and since the fragile nature of the highly cancellous epiphyses usually leads to their erosion and disappearance rather rapidly following skeletonization of the deceased [*1*]. When one has only fragmentary remains available for examination, then even age estimation becomes a difficult task. What alternatives are available to assist us with this problem?

With the loss of dental and epiphyseal data, microscopic cortical remodeling changes and diaphyseal lengths remain the only reasonable parameters for estimating age of prepubertal skeletal material. Because of the current limitations on the variability of age estimation by examining cortical remodeling, that is, about ±5 years, this method is unsuitable for such young individuals. This leaves us with attempting to estimate age from the length of long bone diaphyses as the only alternative when no other evidence is available. Although there have been several attempts to deal with this problem generally by presenting tabulations of average bone lengths versus chronological age [*5,6*], the feeling among some investigators is that diaphyseal length cannot be used with any degree of accuracy for predicting the age of subadult skeletal material [*1*]. The usual criticisms leveled against this approach are that there is too much variability in the linear growth process or that the standards are of radiologic origin [*1*]. In the first instance, high variability precludes even reasonably accurate age estimates and, in the second, radiographic standards present too much distortion to allow direct comparison with dry skeletal material.

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This paper, then, is concerned with examining these criticisms of determining age by diaphyseal lengths in the hopes of finding a reasonably accurate method when no other evidence is available. In another sense it is a direct extension and expansion of the generalized postnatal growth curve of the femur presented by Stewart [7] in various editions of *Gradwohl's Legal Medicine.*

Sample and Methods

The data on diaphyseal lengths and associated chronological ages are from the published statistics of the Child Research Council of the University of Colorado School of Medicine, Denver [*8-10*]. This longitudinal study of the healthy growth and development of middle and upper middle socioeconomic class infants, children, adolescents, and young adults was begun in 1927 and terminated in 1967; it represents one of the longest, in years of duration, largest in sample size, and most thoroughly documented in the range of parameters examined, studies of its kind ever accomplished.

The total study population of 334 subjects contained 240 subjects with at least one enrolled relative as close as first cousin; the remaining 94 subjects had no enrolled relatives. There is thus some degree of genetic homogeneity within the sample that should be kept in mind when the data are interpreted.

Data on diaphyseal lengths are of radiographic origin. The radiographic technique and method of measuring bone lengths have been reported elsewhere [*8,9*] and need not be repeated here except to say that all measurements were made to the nearest 0.5 mm and verified on repeated measurements by the same investigator. The schedule of roentgen examinations and the number of measurements taken per subject have been reported by Maresh [*10*]. The published data do not contain corrections for magnification or distortion factors. These were calculated by the investigators as between 2 and 3%, that is, the published figures are 2 to 3% greater than the true anatomical lengths of the diaphyses. The magnification/distortion error was determined by actually measuring dry bones and then placing them in a standard radiographic position above the film plane and calculating the percentage of error.

The Child Research Council data present summary statistics for males and females separately. Therefore it was not possible to determine mean diaphyseal lengths for the total sample. Female data were then chosen, for several reasons, to represent the linear growth of the various diaphyses. The choice of female data was made because the sample sizes were larger than for the males, because the variability in diaphyseal lengths was greater than in males for nearly all ages examined, and because the diaphyseal lengths were of slightly smaller size than the male lengths, which would help to counteract the slight magnification error resulting from radiography. In addition, female deciduous tooth eruption is more variable than in boys except for the first molars [*11*]. Because of the varying size of cohorts going through the growth study at different times, total sample sizes for any one measurement age ranged from 65 to 86 females.

Dental eruption data were used to compare the variability of age estimates determined from diaphyseal lengths. Because we do not have this eruption data for the sample studied we must rely on other published sources. As many authors have noted, variability of tooth eruption times is seldom published. For this study we have chosen the female deciduous eruption times published by Robinow [*11*] and the female permanent eruption data given by Hurme [*12*] and Krogman [*13*]. These studies were chosen because they present separate data for the sexes, subjects were white Americans, sample sizes are reasonably large, and data on variability of eruption times are given.

To compare the variability of age estimates based on diaphyseal lengths versus the universally applied standards of dental eruption, mean female diaphyseal lengths were plotted first against chronological age. To determine the limits within which 95% of the sample fell, calculations of the mean ± 1.96 standard deviations were made. These data were then plotted with the mean diaphyseal lengths and constitute the basic data presented in the study. Similar determinations of the mean and the mean ± 1.96 standard deviations were made for the deciduous and permanent tooth eruption data. The dental data were then plotted on the same graphs as the diaphyseal length data. The dental eruption data were plotted such that the mean eruption time for each tooth crossed the plot of the mean diaphyseal length at that mean age of eruption. Only two diaphyseal length/dental eruption comparisons were made, for the radius and for the femur. These bones were chosen because they represent the slowest and fastest growing long bones in the body, respectively. Making comparisons with the other four long bones was felt to be superfluous and not capable of adding more information to the study.

Results

Figures 1 and 2 represent the graphed data of diaphyseal lengths, dental eruption, and chronological ages for the radius and femur, respectively. The striking aspect of these figures is that the range of variability for diaphyseal lengths is either about the same or actually less than the variability for tooth eruption ages. This is especially seen in Fig. 2 for the femur, where the variability for diaphyseal lengths is actually less at all ages than for the tooth eruption times. A second notable feature is that as chronological age increases the ranges of variability for both diaphyseal lengths and tooth eruption times increase also, with the variability for both events rising at about the same rate.

We must recognize, though, that the two classes of data variability (diaphyseal length and tooth eruption times) are not exactly comparable and this should be kept in mind. The variability for diaphyseal lengths is actually the length variation at a single age, while the tooth data are the age variations at which any particular tooth erupts. Despite this

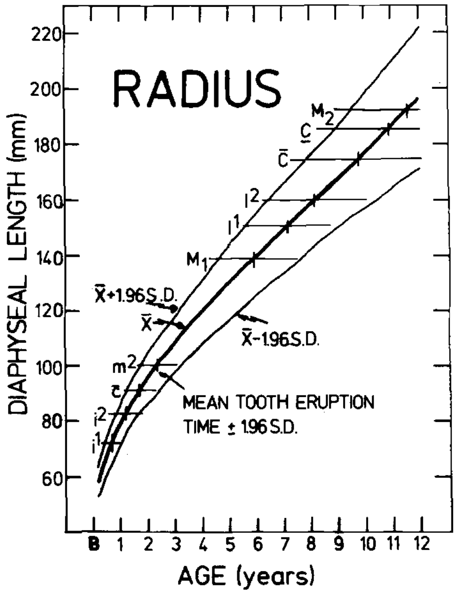

FIG. 1—*Graph of maximum diaphyseal length variation of the radius (two months to twelve years) compared to tooth eruption time variance. Note: in this and all subsequent figures the middle curve is the mean maximum diaphyseal length while the lower and upper curves are for the mean maximum diaphyseal length ± 1.96 standard deviations.*

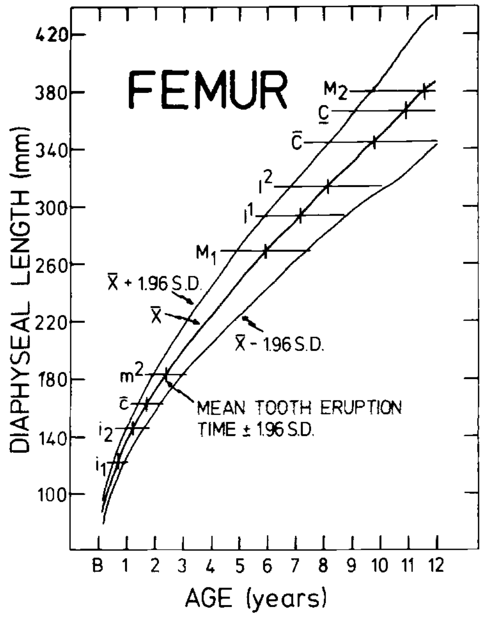

FIG. 2—*Graph of maximum diaphyseal length variation for the femur (two months to twelve years) compared to tooth eruption time variation.*

disparity it is thought that the results generally support the observation that diaphyseal length variation is at least no more variable than dental eruption times and can therefore be used as a reasonable source for estimating age in subadult skeletal material.

Figures 3 through 8 present graphs of diaphyseal length variability versus chronological age for the humerus, radius, ulna, femur, tibia, and fibula, respectively. Given any complete diaphysis, then, it is an easy task to determine its probable mean age and associated 95% confidence limits.

Discussion and Conclusions

With the loss of dental and epiphyseal information, age estimation by diaphyseal lengths becomes the only remaining reasonable method available, at least for individuals twelve years of age and less. For many years Stewart's [7] figure of the generalized postnatal growth curve of the femur and the associated percentile relationships of the other major long bones was the only attempt to deal with this problem. Even though longitudinal growth data have been published for other long bones [8-10,14] for over two decades now, forensic scientists have been reluctant to use them primarily because of the magnification error problem inherent to all radiographic work. Implicit in this rejection of diaphyseal length data has been the feeling that the linear growth process of the individual long bones was too variable to yield meaningful standards for the problem under discussion.

Our data have shown that this last objection, at least when compared to dental eruption data, should no longer deter the forensic scientist from using this kind of data. Also, the magnification error problem is rather slight (2 or 3%) and, when compared to the normal range of variation within which 95% of the population falls for diaphyseal length, becomes a problem of rather slight concern.

It is interesting to note also that the growth curve of the femur presented here is rather different from Stewart's [7], showing greater mean lengths (about 40 to 60 mm greater, depending on age) at most ages. For the same diaphyseal length, then, Stewart's curve

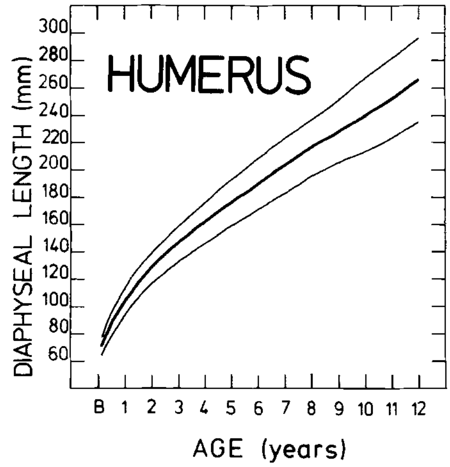

FIG. 3—*Graph of maximum diaphyseal length variation of the humerus (two months to twelve years).*

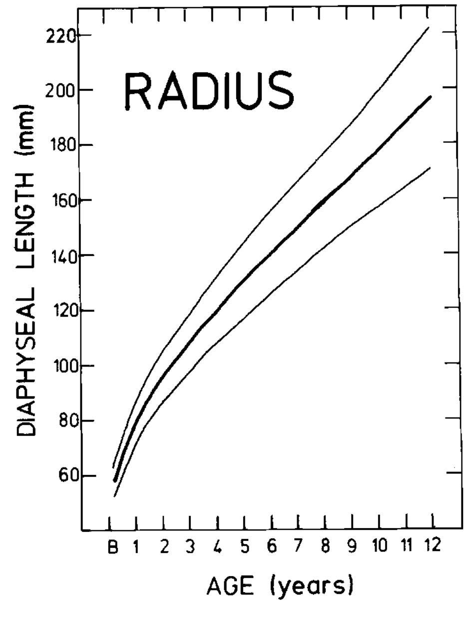

FIG. 4—*Graph of maximum diaphyseal length variation of the radius (two months to twelve years).*

would tend to overage individuals by as much as 2 to 3 years. For those forensic scientists who may have tested diaphyseal lengths in individuals of known age against Stewart's generalized curve, this result may have been a primary source of frustration and ultimate rejection of diaphyseal lengths for estimating ages.

This is not to say the method is without certain drawbacks. The data presented herein are population-specific (white, middle-class Americans); they were collected during a period of secular change in growth; there is some slight magnification error; and the data have been generalized from specifically female data. These are honest criticisms and they should be addressed. But until additional contemporary, population-specific data can be

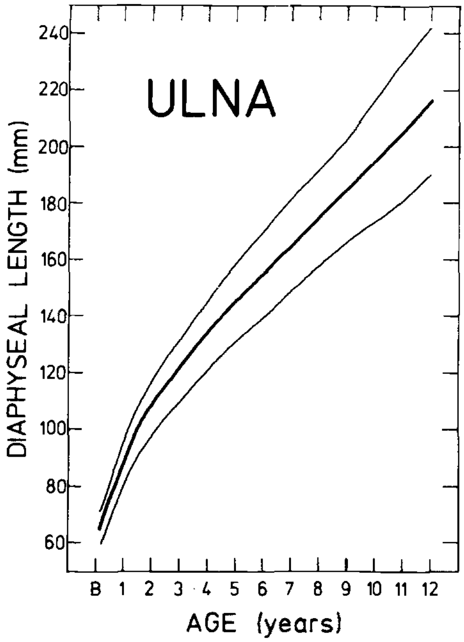

FIG. 5—*Graph of maximum diaphyseal length variation of the ulna (two months to twelve years).*

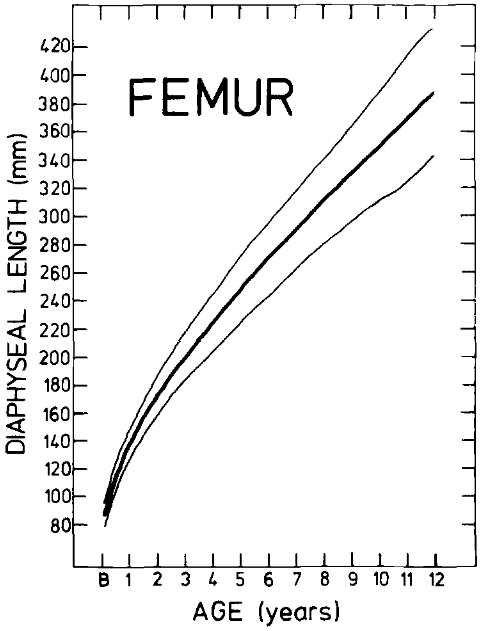

FIG. 6—*Graph of maximum diaphyseal length variation of the femur (two months to twelve years).*

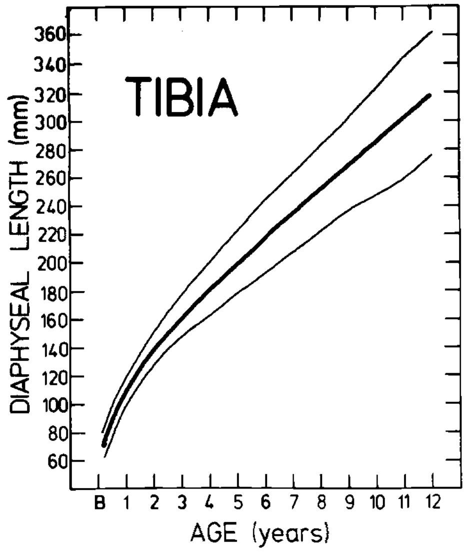

FIG. 7—*Graph of maximum diaphyseal length variation of the tibia (two months to twelve years).*

generated we should not hesitate to use these standards with appropriate caution—as we have done for many years with other standardized data sets.

A more indirect line of evidence to support the use of diaphyseal lengths as age estimators comes from the recent work of Ubelaker [*15*] on a prehistoric ossuary sample from the tidewater Potomac region of Maryland. In his attempt to reconstruct accurate demographic profiles Ubelaker compared several methods of estimating age from skeletal/dental evidence. His comparisons of juvenile data indicate that dental calcification and long bone lengths are more reliable age estimators than dental eruption. And, as our data show here, he thinks femoral diaphyseal lengths are the most reliable of all the long

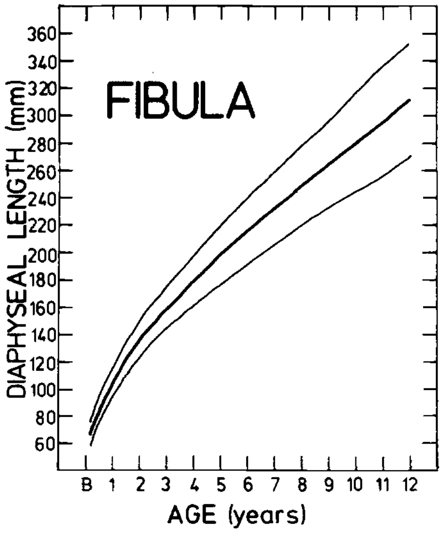

FIG. 8—*Graph of maximum diaphyseal length variation of the fibula (two months to twelve years).*

bones. These conclusions are based on his assuming that dental calcification is the least variable, and hence most reliable, estimator of juvenile age and then comparing other methods against this standard. The dental literature supports this assumption [*16,17*]. Similar support comes from the recent work of Lovejoy et al [*18*].

In conclusion, when complete skeletal material is available for estimating the age of a subadult (less than twelve years old), dental calcification standards are the most reliable. If the dental and epiphyseal data are missing, however, diaphyseal lengths can be used with appropriate caution. In fact, age estimations based on long bone lengths may be as good as or even better than those based on dental eruption standards. If the femoral diaphysis is available it should be used as the most reliable indicator. All forensic scientists should remember, though, that the standards presented here are population-specific and sex-specific, and should be used accordingly (see Ref *19* for stature estimations).

Acknowledgment

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