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Dental Maturity in South France: A Comparison Between Demirjian's Method and Polynomial Functions

ABSTRACT: The dental maturity of 1031 healthy southern French subjects aged between 2 and 18 years was studied with dental panoramic tomograms. Demirjian's method based on seven and eight teeth has been used to determine maturity scores as a function of age and polynomial functions to determine age as a function of score. We give gender-specific tables of maturity scores and development graphs for each method. The goal of these methods is different because of the nature of the predictions. The percentiles give the dental maturity compared to a standard for a specific age, and polynomial functions give an age prediction with a confidence interval for age. The variations in dental maturity are specific to each population. Thus, the aim of this study is to give the dental maturity standards for southern French children and to compare both the efficiency and applicability of each method in several fields such as forensic sciences or dental health for the clinicians. The addition of the third molar increased the reliability and the capacity of prediction up to 18 years. The polynomial functions showed the best reliability (1.3% of misclassified) and the percentile methods the best accuracy (more or less 1.2 years, on average, between 2 and 18 years of age).

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

There are several methods to estimate dental maturity that show variation in degrees of maturation. The most frequently used methods are based on dental calcification with orthopantomograms (5,9,14,17); these methods have the advantage of being noninvasive and easy to use.

The most currently used method is the Demirjian's method (4,5) based on 8 calcification stages that represent the crown and root calcification to the apex closure for the 7 left permanent mandibular teeth. 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. Demirjian's study is based on data derived from a reference sample comprising 4756 French-Canadians children. However, Davis and Hägg (2) show that the results are less accurate if a Chinese population is computed with Demirjian's standards. Several authors note an overestimation of dental age from studies based on another population if Demirjian's standards are used (10,19,24).

These results show the necessity to create databases representative to each population. These databases would take into account the biological inter-ethnic differences that can present a major bias in age estimation.

This system does not tolerate the missing data and Demirjian and Goldstein (5) have excluded the third molar because this tooth is often extracted. But for age prediction all the variables are important (13), and for dental maturity the third molar is the only one giving a prediction past 16 years of age.

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Moreover, the Demirjian's method calculates a score as a function of age and the predictive interval is given for the maturity score and computed to obtain an age interval. This way is adapted for clinicians to know the deviation of the dental maturity for one individual but is inappropriate for age determination (23,26). Several authors (20,26) propose polynomial or multiple regressions to obtain an age with confidence interval, as a function of score, and also to limit the problem of missing data.

The main aim of this study was to present the development of dental maturity in southern French girls and boys as a continuous function of age using Demirjian's method. The second aim was to compare the accuracy of age determination between this method, polynomial regression (13,22,23), and Demirjian's method modified including the third molar.

Materials and Methods

The study sample consisted of dental panoramic tomograms of 1031 healthy French subjects (561 girls and 470 boys) from southern France in the period 1975 to 2000, and aged between 2 and 18 years. Subjects with missing teeth have been excluded. These panoramics have been collected from hospitals or universities specializing in dental radiology in Bordeaux, Nice, Dijon, and Marseille. The distribution of dental panoramics by age and sex is given in Table 1*a*.

The seven left mandibular teeth were rated on an 8-stage scale from A to H according to Demirjian's method revisited (4,5). To construct mathematical models, the stages were converted to numbers (from 2 to 9). Moreover, for more accuracy we added the stage 0 and the stage 1, called the crypt stage. This stage represents the time when the bone crypt is visible without dental germ inside it. The tooth not yet calcified, corresponds to stage 0. Then for each orthopantomogram there are ten stages from 0 to 9 for each tooth.

Each stage of the seven teeth has been given a gender specific, biologically weighted score. A method for deriving the score is

TABLE 1*a*—*Age and sex distribution.*

Age (years)	Girls	Boys	Total
2–5	20	15	35
6	21	15	36
7	27	28	55
8	47	28	75
9	63	58	121
10	63	53	116
11	57	46	103
12	78	37	115
13	53	50	103
14	53	41	94
15	36	43	79
16	21	24	45
17	14	19	33
18	8	13	21
Total	561	470	1031

TABLE 1*b*—*Specific weighted scores, standardized to 100, for girls and boys for each stage and left mandibular teeth*, Demirjian 7-teeth method.*

Stages	Teeth						
Girls	31	32	33	34	35	36	37
0							
1							3.08
2					2.92		
3				3.07	4.11		3.18
4			3.05	4.24	4.60		4.91
5	3.10	3.18	3.77	6.10	6.90	3.10	7.82
6	3.71	5.44	6.47	7.57	8.17	3.89	9.59
7	6.01	6.48	8.62	9.70	10.44	5.09	10.95
8	7.99	8.43	11.06	11.78	12.96	8.26	13.21
9	12.73	13.07	14.38	14.74	15.35	13.13	16.61
Boys	31	32	33	34	35	36	37
0							2.01
1					2.01		3.52
2				2.01	2.68		4.02
3			2.01	2.35	4.02		5.60
4			3.16	4.17	4.02		5.76
5	2.73	3.02	5.13	6.13	6.61	2.51	7.90
6	5.14	5.56	7.25	7.64	8.23	4.40	9.32
7	6.10	6.80	8.97	9.66	10.24	5.83	10.71
8	7.76	8.24	11.24	11.62	12.57	8.26	13.14
9	12.60	12.89	14.83	14.85	15.48	13.25	16.10

* The numbers 31 to 37 (FDI system) represent the permanent lower left first incisor until the permanent lower left second molar; Stages: 0 to 4 = crown calcification; 5 to 8 = root calcification; 9 = apex closure.

described in Goldstein (7) and Tanner et al. (25). These scores and those including the third molar are given in Tables 1*b* and 1*c*. The missing scores for the permanent lower left 2nd molar (tooth 37 in FDI system) in girls are explained by the small number of individuals aged between 2 and 4 years. The sum of the score for each tooth is a dental maturity score rescaled linearly to 100. This score is converted in dental age using appropriate tables of percentiles (Tables 2 and 3). We obtain the percentiles curves using fifth-degree polynomial interpolation in accordance with Goldstein (6). The percentiles curves (Figs. 1 and 2) were calculated for 1st, 5th, 16th, 50th, 84th, 95th, and 99th percentiles.

For the Demirjian's modified method, we added the third molar in the calculation of the dental maturity score using the same method to obtain specific weighted score and percentiles curves (Tables 4 and 5, Figs. 3 and 4).

TABLE 1*c*—*Specific weighted scores, standardized to 100, for girls and boys for each stage and left mandibular teeth*, Demirjian 8-teeth method and polynomial functions.*

Stages	Teeth							
Girls	31	32	33	34	35	36	37	38
0								6.40
1							2.57	7.74
2					2.43			8.92
3				2.56	3.43		2.65	9.31
4			2.55	3.54	3.83		4.10	10.22
5	2.58	2.65	3.15	5.09	5.75	2.58	6.51	11.04
6	3.10	4.54	5.40	6.31	6.81	3.25	8.00	12.65
7	5.02	5.40	7.19	8.09	8.70	4.25	9.13	13.77
8	6.66	7.02	9.22	9.82	10.80	6.88	11.00	14.45
9	10.61	10.89	11.99	12.29	12.79	10.94	13.84	16.65
Boys	31	32	33	34	35	36	37	38
0							1.70	6.19
1					1.69		2.98	7.64
2				1.70	2.27		3.41	8.28
3			1.70	1.98	3.41		4.74	8.86
4			2.67	3.52	3.41		4.88	9.89
5	2.31	2.55	4.34	5.19	5.59	2.13	6.69	11.17
6	4.35	4.71	6.14	6.47	6.96	3.73	7.89	12.25
7	5.16	5.75	7.59	8.18	8.68	4.94	9.08	13.66
8	6.56	6.97	9.52	9.84	10.64	7.00	11.13	14.07
9	10.68	10.91	12.56	12.57	13.11	11.22	13.63	15.32

* The numbers 31 to 37 (FDI system) represent the permanent lower left first incisor until the permanent lower left second molar; Stages: 0 to 4 = crown calcification; 5 to 8 = root calcification; 9 = apex closure.

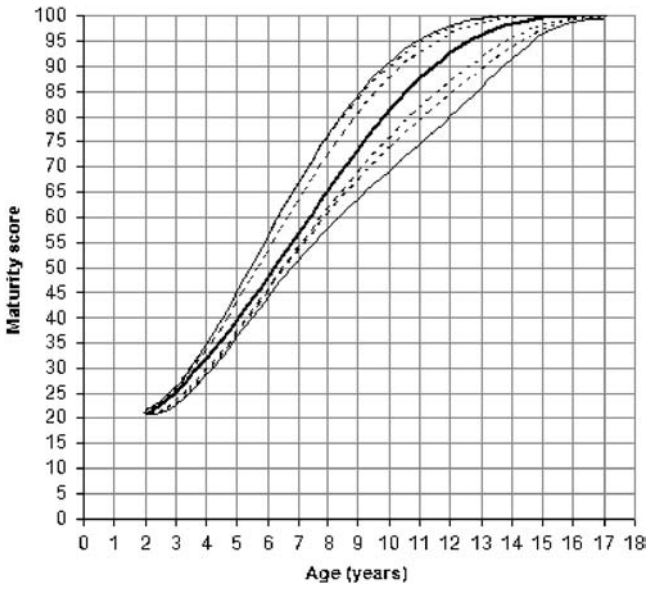

FIG. 1—*Dental maturity percentiles for girls, Demirjian 7-tooth method 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles.*

In another way, third-degree polynomial regression (26) was employed, with 95 and 99% CI, in calculations of age as a function of maturity score with the mandibular eight teeth. The cubic function gives the best fit to the plots with an R^2 of about 0.92. The maturity score (Tables 6 and 7, Figs. 5 and 6) is obtained using a specific weighted score calculated for Demirjian's method modified.

We compare the accuracy and the reliability to determine the advantages and inconveniences of each method. The accuracy is

TABLE 2—*Dental maturity score per age in southern French girls, Demirjian 7-tooth method.*

Age	1%	5%	16%	50%	84%	95%	99%
2.00	20.70	20.76	20.80	21.12	21.29	21.56	21.83
2.25	20.73	20.80	20.89	21.41	22.02	22.22	22.45
2.50	21.06	21.19	21.52	22.61	23.01	23.21	23.42
2.75	21.72	21.88	22.39	23.91	24.24	24.5	24.69
3.00	22.66	22.85	23.47	25.31	25.69	26.06	26.24
3.25	23.85	24.05	24.74	26.80	27.33	27.85	28.02
3.50	25.23	25.44	26.16	28.38	29.15	29.84	30.02
3.75	26.79	27.01	27.73	30.05	31.12	32.01	32.20
4.00	28.48	28.72	29.42	31.79	33.22	34.32	34.53
4.25	30.27	30.55	31.22	33.61	35.44	36.76	36.99
4.50	32.15	32.47	33.09	35.49	37.76	39.31	39.56
4.75	34.08	34.47	35.04	37.44	40.15	41.93	42.21
5.00	36.04	36.52	37.04	39.44	42.62	44.61	44.93
5.25	38.03	38.6	39.09	41.50	45.13	47.33	47.68
5.50	40.01	40.71	41.16	43.59	47.68	50.07	50.46
5.75	41.98	42.83	43.25	45.73	50.25	52.82	53.25
6.00	43.93	44.94	45.36	47.89	52.83	55.56	56.03
6.25	45.84	47.04	47.46	50.08	55.40	58.27	58.79
6.50	47.72	49.12	49.56	52.28	57.96	60.95	61.50
6.75	49.55	51.16	51.64	54.50	60.50	63.58	64.17
7.00	51.34	53.17	53.71	56.72	63.00	66.15	66.78
7.25	53.07	55.15	55.75	58.93	65.46	68.66	69.32
7.50	54.75	57.07	57.76	61.14	67.86	71.08	71.78
7.75	56.39	58.96	59.74	63.33	70.20	73.43	74.16
8.00	57.97	60.79	61.68	65.50	72.48	75.68	76.44
8.25	59.51	62.58	63.59	67.64	74.68	77.84	78.62
8.50	61.00	64.31	65.46	69.74	76.80	79.90	80.70
8.75	62.46	66.00	67.28	71.80	78.83	81.86	82.67
9.00	63.88	67.64	69.07	73.82	80.78	83.71	84.53
9.25	65.27	69.24	70.81	75.79	82.63	85.45	86.27
9.50	66.64	70.79	72.51	77.69	84.39	87.08	87.91
9.75	67.99	72.31	74.16	79.54	86.04	88.61	89.42
10.00	69.33	73.78	75.77	81.32	87.60	90.02	90.82
10.25	70.66	75.22	77.34	83.02	89.06	91.33	92.11
10.50	71.99	76.63	78.87	84.66	90.41	92.52	93.28
10.75	73.32	78.01	80.35	86.21	91.66	93.62	94.34
11.00	74.66	79.36	81.80	87.68	92.80	94.61	95.29
11.25	76.01	80.68	83.20	89.07	93.85	95.50	96.14
11.50	77.37	81.98	84.55	90.37	94.79	96.29	96.89
11.75	78.75	83.26	85.87	91.58	95.64	97.00	97.54
12.00	80.14	84.52	87.14	92.70	96.39	97.61	98.10
12.25	81.55	85.76	88.37	93.74	97.06	98.14	98.57
12.50	82.98	86.97	89.55	94.68	97.63	98.59	98.96
12.75	84.41	88.16	90.68	95.53	98.12	98.97	99.27
13.00	85.85	89.33	91.77	96.29	98.53	99.29	99.52
13.25	87.30	90.47	92.80	96.97	98.87	99.54	99.71
13.50	88.73	91.58	93.77	97.56	99.14	99.74	99.84
13.75	90.14	92.65	94.69	98.07	99.35	99.88	99.92
14.00	91.52	93.67	95.54	98.50	99.51	99.92	99.96
14.25	92.86	94.64	96.32	98.85	99.62	100	100
14.50	94.13	95.55	97.02	99.14	99.69	100	100
14.75	95.31	96.38	97.64	99.36	99.72	100	100
15.00	96.39	97.13	98.16	99.53	99.73	100	100
15.25	97.24	97.77	98.58	99.66	99.74	100	100
15.50	97.92	98.30	98.89	99.74	99.76	100	100
15.75	98.42	98.79	99.07	99.79	99.81	100	100
16.00	98.79	99.14	99.19	99.82	99.85	100	100
16.25	99.12	99.21	99.32	99.85	99.87	100	100
16.50	99.30	99.36	99.44	99.88	99.91	100	100
16.75	99.44	99.50	99.59	99.92	100	100	100
17.00	99.52	99.60	99.74	100	100	100	100

TABLE 3—*Dental maturity score per age in southern French boys, Demirjian 7-tooth method.*

Age	1%	5%	16%	50%	84%	95%	99%
2.00	16.04	16.19	16.39	17.04	17.17	17.28	17.61
2.25	17.66	17.73	17.90	18.72	19.03	19.06	19.39
2.50	19.23	19.25	19.42	20.42	20.80	20.85	21.45
2.75	20.76	20.77	20.95	22.13	22.63	22.73	23.48
3.00	22.27	22.33	22.50	23.85	24.53	24.67	25.48
3.25	23.75	23.76	24.07	25.60	26.50	26.67	27.45
3.50	25.22	25.24	25.66	27.37	28.55	28.72	29.42
3.75	26.67	26.74	27.27	29.15	30.65	30.81	31.37
4.00	28.13	28.24	28.89	30.96	32.81	32.94	33.33
4.25	29.58	29.76	30.54	32.79	34.99	35.11	35.51
4.50	31.04	31.29	32.20	34.64	36.95	37.30	37.56
4.75	32.50	32.84	33.89	36.51	38.93	39.52	39.85
5.00	33.98	34.41	35.59	38.40	40.91	41.77	42.17
5.25	35.47	35.99	37.31	40.30	42.91	44.02	44.51
5.50	36.98	37.60	39.05	42.23	44.93	46.29	46.87
5.75	38.51	39.23	40.81	44.16	46.95	48.55	49.24
6.00	40.05	40.88	42.57	46.11	48.99	50.82	51.61
6.25	41.62	42.56	44.36	48.06	51.04	53.08	53.99
6.50	43.21	44.25	46.15	50.03	53.10	55.33	56.35
6.75	44.81	45.96	47.96	51.99	55.17	57.57	58.50
7.00	46.44	47.70	49.77	53.96	57.24	59.78	60.74
7.25	48.08	49.45	51.60	55.93	59.30	61.97	63.04
7.50	49.74	51.21	53.42	57.89	61.37	64.13	65.32
7.75	51.42	52.99	55.26	59.85	63.43	66.25	67.55
8.00	53.11	54.78	57.09	61.79	65.47	68.33	69.75
8.25	54.82	56.58	58.92	63.72	67.50	70.37	71.89
8.50	56.53	58.38	60.74	65.63	69.50	72.36	73.99
8.75	58.26	60.19	62.56	67.51	71.48	74.30	76.02
9.00	59.98	62.00	64.38	69.38	73.43	76.19	77.99
9.25	61.71	63.8	66.18	71.21	75.34	78.01	79.89
9.50	63.44	65.6	67.96	73.01	77.21	79.78	81.72
9.75	65.17	67.38	69.73	74.77	79.03	81.48	83.48
10.00	66.89	69.16	71.48	76.50	80.80	83.11	85.16
10.25	68.60	70.92	73.21	78.18	82.51	84.66	86.75
10.50	70.29	72.65	74.91	79.81	84.15	86.15	88.26
10.75	71.97	74.36	76.58	81.40	85.74	87.56	89.68
11.00	73.63	76.05	78.22	82.93	87.25	88.90	91.02
11.25	75.26	77.70	79.83	84.41	88.68	90.15	92.26
11.50	76.87	79.32	81.4	85.83	90.04	91.33	93.41
11.75	78.45	80.90	82.92	87.19	91.31	92.42	94.47
12.00	79.99	82.44	84.41	88.49	92.50	93.44	95.43
12.25	81.5	83.93	85.84	89.72	93.61	94.37	96.30
12.50	82.97	85.37	87.23	90.88	94.62	95.23	97.08
12.75	84.39	86.76	88.56	91.97	95.54	96.00	97.77
13.00	85.78	88.10	89.84	93.00	96.37	96.70	98.37
13.25	87.11	89.38	91.05	93.95	97.11	97.32	98.88
13.50	88.40	90.60	92.20	94.83	97.76	97.86	99.31
13.75	89.63	91.75	93.29	95.63	98.32	98.33	99.67
14.00	90.81	92.84	94.30	96.36	98.73	98.80	99.94
14.25	91.94	93.87	95.25	97.02	99.07	99.19	99.95
14.50	93.01	94.82	96.12	97.61	99.34	99.50	100
14.75	94.03	95.71	96.91	98.13	99.56	99.73	100
15.00	94.99	96.52	97.62	98.57	99.72	99.90	100
15.25	95.89	97.26	98.24	98.95	100	100	100
15.50	96.74	97.93	98.78	99.25	100	100	100
15.75	97.53	98.53	99.23	99.50	100	100	100
16.00	98.26	99.05	99.58	99.69	100	100	100
16.25	98.95	99.51	99.74	99.81	100	100	100
16.50	99.58	99.89	100	100	100	100	100
16.75	100	100	100	100	100	100	100
17.00	100	100	100	100	100	100	100

symbolized by the mean differences between the lower and upper limit of 99% prediction interval with the real age. The reliability of the estimation is given by the percentage of individuals whose real age isn't within the 99% confidence interval. All statistical analyses have been performed with SPSS and STATISTICA software for PC.

Results

Inter and Intra Observers' Error

Thirty orthopantomograms (240 teeth) were examined twice by two different observers, for boys and girls aged between 2 and 16 years. Inter and intra observers' error was calculated and there

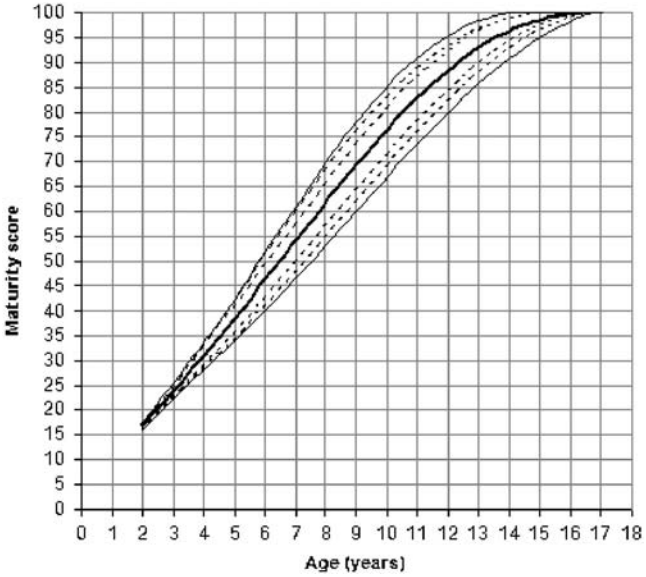

FIG. 2—*Dental maturity percentiles for boys, Demirjian 7-tooth method 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles.*

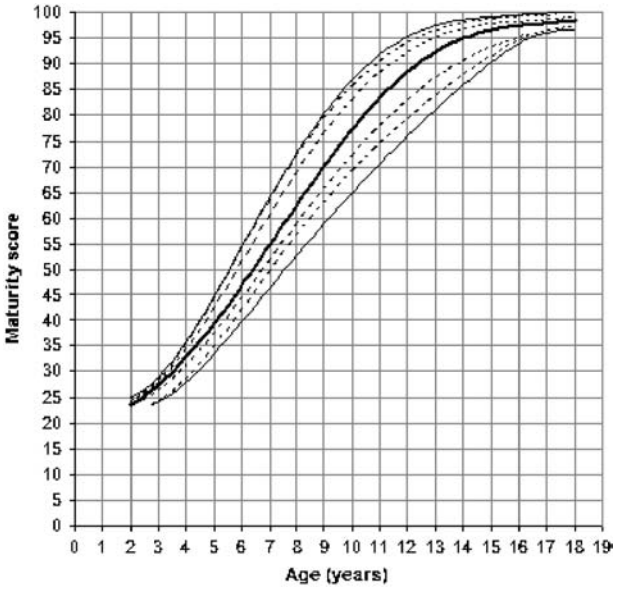

FIG. 3—*Dental maturity percentiles for girls, Demirjian 8-tooth method 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles.*

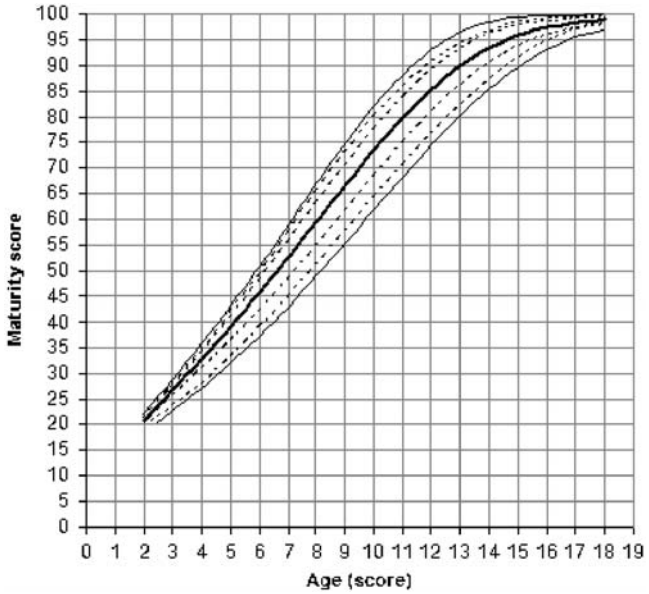

FIG. 4—*Dental maturity percentiles for boys, Demirjian 8-tooth method 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles.*

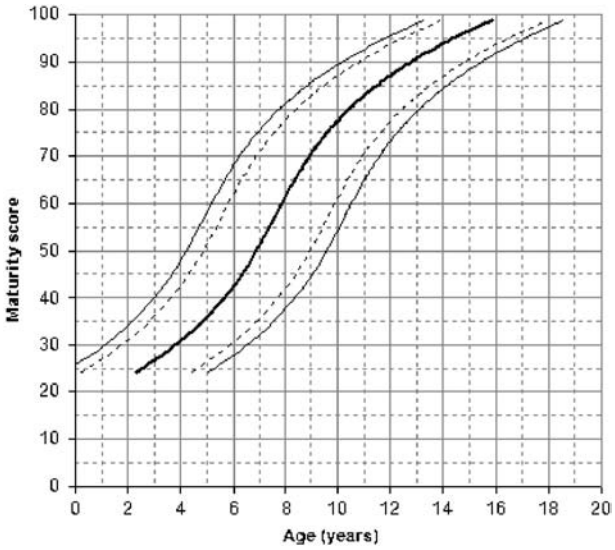

FIG. 5—*Dental maturity, 95 and 99% CI for girls, polynomial function, $R^2 = 0,\ 91$ Age = 6, 15E-05*Score^3–0, 0106*Score^2 + 0, 6997*Score–9, 3178 ± 2, 01 yrs (95% CI).*

are no significant differences. Intra observers' Student's paired t-test: $t = 0.0045$, $p = 0.9964$ ($dof = 29$, $\alpha = 0.05$, $1\text{-}\beta = 92\%$), inter observers' Student's paired t-test: $t = 0.0271$, $p = 0.9786$ ($dof = 29$, $\alpha = 0.05$, with statistical power of 85%, 1-error β expressed in percentage). With the t-test, the alpha error increases when several variables are considered, leading to the use of an ANOVA (analysis of variance) test (13,23). This method gives the same result between two observers and for two repetitions by observers ($\nu_1 =, 1, \nu_2 = 28$ and $F_{0,05} < 4, 2$ for each case).

Dental Maturity

Maturity score as a function of age with Demirjian's method with teeth 7 are presented for girls and boys in Tables 2 and 3 and dental maturity percentile graphs for southern French in Fig. 1 for girls and Fig. 2 for boys. With Demirjian's method with teeth 8, the maturity score is presented for girls and boys in Tables 4 and 5 and the percentile graphs in Fig. 3 for girls and Fig. 4 for boys.

These percentile curves are a function of age and the interval is read vertically. We have an interval for the score for each age group. It's a good approach to detect if the dental maturity of a subject is "advanced" or "delayed" (20) in comparison with subjects of the same age. However, for age prediction it's not appropriate and less reliable because we want an interval of age for a specific maturity score. Of course, we can read the curves horizontally but this approach is not statistically developed for this utilization (26).

We note that the teeth 8 system gives a prediction for the maturity score until 18 years of age and until 16 years for the teeth 7 system. Thus the addition of third molar increases the prediction of two years in comparison with Demirjian's method with 7 teeth.

TABLE 4—*Dental maturity score per age in southern French girls, Demirjian 8-tooth method.*

Age	1%	5%	16%	50%	84%	95%	99%
2.00	23.21	23.28	23.30	23.47	24.20	24.69	25.10
2.25	23.23	23.32	23.83	24.30	24.75	25.14	25.67
2.50	23.35	23.39	24.50	25.24	25.54	25.89	26.50
2.75	23.70	23.74	25.32	26.27	26.54	26.91	27.58
3.00	24.25	24.27	26.26	27.40	27.73	28.18	28.89
3.25	24.97	25.03	27.33	28.62	29.10	29.66	30.38
3.50	25.84	26.03	28.50	29.93	30.63	31.33	32.06
3.75	26.86	27.19	29.77	31.31	32.30	33.16	33.88
4.00	27.99	28.50	31.13	32.78	34.09	35.14	35.84
4.25	29.23	29.93	32.57	34.32	35.99	37.23	37.92
4.50	30.55	31.47	34.08	35.93	37.98	39.43	40.09
4.75	31.96	33.10	35.66	37.60	40.06	41.70	42.34
5.00	33.42	34.80	37.29	39.33	42.19	44.04	44.66
5.25	34.94	36.55	38.97	41.11	44.38	46.42	47.02
5.50	36.50	38.35	40.69	42.94	46.60	48.83	49.42
5.75	38.09	40.18	42.44	44.81	48.86	51.26	51.84
6.00	39.71	42.03	44.22	46.71	51.13	53.69	54.27
6.25	41.34	43.89	46.03	48.64	53.40	56.11	56.69
6.50	42.98	45.76	47.85	50.60	55.67	58.50	59.09
6.75	44.63	47.61	49.67	52.57	57.93	60.87	61.48
7.00	46.27	49.46	51.50	54.56	60.17	63.19	63.82
7.25	47.91	51.28	53.33	56.55	62.38	65.46	66.13
7.50	49.54	53.08	55.16	58.54	64.55	67.68	68.38
7.75	51.16	54.85	56.97	60.53	66.67	69.83	70.57
8.00	52.77	56.59	58.77	62.50	68.75	71.92	72.70
8.25	54.36	58.29	60.55	64.46	70.78	73.93	74.76
8.50	55.93	59.96	62.30	66.39	72.74	75.86	76.75
8.75	57.48	61.59	64.03	68.29	74.64	77.72	78.65
9.00	59.01	63.18	65.73	70.17	76.47	79.49	80.47
9.25	60.52	64.73	67.40	72.00	78.23	81.17	82.21
9.50	62.01	66.24	69.03	73.79	79.91	82.76	83.85
9.75	63.48	67.70	70.63	75.53	81.52	84.27	85.41
10.00	64.93	69.13	72.18	77.22	83.04	85.69	86.87
10.25	66.37	70.53	73.70	78.86	84.49	87.02	88.24
10.50	67.78	71.88	75.16	80.43	85.85	88.27	89.51
10.75	69.18	73.20	76.59	81.94	87.13	89.43	90.69
11.00	70.56	74.49	77.96	83.39	88.33	90.50	91.78
11.25	71.93	75.74	79.29	84.77	89.45	91.49	92.78
11.50	73.28	76.96	80.57	86.07	90.48	92.40	93.69
11.75	74.61	78.16	81.79	87.30	91.43	93.24	94.52
12.00	75.93	79.32	82.97	88.45	92.31	94.00	95.26
12.25	77.24	80.47	84.10	89.53	93.10	94.69	95.91
12.50	78.53	81.58	85.17	90.53	93.82	95.31	96.49
12.75	79.81	82.67	86.19	91.46	94.47	95.86	97.00
13.00	81.07	83.74	87.16	92.30	95.05	96.36	97.43
13.25	82.31	84.79	88.08	93.07	95.56	96.80	97.80
13.50	83.53	85.82	88.94	93.77	96.00	97.18	98.11
13.75	84.73	86.82	89.76	94.39	96.39	97.52	98.36
14.00	85.91	87.80	90.52	94.94	96.72	97.81	98.57
14.25	87.05	88.75	91.24	95.42	97.00	98.06	98.73
14.50	88.17	89.67	91.91	95.84	97.23	98.27	98.85
14.75	89.25	90.57	92.53	96.19	97.42	98.44	98.94
15.00	90.29	91.43	93.10	96.50	97.58	98.59	99.09
15.25	91.27	92.25	93.63	96.75	97.70	98.71	99.21
15.50	92.20	93.03	94.11	96.96	97.80	98.80	99.30
15.75	93.07	93.76	94.55	97.13	97.87	98.87	99.37
16.00	93.86	94.43	94.95	97.27	97.93	98.92	99.42
16.25	94.57	95.04	95.31	97.39	98.03	98.95	99.55
16.50	95.19	95.57	95.63	97.50	98.09	98.97	99.67
16.75	95.70	96.03	96.04	97.61	98.19	99.02	99.72
17.00	96.09	96.29	96.31	97.74	98.36	99.17	99.81
17.25	96.35	96.44	96.49	97.88	98.42	99.31	99.86
17.50	96.45	96.58	96.68	98.05	98.59	99.57	99.90
17.75	96.49	96.78	96.85	98.28	98.79	99.65	99.95
18.00	96.55	96.80	96.88	98.56	99.10	99.74	100.00

TABLE 5—*Dental maturity score per age in southern French boys, Demirjian 8-tooth method.*

Age	1%	5%	16%	50%	84%	95%	99%
2.00	18.42	19.73	19.75	20.63	21.42	21.98	22.46
2.25	19.49	20.64	21.34	22.19	22.96	23.50	24.01
2.50	20.55	21.59	22.85	23.72	24.50	25.04	25.59
2.75	21.62	22.58	24.31	25.24	26.06	26.62	27.19
3.00	22.70	23.62	25.72	26.74	27.49	28.05	28.64
3.25	23.78	24.69	27.10	28.24	29.15	29.70	30.52
3.50	24.88	25.80	28.45	29.73	30.81	31.41	32.24
3.75	26.00	26.95	29.79	31.24	32.37	32.98	34.00
4.00	27.13	28.14	31.12	32.75	34.05	34.70	35.69
4.25	28.29	29.37	32.45	34.28	35.74	36.17	37.63
4.50	29.48	30.63	33.79	35.83	37.45	38.07	39.40
4.75	30.69	31.93	35.14	37.39	39.18	40.01	41.31
5.00	31.92	33.26	36.51	38.98	40.92	41.99	43.06
5.25	33.19	34.62	37.89	40.59	42.69	43.60	44.83
5.50	34.48	36.02	39.30	42.22	44.48	45.50	46.63
5.75	35.80	37.44	40.74	43.87	46.29	47.31	48.46
6.00	37.16	38.90	42.20	45.54	48.12	49.13	50.61
6.25	38.54	40.38	43.70	47.24	49.96	51.20	52.47
6.50	39.95	41.88	45.22	48.95	51.82	53.27	54.55
6.75	41.39	43.41	46.76	50.69	53.70	55.34	56.63
7.00	42.85	44.96	48.34	52.43	55.58	57.41	58.71
7.25	44.34	46.53	49.94	54.19	57.47	59.47	60.80
7.50	45.86	48.11	51.57	55.96	59.37	61.51	62.87
7.75	47.40	49.71	53.21	57.74	61.26	63.53	64.94
8.00	48.95	51.32	54.88	59.52	63.15	65.53	66.98
8.25	50.53	52.94	56.57	61.30	65.03	67.50	69.00
8.50	52.12	54.57	58.26	63.08	66.90	69.43	70.99
8.75	53.72	56.21	59.97	64.85	68.75	71.32	72.95
9.00	55.34	57.85	61.68	66.61	70.58	73.17	74.87
9.25	56.96	59.49	63.39	68.35	72.39	74.98	76.74
9.50	58.59	61.12	65.11	70.07	74.16	76.73	78.56
9.75	60.23	62.76	66.81	71.77	75.90	78.42	80.32
10.00	61.86	64.39	68.50	73.44	77.59	80.06	82.02
10.25	63.49	66.00	70.18	75.08	79.24	81.64	83.66
10.50	65.11	67.61	71.83	76.68	80.84	83.15	85.23
10.75	66.72	69.20	73.46	78.24	82.39	84.60	86.73
11.00	68.32	70.78	75.07	79.76	83.88	85.97	88.15
11.25	69.91	72.33	76.63	81.23	85.31	87.27	89.49
11.50	71.47	73.87	78.16	82.64	86.67	88.50	90.75
11.75	73.02	75.38	79.65	84.01	87.96	89.66	91.93
12.00	74.54	76.86	81.08	85.31	89.19	90.74	93.01
12.25	76.02	78.31	82.47	86.56	90.33	91.74	94.01
12.50	77.48	79.73	83.81	87.74	91.40	92.66	94.92
12.75	78.91	81.11	85.08	88.86	92.40	93.51	95.75
13.00	80.29	82.46	86.30	89.91	93.31	94.28	96.48
13.25	81.64	83.76	87.46	90.89	94.14	94.98	97.12
13.50	82.94	85.03	88.55	91.81	94.90	95.60	97.68
13.75	84.19	86.24	89.57	92.65	95.57	96.16	98.16
14.00	85.40	87.41	90.53	93.43	96.17	96.69	98.56
14.25	86.56	88.53	91.42	94.14	96.68	97.23	98.88
14.50	87.66	89.59	92.24	94.78	97.13	97.64	99.13
14.75	88.71	90.60	92.99	95.35	97.50	98.04	99.32
15.00	89.71	91.55	93.68	95.86	97.80	98.33	99.45
15.25	90.64	92.45	94.30	96.31	98.05	98.50	99.53
15.50	91.52	93.28	94.86	96.71	98.23	98.70	99.56
15.75	92.33	94.04	95.36	97.05	98.37	98.85	99.61
16.00	93.08	94.74	95.80	97.35	98.46	98.91	99.63
16.25	93.77	95.37	96.20	97.60	98.51	98.95	99.67
16.50	94.40	95.92	96.55	97.82	98.64	99.10	99.69
16.75	94.97	96.41	96.86	98.02	98.76	99.13	99.72
17.00	95.47	96.82	97.15	98.19	98.90	99.23	99.75
17.25	95.91	97.15	97.41	98.36	98.99	99.30	99.80
17.50	96.28	97.41	97.66	98.53	99.09	99.39	99.85
17.75	96.60	97.58	97.90	98.71	99.14	99.46	99.98
18.00	96.86	97.68	98.16	98.92	99.28	99.59	100.00

TABLE 6—*Predicted age for 95, 97, 99% CI per maturity score in girls, polynomial function.*

Score	1%	3%	5%	50%	95%	97%	99%
20.0	0.00	0.00	0.00	0.94	3.02	3.35	3.68
22.5	0.00	0.00	0.00	1.77	3.85	4.18	4.51
25.0	0.00	0.22	0.44	2.52	4.60	4.93	5.26
27.5	0.50	0.82	1.13	3.20	5.28	5.60	5.93
30.0	1.12	1.44	1.75	3.81	5.88	6.21	6.53
32.5	1.67	1.99	2.31	4.36	6.42	6.75	7.07
35.0	2.17	2.49	2.81	4.85	6.91	7.23	7.56
37.5	2.61	2.93	3.25	5.29	7.34	7.66	7.99
40.0	3.01	3.33	3.65	5.68	7.73	8.05	8.37
42.5	3.36	3.68	4.00	6.03	8.07	8.40	8.72
45.0	3.68	4.00	4.32	6.35	8.39	8.71	9.03
47.5	3.97	4.29	4.61	6.64	8.67	8.99	9.31
50.0	4.24	4.56	4.88	6.90	8.93	9.25	9.57
52.5	4.49	4.81	5.13	7.15	9.18	9.50	9.82
55.0	4.73	5.05	5.37	7.39	9.41	9.73	10.05
57.5	4.96	5.28	5.60	7.63	9.64	9.96	10.28
60.0	5.20	5.52	5.84	7.86	9.87	10.19	10.51
62.5	5.44	5.76	6.07	8.10	10.11	10.43	10.75
65.0	5.69	6.01	6.33	8.35	10.36	10.68	11.00
67.5	5.96	6.28	6.60	8.62	10.63	10.95	11.27
70.0	6.25	6.57	6.89	8.91	10.92	11.24	11.56
72.5	6.58	6.89	7.21	9.23	11.24	11.56	11.88
75.0	6.93	7.25	7.57	9.59	11.60	11.92	12.24
77.5	7.34	7.65	7.97	9.98	12.00	12.32	12.64
80.0	7.78	8.10	8.42	10.43	12.45	12.77	13.09
82.5	8.28	8.60	8.92	10.92	12.95	13.27	13.59
85.0	8.84	9.16	9.48	11.48	13.51	13.83	14.15
87.5	9.47	9.79	10.10	12.09	14.14	14.46	14.77
90.0	10.16	10.48	10.80	12.78	14.84	15.15	15.47
92.5	10.94	11.25	11.57	13.54	15.61	15.93	16.25
95.0	11.79	12.11	12.43	14.39	16.47	16.78	17.10
96.0	12.16	12.48	12.79	14.75	16.83	17.15	17.47
97.0	12.54	12.86	13.17	15.12	17.21	17.53	17.85
98.0	12.93	13.25	13.57	15.51	17.61	17.93	18.25
98.5	13.14	13.46	13.77	15.71	17.81	18.13	18.45
99.0	13.35	13.66	13.98	15.92	18.02	18.34	18.66
99.5	13.56	13.88	14.19	16.13	18.23	18.55	18.87
100.0	13.77	14.09	14.41	16.34	18.45	18.77	19.09

TABLE 7—*Predicted age for 95, 97, 99% CI per maturity score in boys, polynomial function.*

Score	1%	3%	5%	50%	95%	97%	99%
20.0	0.00	0.00	0.00	1.15	3.00	3.29	3.58
22.5	0.00	0.08	0.17	1.96	3.78	4.07	4.36
25.0	0.33	0.62	0.90	2.68	4.50	4.79	5.07
27.5	1.00	1.29	1.57	3.35	5.15	5.43	5.72
30.0	1.61	1.90	2.18	3.95	5.74	6.02	6.31
32.5	2.17	2.45	2.73	4.49	6.27	6.56	6.84
35.0	2.67	2.95	3.23	4.99	6.76	7.04	7.32
37.5	3.12	3.40	3.68	5.43	7.20	7.48	7.76
40.0	3.53	3.81	4.09	5.84	7.60	7.88	8.15
42.5	3.91	4.18	4.46	6.21	7.96	8.24	8.52
45.0	4.25	4.53	4.80	6.55	8.30	8.57	8.85
47.5	4.57	4.85	5.12	6.86	8.61	8.88	9.16
50.0	4.87	5.14	5.42	7.16	8.90	9.17	9.45
52.5	5.15	5.42	5.70	7.44	9.18	9.45	9.72
55.0	5.42	5.69	5.97	7.71	9.44	9.72	9.99
57.5	5.69	5.96	6.23	7.97	9.71	9.98	10.25
60.0	5.95	6.23	6.50	8.24	9.97	10.24	10.52
62.5	6.22	6.50	6.77	8.51	10.24	10.51	10.79
65.0	6.51	6.78	7.05	8.79	10.52	10.79	11.07
67.5	6.80	7.08	7.35	9.09	10.82	11.09	11.36
70.0	7.12	7.40	7.67	9.40	11.14	11.41	11.68
72.5	7.47	7.74	8.01	9.75	11.48	11.75	12.03
75.0	7.84	8.11	8.39	10.12	11.86	12.13	12.40
77.5	8.25	8.53	8.80	10.54	12.27	12.54	12.81
80.0	8.71	8.98	9.25	10.99	12.73	13.00	13.27
82.5	9.21	9.48	9.75	11.49	13.23	13.50	13.77
85.0	9.76	10.03	10.31	12.04	13.78	14.05	14.32
87.5	10.37	10.64	10.92	12.65	14.39	14.66	14.93
90.0	11.04	11.31	11.59	13.33	15.06	15.33	15.61
92.5	11.78	12.05	12.33	14.07	15.80	16.07	16.35
95.0	12.59	12.86	13.14	14.88	16.61	16.89	17.16
96.0	12.94	13.21	13.48	15.22	16.96	17.23	17.50
97.0	13.29	13.57	13.84	15.58	17.32	17.59	17.86
98.0	13.67	13.94	14.21	15.96	17.69	17.96	18.23
98.5	13.86	14.13	14.41	16.15	17.88	18.15	18.42
99.0	14.05	14.33	14.60	16.34	18.08	18.35	18.62
99.5	14.25	14.52	14.80	16.54	18.27	18.54	18.81
100.0	14.45	14.73	15.00	16.74	18.47	18.75	19.02

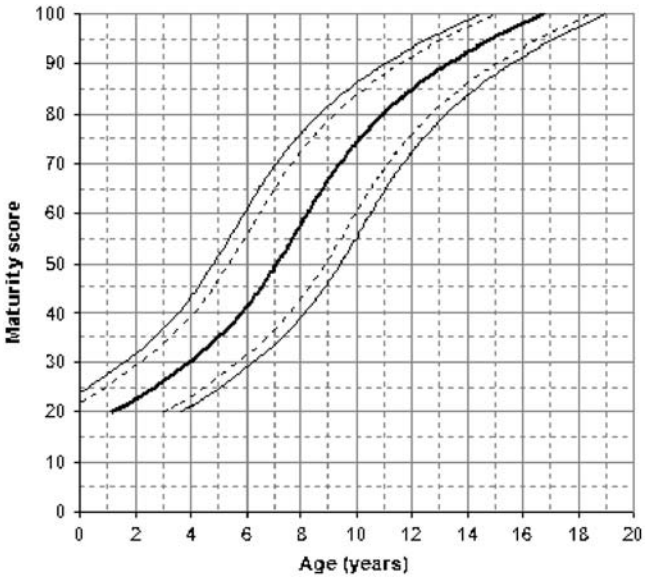

FIG. 6—*Dental maturity, 95 and 99% CI for boys, polynomial function, $R^2 = 0,\ 93$ Age = 5, 50E-05*Score^3–0, 0095*Score^2 + 0, 6479*Score–8, 4583 ± 1, 73 yrs (95% CI).*

To obtain age as a function of the maturity score, we calculated a cubic function between the real age and the maturity score for the eight mandibular teeth ($Y = aX^3 + bX^2 + cX + d$, with Y as age and X as maturity score). We obtain an age prediction with 95, 97, and 99% CI (Tables 6 and 7, Figs. 5 and 6 for girls and boys). Moreover, this analysis is easy to perform to calculate new maturity curves if teeth are missing or for another population.

$$\text{Girls: Age} = (6,15\text{E}-05 * \text{Score}^3) - (0,0106 * \text{Score}^2) + (0,6997 * \text{Score}) - 9,3178$$
$$\pm 2,01 \text{ yrs (95\% CI)},\ \pm 2,33 \text{ yrs (97\% CI)},$$
$$\pm 2,65 \text{ yrs (99\% CI)},\ R^2 = 0,91$$

$$\text{Boys: Age} = (5,50\text{E}-05 * \text{Score}^3) - (0,0095 * \text{Score}^2) + (0,6479 * \text{Score}) - 8,4583$$
$$\pm 1,73 \text{ yrs (95\% CI)},\ \pm 1,97 \text{ yrs (97\% CI)},$$
$$\pm 2,28 \text{ yrs (99\% CI)},\ R^2 = 0,93$$

The confidence interval is homogenous for all the age groups. The reliability of the polynomial method is higher than the percentiles score's one but its accuracy is lower (Table 8). This method is appropriate for the study of age prediction if the aim is the reliability (for example, in forensic analysis).

TABLE 8—*Comparison of the percentage of individuals misclassified in age prediction and of the accuracy* of the three methods.*

Method	Misclassified %	Mean accuracy
Demirjian 7-teeth 99% CI	10.2%	2.57
Demirjian 8-teeth 99% CI	4.2%	3.91
Polynomial regression 95% CI	4.1%	3.47
Polynomial regression 97% CI	1.3%	3.95
Polynomial regression 99% CI	0.0%	4.57

* Mean accuracy represents the mean of the residual minimum and maximum in years for all boys from the age of 2 to 16 years.

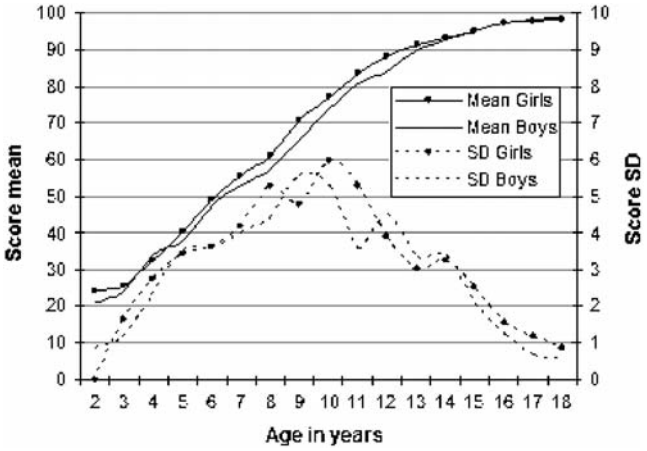

FIG. 7—*Means and SD of maturity scores in boys and girls for the southern French, Demirjian 8-teeth method.*

The performance of these methods is given in Table 8. All the boys are observed from 2 to 16 years of age, because Demirjian's 7 teeth method isn't adapted after 16 years. We observe the reliability and the accuracy of each method for all 470 boys. We note that for age prediction, the polynomial interpolation is the most reliable method but less accurate than Demirjian's method for 7 teeth.

Sexual Differences

Figure 7 shows the mean scores and the SD from each age group to one year for boys and girls. The mean score is given by the maturity score calculated for the 8 teeth system with gender specific weighted score. We note that a difference exists between girls and boys from 5 to 14 years old according to the Demirjian study (3). But this difference is not really correct because the weighted scores used to obtain the maturity are gender specific. Nyström (20) determines gender differences using the mean of these gender-specific weighted scores to calculate a new gender-independent maturity score in order to compare the mean differences of estimated age for girls and boys.

We use the same method, but here we calculated new weighted scores sex independent. We note an advance in dental maturity (Fig. 8) for girls for the whole age group and beginning since three years of age. The gender dimorphism increase gradually until 10 years and increase strongly until 12–13 years. The catch-up growth for boys begins at 13–14 years and continues through 15 years slowly and strongly until 17 years.

Discussion

The goal of this study was to present the development of dental maturity in southern French subjects. We used the percentiles

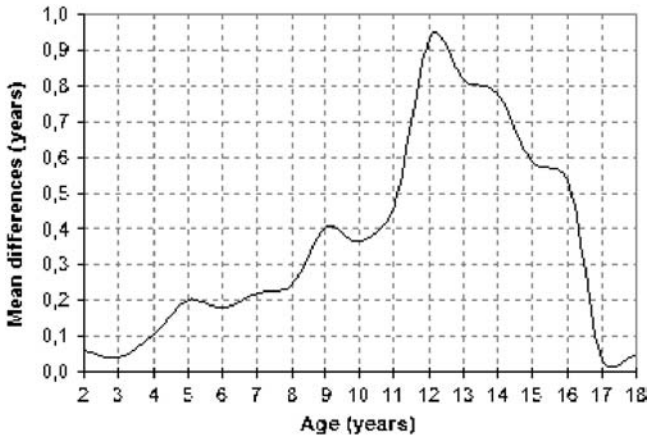

FIG. 8—*Differences in dental age between girls and boys from the age of 2 to 18 years (girls age estimate—boys age estimate). Nonspecific gender weighted score is used with Demirjian 8-tooth method.*

Demirjian's method (Tables 2–5, Figs. 1–4) and polynomial functions (Tables 6 and 7, Figs. 5 and 6) for a better comprehension of the specifics advantages of these methods.

The Demirjian's 7-teeth method has a high accuracy (Table 8) but poor reliability. It's difficult to be accurate and reliable; in fact, the accuracy and the reliability move in a contrary way. The goal is to minimize these two factors using the best method and the most adapted biological indicators.

Adding the third molar, we have increased the possibility of prediction until 18 years of age. Demirjian's 8-teeth method became more reliable (from 10, 2% to 4, 2% of error) but the mean accuracy (from 2 to 18 years) decreases after more or less eight months. The high variability of the third molar (8,16) explains the reduction of the accuracy.

The polynomial functions show a high reliability and the accuracy is the same as that of Demirjian's 8-teeth method. However, Demirjian's 7-teeth method is more accurate particularly from 2 to 9 years of age. The polynomial functions give the same confidence interval for all age groups, explaining the low accuracy from the first age group. The 97% CI with the polynomial functions is the best compromise to use this method.

In regard to these results, the polynomial functions (age as a function of score) are suitable methods in forensic science. The reliability is the most important factor because the legal authorities want to know the age of children to make a decision as a function of law for the legal age groups.

The percentile curves (score as a function of age) seem most adapted for clinicians who could detect the aspect advanced or delayed compared with reference subjects of the same age for one individual. Moreover, they will be able to use Demirjian's 8-teeth method, if the third molar is present, for more reliability and to observe the maturity score for the oldest boys. These two percentile methods are given as a function of the presence or absence of the third molar.

However, these systems have limits. The number of 2-to-4-year-old children was too small to give accurate estimates and the maturity score may be underestimated for this age group.

Also, if a tooth is missing on the left side, Demirjian uses the homologous or the contralateral tooth. But if a tooth is missing bilaterally, Demirjian's method can't calculate a maturity score. Overall, the efficiency of dental age estimation with several teeth missing will be considerably decreased. It seems that dental maturity doesn't follow a linear progression (26) and the polynomial

functions are recommended; here the cubic functions give the best correlations with dental maturity. Nyström (20) proposed a set of linear regressions to resolve the problem of missing data but the dental development is curvilinear with accelerations and stops. The solution will be a set of multiple polynomial interpolations (6,23) computed with missing teeth for increasing the efficiency of dental age estimation. In this study, the R^2 for girls with linear interpolation is 0.85 against 0.91 and the prediction stops to 15.1 years of age against 16.3 for cubic interpolation. The multiple polynomial interpolations, calculated with correlation matrices, seem to be a more suitable method for addressing the missing teeth problem.

Moreover, after 15 years of age, the accuracy of age prediction decreases because the analysis is computed only with the third molar. This is the limit of the accuracy of the dental maturity as a biological indicator. Other biological indicators like skeletal maturity of bones (12,27) or baseline of the head (1,15,21) could increase the accuracy of age estimation of the oldest boys.

The differences in dental maturity between the populations show the importance of the construction of new dental maturity standards for each population (2,11,18,19,28). In the future, the constitution of large specific databases, with Demirjian's dental stages and other biological indicators, will constitute an important field of interest for a better determination of human variability.

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