Dental maturity in Finns and the problem of missing teeth

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Development of teeth was studied from 2483 dental panoramic tomograms of 1651 healthy Finns ranging in age from 2 to 25 years. Dental maturity was assessed using a method based on developmental stages of 7 left mandibular teeth. We give sex-specific tables of maturity scores as a function of ages and of ages as a function of maturity scores. Also generated are percentile graphs for visual evaluations of dental maturity in children and adolescents. Since maturity scales do not tolerate any missing data, a great limitation for their use, we have developed linear regression models for predicting the formation stages of each of the 7 mandibular teeth. It was easiest to predict the formation stage of the mandibular first molars (correct in 87% within the study material) and most difficult to predict second molars and second premolars (correct in 69% and 70%, respectively). We expect the data and formulae presented in this study to prove useful in research and in clinical and forensic dentistry. □ *Dental age; dental radiography; missing teeth; tooth development; tooth mineralization*

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Children of the same chronological age show variation in degree of maturation. The radiographic methods for assessing dental maturation presented by Demirjian and co-workers (1, 2) have gained widespread use (3–7). Their dental maturity percentile graphs based on a large French–Canadian sample (2) function today as general references. The method has been reported to work best in young children, whereas the accuracy in age estimations is lower in older age groups (8). Studies conducted among other populations using the same methods show inter-population differences in dental maturation (9–14). Even regional, intrapopulation variations in dental maturation have been noted (15).

The original standards of dental maturity are based on formation stages of 7 left mandibular teeth (1). In addition, Demirjian and Goldstein (2) constructed 2 different 4-tooth systems convenient for rating purposes. These 4-tooth systems have gained very limited use, however (11, 13). As in the case of any systems assessing maturity, the Demirjian methods do not tolerate any missing data (16), although if a tooth is absent on one side only, the contralateral, homologous tooth may substitute for it. None of the 3 systems can be used if mandibular second premolars are missing bilaterally. This has been a serious limitation for the use of these methods, since the mandibular second premolars are the most frequently missing teeth excluding 3rd molars (17).

The main aim of this study was to present the development of dental maturity in Finnish boys and girls as continuous functions of age using the Demirjian 7-tooth method (2). The second aim was to create mathematical models for predicting developmental stages of 7 mandibular teeth to be used when teeth are missing or the radiographic image is obscure.

Material and methods

The study sample consisted of 2486 dental panoramic tomograms of 1653 healthy, ethnic Finns from southern Finland. Subjects with bilaterally missing mandibular teeth other than 3rd molars had been excluded. The material included 248 participants of a longitudinal growth study on dental and craniofacial development (18). A total of 1081 radiographs were taken in this longitudinal study in the period 1971 to 1993. The cross-sectional part of the material consisted of several samples. Radiographs of 205 subjects were taken in Turku in 1971–85 (11, 19) because of dental trauma. The cross-sectional Helsinki material, which consisted of 1011 radiographs representing a nursery and entire school classes, was collected in the period 1964 to 1968 (20). The remaining 189 cross-sectional radiographs, which had been taken because of caries and trauma in the period 1965 to 1995, came from the files of the Institute of Dentistry, University of Helsinki. Of these 2486 radiographs, 3 were later excluded from the final sample, since dental maturity was more than 4.0 SD delayed and in the statistical sense they were not part of a normal population. The final sample consisted of 2483 radiographs of 1651 children. The distribution of dental panoramic tomograms by age in attained years, sex, and source of the material is given in Table 1. In other tables and graphs the centered system is used in ages. So, for

Table 1. Distribution of panoramic tomograms by age and source of the material

	Boys					Girls				
		Cross–sectional					Cross–sectional			
Age (years)	Long.	Turku	H	Files	Total	Long.	Turku	H	Files	Total
2	–	–	3	–	3	1	–	3	1	5
3	5	6	4	7	22	9	2	10	4	25
4	23	10	14	7	54	31	2	19	3	55
5	41	4	17	12	74	37	–	25	13	75
6	44	13	42	12	111	38	7	22	9	76
7	54	–	35	7	96	46	8	61	9	124
8	38	5	67	5	115	47	6	50	7	110
9	47	–	43	15	105	52	15	27	10	104
10	33	3	54	11	101	32	6	82	14	134
11	22	5	23	11	61	34	9	51	6	100
12	29	7	51	8	95	30	8	19	10	67
13	28	10	23	2	63	35	11	26	1	73
14	24	14	55	2	95	29	16	27	1	73
15	26	6	15	–	47	19	8	7	–	34
16	14	12	4	–	30	22	9	20	–	51
17	20	1	54	–	75	17	2	50	–	69
18	21	–	4	–	25	21	–	2	–	23
19	21	–	–	–	21	30	–	2	–	32
20–25	31	–	–	–	31	29	–	–	–	29
Total	521	96	508	99	1224	559	109	503	88	1259

Long. = Helsinki growth study; Turku = children treated for dental trauma in Turku; H = children from Helsinki nurseries and schools (20); Files = children treated for caries or dental trauma in Helsinki.

instance, age group 10 years in Tables 2 and 3 includes ages 9.875–10.124 years.

The 7 left mandibular teeth were rated on an 8-stage scale from A to H using the method of Demirjian and associates (1). With this method, each stage of the 7 teeth has been given a sex-specific, biologically weighted score. The sum of the scores is the dental maturity score of the subject measured on a scale from 0 to 100. The scores can be converted to dental age by means of given percentile graphs. In the present study we used the self-weighed scores for dental stages given in the revised version (2). If a tooth was missing or its image was unclear, the contralateral, homologous tooth was used. Of the 2486 evaluations, 2281 (92%) were performed by the first author and the remaining 205 (8%) by the second author (LA). The evaluations were made between 1986 and 1996. The first observer calibrated herself regularly with the help of the Demirjian dental development computer program (Silver-Platter Multimedia Database, SilverPlatter Information Inc., Norwood, MA, USA). The last author (MK) selected the statistical methods used, developed the computational methods and made all calculations. The French–Canadian 7-tooth maturity graphs were enlarged to 5 times their published size (2) and measured. The figures were drawn with the Harvard Graphics computer programme, version 2.12 (Software Publishing Corporation, Mountain View, CA, USA). All figures are presented exactly the way they were calculated except for the minor smoothing which is built into the Harvard Graphics program.

To construct mathematical models for assessing the formation stages of individual teeth, the names of the 8 stages were converted to numbers (i.e., A = 1, B = 2, etc.). Moreover, we added stage "0", representing tooth mineralization not yet begun. This was used in situations where crypt formation could be visualized or where the tooth appeared first in a later tomogram of the same child. These numbers were used in calculations. The 9 variables given to the stepwise regression analysis were: dental formation stages of all left-side mandibular teeth, except the tooth to be estimated and the 3rd molar; age in years; its reciprocal (1/age); and sex.

Statistics

The primary statistical tools were median, percentiles, mean and standard deviation (SD). Figures 1–3 and Tables 2 and 3 were smoothed using 3-point moving averages. Curvilinear interpolation was employed in calculations of scores as a function of age. Scores as a function of age (Tables 2, 3 and Figs 1–3) increased in about the same direction in the French–Canadian (2) and the present population. To minimize bias within the presented data, the derivatives of the median curves in the Demirjian standards (2) were utilized in calculations. For example, in half-year steps (Figs 1–3), the 4.0-year value was interpolated between 3.75 and 4.24 years also using the form of the Demirjian standard curve at 4.0 years (1st and 2nd derivatives). For each point, a 2nd-degree polynomial was fitted using 4 points from both sides. Linear interpolation was employed in calculations of ages as a function of scores (Tables 4 and 5). Stepwise

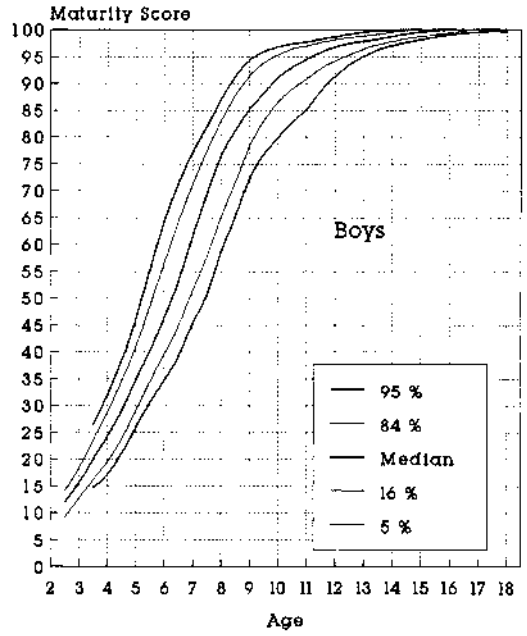

Fig. 1. Dental maturity percentiles for boys in southern Finland (Demirjian 7-tooth method). Three-point smoothing.

regression analysis was used to build mathematical models for estimating the formation stages of individual mandibular teeth. Agreement percentage and Kappa index (21) were calculated in estimations of intra-rater agreement.

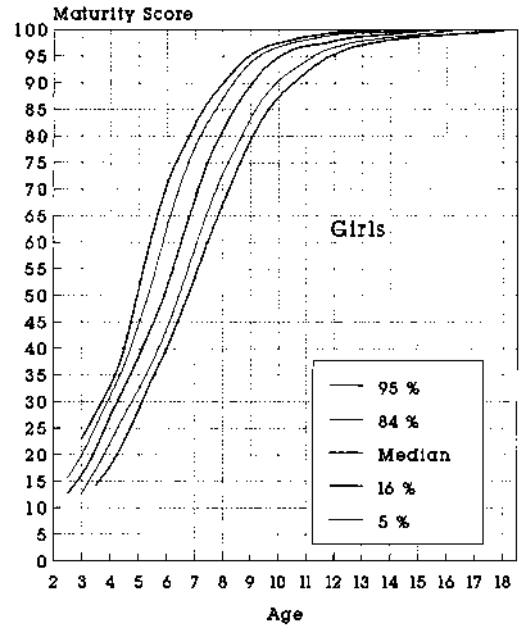

Fig. 2. Dental maturity percentiles for girls in southern Finland (Demirjian 7-tooth method). Three-point smoothing.

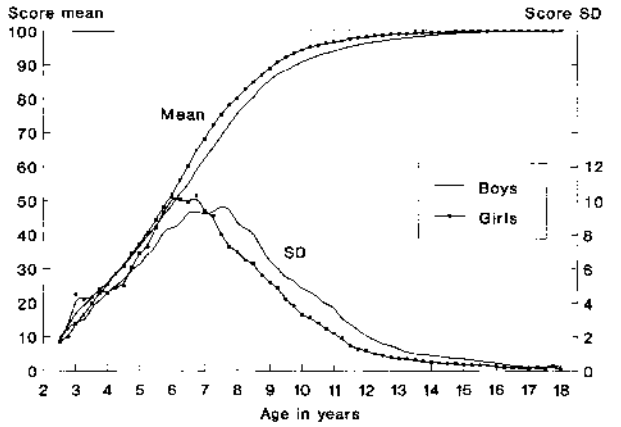

Fig. 3. Means and standard deviations (SDS) of maturity scores in boys and girls in southern Finland (Demirjian 7-tooth method). Three-point smoothing.

Intra-rater agreement

The first author re-evaluated developmental stages of teeth in 1997, several years after the first rating. For this control study, the radiographs of the youngest and the oldest boy and girl in 1-year age groups from 3 to 15 years were selected. Thus, 52 panoramic tomograms with 364 left mandibular teeth were re-rated. The ratings of 341 teeth (93.7%) concurred. In 23 teeth (6.9%) the difference was one grade, in 12 teeth advanced and in 11 delayed. The Kappa index was calculated expecting the proportion of agreement by chance to be 1/3, resulting in Kappa = 0.91 (95% CI, 0.87–0.94).

Results

Dental maturity

Maturity scores as a function of age are presented in 3-month steps for boys (Table 2) and girls (Table 3). Dental maturity percentile graphs for Finnish boys using the 7-tooth system (2) are given in Fig. 1 and those for girls in Fig. 2. The score percentiles, within which the scores of children of known ages lie, are read vertically. Accordingly, if aspects "advanced" or "delayed" compared with reference subjects of the same age are of interest, the graphs are read vertically. If the score is known and the age is of interest, these percentile graphs do not quite illustrate age variation correctly; it is better to use Tables 4 and 5.

Variation in maturity scores in girls was greatest between the ages 5 and 8 years, and in boys about half a year later (Fig. 3). The maturity curves end at the age of 18.0 years. Six (4.3%) of the 139 subjects with 164 radiographs taken at a later age still showed mandibular second molars with open apices. All these molars demonstrated only one cone-shaped root. One such molar showed two root canals; the other 5 had only 1

Table 2. Dental maturity scores† in Finnish boys. Seven-tooth method (2)

Age	5%	16%	50%	84%	95%	Mean	SD
2.5	9.2	12.0	14.2			9.9	2.63
2.75	10.6	11.0	13.9	15.9	16.2	12.0	2.64
3.0	12.1	12.7	15.4	17.8	19.3	16.4	2.95
3.25	12.8	14.0	17.6	20.3	21.4	18.2	3.19
3.5	14.7	16.4	20.1	23.9	26.5	21.5	3.81
3.75	15.2	18.1	22.6	26.3	28.3	23.6	4.11
4.0	16.8	19.3	24.4	28.7	32.1	25.8	4.59
4.25	18.2	22.4	27.5	32.2	34.8	28.5	5.06
4.5	21.0	23.8	29.0	34.7	38.1	30.7	5.30
4.75	21.3	27.0	31.8	38.0	41.9	33.5	6.00
5.0	26.1	29.1	35.0	40.7	45.9	36.6	6.15
5.25	27.4	32.4	37.1	44.4	51.5	39.5	6.93
5.5	30.7	34.7	40.1	48.6	55.3	42.4	7.23
5.75	32.6	37.2	42.6	53.0	61.7	45.6	8.30
6.0	34.9	39.6	46.4	56.5	64.6	48.6	8.42
6.25	38.7	42.7	49.5	60.4	68.3	52.0	8.59
6.5	38.6	44.5	52.6	64.3	71.5	54.7	9.36
6.75	41.8	47.7	57.9	68.9	74.6	58.8	9.48
7.0	45.9	51.6	61.6	71.3	77.4	62.3	9.19
7.25	46.7	54.0	65.5	74.8	79.6	65.3	9.40
7.5	49.6	57.2	69.3	77.5	81.9	68.6	9.73
7.75	52.5	61.3	72.9	81.2	86.4	72.0	9.70
8.0	59.3	65.6	77.2	83.3	87.3	75.6	8.62
8.25	61.9	69.2	78.8	86.2	90.7	78.2	8.42
8.5	64.8	71.4	81.2	88.0	91.5	80.3	8.08
8.75	69.1	76.1	84.2	90.1	93.5	83.5	7.21
9.0	73.0	78.8	85.5	91.7	94.7	85.3	6.36
9.25	75.0	80.9	88.0	93.3	95.5	87.3	6.07
9.5	77.0	83.3	88.0	94.1	96.1	88.2	5.42
9.75	77.6	84.4	90.2	95.0	96.4	89.5	5.34
10.0	79.9	86.7	91.3	95.4	96.9	90.8	4.80
10.25	81.6	87.4	92.1	96.2	97.3	91.5	4.66
10.5	83.0	89.1	93.1	96.6	97.5	92.6	4.30
10.75	84.5	90.3	93.8	96.9	97.9	93.3	3.94
11.0	84.9	90.8	94.6	97.0	97.7	93.8	3.76
11.25	88.7	92.4	95.3	97.3	98.2	94.6	2.97
11.5	88.9	93.0	95.9	97.7	98.3	95.3	2.79
11.75	90.8	93.6	96.4	98.0	98.7	95.8	2.39
12.0	91.4	94.3	96.9	98.2	98.7	96.2	2.12
12.25	93.2	94.7	97.3	98.5	99.0	96.6	1.83
12.5	93.7	95.4	97.5	98.5	99.2	96.9	1.57
12.75	94.4	95.9	97.7	99.0	99.4	97.3	1.46
13.0	95.1	96.5	97.9	98.9	99.6	97.5	1.32
13.25	95.9	96.9	98.0	99.1	99.5	97.7	1.13
13.5	96.4	97.3	98.2	99.1	99.7	98.0	1.00
13.75	96.9	97.5	98.5	99.4	99.6	98.3	0.92
14.0	97.1	97.8	98.8	99.6	99.9	98.5	0.91
14.25	97.5	98.1	99.0	99.6	99.9	98.7	0.86
14.5	97.7	98.4	99.2	99.8	100.0	99.0	0.77
14.75	98.1	98.8	99.4	99.9	100.0	99.2	0.73
15.0	98.1	98.7	99.6	100.0	100.0	99.3	0.71
15.25	98.5	99.1	99.7	100.0	100.0	99.5	0.63
15.5	98.7	99.1	99.8	100.0	100.0	99.6	0.57
15.75	99.0	99.4	99.9	100.0	100.0	99.7	0.49
16.0	99.0	99.4	100.0	100.0	100.0	99.7	0.45
16.25	99.2	99.6	100.0	100.0	100.0	99.8	0.38
16.5	99.4	99.8	100.0	100.0	100.0	99.9	0.29
16.75	99.4	99.8	100.0	100.0	100.0	99.9	0.26
17.0	99.5	100.0	100.0	100.0	100.0	99.9	0.21

Table 3. Dental maturity scores† in Finnish girls. Seven-tooth method (2)

Age	5%	16%	50%	84%	95%	Mean	SD
2.5	11.3	11.5	12.7	15.6	17.3	11.6	0.68
2.75	10.3	10.5	14.6	18.9	20.7	12.4	3.17
3.0	12.3	12.8	15.7	19.5	21.8	15.0	3.10
3.25	12.3	13.8	19.1	22.8	24.7	17.2	4.12
3.5	14.2	17.0	20.8	25.5	28.0	19.7	4.28
3.75	15.9	19.3	24.6	28.5	31.0	22.5	4.77
4.0	17.5	22.2	27.6	31.1	32.4	25.3	4.55
4.25	21.2	24.9	31.0	33.9	36.3	28.2	4.95
4.5	22.7	27.8	32.7	36.7	39.5	30.8	4.97
4.75	26.9	30.4	35.8	40.8	46.6	34.3	6.10
5.0	28.4	32.2	38.5	44.6	51.6	37.2	6.87
5.25	32.9	35.3	41.0	47.8	55.3	40.3	7.27
5.5	34.7	37.6	44.5	52.7	62.2	44.2	8.38
5.75	37.7	40.3	47.8	58.5	65.5	47.9	9.33
6.0	39.8	43.5	51.2	63.2	71.5	51.8	10.16
6.25	43.0	46.8	55.2	67.2	72.3	55.6	10.10
6.5	46.6	50.9	60.0	71.3	76.8	60.3	9.93
6.75	49.7	54.5	64.6	76.3	81.0	64.5	10.29
7.0	53.4	59.0	68.1	78.4	82.4	68.1	9.37
7.25	56.8	62.6	72.3	81.5	86.3	71.8	9.15
7.5	60.9	66.7	76.2	83.0	86.9	75.2	8.03
7.75	65.5	70.5	79.0	85.4	89.1	77.9	7.36
8.0	67.4	73.2	81.2	87.2	90.0	80.2	7.01
8.25	71.2	76.3	83.8	89.1	91.4	82.8	6.54
8.5	73.6	78.2	86.1	91.2	93.1	84.9	6.31
8.75	76.8	81.6	87.8	92.1	93.9	86.9	5.59
9.0	79.7	83.7	89.8	94.2	95.5	89.0	5.13
9.25	81.3	85.9	91.5	95.2	96.8	90.8	4.91
9.5	84.3	87.8	93.1	95.9	96.9	92.2	4.12
9.75	85.8	89.5	94.0	96.4	97.8	93.3	3.74
10.0	87.9	90.8	94.9	96.9	97.5	94.2	3.20
10.25	88.8	91.5	95.9	97.3	98.4	95.0	3.13
10.5	89.9	92.5	96.5	97.7	98.3	95.7	2.76
10.75	91.0	93.2	96.7	97.9	98.8	96.1	2.52
11.0	92.1	94.1	97.0	98.1	98.7	96.5	2.17
11.25	93.2	94.6	97.1	98.4	99.1	96.9	1.92
11.5	94.1	96.0	97.4	98.7	99.2	97.5	1.50
11.75	95.1	96.4	97.8	98.9	99.4	97.8	1.25
12.0	95.5	96.7	97.9	99.1	99.5	98.0	1.16
12.25	96.1	97.1	98.3	99.2	99.6	98.3	1.04
12.5	96.5	97.5	98.5	99.4	99.7	98.6	0.91
12.75	97.0	97.8	98.8	99.5	99.8	98.8	0.80
13.0	97.3	98.0	98.8	99.5	99.9	98.9	0.72
13.25	97.6	98.1	98.9	99.6	100.0	99.0	0.68
13.5	97.7	98.3	99.0	99.5	100.0	99.1	0.62
13.75	98.0	98.4	99.1	99.7	100.0	99.2	0.57
14.0	98.2	98.7	99.2	99.7	100.0	99.2	0.50
14.25	98.4	98.8	99.4	99.8	100.0	99.4	0.46
14.5	98.5	98.9	99.6	99.8	100.0	99.5	0.44
14.75	98.7	99.0	99.7	100.0	100.0	99.6	0.41
15.0	98.8	99.2	99.8	100.0	100.0	99.7	0.36
15.25	98.8	99.4	99.9	100.0	100.0	99.8	0.33
15.5	98.9	99.4	100.0	100.0	100.0	99.8	0.33
15.75	98.9	99.4	100.0	100.0	100.0	99.8	0.30
16.0	99.1	99.8	100.0	100.0	100.0	99.9	0.24
16.25	99.0	99.8	100.0	100.0	100.0	99.9	0.21
16.5	99.3	100.0	100.0	100.0	100.0	99.9	0.18
16.75	99.3	99.8	100.0	100.0	100.0	99.9	0.18
17.0	99.5	100.0	100.0	100.0	100.0	100.0	0.14

† Calculations were performed in 2 separate turns. The 1st turn gave scores corresponding to *0.0 and *0.5 years and the 2nd turn scores corresponding to *0.25 and *0.75 years. The width of the calculation window was 0.25 years to both sides of the given age. Three-point moving average was applied.

Table 4. Ages (years) corresponding to dental maturity scores in Finnish boys. Seven-tooth method (2)

Score	5%	16%	50%	84%	95%	Mean	SD
10		2.4	2.40	3.4		2.71	0.57
15		3.0	3.38	4.0		3.48	0.36
20	3.2	3.3	3.81	4.5	4.8	3.86	0.53
25	3.5	3.7	4.11	4.9	5.3	4.24	0.52
30	3.7	3.9	4.53	5.4	5.8	4.58	0.62
35	4.1	4.4	4.99	5.5	6.0	4.98	0.56
40	4.4	4.8	5.47	6.1	6.6	5.49	0.67
45	5.0	5.3	5.96	6.6	7.0	5.95	0.61
50	5.3	5.6	6.32	6.9	7.7	6.32	0.65
55	5.6	6.2	6.55	7.4	7.8	6.69	0.62
60	6.0	6.5	6.93	7.7	8.2	6.98	0.63
65	6.2	6.6	7.38	8.1	8.8	7.36	0.74
70	6.3	6.9	7.68	8.5	9.2	7.68	0.84
75	6.9	7.3	8.24	9.0	9.6	8.16	0.87
80	7.3	7.7	8.56	9.7	10.4	8.66	0.95
85	7.7	8.1	9.03	10.1	11.0	9.16	0.99
90	8.2	8.7	9.71	10.9	11.7	9.84	1.07
92	8.4	8.9	10.07	11.5	12.1	10.17	1.19
94	8.7	9.4	10.61	12.0	12.6	10.62	1.23
95	8.7	9.5	10.90	12.4	12.9	10.92	1.32
96	9.2	10.0	11.38	12.8	13.4	11.38	1.32
97	9.6	10.6	12.02	13.2	14.0	11.91	1.36
98	9.9	10.8	12.44	13.7	14.4	12.33	1.44
98.5	10.2	11.3	13.01	14.3	15.0	12.85	1.49
99	10.6	11.5	13.60	14.8	16.0	13.43	1.68
99.5	10.9	11.9	13.96	15.2	16.4	13.81	1.74

Table 5. Ages (years) corresponding to dental maturity scores in Finnish girls. Seven-tooth method (2)

Score	5%	16%	50%	84%	95%	Mean	SD
10		2.4	2.90	3.2		2.87	0.30
15	2.6	2.9	3.41	4.0	4.3	3.42	0.47
20	2.9	3.3	3.68	4.4	4.7	3.78	0.52
25	3.3	3.5	4.10	4.5	4.7	4.05	0.47
30	3.5	4.0	4.52	5.0	5.4	4.52	0.51
35	4.3	4.5	4.97	5.5	5.7	4.99	0.45
40	4.6	4.9	5.34	5.8	6.1	5.35	0.48
45	5.0	5.3	5.72	6.4	6.6	5.75	0.47
50	5.3	5.6	6.14	6.7	7.1	6.16	0.52
55	5.4	5.8	6.53	7.1	7.5	6.47	0.61
60	5.8	6.1	6.77	7.5	7.9	6.79	0.64
65	6.1	6.6	7.29	7.9	8.5	7.24	0.70
70	6.3	6.8	7.53	8.2	8.7	7.50	0.78
75	6.5	7.1	7.71	8.6	9.1	7.80	0.83
80	6.7	7.3	8.16	9.1	9.8	8.19	0.89
85	7.0	7.7	8.51	9.6	10.4	8.63	1.00
90	7.6	8.3	9.41	10.6	11.0	9.41	1.09
92	7.9	8.6	9.79	10.8	11.7	9.78	1.18
94	8.5	8.9	10.12	11.4	12.2	10.17	1.26
95	8.5	9.0	10.37	11.7	12.3	10.39	1.32
96	8.6	9.2	10.52	11.9	12.6	10.61	1.37
97	8.9	9.7	10.79	12.0	12.9	10.90	1.29
98	9.2	10.2	11.27	12.8	13.7	11.40	1.37
98.5	9.6	10.5	11.72	13.3	13.9	11.75	1.42
99	10.0	10.9	12.21	13.9	14.9	12.30	1.53
99.5	10.1	11.1	12.57	14.5	15.3	12.87	3.19

large, seemingly fused root canal. One of these teeth with an open apex had been radiographed at the age of 24 years.

Sexual differences

Since the self-weighed scores for dental stages of teeth given by Demirjian and Goldstein (2) are sex-specific, and mathematical comparisons can be made only if the scale is the same, we used the means of these sex-specific scores for dental stages in the comparisons. Using these common scores, female advance in dental maturity was seen at all ages beginning at 3 years, which was the youngest age group compared (Fig. 4). The advance was greatest, about 1 year, from 9.5 to 13.5 years of age.

Mathematical models for assessing developmental stages of individual teeth

We obtained the following formulae for inputing formation stages of individual teeth:

In these formulae, X1 through X7 are the radiographic formation stages of the mandibular central and lateral incisor, the canine, the first and second premolars, and the first and second molars, respectively. When the formulae are used, age is given in years with at least 1 decimal. Sex is designated as "0" for boys and "1" for girls. The result of a calculation is rounded to integer and to 8 if it is greater than 8. This integer is then converted back to the Demirjian stage from A to H. If the result is zero or negative, the estimation is that tooth mineralization has not yet begun.

In our study material, the mandibular 2nd molar and 2nd premolar were the most difficult teeth to predict, resulting in 69% and 70% correct classifications, respectively, in the total study material. In most cases of mistaken classification the magnitude of error was only 1 stage, roughly evenly distributed in both directions. The models predicted 2 stages delayed in 12 (0.07%) out of 17,381 (2,483 multiplied by 7) estimations and 2 or more stages too advanced in 87 (0.50%) estimations. Of those 87 predictions, which were predicted 2 or more stages too

Tooth	Regression equation	Correct estimate
I1:	X1 = 0.66*X2 − 0.14*X4 + 0.24*X6 − 3.75/Age + 2.23	83.3%
I2:	X2 = 0.73*X1 + 0.14*X3 + 0.07*X4 + 0.20*X6 − 0.98	83.5%
C:	X3 = 0.22*X2 + 0.57*X4 + 0.26*Sex + 0.05*Age + 0.58	80.1%
P1:	X4 = 0.48*X3 + 0.25*X5 + 0.16*X6 + 0.17*X7 − 0.40	78.1%
P2:	X5 = 0.12*X2 + 0.52*X4 + 0.38*X7 − 3.73/Age − 0.02	70.1%
M1:	X6 = 0.24*X1 + 0.18*X2 + 0.12*X4 − 5.35/Age + 4.03	86.7%
M2:	X7 = 0.16*X3 + 0.29*X4 + 0.35*X5 + 0.12*Age − 0.60	68.6%

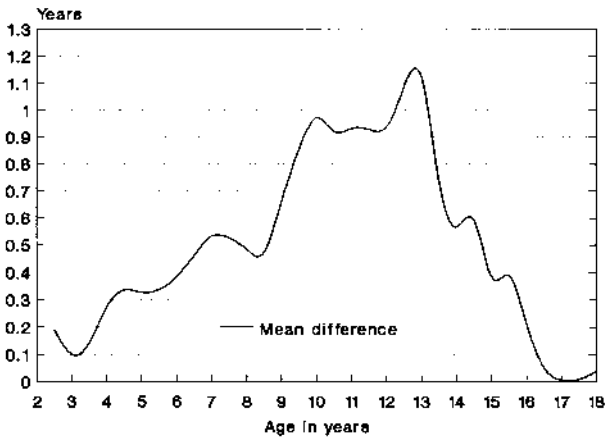

Fig. 4. Difference in dental age between girls and boys from the age of 2.5 years to 18 years. Common scores used in comparison are means of sex-specific scores for developmental stages of teeth (Demirjian 7-tooth method).

advanced, 47 (54%) of the teeth were 2nd premolars and 27 (31%), 2nd molars.

Discussion

Dental maturity

The goal of the study was to present the development of dental maturity in Finns as continuous functions of age using the Demirjian 7-tooth method (2). The number of 2-year-old children was too small to give good estimates, but in older children and in adolescents the goal was reached by means of mathematical methods. The panographic tomograms were taken during the course of 30 years. Since tooth mineralization is genetically determinined (6, 22, 23) it is very unlikely that this wide time range influenced the results. While a secular trend has been found in the emergence of teeth (24), this phenomenon has not, to our knowledge, been reported in the mineralization of the 7 mandibular teeth.

When dental maturity of adolescents is estimated, attention should also be paid to the morphology of the mandibular 2nd molar. The completion of root development in 1-rooted, conical 2nd molars seems to occur considerably later than in 2-rooted, which must be taken into account when the information given by maturity scores is interpreted. The Demirjian scoring system does not work well during the first developmental stages of early developing teeth. The canine, for instance, gets score zero when its development has not begun and also when the crown is almost complete (stage C).

Tooth maturity percentile charts are best suited for clinical circumstances in which dental maturity of children of known age is analysed. It is relatively easy to plot a child's maturity score on a chart to determine visually whether his or her stage of dental development lies within the normal range. When growth and development have been studied, it has been customary to express deviations from population means in standard deviation scores (SDS, Z-score) (25, 26). The possibility to express deviations of maturity in SDS is even more important in cases displaying abnormal somatic development, where a child's developmental age may fall outside the percentile curves. Deviations of dental maturity using the Demirjian method have likewise been expressed in SDS (3, 19, 27). In lack of tables standard deviations needed for calculation of SDS have been estimated from dental maturity charts. In the present study, dental maturity percentiles and means with standard deviations are presented in tables with small steps to be used in research and in clinical and forensic dentistry. If the age of the child lies in between the given ages, linear interpolation can be used to get a more precise score assessment (Tables 2 and 3). Interpolation procedure is suitable also for ages, which are given at 5-point score intervals in Tables 4 and 5.

Since the dental maturity score cannot exceed 100 or go below zero, distributions of scores close to these limits are skewed. To be strict, SDS can be used only when the distribution is normal (28). Standard deviation varies with age (Fig. 3), which must be taken into account in the interpretation of SDS. If a child is greatly advanced or delayed dentally, radiographs taken at an interval of a couple of years may give considerably different SDS values, although dental development has proceeded smoothly and only the reference SD has changed markedly. An essential cause for these difficulties lies in the discrete nature of the Demirjian score. The maturity scale is not continuous, but based on 8 stages of 7 teeth and in practice the number of stages available for a tooth at a certain age is much lower than 8. Because of this discrete nature of the Demirjian score, the average child's dental development will not follow the normal curve exactly, but advance in steps, which would be detected if it were possible to take radiographs at very frequent intervals.

Sexual differences

Girls were ahead of boys in dental maturation from the age of 2.5 years onwards. In this comparison we used identical maturity scores for dental stages in boys and girls (Fig. 4). Figure 3 in the present study gives the impression that female advance in dental maturity first begins after 5 years of age. This impression is misleading, however, since maturity scores for dental stages in the Demirjian system (2) are not the same for girls and boys. Similarly, in a previous study using the same method (29), female advance in maturity curves is first seen at 5 to 6 years of age, whereas this advance can also be observed earlier in the attainment of developmental stages of individual teeth.

Estimation of developmental stages of teeth

A marked limitation for the use of maturity scales is that no allowance is made for missing data (16). Second

premolars are particularly problematic because none of the 3 methods for estimating dental maturity (2) can be employed if they are bilaterally absent. Since only the 7-tooth system has gained widespread use, we also present formulae to estimate the developmental stages of the other 6 mandibular teeth (excluding the 3rd molar).

The stepwise regression analysis was used in building-up models for the best possible guess of the formation stages of missing individual teeth. This method has limits theoretically, since grade assessments are not measurements. The regression model, however, was chosen since it works well. The best and the least biased way of estimating success rates is to validate the formulae with other data. Since such data were not available, our estimations were made in the same population, which may lead to too high success rates. Considering the large number of observations (over 2400 each) the difference cannot be great. We also experimented with some 5-variable models, which gave slightly fewer prediction errors for some teeth, but we selected the fixed number of 4 for the convenience of use. Dropping the number of variables to 3 caused more prediction errors. Separate models for estimating early and late tooth formation stages were also constructed, but they did not work as fluently as the general model. Differences in sex-specific models were so small that we present only one model with pooled boys and girls. In this model with 4 variables, the stepwise regression analysis chose sex only for the prediction of the developmental stage of the canine. This is in accordance with the finding that the mineralization schedule of the mandibular canine differs most between boys and girls (20). When we built models with 5 variables, also the prediction model of the 1st premolar included sex.

Since the prediction models worked well in our material consisting of healthy children with 7 mandibular teeth, they can be expected to work similarly if a tooth has been extracted or if a radiographic image is obscure. In practice, models to compensate for the absence of teeth are usually needed when teeth are congenitally missing. Tooth formation has been observed to be delayed in children with hypodontia (30–32). Since the prediction models of missing teeth have formation stages of other teeth as variables, they are able to take this delay into account. If the prediction differed more than one grade from the real developmental stage (0.57%), the models predominantly predicted too advanced a stage. More than a half of these significantly advanced predictions involved 2nd premolars and almost a third, 2nd molars. Retarded development of mandibular 2nd premolars is a well-known phenomenon which also has clinical concerns.

The developmental stages of the incisors and the 1st molar were the easiest to estimate, and those of the 2nd premolar and the 2nd molar the most difficult. Thus the prediction of tooth formation stages is most difficult in teeth which begin their development late. In this respect, the results of our study correspond with earlier findings (26, 33) that late-forming teeth are more variable than early-forming teeth.

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References

1. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol 1973;45:211–27.
2. Demirjian A, Goldstein H. New systems for dental maturity based on seven and four teeth. Ann Hum Biol 1976;3:411–21.
3. Myllärniemi S, Lenko HL, Perheentupa J. Dental maturity in hypopituitarism, and dental response to substitution treatment. Scand J Dent Res 1978;86:307–12.
4. Proy E, Sempé M, Ajacques J-C. Étude comparée des maturations dentaire et squelettique chez des enfants et adolescents français. Rev Orthop Dento Fac 1981;15:309–26.
5. Midtbø M, Halse A. Skeletal maturity, dental maturity, and eruption in young patients with Turner syndrome. Acta Odontol Scand 1992;50:303–12.
6. Pelsmaekers B, Loos R, Carels C, Derom C, Vlietinck R. The genetic contribution to dental maturation. J Dent Res 1997; 76:1337–40.
7. Nykänen R, Espeland L, Kvaal SI, Krogstad O. Validity of the Demirjian method for dental age estimation when applied to Norwegian children. Acta Odontol Scand 1998;56:238–44.
8. Hägg U, Matsson L. Dental maturity as an indicator of chronological age: the accuracy and precision of three methods. Eur J Orthod 1985;7:25–34.
9. Prahl-Andersen B, Roede MJ. The measurement of skeletal and dental maturity. In: Prahl-Andersen B, Kowalski CJ, Heyendael PHJM, editors. A mixed-longitudinal interdisciplinary study of growth and development. Academic Press; 1979. p. 491–519.
10. Loevy HT. Maturation of permanent teeth in black and latino children. Acta Odontol Pediatr 1983;4:59–62.
11. Kataja M, Nyström M, Aine L. Dental maturity standards in southern Finland. Proc Finn Dent Soc 1989;85:187–97.
12. Davis PJ, Hägg U. The accuracy and precision of the "Demirjian system" when used for age determination in Chinese children. Swed Dent J 1994;18:113–6.
13. Mörnstad H, Reventlid M, Teivens A. The validity of four methods for age determination by teeth in Swedish children. Swed Dent J 1995;9:121–30.
14. Koshy S, Tandon S. Dental age assessment: the applicability of Demirjian's method in south Indian children. Forensic Sci Int 1998;94:73–85.
15. Nyström M, Ranta R, Kataja M, Silvola H. Comparisons of dental maturity between the rural community of Kuhmo in northeastern Finland and the city of Helsinki. Community Dent Oral Epidemiol 1988;16:215–7.
16. Smith BH. Standards of human tooth formation and dental age assessment. In: Kelley MA, Larsen CS, editors. Advances in dental anthropology. New York: Wiley-Liss; 1991. p. 143–68.
17. Haavikko K. Hypodontia of permanent teeth. An orthopantomographic study. Proc Finn Dent Soc 1971;67:219–25.
18. Nyström M, Haataja J, Kataja M, Evälahti M, Peck L, Kleemola-Kujala E. Dental maturity in Finnish children, estimated from the development of seven permanent mandibular teeth. Acta Odont Scand 1986;44:193–8.
19. Aine L. Dental enamel defects and dental maturity in children and adolescents with coeliac disease. Thesis. Proc Finn Dent Soc 1986;82 (Suppl III):1–59.
20. Haavikko K. The formation and the alveolar and clinical eruption of the permanent teeth. An orthopantomographic study. Proc Finn Dent Soc 1970;66:103–70.
21. Altman DG. Practical statistics for medical research. Chapman & Hall; 1992. p. 403.
22. Garn SM, Lewis AB, Polacheck DL. Sibling similarities in dental development. J Dent Res 1960;39:170–5.

23. Green JL, Aszkler SE. Intra-alveolar dental development in twins. J Dent Res 1070;49:631–4.
24. Demirjian A. Dentition. In: Falkner F, Tanner JM, editors. Human growth: a comprehensive treatise. 2nd ed. New York: Plenum Press; 1986. p. 269–98.
25. Tanner JM, Whitehouse RH, Hughes PCR, Vince FP. Effect of human growth hormone treatment for 1 to 7 years on growth of 100 children, with growth hormone defiency, low birthweight, inherited smallness, Turner's syndrome, and other complaints. Arch Dis Child 1971;46:745–82.
26. Moorrees CFA, Fanning EA, Hunt EE Jr. Age variation of formation stages for ten permanent teeth. J Dent Res 1963; 42:1490–502.
27. Kotilainen J, Hölttä P, Mikkonen T, Arte S, Sipilä I, Pirinen S. Craniofacial and dental characteristics of Silver–Russel syndrome. Am J Med Genet 1995;56:229–36.
28. Cantu G, Buschang PH, Gonzales JL. Differential growth and maturation in idiopathic growth-hormone-deficient children. Eur J Orthod 1997;19:131–9.
29. Demirjian A, Levesque G-Y. Sexual differences in dental development and prediction of emergence. J Dent Res 1980; 59: 1110–22.
30. Rune B, Sarnäs K-V. Tooth size and tooth formation in children with advanced hypodontia. Angle Orthod 1974;44:316–21.
31. Ranta R. Comparison of tooth formation in noncleft and cleft-affected children with and without hypodontia. ASDC J Dent Child 1982;49:197–9.
32. Schalk van der Weide Y, Prahl-Andersen B, Bosman F. Tooth formation in patients with oligodontia. Angle Orthod 1993;63: 31–7.
33. Garn SM, Lewis AB, Polacheck DL. Variability of tooth formation. J Dent Res 1959;38:135–48.

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