

Brief Communication: The London Atlas of Human Tooth Development and Eruption

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ABSTRACT The aim of this study was to develop a comprehensive evidence-based atlas to estimate age using both tooth development and alveolar eruption for human individuals between 28 weeks in utero and 23 years. This was a cross-sectional, retrospective study of archived material with the sample aged 2 years and older having a uniform age and sex distribution. Developing teeth from 72 prenatal and 104 postnatal skeletal remains of known age-at-death were examined from collections held at the Royal College of Surgeons of England and the Natural History Museum, London, UK (M 91, F 72, unknown sex 13). Data were also collected from dental radiographs of living individuals (M 264, F 264). Median stage for tooth development and eruption

for all age categories was used to construct the atlas. Tooth development was determined according to Moorrees et al. (*J Dent Res* 42 (1963a) 490–502; *Am J Phys Anthropol* 21 (1963b) 205–213) and eruption was assessed relative to the alveolar bone level. Intraexaminer reproducibility calculated using Kappa on 150 teeth was 0.90 for 15 skeletal remains of age <2 years, and 0.81 from 605 teeth (50 radiographs). Age categories were monthly in the last trimester, 2 weeks perinatally, 3-month intervals during the first year, and at every year thereafter. Results show that tooth formation is least variable in infancy and most variable after the age of 16 years for the development of the third molar. *Am J Phys Anthropol* 142:481–490, 2010. © 2010 Wiley-Liss, Inc.

Age estimation for humans plays an important role in mass disasters and unaccompanied or asylum-seeking minors in the absence of proper documents. It also contributes to anthropology and forensic sciences, where age at death is estimated for skeletal remains (Hillson, 1996). Teeth survive inhumation well and show less variability than skeletal age, and the developing dentition is therefore better than other developmental indicators available for age estimation up to maturity (Garn et al., 1960; Demirjian, 1986; Smith, 1991). Humans have two generations of teeth: the deciduous dentition, which begins to develop around the sixth week in utero, and the permanent dentition, which reaches completion in early adult life. This long span of tooth development, eruption, shedding, and maturing is an orderly and sequential process. Crown or root growth and maturation stages as well as eruption relative to the alveolar bone level can be used to estimate dental age in both living and skeletal remains. (Demirjian, 1986) The aim of this study was to develop a comprehensive evidence-based atlas to estimate age using both tooth development and alveolar eruption for individuals between 28 weeks in utero and 23 years.

MATERIALS AND METHODS

Materials

This was a cross-sectional retrospective study of 704 archived records: radiographs of known age individuals and known age-at-death skeletal remains.

Individuals aged 28 weeks in utero to less than two years of age. All available individuals aged between 28 weeks in utero and 2 years of age were examined from two collections of known age-at-death human remains detailed in Table 1. The first was the Spital-

fields Collection at the Human Origins Group, Paleontology Department, Natural History Museum, London (Molleson and Cox, 1993), that consists of 15 females, 22 males, and 13 unknown sex ($N = 50$); the second was Maurice Stack's collection, which is part of the Odontological Collection at the Royal College of Surgeons of England (Stack, 1960) made up of 69 males and 57 females ($N = 126$).

Individuals aged 2–24 years of age. Good quality archived dental panoramic radiographs were selected, with all teeth in focus, of healthy individuals ($N = 528$) aged 2–24 years from the Institute of Dentistry, Barts and the London School of Medicine and Dentistry. All radiographs had previously been taken for diagnosis and treatment. The sample was made up of two ethnic groups: about half were white and half Bangladeshi. Mean ages of tooth development are not significantly different in these groups (Liversidge, 2009). Each chronological year was represented by 12 males and 12 females. A uniform age distribution was chosen to equalize accuracy over all age groups (Konigsberg and Frankenberg,

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TABLE 1. Sample and sex distribution for each age group used to develop the atlas of tooth development and eruption

Age	Spitalfields			Stacks		Radiographs		Total		Sum
	Male	Female	Unknown	Male	Female	Male	Female	Male	Female	
Skeletal remains										
28 to <32 weeks in utero	–	–	–	8	4	–	–	8	4	12
32 to <36 weeks in utero	–	–	–	8	7	–	–	8	7	15
36 to <39 weeks in utero	–	–	–	15	15	–	–	15	15	30
39 weeks in utero to <1 week after birth	–	–	–	15	15	–	–	15	15	30
1 week to <3 months	1	7	1	14	11	–	–	15	18	34
3 months to <6 months	4	1	1	6	2	–	–	10	3	14
6 months to <9 months	3	3	1	1	2	–	–	4	5	10
9 months to <12 months	5	–	6	2	1	–	–	7	1	14
1+ year ^a	9	4	4	–	–	–	–	9	4	17
Radiographs										
2+ years	–	–	–	–	–	12	12	12	12	24
3+ years	–	–	–	–	–	12	12	12	12	24
4+ years	–	–	–	–	–	12	12	12	12	24
5+ years	–	–	–	–	–	12	12	12	12	24
6+ years	–	–	–	–	–	12	12	12	12	24
7+ years	–	–	–	–	–	12	12	12	12	24
8+ years	–	–	–	–	–	12	12	12	12	24
9+ years	–	–	–	–	–	12	12	12	12	24
10+ years	–	–	–	–	–	12	12	12	12	24
11+ years	–	–	–	–	–	12	12	12	12	24
12+ years	–	–	–	–	–	12	12	12	12	24
13+ years	–	–	–	–	–	12	12	12	12	24
14+ years	–	–	–	–	–	12	12	12	12	24
15+ years	–	–	–	–	–	12	12	12	12	24
16+ years	–	–	–	–	–	12	12	12	12	24
17+ years	–	–	–	–	–	12	12	12	12	24
18+ years	–	–	–	–	–	12	12	12	12	24
19+ years	–	–	–	–	–	12	12	12	12	24
20+ years	–	–	–	–	–	12	12	12	12	24
21+ years	–	–	–	–	–	12	12	12	12	24
22+ years	–	–	–	–	–	12	12	12	12	24
23+ years	–	–	–	–	–	12	12	12	12	24

^a Sample is 1 year to <2 years, and the same applies to all ages to the age of 24.

2002). Exclusions were the following: retained deciduous tooth, an impacted tooth, or a resorbing deciduous root associated with a permanent tooth other than its successor. Other exclusions were the presence of a developmental anomaly, a developmental absence of a tooth, or extracted tooth/teeth.

Methods

Stage identification was done by the first author (SJA). Tooth developmental and alveolar eruption stages of the right side of the jaw from each radiograph were identified on a radiographic viewer with the help of a magnifying glass. Isolated teeth for the human skeletal remains collections were observed directly when radiographs were not available. Each developing tooth (crown and root) was assessed according to modified Moorrees stages (Moorrees et al., 1963a,b) shown in Figures 1–3. The last three stages of tooth development (Rc, A 1/2, and Ac) are differentiated by subtle differences that relate to the dentin edges at the root end, the apex width, and the width of the periodontal ligament space (PDL). Root length is complete (Rc) when the dentin edges are parallel with an open apical end and a wide PDL. Apex half (A 1/2) is the stage where the root terminal is maturing by narrowing at the apical end and making the dentin root ends converge but still having the PDL space wide. Tooth development reaches completion

(Ac) when the root apex is closed radiographically with normal PDL space.

The remaining root and the distal root of molars were selected when root resorption and formation stages were assessed. Modified Bengston's stages (Bengston, 1935; Liversidge and Molleson, 2004) were used in assessing tooth eruption stage in relation to bone level, ranging from occlusal or incisal surface of a tooth below bone for mandibular teeth or above bone for maxillary teeth, at alveolar crest, at midway between alveolar bone and occlusal plane, and at occlusal plane (see Fig. 4). After assessing the developmental and eruption stages, the median was identified from minimum to maximum stages for each stage and for each tooth. These were tabulated for males, females, and combined sex for each of the following age groups: the seventh, eighth, and ninth month of gestation; birth at midpoint of 2 weeks; the first, second, third, and fourth 3 months of life; and for each chronological year over the age of 1 up to the age of 23 years. Tooth development and eruption stages were assessed twice for 15 skeletal remains (150 teeth) and 50 radiographs (605 teeth) at different occasions to determine the intraexaminer reliability calculated using Kappa.

Each tooth was drawn by hand by the first author (SJA) as an international paper size A4 scale using a pigment liner (Staedtler[®]) size 0.8 on a tracing pad over a 5-mm isometric graphic pad. Each drawing was














	ci: initial cusp formation		Ri: initial root formation with diverge edges
	Cco: Coalescence of cusps		R 1/4: root length less than crown length
	Coc: Cusp outline complete		R 1/2: root length equals crown length
	Cr 1/2: crown half completed with dentine formation		R 3/4: three quarters of root length developed with diverge ends
	Cr 3/4: crown three quarters completed		Rc: root length completed with parallel ends
	Crc: crown completed with defined pulp roof		A 1/2: apex closed (root ends converge) with wide PDL
			Ac: apex closed with normal PDL width

Fig. 1. Description of modified Moorrees' stages (Moorrees et al., 1963a,b) used to identify tooth developmental stages of single rooted teeth. PDL refers to "periodontal ligament space." [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]














	Ci: initial cusp formation		
	Cco: Coalescence of cusps		R 1/4: root length less than crown length with visible bifurcated area
	Coc: Cusp outline complete		R 1/2: root length equals crown length
	Cr 1/2: crown half completed with dentine formation		R 3/4: three quarters of root length developed with diverge ends
	Cr 3/4: crown three quarters completed		Rc: root length completed with parallel ends
	Crc: crown completed with defined pulp roof		A 1/2: apex closed (root ends converge) with wide PDL
	Ri: initial root formation with diverge edges		Ac: apex closed with normal PDL width

Fig. 2. Description of modified Moorrees' stages (Moorrees et al., 1963a,b) used to identify tooth developmental stages of multi-rooted teeth. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

based on the "ideal" or "model" tooth supplied in the Wheeler's Atlas of Tooth Form (Wheeler, 1984). The drawing was then scanned, finished, and colored using Adobe Photoshop[®] software 7.0. Three drawings were made for the prenatal dentition each representing a midpoint of 1 month for the last 3 months of pregnancy and one drawing was made for birth representing a midpoint of 2 weeks around a full-term pregnancy birth; corrected age around 40 gestational weeks was used (O'Neill, 2005); four drawings for the first year of life each representing a midpoint of 3 months for each quadrant of the year were done and one drawing for each chronological year thereafter was made representing midpoint of 1 year each. The diagrams illustrate the median tooth developmental and alveolar eruption stages. Diagrams were made for males, females, and combined sex.

RESULTS

Kappa value was 0.90 and 0.81 for skeletal material and radiographs, respectively (combined 0.85), indicating excellent agreement (Landis and Koch, 1977). Figure 5 shows the dentition of a 5-year-old child with explanation of the illustration. The full atlas for combined sex is shown in Figure 6. Teeth in this new atlas mimic the radiographic presentation with the pulp area black and the enamel white; the dentin is gray for deciduous teeth and green for permanent. Teeth were spaced with accentuated developmental stages to ease identification. Developing third molars for the ages 16–23 years were presented separately on the right hand side with the second molars, because the rest of the permanent dentition was fully matured by the age of 15. Data from males and females were pooled in view of the fact that the median of tooth development in females preceded males between the ages 6 and 14, but by usually only one stage and not in all teeth, and this was not consistent. The

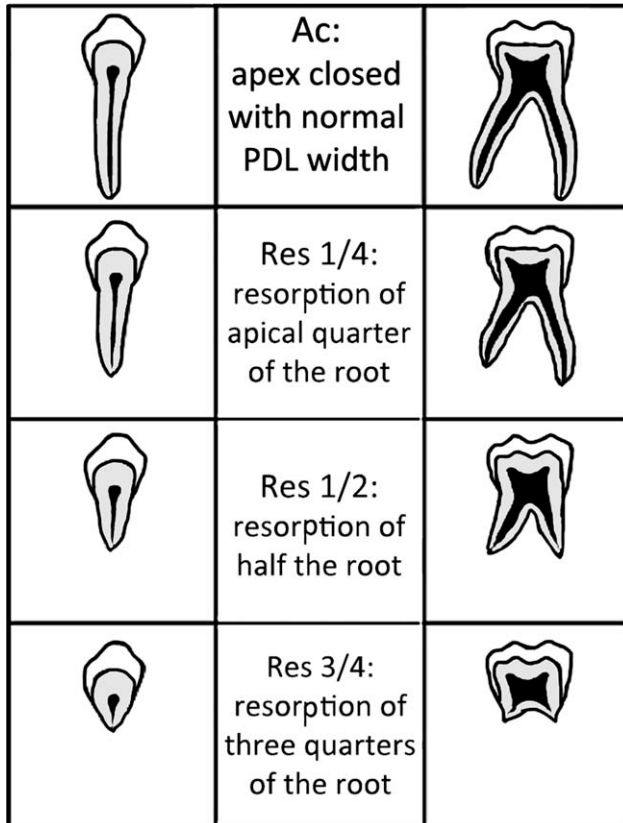


Fig. 3. Description of modified Moorrees' stages (Moorrees et al., 1963b) used to identify root resorption in single and multi-rooted teeth.

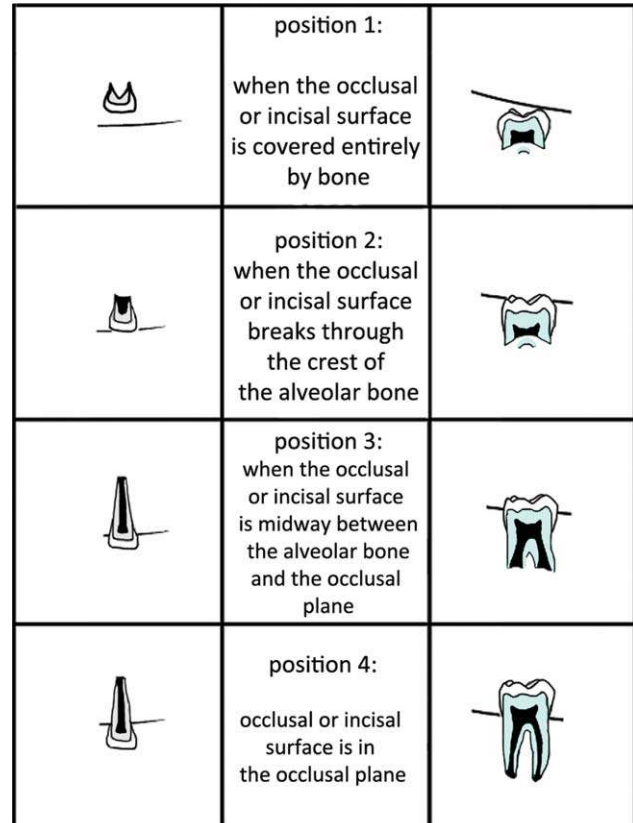


Fig. 4. Description of modified Bengston's stages (Bengston, 1935) used to identify tooth eruption. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

combined sex data are presented in Tables 2–9 with minimum, maximum, and median stages. The spread of the stages around the median was minimal and was usually limited to plus or minus one stage, which is expected in regard to the biological variation between different individuals. Females in general preceded males in tooth development; this was particularly noticeable between the ages 6–14 years. After the age of 15, males were more advanced in third molar maturation; this was also the tooth with the most pronounced variation between subjects in the same age group. Tables 10 and 11 give median age of alveolar eruption and full eruption from our study with estimated clinical emergence from Lysell et al. (1962) and Haavikko (1970).

DISCUSSION

The early history of illustrating tooth development during childhood is reviewed by Smith (1991). The best known atlas is by Schour and Massler (1941) consisting of 21 diagrams with an age range from 5 months in utero to 35 years. Each diagram is an anatomical drawing showing whole teeth in their developmental position. Each diagram is labeled with an age in months or years with a range of ± 3 , 6, or 9 months, some of which overlap. No details of sample size are given, but Smith (1991) points out it was probably based on Logan and Kronfeld's anatomical and radiographic data of 26 or 29 autopsy specimens, 20 of whom were younger than two (Logan and Kronfeld, 1933; Kronfeld, 1935a,b,c; Logan,

1935). This atlas or adaptations of it thereof are to be found in most standard dental anatomy textbooks.

Gustafson and Koch (1974) constructed a schematic representation of tooth formation and eruption from 20 sources combining anatomical, radiographic, and gingival eruption data. This extends from prenatal to 16 years and shows the range and peak age for each stage. Ubelaker's atlas (Ubelaker, 1978) of dental formation and eruption among American Indians was also compiled from a variety of sources, and it used the "early end of the published variation in preparing the chart" because "some studies suggest that teeth probably form and erupt earlier among Indians" (Ubelaker, 1978). Kahl and Schwarze (1988) updated Schour and Massler's atlas using 993 radiographs of children aged 5–24 and produced charts for separate sex for each age. Both Kahl and Schwarze (1988) and Ubelaker (1978) present anatomical drawings with no internal dental structure, yet are based fully or partly on the radiographic data. Internal hard tissues of a developing tooth can help distinguish between developmental stages thus improving sensitivity and accuracy.

Previous atlases and charts are hampered by inadequate age ranges not covering the entire developing dentition. The new atlas covers as much of the developing dentition as possible and all ages are represented. Each illustration in the new atlas from ages 1 to 23 shows tooth development and eruption at the midpoint of the chronological year. Developmental stages were

illustrated as radiographic representations and clarified by the addition of written descriptions. Teeth were spaced to ease stage assessment making it applicable to both radiographs and direct observation. Initially, we based the atlas on data from Spitalfields and archived radiographs, and the first year of life was represented by only two illustrations of 6 months duration, with midpoints at 3 and 9 months. Pilot testing of this on neonatal skeletal remains revealed numerous individuals

dentally more advanced than 3 months but less advanced than 9 months. This fast rate of deciduous tooth development indicated the need for shorter age group intervals of 3 months for the first year. Adding data from Stack's collection extended the age range to include the last trimester and the data were sufficient to have 1 month age groups for the prenatal and birth (39–41 weeks) age categories. We aimed for a uniform age distribution for the new atlas by selecting similar numbers of males and females in each age group from radiographic data and by using all available data from the skeletal remains; however, four age groups were uneven (see Table 1). The Spitalfields and Maurice Stack's collections of known age-at-death reference samples are unique and valuable and fill an important age gap for which radiographic data are scarce. However, some skeletal remains from Spitalfields are fragmentary with an incomplete developing dentition. Few individuals were aged between 6 months and less than 2 years, and as a result, the sex and age distribution for children in those age groups in our atlas is not ideal. This is reflected by a jump in tooth formation stages from 1.5 to 2.5 years for the deciduous canine and deciduous second molar from root initiation stage (Ri) to root three quarters (R 3/4) stage. From the radiographic sample, the maximum age was determined from the age where all teeth have reached maturity; our data showed this to be

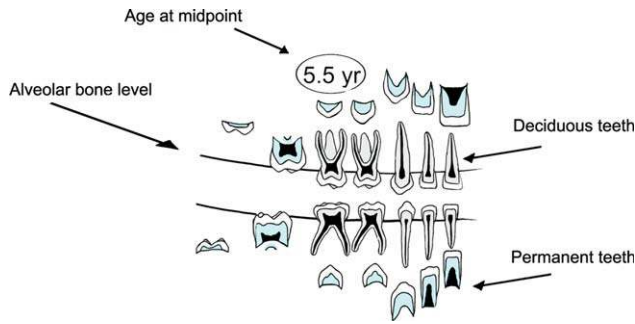


Fig. 5. Explanation of the illustration of a 5-year-old child's dental development. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

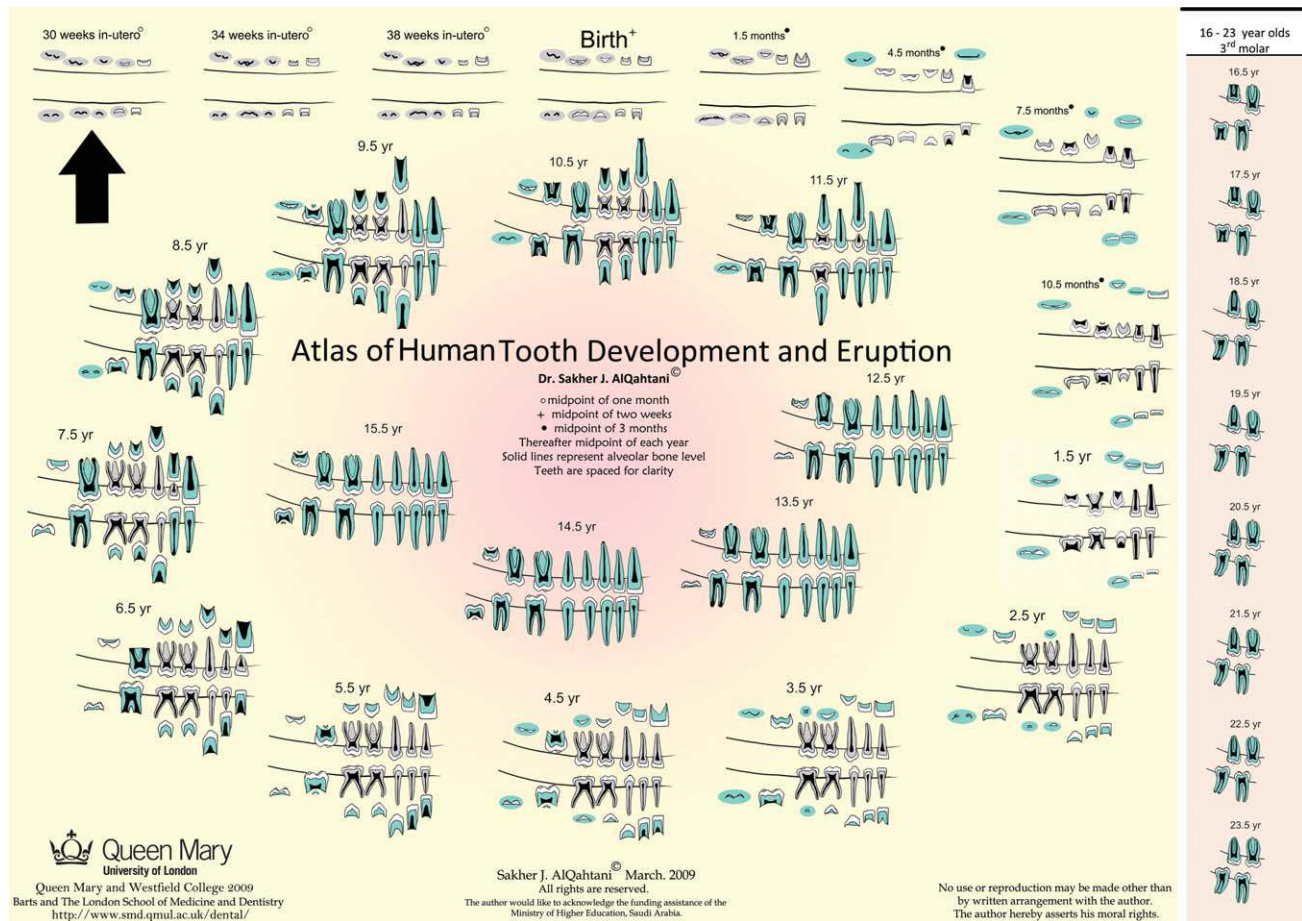


Fig. 6. Atlas of human tooth development and eruption. The arrow indicates the starting point. The dentine is presented in gray for deciduous teeth and in green for permanent.

TABLE 2. Tooth development data from autopsied infants^a (combined sex)

Age	Maxilla					Mandible				
	Tooth	Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage		
			Minimum	Median	Maximum			Minimum	Median	Maximum
30 weeks in utero ^b	i ¹	12	Coc	Cr ½	Cr ¾	i ₁	12	Coc	Cr ½	Cr ¾
	i ²	12	Cco	Coc	Cr ¾	i ₂	12	Cco	Coc	Cr ¾
	c'	12	Ci	Ci	Coc	c,	12	Ci	Ci	Coc
	m ¹	12	Ci	Cco	Coc	m ₁	12	Ci	Cco	Coc
	m ²	12	Ci	Ci	Cco	m ₂	12	Ci	Ci	Cco
34 weeks in utero ^b	i ¹	13	Cr ½	Cr ¾	Cr ¾	i ₁	15	Cr ½	Cr ¾	Crc
	i ²	13	Cr ½	Cr ½	Cr ¾	i ₂	7	Cr ½	Cr ¾	Cr ¾
	c'	13	Ci	Ci	Coc	c,	12	Ci	Ci	Coc
	m ¹	15	Cco	Cco	Coc	m ₁	14	Cco	Cco	Coc
	m ²	13	Ci	Ci	Cco	m ₂	12	Ci	Ci	Cco
38 weeks in utero ^b	i ¹	26	Cr ½	Cr ¾	Crc	i ₁	23	Cr ½	Cr ¾	Crc
	i ²	20	Cr ½	Cr ½	Cr ¾	i ₂	15	Cr ½	Cr ¾	Crc
	c'	26	Ci	Ci	Coc	c,	26	Ci	Cco	Coc
	m ¹	29	Cco	Cco	Cr ½	m ₁	29	Cco	Cco	Cr ½
	m ²	27	Ci	Ci	Cco	m ₂	26	Ci	Ci	Cco
Birth ^c	i ¹	23	Cr ¾	Cr ¾	Crc	i ₁	27	Cr ¾	Crc	Crc
	i ²	20	Cr ½	Cr ¾	Cr ¾	i ₂	18	Cr ¾	Cr ¾	Crc
	c'	30	Ci	Coc	Cr ½	c,	28	Ci	Coc	Coc
	m ¹	25	Cco	Coc	Cr ½	m ₁	29	Cco	Coc	Cr ½
	M ²	29	Ci	Cco	Coc	m ₂	26	Ci	Ci	Coc

^a Twelve children from 28 to <32 weeks in utero, 15 children from 32 to <36 weeks in utero, 30 children from 36 to 39 weeks in utero, and 30 children from >39 weeks in utero to <1 week after birth.

^b Midpoint of 4 weeks.

^c Midpoint of 2 weeks.

TABLE 3. Tooth development data from skeletal remains^a (combined sex)

Age (months)	Maxilla					Mandible				
	Tooth	Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage		
			Minimum	Median	Maximum			Minimum	Median	Maximum
1.5 ^b	i ¹	34	Cr ¾	Crc	Ri	i ₁	29	Cr ¾	Crc	Ri
	i ²	31	Cr ½	Cr ¾	Crc	i ₂	25	Cr ¾	Crc	Ri
	c'	34	Coc	Coc	Cr ½	c,	29	Coc	Coc	Cr ½
	m ¹	33	Cco	Coc	Cr ½	m ₁	28	Cco	Coc	Cr ½
	m ²	27	Ci	Cco	Coc	m ₂	25	Ci	Cco	Cr ½
	M ¹	4	—	—	Ci	M ₁	3	—	—	Cco
4.5 ^b	i ¹	13	Crc	Ri	R ¼	i ₁	11	Crc	Ri	R ¼
	i ²	11	Crc	Crc	Ri	i ₂	13	Cr ¾	Ri	R ¼
	c'	14	Coc	Cr ½	Cr ¾	c,	16	Coc	Cr ½	Cr ¾
	m ¹	7	Cr ½	Cr ½	Cr ¾	m ₁	11	Cr ½	Cr ¾	Crc
	m ²	8	Coc	Cr ½	Cr ¾	m ₂	11	Cr ½	Cr ¾	Crc
	I ¹	4	Ci	Ci	Coc	i ₁	1	—	—	Ci
7.5 ^b	M ¹	4	Ci	Ci	Ci	M ₁	5	Ci	Ci	Cco
	i ¹	6	Ri	R ¼	R ½	i ₁	5	R ¼	R ½	R ½
	i ²	6	Crc	R ¼	R ¼	i ₂	4	Ri	R ¼	R ¼
	c'	8	Cr ¾	Crc	Crc	c,	6	Cr ½	Cr ¾	Crc
	m ¹	9	Crc	Ri	Cr ½	m ₁	10	Cr ¾	Crc	Ri
	m ²	5	Cr ¾	Crc	Crc	m ₂	10	Cr ½	Cr ¾	Cr ¾
10.5 ^b	I ¹	4	Coc	Coc	Cr ½	I ₁	3	Coc	Coc	Cr ½
	C'	4	Ci	Ci	Ci	C,	1	—	—	Ci
	M ¹	4	Cco	Cco	Coc	M ₁	4	Cco	Coc	Coc
	i ¹	5	Ri	R ½	R ½	i ₁	9	R ¼	R ¾	R ¾
	i ²	4	Ri	R ¼	R ½	i ₂	10	Ri	R ½	R ½
	c'	6	Cr ¾	Crc	Ri	c,	12	Cr ¾	Crc	Crc
10.5 ^b	m ¹	4	Crc	R ¼	R ¼	m ₁	12	Crc	R ¼	R ½
	m ²	6	Cr ¾	Crc	Ri	m ₂	12	Cr ¾	Crc	Ri
	I ¹	4	Coc	Cr ½	Cr ½	I ₁	5	Cr ½	Cr ½	Cr ½
	C'	4	Ci	Ci	Ci	C,	4	Ci	Ci	Ci
	M ¹	4	Cco	Coc	Coc	M ₁	10	Cco	Coc	Coc

^a Thirty-four children from 1 week to <3 months, 14 children from 3 to <6 months, 10 children from 6 to <9 months, and 14 children from 9 to <12 months.

^b Midpoint of 3 months.

TABLE 4. Combined sex tooth development data for 17 children (skeletal remains) from 1 to <2 years, 24 children from 2 to <3 years, and 24 children from 3 to <4 years

Age (years)	Maxilla					Mandible					
	Tooth	Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage			
			Minimum	Median	Maximum			Minimum	Median	Maximum	
1.5 ^a	i ¹	5	R ¼	R ¾	R ¾	i ₁	7	R ¾	R ¾	Rc	
	i ²	6	Ri	R ½	R ¾	i ₂	7	R ¾	R ¾	Rc	
	c'	6	Crc	Ri	R ½	c,	7	Cr ¾	Ri	R ½	
	m ¹	7	Ri	R ½	R ¾	m ₁	8	Ri	R ½	R ¾	
	m ²	8	Crc	Ri	R ¼	m ₂	8	Cr ¾	Ri	R ¼	
	I ¹	6	Cr ½	Cr ½	Cr ½	I ₁	6	Cr 1/2	Cr ½	Cr ¾	
	I ²	4	–	Coc	Coc	I ₂	6	Coc	Cr ½	Cr ½	
	C'	8	Coc	Coc	Coc	C,	4	–	Coc	Coc	
	M ¹	4	–	Coc	Cr ½	M ₁	8	Cco	Coc	Cr ½	
	2.5 ^a	i ¹	24	Rc	Ac	Ac	i ₁	24	Rc	Ac	Ac
i ²		24	Rc	Ac	Ac	i ₂	24	Rc	Ac	Ac	
c'		24	R ¾	Rc	Rc	c,	24	R ¾	Rc	Rc	
m ¹		24	R ¾	Rc	Ac	m ₁	24	R ¾	Rc	Ac	
m ²		24	R ¼	R ¾	Ac	m ₂	24	R ½	R ¾	Ac	
I ¹		24	Cr ½	Cr ¾	Cr ¾	I ₁	24	Cr ½	Cr ¾	Cr ¾	
I ²		24	Coc	Cr ½	Cr ¾	I ₂	24	Cr ½	Cr ¾	Cr ¾	
C'		21	–	Cr ½	Cr ½	C,	24	Coc	Cr ½	Cr ½	
P ¹		19	–	Ci	Cco	P ₁	20	–	Cco	Cco	
P ²		10	–	–	Ci	P ₂	18	–	Ci	Ci	
M ¹		24	Cr ½	Cr ¾	Cr ¾	M ₁	24	Cr ½	Cr ¾	Cr ¾	
M ²		16	–	Ci	Ci	M ₂	15	–	Ci	Ci	
3.5 ^a		i ¹	24	Ac	Ac	Ac	i ₁	24	Ac	Ac	Ac
		i ²	24	Ac	Ac	Ac	i ₂	24	Ac	Ac	Ac
	c'	24	Ac	Ac	Ac	c,	24	Ac	Ac	Ac	
	m ¹	24	Ac	Ac	Ac	m ₁	24	Ac	Ac	Ac	
	m ²	24	Ac	Ac	Ac	m ₂	24	Ac	Ac	Ac	
	I ¹	24	Cr ¾	Cr ¾	Ri	I ₁	24	Cr ¾	Cr ¾	Ri	
	I ²	24	Cr ½	Cr ½	Crc	I ₂	24	Cr ½	Cr ¾	Cr ¾	
	C'	24	Cr ½	Cr ½	Cr ¾	C,	24	Coc	Cr ½	Cr ¾	
	P ¹	24	Ci	Coc	Cr ½	P ₁	24	Ci	Cr ½	Cr ½	
	P ²	20	–	Ci	Cco	P ₂	22	–	Ci	Coc	
	M ¹	24	Cr ½	Crc	R ¼	M ₁	24	Cr ½	Ri	Ri	
	M ²	20	–	Cco	Coc	M ₂	22	–	Cco	Coc	

^a Midpoint of 1 year.

TABLE 5. Tooth development data (combined sex) for 24 children in each age group: 4 to <5 years, 5 to <6 years, and 6 to <7 years

Age (years)	Maxilla					Mandible					
	Tooth	Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage			
			Minimum	Median	Maximum			Minimum	Median	Maximum	
4.5 ^a	i ¹ to m ²	24 each	Ac	Ac	Ac	i ₁ to m ₂	24 each	Ac	Ac	Ac	
	I ¹	24	Cr ¾	Crc	Ri	I ₁	24	Cr ¾	Ri	R ¼	
	I ²	24	Cr ¾	Cr ¾	Ri	I ₂	24	Cr ¾	Ri	Ri	
	C'	24	Cr ¾	Cr ¾	Ri	C,	24	Cr ½	Cr ¾	Ri	
	P ¹	24	Cr ½	Cr ½	Cr ¾	P ₁	24	Cr ½	Cr ½	Crc	
	P ²	24	Coc	Cco	Cr ¾	P ₂	24	Ci	Coc	Cr ½	
	M ¹	24	R ¼	R ¼	R ½	M ₁	24	R ¼	R ¼	R ½	
	M ²	24	Ci	Coc	Cr ½	M ₂	24	Cco	Coc	Cr ½	
	5.5 ^a	i ¹	24	Ac	Ac	Res 1/4	i ₁	24	Ac	Ac	Res 1/2
		i ²	24	Ac	Ac	Res 1/4	i ₂	24	Ac	Ac	Res 1/4
c' to m ²		24 each	Ac	Ac	Ac	c, to m ₂	24 each	Ac	Ac	Ac	
I ¹		24	Crc	Ri	R ¼	I ₁	24	Ri	R ¼	R ½	
I ²		24	Crc	Crc	Ri	I ₂	24	Crc	R ¼	R ¼	
C'		24	Cr ¾	Crc	Ri	C,	24	Cr ¾	Crc	Ri	
P ¹		24	Cr ½	Cr ¾	Crc	P ₁	24	Coc	Cr ¾	Crc	
P ²		24	Cco	Cr ½	Cr ¾	P ₂	24	Cco	Cr ¾	Cr ¾	
M ¹		24	R ¼	R ¼	R ½	M ₁	24	R ¼	R ¼	R ½	
M ²		24	Coc	Cr ½	Cr ¾	M ₂	24	Coc	Cr ½	Cr ¾	
6.5 ^a	i ¹	14	Ac	Res ¾	–	i ₁	11	Ac	–	–	
	i ²	22	Ac	Res ¼	Res ¾	i ₂	13	Ac	Res ½	–	
	c'	24	Ac	Ac	Ac	c,	24	Ac	Ac	Ac	
	m ¹	24	Ac	Ac	Res ¼	m ₁	24	Ac	Ac	Res ¼	
	m ²	24	Ac	Ac	Ac	m ₂	24	Ac	Ac	Res ¼	
	I ¹	24	Crc	R ¼	R ¾	I ₁	24	R ¼	R ½	Rc	
	I ²	24	Crc	Ri	R ½	I ₂	24	Ri	R ¼	R ¾	
	C'	24	Crc	Ri	R ¼	C,	24	Cr ¾	Ri	R ¼	
	P ¹	24	Cr ¾	Crc	Ri	P ₁	24	Cr ½	Crc	Ri	
	P ²	24	Cr ½	Crc	Crc	P ₂	24	Coc	Crc	Ri	
	M ¹	24	R ¼	R ½	R ¾	M ₁	24	R ¼	R ½	R ¾	
	M ²	24	Coc	Cr ½	Crc	M ₂	24	Coc	Cr ½	Crc	

^a Midpoint of 1 year.

TABLE 6. Tooth development data (combined sex) for 24 children in each age group: 7 to <8 years, 8 to <9 years, and 9 to <10 years

Age (years)	Maxilla					Mandible					
	Tooth	Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage			
			Minimum	Median	Maximum			Minimum	Median	Maximum	
7.5 ^a	i ¹	2	Res 3/4	—	—	i ₁	—	—	—	—	
	i ²	13	Res 1/2	Res 3/4	—	i ₂	2	Ac	—	—	
	c'	24	Ac	Ac	Ac	c,	24	Ac	Ac	Ac	
	m ¹	24	Ac	Ac	Res 1/2	m ₁	24	Ac	Ac	Res 1/2	
	m ²	24	Ac	Ac	Res 1/2	m ₂	24	Ac	Ac	Res 1/4	
	I ¹	24	R 1/4	R 3/4	Rc	I ₁	24	R 3/4	Rc	A 1/2	
	I ²	24	R 1/4	R 1/2	Rc	I ₂	24	R 1/4	R 3/4	A 1/2	
	C'	24	Ri	R 1/4	R 1/2	C,	24	Ri	R 1/4	R 1/4	
	P ¹	24	Cr 3/4	Ri	R 1/4	P ₁	24	Ri	Ri	R 1/4	
	P ²	24	Cr 3/4	Crc	R 1/4	P ₂	24	Crc	Crc	R 1/4	
	M ¹	24	R 1/4	R 3/4	A 1/2	M ₁	24	R 3/4	R 3/4	A 1/2	
	M ²	24	Cr 1/2	Cr 3/4	R 1/4	M ₂	24	Cr 1/2	Cr 3/4	R 1/4	
	M ³	4	—	—	Ci	M ₃	8	—	—	Ci	
	8.5 ^a	i ²	6	Res 3/4	—	—	i ₂	—	—	—	—
c'		24	Ac	Ac	Res 1/4	c,	24	Ac	Ac	Res 1/2	
m ¹		24	Res 1/4	Res 1/2	Res 1/2	m ₁	24	Res 1/4	Res 1/4	Res 1/2	
m ²		24	Ac	Res 1/2	Res 1/2	m ₂	24	Ac	Ac	Res 1/4	
I ¹		24	R 1/2	Rc	A 1/2	I ₁	24	R 3/4	Ac	Ac	
I ²		24	R 1/4	R 3/4	Rc	I ₂	24	R 1/4	A 1/2	Ac	
C'		24	Ri	R 1/4	R 3/4	C,	24	R 1/4	R 1/4	R 3/4	
P ¹		24	Ri	Ri	R 1/2	P ₁	24	Ri	R 1/4	R 1/2	
P ²		24	Ri	Ri	R 1/2	P ₂	24	Crc	Ri	R 1/4	
M ¹		24	R 1/2	Rc	Ac	M ₁	24	R 3/4	R 3/4	A 1/2	
M ²		24	Crc	Ri	R 1/4	M ₂	24	Cr 3/4	Ri	R 1/4	
M ³		13	—	Ci	Coc	M ₃	20	—	Ci	Cco	
9.5 ^a		c'	22	Ac	Ac	—	c,	22	Ac	Res 1/4	—
		m ¹	24	Res 1/4	Res 1/2	Res 3/4	m ₁	24	Res 1/4	Res 1/4	Res 3/4
	m ²	24	Res 1/4	Res 1/2	Res 3/4	m ₂	24	Ac	Res 1/4	Res 1/2	
	I ¹	24	R 3/4	Rc	A 1/2	I ₁	24	Rc	Ac	Ac	
	I ²	24	R 1/2	Rc	A 1/2	I ₂	24	Rc	A 1/2	Ac	
	C'	24	R 1/4	R 1/2	R 3/4	C,	24	R 1/4	R 1/2	R 3/4	
	P ¹	24	R 1/4	R 1/4	R 3/4	P ₁	24	R 1/4	R 1/2	R 3/4	
	P ²	24	Ri	R 1/4	R 3/4	P ₂	24	Ri	R 1/4	R 3/4	
	M ¹	24	Rc	Ac	Ac	M ₁	24	R 3/4	A 1/2	Ac	
	M ²	24	Ri	R 1/4	R 1/2	M ₂	24	Ri	R 1/4	R 1/2	
	M ³	17	—	Coc	Cr 3/4	M ₃	22	—	Cco	Cr 3/4	

^a Midpoint of 1 year.

TABLE 7. Tooth development data (combined sex) for 24 children in each age group: 10 to <11 years, 11 to <12 years, and 12 to <13 years

Age (years)	Maxilla					Mandible					
	Tooth	Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage			
			Minimum	Median	Maximum			Minimum	Median	Maximum	
10.5 ^a	c'	20	Ac	Res 1/4	—	c,	—	—	—	—	
	m ¹	17	Res 1/4	Res 1/2	—	m ₁	16	Res 1/4	Res 1/2	—	
	m ²	21	Res 1/4	Res 1/2	—	m ₂	18	Ac	Res 1/4	—	
	I ¹	24	Rc	A 1/2	Ac	I ₁	24	A 1/2	Ac	Ac	
	I ²	24	Rc	A 1/2	Ac	I ₂	24	Rc	Ac	Ac	
	C'	24	R 1/2	R 3/4	R 3/4	C,	24	R 3/4	R 3/4	Rc	
	P ¹	24	R 1/4	R 1/2	Rc	P ₁	24	R 1/4	R 1/2	Rc	
	P ²	24	Ri	R 1/2	Rc	P ₂	24	R 1/4	R 1/2	R 3/4	
	M ¹	24	Rc	Ac	Ac	M ₁	24	Rc	Ac	Ac	
	M ²	24	R 1/4	R 1/2	R 1/2	M ₂	24	R 1/4	R 1/2	R 1/2	
	M ³	23	—	Coc	Cr 1/2	M ₃	23	—	Cco	Cr 1/2	
	11.5 ^a	c'	17	Ac	Res 3/4	—	c,	4	Res 1/4	—	—
		m ¹	8	Res 1/2	—	—	m ₁	6	Res 1/4	—	—
		m ²	17	Res 1/4	Res 3/4	—	m ₂	18	Ac	Res 1/2	—
I ¹		24	Rc	Ac	Ac	I ₁	24	Rc	Ac	Ac	
I ²		24	R 3/4	Ac	Ac	I ₂	24	A 1/2	Ac	Ac	
C'		24	R 1/2	R 3/4	Rc	C,	24	R 3/4	R 3/4	A 1/2	
P ¹		24	R 1/2	R 3/4	A 1/2	P ₁	24	R 1/2	R 3/4	A 1/2	
P ²		24	R 1/4	R 3/4	Rc	P ₂	24	R 1/4	R 3/4	A 1/2	
M ¹		24	A 1/2	Ac	Ac	M ₁	24	A 1/2	Ac	Ac	
M ²		24	R 1/4	R 1/2	Rc	M ₂	24	R 1/4	R 1/2	R 3/4	
M ³		24	Ci	Cr 1/2	Ri	M ₃	24	Ci	Coc	R 1/4	
12.5 ^a		m ²	2	Res 3/4	—	—	m ₂	10	Res 1/4	—	—
		I ¹	24	Rc	Ac	Ac	I ₁	24	A 1/2	Ac	Ac
		I ²	24	Rc	Ac	Ac	I ₂	24	A 1/2	Ac	Ac
	C'	24	R 3/4	Rc	Rc	C,	24	R 3/4	A 1/2	Ac	
	P ¹	24	R 3/4	Rc	A 1/2	P ₁	24	R 3/4	Rc	Ac	
	P ²	24	R 1/2	R 3/4	A 1/2	P ₂	24	R 1/2	Rc	Ac	
	M ¹	24	Ac	Ac	Ac	M ₁	24	Ac	Ac	Ac	
	M ²	24	R 1/4	R 3/4	Rc	M ₂	24	R 1/4	R 3/4	Rc	
	M ³	24	Cco	Cr 3/4	R 1/4	M ₃	24	Ci	Cr 1/2	R 1/4	

^a Midpoint of 1 year.

TABLE 8. Tooth development data (combined sex) for 24 children in each age group: 13 to <14 years, 14 to <15 years, 15 to <16 years, 16 to <17 years, and 17 to <18 years

Age (years)	Tooth	Maxilla				Mandible				
		Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage		
			Minimum	Median	Maximum			Minimum	Median	Maximum
13.5 ^a	I ¹	24	Ac	Ac	Ac	I ₁	24	Ac	Ac	Ac
	I ²	24	Ac	Ac	Ac	I ₂	24	Ac	Ac	Ac
	C'	24	Rc	Rc	A ½	C,	24	Rc	A ½	Ac
	P ¹	24	Rc	A ½	Ac	P ₁	24	R ¾	A ½	Ac
	P ²	24	R ½	Rc	Ac	P ₂	24	R ¾	Rc	Ac
	M ¹	24	Ac	Ac	Ac	M ₁	24	Ac	Ac	Ac
	M ²	24	Coc	R ¾	A ½	M ₂	24	R ½	R ¾	A ½
14.5 ^{a,b}	M ³	24	Ci	Cr ¾	R ¼	M ₃	24	Ci	Cr ½	R ¼
	C'	24	Rc	A ½	Ac	C,	24	A ½	Ac	Ac
	P ¹	24	A ½	Ac	Ac	P ₁	24	A ½	Ac	Ac
	P ²	24	Rc	Ac	Ac	P ₂	24	Rc	Ac	Ac
	M ²	24	Rc	Rc	Ac	M ₂	24	Rc	Rc	Ac
15.5 ^{a,b}	M ³	24	Cr ¾	R ¼	R ¼	M ₃	24	Cr ½	R ¼	R ¼
	C'	24	R ¾	Ac	Ac	C,	24	Ac	Ac	Ac
	P ¹	24	Ac	Ac	Ac	P ₁	24	Ac	Ac	Ac
	P ²	24	Ac	Ac	Ac	P ₂	24	Ac	Ac	Ac
	M ²	24	Rc	A ½	Ac	M ₂	24	Rc	A ½	Ac
16.5 ^{a,c}	M ³	24	Cr ½	R ¼	R ¾	M ₃	24	Cr ½	R ¼	R ¾
	C'	24	Ac	Ac	Ac	C'	24	Ac	Ac	Ac
	M ²	24	A ½	Ac	Ac	M ₂	24	A ½	Ac	Ac
	M ³	24	Ri	R ½	R ¾	M ₃	24	Crc	R ½	R ¾
17.5 ^{a,c}	M ²	24	Ac	Ac	Ac	M ₂	24	Ac	Ac	Ac
	M ³	24	Crc	R ½	Rc	M ₃	24	R ¼	R ½	Rc

^a Midpoint of 1 year.

^b Teeth that reached radiographic apical closure stage (Ac) are permanent upper and lower incisors and first molars.

^c Teeth that reached radiographic apical closure stage (Ac) are permanent incisors, premolars, and first molars.

TABLE 9. Third molar development for 24 individuals (combined sex) from 18 to <24 years

Age (years)	Tooth	Maxilla				Mandible				
		Number of teeth	Tooth formation stage			Tooth	Number of teeth	Tooth formation stage		
			Minimum	Median	Maximum			Minimum	Median	Maximum
18.5 ^a	M ³	24	Crc	R ¾	Rc	M ₃	24	R ¼	R ¾	Rc
19.5 ^a	M ³	24	R ¼	Rc	A ½	M ₃	24	R ¼	Rc	A ½
20.5 ^a	M ³	24	R ½	A ½	A ½	M ₃	24	R ¾	A ½	A ½
21.5 ^a	M ³	24	Rc	A ½	Ac	M ₃	24	Rc	A ½	Ac
22.5 ^a	M ³	24	Rc	A ½	Ac	M ₃	24	Rc	A ½	Ac
23.5 ^a	M ³	24	Ac	Ac	Ac	M ₃	24	Ac	Ac	Ac

Teeth that reached radiographic apical closure stage (Ac) are permanent incisors, canines, premolars, first and second molars.

^a Midpoint of 1 year.

TABLE 10. Median age of eruption for deciduous teeth (combined sex)^a

Maxilla				Mandible			
Tooth	Alveolar eruption	Clinical emergence ^b	Full eruption	Tooth	Alveolar eruption	Clinical emergence ^b	Full eruption
i ¹	4.5 months	9.96 months	10.5 months	i ₁	4.5 months	8.04 months	10.5 months
i ²	7.5 months	11.4 months	1.5 years	i ₂	7.5 months	1.08 years	1.5 years
c'	10.5 months	1.58 years	2.5 years	c,	10.5 months	1.67 years	2.5 years
m ¹	10.5 months	1.33 years	1.5 years	m ₁	10.5 months	1.33 years	1.5 years
m ²	1.5 years	2.42 years	2.5 years	m ₂	1.5 years	2.25 years	2.5 years

^a Midpoint of 3 months for younger than 1 year and midpoint of 1 year otherwise.

^b From Lysell et al. (1962).

23 years of age. It is important to note that corrected age around 40 gestational weeks was used (O'Neill, 2005), and the new atlas should be interpreted with this in mind. Birth is not an age, but an event that has no effect on dental formation stage (Backstrom et al., 2000; Paulsson et al., 2004; Ramos et al., 2006). If a child is

born at 36 weeks and survives 1 month, its dental development will correspond to a full-term dentition.

Eruption in this atlas refers to emergence from *alveolar bone*, which contrasts to Ubelaker's atlas (Ubelaker, 1978) where "eruption refers to emergence through the gum, not to emergence from the bone or to reaching the

TABLE 11. Median age (years) of eruption for permanent teeth (combined sex)^a

Tooth	Maxilla				Mandible				
	Alveolar eruption	Clinical emergence ^b		Full eruption	Tooth	Alveolar eruption	Clinical emergence ^b		Full eruption
		Boys	Girls				Boys	Girls	
I ¹	6.5	6.9	6.7	7.5	I ₁	5.5	6.3	6.2	7.5
I ²	7.5	8.3	7.8	9.5	I ₂	6.5	7.3	6.8	7.5
C ¹	11.5	12.1	10.6	12.5	C ₁	9.5	10.4	9.2	11.5
P ¹	10.5	10.2	9.6	11.5	P ₁	10.5	10.3	9.6	11.5
P ²	11.5	11.4	10.2	12.5	P ₂	11.5	11.1	10.1	12.5
M ¹	5.5	6.4	6.4	6.5	M ₁	5.5	6.3	6.3	6.5
M ²	10.5	12.8	12.4	13.5	M ₂	10.5	12.2	11.4	12.5
M ³	16.5	—	—	20.5	M ₃	16.5	—	—	20.5

^a Midpoint of 1 year.

^b From Haavikko (1970).

occlusal plane". Allowance should be made for gingival eruption when using this atlas in the presence of oral soft tissues (see Tables 10 and 11).

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