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Dental Maturity Curves in Finnish Children: Demirjian's Method Revisited and Polynomial Functions for Age Estimation

ABSTRACT: Dental maturity was studied from 2213 dental panoramic radiographs of healthy ethnic Finns from southern Finland, aged between 2 and 19 years. The aim was to provide new Finnish maturity tables and curves and to compare the efficiency of Demirjian's method when differently weighted scores and polynomial regressions are used. The inter-ethnic variations lead us to calculate specific Finnish weighted scores. Demirjian's method gives maturity score as a function of age and seems better adapted for clinicians because, in their case, the maturity score is unknown. Polynomial functions give age as a function of maturity score and are statically adapted for age estimation studies. Finnish dental maturity tables and development curves are given for Demirjian's method and for polynomial functions. Sexual dimorphism is established for the same weighted score for girls and boys, and girls present a greater maturity than boys for all of age groups. Polynomial functions are highly reliable (0.19% of misclassifies) and the percentile method, using Finnish weighted scores, is very accurate (±1.95 years on average, between 2 and 18 years of age). This suggests that polynomial functions are most useful in forensic sciences, while Demirjian's method is most useful for dental health clinicians.

KEYWORDS: forensic science, age estimation, Demirjian's method, dental maturity, polynomial functions

Age determination studies have an important role in forensic sciences and for clinicians to know the variations in degree of maturation. Several authors (4,11,12,21,22,27,38) showed that dental development is suitable for children's age determination because of low variability. The most frequently used methods are based on dental calcification measured from radiographs (6,11,17,22,23,25,33,39); these methods present the advantage to be non-invasive and easy to use.

Currently, the most frequently used method is the Demirjian's method (4,6) based on eight calcification stages, which span from crown and root calcification to the apex closure for the seven left permanent mandibular teeth. Demirjian and Goldstein (6) have excluded the third molar because this tooth is often missing. A score is allocated for each stage, and the sum of the scores provides an estimation of the subject's dental maturity. The overall maturity score may then be converted into a dental age by using available tables and percentiles curves based on a large French-Canadian sample.

However, several authors (3,12,13,18,24,26,27,36,39) showed that the results are less accurate if another population is computed with Demirjian's standards. These results show the necessity to create databases representative to each population. These databases would take into account the biological interethnic differences that can cause a major bias in age estimation. Nyström (27) gives specific percentile curves for Finnish children, but the weighted scores for French-Canadian children are used, and these scores seem less appropriate than specific Finnish weighted scores for a good fit of the Finnish dental maturity.

Demirjian's method is adapted for clinicians because the maturity score is calculated as a function of age (27), and a predictive interval is given for the maturity score and computed to obtain an age interval. Indeed, the clinicians know the real age of children and want to know if they deviate from the norm to determine if their dental maturity is advanced or delayed. However, this method is inappropriate for age determination (27,35). Several authors (21,38) propose to use polynomial or multiple regression to obtain a predicted age with confidence interval, as a function of maturity score. This method allows a high reliability and gives an approximation of the biological reality. The aim, in this case, is not to give the most realistic biological model but instead the most reliable age prediction. In contrast, the percentile curves are less reliable and more accurate. We chose one of these two methods according to the aim of age prediction, accuracy, and reality for clinicians or reliability for legal authorities.

The main aim of this study was to calculate specific Finnish weighted scores in order to give new dental maturity curves for Finnish children using Demirjian's method. The second aim was to compare the efficiency and applicability, in age prediction, of the polynomial regression (16,34,35), Demirjian's method using French-Canadian and Finnish scores, and the Demirjian's method revisited by Nyström (27).

Materials and Methods

Dental Database

The sample of Finnish children is the same as the Marjatta Nyström study (27) and consists of 1119 girls and 1094 boys'

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TABLE 1—*Age and gender distribution.*

Age (years)	Girls	Boys	Total
1	0	0	0
2	5	3	8
3	23	17	40
4	54	45	99
5	75	69	144
6	69	98	167
7	116	96	212
8	103	110	213
9	88	105	193
10	127	98	225
11	90	55	145
12	58	87	145
13	63	53	116
14	57	79	136
15	26	41	67
16	42	18	60
17	67	74	141
18	23	25	48
19	33	21	54
Total	1119	1094	2213

radiographs for a total of 2213 dental panoramic tomograms of healthy, ethnic Finns from southern Finland. Subjects with bilaterally missing mandibular teeth other than third molar had been excluded. The great majority of the radiographs represented voluntary participants in a growth study, a nursery, and entire school classes. The remaining radiographs (n = 189; 8.5%) have been taken because of caries or trauma at the Institute of Dentistry, University of Helsinki. The distribution by age and gender of dental panoramic radiographs is given in Table 1.

Dental Maturation Determined by Demirjian's Method

Dental age estimation was performed according to a revised version of Demirjian's method (4,6). The seven left mandibular teeth were rated on an 8-stage scale from A–H. The first observer calibrated herself regularly with the help of the Demirjian dental development computer program (Silver-Platter Multimedia Database, Silver Platter Information Inc., Norwood, MA). Intra-observer agreement was tested and did not show significant differences (27). To construct mathematical models, the 8-stages scale (A–H) was converted in a numerical scale (2–9). Moreover for more accuracy, we added the Stage 0 when the dental calcification is not yet begun and the Stage 1, or crypt's stage, representing the period when the bone crypt is visible without a dental germ inside it. Thus, each tooth is rated on 10-stage scale from 0–9. For each stage of the seven teeth, we calculated a biologically weighted score for girls and boys specific to the Finnish sample. A method for deriving the score is described in Goldstein (9) and Tanner (37). These scores are given in Table 2. Missing scores are explained by the lack of individuals for the age groups considered. Each score for the 7 teeth is added to obtain the dental maturity score rescaled linearly to 100. This score is converted in dental age using appropriate tables of percentiles (Tables 3 and 4) for girls and boys with maturity score as a function of age. We obtained the percentiles curves using 5th-degree polynomial interpolation in accordance with Goldstein (8). The percentiles curves (Figs. 1 and 2) were calculated for 1st, 5th, 16th, 50th, 84th, 95th, and 99th percentiles. Demirjian's method is strongly influenced by the calculation of the weighted scores, thus, these scores should be representative of the studied population. In this study we compared the dental age determined by

TABLE 2—*Specific weighted scores standardized to 100, for Finnish girls and boys for each stage and left mandibular teeth,* Demirjian's method.*

Stages**	Teeth						
Girls	31	32	33	34	35	36	37
No sign/0					3.62		3.44
Crypt/1					3.71		3.53
A/2					4.26		4.18
B/3				3.16	4.86		4.74
C/4	2.28	3.34	3.71	4.67	5.75	2.58	5.92
D/5	3.57	4.24	5.06	6.09	7.16	3.38	7.50
E/6	4.96	5.53	6.74	7.55	8.10	4.78	9.08
F/7	6.12	6.82	8.38	9.35	10.07	5.86	10.51
G/8	7.21	7.75	10.18	10.66	11.71	7.83	12.65
H/9	12.08	12.68	14.71	15.02	15.81	13.08	16.62
Boys	31	32	33	34	35	36	37
No sign/0					3.71		2.96
Crypt/1					4.04		3.86
A/2				2.47	4.34		3.99
B/3				3.54	4.84		4.55
C/4	3.53	3.65	4.20	4.75	5.89	2.28	5.98
D/5	3.84	4.65	5.68	6.29	7.13	3.53	7.61
E/6	5.19	5.90	7.28	7.78	8.58	4.93	9.23
F/7	6.32	6.84	9.31	9.51	10.11	6.16	10.70
G/8	7.16	8.16	11.41	11.23	12.08	8.07	13.00
H/9	12.08	12.71	15.22	14.93	15.60	13.19	16.28

*Numbers 31–37 (FDI system) represent the permanent lower left first incisor to the permanent lower left second molar; Stages 2–5 = Crown mineralization; 5–8 = Root mineralization; 9 = Apex closure.

**No sign, crypt stage and Demirjian's scale (4)/new numerical stage (0–9).

the Demirjian's method using French-Canadian scores (6) with the Demirjian's method using specific weighted score of the Finnish population, with the Demirjian's method revisited by Nyström (using the French-Canadian weighted scores but with specific Finnish developmental curves), and with polynomial regressions.

Polynomial Regressions and Efficiency of Each Method

Demirjian's method gives a maturity score as a function of age, so when the age is unknown this method is statistically inappropriate (35). In order to obtain an estimate age as a function of maturity score, a cubic function (21,38) was employed, with 95 and 99% CI. Third degree showed the best fit of the plots with an R^2 of about 0.93 and represents the best compromise for the polynomial regression. The maturity score (Tables 5 and 6, Figs. 3 and 4) is obtained using Finnish weighted score for girls and boys according to Demirjian's method (4,6).

To determine the efficiency and the field of application of each method, we calculated the accuracy and the reliability of Demirjian's method using the differently weighted scores and a 3rd degree polynomial regression. The accuracy represents the mean of each minimum and maximum residue (in years) for all 2213 girls and boys. The minimum residue for one individual is symbolized by the difference between the inferior limit at 99% CI of the predicted age and the real age, and the maximum residue is symbolized by the difference between the upper limit at 99% CI of the predicted age and the real age. The reliability of age prediction is given by the percentage of individuals whose real age isn't within the 99% confidence interval.

Moreover for all these methods, to consider age in decimal years in order to obtain a high accuracy in month is not reliable enough for applications in forensic sciences, because predicting this high accuracy becomes very difficult without lowering reliability. Indeed,

TABLE 3—*Dental maturity score per age in Finnish girls, Demirjian's method.*

Age	1%	5%	16%	50%	84%	95%	99%
2.50	21.68	22.44	23.19	23.99	25.42	25.97	26.52
2.75	22.19	22.86	23.53	24.60	26.26	26.84	27.42
3.00	22.86	23.45	24.04	25.36	27.29	27.99	28.92
3.25	23.87	24.29	24.70	26.26	28.50	29.41	30.63
3.50	24.63	25.07	25.51	27.30	29.88	30.97	32.53
3.75	25.56	26.00	26.44	28.47	31.40	32.66	34.61
4.00	26.47	26.99	27.50	29.75	33.06	34.46	36.75
4.25	27.57	28.12	28.67	31.14	34.84	36.38	38.96
4.50	28.50	29.22	29.94	32.63	36.72	38.39	41.22
4.75	29.44	30.37	31.30	34.21	38.69	40.48	43.52
5.00	30.42	31.58	32.74	35.87	40.74	42.64	45.85
5.25	31.45	32.94	34.26	37.60	42.85	44.87	48.21
5.50	32.53	34.12	35.85	39.41	45.01	47.14	50.59
5.75	33.67	35.35	37.49	41.27	47.22	49.46	52.97
6.00	34.87	36.64	39.19	43.18	49.46	51.80	55.35
6.25	36.14	37.99	40.93	45.13	51.71	54.17	57.72
6.50	37.47	39.42	42.71	47.12	53.98	56.55	60.08
6.75	38.88	40.91	44.51	49.13	56.25	58.92	62.42
7.00	40.35	42.46	46.34	51.17	58.51	61.29	64.73
7.25	41.88	44.08	48.20	53.22	60.76	63.65	67.00
7.50	43.48	45.77	50.06	55.28	62.98	65.97	69.23
7.75	45.14	47.51	51.93	57.34	65.18	68.27	71.42
8.00	46.86	49.30	53.81	59.39	67.33	70.53	73.55
8.25	48.63	51.14	55.68	61.43	69.45	72.74	75.62
8.50	50.44	53.02	57.55	63.46	71.51	74.89	77.63
8.75	52.30	54.94	59.40	65.46	73.52	76.98	79.57
9.00	54.19	56.88	61.24	67.44	75.47	79.01	81.44
9.25	56.11	58.84	63.07	69.38	77.36	80.97	83.23
9.50	58.04	60.81	64.87	71.28	79.18	82.85	84.94
9.75	59.99	62.79	66.65	73.14	80.92	84.64	86.57
10.00	61.94	64.76	68.40	74.96	82.60	86.36	88.12
10.25	63.89	66.72	70.12	76.73	84.20	87.98	89.58
10.50	65.82	68.65	71.81	78.44	85.72	89.51	90.94
10.75	67.74	70.55	73.46	80.09	87.16	90.94	92.22
11.00	69.63	72.41	75.07	81.68	88.52	92.28	93.40
11.25	71.48	74.23	76.65	83.22	89.79	93.52	94.50
11.50	73.29	75.99	78.18	84.68	90.99	94.65	95.49
11.75	75.05	77.68	79.67	86.08	92.10	95.69	96.51
12.00	76.76	79.31	81.11	87.41	93.12	96.62	97.51
12.25	78.40	80.86	82.51	88.66	94.07	97.46	98.56
12.50	79.97	82.34	83.86	89.85	94.93	98.19	99.11
12.75	81.48	83.73	85.16	90.96	95.72	98.83	99.77
13.00	82.90	85.03	86.42	92.00	96.43	99.18	100
13.25	84.25	86.24	87.62	92.96	97.06	99.53	100
13.50	85.51	87.35	88.77	93.85	97.62	99.96	100
13.75	86.68	88.38	89.87	94.67	98.21	100	100
14.00	87.78	89.31	90.91	95.42	98.53	100	100
14.25	88.78	90.31	91.91	96.10	99.19	100	100
14.50	89.71	91.25	92.85	96.71	99.48	100	100
14.75	90.55	92.13	93.73	97.25	99.89	100	100
15.00	91.32	92.96	94.46	97.74	100	100	100
15.25	92.01	93.74	95.24	98.16	100	100	100
15.50	92.65	94.36	95.96	98.52	100	100	100
15.75	93.22	95.13	96.63	98.83	100	100	100
16.00	93.76	95.74	97.34	99.09	100	100	100
16.25	94.26	96.30	97.90	99.31	100	100	100
16.50	94.74	96.60	98.20	99.49	100	100	100
16.75	95.21	97.04	98.64	99.84	100	100	100
17.00	95.70	97.44	99.04	100	100	100	100
17.25	96.23	97.77	99.37	100	100	100	100
17.50	96.80	98.05	99.65	100	100	100	100
17.75	97.46	98.75	99.95	100	100	100	100
18.00	98.22	99.22	100	100	100	100	100
18.25	99.11	99.83	100	100	100	100	100
18.50	99.77	100	100	100	100	100	100
18.75	100	100	100	100	100	100	100
19.00	100	100	100	100	100	100	100

TABLE 4—*Dental maturity score per age in Finnish boys, Demirjian's method.*

Age	1%	5%	16%	50%	84%	95%	99%
2.50	23.85	24.18	24.50	25.22	25.87	26.51	27.34
2.75	24.25	24.59	24.93	25.71	26.56	27.40	28.23
3.00	24.69	25.02	25.34	26.16	27.38	28.43	29.26
3.25	25.18	25.56	25.93	26.90	28.43	29.72	30.73
3.50	25.71	26.17	26.63	27.86	29.62	31.17	32.42
3.75	26.29	26.86	27.42	28.82	30.95	32.74	34.12
4.00	26.92	27.52	28.11	29.98	32.41	34.43	36.01
4.25	27.60	28.35	29.09	31.25	33.98	36.23	37.99
4.50	28.33	29.24	30.15	32.73	35.64	38.12	40.05
4.75	29.10	30.12	31.28	34.21	37.40	40.09	42.17
5.00	29.92	31.08	32.50	35.65	39.23	42.12	44.34
5.25	30.80	32.10	33.78	37.28	41.13	44.22	46.56
5.50	31.72	33.16	35.12	38.96	43.08	46.35	48.80
5.75	32.68	34.28	36.53	40.69	45.08	48.53	51.08
6.00	33.70	35.45	37.98	42.47	47.12	50.73	53.36
6.25	34.76	36.67	39.49	44.29	49.19	52.94	55.65
6.50	35.87	37.93	41.04	46.13	51.28	55.17	57.94
6.75	37.03	39.24	42.63	48.00	53.38	57.39	60.22
7.00	38.24	40.59	44.26	49.88	55.48	59.60	62.48
7.25	39.48	41.99	45.92	51.76	57.59	61.79	64.71
7.50	40.78	43.42	47.61	53.66	59.68	63.97	66.91
7.75	42.11	44.89	49.31	55.55	61.76	66.11	69.07
8.00	43.49	46.39	51.04	57.43	63.82	68.21	71.19
8.25	44.91	47.93	52.78	59.30	65.85	70.27	73.26
8.50	46.37	49.50	54.53	61.16	67.85	72.28	75.27
8.75	47.87	51.09	56.29	63.00	69.81	74.24	77.22
9.00	49.41	52.71	58.04	64.82	71.73	76.14	79.10
9.25	50.98	54.35	59.80	66.61	73.60	77.98	80.92
9.50	52.58	56.00	61.55	68.38	75.43	79.75	82.66
9.75	54.21	57.68	63.29	70.12	77.20	81.45	84.33
10.00	55.87	59.36	65.02	71.82	78.92	83.09	85.91
10.25	57.55	61.06	66.73	73.49	80.58	84.64	87.42
10.50	59.26	62.76	68.42	75.13	82.18	86.13	88.84
10.75	60.99	64.46	70.09	76.72	83.72	87.53	90.18
11.00	62.73	66.17	71.74	78.28	85.19	88.85	91.43
11.25	64.49	67.87	73.35	79.80	86.59	90.10	92.59
11.50	66.25	69.57	74.94	81.27	87.93	91.26	93.67
11.75	68.02	71.25	76.49	82.70	89.20	92.35	94.65
12.00	69.79	72.92	78.00	84.09	90.40	93.35	95.55
12.25	71.56	74.57	79.48	85.43	91.52	94.27	96.37
12.50	73.33	76.20	80.91	86.73	92.58	95.12	97.10
12.75	75.08	77.81	82.31	87.97	93.57	95.88	97.74
13.00	76.81	79.39	83.65	89.17	94.49	96.57	98.31
13.25	78.52	80.94	84.96	90.32	95.33	97.19	98.79
13.50	80.21	82.45	86.21	91.42	96.11	97.73	99.20
13.75	81.86	83.92	87.41	92.47	96.82	98.21	99.54
14.00	83.47	85.35	88.86	93.47	97.46	98.62	99.81
14.25	85.04	86.74	89.87	94.41	98.04	98.97	100
14.50	86.55	88.07	90.91	95.29	98.55	99.25	100
14.75	88.01	89.35	91.91	96.12	99.00	99.89	100
15.00	89.40	90.58	92.85	96.89	99.38	100	100
15.25	90.71	91.74	93.73	97.60	99.71	100	100
15.50	91.95	92.84	94.57	98.24	99.98	100	100
15.75	93.09	93.88	95.34	98.82	100	100	100
16.00	94.14	94.84	96.06	99.33	100	100	100
16.25	95.08	95.91	96.73	99.77	100	100	100
16.50	95.91	96.63	97.35	100	100	100	100
16.75	96.41	97.16	97.91	100	100	100	100
17.00	97.18	97.80	98.42	100	100	100	100
17.25	97.60	98.24	98.88	100	100	100	100
17.50	97.97	98.63	99.29	100	100	100	100
17.75	98.47	99.16	99.85	100	100	100	100
18.00	98.72	99.56	100	100	100	100	100
18.25	99.18	99.89	100	100	100	100	100
18.50	99.48	100	100	100	100	100	100
18.75	99.92	100	100	100	100	100	100
19.00	100	100	100	100	100	100	100

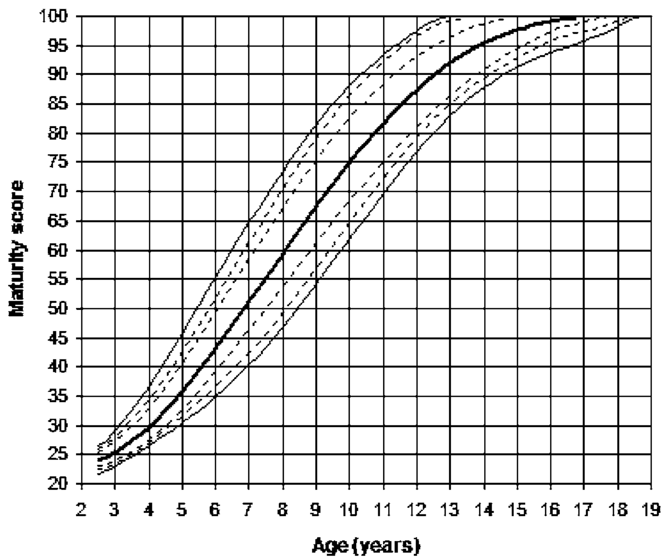

FIG. 1—*Dental maturity percentiles for Finnish girls using weighted scores for Finns, Demirjian's method, 1st, 5th, 16th, 50th, 84th, 95th, and 99th percentiles.*

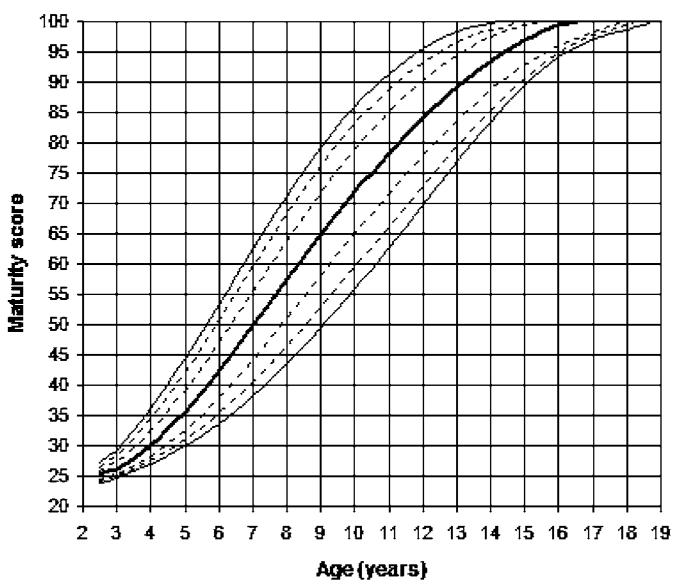

FIG. 2—*Dental maturity percentiles for Finnish boys using weighted scores for Finns, Demirjian's method, 1st, 5th, 16th, 50th, 84th, 95th, and 99th percentiles.*

one-year accuracy is sufficient in forensic anthropology. Thus, we considered also the age in completed years (End years) in the calculation of the efficiency. This method should allow for higher reliability.

To conserve a maximum of individuals in the reference database, we used the method called n − 1 technique, following a Jackknife Resampling Strategy (7). One-by-one, each individual in the database was extracted, tested, and replaced, allowing us to obtain an evaluation sample of n children and to conserve a reference sample of n − 1 children. We used the SPSS Software 11.0 for Windows (SPSS Inc., Chicago, IL) to apply n − 1 method for polynomial regressions and software developed with visual basic macro (Microsoft® Excel 2002, PC) for Demirjian's method.

Results

Dental Maturity

Weighted Scores for Finnish Sample—In order to obtain the dental maturity score, we calculated a gender weighted score for each stage of the seven teeth specific to the Finnish sample. These scores, given in Table 2, have been rescaled linearly to 100 to allow the calculation of the final dental maturity score in accordance with Demirjian's method and Goldstein (4,6,9). The dental maturity score is obtained by the sum of all weighted scores corresponding to each development stage for the seven teeth. This maturation score can then be compared with the appropriate development tables expressed in percentiles.

Percentiles Using Finnish Weighted Scores for Girls and Boys—Dental maturity scores as a function of age with the Demirjian's method using the Finnish weighted scores are presented for girls and boys in Tables 3 and 4, and development curves, expressed in percentiles, in Figs. 1 and 2. This method gives a predicted score with the predictive interval of the maturity score. This approach is appropriate for clinicians to detect if the dental maturity of a subject is "advanced" or "delayed" (28) in comparison with subjects of the same age. Indeed, the clinician knows the real age of the child and wants to know his degree of dental maturity, thus he should use a predictive system giving the maturity score as a function of age, like the Demirjian's method. However, this method is less adapted and less reliable for age estimation, because the real age is unknown and is necessary in the calculation of the maturity score. With curves expressed in percentiles, we must read the confidence interval horizontally to obtain an age interval, but these curves have been developed to give confidence intervals for the maturity score and not for the age. The percentile method is not statistically adapted for age estimation studies (38). Thus, adapted methods, such as polynomial functions, calculate the estimated age as a function of the maturity score.

Also, the Demirjian 7-teeth system gives a maturity score prediction for the 50th percentile only until 16 years of age (Figs. 1 and 2) because the calcification of all seven teeth is finished by then. Only the third molar is not completely calcified at that age. Since Demirjian's method does not use that tooth, age estimation is less accurate past that age.

Polynomial Regressions for Girls and Boys—To obtain age as a function of maturity score, we calculated cubic functions ($y = ax^3 + bx^2 + cx + d$, with y as the estimated age and x as the maturity score) for girls and boys. The maturity score is obtained with the 7-tooth Demirjian's method (4,6) using the Finnish weighted scores. This method gives an estimate age with 95, 97, and 99% CI (Tables 5 and 6, Figs. 3 and 4) for boys and girls. This method has the advantage of being easy to perform for the calculation of new maturity curves for another population. If teeth are absent, Nyström (27) proposes a set of multiple linear regressions to estimate the score of missing teeth for this Finnish sample. The cubic predictive equations for girls and boys are given below.

$$\text{Girls: Age} = 6.45\text{E-}05 * \text{Score}^3 - 0.0113 * \text{Score}^2 + 0.7526 * \text{Score} - 10.2295 \pm 2.06\text{ yrs (95\% CI)}, \pm 2.37\text{ yrs (97\% CI)}, \pm 2.61\text{ yrs (99\% CI)}, R^2 = 0.93$$

$$\text{Boys: Age} = 5.81\text{E-}05 * \text{Score}^3 - 0.0103 * \text{Score}^2 + 0.7182 * \text{Score} - 9.9347 \pm 2.03\text{ yrs (95\% CI)}, \pm 2.34\text{ yrs (97\% CI)}, \pm 2.56\text{ yrs (99\% CI)}, R^2 = 0.93$$

TABLE 5—*Predicted age at 95, 97, and 99% CI per maturity score in Finnish girls, polynomial functions.*

Score	1%	3%	5%	50%	95%	97%	99%
25.0	0.00	0.22	0.44	2.51	4.59	4.92	5.24
27.5	0.51	0.84	1.17	3.24	5.31	5.64	5.97
30.0	1.17	1.50	1.82	3.89	5.96	6.29	6.62
32.5	1.76	2.08	2.41	4.48	6.55	6.87	7.20
35.0	2.28	2.61	2.93	5.00	7.07	7.39	7.72
37.5	2.75	3.07	3.40	5.46	7.53	7.85	8.18
40.0	3.16	3.49	3.81	5.87	7.94	8.27	8.59
42.5	3.53	3.86	4.18	6.24	8.31	8.63	8.96
45.0	3.86	4.19	4.51	6.57	8.64	8.96	9.29
47.5	4.16	4.48	4.81	6.87	8.93	9.26	9.58
50.0	4.43	4.75	5.08	7.14	9.20	9.53	9.85
52.5	4.68	5.00	5.33	7.39	9.45	9.78	10.10
55.0	4.91	5.24	5.57	7.62	9.68	10.01	10.34
57.5	5.14	5.47	5.79	7.85	9.91	10.24	10.56
60.0	5.36	5.69	6.02	8.07	10.13	10.46	10.79
62.5	5.59	5.92	6.24	8.30	10.36	10.69	11.01
65.0	5.83	6.15	6.48	8.54	10.60	10.92	11.25
67.5	6.08	6.41	6.73	8.79	10.85	11.18	11.50
70.0	6.36	6.68	7.01	9.06	11.13	11.45	11.78
72.5	6.66	6.98	7.31	9.37	11.43	11.76	12.08
75.0	6.99	7.32	7.65	9.70	11.77	12.09	12.42
77.5	7.37	7.69	8.02	10.08	12.14	12.47	12.79
80.0	7.79	8.12	8.44	10.50	12.56	12.89	13.22
82.5	8.26	8.59	8.92	10.97	13.04	13.36	13.69
85.0	8.79	9.12	9.45	11.51	13.57	13.90	14.22
87.5	9.39	9.72	10.04	12.10	14.17	14.49	14.82
90.0	10.06	10.38	10.71	12.77	14.83	15.16	15.49
92.5	10.80	11.12	11.45	13.51	15.57	15.90	16.23
95.0	11.62	11.95	12.28	14.33	16.40	16.73	17.05
96.0	11.98	12.30	12.63	14.69	16.75	17.08	17.41
97.0	12.34	12.67	13.00	15.06	17.12	17.45	17.78
100.0	13.54	13.87	14.20	16.25	18.32	18.65	18.97

TABLE 6—*Predicted age at 95, 97, and 99% CI per maturity score in Finnish boys, polynomial functions.*

Score	1%	3%	5%	50%	95%	97%	99%
25.0	0.00	0.21	0.42	2.46	4.50	4.82	5.14
27.5	0.52	0.84	1.16	3.20	5.24	5.56	5.88
30.0	1.19	1.51	1.83	3.87	5.90	6.22	6.54
32.5	1.79	2.11	2.44	4.47	6.50	6.82	7.15
35.0	2.34	2.66	2.98	5.02	7.05	7.37	7.69
37.5	2.84	3.16	3.48	5.51	7.54	7.86	8.18
40.0	3.28	3.60	3.92	5.95	7.98	8.30	8.62
42.5	3.69	4.01	4.33	6.36	8.38	8.70	9.02
45.0	4.06	4.38	4.69	6.72	8.75	9.07	9.39
47.5	4.39	4.71	5.03	7.06	9.08	9.40	9.72
50.0	4.70	5.02	5.34	7.37	9.39	9.71	10.03
52.5	4.99	5.31	5.63	7.66	9.68	10.00	10.32
55.0	5.27	5.58	5.90	7.93	9.95	10.27	10.59
57.5	5.53	5.85	6.17	8.19	10.22	10.54	10.86
60.0	5.79	6.11	6.43	8.45	10.48	10.80	11.12
62.5	6.05	6.37	6.69	8.72	10.74	11.06	11.38
65.0	6.32	6.64	6.96	8.98	11.01	11.33	11.65
67.5	6.60	6.92	7.24	9.27	11.29	11.61	11.93
70.0	6.90	7.22	7.53	9.56	11.59	11.91	12.23
72.5	7.22	7.54	7.86	9.89	11.91	12.23	12.55
75.0	7.57	7.89	8.21	10.24	12.26	12.58	12.90
77.5	7.96	8.27	8.59	10.62	12.64	12.96	13.28
80.0	8.38	8.70	9.01	11.05	13.07	13.39	13.71
82.5	8.85	9.17	9.48	11.52	13.54	13.86	14.18
85.0	9.37	9.68	10.00	12.04	14.06	14.38	14.70
87.5	9.94	10.26	10.58	12.61	14.63	14.95	15.27
90.0	10.58	10.90	11.21	13.25	15.27	15.59	15.91
92.5	11.28	11.60	11.92	13.95	15.97	16.29	16.62
95.0	12.06	12.38	12.69	14.73	16.75	17.07	17.39
96.0	12.39	12.71	13.02	15.06	17.08	17.40	17.72
97.0	12.74	13.05	13.37	15.40	17.42	17.75	18.07
100.0	13.85	14.17	14.48	16.52	18.54	18.86	19.18

FIG. 3—*Age as a function of maturity score in Finnish girls, Dental maturity, 95 and 99% CI, polynomial functions, $R^2 = 0.93$. Age = 6.45E-05 ∗ $Score^3$ – 0.0113 ∗ $Score^2$ + 0.7526 ∗ Score – 10.2295 ± 2.06 yrs (95% CI).*

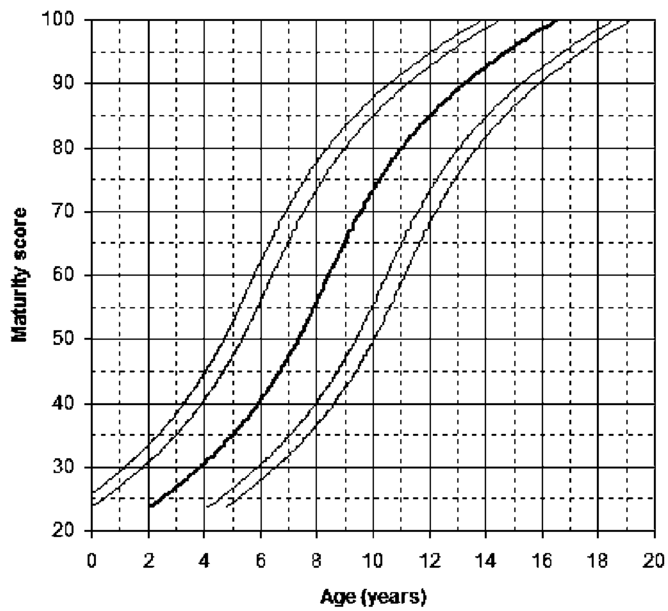

FIG. 4—*Age as a function of maturity score in Finnish boys, Dental maturity, 95 and 99% CI, polynomial functions, $R^2 = 0.93$. Age = 5.81E-05 ∗ $Score^3$ – 0.0103 ∗ $Score^2$ + 0.7182 ∗ Score – 9.9347 ± 2.03 yrs (95% CI).*

In this case, the confidence interval is homogenous for all age groups, but for Demirjian's method, the predictive interval can vary by function of the age groups. This method provides estimate age as a function of maturity score and is better adapted for age estimation studies in which reliability is important (in forensic sciences).

Efficiency

Efficiency is measured by the accuracy and reliability of the methods. Results are given in Table 7. The Finnish sample is

TABLE 7—*Comparison of the percentage of individuals misclassified in age prediction and of the accuracy* between Demirjian's method using French-Canadian and Finnish weighted scores and polynomial regressions.*

Methods	Misclassifies %	Mean Accuracy	Misclassifies % (End Years)	Mean Accuracy (End Years)
Demirjian French-Canadian Scores 97% CI	22.56	3.36	12.55	3.32
(27) Nyström Finnish Scores 95% CI	17.74	3.68	10.42	3.79
Demirjian Finnish Scores 95% CI	11.44	3.14	3.84	3.18
Demirjian Finnish Scores 99% CI	3.75	3.86	1.07	3.90
Polynomial regression 97% CI	2.92	4.71	0.69	4.75
Polynomial regression 99% CI	1.20	5.17	0.19	5.21

* Mean accuracy represents the mean of the residues minimum and maximum in years (e.g., 3.74 represents ± 1.87 years from 2–18 years) and Misclassifies represent the number of individuals out of the confidence interval for the 2159 children from the age of 2–18 years. End years represent the same determination of the efficiency of these methods with the age in completed years.

analyzed from 2–18 years using the Jacknife method. We note that the polynomial method is more reliable and less accurate than the percentile method.

These results are obtained considering decimal age, but in forensic sciences one-year accuracy is sufficient. Thus, for more efficiency, the polynomial and percentile standards are calculated with decimal age, but the results are also expressed with completed years (one-year age groups). For example, if the real age is 6.13 years, and the predicted age is 6.74 to 7.56 years at 99% CI, we will consider that the predicted age is 6 to 7 years (6.00 to 7.99 in completed years), and the real age is 6 years. If we take into account the decimal age, the real age is out of the predictive interval; but if we accept a smaller accuracy considering completed years, this prediction becomes correct. Indeed, we note that the reliability with completed years is higher for almost the same accuracy than the method taking into account the decimal age. In fact, what accuracy and reliability are recommended in our analysis? To want a high accuracy is correct for elaborating biological models, but here we want to give reliable results to forensic scientists and clinicians. Indeed, the law considers only the age in completed years, and to give a high accuracy will increase the percentage of misclassifies (Table 7). So we chose to express the results also in completed years in order to increase the reliability, but all the calculations are expressed with decimal age. Thus, the development curves allow obtaining also an age prediction with decimal age to draw biological models. So we give both results in this analysis.

We calculated the efficiency of the Demirjian's method using French-Canadian weighted scores (4,6) and the Demirjian's method revisited by Nyström (27) using the same weighted scores but with Finnish specific percentile curves. The low reliability for the Demirjian's method using French-Canadian weighted scores is explained by the inter-ethnic differences between Canadian and Finnish samples and demonstrates the necessity to calculate new specific weighted scores for each population. The same conclusion is drawn from the Nyström method, but the reliability is higher since the curves have been adapted to Finnish samples, but the weighted scores have not. The accuracy of these two methods is very high showing the robusticity of Demirjian's method.

Sexual Dimorphism

Figure 5 represents the mean maturity score and the SD calculated with Finnish gender specific weighted score. Dental maturation of girls from 5–15 years old is more advanced than boys, according to Demirjian studies (5). Since the weighted scores used in the analysis are gender specific and take into account the gender differences, sexual dimorphism is underestimated by this mathematical method. To resolve this problem, Nyström (27) calculates

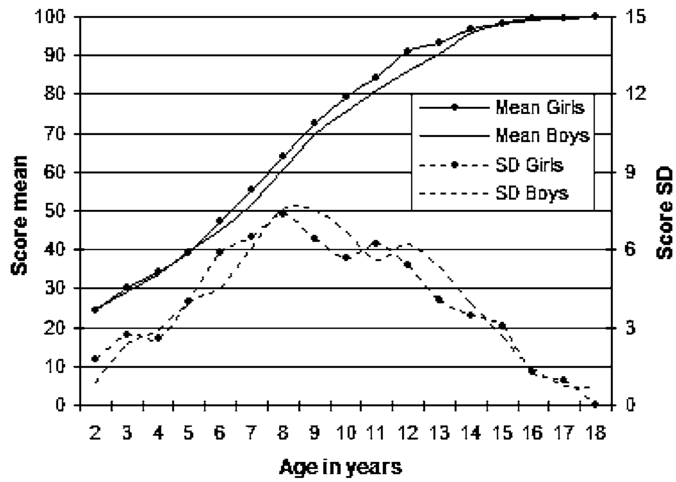

FIG. 5—*Means and SD of maturity scores in girls and boys, modified from Nyström (27), using weighted scores for Finns, Demirjian's method.*

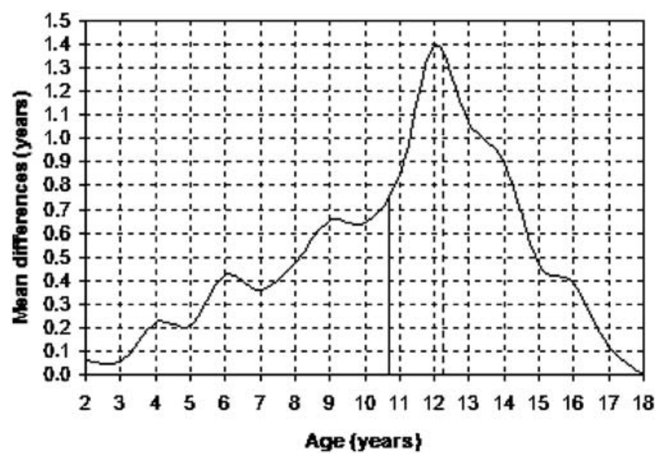

FIG. 6—*Differences in dental age between girls and boys from the age of 2–18 years. Girls' age estimate minus boys' age estimate, modified from Nyström (27), using gender independent weighted scores for Finns, Demirjian's method. The vertical straight line represents the beginning of puberty in girls for Finns, and the vertical dashed line represents the beginning of puberty in boys for Finns (29).*

the mean of French-Canadian weighted scores for girls and boys in order to obtain only one gender independent weighted score to determine the true nature of the sexual dimorphism without bias. For more accuracy, we calculated a new weighted score for the combined genders from the original Finnish data, and we determined the maturity score for all 2213 children (Fig. 6).

The results obtained with gender combined scores differ completely from those using gender specific scores; we note an advance of maturity for girls during the totality of dental growth. The sexual dimorphism increased gradually until 10 years, and from that age, which corresponds to the beginning of puberty in Finnish girls, it accelerates until 12 years. The catch-up growth for Finnish boys begins at 12–13 years, at the beginning of their puberty, and continues strongly until 18 years of age. In accordance with Ojajärvi (29), this shows that the mean age of the beginning of puberty for Finnish girls is 10.8 years and 12.2 years for Finnish boys. It is interesting to note that the girls are always in advance of boys during the dental growth.

Discussion

The aim of this study was to present the dental maturity in Finnish children and to provide new dental development tables and curves of children whose age is known. We compared the Demirjian's method using French-Canadian and Finnish weighted scores, Demirjian's method revisited by Nyström (27), and polynomial functions to determine the advantages and disadvantages of each method to their fields of application. For each of these methods, the efficiency is higher when completed years are used. Thus, to give a one-year age group in the results seems to be a more suitable approach for the age estimation studies. In fact, legal authorities and anthropologists want to determine the children's age with only one-year accuracy; the decimal age is too accurate and decreases the reliability. In this study, the mathematical models are established with decimal age, but the efficiency is determined with completed years in order to improve the reliability and still keep the most frequently used accuracy.

When using French-Canadian scores, we observed a good accuracy but a poor reliability (12.55% of misclassifies). With the Demirjian's method revisited by Nyström, the reliability increases (10.42% of misclassifies) but is lower than the Demirjian's method using the Finnish weighted score (1.07% of misclassifies). Moreover, the accuracy is high with the Finnish scores. For polynomial methods, the reliability is the strongest (0.19% of misclassifies), but the accuracy decreases. Indeed, reliability and accuracy move in opposite ways; if reliability increases, accuracy decreases. The aim in age estimation studies is to use the best compromise to reach one's objectives (great reliability in forensic sciences, maturity score as a function of age for the clinicians).

In this study we analyzed two classes of methods: the first with percentiles, giving the maturity score as a function of age, is adapted for the clinicians and gives a strong accuracy, but reliability (1.07% of misclassifies) is lower than for polynomial functions; the second with polynomial interpolation, giving estimated age as a function of the maturity score, is useful in forensic contexts and allows for higher reliability (0.19% of misclassifies), but accuracy decreases by $\pm$7.5 months.

However, these methods have limitations, for example, if a tooth is missing on left side, Demirjian propose to use the contralateral tooth, but if a tooth is missing bilaterally, it is impossible to calculate the maturity score. In a forensic context, a child with bilaterally missing teeth must still be aged. In addition, dental maturity doesn't follow a linear progression (38); dental development is curvilinear with acceleration and stops, so polynomial functions are recommended. It has been shown that cubic functions give the best correlations with dental maturity. To resolve the problem of missing data, Nyström (27) proposed a method based on a set of linear regressions to predict the development stage of a missing tooth. Another solution could be a set of multiple polynomial interpolations (8,35) or new tables taking into account missing teeth. Of course, in such a case, the efficiency of dental age estimation with several absent teeth will be decreased considerably. Also, a probabilistic method, like the Bayesian approach (19), which takes into account the missing data, could be an interesting method to develop in prediction applications.

The power of prediction decreases after 15 years of age because the number of teeth providing information decreases. Indeed, during the dental development, all teeth do not achieve maturation at the same time, and the predicting capacity decreases as the number of teeth giving biological information decreases. Other biological indicators, like skeletal maturity of bones (1,10,15,30,32) or base line of the head (2,20,31), could increase the accuracy of age estimation of the older children. All indicators could be combined with a probabilistic approach to use the advantages of each one.

In conclusion, we advise to use Demirjian's method with specific Finnish scores when the aim is the prediction of the maturity score of Finnish children, and to use the polynomial functions when the aim is to estimate age in a forensic context. In the same way, it is necessary to adapt specific weighted scores of studied populations for more efficient age estimation. In the future, age estimation studies will benefit from the creation of a large international database.

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