Technical Note: Primary Tooth Mineralization and Exfoliation Ages Calculated from the Moorrees-Fanning-Hunt Study

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ABSTRACT Staging of the formation of teeth and shedding of the primary teeth are particularly useful for age estimation of archaeological and forensic specimens, as well as for gauging whether a child's tempo of maturation is progressing within normal limits. Staging can be done using radiographs or with direct inspection of dental remains. Standards for the primary dentition are scarce, but obviously needed for young children. This note provides tables, by sex, of the normative ages of the mineralization of three mandibular tooth types (c, m1, m2) as well as of root resorption and times of shedding of these tooth types. The data are transformed from charts developed by Moorrees, Fanning and Hunt (1963 *Am J Phys Anthropol* 21:99-108). Conversion to numeric form is intended to aid in using these data for statistical comparisons. *Dental Anthropology* 2010;23(2):61-65.

Tooth-formation standards for the primary teeth are quite scarce, largely because these teeth begin developing *in utero* where analysis is complicated and because dental researchers have avoided dealing with very young children, especially where irradiation is involved. A singular exception, due in large part to the tireless efforts of Arthur B. Lewis, is the analysis of primary tooth mineralization in children between birth and about 16 years of age (Moorrees *et al*., 1963a).

While data from the earliest-forming teeth, the incisors, are unavailable, Moorrees, Fanning and Hunt (1963a) reported on the formative stages and the later exfoliation of three primary tooth types, specifically the canine, first and second molars in the mandible. This report, in the *American Journal of Physical Anthropology*, accompanies these authors' better-known study of the permanent dentition (Moorrees *et al*., 1963b). Their study of the primary teeth has been useful in several studies, but the authors chose to present their data in graphical form only, which has been an impediment to using the data statistically. In hopes that these tabulated data will be more useful to others, I have converted the graphical data into more applicable tables of medians and standard deviations.

To my knowledge, these are the only published data on the tooth mineralization of primary teeth that span the relevant postnatal age interval (neonates up to school age). Comparable radiographic data were collected in the Bolton-Brush Study (Cleveland, Ohio) as reviewed by Behrents (1985) and in the Child Research Council (Denver, Colorado) as reviewed by McCammon (1970), but these radiographs do not seem to have been analyzed to develop tooth-formation data. Demirjian and colleagues (*e.g*., Demirjian *et al*., 1982) also collected the needed data from their longitudinal study of French-Canadian children in Montreal, though these data do not seem to be published.

In contrast, there are several studies that report on the *eruption* ages of the primary teeth (*e.g*., Falkner, 1957; Infante, 1974; Delgado *et al*., 1975; Tanguay *et al*. 1986), based either on direct intraoral examinations or on serial dental casts (Moorrees, 1959).

TABLE 1. The stages of tooth formation and resorption developed by Moorrees and coworkers

Stage	Code
Tooth Mineralization	
Coalescence of cusp	C co
Cusp outline complete	C oc
Crown ½ complete	Cr ½
Crown ¾ complete	Cr ¾
Crown complete	Cr c
Initial root formation	R i
Initial cleft formation	Cl i
Root length ¼	R ¼
Root length ½	R ½
Root length ¾	R ¾
Root length complete	R c
Apex ½ closed	A ½
Apex closure complete	A c
Tooth Exfoliation	
One-fourth root reorption	Res ¼
One-half root resorption	Res ½
Three-Fourths root resorption	Res ¾

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TABLE 2. Median ages (years), by sex, for stages of mandibular primary tooth formation[1]

Formation Stage	Girls median	sd	Boys median	sd
Primary canine				
C co	•	•	•	•
C oc	0.1	0.09	0.2	0.09
Cr ½	0.3	0.10	0.3	0.10
Cr ¾	0.5	0.12	0.5	0.12
Cr c	0.7	0.14	0.7	0.14
R i	0.9	0.15	0.8	0.16
R ¼	1.1	0.17	1.0	0.17
R ½	1.3	0.20	1.3	0.20
R ¾	1.8	0.25	1.9	0.25
R c	2.1	0.27	2.0	0.26
A ½	2.5	0.32	2.5	0.32
A c	3.0	0.36	3.1	0.37
Primary first molar				
C co	•	•	•	•
C oc	•	•	•	•
Cr ½	0.1	0.09	0.2	0.09
Cr ¾	0.2	0.10	0.3	0.09
Cr c	0.3	0.11	0.5	0.12
R i	0.6	0.12	0.6	0.13
Cleft	0.6	0.12	0.7	0.14
R ¼	0.6	0.14	0.8	0.15
R ½	0.9	0.16	0.9	0.16
R ¾	1.1	0.18	1.2	0.19
R c	1.3	0.19	1.3	0.20
A ½	1.5	0.22	1.7	0.24
A c	1.8	0.25	2.0	0.26
Primary second molar				
C co	•	•	•	•
C oc	•	•	0.2	0.09
Cr ½	0.2	0.10	0.3	0.10
Cr ¾	0.5	0.12	0.5	0.12
Cr c	0.7	0.14	0.7	0.14
R i	0.9	0.16	0.9	0.16
Cleft	1.0	0.16	1.0	0.16
R ¼	1.3	0.20	1.3	0.21
R ½	1.6	0.22	1.9	0.23
R¾	1.9	0.26	2.0	0.21
R c	2.0	0.27	2.0	0.27
A ½	2.4	0.30	2.4	0.31
A c	2.8	0.35	3.1	0.37

[1]Statistics are the median chronologic age and its standard deviation (sd). These norms were developed from serial x-rays taken on 136 boys and 110 girls from among those enrolled in the Fels Longitudinal Study, Yellow Springs, Ohio.

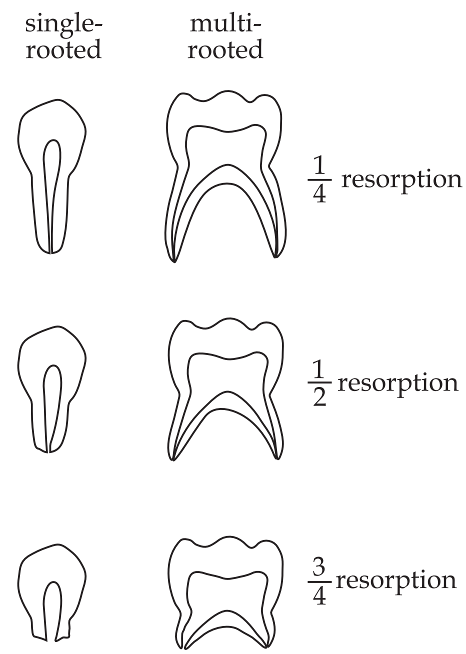

Fig. 1. Sketches of the 3 stages of primary tooth root resorption used byMoorrees, Fanning and Hunt (1963a).

THE DATA

As stated in their article, Moorrees *et al*. (1963b) collected data from the Fels Longitudinal Study located in Yellow Springs, Ohio (Roche, 1992). This is one of the premiere longitudinal growth studies in the world, following children from birth into biological adulthood. The Fels study had its inception in 1929, and from then until the early 1960s (when Moorrees and coworkers collected their data), between 500 and 600 children had been enrolled (Roche, 1992). Lateral and oblique headfilms (radiographs) were taken at 3-month intervals during the first year of life and at 6-month intervals thereafter (Moorrees *et al*., 1963a). These planar radiographs were an efficient means of visualizing all of the teeth with one or two films; this was in the era before panoramic films were available (Graber, 1966). Experience suggests that the researchers focused on the mandibular teeth because the tooth images are clearer in this arch, whereas the maxillary images are overlain with complex bony shadows. Strong intercorrelations between stages of homologous teeth in the two arches (Moorrees and Reed, 1954; Kent *et al*., 1978) can be used as an argument for restricting attention to just one arch.

Moorrees *et al*. state that their standards are based on the serial radiographic records of 136 boys and 110 girls.

Moorrees and coworkers thought the charts that they developed were most useful for clinical application. For a single case, this might be true. I used Photoshop CS3 to measure high-quality scans of he charts and then transformed these measurements back to decimal years. (Comparable tabulations of permanent tooth formation

TABLE 3. Median ages (years), by sex, for stages of mandibular primary tooth resorption and exfoliation

Stage	Girls median	Girls sd	Boys median	Boys sd
Canine				
Res ¼	4.93	0.45	6.08	0.55
Res ½	7.26	0.65	8.41	0.74
Res ¾	8.73	0.76	9.79	0.84
Exfoliation	9.53	0.83	10.64	0.92
First molar, mesial root				
Res ¼	4.90	0.45	5.45	0.49
Res ½	7.25	0.64	7.58	0.68
Res ¾	8.85	0.77	9.41	0.82
Exfoliation	10.12	0.87	10.79	0.93
First molar, distal root				
Res ¼	5.17	0.48	6.39	0.58
Res ½	7.68	0.66	8.35	0.73
Res ¾	9.75	0.81	10.01	0.87
Exfoliation	10.12	0.87	10.79	0.93
Second molar, mesial root				
Res ¼	6.09	0.55	6.65	0.59
Res ½	8.31	0.73	8.61	0.74
Res ¾	10.02	0.87	10.42	0.90
Exfoliation	11.13	0.96	11.67	1.00
Second molar, distal root				
Res ¼	6.95	0.62	7.45	0.65
Res ½	8.61	0.76	9.51	0.82
Res ¾	9.95	0.87	11.08	0.95
Exfoliation	11.12	0.96	11.64	1.00

standards [Moorrees *et al*., 1963b] are available in Harris and Buck, 2002.)

THE RESEARCHERS

As an aside, it is interesting to note the serendipity (synergism) of Moorrees, Fanning, and Hunt's collaboration. Moorrees (b. 1916 – d. 2003) certainly had a knowledgeable interest in development of the dentition (see, *e.g*., Moorrees, 1959), and he was in a position at the Forsyth Dental Infirmary (Harvard School of Dental Medicine) to coordinate the study (Moorrees, 1993; Peck and Will, 2004). Elizabeth Fanning (b. 1918 – d. 2007) was trained in Australia as a dentist (Townsend, 2007), and she brought her expertise in scoring tooth-mineralization stages. Beginning with her thesis (Fanning, 1960), Fanning developed elaborate grading systems; these have generally been eschewed by subsequent workers as too detailed to allow high intraobserver reliability in their hands. However, if mastered, these stages of short duration provide fine-grained analysis. Ed Hunt (b. 1922 – d. 1991) a physical anthropologist at Harvard University had research interests in growth and development, but he also had a strong background in quantitative methods (Baker, 1992), and he was the team member who actually calculated the probit analyses (*e.g*., Finney, 1971) that yielded the median ages at each stage of tooth formation and of exfoliation. The collaboration involved Moorrees overseeing the study, Fanning scoring the tooth stages from the films, and Hunt calculating the statistics.

The unsung hero in this scenario is Arthur B. ("Buzz") Lewis, a dental specialist in orthodontics, who maintained a private practice as well as an appointment on the orthodontic faculty at Ohio State University throughout his professional life. Lewis also was a research associate at the Fels Research Institute for a full half-century (Mayerson, 1996), and most dental anthropologists will recall his numerous publications with Stanley Garn. Lewis is the man responsible for taking the dental radiographs of the participants at Fels, with X-rays taken every 3 months for the first year, then at 6-month intervals after that. Without the radiographs of these infants—a considerable undertaking in itself—there would have been no data to collect.

PRIMARY TOOTH FORMATION

The original charts record two sequential processes, one is the formation of these three primary teeth (c, m1, m2) that begin mineralization as early as the second trimester (Lunt and Law, 1974) and continue till about 3 years of age. The second process, some years later, occurs during the "second transition" of dental development (van der Linden and Duterloo, 1976), when these primary teeth are exfoliated and replaced by the permanent canine and premolars in each quadrant. Shedding of these primary teeth occurs between 9 and 11 years of age, with subsequent emergence of the successors.

Moorrees *et al*. used the same 12 stages of tooth mineralization as they used elsewhere to score the permanent teeth (Moorrees *et al*. 1963b). One additional stage (cleft formation) was used to note the interradicular area of multi-rooted teeth.

The interval from about 2 ½ years (when all 20 primary teeth have emerged into occlusion) to about 6 years of age (when the permanent first molar emerges) is viewed as the interval of the intact primary dentition. These data (Tables 1, 2) show that these three teeth begin their resorptive processes by about 5 years of age (somewhat later in boys) when the canines and first molars initiate root resorption. This is, of course, some years before exfoliation.

Histologically, osteoclasts are congregated and mature ahead of the successor's dental sac (Wise *et al*., 1999, 2002, 2008), and these multinucleated cells remove the bone and deciduous tooth roots ahead of the replacement tooth. Timely resorption of the primary tooth's root is necessary for normal eruption of the permanent tooth. The biochemical signaling for lysis is from the dental follicle of the permanent successor. This is why, when the successor is congenitally absent, exfoliation of the primary tooth is delayed, often for many years though roots still tend to

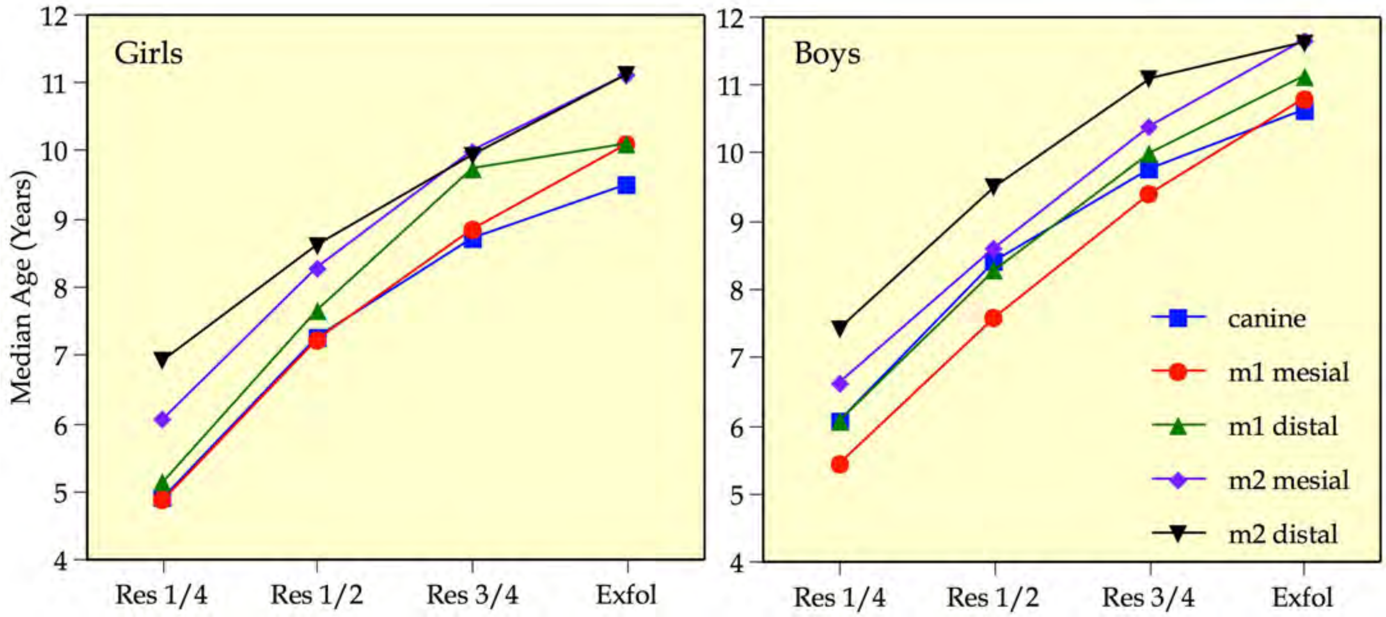

Fig. 2. Plots of the median ages of primary tooth resorption. Girls tend to be developmentally ahead of boys, though the patterns of change and the sequencing are similar in the two sexes. Mesial root of m1 tends to be the first of these three teeth to exhibit resorption, while the distal root of m2 is the last to resorb. Sequencing coincides with the high prevalence of cases where m1 exfoliates earlier than m2 (and the first premolar emerges earlier than the second).

resorb albeit slowly (*e.g.*, Haselden *et al*., 2001; Nordquist *et al*. 2005; Bjerklin *et al*., 2008).

Primary tooth mineralization progresses more rapidly than in the permanent successors, and this is reflected in smaller overall sizes, thinner tissue components, and lower enamel and dentin densities (*e.g.*, McDonald, 1978; Wilson 1989; Hunter, 2000). The Moorrees charts (Table 2) show that about half of the crowns are mineralized *in utero*, so their staging is missed even when radiographs are taken at birth.

Results show that girls progress faster than boys. Differences are small and not significant statistically (based on univariate comparisons of 95% confidence limits), but younger median ages in girls are widespread across the data. Parenthetically, this raises the interesting question of ethnic and environmental influences on rates of development. Assessed multivariately, Tanguay and coworkers (1986) found earlier tooth primary emergence for *boys*, though other studies have reported different results, generally no discernible sex difference (Demirjian, 1978).

The first molar is particularly fast-forming. It completes crown formation (amelogenesis) by about 4 months after birth and roots are apexified by 2 years of age. The other two tooth types form more slowly, with average crown completion at about 0.7 years (~ 8 months), and with root completion (A_c) by 3 years of age.

TOOTH EXFOLIATION

Shedding of these teeth occurs between about 10 and 11 years of age (Table 3), which is consistent with conventional mnemonics that these primary teeth are shed and their successors emerge around the 2-year interval of the second transition (van der Linden and Duterloo, 1976)

Interestingly, resorption of the roots of these primary teeth begins several years earlier. Resorption is noted on the canine and first molar by about 5 years of age. Three stages of root resorption were scored, along with exfoliation as the ultimate event (Fig. 1). Initial evidence (R¼) of resorption occurs late, between 6 and 7 years of age, for the second molar. Durations of the exfoliation process can be gauged by comparing the earliest evidence of root loss (R¼) to when the tooth actually is lost. The process takes 4 to 5 years on the average, but somewhat less for the canine (~ 4 years) than the two molars.

Fanning's attention to detail allows us to see that the mesial root of the molars resorb faster than the distal root. This may be due to the mesial crown tip of molars (*e.g.*, Dempster *et al.* 1963), so the mesial root is under greater compression when the molar is under pressure. This cause is speculative, but precocity of the mesial root attaining resorption stages is consistent across the data.

Table 3 also discloses the strong trend for girls to shed these teeth ahead of boys. Normal shedding of a primary tooth involves lysis of the roots and of the bone ahead of the succeeding tooth (Wise and King, 2008), so the female precedence that has long been known for permanent tooth emergence (Hurme 1949) is part and parcel of this process.

OVERVIEW

This note presents tabled statistics for three primary mandibular tooth types (c, m1, m2) with regard to their mineralization (Table 2) and their subsequent resorption (Table 3). Tables are transformed from the graphs produced by Moorrees *et al*. (1963a) with the intent of making the data more usable for statistical applications.

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