DENTAL DEVELOPMENT STANDARDS FOR THE PRE- AND POST-CONTACT ARIKARA

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INTRODUCTION

The purpose of this paper is to examine the evidence for or against the creation of dental development standards specific to the Arikara population and, by extension, to Native American samples. The research is based on radiographic and macroscopic analysis of a sample of pre- and post-Contact Arikara subadult mandibles.

A total age was determined for each specimen in this sample based on the Moorrees, Fanning, and Hunt Method (1963a,b). Four mandibular teeth for each specimen were then examined specifically to assess: 1) the degree of crown and root development with respect to one another and to tooth development patterns for a reference standard as displayed by the MFH method; and 2) the degree of dental eruption with respect to one another and the Hurme, Moyers, and Ten State Nutritional Survey Standards.

The method of Moorrees, Fanning, and Hunt, based upon a European-derived sample, is thought to provide the most discrimination and best reproducibility (Smith, 1991; Saunders, 1992; Saunders et al., 1993). In the MFH method (based on material from the Fels growth study), radiographs of six mandibular teeth (left canines to third molars) were taken on 246 North American children of European ancestry at half-yearly intervals. Diagrams were produced which specified the mean age of crown and root development and calcification to be expected at each interval. In order develop the MFH method for all eight teeth in the left lower quadrant, data for the Fels sample were pooled with those for a separate sample of 99 children from the Stuart collection of Boston. This, then, is the MFH standard to which dental development in the Arikara sample is compared. The MFH method has been used so widely that a considerable body of data has been accumulated which should permit inter-population comparisons.

A consensus in favor of creating and using individual standards for each population sampled has never developed, however. Although some authors (Davis and Hagg, 1994; Hagg and Matsson, 1985; Staaf et al., 1991) have used the Demirjian data (Demirjian et al., 1985; Demirjian 1986) to demonstrate systematic interpopulation differences, none of their results exceed the intra-sample variance. Moreover, none have done comparative studies employing the MFH method.

Owsley and Jantz (1983) suggested that variation over time in dental development is a real phenomenon and that European-derived children's dental development is qualitatively different from that of Native American populations. These workers cite evidence that the mandibular permanent second molar erupted before the mandibular second premolar in past and present Native American populations. Some of the information on which this observation is based, however, lacks data obtained by analysis of radiographs. Therefore, the degree of relationship between eruption patterns and intra-alveolar crown and root development is unclear.

In order to determine whether a population specific standard is required for historic or prehistoric European-derived and Native American samples, identical methods (specifically, the MFH method) should be applied to skeletal samples of relevant groups. If genes determine eruption times and root elongation occurs only in response to the primary eruptive force (Moyers, 1988), the presence of different eruption patterns would suggest a different genetic pattern requiring a sample-specific dental development standard.

Eruption data in living populations are based upon intraoral observations of tooth emergence through the gingiva (Steggerda and Hill, 1942; Kent et al., 1978; Mayhall et al., 1978; Smith and Garn, 1987). Whether eruption into the mouth has any distinct relationship with the initial resorption of the overlying alveolus is unclear. In fact, the intervals from alveolar resorption to occlusion vary widely from tooth to tooth (12-20 months) and within populations (Moyers, 1988).

Comparability of data for living and skeletal samples is extremely problematical. No data for time of eruption through the gingiva exist for skeletal populations in which the only comparable data are those for emergence through the alveolus. To compound the problem, the overlying alveolus may have been so fragile that taphonomic processes destroyed it, creating the impression of an earlier eruption time than had actually occurred.

Much less guesswork is involved in comparing dental development stages assessed radiographically than those evaluated visually. However, only radiographic data may be equated properly with radiographic data. Results of comparisons of actual teeth with radiographic standards for root and crown development (Owsley and Jantz, 1983; Owsley, pers. comm.) may not be accurate for two reasons. First, radiographic standards are based on visualization of root structures which are radiographically opaque, because tooth structure must be at least 70.0% calcified to be visible radiographically (Goaz and White, 1994). Thus, root structure seen macroscopically on a skeletal tooth might not be visible on an x-ray. Second, taphonomic processes, particularly in teeth avulsed from the alveolus post mortem, may have resulted in the loss of incompletely calcified root structure in quantities approximating the result of radiographic "burn out" in living patients. Unfortunately, no good studies have shown the percentage of partially calcified dentin that may be lost after burial and before recovery. Thus, determination whether or not comparable stages scored by gross examination of the burial specimen are being equated accurately with the appropriate radiographic standards is impossible.

Finally, in this study, as well as in all studies of skeletal samples for which no burial records exist, chronological age is unavailable. Therefore, while dental age is well-correlated with chronological age in modern children

(Demirjian et al., 1985; Demirjian, 1986), the correlation is not perfect. This introduces another source of inaccuracy in the equation which is, unfortunately, unavoidable. The possibility exists that both sexes are unequally represented in this skeletal sample and in others. If one sex is significantly under-represented, the assumption may be invalid that dental ages of specimens may be compared properly to averaged means of male and female attainment of comparable dental development stages (Smith, 1991; Tomkins, 1996).

MATERIALS

The sample consists of 53 subadult specimens in the Arikara collection in the Smithsonian Institution, Washington, D.C. The materials came from sites in South Dakota and date from 900 to 1832 AD. Teeth evaluated were the permanent mandibular canine, first and second premolar, and second permanent molar. Where a tooth was missing, its antimere was substituted.

This study addresses itself to the issue of whether or not the permanent second molar in this sample was significantly advanced in its development over that of the other teeth, whose developmental schedule significantly overlaps that of the second molar. Therefore, in each specimen, one representative of the permanent canine, first premolar, second premolar, and permanent second molar was also analyzed individually. The incisors and third molars were not analyzed separately because the development of the root apices of the incisors are completed early in the development of the second molar and the development of the third molar is variable.

For selection as subadults, specimens had to fulfill criterion 1, 2, or 3, and also 4 (Bass, 1987) of the following criteria: 1) the erupted third molar was unworn and had incomplete root development; 2) the third molar was in the process of erupting; 3) the third molar was unerupted; and 4) the basioccipital suture was not closed.

METHODS

The MFH system was used to determine dental age by reference to the radiographic images and of actual teeth. The male and female standards of the MFH method were averaged because previous attempts (Owsley, 1982) to determine the sex of a sample via discriminant analysis of tooth size did not produce a bimodal distribution in this sample. Moreover, the discriminant function failed to accurately identify the sex of the few specimens for whom sex determination via pelvic shape had been noted in the Smithsonian Institution archives.

For the radiographic analysis, three to four periapical radiographs were taken for each of the mandibles, depending on the size of the specimen. To obtain maximum detail and to avoid "burning out" partially calcified root structure, exposure timing was adjusted so that larger and denser mandibles were exposed at 0.30 second, while 0.25 second exposures were sufficient for smaller specimens or the anterior portion of the arch (Goaz and White, 1994). A GE100 Dental X-Ray Machine at 15 MA and 60 KVP, using Kodak DF 54 Ultra-Speed dental x-Ray film in adult and pediatric sizes were employed.

Age estimation was done by assessing the degree of crown and root development observed in the radiographs. All teeth judged to have been at less than the closed root apex stage were scored. Teeth with closed apices were assigned the mean age at apex completion for that tooth if the age was no more than 6 months younger or older than the dental age of other teeth with incomplete apices in the same specimen. Teeth with closed apices were dropped in cases where their age of completion was more than six months younger than that of teeth with incomplete apices.

When an individual had both developing permanent teeth and overlying deciduous teeth in the process of resorption, both were assigned a dental age according to the MFH methods (Moorrees et al., 1963a,b). If a discrepancy between the assigned ages of the deciduous tooth and its developing permanent successor occurred, the dental ages were averaged.

When the second molar root apices were complete, the developmental stage of the third molar was used to estimate age. Developing third molars, however, were not scored where the apex of the second molar was not complete. The third molar was evaluated only to improve age discrimination in second molars obviously older than the age assigned by root apex completion, because the developmental stages in the third molar vary broadly (Kullman et al., 1992; Mincer et al, 1992).

For the visual evaluation, the 53 cases were examined macroscopically for eruption of the mandibular permanent canine, first and second premolar, second permanent molar, and total dental age using the MFH method. Only teeth with moderate (W_2) or less wear were assessed for eruption level. Only teeth at eruption levels beyond the cemento-enamel junction of the first molar (E_3 and E_4) were deemed to have pierced the gingiva in life.

Eruption of teeth was scored as follows: E_1: crown just visible in crypt (initial appearance through the alveolus); E_2: crown erupting but the incisal edge or cusp tips had not yet reached the level of the cemento-enamel junction of the first permanent molar; E_3: crown erupted to the level of the first permanent molar's cemento-enamel junction, but was not in occlusion; and E_4: crown in occlusion with opposing tooth.

Teeth in either stage E_1, E_2, or E_3 were clearly scorable. Stage E_4 was judged to be useful to this examination only if a tooth had erupted just prior to death when minimal wear would be expected.

To determine the degree of wear which reasonably could be assumed to have occurred in less than a six month interval a new standard was created. Because other methods for determining occlusal attrition (Miles, 1963; Molnar, 1971; Scott, 1979) incorporate no means for determining minimal wear, the following criteria were created. These wear criteria are W_0: no visible wear W_1; wear in one or two planes only, comprising less than one-third of the area of any cusp; W_2: wear in 3 or more planes but comprising less than one-half the area of any cusp; and W_3: wear on more than half the area of any cusp. This minimal wear was observed visually with the aid of a 15X magnifying lens (lupe).

The 18 specimens with a permanent canine, first and second premolars, and permanent second molars in eruption stages E_3 and E_4 and dental wear stages of W_2 or less were placed in a sub-sample. Eruption stages were compared with dental development ages for the same tooth in each of the 18 specimens. Dental development ages of the sub-sample were also compared with those of the total sample.

For the entire sample and sub-sample, data were entered into and analyzed in Stata 3.1 (College Station, Texas). Student's t-tests, bivariate regression analyses, and analyses of variance were performed on the total dental development ages, individual dental development ages for the mandibular canines, first and second premolars, and second molars and eruption stages of the same teeth.

A test for intra-observer reliability through double determination of scores was done on two separate occasions. Results showed that intraclass correlation was within acceptable limits (r=.96).

RESULTS

The Wilcoxson sign rank tests of canine development compared with that of first and second premolars and second molars produced negative scores in all three comparisons. In other words, either the mean of second permanent molar dental development age was significantly advanced over that of the canine, or the canine was delayed by comparison with other mandibular teeth assessed.

Student's t-tests demonstrated that the mean of permanent second molar development stage was significantly different from that of canine and first and second premolar ages (Table 1). The Wilcoxson sign rank test clearly indicated in two out of three cases that the sum of positive ranks exceeded that of negative ranks. In other words, second molar development was advanced over that of the other teeth assessed.

In spite of significant differences in the means of the dental ages of the permanent canine, the premolars, and the second permanent molar, all the mandibular teeth assessed were shown in bivariate regressions to be significant predictors of each others' dental developmental stage (Table 2). The clearest association was between the premolars (R^2=0.98), with all other associations greater than R^2 = 0.90. In two specimens, upon visual inspection, the second permanent molar was found to have been erupting in advance of the canines and premolars.

The small size of the sub-sample with mandibular canines, first and second premolars, and second molars in the process of erupting or newly erupted conceivably could have increased the likelihood of a non-normally distributed data set. After a Scheffe multiple comparisons normalization was employed, Bartlett's test ruled out unequal variances between developmental and eruption stages.

Two way analysis of variance in which eruption stage was the predictor of the MFH dental age indicated that the eruption stages of all four teeth surveyed were significant predictors of total dental age (Table 3). By contrast, the individual dental ages of the four teeth examined separately were less consistent predictors of the eruption stage of the same tooth (R^2 between 0.36 and 0.67) (Table 4).

Graphical analysis of data produced several interesting associations. Figure 1 illustrates that the regression curve of dental development age for the four teeth displays a nonlinear distribution, with early development proceeding at a more rapid rate than later development. This may be ascribed to the well-known phenomenon in which the stages of root development appear more slowly than do the stages of crown development (Moorrees, 1963a). Canine development lags behind that of the other teeth at all ages. The premolars follow the same curve as that of the canines until approximately age 9. The slope of the second premolar development eventually overtakes that of second permanent molar development at approximately age 11.

Because of the shape of these curves, transformation of individual tooth ages to their logs was performed and these logs were regressed against total dental age. Figures 2, 3 and 4 give a clearer picture of the progression through developmental stages of the canine, first and second premolar by comparison with the second molar over the age ranges surveyed. The canine is delayed in its dental development age by comparison with that of the second permanent molar, most notably in individuals less than five years of age at death.

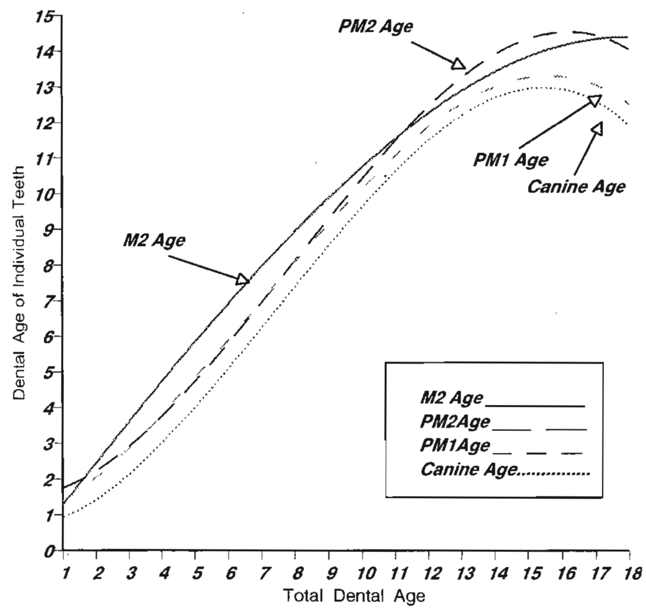

Fig. 1. Regression curves of developmental age for permanent mandibular teeth in the Arikara sample. The canine, the only tooth whose development has been determined to be sexually dimorphic, appears to lag behind the other teeth most dramatically in the youngest and oldest age ranges.

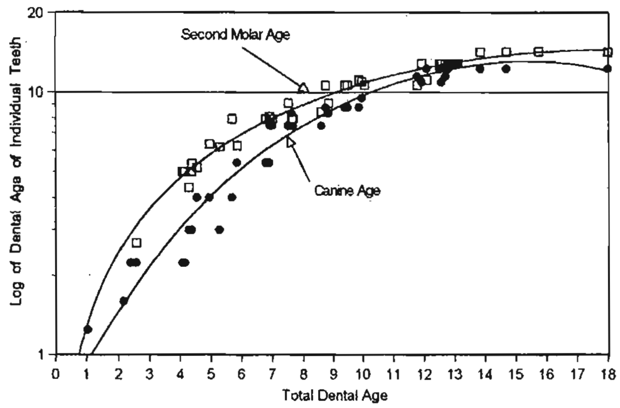

Fig. 2. The lag of canine developmental age behind the developmental age of the second molar in this sample is highlighted by plotting the log of the individual developmental ages for each tooth against total dental age. The highest degree of lag appears in the 2 to 5.5 year age range.

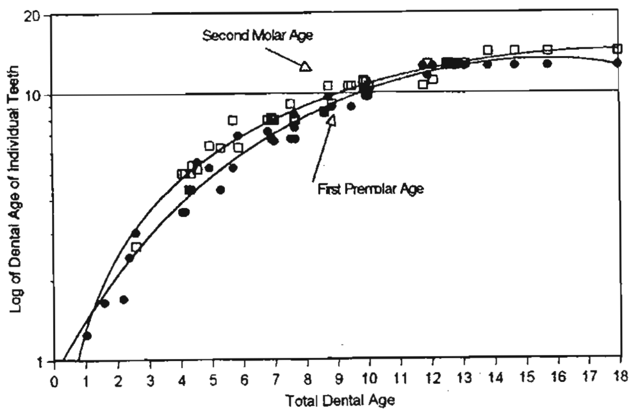

Fig. 3. Lag in first molar development is less impressive in this sample than the discrepancy between the second molar and the canine. Like the canine, the first premolar development never catches up with second molar development.

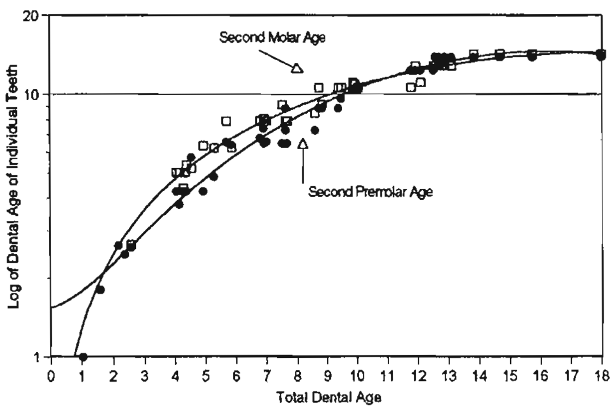

Fig. 4. The second premolar lags behind the developmental stage of the first premolar. However, the delay is less than that seen in the canine and first molar. The developmental ages of both the second premolar and the second molar follow essentially the same curve after the dental age of 10.0.

DISCUSSION

The results may be interpreted in a variety of different ways. The second premolar and permanent second molar may be significantly advanced in dental development age and eruption because the genetic program guiding the eruption schedule in this sample is different from that of the reference samples 246 European-derived individuals on which the MFH standards are based. Possibly, heavy occlusal function may have contributed to a more rapid rate of eruption in this sample than in the MFH sample and root development followed. However, explaining how occlusal loading could have been restricted to the posterior portion of the arch is difficult, if not impossible.

Alternatively, the canine and first premolar may be viewed as being significantly delayed by comparison with the dental development ages of the second premolar and the second permanent molar. This may be ascribed to the possibility that these children were ill or malnourished for some time before their death. The small amount of literature about dental development and eruption in children who are chronically ill or malnourished (Garn et al., 1973; Ghafari and Markowitz: in press) suggests that some delay may occur in canine and first premolar development. Another explanation of the results is that they indicate that most of the children in the sample were boys. However, no reports in the literature suggest that the first premolar erupts or develops any later in boys than in girls, although ample evidence exists for late male canine development and eruption (Demirjian and Levesque, 1980; Tomkins, 1996). Since the canine's development is most closely associated with that of the tooth most distal to it (R^2=0.98, $p<0.0005$), it is not unlikely that the first premolar would have been delayed due to a field effect (Kieser, 1986).

The possibility that the canine is significantly delayed in this sample must be examined not only for its possible causes (a preponderance of males, the effects of chronic illness and/or malnutrition, particularly in newly-weaned children) but for its effects. Calculation of the MFH dental age requires that the scores of eight individual mandibular teeth be used. Thus, delayed dental development in the canine could skew the dental age toward a younger total age. This might lead to the impression that the mandibular second molar erupted at an earlier age than it, in fact, did. A preponderance of males in the sample could produce such underestimation of dental ages.

Within the subsample, the number of teeth which had pierced the alveolus was too small for robust comparison with dental age. Nevertheless, the dental age of the teeth which were in the process of erupting or had newly erupted was very close to the median age of eruption for the four mandibular teeth taken from the Ten State Nutrition Survey (Smith, 1991). Moyers (1988) data (after Hurme) present considerably older means of eruption of the four mandibular teeth than does the Ten State Nutrition Study (Table 5). Yet, Table 5 shows that an approximately two and a half year range exists in the Hurme data. Thus, with the exception of the development seen on eruption of the few second molars observed erupting in this sample, both the Arikara percent of both root development (a rough guide to the range of stages seen at eruption) and eruption ages do not deviate from the

TABLE 1. Mean ages, t-scores, z-scores for mandibular permanent canine, first and second premolar, and second permanent molar dental development in the Arikara sample.

Variable	Number of observ-ations	Mean Age	s.d.	t-score	p>|t|	Wilcoxson sign-rank z	p>|z|
Canine age	40	7.34	3.83				
First premolar age	40	7.97	3.68				
Difference				-5.38	0.00	-4.15	0.00
Canine age	39	7.32	3.87				
Second premolar age	39	8.17	4.01				
Difference				-5.15	0.00	-4.17	0.00
First premolar age	43	8.17	3.88				
Second premolar age	43	8.46	4.24				
Difference				-2.63	0.01	-2.16	0.03
Second molar age	38	7.82	3.56				
Canine age	38	9.19	3.17				
Difference				-7.47	0.00	-4.85	0.00
Second molar age	42	9.55	3.25				
First premolar age	42	8.84	3.33				
Difference				4.82	0.00	4.08	0.00
Second molar age	40	9.55	3.32				
Second premolar age	40	9.12	3.81				
Difference				2.70	0.01	2.63	0.01

Mean is the average age of dental development; s.d. is standard deviation; p>|t| is the probability that the t statistic is wrong (in other words, that the confidence interval does not include the t statistic); p>|z| is the probability that the z (normalized data expressed as standard deviations from the mean) is wrong (that the confidence interval does not include the value of the z statistic).

TABLE 2. Bivariate regressions of dental development ages for four mandibular teeth.

Variable y	Variable x	Number of observ-ations	Coeff.	S.E.	t	p>|t|	R^2	p>F
Canine age	Second molar age	38	1.06	0.06	18.32	0.00	0.90	0.00
Canine age	Second premolar	39	0.93	0.04	22.72	0.00	0.93	0.00
Canine age	First premolar age	40	1.02	0.03	31.13	0.00	0.96	0.00
Second molar age	Canine age	42	0.94	0.04	21.35	0.00	0.92	0.00
Second molar age	First premolar age	40	0.84	0.04	24.31	0.00	0.94	0.00
Second molar age	Second premolar age	43	0.90	0.02	39.71	0.00	0.98	0.00

All x variables are regressed on all y variables. The purpose is to estimate how well dental ages of individual teeth will predict the dental ages of other individual teeth. Coeff. is the coefficient of the slope β ($Y=a+\beta x$); S.E. is standard error; R^2 is the percentage of error that is explained by the model; p>F is the probability that the F statistic is wrong, where F = the explained divided by the unexplained variance in the two means in an ANOVA.

TABLE 3. Analysis of variance with total MFH age as the predicted variable.

MFH age:	Tooth erupting	Number of observ-ations	Root MSE	F	R^2	p>F
Total MFH age	Canine	18	1.89	3.96	0.43	0.00
Total MFH age	First premolar	18	1.36	18.68	0.69	0.00
Total MFH age	Second premolar	18	1.54	12.46	0.59	0.00
Total MFH age	Second molar	18	1.56	6.48	0.64	0.00

The x or predictor variables are the four individual teeth. MSE is mean standard error.

range of variation normally seen in U.S. samples (Table 5). Also, personal experience of this author in 17 years of dental practice demonstrates that, while earlier eruption of the second molar is not the usual pattern, the occurrence is not rare in children of European ancestry.

The evidence for eruption sequences in non-European populations (Steggerda and Hill, 1952; Kent et al., 1978; Mayhall et al., 1978; Smith and Garn, 1987) may fail to take into account the effects of a high caries rate and poor dental care. Premature loss or extraction of the deciduous molars, as is often seen with access to refined sugar but in the absence of comprehensive dental care, can delay the eruption of the premolars (Brauer et al., 1966). Thus, studies purporting to demonstrate a routinely earlier eruption of the second permanent molar than of the permanent canine and premolar in nonindustrial populations may have failed to document delay in the eruption of the premolars.

This small subsample shows varying degrees of concordance between dental development age for each of the four teeth (particularly the canine) and the corresponding eruption time for those individuals in whom the four teeth were in the process of erupting or were newly erupted at death. The most likely explanations are sampling error and/or the less than perfect concordance between development (dental age) and eruption time in the permanent canine, first and second premolar, and second permanent molar in living patients (Table 5).

The difference in the means of dental development age at eruption for the permanent second molar between the European-derived population and the Arikara sample is just over nine months. Thus, creation of a separate standard for the second molar would be justified because of the early development of the second permanent molar, were it not for the conceivably confounding effect of the delay in the canine and first premolar.

In most of the specimens, canine and first premolar developmental stages are significantly delayed by comparison with second molar development. As the ages of individual teeth contribute to the MFH total dental age, delay in these two teeth likely has skewed the total age estimation toward younger ages. The possibility exists, then, that dental age has been systematically underestimated in this sample.

If canine development and that of its nearest neighbor, the first premolar, were affected in this sample by the ill health and possibly the poor nutrition that ultimately claimed these children's lives (Garn et al, 1973; Ghafari and Markowitz, in press), other evidence should corroborate this. Slight *cribra orbitalia*, considered an indication of nutritional stress, was observed in 13 cases in the entire sample. However, the means of the MFH dental age and comparative delay of the premolars and canine did not differ in this sub-sample (of those with *cribra orbitalia*) significantly from those of the full sample. Assuming that sampling error is not responsible for this result, *cribra orbitalia* apparently is not associated with delay in canine development in this group.

TABLE 4. Analysis of variance with individual dental ages used to predict their individual eruption stages.

Tooth Examined	Number of observ-ations	Root MSE	F	R^2	p>F
Canine eruption stage (y) dental age (x)	18	1.15	8.55	0.36	0.01
First premolar eruption stage (y) dental age (x)	18	0.57	30.13	0.65	0.00
Second premolar eruption stage (y) dental age (x)	18	0.59	30.14	0.65	0.00
Second molar eruption stage (y) dental age (x)	18	0.82	34.00	0.67	0.00

Root MSE is the variance of the estimator plus the square of its bias. R^2 is the percent of variance in y that is explained by the variance in x (estimator).

TABLE 5. Chronological ages at eruption for four mandibular teeth in modern North American whites and dental development ages at eruption stages E_3 and E_4 for the Arikara sample.

Tooth erupting	% root at eruption[1]	Minimum age[2]	Mean age[2]	Maximum age[2]	Mean eruption age Ten State Nutrition Survey[3]	Arikara % root at eruption	Arikara mean age
Canine	25.00-50.00	9.46	10.65	11.63	9.70	30.00-60.00	11.17
First premolar	50.00	9.05	10.05	12	10.00	25.00-50.00	11.26
Second premolar	50.00	9.40	11.18	12.40	10.90	25.00-50.00	12.05
Second Molar	70.00	10.50	11.89	13.25	11.24	70.00-100.00	11.07

[1]After Moyers (1988). [2]After Hurme reproduced in Moyers (1988). Hurme's data are the means of the male and female scores. Moyers also presents his own data on eruption in which eruption times are approximately six months later than those in Hurme's chart. Hurme's data are for individuals of known chronological age, whereas the Arikara means are based on MFH dental aging. Although dental age is well correlated with chronological age (Demirjian et al., 1985), the association is not perfect. [3]Data from Smith et al. (1991) are averaged means.

Because the only clinically significant difference in development rate in the teeth between boys and girls is in the canine and because the canine appears consistently delayed in this sample by comparison with other teeth, the only plausible suggestion that can be made based upon the analyses to date — particularly in the absence of positive evidence of prolonged ill health or malnutrition — is that this is a sample largely composed of boys, particularly in the absence of positive evidence of prolonged ill health and/or malnutrition. Highly detailed dental casts of each specimen should be examined for enamel hypoplasia, which would corroborate the suggestion of a prolonged period of ill health for these children before death.

CONCLUSIONS

The data, as analyzed in this study, do not justify the creation of a separate standard for Arikara dental development. The sample contains too few specimens in which the second permanent molar was actually erupting to state securely that early eruption of this tooth was the pattern in this population. Some evidence suggests that the crown and root development of the mandibular second molar in this sample may have proceeded more rapidly than that in the MFH reference sample. However, if this sample contains a preponderance of boys, normal delay in canine and premolar development, by comparison with an average of the MFH male and female dental ages for these tooth, would lead to a systematic underestimation of the total age. Mandibular second permanent molar and second premolar development then would appear relatively precocious for the assigned dental age.

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