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THE RELATIONSHIP BETWEEN DENTAL AGE AND LONG BONE GROWTH IN ARIKARA INFANTS

A Thesis

Presented for the

Master of Arts

Degree

The University of Tennessee, Knoxville

Suzanne A. Hyman

August 1987

This effort is dedicated to Dr. Ted Rathbun.

ACKNOWLEDGMENTS

Much of the skeletal material was excavated by Dr. William Bass under grants by the National Science Foundation (GS837, GS1635, GS2717) and by the National Geographic Society (699, 912). A major part of the data collection and assimilation was done by Dr. Douglas Owsley and was supported by grants from the Southern Regional Education Board and the National Science Foundation (BNS-8102650, BNS-8510588). I thank both Dr. Bass and Dr. Owsley for access to these data.

I am grateful for all the help and encouragement I received while working towards this degree. In particular I wish to thank Dr. Richard Jantz, Dr. Fred Smith, and Dr. P. Willey, the members of my committee. I am indebted to all three professors for their willingness to work with me given such short notice and strict time constraints. Dr. Smith was especially helpful in preparing me for my oral defense while Dr. Willey's careful attention to detail greatly improved the written work. As chairman of my committee, Dr. Jantz deserves a special thanks for steering the direction of this research. His patient acceptance of my persistent procrastination and unexpected appearances at his office door is sincerely appreciated.

I also wish to acknowledge the encouragement I received from my friends at JBF Associates and my friends in the department. Rick Stoops earns a special thanks for becoming my personal computer consultant.

I am truly grateful to the members of my family for their patient, yet persistent, encouragement and their ability to understand, empathize, and advise. In particular I thank my mother for her financial and emotional support and my grandmother for her "subtle" inquiries about my progress. Robyn and Michael Bunch, the members of my "other" family, also deserve special acknowledgment for their patience, sympathy, and company. Finally, thanks goes to Thom Mobley for his listening and loyalty.

ABSTRACT

The relatively advanced timing of tooth calcification and eruption has been documented in living Native American children. This study uses least squares regression analysis to demonstrate similar precocious patterns of dental development in an archaeological American Indian sample from South Dakota.

Diaphyseal lengths of the femur, tibia, humerus, and radius from Arikara subadults between about birth and three years of age were analyzed using the model, bone length = $b_0 + b_1(\text{age}) + b_2(\text{age})^2$. Age was estimated using three deciduous teeth and dental calcification standards based on White children. The resulting intercepts were compared to modal perinatal long bone lengths, determined by frequency distributions of the Arikara long bones. If the modal lengths accurately represent mean birth lengths in the Arikara then the intercepts are lower than expected. This discrepancy suggests that the White dental standards are over-aging the Arikara subadults.

By slightly lowering the ages assigned to developmental stages of the second deciduous mandibular molar (DM2), the intercepts were raised so that they approximated the modal perinatal lengths. Regression curves for the deciduous mandibular canine (DC) and the deciduous mandibular first molar (DM1) were then adjusted to fit the adjusted DM2 line. Timing differences among the teeth were noticed. While Arikara DM2 consistently develops relatively early, DC and DM1 are more advanced only until about 0.5 years. A comparison of the adjusted Arikara curves to growth curves for White samples reveals differences in patterns of relative long bone growth and suggests

that rates of long bone growth in Arikara infants are advanced relative to the long bone growth rates for White infants.

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CHAPTER I

INTRODUCTION

Tooth emergence and dental calcification have long been accepted by physical anthropologists as reasonable and relatively reliable, aging tools. Recently, however, researchers have begun to realize that individual variation within populations, inter-population variation, as well as secular trends, may limit the applicability of aging standards developed from all-White, relatively homogenous, samples. Within the last few decades, the appropriateness of applying White dental standards to American Indian samples has been seriously challenged. Indeed, Moorrees et al. (1963a), developers of one of the most widely used dental aging techniques, warn that their dental calcification standards for White children should be cautiously applied to non-White samples.

Unfortunately, dental development is the best criterion skeletal biologists have for aging subadult skeletal material (Ubelaker 1978). This fact, along with lack of dental standards for American Indians, has led to the continued use of White dental standards, despite the awareness that these standard are probably not aging Indian subadults accurately. Researchers have attempted to deal with the discrepancy between White and Native American dental development with varying levels of success.

Y'edynak (1976), in her study of Western Eskimo and Aleut skeletons, explains that she used White dental standards only because no standards existed for Eskimo and Aleut populations. She proposes that the probable earlier dental development of the Aleuts and Eskimos, as reflected by an over-estimation of dental age, could be compensated by an under-estimation of skeletal age.

Johnston (1969) goes a step further by developing his own standards of calcification for the mandibular third molar for use specifically with the Indian Knoll sample. Johnston then attempts to assign chronological ages "based upon studies of the living and corrected for the earlier dental formation exhibited by American Indians." Sundick (1978) warns against applying chronological ages to skeletal samples. He developed his system of 18 dental stages as an effort to compare skeletons from Indian Knoll and Altenerding without relying on chronological ages:

> The skeletons from the two sites were then placed in these dental age categories and thus individuals within each category are biologically similar to one another in terms of their dental development. In terms of a chronological age, however, the skeletons in each age class may not necessarily be similar to each other if one or the other of the populations showed more rapid calcification or eruption than the other.

Sundick echoes Merchant and Ubelaker's (1977) earlier warning that White standards should not be used when aging non-White populations. In addition to their concern that White standards would over-estimate the age of Indian samples, Merchant and Ubelaker (1977) also discuss discrepancies they discovered when using different types of accepted aging techniques to age the same teeth. Ubelaker (1978) has also prepared a chart of dental development for Indians. However, due to the lack of data on living Native Americans, he selectively combined non-White and White data from studies in which tooth development and eruption occurred at relatively early ages.

Although the need for establishing non-White standards of dental aging for American Indian populations has been expounded in the literature, few studies have actually explored the variation in dental development between Whites and Native Americans. Previous research has dealt generally with differences in timing of gingival emergence rather than with differences in timing of dental calcification. An increasingly accepted view, however, is that tooth calcification, rather than gingival eruption, is the best index of dental maturation (Demirjian 1986). Trodden (1982), in one of the few studies of population variation in tooth calcification rates, explains that local environmental factors, such as availability of dental services and changes in diet, have a strong effect on permanent tooth emergence. She claims that rates of calcification are not affected nearly as much by exogenous forces as are rates of eruption. She used radiographs of permanent teeth from American Indian and Inuit children from various reserves in Northwest Canada to develop her own dental calcification index for the American Indian and Inuit populations. In a comparison of her sample to a White sample from Manitoba, she finds that Whites had later mean ages of calcification than both the Indian and Inuit samples.

Owsley and Jantz (1983b) have also examined permanent tooth calcification in American Indians. Using a skeletal sample of Arikara Indians from South Dakota, they discovered that ages assigned to different teeth from the same individual varied, and conclude that timing in dental development between Whites and the Arikara varies from tooth to tooth.

This thesis, following a procedure outlined by Owsley and Jantz (1983a), uses weighted least squares regression analysis to demonstrate the overall timing differences between White and Arikara dental development, and to adjust the widely-used Moorrees et al. (1963b) dental stages to Arikara calcification rates. In addition, an analysis of the curves generated by the regressions results in a description of differences in patterns of long bone growth between White and Arikara children.

CHAPTER II

MATERIALS AND METHODS

Archaeological Sample

Description and History

Samples from eight Arikara Indian archaeological sites, located in central and northern South Dakota, were analyzed. The sites, ranging in age from about AD 1600 to 1832, are listed in Table 1. According to Jantz and Owsley (1985) "these cemeteries were systematically excavated as part of the Missouri Basin salvage program by crews experienced in burial recovery."

Although in this study, material from the different sites was analyzed collectively, the sites may be grouped temporally into three variants: the Extended Coalescent, the Postcontact Coalescent, and the Disorganized Coalescent. Ecological and social stresses that affected overall Arikara health, and probably influenced growth patterns, changed through time across the variants. Excellent discussions of the archaeological evidence and ethnographic documentation of these changing environmental conditions, especially as the changes relate to Arikara health, are found in Jantz and Owsley (1984a) and Owsley and Jantz (1985). A short synopsis of Arikara history, drawn from these works by Jantz and Owsley, follows.

Arikara subsistence focused primarily on a combination of horticulture and bison hunting. During the Extended Coalescent (AD 1550 to 1675), unfavorable ecological conditions, resulting in

Table 1. Coalescent tradition sites by archaeological variant[a].

Archaeological Variant	Site	Date
Disorganized	Leavenworth (39CO9)	1802-1832
	Leavitt (39ST215)	1784-1792
Postcontact	Four Bear (39DW2)	1758-1774
	Larson (39WW2)	1679-1733
	Swan Creek (39WW7)	1675-1725
	Sully E (39SL4)	1679-1733
	Mobridge 2 (39WW1)	1675-1700
Extended	Sully A, D (39SL4)	1650-1694
	Mobridge 1, 3 (39WW1)	1600-1650
	Rygh (39CA4)	1600-1650

[a]from Jantz and Owsley (1985b)

shorter growing seasons and decreased availability of bison, probably led to seasonal food shortages. During the Postcontact Coalescent (AD 1675 to 1780), improvement of climatic conditions, along with the introduction of guns and horses, probably resulted in a relatively stable and satisfactory subsistence base. During the Disorganized Coalescent (AD 1780 to 1862), conditions deteriorated quickly: epidemic diseases, inter-tribal warfare, and internal socio-cultural conflicts resulted in severe and extended food shortages.

Jantz and Owsley (1984a) propose that the varying availability of food during the Extended Coalescent might be reflected by variation in growth rates. On the other hand, in the Disorganized Coalescent, the extreme depletion of resources, along with the introduction of epidemic diseases, resulted in overall growth impairment. In contrast, the Post-Contact Coalescent, characterized by good nutrition and health conditions, probably provides no evidence of growth impairment.

The largest proportion of the Arikara sample used in this analysis dates from the Postcontact Coalescent. However, the Extended and Disorganized Coalescents are adequately represented. Thus, the sample used in this analysis reflects a temporally wide range of changing health conditions.

Data Collection

All measuring of long bones and coding of dental stages were performed prior to this analysis and the data were given to this researcher as an ASCII file. Long bone diaphyses were measured with sliding calipers (Owsley and Jantz 1985). In this analysis, bones from the right side were used only if bones from the left side were missing. Dental aging was done by assigning dental calcification stages, as developed by Moorrees et al. (1963b) and seen in Table 2, to the deciduous mandibular canine (DC), first molar (DM1), and second molar (DM2). Owsley and Jantz (1983b) provide a detailed description of the coding process:

> Periapical dental x-rays (generally Kodak size DF42) were taken for subadults to allow dental maturity scores to be obtained. Ratings for loose teeth recovered from damaged mandibles were scored by visual inspection....The reliability of distinguishing between two stages of crown or root development was enhanced by double determination for many specimens on separate occasions. All scores were obtained by Owsley. Differences that occurred never exceed one stage. Scores were transformed into dental ages for analysis. Tooth specific means ages (sexes pooled) relating to each stage of formation were assigned.

The Moorrees, Fanning, and Hunt (MFH) system of dental aging used by Owsley has been described as one of the best methods available for dental aging due to its basis on large, longitudinal samples, statistical procedures, and controlled assignment to objectively defined stages. (Merchant and Ubelaker 1977; Stewart 1979). The MFH standards were developed from a series of dental x-rays from 136 boys and 110 girls who participated in a growth study of White, middle-class children at Fels Research Institute in Ohio (Moorrees et al. 1963b).

The lack of methods for accurate sexing of subadult skeletal material results in a necessary pooling of males and females for both the long bone and the dental data. However, sexual differentiation is thought to have relatively small effects on both long bone growth

Table 2. Dental calcification stages[a].

Description	Stage Number
Coalescence of cusps	1
Cusp outline complete	2
Crown 1/2 complete	3
Crown 3/4 complete	4
Crown complete	5
Initial root formation	6
Initial cleft formation	7
Root length 1/4	8
Root length 1/2	9
Root length 3/4	10
Root length complete	11
Apex 1/2 closed	12

[a]from Moorrees et al. (1963b)

(Tanner 1978; Mensforth 1985) and deciduous dental calcification (Demirjian 1986; Merchant and Ubelaker 1977) during infancy and early childhood.

Modern Samples

Denver

The sample from Denver is drawn from a series of long bone measurements from a group of middle and upper middle-class White children who participated in the longitudinal Child Research Council Study in Denver, Colorado from 1935 through 1967. The data have been published by McCammon (1970). A total of 5980 measurements were taken from x-rays of long bones from 123 males and 121 females. (Maresh 1970). Before 1957, all measurements were made by Maresh. After 1957, Hansman assisted in taking the measurements. Maresh (1970) describes the measurement procedure: "from two months to ten years, the length was measured parallel to the axis of the bone from the most proximal edge to the most distal edge of the diaphysis." She adds that no correction was made for the 2-3% magnification of the x-rays and warns that the measurements are not equivalent to anatomical long bone lengths. Because the procedure for correcting radiographic distortion is not straightforward (see Gindhart 1973), no attempt to reduce the lengths was made by this researcher.

Fels

This sample of tibia and radius measurements from White middle-class children from Ohio "includes nearly all individuals enrolled in the longitudinal program of the Fels Research Institute for the Study of Human Development by mid-1967." (Gindhart 1973). The sample size varies at different ages, ranging from 84 to 200 measurements. Gindhart (1973) describes the measurement techniques:

> Using radiographs of the left limbs only, measurements of the maximum calcified length of the diaphysis were made to the nearest 0.1 mm. for each long bone along its longitudinal axis. The majority of the tibia measurements were made on a Gerber Analog Data Reduction System (RADRS) with simultaneous card-punching and typewriter output. All of the radii and the remainder of the tibiae were measured by hand with a millimeter ruler to the nearest 0.1 mm.

Unlike Maresh, Gindhart did make a 2-3% correction for radiographic enlargement. However, mean lengths for the tibiae and radii from Fels were still 6-8% larger than the mean lengths from Denver. The statistical significance of the differences between the two samples was not tested due to a decision by both Maresh and Gindhart that the uncorrected radiographic distortion in the Denver sample made statistical tests "inapplicable" (Gindhart 1973).

Gindhart suggests that the differences may result from the fact the Fels sample size is larger than the Denver sample size. Another suggestion is that the suppressed lengths in the Denver sample might reflect the effect of high altitude stress on long bone growth.

Statistical Analysis

Description of Sample

The successful application of parametric statistics depends in part on how well the statistical sample represents the study population. Using skeletal material in statistical analyses presents a number of problems that have been outlined by Johnston (1968) and include the relatively small numbers in skeletal samples, the tendency of the samples to be chronologically diverse, and the skewed distribution of subadult samples towards birth. One of Johnston's major criticisms of the use of skeletal material in growth studies is that "a skeletal sample, and especially one still growing, is not normal in the clinical sense of the word." Sundick (1978), after an examination of the effects of disease on growth patterns in modern children, counters that many of the children in skeletal samples may have died quickly, before growth could be retarded:

> It may be possible to assume that the subadult skeletons which are present in our archaeological collections are not very different from those who survived in terms of their size. They may just have succumbed to a relative stressful situation that lasted for a short time.

Although the infants from the Disorganized Coalescent are undersized due to long term prenatal and postnatal nutritional stress (Jantz and Owsley 1985), Sundick's suggestion might apply to the subadults from the Extended and Postcontact Coalescents. If Sundick's assertion is correct, then the Arikara sample has an overall range of relatively normal sized children to slightly undersized children, which probably represents the distribution of growth for the larger Arikara population fairly well.

Jantz and Owsley (1984a) have examined the variation in long bone growth rates among the variants using least squares regression analysis. The test for slope heterogeneity among the variants revealed significantly different slopes for all bones except the femur. In contrast, an examination of the plots suggests that for the first few years of life, patterns of growth, as well as lengths of the bones, are similar. As expected, Postcontact has slightly longer lengths than Extended. However, Disorganized deviates from the expected pattern by having longer lengths in early childhood than both Postcontact and Extended for all bones except the tibia. Still, these slight differences observed in early childhood for bone lengths and growth rates among the variants do not necessarily warrant a temporal division of the sample used in this study.

The Arikara sample used in this analysis is relatively large. Table 3 shows the distribution of numbers of bones in each age stage for each of the three deciduous teeth. The smallest total number used in any one regression analysis is 225 for the radius as grouped by DC ages. The smallest number for a single stage is seven for radius lengths for DM1 age 0.6 years. However, most of the samples are larger than ten.

Descriptive Statistics

The SAS (1985) PROC FREQ subroutine was used to produce frequency distributions for long bone lengths. SAS PROC MEANS was used to produce the means, ranges, variances, and coefficients of variation for long bone lengths for each dental stage for all three teeth.

Weighted Least Squares Regression

> Regression analysis, in essence, provides a procedure for determining the regression line, which is the best straight line (or linear) approximation of the relationship between C [dependent variable] and I [independent variable]. This procedure is equivalent to finding particular values for the slope and intercept. (Schroeder et al. 1986)

Least squares regression attempts to find the best fitting regression line, as described by Schroeder et al. (1986), by

Table 3. Number of bones grouped by dental age stages.

	Age	Femur	Tibia	Humerus	Radius
DC	0.000	0	0	0	0
	0.150	24	20	23	24
	0.250	53	51	55	47
	0.450	22	18	18	18
	0.675	14	13	14	10
	0.850	23	19	27	18
	1.000	21	24	24	19
	1.275	39	29	36	32
	1.875	20	17	22	19
	2.000	15	14	17	11
	2.500	25	27	29	27
	Total	256	232	265	225
DM1	0.000	15	15	13	17
	0.175	78	75	82	74
	0.250	64	54	59	48
	0.400	30	31	27	27
	0.550	15	12	14	11
	0.650	13	9	13	7
	0.700	37	28	35	23
	0.925	30	24	31	23
	1.150	24	22	28	22
	1.250	25	20	18	19
	1.550	20	18	24	20
	Total	351	308	344	291
DM2	0.000	0	0	0	0
	0.075	77	71	81	73
	0.250	42	33	38	30
	0.450	22	18	20	17
	0.700	21	22	28	14
	0.900	25	21	24	16
	0.950	36	26	32	27
	1.300	22	20	24	19
	1.525	31	26	28	26
	1.850	15	12	15	14
	1.975	17	14	19	14
	2.400	10	10	11	7
	Total	318	273	320	257

calculating the sum of the squared differences between observed values of y and the values of y that are predicted by the function equation generated by the observed values for x and y. In this research, least squares regression was used in an attempt to find the line (or curve) which would best demonstrate the relationship between age (x) and long bone length (y).

Regression analysis of the Arikara data can be done on individual lengths for each age stage. However, the Denver and Fels studies provide only the mean lengths and numbers for each age--not the original individual values. Thus, comparison between the samples required that the regressions be run using mean lengths. Regression analysis is used to demonstrate not only the variation between values of y (the dependent variable) at different levels of x (the independent variable), but also the variation among the different values of y at the same stage of x. When only one value of y (in this case, mean length) is provided for each level of x, the variation among y's for a given x can not be considered.

The use of the weighted least squares approach, in which each observation is emphasized differently due to the introduction of some weight factor, compensates for collapsing all the individual lengths into a single mean value. In this analysis, the number of lengths used to compute mean length was used as the weight factor. Three weighted least squares regressions were run on the Arikara femur, tibia, humerus, and radius lengths, with DC, DM1, and DM2 ages substituted, in turn, for x. Weighted least squares regressions were also run for the Denver femur, tibia, humerus, and radius lengths, and the Fels tibia and radius lengths, with chronological age serving as x. Male and female measurements were pooled in these samples. All regressions were performed using SAS PROC GLM procedure, with WEIGHT = the number of measurements per mean. PROC GLM was also used to predict regression lines for the Arikara long bone lengths using the individual lengths.

Quadratic Model

The regression model $y = b_0 + b_1(\text{age}) + b_2(\log)(\text{age})$ has been accepted as an accurate model for generating the curve of human growth from a few months after birth until about ten years (Harrison et al. 1964). Jantz and Owsley (1984a) state that this model has also been used to model linear growth in both longitudinal and cross-sectional samples. They explain further: "the coefficient b_2 can be interpreted as the rapid growth of early childhood, while b_1 reflects the linear component of childhood growth." Mensforth (1985), in a study of tibia growth, computed a series of polynomials and discovered that the quadratic equation $y = b_0 + b_1x + b_2x^2$ best fit his data. He claims:

> The [resulting] growth curves are quite compatible with patterns obtained using the human growth equation $y = b_0 + b_1(x) + b_2(\log)(x)$.... but have additional advantages such that the resultant growth curves provide a more accurate measure of the tibia long bone growth for the first year of life.

The quadratic model was used in this analysis because this regression function was the one chosen by Owsley and Jantz (1983a) in their earlier work with adjusting Arikara dental ages. However, Mensforth's research does support the use of the quadratic model when assessing the relationship between age and long bone growth.

Quadratic Formula

Further manipulation of the regression lines included both the adjustment of the DM2 line to a higher intercept and the adjustment of the DC and DM1 lines to the DM2 line. These adjustments were accomplished by solving the quadratic equation $ax^2 + bx + c = 0$ with the use of the quadratic formula:

$$x = \frac{b \pm \sqrt{b^2 - 4ac}}{2a}$$

The adjustment of the DM2 line to the desired intercept used the regression equation generated by the analysis of DM2 and femur length. The quadratic formula was used to solve for the x (age) in this equation when y = 77 (expected femur length at birth). This x-value was then subtracted from the MFH ages assigned to the dental stages. A revised regression was run on the femur using the adjusted ages. The resulting regression equation was used to adjust DM1 and DC ages by placing the mean femur lengths for each stage of DC and DM1 into the y-value and solving for the new values of x.

Paired-t Tests

Using SAS PROC MEANS, paired comparisons tested the mean differences between the three ages assigned by the three teeth to a single individual.

CHAPTER III

RESULTS AND DISCUSSION

Frequency Distributions

Results

Figures 1 through 4 are frequency histograms for perinatal Arikara long bones. The distinct mode of 77 mm. for femur length, as seen in Figure 1, has a frequency of 60. The next most frequently occurring lengths are 78 and 80 mm., each with frequencies of 40. In Figure 2, tibia lengths of 69 mm. and 68 mm. have the highest frequencies: 46 and 44, respectively. The next most frequent length, 70 mm., drops to a frequency of 30. In Figure 3, a distinct mode in humerus lengths is less discernable. Sixty-eight mm. has the highest frequency of 44. However, 65 mm. and 67 mm. occur 41 times each and 69 mm. occurs 39 times. As seen in Figure 4, the radius lengths' more distinct mode of 55 mm. occurs 51 times. A length of 57 mm., which occurs 46 times, is the next most frequent radius length. Acceptance of the proposal that the highest number of perinatal deaths actually occurs at birth leads to the conclusion that the observed modal lengths should approximate mean lengths at birth.

Comparative Samples

Acceptance of the Arikara modal lengths as expected birth lengths requires that these lengths fall within a range of reasonably expected values for diaphyseal lengths at birth. In order to

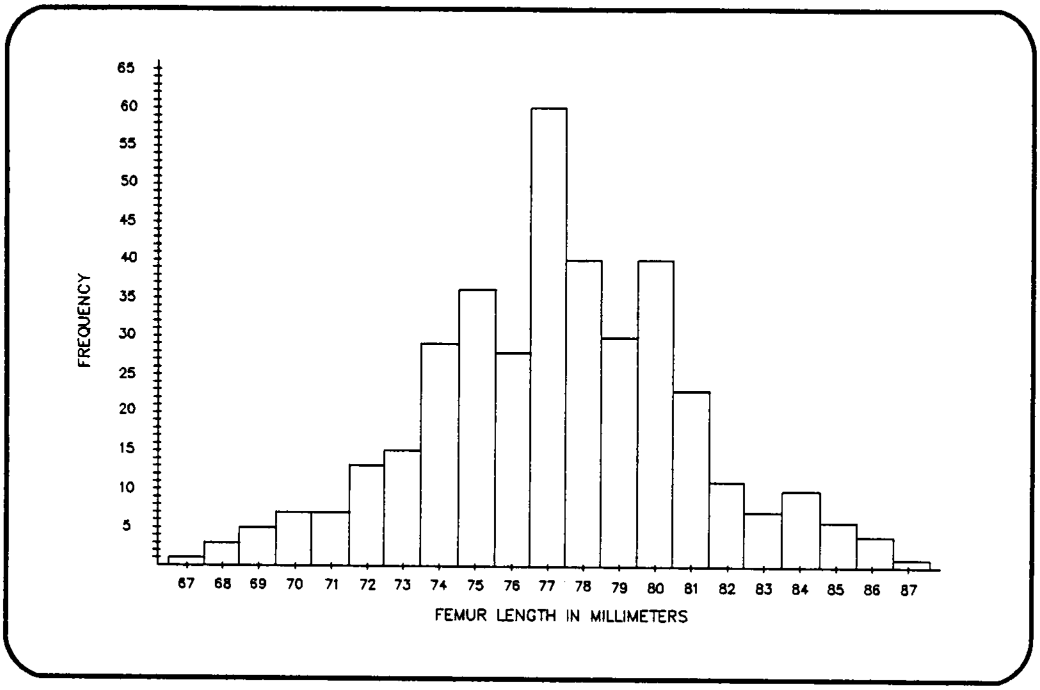

Figure 1. Frequency histogram--perinatal femur lengths.

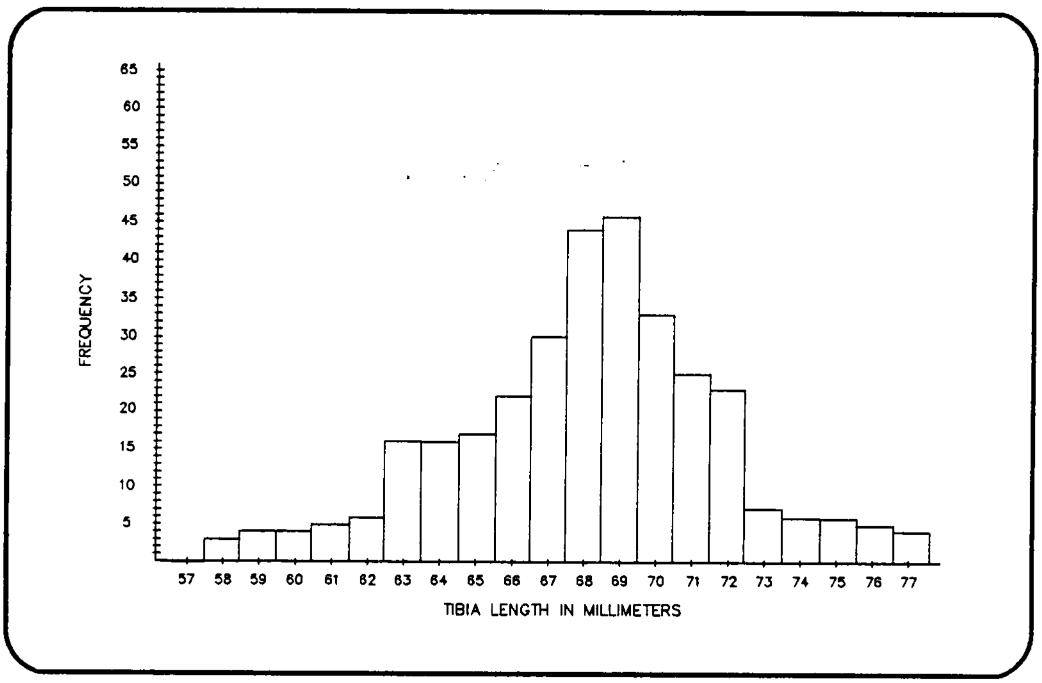

Figure 2. Frequency histogram--perinatal tibia lengths.

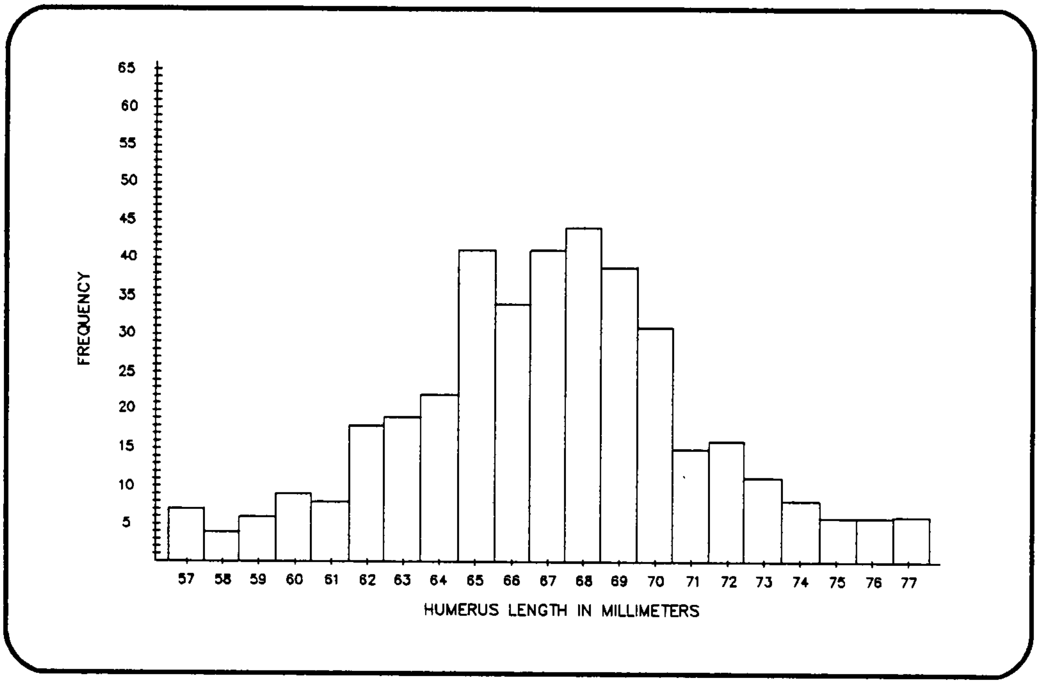

Figure 3. Frequency histogram--perinatal humerus lengths.

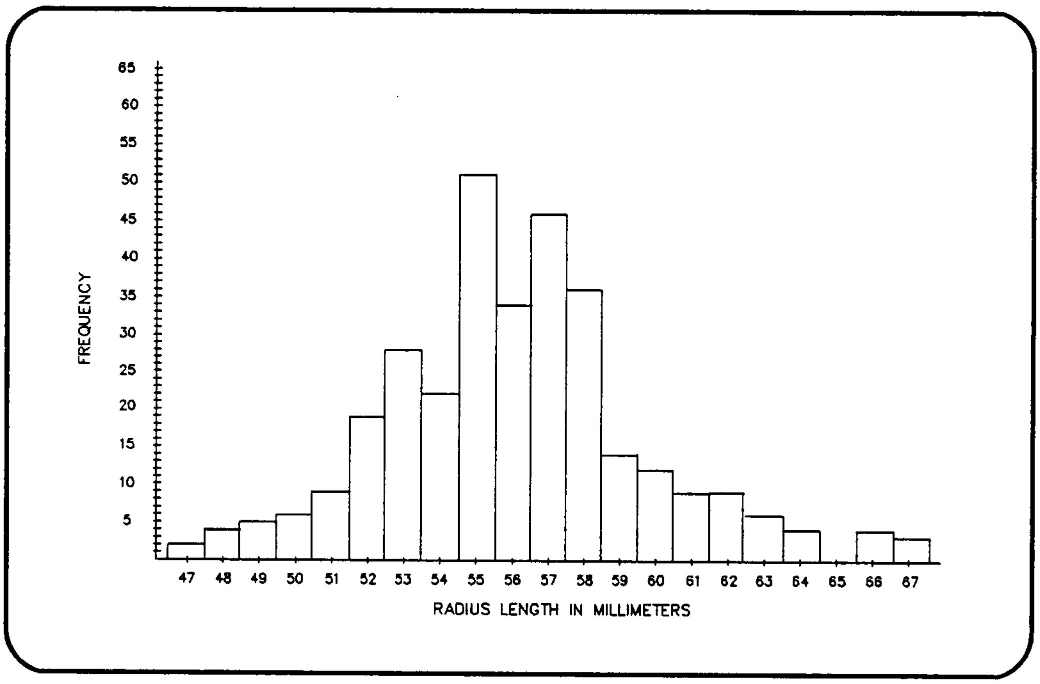

Figure 4. Frequency histogram--perinatal radius lengths.

establish this range at birth, comparative samples of long bone lengths at birth must be found. Such samples may be drawn from several sources: measurements of other fetal and infant diaphyses from archaeological and non-archaeological samples, measurements of fetal and infant long bones taken from roentgenograms, and measurements of fetal long bones during ultrasound examinations. An extensive search uncovered only a few references from each type of source.

Table 4 summarizes the available archaeological data. Mensforth (1985) gives mean lengths for the tibia only. Stewart (1979) lists an average length for the femur, but only includes ranges for the other bones. His ranges are established by frequency distributions produced from Arikara material from the Mobridge site. Sundick (1978) and Johnston (1962) provide mean lengths for a range of dental ages of birth to 0.5 years. Johnston explains that the mean age for the range is 0.25 years and suggests that the large number of skeletons in this range, consistent with the high mortality rate at birth, results in a lowering of this age to an age closer to birth. Compensation for the expected over-aging of White dental standards might also lower the mean age. Indeed, the fact that the archaeological studies must depend on dental ages to age associated long bone lengths is a major problem with using archaeological samples to define expected birth length ranges. Still, the means given by both Sundick and Johnston are close to the modal lengths of this Arikara sample.

Table 4. Comparative archaeological samples--mean diaphyseal length in mm.

Source	Femur	Tibia	Humerus	Radius	Age
Mensforth (1985)[a]	-	64	-	-	0 years (Dental)
Stewart (1979)[b]	77.5	74-63	71-63.5	60-50.5	-
Sundick (1978)[c]	80.0	70.1	67.4	54.8	Mean Age NB-.5yrs (Dental)
Johnston (1962)[d]	78.84	69.28	67.66	55.05	Mean Age NB-.5yrs (Dental)

[a]Woodland Indians, Bt-5 and Libben, Ohio

[b]Protohistoric Arikara, Mobridge, South Dakota

[c]Archaic Indians, Indian Knoll, Kentucky

[d]Archaic Indians, Indian Knoll, Kentucky

Table 5 is taken from tables presented in Fazekas and Kosa (1978). The major problem with these studies is the limited sample sizes. With the exception of Lambertz (1900), most of the lengths are lower than the Arikara modal lengths.

Unfortunately, the major growth studies in the United States, which use radiographic measurements of subadult long bones, all begin their measurements at least one month after birth (Maresh 1970; Gindhart 1973; Francis 1939). Table 6 presents mean radiographic measurements taken from other studies of fetuses in-utero. In all cases, the mean lengths are slightly higher than the Arikara lengths. These differences in lengths might be linked to population differences in growth but could also be due to radiographic magnification and distortion.

Table 7 lists data available from ultrasound studies. Haines et al. (1986) recorded comparatively shorter lengths for their Australian sample throughout gestation, leading them to call for "the necessity for collating data on the local population." O'Brien and Queenan's (1981) racially mixed sample is 30% Hispanic which may explain the difference between their lengths and the means from the all-White, middle-class sample examined by Hadlock et al. (1982).

The ultrasound studies emphasize the femur because of the increased difficulty in measuring the other long bones (Haines et al. 1986) and a focus of ultrasonic research on developing regression equations that use the femur to predict gestational age. Table 8 provides the regression equations from two such studies. The

Table 5. Comparative non-archaeological samples--mean diaphyseal length in mm.

Source[a]	No.	Femur	Tibia	Humerus	Radius	Age
Fazekas and Kosa (1978)	10	74.3	65.1	64.9	51.8	10 lunar months
Algot Key Aberg (1917)	7	73	64	65	52	Mature fetuses
Lambertz (1900)	18	80	70	67	53	Body Length 49-52 cm.
Toldt (1882)	1 1	73 75	63 67	65 66	55 54	Newborn Fetus

[a]All information in this table is taken from Fazekas and Kosa (1978) where original references may be found.

Table 6. Comparative samples--mean radiographic measurements of diaphyseal length in mm.

Source	Femur	Tibia	Humerus	Radius	Age
Russell et al. (1972)	84.5	74.3	70.5	56.1	40 weeks GA[a]
Owen (1971)	84	74	74	60	40 weeks GA
Brandfass and Howland (1967)	86	70	75	56	Birth weight at least 2500 gm.

[a]Gestational age

Table 7. Comparative samples--mean ultrasonic measurements of diaphyseal length in mm.

Source	No.	Femur	Age
Haines et al. (1986)	17	70.8	40 weeks [a]GA
Hadlock et al. (1982)	338	78	40 weeks GA
O'Brien and Queenan (1981)	28	75.4	40 weeks GA

[a]Gestational age

Table 8. Comparative samples--measurements calculated from regression equations.

Source		Regression Equations	Length[a]
Jeanty et al. (1982)	Femur:	$4.1626(w^b) - .03464(w^2) - 36.0405^c$	75.05
	Tibia:	$3.8822(w) - .03519(w^2) - 34.2262$	64.75
	Humerus:	$4.1234(w) - .04246(w^2) - 33.8953$	63.10
	Radius:	$3.8001(w) - .04357(w^2) - 32.0188$	50.30
Scheuer et al. (1980)	Femur:	$(w - 13.4483)/.3303^d$	80.00
	Tibia:	$(w - 11.4724)/.4207$	67.81
	Humerus:	$(w - 8.6563)/.4585$	68.36
	Radius:	$(w - 7.7100)/.5850$	55.20

[a]Length in mm. as calculated by the equation

[b]w = 40 gestation weeks

[c]Values were rounded to five significant digits

[d]Algebraic transformation of the original regression equations

predicted lengths were calculated by solving the equations using a gestational age of 40 weeks (the average gestational age at birth).

The fact that the Scheuer et al. (1980) predicted lengths are larger than those of Jeanty et al. (1982) may be linked to differences in the kinds of measurements used to generate the equations. Scheuer et al. used radiographic measurements that, as seen Table 6, seem to yield slightly higher values than the sonographic measurements used by Jeanty et al. On the other hand, Cronk et al. (1986) mention that prenatal ultrasound measurements are, on the average, about 1 to 2 mm. longer than postnatal radiographic measurements.

Hadlock et al. (1982) warn that after about 23 gestational weeks, femur length variability increases greatly and that equations based on measurements taken after 23 weeks are less homogeneous than those taken before 23 weeks. In their two equations, based on sets of measurements taken at 12 to 23 weeks and 23 to 40 weeks, variability in predicting gestational ages increased from ± 9.5 days to ± 22 days. A major problem with both the ultrasonic and in-utero roentgenologic studies is their reliance on the use of gestational age. Some studies use crown-rump lengths to estimate gestational age, while other studies depend on reports of elapsed time since last menstrual periods. In either case, gestational age is a fairly tenuous estimation. In addition to potential errors in gestational age estimation, in-utero measurements taken on a child who actually has an age of 40 gestational weeks are not equivalent to measurements taken on a child at birth.

Lack of comparable methods of measuring both age and long bone lengths makes the search for standards of long bone birth lengths frustrating. However, the Arikara modal lengths do seem to fall within the wide range of values presented in Tables 4 through 8. The close correlation between the lengths from the Indian Knoll sample and the Arikara modal lengths provides the strongest support for using the Arikara modal lengths to represent average lengths at birth.

Means

Tables 9, 10, 11, and 12 present the means, numbers, ranges, variances, and coefficients of variation for the four long bones for all the dental stages of each tooth. The highest frequencies for all four long bones occur at 0.25 years for DC, 0.175 years for DM1 and 0.075 years for DM2, suggesting that these ages probably represent birth. The most striking observation is that the DM1 mean lengths for both the femur and tibia at 0.175 years are smaller than the mean lengths at 0.0 years. The lower end of the ranges for 0.175 years are consistently lower than the lower ends of the ranges for 0.0 years. Neither the cause nor the meaning of this discrepancy is clear. However, one explanation might be that a consistent coding error was made in the aging of these teeth.

An overall examination of length ranges reveals the existence of wide ranges that overlap from one dental age to the next. Variance seems to increase as mean size increases: the largest mean, a femur length of 203 mm. from DC-age 2.5 years, has the largest variance of 543. The coefficient of variation (C.V.) can be used to measure

Table 9. Mean femur diaphyseal lengths in mm. and other descriptive statistics.

	Age	Mean Length	Range	No.	Variance	C.V.[a]
DC	0.000	-	-	-	-	-
	0.150	76.33	69-81	24	11.45	4.43
	0.250	78.85	68-95	53	21.98	5.95
	0.450	85.64	73-98	22	49.29	8.20
	0.675	99.50	84-118	14	65.50	8.13
	0.850	110.91	93-130	23	82.54	8.19
	1.000	135.05	108-148	21	78.15	6.55
	1.275	147.90	109-176	39	198.57	9.53
	1.875	166.80	147-186	20	128.91	6.80
	2.000	175.07	159-198	15	130.64	6.53
	2.500	203.44	166-244	25	543.26	11.46
DM1	0.000	77.13	69-85	15	14.84	4.99
	0.175	76.64	65-84	78	12.29	4.57
	0.250	79.42	68-95	64	24.50	6.23
	0.400	88.03	73-106	30	52.79	8.25
	0.550	101.27	92-114	15	34.35	5.79
	0.600	109.77	96-118	13	55.03	6.76
	0.700	120.95	105-145	37	80.44	7.41
	0.925	131.53	104-160	30	98.46	7.54
	1.150	137.29	108-160	24	169.61	9.49
	1.250	147.32	119-176	25	199.39	9.59
	1.550	164.70	143-191	20	145.70	7.33
DM2	0.000	-	-	-	-	-
	0.075	77.14	68-84	77	9.19	4.08
	0.250	84.00	73-99	42	47.56	8.21
	0.450	93.64	80-115	22	51.58	7.67
	0.700	111.14	96-127	21	57.93	6.85
	0.900	120.36	105-132	25	85.16	7.67
	0.950	126.83	104-145	36	78.83	7.00
	1.300	137.91	108-161	22	148.94	8.85
	1.525	149.41	128-173	31	109.18	6.99
	1.850	163.67	119-186	15	282.81	10.28
	1.975	168.35	142-191	17	181.87	8.01
	2.400	180.30	159-200	10	156.90	6.94

[a]Coefficient of Variation

Table 10. Mean tibia diaphyseal lengths in mm. and other descriptive statistics.

	Age	Mean Length	Range	No.	Variance	C.V.[a]
DC	0.000	-	-	-	-	-
	0.150	67.50	61-72	20	8.89	4.42
	0.250	69.51	62-80	51	11.73	4.93
	0.450	75.72	64-84	18	35.03	7.82
	0.675	85.31	70-101	13	91.90	11.24
	0.850	94.11	80-108	19	48.77	7.42
	1.000	112.25	99-126	24	47.85	6.16
	1.275	122.21	107-145	29	113.67	8.72
	1.875	139.76	123-158	17	83.44	6.54
	2.000	143.57	130-162	14	121.65	7.68
	2.500	168.78	136-203	27	406.41	11.95
DM1	0.000	67.80	61-74	15	11.46	4.99
	0.175	67.37	59-73	75	9.59	4.60
	0.250	69.81	59-81	54	17.02	5.91
	0.400	78.68	67-100	31	60.49	9.87
	0.550	86.33	80-93	12	19.15	5.07
	0.600	93.22	80-103	9	51.44	7.69
	0.700	102.25	87-123	28	78.63	8.67
	0.925	110.38	101-128	24	43.46	5.97
	1.150	113.91	99-130	22	68.47	7.26
	1.250	121.15	103-144	20	126.56	9.29
	1.550	136.50	112-161	18	128.26	8.30
DM2	0.000	-	-	-	-	-
	0.075	67.76	59-75	71	9.44	4.54
	0.250	73.39	64-86	33	27.62	7.16
	0.450	80.67	70-100	18	46.24	8.43
	0.700	92.82	81-104	22	37.39	6.59
	0.900	102.10	87-117	21	66.99	8.01
	0.950	108.50	96-123	26	40.02	5.83
	1.300	113.85	99-132	20	86.34	8.16
	1.525	121.92	103-143	26	92.55	7.89
	1.850	139.25	123-158	12	116.57	7.75
	1.975	139.64	129-161	14	88.09	6.72
	2.400	150.10	135-164	10	97.88	6.59

[a]Coefficient of Variation

Table 11. Mean humerus diaphyseal lengths in mm. and other descriptive statistics.

	Age	Mean Length	Range	No.	Variance	C.V.[a]
DC	0.000	-	-	-	-	-
	0.150	66.22	62-70	23	6.63	3.89
	0.250	68.55	62-81	55	11.47	4.94
	0.450	73.50	64-86	18	32.62	7.77
	0.675	85.36	71-97	14	37.32	7.16
	0.850	90.67	77-110	27	55.08	8.16
	1.000	108.96	93-137	24	74.39	7.92
	1.275	116.47	101-134	36	68.66	7.11
	1.875	129.50	115-146	22	67.12	6.33
	2.000	135.94	119-151	17	89.81	6.97
	2.500	153.55	127-179	29	230.26	9.88
DM1	0.000	66.39	62-72	13	6.92	3.96
	0.175	66.94	60-77	82	8.70	4.41
	0.250	68.88	62-79	59	13.42	5.32
	0.400	77.44	64-94	27	50.95	9.22
	0.550	84.43	80-91	14	8.88	3.53
	0.600	89.23	82-96	13	21.56	5.20
	0.700	97.11	84-111	35	38.57	6.40
	0.925	106.45	95-120	31	33.52	5.44
	1.150	111.61	93-137	28	93.06	8.64
	1.250	114.22	101-134	18	73.95	7.53
	1.550	130.08	114-169	24	144.17	9.23
DM2	0.000	-	-	-	-	-
	0.075	66.94	60-77	81	8.66	4.40
	0.250	71.68	63-85	38	20.06	6.25
	0.450	80.80	71-94	20	40.59	7.89
	0.700	89.46	82-100	28	24.85	5.57
	0.900	97.25	84-109	24	51.93	7.41
	0.950	104.56	93-137	32	62.77	7.58
	1.300	108.67	93-121	24	55.36	6.85
	1.525	116.36	101-130	28	54.68	6.35
	1.850	128.40	115-140	15	73.54	6.68
	1.975	134.16	119-169	19	155.58	9.30
	2.400	137.91	124-151	11	81.09	6.53

[a]Coefficient of Variation

Table 12. Mean radius diaphyseal lengths in mm. and other descriptive statistics.

	Age	Mean Length	Range	No.	Variance	C.V.[a]
DC	0.000	-	-	-	-	-
	0.150	54.50	50-58	24	5.13	4.16
	0.250	56.57	51-64	47	6.34	4.45
	0.450	59.50	51-68	18	17.79	7.09
	0.675	64.70	56-71	10	25.79	7.85
	0.850	71.83	63-81	18	19.79	6.19
	1.000	84.09	74-94	19	21.21	5.43
	1.275	90.66	79-106	32	55.20	8.20
	1.875	98.42	85-105	19	32.15	5.76
	2.000	100.45	93-113	11	28.87	5.35
	2.500	116.93	98-138	27	145.53	10.32
DM1	0.000	54.94	50-58	17	4.56	3.89
	0.175	55.16	46-62	74	7.64	5.01
	0.250	56.63	51-73	48	8.32	5.10
	0.400	61.15	52-73	27	26.90	8.48
	0.550	67.73	63-73	11	9.02	4.43
	0.600	73.43	66-80	7	28.62	7.29
	0.700	77.70	66-88	23	29.13	6.95
	0.925	84.61	78-93	23	15.70	4.68
	1.150	86.05	74-101	22	44.62	7.76
	1.250	89.74	79-106	19	62.65	8.82
	1.550	96.50	85-105	20	36.05	6.22
DM2	0.000	-	-	-	-	-
	0.075	54.66	46-60	73	5.81	4.41
	0.250	58.77	52-68	30	13.43	6.25
	0.450	63.71	57-77	17	25.10	7.86
	0.700	71.93	63-80	14	24.38	6.84
	0.900	76.44	66-89	16	54.13	9.63
	0.950	82.48	74-91	27	14.72	4.65
	1.300	85.26	74-94	19	31.31	6.56
	1.525	90.73	80-106	26	45.00	7.39
	1.850	98.00	79-108	14	55.69	7.62
	1.975	99.79	93-108	14	17.87	4.24
	2.400	107.14	102-115	7	25.81	4.74

[a]Coefficient of Variation

sample variability independent of mean size (Thomas 1976). The established accepted range for the C.V. for biological variables is between 4% and 10%. Below 4%, the sample probably does not accurately reflect overall variability, while above 10%, the sample probably contains extrinsic sources of variability. The C.V. values for these samples generally fall within the optimal C.V. range.

Mean lengths for the Denver and Fels data are found in Tables 13 and 14. These tables are provided as a reference for the reader.

Regression Analyses

Results

Table 15 shows the parameter estimates, the results of t-tests on the significance of the estimates, and the correlation coefficients (r^2's) for the regression models produced by using individual bone lengths rather than mean lengths as y-values. These regression analyses are important because they generate equations almost identical to the ones produced by using the weighted least squares regressions, and they demonstrate the validity of using weighted means in the final analysis. Also, analysis of residuals is more meaningful when more than one observation is present for each value of x.

For all three regressions run on each bone, the r^2 values, which quantify the relationship between y and x, are high. In all the models, t-tests on the b_0 values (the intercepts), and the b_1 values (the slopes) are highly significant. In most cases, the b_2 values,

Table 13. Mean diaphyseal lengths in mm. from the Denver sample.[a]

Age	Mean Male Length	No.	Mean Female Length	No.
		Femur		
0.167	86.0	59	87.2	68
0.330	100.7	59	100.8	65
0.500	112.2	67	111.1	78
1.000	136.6	72	134.6	81
1.500	155.4	68	153.9	84
2.000	172.4	68	170.8	84
2.500	187.2	72	185.2	82
		Tibia		
0.167	70.8	59	70.3	69
0.330	81.9	58	80.8	65
0.500	91.0	67	88.9	78
1.000	110.3	72	108.5	81
1.500	126.1	68	124.0	84
2.000	140.1	68	138.2	84
2.500	152.5	72	150.1	82
		Humerus		
0.167	72.4	59	71.8	69
0.330	80.6	59	80.2	65
0.500	88.4	67	86.8	78
1.000	105.5	72	103.6	81
1.500	118.8	68	117.0	84
2.000	130.0	68	127.7	84
2.500	139.0	71	136.9	82
		Radius		
0.167	59.7	59	57.8	69
0.330	66.0	59	63.4	65
0.500	70.8	67	67.6	78
1.000	82.6	72	78.9	81
1.500	91.4	68	87.5	83
2.000	98.6	68	95.0	84
2.500	105.6	71	101.4	82

[a]from Maresh (1970)

Table 14. Mean diaphyseal lengths in mm. from the Fels sample.[a]

Age	Mean Male Length	No.	Mean Female Length	No.
		Tibia		
0.083	72.14	156	71.34	108
0.250	84.83	118	84.95	98
0.500	99.26	176	97.06	132
0.750	110.06	116	109.49	101
1.000	119.57	155	117.08	122
1.500	135.53	110	134.24	90
2.000	150.14	133	149.08	108
2.500	162.74	92	163.04	84
		Radius		
0.083	55.84	138	54.00	123
0.250	62.42	117	59.85	102
0.500	69.72	200	66.93	176
0.750	75.84	115	73.50	105
1.000	82.29	198	79.52	169
1.500	92.52	117	89.44	106
2.000	100.20	183	97.46	162
2.500	107.52	110	104.28	104

[a]from Gindhart (1973)

Table 15. Results of regressions using individual values.

Bone	Coefficient	Estimate	t	PR > |t|	r^2
		x = DC Age			
Femur	b_0	61.13	32.39	-	.92
	b_1	71.47	18.50	-	
	b_2	-6.07	-4.06	.0001	
Tibia	b_0	56.44	33.86	-	.92
	b_1	53.24	15.61	.0001	
	b_2	-3.52	-2.72	.0007	
Humerus	b_0	55.94	41.79	-	.92
	b_1	51.37	19.06	-	
	b_2	-5.90	-4.94	.0001	
Radius	b_0	47.73	44.20	-	.91
	b_1	35.18	15.82	.0001	
	b_2	-3.20	-3.76	.0002	
		x = DM1 Age			
Femur	b_0	64.26	52.28	-	.91
	b_1	75.67	17.38	-	
	b_2	-7.01	-2.46	.0145	
Tibia	b_0	58.56	56.61	-	.90
	b_1	56.86	15.08	.0090	
	b_2	-4.55	-1.84	.0665	
Humerus	b_0	58.04	65.13	-	.91
	b_1	54.23	17.38	-	
	b_2	-5.31	-2.64	.0088	
Radius	b_0	48.75	69.56	-	.89
	b_1	40.70	15.74	-	
	b_2	-6.09	-3.62	.0004	

Table 15. (Continued)

Bone	Coefficient	Estimate	t	PR > |t|	r^2
		x = DC Age			
Femur	b_0	71.31	70.90	-	.93
	b_1	60.73	24.52	-	
	b_2	-6.11	-5.24	.0001	
Tibia	b_0	63.65	74.56	-	.93
	b_1	45.66	21.69	-	
	b_2	-3.81	-3.88	.0001	
Humerus	b_0	63.01	83.01	-	.92
	b_1	42.99	23.10	-	
	b_2	-4.44	-5.11	.0001	
Radius	b_0	51.94	89.61	-	.92
	b_1	31.85	21.21	-	
	b_2	-3.82	-5.29	.0001	

which represent the curvilinear part of the equation, also contribute significantly to the model. That the model fits the data is not surprising because the curvilinear relationship between growth and age has been previously established.

For each of the four long bones, the DM2 regressions provide the highest intercepts and the lowest slopes while the DC regressions provide the lowest intercepts and the highest slopes. Indeed, the difference between the two intercepts averages almost 10 mm.. Caution should be used when discussing y-values whose corresponding x-values are not included in the original observations. In fact, most introductory statistics texts have warnings against predicting values of y for values of x which fall outside the range of observations. Still, Neter et al. (1985) claim that as long as the x-value is not very far outside the range of observed x's, the prediction can be made with "reasonable confidence." In this analysis, because 0.0 years (age at the intercept) falls close to the lower limit of the ranges of ages, intercepts will be used in interpretations about expected lengths at birth even if the original range of ages does not encompass birth.

Analysis of the residuals plotted against the y-values reveals patterns for each tooth that occur consistently in all the regressions. For the DC regressions, the widest spread of residuals occurs at 2.5 years, with a smaller, yet still noticeable, spread occurring at 1.275 years. This increased variability of the y-values is probably because 0.5 years, the length of time between these age stages and the next closest stage, is longer than the lengths of time between other stages.

In all the DM1 regressions, a band of positive residuals appears at 0.0 years, showing that the observed y-values for this x are all larger than the predicted y-values. This observation is not unexpected because the analysis of mean bone lengths revealed that the mean values for DM1 at birth were consistently larger than the mean values for the next higher age stage.

Although along with these described patterns of variation, a few outliers are observed, the residuals generally fall in fairly narrow bands above and below the 0-horizontal axes. No extreme patterns of heteroscedacity are noted.

Table 16 presents the parameter estimates, the results of t-tests on the significance of the estimates, and the r^2's for the regressions run using mean values rather than individual values for y. In all cases, differences between the parameters of these regression models and those produced in the individual models do not occur before two decimal places after zero. This agreement between the estimated parameters demonstrates that weighted means may be used in place of individual values without drastically changing the regression model.

The overall increase in r^2 values results from the reduction of the error term associated with variation among values of y for a given level of x. This difference between the two groups of regressions shows that some information <u>is</u> lost when individual

Table 16. Results of regressions using mean values.

Bone	Coefficient	Estimate	t	PR > |t|	r^2
		x = DC Age			
Femur	b_0	61.13	12.91	.0001	.99
	b_1	71.48	7.38	.0002	
	b_2	-6.07	-1.62	.1498	
Tibia	b_0	56.44	16.48	.0001	.99
	b_1	53.24	7.60	.0001	
	b_2	-3.52	-1.32	.2278	
Humerus	b_0	55.94	16.92	.0001	.99
	b_1	51.37	7.72	.0001	
	b_2	-5.90	-2.00	.0855	
Radius	b_0	47.73	17.29	.0001	.98
	b_1	35.18	6.19	.0005	
	b_2	-3.20	-1.47	.1847	
		x = DM1 Age			
Femur	b_0	64.26	16.27	.0001	.98
	b_1	75.68	5.41	.0006	
	b_2	-7.01	-0.77	.4661	
Tibia	b_0	58.55	19.81	.0001	.98
	b_1	56.87	5.28	.0007	
	b_2	-4.56	-0.65	.5367	
Humerus	b_0	58.04	25.07	.0001	.98
	b_1	54.23	6.69	.0002	
	b_2	-5.31	-1.01	.3399	
Radius	b_0	48.75	23.97	.0001	.97
	b_1	40.71	5.43	.0006	
	b_2	-6.09	-1.25	.2474	

Table 16. (Continued)

Bone	Coefficient	Estimate	t	PR > |t|	r^2
		x = DM2 Age			
Femur	b_0	71.31	52.43	.0001	.99
	b_1	60.73	18.13	.0001	
	b_2	-6.11	-3.88	.0047	
Tibia	b_0	63.65	40.37	.0001	.99
	b_1	45.66	11.75	.0001	
	b_2	-3.81	-2.10	.0690	
Humerus	b_0	63.01	40.61	.0001	.99
	b_1	42.99	11.30	.0001	
	b_2	-4.43	-2.50	.0370	
Radius	b_0	51.95	52.39	.0001	.99
	b_1	31.84	12.40	.0001	
	b_2	-3.83	-3.09	.0148	

values of y are collapsed into a single mean. However, no information about the relationship of bone length and age is lost.

Another difference between the two groups of equations is that b_2 values are consistently lower in the second group of equations. This difference is due to a change in degrees of freedom rather than a difference in the actual contribution of b_2 to the model.

All intercepts and slopes are highly significant, reflecting the excellent fit of the model. However, all values for the intercepts are lower than what would be expected if the modal lengths determined from the perinatal frequency distributions are actually equivalent to mean birth lengths.

Table 17 contains information about the regressions using the Denver data. Once again, the extremely high values of r^2 result from the lack of variation among y observations at the same level of x. One important observation is that the intercept values for the tibia and humerus are almost as low as the parameters in the DM2 regressions for the Arikara and humerus. If the modal lengths of about 69 mm. and 68 mm. for the tibia and humerus correctly represent the lengths of these bones at birth in the Arikara, then the expected lengths for tibia and humerus at birth in the Denver children are lower than those of the Arikara.

Table 18 presents the results of regressions using the Fels Institute sample. Once again, a good fit of the regression model and an extremely high r^2 are noted. Also of note is the difference between the intercepts for the Fels tibia and radius compared to the intercepts from Denver. The predicted birth length of the tibia from

Table 17. Results of regressions using the Denver sample.

Bone	Coefficient	Estimate	t	PR > |t|	r^2
Femur	b_0	79.26	34.23	.0001	.99
	b_1	64.24	14.14	.0001	
	b_2	-8.76	-5.19	.0065	
Tibia	b_0	64.37	39.49	.0001	.99
	b_1	50.95	15.93	.0001	
	b_2	-6.60	-5.56	.0051	
Humerus	b_0	66.05	69.72	.0001	.99
	b_1	44.28	23.80	.0001	
	b_2	-6.30	-9.12	.0008	
Radius	b_0	54.91	68.55	.0001	.99
	b_1	29.29	18.60	.0001	
	b_2	-4.06	-6.95	.0023	

Table 18. Results of regressions using the Fels sample.

Bone	Coefficient	Estimate	t	PR > |t|	r^2
Tibia	b_0	69.84	37.12	.0001	.99
	b_1	57.23	14.50	.0001	
	b_2	-8.30	-5.39	.0030	
Radius	b_0	53.02	109.84	.0001	.99
	b_1	32.35	33.02	.0001	
	b_2	-4.56	-12.08	.0001	

the Fels children is closer to the higher modal length of the Arikara tibia around birth than to the lower predicted length for the Denver tibia. On the other hand, the predicted birth length for the Fels radius is lower than that for the Denver radius.

Figure 5 superimposes the three regression lines for the Arikara femur on the regression line for the Denver femur. The DM1 and DC lines parallel each other while the DM2 line has a shape more like the Denver line. The DM1 line crosses the Denver line at about 1.1 years and the DC line follows at about 1.5 years. After intersecting the Denver line, these two lines continue an upward trend which results in a wide divergence from the Denver line. By about 2.5 years, femur length for the DC-aged Arikara seems to be almost 20 mm. longer than femur length for the Denver sample.

This basic pattern of relatively early intersections of the DM1 and DC lines with the Denver line, followed by increasingly wide divergences between these Arikara lines and the Denver line, occurs repeatedly in the plots of long bone lengths against age, found in Figures 6 through 8. In all the plots, the DM2 line continues to closely parallel the Denver line, even after intersection has occurred.

The ages that the Arikara lines pass through the Denver line vary from bone to bone. The DM1 line crosses the Denver line at approximately .7 years in the tibia plot, .75 years in the humerus plot, and .55 years in the radius plot. The DC lines intersect the Denver lines slightly later than DM1: at approximately 1.1 years in the tibia plot, 1.2 years in the humerus plot, and 1.07 years in the

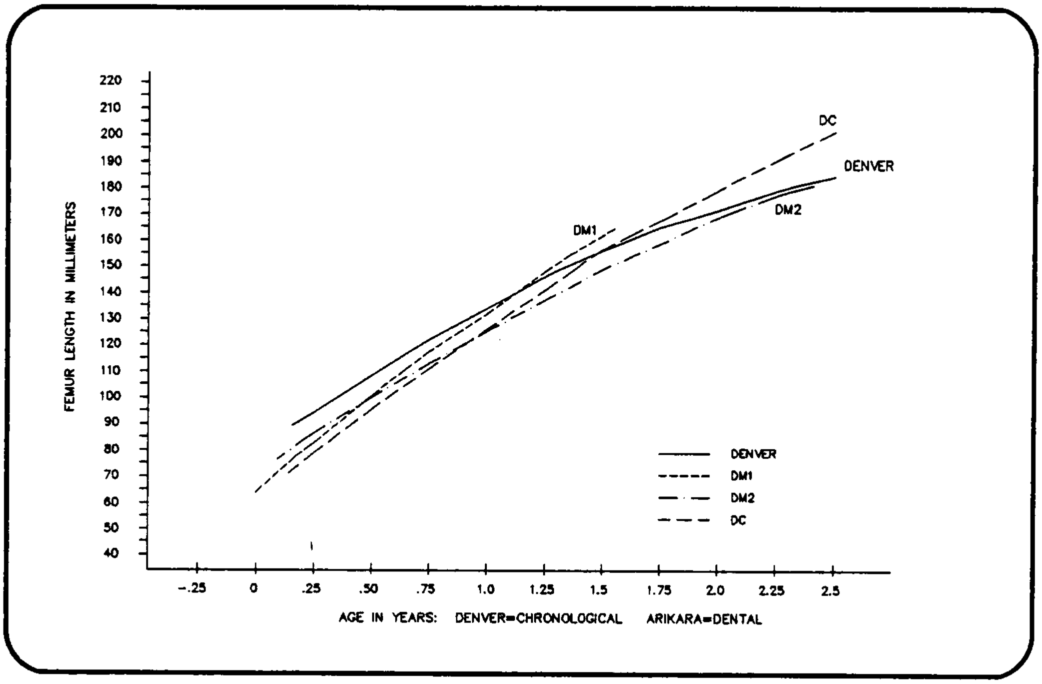

Figure 5. Growth curves for Arikara and Denver femur diaphyseal lengths.

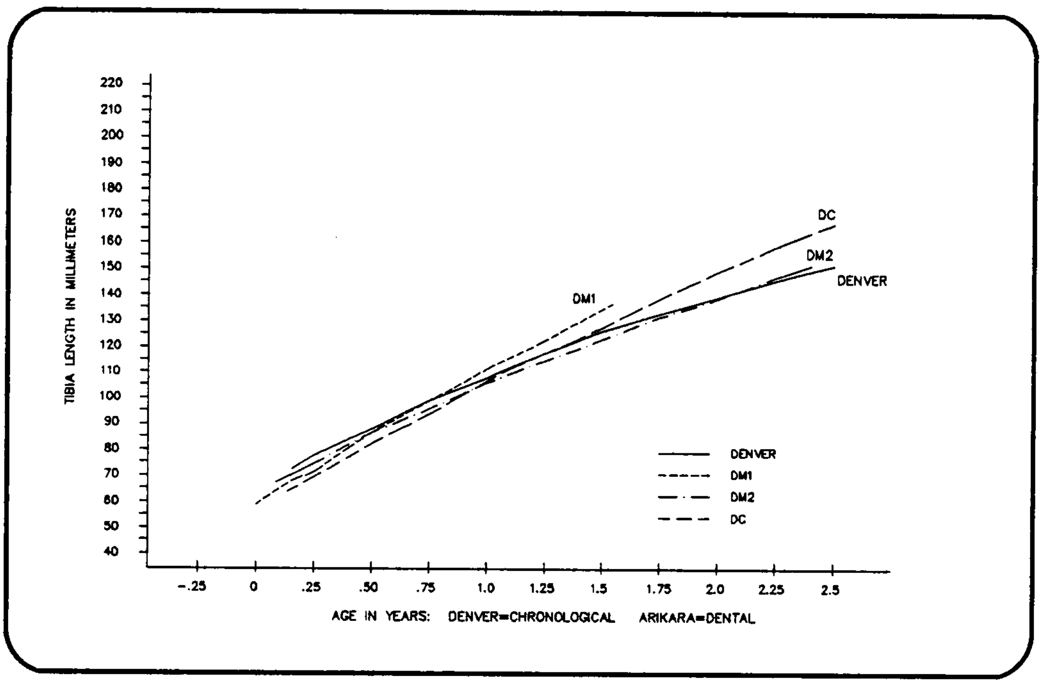

Figure 6. Growth curves for Arikara and Denver tibia diaphyseal lengths.

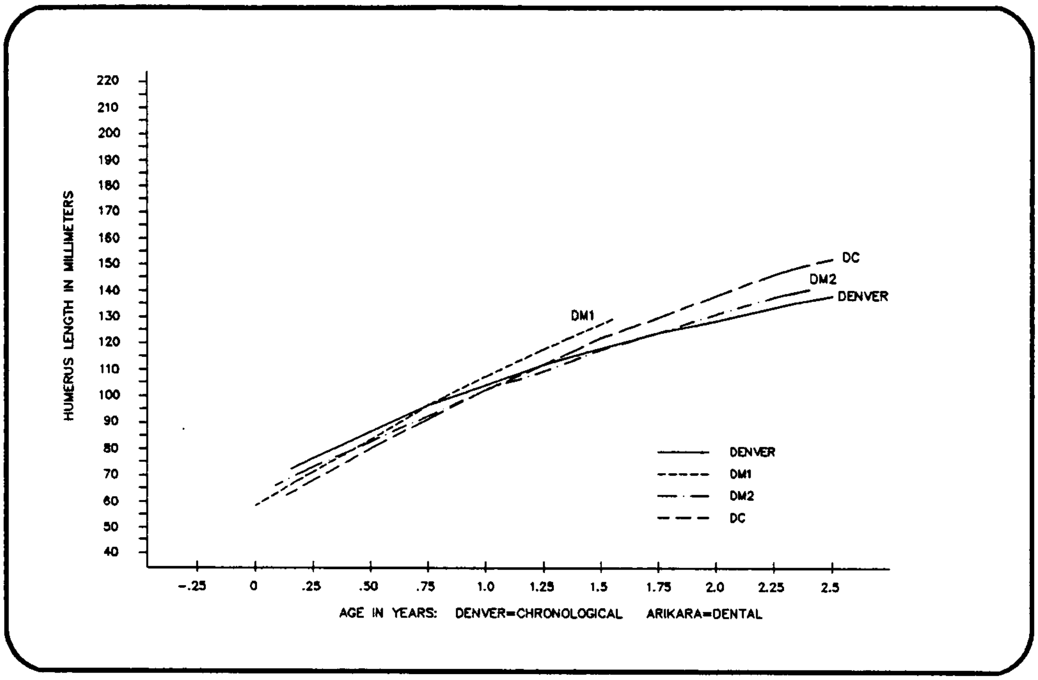

Figure 7. Growth curves for Arikara and Denver humerus diaphyseal lengths.

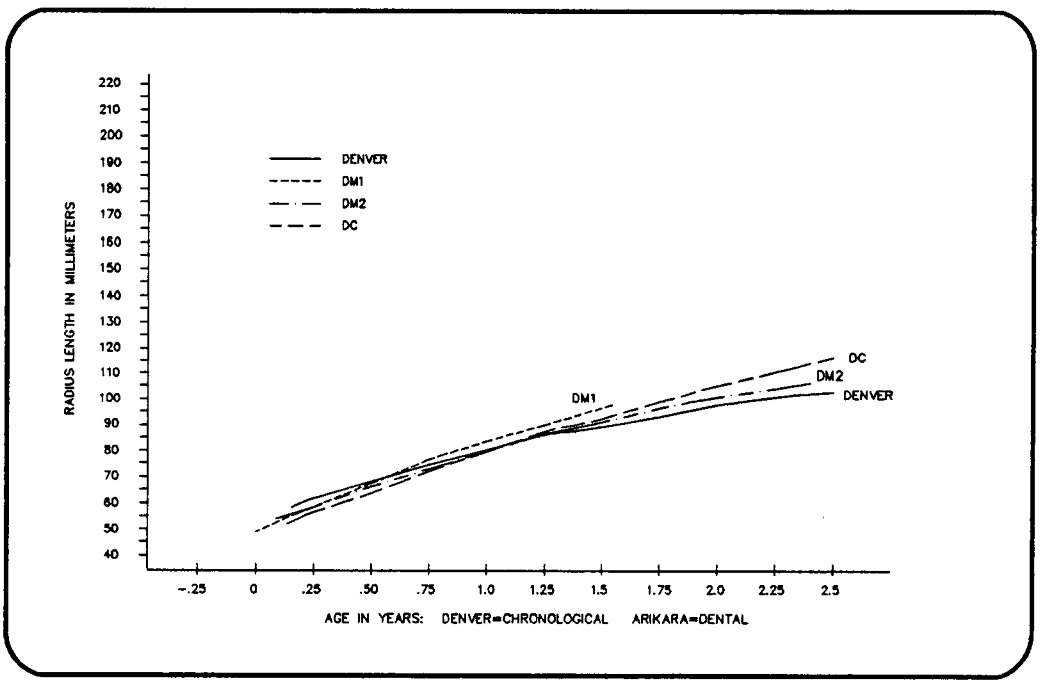

Figure 8. Growth curves for Arikara and Denver radius diaphyseal lengths.

radius plot. The DM2 lines, the slowest to intersect the Denver lines, cross at approximately 2.1 years in the tibia plot, 1.57 years in the humerus plot, and 1.07 years in the radius plot.

Proportional Growth

The fact that the regressions lines for the three teeth intersect the Denver lines at different ages suggests that the intertooth relationships in Arikara differ from the intertooth relationships in the White sample used by Moorrees et al. The variation in intersection ages for lines generated by the same tooth, for different long bones, is an expression of the variability in the relative growth rates of the long bones. In particular, the relatively early intersection ages for DM1 and DC seen in the tibia and radius lines may indicate that the development of these bones relative to the development of the femur and humerus is faster in the Arikara sample than in the Denver sample. In addition, the humerus seems to be developing faster relative to the femur in the Arikara sample. The faster development of bones along distal-to-proximal maturity gradients which has been described by Tanner (1978), seems to match the pattern of proportional long bone growth variation exhibited by the Arikara. Tanner (1978) also discusses the fact that the length of the forearm relative to the upper arm is greater in males than in females. The longer radii of the Arikara might also reflect a larger representation of males than females in the skeletal sample.

Earlier research by this student, using the regression equations of Scheuer et al. (1980) to calculate gestational age, supports the proportional growth differences suggested by the plots (Hyman 1984).

Scheuer et al. provide regression equations to predict gestational age using the femur, tibia, humerus, and radius. If four long bones from an individual are all growing at rates similar to the White sample used by Scheuer et al. in developing their equations, then the bones should predict the same gestational age.

In the work done by this researcher, these formulae were used on Arikara long bones from individuals who had all four bones present. In a paired comparison of predicted ages, the only predictions that were not significantly different were those of the tibia and radius. Indeed, these two bones predicted gestational ages that were significantly older than the ages predicted by the femur and the humerus, suggesting that Arikara distal long bones develop proportionately faster than proximal bones relative to the Scheuer et al. sample.

Robinow and Chumlea (1982) have developed diaphyseal bone length ratios from the Denver radiographs. These indices are found in Table 19. Similar ratios, computed from the Arikara data, are presented in Table 20. Direct comparisons are difficult because Robinow and Chumlea used age ranges of 0.5 years rather than exact ages, but general trends may be described.

The most notable difference between the two groups is in the tibia/femur ratios (TFRs) with the Arikara having consistently higher TFRs than the Denver sample until about age two. Not much difference is noted between the radius/humerus ratios (RHRs). However, the examination of the regression lines does suggest that the Arikara

Table 19. Diaphyseal length ratios of the Denver sample[a].

Bone Ratio	Age (years)	No.	Mean
Radius / Humerus	0.2-0.49	134	0.82
	0.5-0.99	132	0.79
	1.0-1.49	45	0.77
	1.5-1.99	123	0.76
	2.0-9.99	218	0.75
Tibia / Femur	0.2-0.49	133	0.81
	0.5-0.99	132	0.81
	1.0-1.49	45	0.81
	1.5-1.99	124	0.81
	2.0-9.99	218	0.81
Humerus / Femur	0.2-0.49	133	0.83
	0.5-0.99	132	0.79
	1.0-1.49	45	0.77
	1.5-1.99	124	0.76
	2.0-9.99	218	0.71
Radius / Tibia	0.2-0.49	134	0.84
	0.5-0.99	132	0.77
	1.0-1.49	45	0.74
	1.5-1.99	123	0.71
	2.0-9.99	218	0.65

[a]from Robinow and Chumlea (1982)

Table 20. Diaphyseal length ratios of the Arikara sample.

Bone Ratio	Age (years)	No.	Mean
Radius / Humerus	0.075	69	0.82
	0.250	25	0.82
	0.450	13	0.81
	0.700	14	0.80
	0.900	15	0.80
	0.950	22	0.79
	1.300	17	0.79
	1.525	22	0.78
	1.850	10	0.77
	1.975	12	0.78
	2.400	7	0.77
Tibia / Femur	0.075	65	0.88
	0.250	31	0.87
	0.450	16	0.86
	0.700	17	0.84
	0.900	20	0.84
	0.950	22	0.84
	1.300	16	0.83
	1.525	25	0.82
	1.850	10	0.81
	1.975	12	0.83
	2.400	10	0.83
Humerus / Femur	0.075	72	0.87
	0.250	32	0.86
	0.450	16	0.84
	0.700	18	0.81
	0.900	21	0.81
	0.950	28	0.81
	1.300	18	0.80
	1.525	26	0.79
	1.850	12	0.77
	1.975	15	0.77
	2.400	10	0.76

Table 20. (Continued)

Bone Ratio	Age (years)	No.	Mean
Radius Tibia	0.075	60	0.81
	0.250	25	0.80
	0.450	11	0.79
	0.700	13	0.78
	0.900	15	0.76
	0.950	18	0.76
	1.300	14	0.75
	1.525	23	0.74
	1.850	8	0.72
	1.975	11	0.72
	2.400	7	0.71

humeri were also growing relatively quickly compared to the Denver humeri. Simultaneous faster growth rates of the humerus and the radius would result in RHRs compatible to those of the Denver sample. Higher humerus/femur ratios (HFRs) for the Arikara, which are especially noticeable at earlier ages, support the suggestion that the relative growth of humerus to femur is faster in the Arikara than in Denver Whites.

Jantz and Owsley (1984a), in an among-variant comparison of slopes of regression lines of Arikara long bone length and age, found that the slopes of the distal bones were more heterogeneous through time than the slopes of the proximal bones. In fact, only the femur had slopes which were homogeneous through time. Thus, proportional growth differences that are suggested by the plots using a sample composed of all three Arikara variants, may reflect temporal patternings of growth.

Maresh (1955) suggests that proportional growth has a strong individual-variability component:

> In infancy, growth in length was seldom along channelled zones as set up from percentile lines. Instead, the rate of growth of one or more of the long bones of the extremities was sometimes faster than that of the group average, sometimes slower, and sometimes revealed periods of either temporary acceleration and deceleration. Variation in percentile levels were observed that might be as great as 50 percentiles.

The existence of potential large amounts of proportional growth variability within an individual, restricts conclusions about inter-group proportional growth variation.

Aging Adjustment

Along with proportional growth variation of the long bones and differential development rates among the teeth, the results of the regression analyses suggest a timing difference between the overall dental development of the Arikara and dental development of Whites as outlined by the MFH standards. This difference is implied by the lower-than-expected birth lengths, represented by the intercepts of the regression lines. The relatively precocious development and eruption of teeth in Native Americans has been documented (see Trodden 1982). If the Arikara teeth are developing earlier then the teeth of the sample used to develop the MFH standards, then the MFH standards are consistently over-aging the Arikara teeth. If this is the case, then the long bones corresponding to the MFH stage of 0.0 years actually belong to fetuses rather than neonates.

One way to compensate for the over-aging of the MFH standards is to adjust the dental ages so that the intercepts of the regression lines fall on the expected modal birth lengths. In their previous work with Arikara dental ages, Owsley and Jantz (1983a) began their adjustments using DC because its regression line paralleled most the Denver regression line. The results of this research suggest that the DM2 line most closely parallels the Denver line.

The decision to use the line that best fits the Denver growth curve is based on the underlying assumption that patterns of Arikara and Denver growth are basically the same. Use of the DM1 or DC lines, which diverge widely from the Denver line, would imply acceptance of the idea that at a given stage, Arikara subadult long bones are much larger than Denver subadult long bones. This suggestion conflicts with documented size differences between Arikara adults and Denver adults. Stature for the Arikara has been estimated from adult long bones from the Leavenworth site (Bass et al. 1971) as being 169 cm. for males and 159.45 cm. for females. Using long bones from all three variants, Owsley (1985) has found no evidence for secular changes in stature. Average heights for males of age 25 from the Denver sample is 179.8 cm, and for females of age 25 is 165.7 cm. (Hansman 1970). The estimated stature for Arikara males is equal to the minimum height measured in the Denver male sample. The evidence that the Arikara adults were probably shorter than Denver adults, leads to the conclusion that Arikara children were probably smaller, or, at any rate, not much larger than Denver children as the DM1 and DC lines suggest. Thus, the DM2-femur regression model, which shows no wide divergence from the Denver model, was chosen for the initial age adjustment.

The frequency distribution for the Arikara femur has the most distinct mode; therefore, the quadratic formula was used to solve for the value of x, which when inserted into the DM2-femur equation yields a y-value of 77. The solution, 0.095 years, was subtracted from the MFH ages assigned to each stage of dental development and new regressions were run for all long bones using the adjusted dental ages. The resulting regression parameters are found in Table 21. Note that all the new intercepts are much closer to the expected birth lengths as determined by the modes.

Table 21. Results of regressions using DM2 adjusted ages.

Bone	Coefficient	Estimate	t	PR > |t|	r^2
Femur	b_0	77.03	67.56	.0001	.99
	b_1	59.57	19.14	.0001	
	b_2	-6.11	-3.88	.0047	
Tibia	b_0	67.95	51.32	.0001	.99
	b_1	44.93	12.62	.0001	
	b_2	-3.81	-2.10	.0690	
Humerus	b_0	67.06	51.48	.0001	.99
	b_1	42.15	12.10	.0001	
	b_2	-4.43	-2.50	.0370	
Radius	b_0	54.94	66.14	.0001	.99
	b_1	31.12	13.27	.0001	
	b_2	-3.83	-3.09	.0148	

Figure 9 shows the adjusted femur regression line overlayed on the Denver femur regression line. Figure 10, a plot of the original DM2 and Denver femur regression lines, is provided for comparison. Figures 11 and 12, Figures 13 and 14, and Figures 15 and 16 are corresponding plots for the tibia, humerus, and radius, respectively. No adjustment was made to the slope of the equation so the shapes of the new lines are the same as before.

The Arikara femur still begins below the Denver femur, but eventually crosses at about 2 years. Both the Arikara tibia and humerus lines start slightly above the Denver line and then lie almost directly above the Denver line until about 1.5 years in the tibia and about 1.25 years in the humerus. After those ages, the Arikara lines are once again above the Denver lines. The radius lines begin diverging after about 0.25 years, with the Arikara line gradually becoming higher than the Denver line.

Figures 17 and 18 are plots of Denver and adjusted Arikara tibia and radius regression lines as compared with the Fels tibia and radius regression lines. According to the lines seen in Figure 17, the Fels tibiae are always longer than both the Denver and the Arikara tibiae. However, the slopes of the Fels and Denver lines appear to be equivalent, with the difference in heights between the two lines staying constant through time. The Fels radius line is lower than the Denver line at first but intersects it just before 1.0 years, while the Arikara radius line is consistently higher than the Fels line.

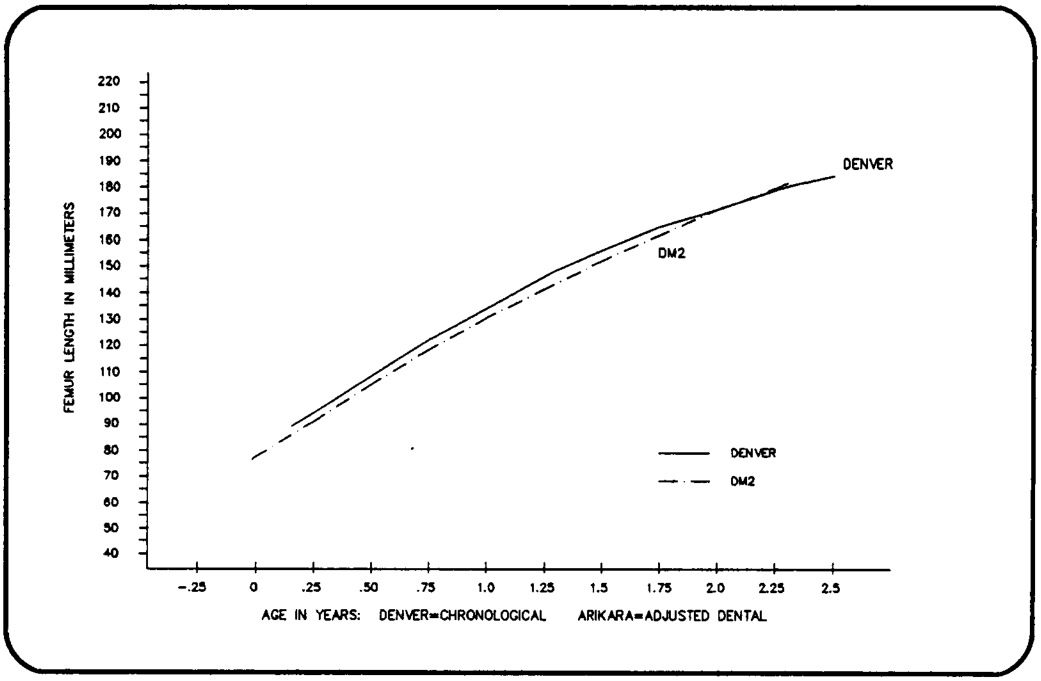

Figure 9. Growth curves for Arikara and Denver femur diaphyseal lengths--DM2 intercept-adjusted Arikara ages.

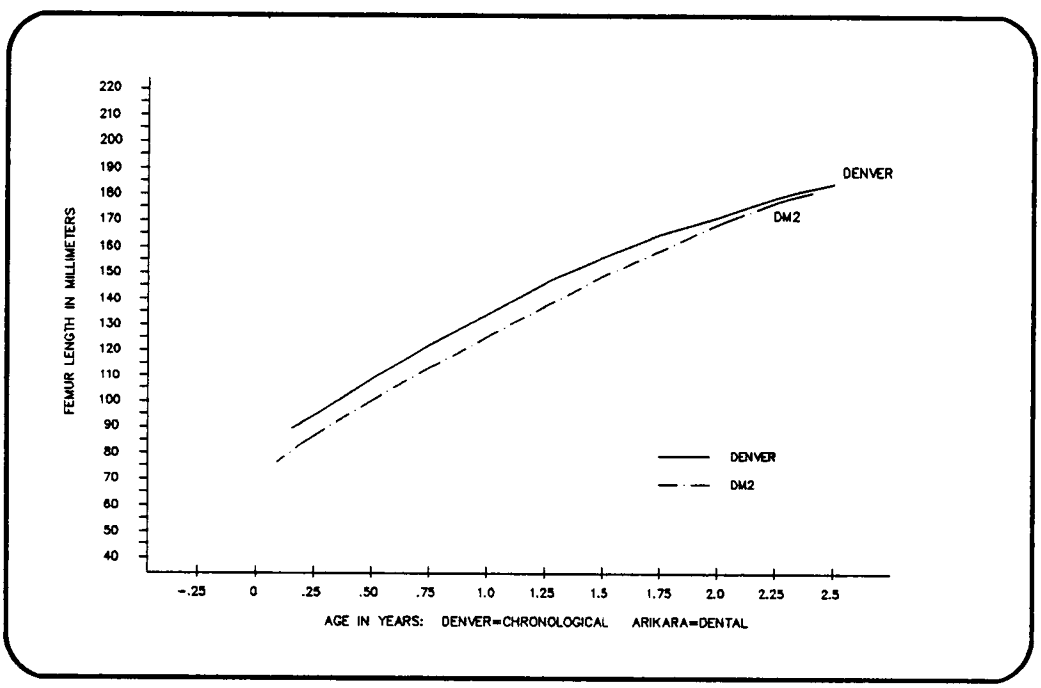

Figure 10. Growth curves for Arikara and Denver femur diaphyseal lengths--DM2 unadjusted Arikara ages.

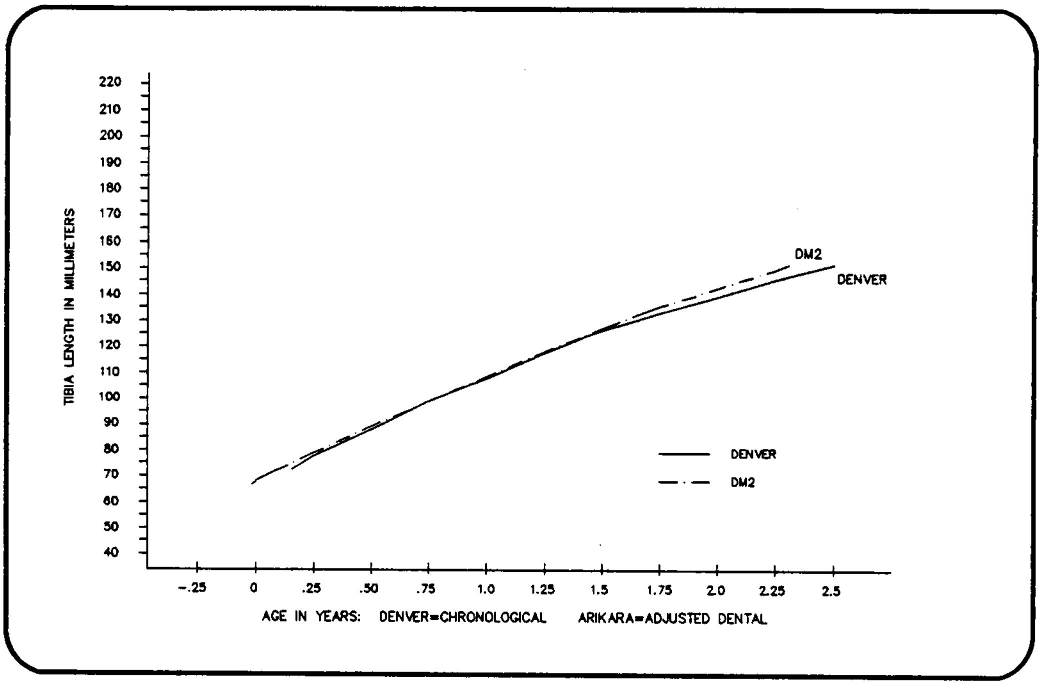

Figure 11. Growth curves for Arikara and Denver tibia diaphyseal lengths--DM2 intercept-adjusted Arikara ages.

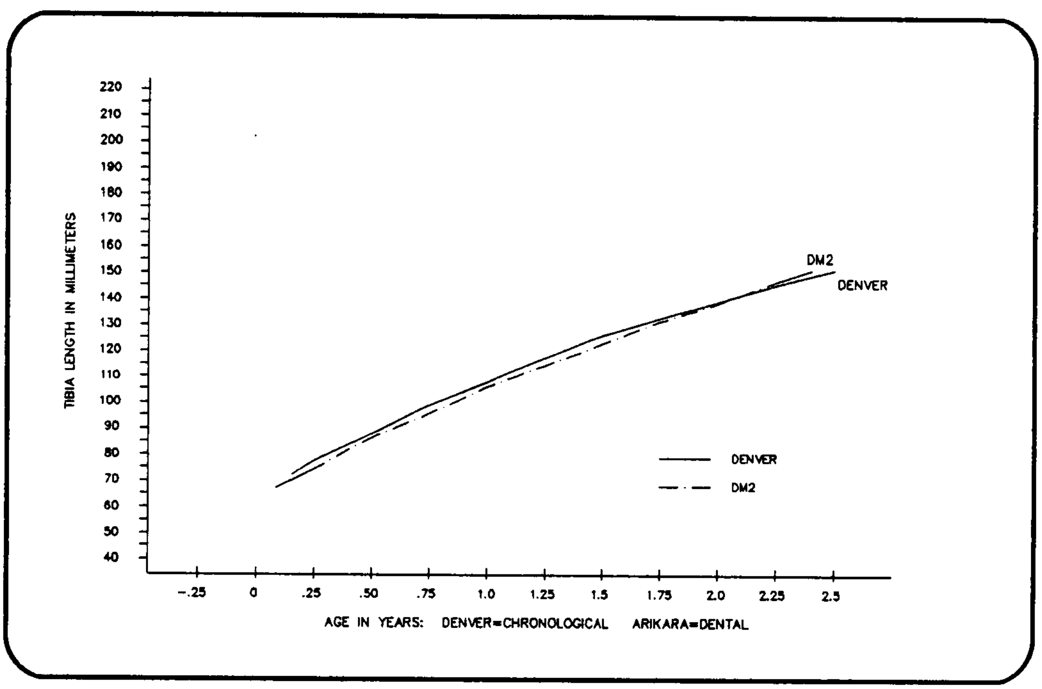

Figure 12. Growth curves for Arikara and Denver tibia diaphyseal lengths--DM2 unadjusted Arikara ages.

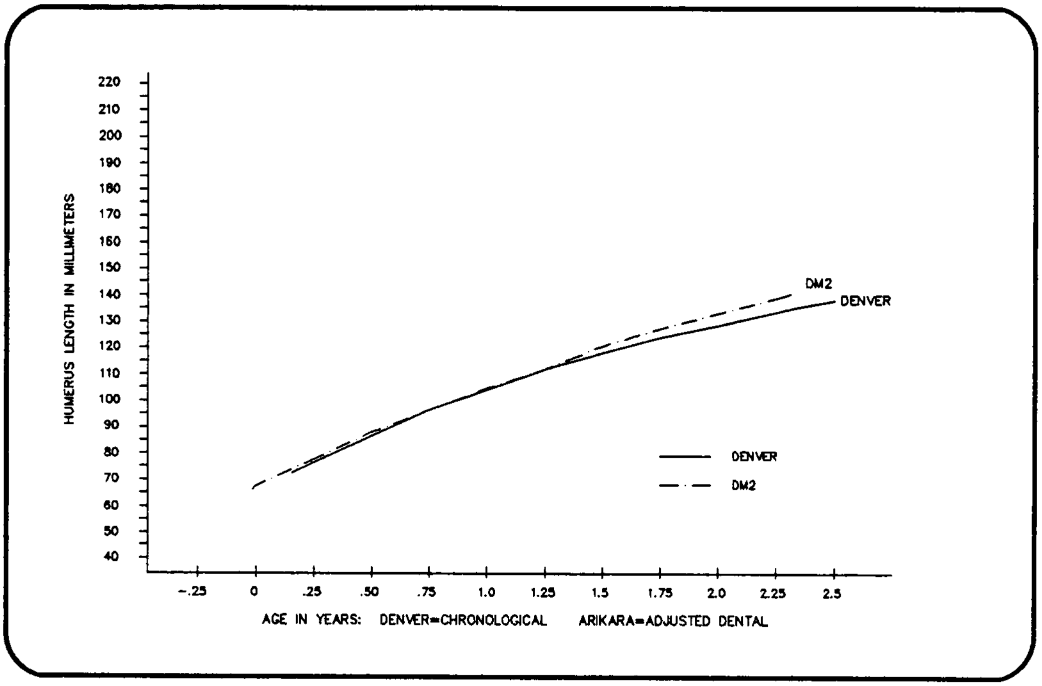

Figure 13. Growth curves for Arikara and Denver humerus diaphyseal lengths--DM2 intercept-adjusted Arikara ages.

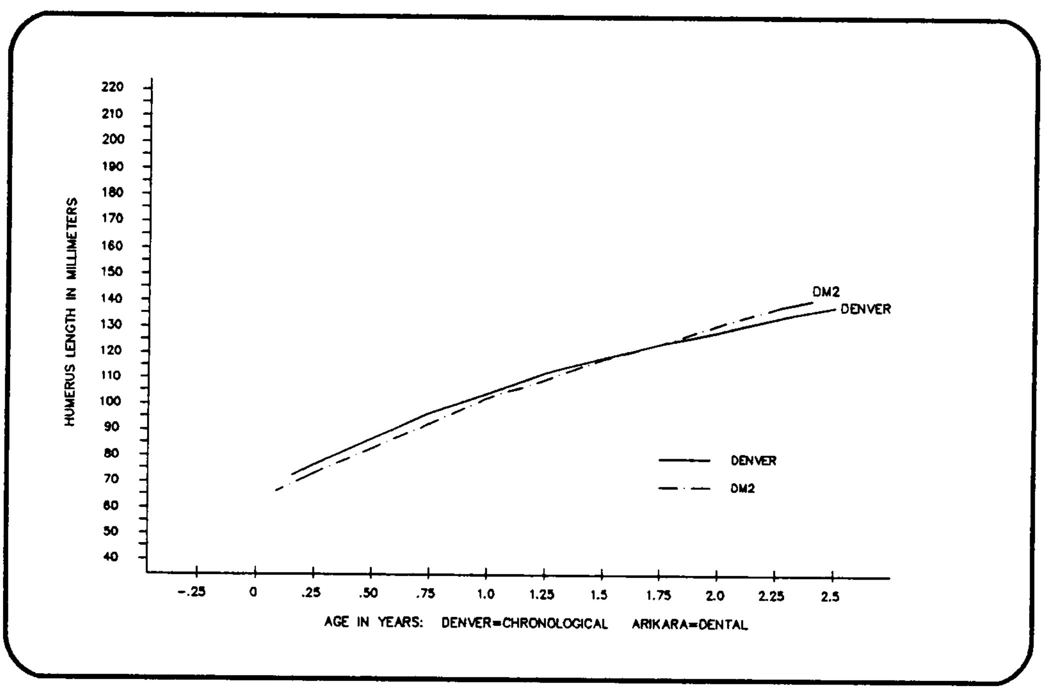

Figure 14. Growth curves for Arikara and Denver humerus diaphyseal lengths--DM2 unadjusted Arikara ages.

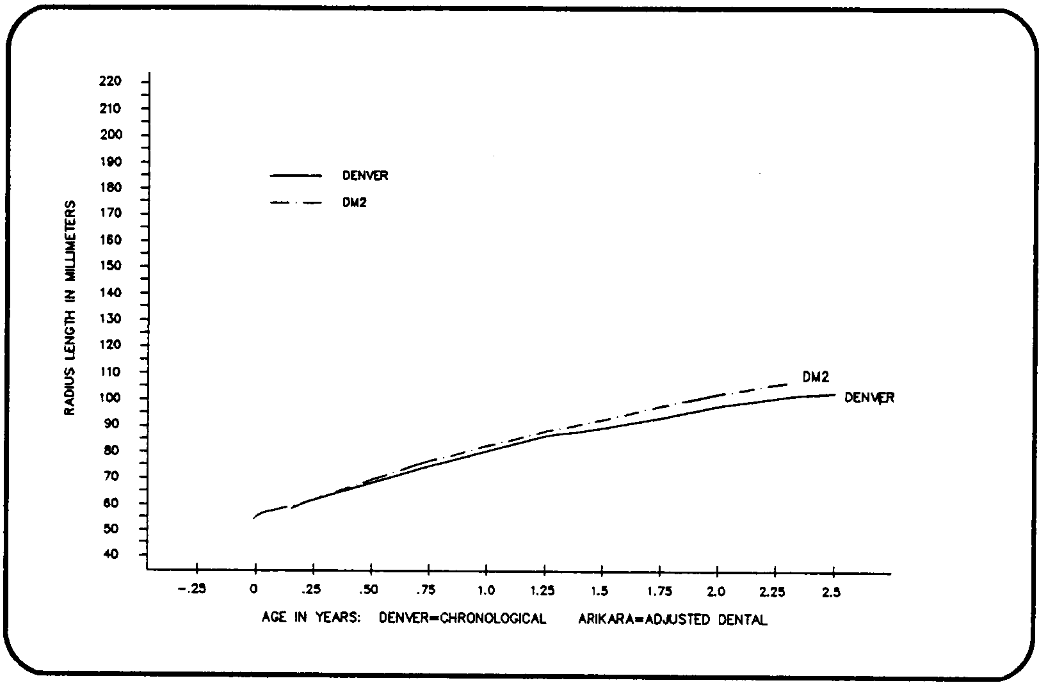

Figure 15. Growth curves for Arikara and Denver radius diaphyseal lengths--DM2 intercept-adjusted Arikara ages.

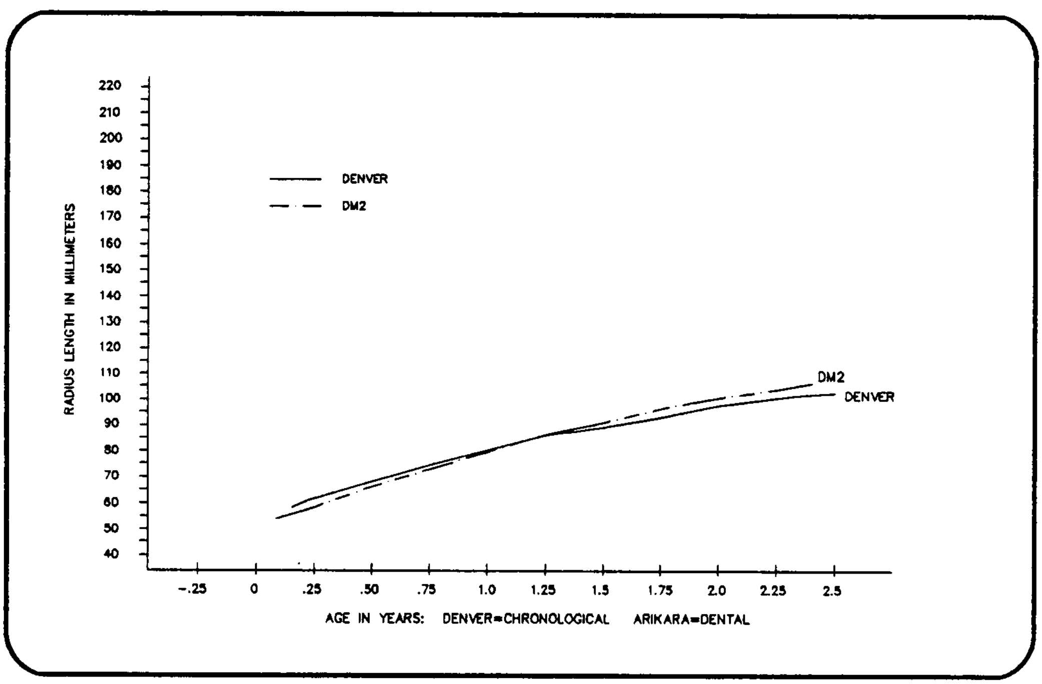

Figure 16. Growth curves for Arikara and Denver radius diaphyseal lengths--DM2 unadjusted Arikara ages.

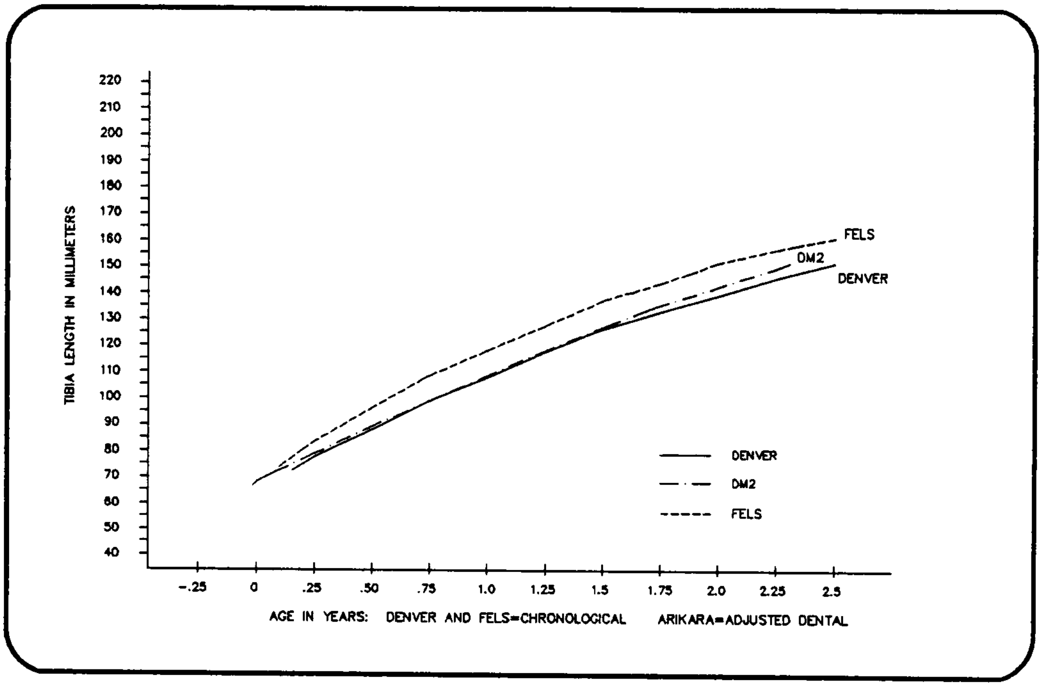

Figure 17. Growth curves for tibia diaphyseal lengths--Denver, Fels, and intercept-adjusted Arikara.

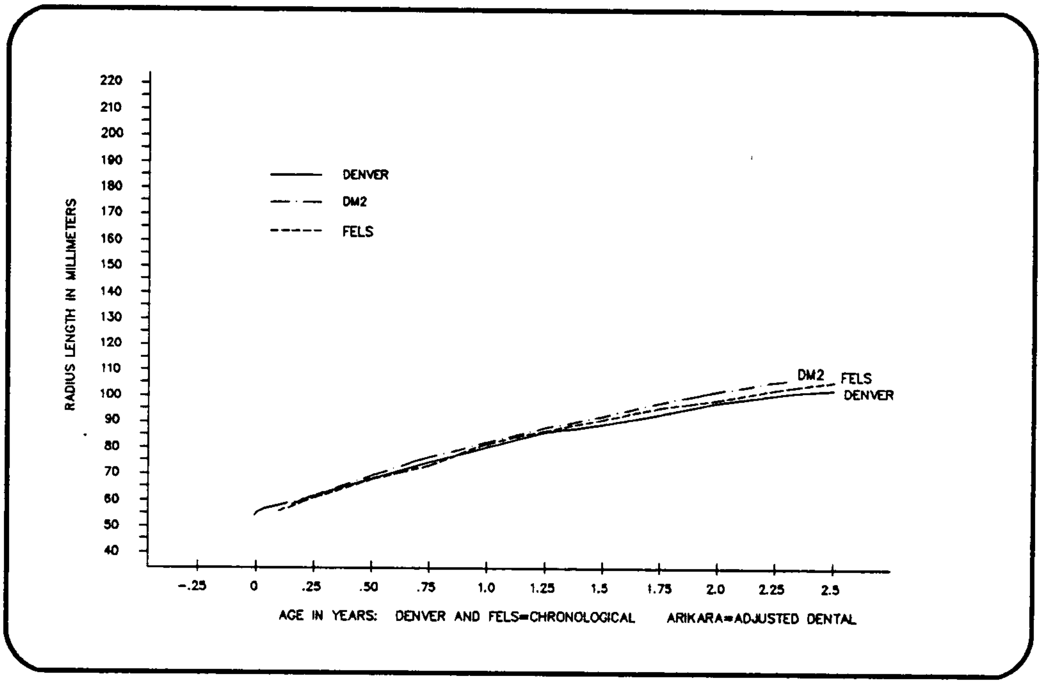

Figure 18. Growth curves for radius diaphyseal lengths--Denver, Fels, and intercept-adjusted Arikara.

The patterns of these regression lines agree with Gindhart's (1973) statement that the bones in the Fels study were, on the average, 6-8% longer than the bones from Denver. The fact that Arikara radii are longer at all ages than both Denver and Fels radii, agrees with the earlier suggestion that the growth rate for the Arikara radius is faster than White radii.

Using the assumption that the DM2 line represents reality, the DM1 and DC lines may be adjusted to fit the DM2 line so that bones from an individual may be matched to an age that is common for all three teeth. This process of adjusting DM1 and DC ages uses the DM2 adjusted-age regression equation to solve for the DM1 and DC ages which, given the observed means for the stages of these teeth, fit the model. The quadratic formula:

$$x = \frac{b \pm \sqrt{b^2 - 4ac}}{2a}$$

where x = age, b = 59.57 (b_1), a = -6.11 (b_2), and c = (77.03 (b_0) - mean age per dental stage), was used to solve for the new age values.

The resulting adjusted ages for DM1 and DC, along with the adjusted ages for DM2, are found in Table 22. The adjusted DM2 ages are consistently younger than the original MFH ages because their calculation was based on the subtraction of a constant from the standard age. Adjusted DM1 ages are younger until about 0.5 years, then the adjusted ages are older than the MFH ages. This reversal pattern is also observed in a comparison of the adjusted DC ages to the MFH ages. At earlier ages, the Arikara DM1 and DC seem to be

Table 22. Adjusted Arikara dental ages and corresponding MFH ages.

	Stage	Arikara[a]	Arikara[b]	MFH[c]
DC	2	-0.110	-0.070	0.150
	3	0.030	0.030	0.250
	4	0.146	0.230	0.450
	5	0.395	0.450	0.675
	6	0.606	0.630	0.850
	7	-	-	-
	8	1.097	0.780	1.000
	9	1.387	1.050	1.275
	10	1.863	1.600	1.825
	11	2.097	1.780	2.000
	12	3.120	2.280	2.500
DM1	2	0.002	-0.120	0.000
	3	-0.007	0.060	0.175
	4	0.040	0.140	0.250
	5	0.188	0.300	0.400
	6	0.430	0.480	0.550
	7	0.585	0.540	0.600
	8	0.804	0.660	0.700
	9	1.022	0.950	0.925
	10	1.146	1.270	1.150
	11	1.373	1.420	1.125
	12	1.806	1.950	1.550
DM2	2	-0.020	-0.040	0.075
	3	0.155	0.140	0.250
	4	0.355	0.350	0.450
	5	0.605	0.610	0.700
	6	0.805	0.820	0.900
	7	0.855	0.870	0.950
	8	1.205	1.240	1.300
	9	1.430	1.480	1.525
	10	1.755	1.840	1.850
	11	1.880	1.980	1.975
	12	2.305	2.480	2.400

[a]from this analysis

[b]from Owsley and Jantz (1983a)

[c]from Moorrees et al. (1963b)

developing faster than teeth from the White sample. After about six months, the development of these Arikara teeth decreases as the White teeth begin developing faster.

The fact that the DM1 age for MFH Stage 2 is larger than the age for Stage 3 results from the mean femur length for Stage 2 being larger than the mean length for Stage 3. Using the original regression models for the humerus or radius, in which the mean lengths for Stage 2 are shorter than the mean lengths for Stage 3, to generate the adjusted ages, could correct this problem.

Comparison to Previous Research

The adjusted dental ages originally obtained by Owsley and Jantz (1983) are also included in Table 22. Because Owsley and Jantz used DC as their standard adjustment tooth, their adjusted ages for DC, rather than DM2, are consistently lower than those of MFH. Before about 0.5 years, the adjusted ages of DC from this analysis are slightly younger than those of Owsley and Jantz. After six months, the Owsley and Jantz DC ages are consistently younger. For DM2, the standard adjustment tooth in this analysis, a close correlation exists between the Owsley and Jantz ages and the new ages. The Owsley and Jantz DM2 ages are slightly older until Stage 4 when they become slightly younger. In DM1 ages, the Owsley and Jantz ages are older at first but are younger after Stage 7.

Table 23 compares the regression equations obtained by Owsley and Jantz (they used the femur only) with the unadjusted regression equations from this study. The cause of differences between the sets

Table 23. Comparison of regression equations--unadjusted ages.

Data	Regression Equation
Results Obtained by Owsley and Jantz (1983a)	
Denver	$FL = 61.59(age) - 8.18(age^2) + 79.80$
Arikara--DC Age	$FL = 62.94(age) - 7.25(age^2) + 63.31$
Arikara--DM1 Age	$FL = 62.55(age) - 0.24(age^2) + 69.47$
Arikara--DM2 Age	$FL = 62.68(age) - 6.94(age^2) + 70.09$
Results Obtained by this Analysis	
Denver	$FL = 64.24(age) - 8.76(age^2) + 79.27$
Arikara--DC Age	$FL = 71.47(age) - 6.07(age^2) + 61.13$
Arikara--DM1 Age	$FL = 75.68(age) - 7.01(age^2) + 64.26$
Arikara--DM2 Age	$FL = 60.73(age) - 6.11(age^2) + 71.31$

of equations from the two analyses is unclear. The slight difference between the Denver models is especially puzzling because the Denver data should not have changed between the two studies. Approximately 64 additional subadult skeletons, mostly from the Postcontact Coalescent (Jantz, personal communication), have been added to the Arikara sample since the original work. However, only a few of these skeletons had both deciduous teeth and long bone diaphyses, a requirement for inclusion in the analysis. Lack of changes in the data base leads to the conclusion that differences in computational methods or discrepancies in data entry are present between the two studies.

Owsley and Jantz also report a difference in the patterns of the regression lines: their DC line runs parallel to the Denver line rather than diverging along with the DM1 line. Their DM2 and DM1 lines are similar to the ones obtained by this researcher, with the DM2 line also running parallel to the Denver line and the DM1 line diverging from the Denver line. Still, the contrast between the two DC lines is striking.

The results of a paired comparison between dental ages assigned to individuals having all three teeth are found in Table 24. A review of these scores reveals a pattern more consistent with Owsley and Jantz's results, with DM1 ages differing significantly from DM2 and DC ages, and DM2 and DC ages not differing significantly. However, as noted by Owsley and Jantz (1983b), a statistically significant difference in the relatively fine dental age categories

Table 24. Paired comparison of mean differences in dental ages.

Variable	Mean Difference	Number[a]	T	PR > |T|
DC-DM1	0.10	221	8.51	.0001
DC-DM2	0.02	221	1.07	.2875
DM1-DM2	-0.09	221	-6.27	.0001

[a]Only cases in which all three teeth were present were used in these tests.

does not necessary mean a substantive difference in years. Also, the ages in the comparison actually represent age stages of different lengths. Thus, the usefulness of using the paired t-test to support Owsley and Jantz's results is questionable. On the other hand, the fact the shape of the DC femur line obtained in this analysis is mirrored by the DC line for the other long bones seems to support the acceptance of this DC femur line as reflecting actual Arikara growth patterns.

CHAPTER IV

SUMMARY AND CONCLUSIONS

An attempt to duplicate Owsley and Jantz's efforts to establish a set of adjusted deciduous dental ages for Arikara subadults yielded an unexplainable difference between the two studies concerning the developmental rate of DC. However, results of both analyses suggest that the MFH dental standards do not fit the timing pattern of Arikara dental development. Adjusting the MFH standards by subtracting a constant from the ages assigned to DM2, successfully raised the intercepts of the regression lines for all four long bones so that the predicted lengths at 0.0 years were close to the modal birth lengths obtained from frequency distributions of the perinatal Arikara long bones.

DM1 and DC ages were adjusted so that they fit the adjusted DM2 equation. This adjustment was based on the proposition that subadult long bones from a smaller-sized adult population should not be longer than subadult long bones from a larger-sized adult population. However, as Eveleth and Tanner (1976) explain, the validity of this suggestion is questionable: "Tempo of physical development has to be studied separately from body size; there are differences between populations and no _a priori_ reason why these differences should be related to differences in height and weight."

One problem with this study is its focus on long bone length attained by a given age. Mensforth (1985) suggests that shifting the unit of analysis to ratios of subadult to adult diaphyseal lengths rather than subadult lengths attained by age stage, compensates for the effects of adult size. Mensforth assumes that in samples where adults are larger, subadult long bones will be consistently larger. However, in this analysis, the Arikara children appear to have longer bones than the Denver children even though the Arikara adults were probably shorter than the Denver adults. This observation was most noticeable in the wide diversions of the DC and DM1 lines from the Denver line. However, the DM2 lines also intersected the Denver lines: in the case of the radius, the DM2 line lies above the Denver line for the entire length of the lines.

This analysis is limited to the range of observations associated with the development of the deciduous teeth, lasting from about birth to three years. The shapes the curves take after this age is not known. Possibly, the Arikara curve flattens, allowing the Denver line to exceed it, as the growth rates of the Denver children pass the growth rates of the Arikara children. In this scenario, the Denver children might have smaller bones than the Arikara children in early childhood, but the trend would eventually be reversed. Eveleth and Tanner (1976), in their study of worldwide growth variation, note that Asiatics initially appear to have longer legs but by mid-childhood, have shorter legs than Europeans populations. Indeed, a pattern of long bone growth where Arikara children develop faster at earlier ages, and then slower at older ages, is consistent with the pattern of development noted for Arikara deciduous teeth.

Further research could use dental ages for the permanent teeth, as well as the deciduous teeth, to extend the Arikara growth curves.

Individual long bone measurements as well as dental records, x-rays, and casts are available for the Denver sample (McCammon 1970). If MFH standards were used to age these dental data, then long bone lengths could be correlated with dental age rather than chronological age for the Denver sample. If the children from Fels Institute that Moorrees et al. (1963b) used in their development of dental standards are the same children whose long bone lengths Gindhart (1973) reports, the Fels dental and long bone growth data could be combined so that these long bone lengths could also correspond to dental ages. Using the same type of aging for both the Arikara and the White samples would eliminate the problem of trying to compare chronological age with dental age.

In addition to opening new avenues of research, this study provides new deciduous dental aging criteria based on the adjustment of a set of widely-used White dental calcification stages to the calcification rates of an Indian sample. Use of these adjusted ages, which compensate for the precocious dental development of Native Americans, might produce new insights about the rates of long bone growth in archaeological Indian samples.

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