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ORIGINAL ARTICLE

Timing of developmental stages in permanent mandibular teeth of Finns from birth to age 25

MARJATTA ELINA NYSTRÖM[1], HELENA MERI RANTA[2], JAAKKO SAKARI PELTOLA[3] & JORMA MATTI KATAJA[4]

[1]*Department of Orthodontics, Institute of Dentistry, University of Helsinki, Finland,* [2]*Department of Forensic Medicine, University of Helsinki, Finland,* [3]*Department of Oral Radiology, Institute of Dentistry, University of Helsinki, Finland and* [4]*National Public Health Institute, Helsinki, Finland*

Abstract

Objective. The aim was to provide radiographic data on postnatal development of the 8 mandibular teeth to serve as reference norms in clinical dentistry, forensic dentistry, anthropology, and research. ***Material and Methods.*** Developmental stages of teeth were assessed from a total of 2795 radiographs, mostly panoramic, of 1970 Finns (966 M and 1004 F) from birth to age 25. The grading was based on Demirjian's 8 mineralization stages and the crypt stage. ***Results.*** Timing of development in individual mandibular teeth is presented in two ways: as age at attainment of each developmental stage and as age of subjects in a developmental stage. Initiation of mineralization was visible in 1st molars at 0.20 years, in central incisors at 0.22 years, lateral incisors at 0.37 years, and canines at 0.56 years of age. Timing was usually earlier in girls than in boys. Differences were greatest in canines, where females were advanced by 1.74 years at the closure of the apex. Root development in 3rd molars showed an opposite trend, where apical closure was 1.19 years earlier in men. In 3rd molars, age at apical closure in females was 21.50 years, among the highest reported. In general, the early developmental stages had the shortest duration and the last stages the longest. ***Conclusion.*** Timing of postnatal development of individual mandibular teeth in Finns resembled developmental schedules reported for other Caucasian population groups. Any differences were mostly small and inconsequential.

Key Words: *Age assessment, dental radiography, forensic dentistry, tooth development, tooth mineralization*

Introduction

The importance of age assessments was recently emphasized in postmortem investigations of tsunami victims in Thailand. Tooth development is well suited for age assessment in childhood and adolescence and good radiographic methods exist for that purpose. Three approaches describe radiographic dental development: age at attainment of a developmental tooth stage [1,2], age at a stage of tooth development [3], and age at a stage of maturation of a set of teeth [4]. Cumulative distribution methods are suitable for calculating attainment ages for developmental stages of teeth, and these schedules provide the ages for entering a developmental stage. If these schedules are used for age assessments, it must be remembered that attainment tables offer age predictions that are too low [2,5]. A better prediction falls between age at attainment of the stage seen and age at attainment of the next developmental stage [6,7]. In-stage tables contain average ages and variations for developmental stages of teeth and can be used directly for individual age predictions [6]. Use of this method requires that the original data should cover a large enough age range and be evenly distributed in age groups. Schedules and graphs based on maturation of sets of mandibular teeth [4,8] suit age assessments in the populations which they represent, provided that all teeth belonging to the system are present. This method works best during young childhood [9]. In order to be able to use the Demirjian 7-tooth method despite one or two missing teeth, mathematical models have been developed to predict the developmental stage of each tooth included in the method [10]. Demirjian 7-tooth maturity tables and graphs cannot be used, however, if many teeth are missing.

Correspondence: Marjatta Nyström, Department of Orthodontics, Institute of Dentistry, P.O. Box 41, FIN-00014 University of Helsinki, Finland. Tel: +358 9 191 27237. Fax: +358 9 191 27266. E-mail: marjatta.nystrom@helsinki.fi

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Several excellent radiographic attainment schedules of the development of individual teeth exist [1,2,11,12]. Use of one well-chosen individual tooth may give even more accurate age assessments than the mean value of all developing teeth [5]. However, with any method, there is very little information about tooth development during the earliest years, and, to our knowledge, no radiographic study gives the age at initial mineralization of mandibular incisors.

The aim of the present study was to provide such radiographic data on postnatal development of each of the 8 permanent mandibular teeth which could be used as normal references in age assessments in clinical and forensic dentistry, anthropology, and research. The precise goal was to calculate gender-specific age at attainment of 8 anatomically defined radiographic mineralization stages [4] and the crypt stage in permanent mandibular teeth. Furthermore, it was to calculate average ages with variations for the same developmental stages in the same teeth.

Material and methods

Material

The material consisted of 2795 radiograms (Table I) of 1970 ethnic Finns (966 M and 1004 F) from the Helsinki area; ages varying between 0 and 25 years. The radiographs were taken in the period 1964 to 2005, 63% before 1980. The study sample comprised 2314 dental panoramic radiographs (PR) of non-patient subjects in two large materials, one cross-sectional, the other semi-longitudinal [2,10, 13]. In addition, the material included 108 PRs taken of mothers of children participating in the semi-longitudinal study [10] and 214 PRs from the files of the Institute of Dentistry, University of Helsinki. The material also comprised 38 dental PRs taken at the Department of Forensic Medicine, University of Helsinki, during medicolegal autopsies of ethnically Finnish children from 0.0 to 2 years of age [14]. All had been considered healthy before death. The material also included 52 extra-oral oblique lateral radiographs taken of the jaws of healthy non-patients from 0.5 to 3 years of age [15]. Finally, the study material comprised 69 periapical radiographs of the premolar area in children from 2 and 5 years of age. These radiographs were from the files of the Institute of Dentistry, University of Helsinki.

Method

The 8 left mandibular teeth were rated on an 8-stage scale from A to H using the Demirjian grading [4], which has clear descriptive criteria, line drawings, and radiographic illustrations of the stages. In addition, the crypt stage (O) was recorded, representing

Table I. Distribution of radiographs by age, gender, and type of radiograph

Age (years)	Boys				Girls			
	PR	obl	per	Total	PR	obl	per	Total
0–0.4	20			20	9			9
0.5–0.9	4	6		10		5		5
1	1	7		8	2	2		4
2	3	15	1	19	6	13	1	20
3	18	1	11	30	24	3	12	39
4	45		15	60	54		20	74
5	74		4	78	75		5	80
6	98			98	70			70
7	96			96	117			117
8	110			110	104			104
9	105			105	89			89
10	98			98	128			128
11	56			56	91			91
12	88			88	58			58
13	53			53	64			64
14	81			81	57			57
15	41			41	26			26
16	18			18	43			43
17	74			74	67			67
18	27			27	28			28
19	23			23	40			40
20	23			23	43			43
21	32			32	52			52
22	30			30	34			34
23	40			40	28			28
24	30			30	29			29
25	15			15	33			33
Total	1303	29	31	1363	1371	23	38	1432

PR = panoramic tomograph; obl = oblique extra-oral lateral radiograph; per = intra-oral periapical radiograph.

the period when the bone crypt is visible without a dental germ inside. For children in the semi-longitudinal study, we also recorded the stage with no sign of the tooth yet. This information was needed for calculating ages at attaining the crypt stage (Table II). If a tooth was missing or its image was unclear, the contralateral homologous tooth was used. The distribution of evaluated teeth by stage of development and gender is presented in Tables IV and V. The evaluator, the first author, calibrated herself regularly with the help of the Demirjian dental development computer program (Silver-Platter Multimedia Database, Silver Platter Information Inc., Norwood, Mass., USA).

To study ages at attainment of a stage, those radiographs taken before 1.5 years of age were grouped into 0.25-year intervals and the other radiographs into 0.5-year intervals. However, when attainment ages for stages of short duration (stages O, A, and B) were calculated, the 0.25-year grouping was used also for teeth that reached those stages later.

Statistics

As a rule, the age at attaining a given stage is presented as the median age of the youngest age group in which the prevalence of teeth at that stage, together with those at more developed stages, reached 50%. If the 50% limit was not in accord with age group, linear interpolation was provided for more precise age assessment. For example, the prevalence of stage H in first premolars (P1) of girls reached the 50% limit for the first time in the age group 12.50 to 12.99 years (median 12.72). In this age group the prevalence of H was 76%. In the earlier age group, 12.00 to 12.49 years (median 12.25), the prevalence of stage H was 43%. The interpolated age at attaining stage H was 12.35 years (Table II).

Mean, standard deviation of the mean and percentile distribution were employed to calculate age in a stage of tooth development. The Kappa index [16] was used in estimations of intra-examiner agreement. Percentage agreement of stages was also calculated.

Intra-examiner agreement

Intra-examiner agreement in assessment of developmental stages of teeth concerning 2314 panoramic tomograms in this study has been presented previously [10]. Ratings differed in 6.3%. The Kappa index [16] was 0.91 (95% CI, 0.87–0.94). Other radiographs taken of children under 6 years of age (Table I) were re-evaluated about 4 months after the first evaluation. Of the 541 left permanent mandibular teeth, evaluations differed in 47 (8.7%) by one grade. In 22, the second evaluation was advanced and delayed in 25. As in the previous study [10], we expected the first and second ratings of an experienced observer to differ at most by 1 grade and, thus, expected the proportion of agreement by chance to be 1/3 [p(e) = 1/3], resulting in Kappa = 0.87 (95% CI).

Table II. Attainment ages at 8 developmental stages of tooth formation (Demirjian) and the crypt stage (O) in 8 mandibular teeth

Stage	Central incisor	Lateral incisor	Canine	1st premolar	2nd premolar	1st molar	2nd molar	3rd molar
				Boys				
O	–	–	–	–	3.09	0.00	3.08	8.54
A	*0.22*	*0.37*	*0.56*	2.34	3.32	0.20	3.26	9.26
B	*0.52*	*0.88*	*0.93*	2.40	3.67	0.52	3.67	9.75
C	*1.12*	*1.15*	*1.23*	3.26	5.00	1.35	4.90	11.46
D	*1.88*	3.09	4.56	5.51	6.75	2.79	7.00	13.56
E	4.06	5.25	6.52	7.12	7.75	4.03	8.55	15.05
F	6.04	6.65	8.40	8.71	9.81	5.49	10.48	16.73
G	6.96	7.56	10.97	11.25	11.94	6.66	12.19	18.03
H	8.26	9.12	13.56	13.38	14.15	9.65	15.20	20.31
				Girls				
O	–	–	–	–	2.77	0.00	3.05	8.64
A	*0.22*	*0.37*	*0.56*	2.20	3.20	0.19	3.26	9.47
B	*0.52*	*0.88*	*0.93*	2.32	3.58	0.54	3.75	9.53
C	*1.12*	*1.15*	*1.23*	3.51	4.61	1.19	4.89	11.51
D	*1.88*	3.09	3.92	5.19	6.27	2.84	6.42	13.26
E	3.91	4.76	5.85	6.70	7.82	3.81	8.53	15.06
F	5.63	6.29	7.46	8.47	9.32	5.10	9.76	16.51
G	6.76	7.07	9.23	10.10	10.77	6.76	11.84	18.84
H	7.68	8.82	11.82	12.35	13.80	8.94	14.55	21.50

In incisors and canines, ages under 2.0 years are combined values for boys and girls (*italics*).
Ages under 1.5 years in 1st molars show the lowest age where that stage is present, but previous stages are no longer visible.
Ages under 1.5 years for incisors and canine and ages for stages O, A, and B in premolars and 2nd and 3rd molars are based on 0.25-year groups.
All other ages are based on 0.5-year groups.

Results

Attainment ages of the 8 mineralization stages [4] for the 8 mandibular teeth, for the 2nd premolars (P2) and for the molars also of the O-stage are presented in Table II. Attainment ages under 1.5 years in these teeth are combined values for girls and boys. In 1st molars (M1), the earliest developmental stages were clearly grouped by age. Therefore, to gain more accuracy, for M1, attainment ages under 1.5 years are presented as the lowest age when that stage was present, and previous stages no longer occurred. The use of 0.25-year groups would have produced higher attainment ages. Table III gives ages counted as midpoints of attainment ages of successive stages (MA ages) for O-stage and 7 Demirjian stages in mandibular teeth. In-stage ages, counted as mean and median ages of all teeth in the stage (IS age), for boys are given in Table IV and for girls in Table V.

Subtraction of age at attainment of a given stage from age at attainment of the next stage gives the duration of the stage. Early stages of crown development (O, A, B) were the shortest, and late stages of root development (F, G) generally the longest. In most teeth, also stage C had a long duration.

Differences between genders

For all teeth except 3rd molars (M3) and stages combined, attainment ages of girls were usually further advanced than those of boys (39 stages of 49, 80%). Boys were advanced at 7 stages (14%), and at 3 stages (6%) attainment ages were the same (Table II). Differences were greatest in canines, where female advancement increased from 0.64 years at the completion of the crown to 1.74 years at closure of the apex. M3 showed an opposite trend: 6 stages were advanced in males (67%) and 3 in females (33%).

In-stage ages compared with ages counted as midpoints of attainment ages

For all teeth combined, in-stage age (IS age) medians (Tables IV and V) were often later than mid-attainment ages (MA age; Table III) (78/113; 69.0%). Stages attained within the first year of life or slightly later, i.e. stages A and B in incisors and canines, and stages O, A, and B in M1, were of short duration and observations of the stages were within a narrow age range. In these stages, differences between IS ages and MA ages were small.

The greatest differences between IS ages and MA ages (from 0.8 to 1.1 years) in boys were at stage C in the central (I1) and the lateral (I2) incisor and the canine and at stage D in I2. At all stages with attainment ages over 3.5 years in all teeth, the difference between IS age and MA age averages was mainly at most ± 0.25 years (52/76; 68.4%) and never reached 0.5 years.

Discussion

In the present study, developmental schedules for mandibular teeth in Finns are based on a widely used radiographic grading [4], and were calculated in three ways. Thus, clinicians and researchers can choose those reference tables which suit their purposes best. The three choices of presentation also facilitate comparisons with other studies. In order to present developmental sequences as complete as possible, we gave schedules including all mineralization stages of all permanent mandibular teeth

Table III. Ages at a stage presented as midpoint of consecutive attainment ages

Stage	Central incisor	Lateral incisor	Canine	Boys				
				1st premolar	2nd premolar	1st molar	2nd molar	3rd molar
O	–	–	–	–	3.21	0.10	3.17	8.90
A	*0.37*	*0.63*	*0.74*	2.37	3.50	0.36	3.47	9.51
B	*0.82*	*1.02*	*1.08*	2.83	4.34	0.94	4.29	10.61
C	*1.50*	2.12	2.90	4.39	5.88	2.07	5.95	12.51
D	2.97	4.17	5.54	6.32	7.25	3.41	7.78	14.30
E	5.05	5.95	7.46	7.92	8.78	4.76	9.52	15.89
F	6.50	7.11	9.69	9.98	10.88	6.08	11.34	17.38
G	7.61	8.34	12.27	12.32	13.05	8.16	13.69	19.17
				Girls				
O	–	–	–	–	2.99	0.10	3.16	9.06
A	*0.37*	*0.63*	*0.74*	2.26	3.39	0.37	3.51	9.50
B	*0.82*	*1.02*	*1.08*	2.92	4.10	0.86	4.32	10.52
C	*1.50*	2.12	2.58	4.35	5.44	2.01	5.66	12.39
D	2.90	3.93	4.89	5.95	7.05	3.33	7.48	14.16
E	4.77	5.53	6.66	7.59	8.57	4.46	9.15	15.78
F	6.20	6.68	8.35	9.29	10.14	5.93	10.85	17.67
G	7.22	7.95	10.53	11.23	12.28	7.85	13.19	20.17

In incisors and canines, ages for stages A and B, and in central incisor for stage C are combined values for boys and girls (*italics*).

Table IV. In-stage ages* at 7 stages of tooth formation (Demirjian) and at the crypt stage (O) in 8 mandibular teeth in Finnish boys

Tooth	Stage	*n*	Mean	SD	5%	16%	50%	84%	95%
Central incisor	A	2	0.37	0.21	–	–	0.37	–	–
	B	5	0.87	0.18	–	0.78	0.93	0.98	–
	C†	7	2.40	1.01	0.88	1.24	2.49	3.24	4.07
	D†	47	3.62	0.93	2.01	2.41	3.80	4.52	5.06
	E	141	5.35	0.83	3.82	4.50	5.49	6.04	6.63
	F	66	6.66	0.83	5.33	6.00	6.61	7.28	7.88
	G	134	7.70	1.09	6.33	6.69	7.60	8.59	9.43
Lateral incisor	B	4	0.95	0.04	–	0.91	0.95	1.01	–
	C†	36	3.03	0.99	1.46	2.14	2.90	4.01	4.50
	D†	105	4.76	0.92	3.05	3.98	4.70	5.59	6.16
	E	132	6.10	0.73	4.78	5.39	6.12	6.84	7.07
	F	79	7.32	0.92	5.97	6.50	7.22	8.14	8.86
	G	169	8.70	1.17	7.17	7.58	8.52	9.71	10.56
Canine	A	4	0.74	0.23	–	0.59	0.74	0.89	–
	B	6	1.16	0.41	–	0.87	0.95	1.45	–
	C†	93	3.90	1.11	2.07	2.49	4.01	5.05	5.70
	D	142	5.88	0.93	4.29	4.93	5.97	6.85	7.28
	E	209	7.58	1.14	5.93	6.46	7.52	8.52	9.55
	F	234	9.77	1.21	8.03	8.56	9.63	10.84	12.04
	G	207	12.05	1.48	9.65	10.48	12.07	13.40	14.36
1st premolar	A	6	2.57	0.32	–	2.31	2.37	3.01	–
	B†	20	3.38	0.64	2.41	2.58	3.39	4.00	4.44
	C	124	4.88	0.84	3.67	4.04	4.77	5.63	6.38
	D	149	6.56	0.87	5.34	5.69	6.51	7.40	8.03
	E	191	8.10	1.01	6.39	7.05	8.05	9.16	9.68
	F	194	10.02	1.17	8.36	8.70	9.97	11.13	12.08
	G	150	11.91	1.39	9.61	10.45	11.98	13.04	14.32
2nd premolar	A†	19	4.23	1.10	2.88	3.62	3.95	4.71	6.81
	B	57	4.94	1.10	3.43	4.01	4.64	6.12	6.91
	C	164	6.11	1.09	4.32	5.13	6.02	7.01	8.06
	D	125	7.49	1.20	5.77	6.35	7.41	8.68	9.76
	E	158	9.04	1.27	7.11	7.76	8.98	10.27	11.50
	F	198	10.65	1.46	8.52	9.19	10.56	12.12	13.40
	G	186	12.89	1.74	9.91	11.12	12.77	14.51	15.82
1st molar	O	9	0.11	0.05	0.00	0.07	0.12	0.14	0.19
	A	11	0.25	0.10	0.09	0.17	0.22	0.36	0.40
	B	12	0.78	0.22	0.52	0.53	0.90	1.00	1.01
	C	20	2.33	0.49	1.48	1.92	2.37	2.99	3.10
	D	31	3.70	0.55	2.55	3.22	3.74	4.21	4.53
	E	93	5.04	0.73	3.90	4.32	5.00	5.84	6.46
	F	106	6.50	1.03	5.21	5.55	6.39	7.29	7.95
	G	313	8.42	1.35	6.40	7.01	8.40	9.69	10.59
2nd molar	O†	5	3.88	0.47	–	3.41	3.85	4.35	–
	A†	14	4.02	0.53	3.24	3.41	4.15	4.57	4.70
	B	39	4.80	0.79	3.68	4.00	4.70	5.81	6.21
	C	174	6.22	0.97	4.68	5.28	6.19	7.03	7.77
	D	165	7.96	1.08	6.08	6.97	7.96	8.98	9.63
	E	193	9.66	1.18	8.00	8.54	9.55	10.76	11.86
	F	116	11.41	1.29	9.45	10.15	11.35	12.64	13.56
	G	204	13.56	1.55	11.35	12.22	13.54	14.73	16.54
3rd molar	O	61	9.41	1.49	7.46	8.06	8.97	11.34	12.25
	A	57	9.65	1.15	7.71	8.58	9.56	10.69	11.79
	B	111	10.82	1.56	8.48	9.27	10.72	12.48	13.48
	C	144	12.56	1.78	9.85	10.70	12.61	14.28	15.24
	D	64	14.05	1.62	11.72	12.40	14.04	15.62	17.15
	E	78	15.71	1.51	13.54	14.18	15.60	17.31	17.96
	F	39	17.57	2.09	14.92	15.82	17.46	18.45	24.04
	G	66	19.13	2.01	16.08	17.38	18.77	21.32	23.47

*Ages (in years) are given if teeth of at least 2 boys were at that stage.
†Median age differs from mid-attainment age by at least 0.5 years and use of Table III is recommended.

Table V. In-stage ages* at 7 stages of tooth formation (Demirjian) and at the crypt stage (O) in 8 mandibular teeth in Finnish girls

Tooth	Stage	*n*	Mean	SD	5%	16%	50%	84%	95%
Central incisor	B	2	0.45	0.10	–	–	0.45	–	–
	C†	4	2.00	0.65	–	1.19	2.07	2.69	–
	D	41	3.35	0.72	2.32	2.56	3.30	4.01	4.75
	E	117	5.00	0.74	3.83	4.39	5.00	5.62	6.11
	F	55	6.38	0.71	5.32	5.63	6.41	7.01	7.49
	G	101	7.54	0.96	6.13	6.68	7.47	8.46	9.13
Lateral incisor	C†	25	2.89	0.73	1.75	2.30	2.85	3.43	4.38
	D	66	4.23	0.79	3.02	3.43	4.34	5.00	5.57
	E	113	5.64	0.73	4.43	4.96	5.61	6.46	6.93
	F	60	7.05	0.86	5.57	6.20	7.03	7.91	8.56
	G	160	8.10	0.99	6.66	7.17	8.01	9.04	10.05
Canine	B	2	1.09	0.14	–	–	1.09	–	–
	C†	59	3.45	0.84	2.27	2.55	3.29	4.46	4.95
	D	100	5.14	0.72	4.01	4.45	5.06	5.92	6.20
	E	154	6.86	0.93	5.46	5.96	6.87	7.75	8.39
	F	189	8.62	1.11	7.03	7.54	8.50	9.76	10.62
	G	226	10.52	1.28	8.56	9.20	10.50	11.62	12.53
1st premolar	A†	3	2.69	0.40	–	2.24	2.85	2.99	–
	B	28	3.30	0.58	2.43	2.64	3.28	3.82	4.43
	C	98	4.69	0.71	3.43	4.00	4.65	5.47	5.78
	D	98	6.19	0.89	4.92	5.31	6.06	7.09	7.69
	E	180	7.74	0.90	6.35	6.92	7.71	8.66	9.14
	F	178	9.59	1.12	7.86	8.49	9.56	10.72	11.66
	G	166	11.20	1.29	9.55	10.19	11.01	12.32	13.68
2nd premolar	A†	24	4.27	1.33	2.77	3.10	4.14	5.50	7.15
	B†	54	4.88	1.20	3.42	3.86	4.64	5.90	7.32
	C	116	5.84	1.21	4.39	4.87	5.53	7.17	7.82
	D	104	7.31	1.08	5.59	6.30	7.18	8.29	9.11
	E	162	8.46	1.17	6.70	7.39	8.34	9.48	10.58
	F	188	10.27	1.24	8.38	8.95	10.22	11.60	12.37
	G	188	12.15	1.64	9.93	10.56	11.84	13.84	15.01
1st molar	O	4	0.06	0.06	–	0.00	0.07	0.11	–
	A	5	0.31	0.13	–	0.19	0.27	0.52	–
	B	6	0.81	0.39	0.37	0.47	0.66	1.22	1.49
	C†	17	2.38	0.48	1.35	1.87	2.55	2.70	3.08
	D	26	3.40	0.49	2.49	2.98	3.35	3.99	4.21
	E	93	4.81	0.87	3.55	4.17	4.72	5.50	6.02
	F	80	6.05	0.94	4.80	5.12	5.98	6.80	7.51
	G	286	7.89	1.14	6.12	6.80	7.81	8.95	10.16
2nd molar	O	10	3.60	0.95	2.40	2.81	3.25	2.94	5.09
	A	16	4.07	1.17	2.57	3.31	3.63	4.56	7.56
	B	48	4.79	0.98	3.54	4.00	4.55	5.48	6.69
	C	140	6.01	1.00	4.48	5.00	5.80	7.13	7.87
	D	155	7.68	0.97	6.10	6.59	7.73	8.63	9.17
	E	179	9.31	1.22	7.47	8.04	9.20	10.52	11.45
	F	137	10.91	1.05	9.50	9.94	10.81	11.85	12.56
	G	219	12.85	1.61	10.48	11.18	12.83	14.32	15.58
3rd molar	O	52	9.04	1.48	7.10	7.54	8.82	10.54	11.39
	A	50	10.17	1.75	7.87	8.52	9.89	11.59	13.36
	B	101	10.49	1.21	8.79	9.54	10.47	11.39	13.15
	C	151	12.07	1.72	9.67	10.42	11.93	13.81	15.04
	D	72	14.09	1.84	11.18	12.13	13.83	16.13	17.44
	E	73	15.69	2.25	12.69	13.32	15.34	17.51	19.53
	F	57	18.12	2.14	14.98	15.89	17.66	20.90	21.76
	G	112	20.10	2.28	17.05	17.55	20.27	22.38	24.18

*Ages (in years) are given if teeth of at least 2 girls were at that stage.
†Median age differs from mid-attainment age by at least 0.5 years and use of Table III is recommended.

despite very small numbers of observations for some developmental stages in infants (Table II).

Radiographs

Even in radiographs of excellent quality, the earliest mineralization stages may not be visible because there is not enough mineral mass to register above the absorbance of the mandibular bone [17–19]. Furthermore, in small children, and especially in the incisor area, the tomographic layer is seldom ideal, and developing teeth may not conform well to the average sharply depicted plane of the tomographic unit [14,20]. This is probably why crypts of anterior teeth were never visible, and early mineralization stages seldom visible. Thus, we did not quite reach our goal of providing complete gender-specific developmental schedules. Problems with the tomographic layer may also have been the main reason for the late attainment ages of stages D and E in I2 compared with I1. The fact that the image of I2 was often distorted may have affected assessments of these stages.

The great majority of the radiographs were PRs (95.7%). To increase the number of observations in small children, radiographs taken with two other techniques were also included. Radiographs obtained by various techniques have been used [3,19], but they give slightly divergent ages for initial mineralization [14].

Composition of material

Age of subjects in a stage (IS age) is practical for age estimations, but truncated and uneven distributions of ages of subjects in reference samples reduce the value of data for age prediction and may result in serious bias [6,21]. In our material extending from birth to age 25, truncation involved only the O-stage of M1, which was always present at birth indicating that the crypt could already be seen in radiographs prenatally. The greatest problem in observations was the uneven age distribution. The small number of children in age groups 1 and 2 years led to IS ages markedly too high, especially at stage C in incisors and canines, and also at some early mineralization stages of premolars and molars (Tables IV and V).

Age at initial mineralization

Knowledge about timing of initial mineralization in mandibular incisors is based on histological studies. Reported initiation ages [18,22] are slightly earlier than in this Finnish radiographic study. Since radiographic studies give later mineralization schedules than do histological studies [17,19], the present findings support earlier findings and also the view that individual variations in tooth formation in early infancy are small [1,17]. The only radiographic study we found states rather generally that the earliest evidence of mandibular I1 is seen in the first half of the first year [19].

Mineralization of M1 was already evident at birth in a large American study with oblique lateral radiographs [1], but in Finnish PRs it was visible first at 2 months of age. Similarly, the initial mineralization of P1 was later in Finns than in North Americans of Caucasian origin [1], whereas most ages at initial mineralization in canines, P2 and 2nd molars (M2) closely resembled the North American findings [1]. Furthermore, timing of initial mineralization in M3 was in accord with several other populations [1,11,23].

Age at crown completion

True termination of enamel formation occurs on buccal and lingual surfaces. This can be observed in histological, but not in radiographic studies, which allow estimations of the end of crown development on proximal surfaces only. Some recent studies present histological results also in forms that facilitate comparisons with radiological studies [21,24]. Finnish ages at radiographic crown completion of I1 (Table III) were in line with ages based on measurements of an English skeletal material [21]. Compared with recent histological findings of northern Europeans, Finnish ages resembled timing of crown completion in I1, I2, M1 and in canines, but were markedly later for M2 and M3 [24].

In comparisons between radiographic studies, it should be noted that stage D in the Demirjian grading [4] is closest to the stage "initial root formation" in the grading used by Moorrees et al. [1]. Finnish ages of incisors were earlier at that stage than those reported for both North American [11] and Japanese children [25], but, in M1, age at crown completion in Finns was close to that of the Japanese [26]. As a whole, timing of crown completion in canine, P1, P2, and M2 was close to the findings for two North American populations of Caucasian origin [1,11], but earlier than those for children of Caucasian and African origin in the US mid-South [27]. Furthermore, timing in Finns was later than that of French Canadians [12]. On the other hand, Finnish ages for M3 were close to those of Canadians [11,23], but both earlier [1] and later ages [3,28] have been published. To conclude, interpopulation differences in radiographic crown completion are inconsistent and may be obscured by methodological differences and problems.

Age at apical closure

The present ages at apical closure in 7 mandibular teeth resembled those reported for white children from the northeastern USA and eastern Canada [1,11,12]. Compared with the Japanese, ages at root completion in I1, I2, and M1 were earlier in Finns [25,26].

In contrast to other teeth, in M3, female delay was obvious in the last stages of root development, which accords with previous observations [1,3,7,23,28–30]. In men, timing of apical closure in M3 was the same or slightly later than reported for some other populations [1,3,28]. In Finnish women, however, timing was the same as reported for Hispanics in the southern USA [4], but later than in many studies [1,2,7,23,28]. This finding may indicate developmental variability between populations, but it may also reflect different sizes of age groups in the studies.

Concluding remarks

The present schedules, with ages as midpoints between attainments of consecutive stages (MA; Table III) can serve for assessments of average ages in children and adolescents of all ages. The tables presenting age as average ages in all individuals at a given stage (IS; Tables IV and V) can serve the same purposes as MA tables, and they have the advantage of presenting variations. In individuals of known age, they show to what degree the development of a child's tooth is advanced or delayed and whether development falls within normal limits. However, we recommend use of our IS tables without reservations only during the first year of life and from about 5 years of age onwards. Finally, attainment schedules provide average ages for teeth when entering developmental stages. Although the two other types of schedules are often preferred in clinical work, only attainment schedules (Table II) can serve for assessments of apical closure.

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