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A Method for Establishing the Age of Subadults

REFERENCE: Pfau, R. O. and Sciulli, P. W., "**A Method for Establishing the Age of Subadults,**" *Journal of Forensic Sciences,* JFSCA, Vol. 39, No. 1, January 1994, pp. 165–176.

ABSTRACT: Accurate estimates of age-at-death of subadult human skeletal remains are limited because of the dearth of information on the covariance among reliable indicators in recent samples of children. To obtain these kinds of data, namely patterns of maturation among dental development, epiphyseal union, and long bone growth, we focused on a radiographic method using recently deceased children.

A total of 183 subadult cadavers were examined using X-radiographs of the six long bones and the mandibular dentition with measurements and evaluations thereof.

The results of this study show that cadaver samples can relatively inexpensively, provide accurate and precise information on the covariance of subadult age indicators and thus can contribute to the formation of age standards for population lacking such data.

Problems related to age estimation of the increasing numbers of skeletonized or partially skeletonized, unidentified children in Central Ohio have prompted this research. In general, age estimation of children based on dental development is accurate because of the highly canalized nature of human tooth development [*1–4*]. However, difficulties in age estimation arise when teeth, particularly mandibular teeth, are not available. In the absence of teeth, or in the absence of teeth with well-established age standards, long bone lengths and epiphyseal fusion can and have been used to estimate the age of children [*5–12*]. Again, difficulties can arise when using these criteria for age estimation of children because long bone growth and the timing of epiphyseal fusion are more environmentally sensitive than dental development. Thus, age standards established for a given population sample may not yield accurate age estimates when applied to a different population [*13*]. The optimal solution to these problems is to periodically conduct longitudinal studies of dental and skeletal growth and development for the population under consideration. At present, this optimal solution is not feasible because the methods available for obtaining these data for living children are generally considered to pose a health risk.

To begin to address these problems in the Central Ohio region, one of us (ROP) collected data on dental development, long bone growth, and epiphyseal fusion from 186 children brought to the Franklin County (Ohio) Coroner and who had died between 1 July 1990 and 30 June 1991. Although using recently deceased children to obtain data on age related changes in growth and development is not the optimal solution, we believe that the results we present show that useful data for subadult age estimation can be

Received for publication 1 March 1993; revised manuscript received 10 May 1993; accepted for publication 26 May 1993.

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TABLE 1—*Age-sex distribution of the present sample.*

Age	White male	White female	Black male	Black female	Total
0–2 years	37	26	8	9	80
2–6 years	11	1	3	1	16
6–12 years	7	1	3	1	12
12–20 years	37	12	24	2	75
Total	92	40	38	13	183

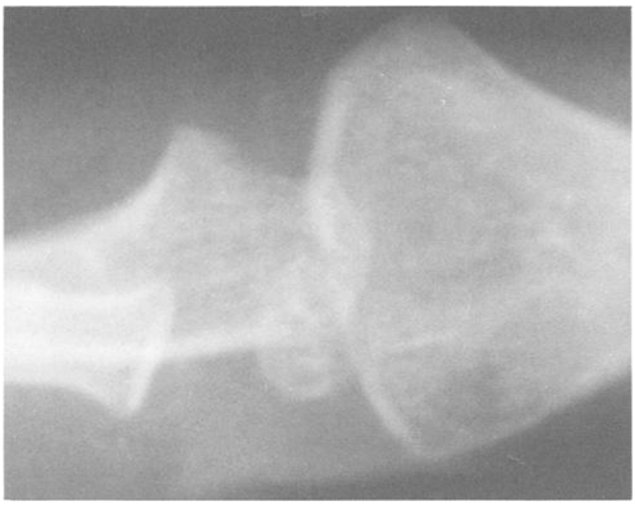

FIG. 1—*X-radiograph of the distal humerus and proximal radius and ulna.*

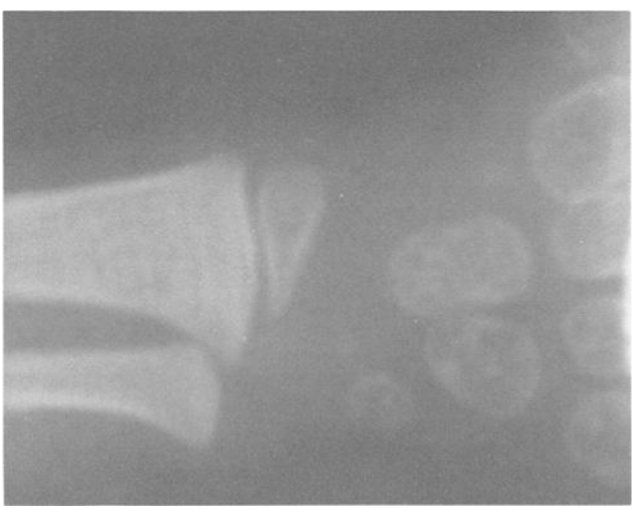

FIG. 2—*X-radiograph of the distal radius and ulna.*

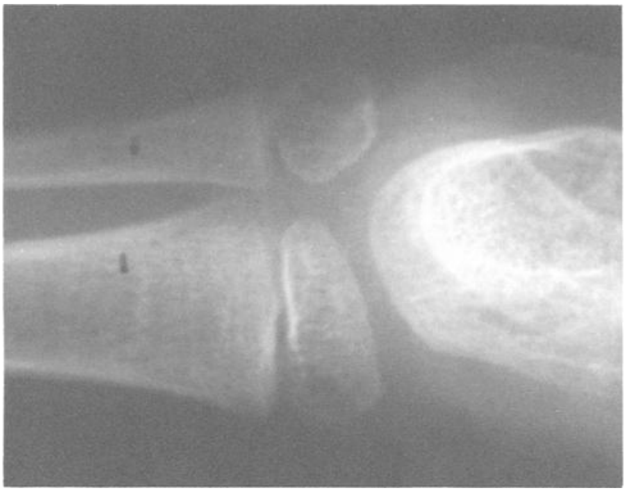

FIG. 3—*X-radiograph of the distal tibia and fibula.*

obtained from cross-sectional samples such as the one used here. Health-risk concerns for the studied individuals are not pertinent in this case and given sufficient time, an investigator can obtain a relatively large sample.

The Sample

Table 1 contains the age-sex distribution of this sample. Dates of birth and death, sex, and ancestry were available for each individual.

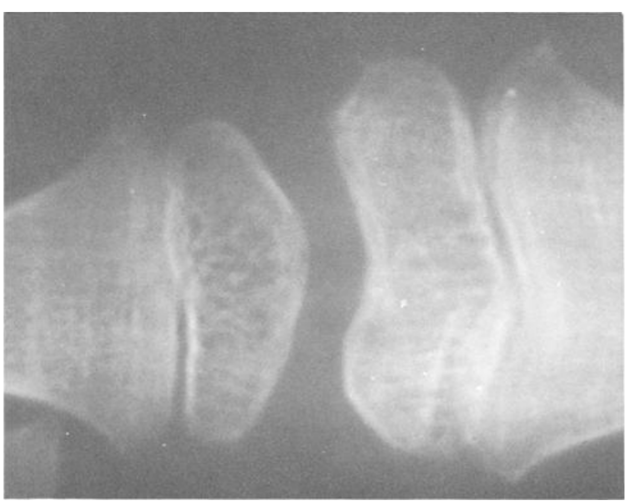

FIG. 4—*X-radiograph of the distal femur and proximal tibia and fibula.*

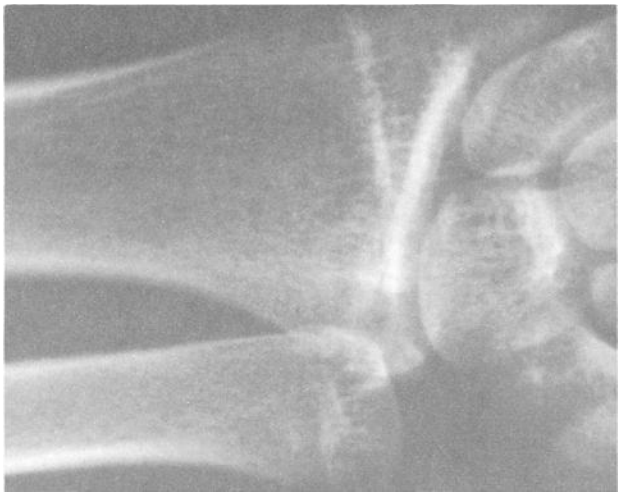

FIG. 5—*X-radiograph of the distal radius and ulna.*

The total number of individuals analyzed is 186 but data from three individuals of Asian ancestry are not included because this subsample is so small.

Methods

One of us (ROP) X-radiographed the six long bones (humerus, radius, ulna, femur, tibia, and fibula) and mandible of each individual. The limbs of the left side where possible were X-radiographed using a General Electric Mobile "225" X-Ray unit. An-

FIG. 6—*X-radiograph of the distal humerus and proximal radius and ulna.*

FIG. 7—*A radiograph used for long bone measurement.*

terior-posterior radiographs were taken at 40 in (101.6 cm) from the radiation source. A radiopaque meter stick was positioned parallel to the long bones in each radiograph.

Each radiograph was made using 14 × 17 in X-ray film placed in a 14 × 17 in cassette equipped with detail screens to ensure a high degree of resolution. Long bones exceeding 17 in (43.18 cm) were X-rayed with the film in a diagonal position. For the few cases where the long bone exceeded 22 in (55.88 cm) two separate but overlapping radiographs were obtained. A radiopaque marker was included as a reference point in each radiograph to ensure accurate measures.

Dental X-rays were obtained using the same X-ray unit with 3.25 × 4 in occlusal film. The film was externally applied with tape to the mandible adjacent to the area of the canine and premolars. The radiation source was positioned so as to effect a lateral oblique image of the teeth. The right and left side of the mandible were used whenever possible.

The following age related data were collected from the radiographs.

Humerus : distal and medial epicondylar epiphyseal fusion.
Radius : diaphyseal length, proximal, and distal epiphyseal fusion.

FIG. 8—*X-radiograph of the right side of the mandible.*

Ulna	:	diaphyseal length, proximal, and distal epiphyseal fusion.
Femur	:	midshaft diameter, distal epiphyseal fusion.
Tibia	:	diaphyseal length, proximal, and distal epiphyseal fusion.
Fibula	:	diaphyseal length, proximal, and distal epiphyseal fusion.
Canine	:	stage of development, deciduous, and permanent.
Premolar 1	:	stage of development, deciduous, and permanent.
Premolar 2	:	stage of development, deciduous, and permanent.

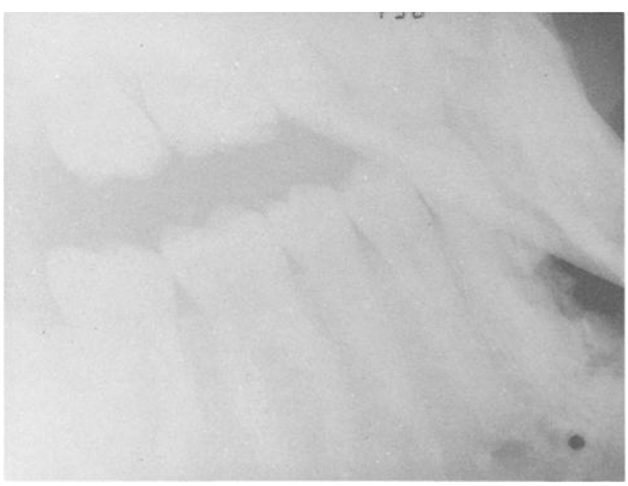

FIG. 9—*X-radiograph of the right side of the mandible.*

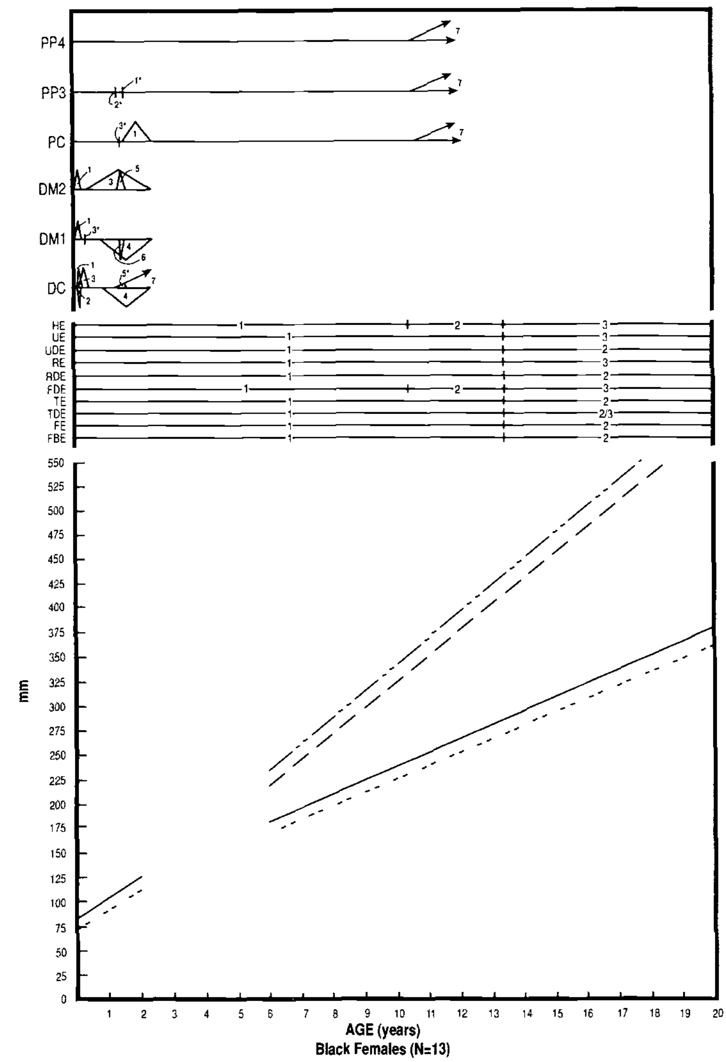

FIG. 10—*Dental development, epiphyseal union, and growth of diaphyseal length of the long bones in white males.*

In older subadults in whom epiphyseal fusion had occurred lengths of the long bones included the diaphysis plus the fused epiphysis(-es).

Epiphyseal fusion was scored as no fusion (Figs. 1 to 3), fusion active (Figs. 4 and 5), and fusion complete (Fig. 6). Diaphyseal lengths were obtained from the radiographs by measuring the maximum calcified lengths to the nearest 0.1 mm. Errors in measurement due to variation in position and radiographic enlargement were minimized by using correction factors specific to each radiograph:

1. A ten cm segment of the radiopaque meter stick included in each radiograph was measured with an osteometric caliper.
2. The observed measure was divided by 10 to provide a specific correction factor.
3. Each long bone measure was multiplied by the specific correction factor.

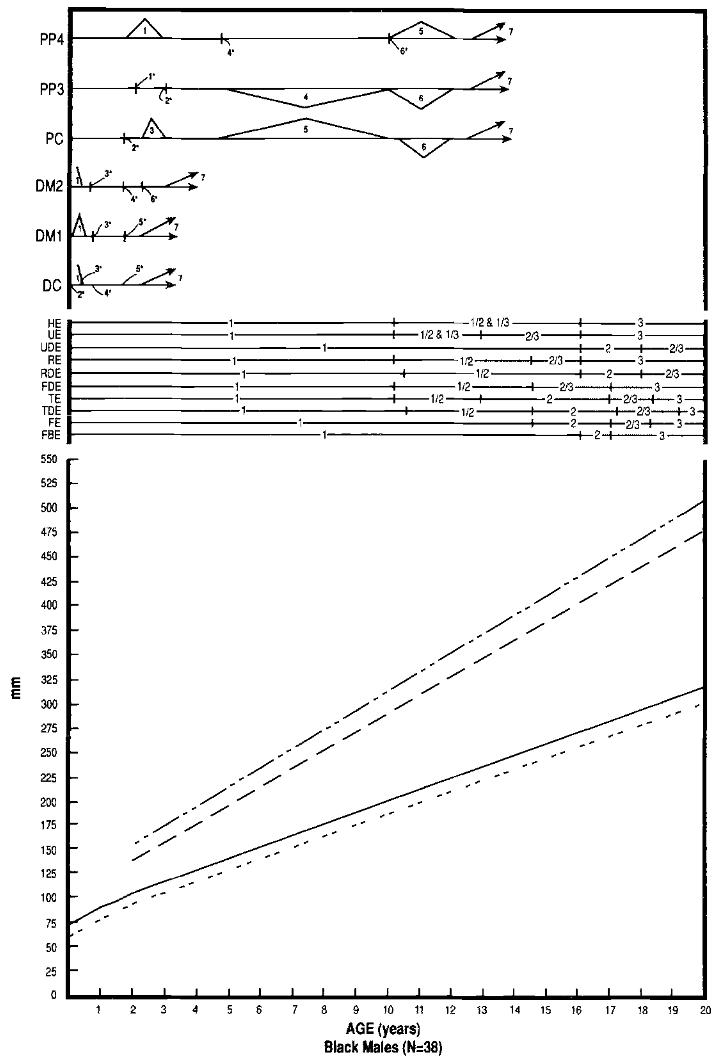

FIG. 11—*Dental development, epiphyseal union, and growth of diaphyseal length of the long bones in white females.*

Figure 7 is an example of a radiograph used for long bone measurement.

Dental development was evaluated using the seven stages of Moorrees et al. [*1*]. Examples of dental radiographs are shown in Figures 8 and 9.

All evaluations were made twice; the second 30 days after the first. Only the first was used as both were statistically the same.

Results

Figures 10 through 13 contain the results of our analyses. The upper section of these figures contain the sequence of dental development, the middle section contains the order

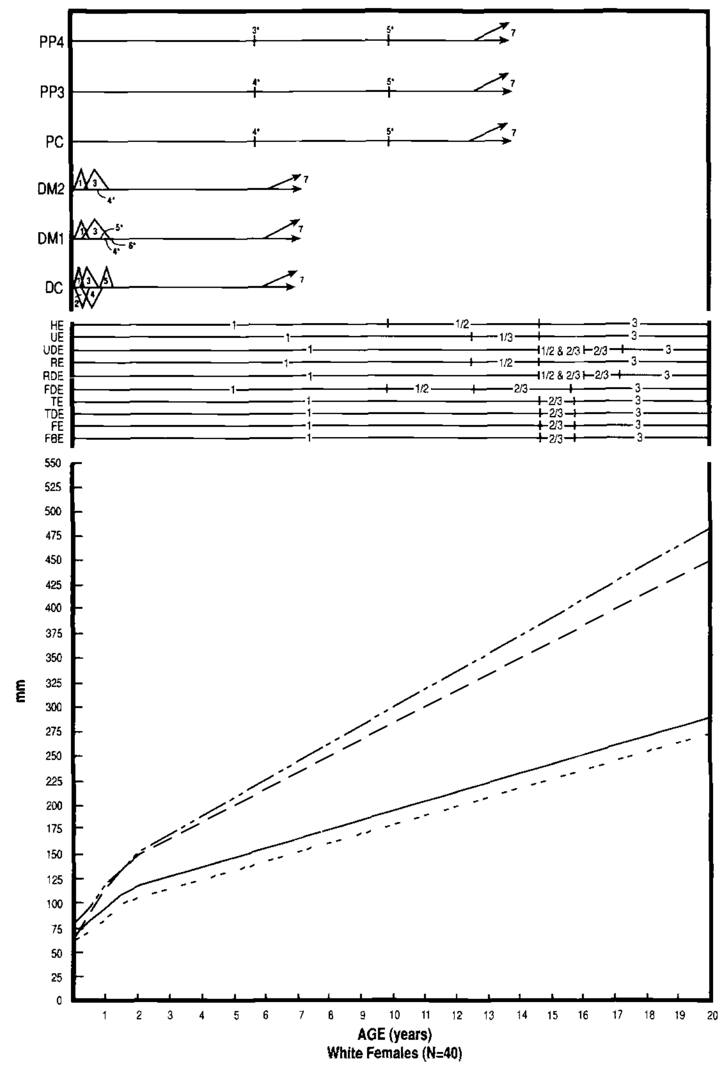

FIG. 12—*Dental development, epiphyseal union, and growth of diaphyseal length of the long bones in black males.*

of epiphyseal union, and the lower section contains the fitted curves for growth of diaphyseal lengths of the radius, ulna, tibia, and fibula.

For the dental development sequences, the triangles originate at the age at which a stage of development was first observed, the apex of the triangle represents the mid-range of age of development of the stage, and the triangle ends at the age at which the stage was last observed. The seven developmental stages are represented numerically.

Epiphyseal union is represented by vertical lines along the x-axis, which delimit the first and last observation of each stage of fusion. The stages of union are numerically represented with fractions used to denote ages where two or more stages of union were observed.

Growth of the diaphysis was modeled separately for individuals >2 years of age and

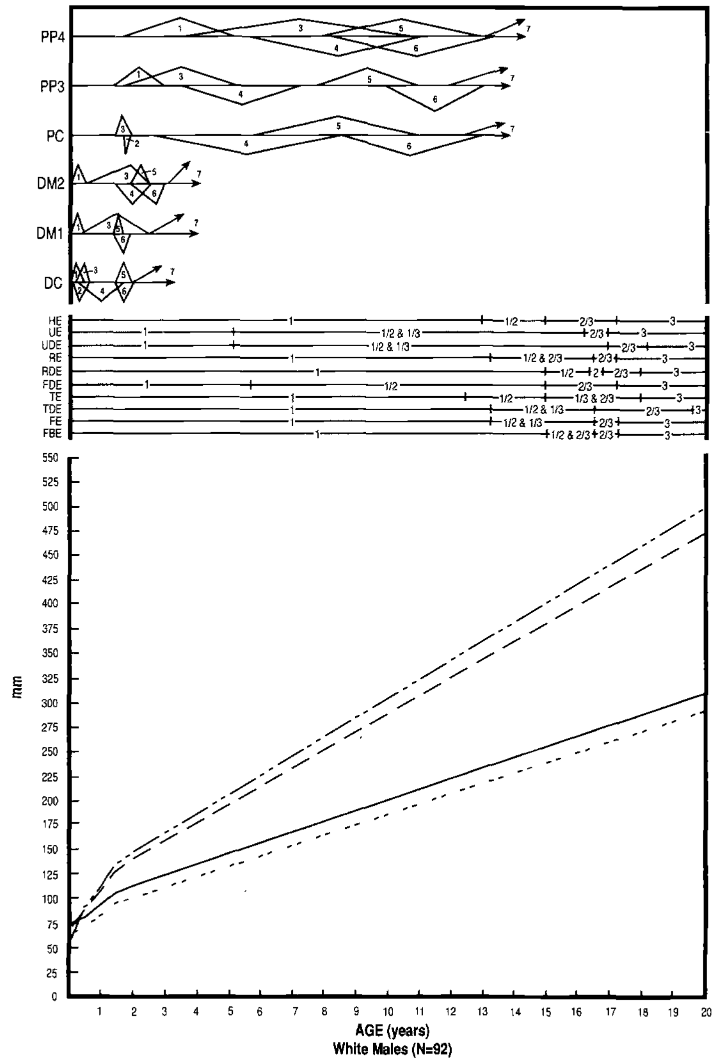

FIG. 13—*Dental development, epiphyseal union, and growth of diaphyseal length of the long bones in black females.*

<2 years of age. For the former group the lengths were fitted by: $Y = A + B_1(X) + B_2LN(X)$, where Y is diaphyseal length (or total length if epiphyses are fused) and X is age in years. For the older children simple linear regression was found to provide the best fit. The following symbols represent the diaphyseal lengths of the long bones:

Radius . . . . . . Ulna ——— Tibia . .—. .— Fibula – – –

The fit of the data to these models is good as is shown by the standard errors of the estimates of the regression equations in Table 2.

TABLE 2—*Standard errors of estimates for age (years) vs. bone length (mm).*

Group/Bone	<2 Years	>2 Years
White males		
Ulna	0.6509	1.898
Radius	0.5485	2.004
Tibia	0.8941	3.719
Fibula	0.7526	3.485
White females		
Ulna	0.5654	1.913
Radius	0.5575	1.923
Tibia	0.7132	4.035
Fibula	0.6795	4.010
Black males		
Ulna	0.9219	2.147
Radius	0.8341	2.019
Tibia	...	4.555
Fibula	...	4.390
Black females		
Ulna	0.6265	0.6668
Radius	0.5678	0.4157
Tibia	...	3.431
Fibula	...	3.945

Conclusion

The results of this investigation show that the type of sample and methods used here can provide precise and accurate data for estimating the age of subadults. For example, 15 individuals were randomly selected from the total sample by one of us (PWS). The sex, ancestry, or lack of this information was also randomly chosen for each individual prior to determining the individuals age by ROP using Figs. 10 to 13. Spearmans correlation between the actual ages of the individuals and the ages estimated from the data in Figs. 10 to 13 is 0.982, $t = 15.52$, $P < 0.001$. For comparison, we also estimated the ages of these 15 individuals using the dental development data of Moorrees et al. [*1,3*], and long bone growth data for the radius and tibia from Maresh [*11*]. Spearmans correlations between the actual age of the individuals and the Moorrees et al., and Maresh radius and tibia standards are respectively: 0.966, 0.989, and 0.970 each with $P < 0.001$.[2]

We recognize that all ages within the subsamples in this study are not well represented and some subsamples themselves are small, thus making a few estimates impossible and others not as accurate as possible. However, we also recognize that this approach provides, relatively inexpensively data that produces accurate age estimates for subadults; data that are often difficult or impossible to obtain by other methods. At present plans are being made to continue this study by adding individuals especially in underrepresented classes. This same approach can be used if investigators feel that current standards do not yield age estimates accurate for their population.

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[2]Pearson product moment correlations for the comparisons are: actual age-estimates from present study, 0.988; actual age-Moorrees et al., 0.985; actual age-Maresh radius, 0.973; actual age-Maresh tibia, 0.959. All product moment correlations are significant at $P < 0.001$.

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