DENTAL MATURITY IN BELGIAN CHILDREN USING DEMIRJIAN'S METHOD AND POLYNOMIAL FUNCTIONS: NEW STANDARD CURVES FOR FORENSIC AND CLINICAL USE

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ABSTRACT

Dental maturity was studied from dental panoramic radiographs of 2523 Belgian children (1255 girls and 1268 boys) aged 2 to 18 years. The aim was to compare the efficiency of two methods of age prediction**:** Demirjian's method, using differently weighted scores, and polynomial functions. The two methods present some differences: Demirjian is used to determine the maturity score as a function of age and polynomial functions are used to determine age as a function of the maturity score. We present, for each method, gender-specific dental maturity tables and curves for Belgian children. Girls always present advanced dental maturity compared with boys. The polynomial functions are highly reliable (0.21% of incorrect classifications) and the percentile method, using Belgian weighted scores, is very accurate (± 2.08 years on average, between 2 and 16 years of age).

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

INTRODUCTION

There are many methods to determine the chronological age of children, which may be divided into two main groups: studies based on bone and on tooth development. The most useful methods using skeletal maturity are based on radiographs of specific structures such as epiphysis-diaphysis fusion of long bones[1-4], medial extremity of the clavicle[5], epiphyseal head of the first rib[6], epiphyseal union of the anterior iliac crest[7] and the fusion of the sphenoid bone with the basilar part of the occipital bone.[8-10] However, these skeletal methods present some inconveniences in view of the important variability of bone maturation, which is influenced by environmental factors. Moreover, some methods were established several decades ago[2,3] and are not strictly applicable nowadays because of secular biological variation.

Several authors[11-17] have shown that dental parameters are more suitable for age estimation in children because the variability is lower since calcification rates are more controlled by genes than by environmental factors.[18] There are several methods for estimating dental maturity that show variation in degrees of maturation. The most frequently used methods are based on dental development visualized by orthopantomograms or cephalometric radiographs.[19-25]

A widely used method is that proposed by Demirjian, Goldstein and Tanner[11,19] based on eight calcification stages which span from the first sign of tooth calcification to apex closure for the seven 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.

The studies by Demirjian *et al*.[11,19] are based on data derived from a reference sample comprising 4756 French-Canadians children. However, several authors[14,16,25-31] have shown that results are less accurate if another population is compared to Demirjian's standards and highlight the necessity to create databases representative for each population. These databases would take into account the biological inter-ethnic differences that can cause a bias in age estimation.

Demirjian's method is designed primarily for use by clinicians who want to know if the dental maturity of an individual deviates from the norm, because the score is calculated as a function of age and the predictive interval is given for the maturity score. Since the predictive interval of Demirjian's dental

Table 1: *Age and gender distribution*

Age (years)	Girls	Boys	Total
1	0	1	1
2	9	13	22
3	39	59	98
4	67	121	188
5	75	92	167
6	75	86	161
7	93	78	171
8	99	106	205
9	102	91	193
10	110	105	215
11	110	93	203
12	94	87	181
13	99	89	188
14	66	68	134
15	68	62	130
16	82	67	149
17	66	49	115
18	1	1	2
Total	1255	1268	2523

Table 2: *Specific weighted scores standardized to 100, for Belgian 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				3,32	3,96		3,51
A / 1				3,58	4,02		4,48
B / 2			2,13	3,84	4,55		4,59
C / 3	2,71	3,14	4,14	4,73	5,93	2,27	5,94
D / 4	4,33	4,54	5,47	6,47	7,39	3,66	7,54
E / 5	5,20	5,84	7,14	8,06	8,82	4,59	9,26
F / 6	6,55	7,08	9,14	10,03	10,64	5,98	10,87
G / 7	7,69	8,69	11,52	11,71	12,67	8,14	13,08
H / 8	12,60	13,09	14,63	14,95	15,54	13,17	16,01
Boys	31	32	33	34	35	36	37
No sign/0				3,25	3,62		3,49
A / 1				3,40	4,25		4,38
B / 2		2,91	2,91	3,70	4,66		4,69
C / 3	3,21	3,48	4,32	4,91	5,85	2,58	5,91
D / 4	4,21	4,51	5,68	6,78	7,49	3,61	7,65
E / 5	5,38	5,94	7,65	8,51	9,14	4,74	9,55
F / 6	6,59	7,58	9,95	10,37	10,96	6,20	11,16
G / 7	8,20	9,09	12,31	12,27	12,98	8,54	13,34
H / 8	12,49	13,12	15,09	14,92	15,40	13,08	15,89

* Numbers 31 to 37 (FDI system) represent the permanent lower left first incisor to the permanent lower left second molar; Stages: 0 to 4 = Crown calcification; 4 to 7 = Root calcification; 8 = Apex closure.
** No sign and Demirjian's scale / new numerical stage (0 to 8)

maturity percentile curves[11] is calculated from the maturity score only it is inappropriate for age estimation.[23,24] Several authors[12,17,32] have proposed the use of polynomial or multiple regressions to obtain an age as a function of score, with confidence intervals. This will also limit the problem of missing data.

The main goal of the present study was to established new dental maturity curves for Belgian children using Demirjian's method by calculating ethnically specific maturity scores for each tooth for girls and boys. The second goal was to compare the efficiency and the application for child age prediction of polynomial regression[33-35], Demirjian's method using French-Canadian weighted scores[19], Demirjian's method using Belgian weighted scores obtained according to the Goldstein method[19,36] and Demirjian's method using Belgian weighted scores obtained by ANOVA.[25]

MATERIALS AND METHODS

Dental Data Base

Dental panoramic radiographs or orthopantomograms of 1255 girls (age ranging from 2.1 to 18.0 years) and 1268 boys (age ranging from 1.8 to 18.0 years) were sampled. The panoramic radiographs were selected from patients' records of the University Hospitals of Leuven, School of Dentistry. Subjects with an age above 18.0 years at the time the panoramic radiographs were taken, non-Belgian Caucasian origin, systemic disease, premature birth, congenital anomalies, unclear panoramic radiographs or aplasia of teeth in the mandible were excluded. The distribution by age and gender of dental panoramic radiographs is given in Table 1. Intra-observer agreement was tested and did not show significant differences.[25]

Dental Maturation Determined by Demirjian's Method

Dental age was estimated, using the left mandibular teeth except the third molar rated on 8-stage scale from A to H, according to Demirjian's revised method.[11] To construct mathematical models, stages were converted to numbers (from 1 to 8). The tooth not yet calcified corresponds to the stage 0. Thus, there are 9 development stages from 0 to 8. For each stage of the 7 teeth, we calculated a biologically weighted score for girls and boys specific to the Belgian sample, using methods for deriving the scores described by Goldstein[36] and Tanner, Whitehouse and Healy.[4] These scores are given in Table 2. Missing scores are due to the lack of individuals in the age groups considered. The sum of the scores for each of the 7 teeth is the dental maturity score, rescaled linearly to 100. This score is converted into a dental age using appropriate tables of percentiles (Table 3 and 4) for girls and boys. Percentile curves (Fig.1 and 2), using 5th-degree polynomial interpolation, in accordance with Goldstein and Pan[37], were calculated for 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles; with Age as the

Table 3: *Dental maturity score per age in Belgian girls, Demirjian's method using Belgian weighted scores obtained according to Goldstein method*

Age	1%	5%	16%	50%	84%	95%	99%
2,00	21,17	22,18	23,19	24,62	27,25	28,29	29,33
2,25	21,45	22,49	23,53	25,01	27,81	28,74	29,66
2,50	22,20	23,02	23,83	25,49	28,24	29,17	30,10
2,75	23,04	23,76	24,48	26,01	28,91	29,87	30,82
3,00	23,71	24,56	25,40	26,73	29,52	30,67	31,81
3,25	24,81	25,51	26,20	27,55	30,55	31,94	33,05
3,50	25,48	26,33	27,17	28,56	31,48	33,09	34,49
3,75	26,52	27,17	27,82	29,64	32,59	34,42	36,14
4,00	27,16	28,01	28,85	30,78	33,89	35,94	37,96
4,25	28,21	29,09	29,97	32,06	35,34	37,61	39,94
4,50	29,18	30,13	31,07	33,27	36,94	39,43	42,05
4,75	30,29	30,99	32,25	34,91	38,67	41,39	44,27
5,00	31,24	32,10	33,61	36,66	40,52	43,45	46,60
5,25	32,24	33,38	35,06	38,50	42,47	45,62	49,00
5,50	33,30	34,64	36,58	40,43	44,52	47,88	51,47
5,75	34,42	35,97	38,17	42,43	46,65	50,21	53,98
6,00	35,61	37,38	39,83	44,50	48,84	52,60	56,53
6,25	36,87	38,87	41,56	46,62	51,09	55,03	59,09
6,50	38,19	40,42	43,35	48,79	53,38	57,50	61,65
6,75	39,59	42,05	45,20	50,98	55,70	59,98	64,21
7,00	41,05	43,75	47,09	53,20	58,05	62,47	66,74
7,25	42,58	45,51	49,03	55,43	60,40	64,96	69,24
7,50	44,18	47,33	51,01	57,67	62,75	67,42	71,69
7,75	45,83	49,20	53,01	59,90	65,08	69,86	74,09
8,00	47,55	51,12	55,04	62,12	67,40	72,26	76,42
8,25	49,31	53,07	57,09	64,33	69,68	74,61	78,67
8,50	51,11	55,06	59,14	66,50	71,93	76,90	80,85
8,75	52,96	57,07	61,20	68,64	74,13	79,13	82,93
9,00	54,84	59,09	63,25	70,73	76,27	81,27	84,92
9,25	56,74	61,12	65,29	72,78	78,34	83,34	86,81
9,50	58,66	63,16	67,31	74,78	80,35	85,30	88,59
9,75	60,59	65,18	69,30	76,71	82,28	87,18	90,26
10,00	62,52	67,18	71,26	78,59	84,13	88,94	91,82
10,25	64,45	69,16	73,18	80,39	85,89	90,60	93,25
10,50	66,37	71,10	75,05	82,12	87,56	92,14	94,57
10,75	68,26	73,01	76,87	83,77	89,13	93,56	95,77
11,00	70,13	74,86	78,63	85,34	90,60	94,87	96,85
11,25	71,96	76,65	80,33	86,83	91,97	96,05	97,80
11,50	73,75	78,38	81,96	88,24	93,23	97,10	98,64
11,75	75,49	80,05	83,51	89,55	94,39	98,04	99,36
12,00	77,17	81,63	84,99	90,78	95,44	98,84	99,96
12,25	78,80	83,14	86,39	91,92	96,38	99,53	100
12,50	80,36	84,56	87,70	92,97	97,22	100	100
12,75	81,84	85,89	88,93	93,94	97,95	100	100
13,00	83,26	87,14	90,07	94,81	98,58	100	100
13,25	84,59	88,29	91,12	95,60	99,11	100	100
13,50	85,85	89,35	92,09	96,30	99,55	100	100
13,75	87,02	90,32	92,97	96,92	99,89	100	100
14,00	88,12	91,21	93,76	97,46	100	100	100
14,25	89,13	92,00	94,48	97,93	100	100	100
14,50	90,07	92,72	95,11	98,32	100	100	100
14,75	90,94	93,36	95,68	98,65	100	100	100
15,00	91,74	93,94	96,18	98,92	100	100	100
15,25	92,47	94,46	96,62	99,14	100	100	100
15,50	93,15	94,94	97,00	99,30	100	100	100
15,75	93,78	95,38	97,35	99,43	100	100	100
16,00	94,38	95,80	97,67	99,52	100	100	100
16,25	94,96	96,22	97,97	99,59	100	100	100
16,50	95,53	96,66	98,26	99,64	100	100	100
16,75	96,11	97,14	98,57	99,83	100	100	100
17,00	96,72	97,68	98,90	100	100	100	100
17,25	97,37	98,30	99,28	100	100	100	100
17,50	98,09	99,03	99,72	100	100	100	100
17,75	98,91	99,91	100	100	100	100	100
18,00	99,84	100	100	100	100	100	100

independent, or explicative, variable plotted on the x-axis.

For Demirjian's method we have a predictive interval for the maturity score for each age group because maturity score is determined as a function of age. This approach is appropriate for clinicians to detect if the dental maturity of a subject is "advanced" or "delayed"[32] in comparison with subjects of the same age. Indeed, the clinician knows the real age of the child and wants to know his/her degree of dental maturity, thus a predictive system giving the maturity score as a function of age should be used. However, for age determination, this method is not appropriated and less reliable because the real age is required to determine the maturity score, but is unknown. Of course, we could read Demijian's dental maturity percentile curves[11] horizontally, instead of vertically as designed by Demijian, but this approach is not statistically developed for such utilization.[17] Instead, polynomial functions were used to calculate the age as a function of the maturity score.

Polynomial Regressions and Efficiency of Each Method

In order to obtain an estimated age as a function of the maturity score, we calculated cubic functions[17] ($y=ax^3+bx^2+cx+d$, with y as estimated age and x as maturity score) with 95 and 99% CI (Table 5), considering Age as the dependent variable and Maturity score as the independent variable. Usually, the dependent variable is plotted on the y-axis for the graphic representation of the regression; here we decided to represent it on the x-axis, in order to compare the percentile method and the polynomial regression with Age on the same axis. However the regression was performed with Age as the dependant variable and Age has been rotated onto the x-axis only for the graphic representation. Third-degree regression showed the best fit to the plots with a coefficient of determination (R^2) of 0.94 and represents the best

***Table 4**: Dental maturity score per age in Belgian boys, Demirjian's method using Belgian weighted scores obtained according to Goldstein method*

Age	1%	5%	16%	50%	84%	95%	99%
2,00	23,55	24,50	25,50	26,48	27,47	28,54	29,40
2,25	23,69	24,64	25,63	26,61	27,61	28,62	29,52
2,50	23,75	24,70	25,65	26,85	27,85	29,04	29,94
2,75	23,91	24,86	25,82	27,07	28,07	29,43	30,63
3,00	24,17	25,12	26,24	27,58	28,58	29,88	31,58
3,25	24,54	25,49	26,55	28,03	29,37	30,83	32,75
3,50	24,99	25,94	26,85	28,62	30,49	32,12	34,13
3,75	25,53	26,48	27,35	29,34	31,73	33,42	35,70
4,00	26,16	27,11	28,04	30,27	32,96	34,90	37,43
4,25	26,87	27,82	28,89	31,38	34,38	36,56	39,30
4,50	27,66	28,41	29,90	32,65	35,95	38,36	41,30
4,75	28,52	29,37	31,04	34,07	37,66	40,29	43,40
5,00	29,45	30,27	32,30	35,62	39,48	42,32	45,60
5,25	30,44	31,51	33,68	37,29	41,41	44,45	47,87
5,50	31,50	32,84	35,15	39,05	43,42	46,66	50,20
5,75	32,62	34,25	36,70	40,90	45,51	48,93	52,57
6,00	33,80	35,71	38,33	42,82	47,65	51,24	54,97
6,25	35,03	37,23	40,01	44,80	49,83	53,58	57,39
6,50	36,31	38,80	41,75	46,82	52,04	55,94	59,81
6,75	37,63	40,40	43,54	48,87	54,27	58,31	62,22
7,00	39,00	42,03	45,36	50,95	56,51	60,67	64,61
7,25	40,41	43,69	47,21	53,05	58,74	63,02	66,98
7,50	41,86	45,36	49,07	55,15	60,96	65,34	69,30
7,75	43,34	47,04	50,95	57,25	63,16	67,62	71,57
8,00	44,85	48,73	52,84	59,34	65,33	69,86	73,79
8,25	46,39	50,43	54,73	61,41	67,46	72,05	75,94
8,50	47,96	52,12	56,62	63,46	69,55	74,18	78,02
8,75	49,55	53,81	58,49	65,48	71,59	76,25	80,03
9,00	51,16	55,50	60,36	67,47	73,58	78,25	81,95
9,25	52,79	57,18	62,21	69,41	75,50	80,17	83,79
9,50	54,43	58,84	64,04	71,32	77,37	82,01	85,53
9,75	56,08	60,50	65,84	73,17	79,16	83,76	87,18
10,00	57,75	62,14	67,62	74,98	80,89	85,43	88,73
10,25	59,42	63,77	69,37	76,73	82,54	87,01	90,18
10,50	61,10	65,39	71,09	78,43	84,12	88,50	91,53
10,75	62,77	66,99	72,78	80,07	85,62	89,89	92,77
11,00	64,45	68,58	74,44	81,66	87,05	91,19	93,91
11,25	66,12	70,15	76,06	83,18	88,39	92,39	94,96
11,50	67,78	71,70	77,64	84,64	89,66	93,50	95,89
11,75	69,44	73,24	79,18	86,03	90,85	94,52	96,73
12,00	71,08	74,76	80,68	87,37	91,96	95,44	97,37
12,25	72,71	76,26	82,14	88,63	93,00	96,27	98,12
12,50	74,32	77,75	83,56	89,84	93,96	97,02	98,67
12,75	75,91	79,22	84,93	90,98	94,84	97,67	99,13
13,00	77,48	80,67	86,26	92,05	95,65	98,25	99,51
13,25	79,02	82,09	87,54	93,06	96,39	98,74	99,81
13,50	80,54	83,50	88,77	94,01	97,06	99,15	100
13,75	82,02	84,88	89,96	94,89	97,66	99,50	100
14,00	83,47	86,23	91,10	95,71	98,19	99,77	100
14,25	84,89	87,56	92,18	96,46	98,66	99,99	100
14,50	86,26	88,85	93,21	97,15	99,07	100	100
14,75	87,59	90,10	94,18	97,78	99,42	100	100
15,00	88,88	91,32	95,09	98,34	99,72	100	100
15,25	90,12	92,49	95,95	98,83	99,96	100	100
15,50	91,30	93,61	96,74	99,26	100	100	100
15,75	92,44	94,68	97,46	99,63	100	100	100
16,00	93,51	95,68	98,11	99,93	100	100	100
16,25	94,52	96,61	98,69	100	100	100	100
16,50	95,47	97,46	99,18	100	100	100	100
16,75	96,35	98,23	99,60	100	100	100	100
17,00	97,16	98,90	99,92	100	100	100	100
17,25	97,89	99,46	100	100	100	100	100
17,50	98,55	99,90	100	100	100	100	100
17,75	99,12	100	100	100	100	100	100
18,00	99,61	100	100	100	100	100	100

compromise for the polynomial regression. The maturity score (Table 6 and 7, Fig.3 and 4) is obtained using Belgian weighted scores for girls and boys according to Demirjian's method.

We calculated the mean accuracy and the reliability for Demirjian's method using French-Canadian and Belgian scores and for the third-degree polynomial regression, in order to compare the efficiency and determine the advantages and field of application of each method. The accuracy represents the mean of each minimum and maximum residual (in years) for all 2523 subjects. The minimum residual, for one individual, is symbolized by the difference between the inferior limit at 95% CI of the predicted age and the real age, and the maximum residual 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 is not within the 99% confidence interval.

For all of these methods we also considered the real age in decimal years in order to obtain accuracy in months for establishing dental models. The results are expressed differently using predicted age in decimal age and predicted age in completed years. Completed years are commonly used in forensic sciences, allowing a better comparison of methods. 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 wider range considering completed years, this prediction becomes correct. Forensic scientists consider age only in completed years, and to give a decimal age will increase the percentage of incorrect

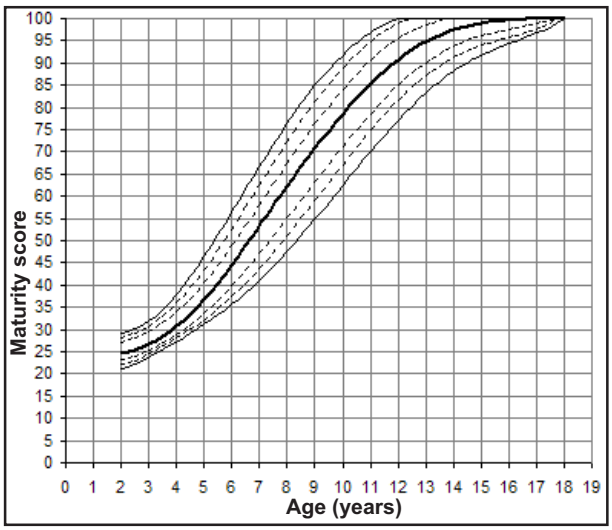

Fig.1: *Dental maturity percentiles for Belgian girls, Demirjian's method using Belgian weighted scores obtained according to Goldstein method, 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles*

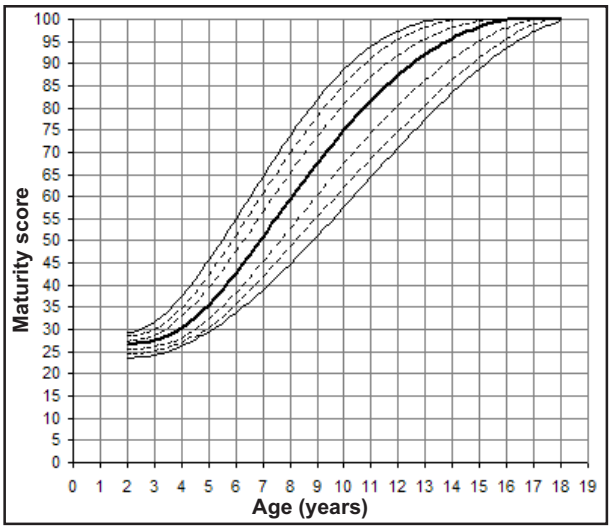

Fig.2: *Dental maturity percentiles for Belgian boys, Demirjian's method using Belgian weighted scores obtained according to Goldstein method, 1st, 5th, 16th, 50th, 84th, 95th and 99th percentiles*

classifications (Table 8). So, we chose to express the results also in completed years in order to increase the reliability. Also, we compared the efficiency of Demirjian's method using French-Canadian weighted scores applied to our Belgian sample and the Demirjian's method revised by Willems using Belgian weighted scores obtained by ANOVA[25].

To conserve a maximum number of individuals in the reference database, we used the method called n -1 technique, following a Jackknife Resampling Strategy.[38] One-by-one, each individual in the database was extracted, tested and replaced, allowing us to obtain an evaluation sample of 2523 children and to conserve a reference sample of 2522 children (n-1). We use the SPSS Software 11.0 for windows* for the n-1 method for polynomial regressions and a software developed with visual basic macro† for Demirjian's method.

RESULTS

Dental Maturity

Weighted Scores for the Belgian Sample

To obtain the dental maturation score, we calculated a biologically weighted score for girls and boys specific to the Belgian sample. These scores, given in Table 2, are standardized to 100. There is one score for each tooth and for each maturation stage rated on 9-stage scale from 0 and A to H according to Demirjian's revised method.[11,19] To determine the maturation score of an individual, we add the scores corresponding to the maturation stage for each tooth. This maturation score can then be compared with the appropriate development tables expressed in percentile. There are missing data for the first calcification stages because of the lack of information for individuals in the sample in early childhood.

Percentiles Using Belgian Scores for Girls and Boys

Maturity scores as a function of age with the Demirjian method using the Belgian weighted scores obtained according to the Goldstein method[19,36] are presented for girls and boys in Table 3 and Table 4 and dental maturity percentile graphs are shown in Fig.1 for girls and Fig.2 for boys. We note an advance of dental maturity for girls.

The Demirjian 7-teeth system gives a maturity score prediction for the 50th percentile only until the 16 year of age (Figs 1 and 2) because the third molar is not considered and the dental mineralization of the other 7 teeth is complete by16 years of age.

Polynomials Regressions for Girls and Boys

The cubic equations for girls and boys are given in Table 5. The maturity score is calculated with Demirjian's method using Belgian weighted scores.[11,19] We obtain an age prediction with 95, 97 and 99% CI (Table 6 and 7, Fig 3 and 4 for girls and boys). The cubic equations for girls and boys are given below in Table 5.

*SPSS Inc., Chicago, USA
†Microsoft® Excel 2002, PC

For the polynomial regressions the confidence interval is large for all the age groups compared with Demirjian's method where the size of the predictive interval can vary in different age groups. The reliability of the polynomial method is higher than the percentiles method but the accuracy is lower (Table 8). This method is more appropriate for the age prediction study in which reliability is important (forensic sciences and forensic odontology).

Efficiency

The efficiency of these methods is given in Table 8. Belgian children from 2 to 16 years of age (i.e. 2406 children) were analyzed, since the Demirjian 7-teeth method is not adapted for children older than 16 years. We observe the reliability and the accuracy of each method and we note that for age prediction, the polynomial method is more reliable but less accurate than the percentile method.

Moreover we determined the efficiency of these methods using completed years, because the decimal age, expressed in months, is unrealistic with biological indicators like dental maturity. The completed years scale allows us to obtain a higher reliability (Table 8) than decimal years for all the methods.

We calculated the efficiency of Demirjian's method using French-Canadian weighted scores[11,19] and the Demirjian's method revisited by Willems using Belgian weighted scores obtained by ANOVA analysis.[25] The method using ANOVA to obtain the weighted scores and Demirjian's method using Belgian weighted scores give a better reliability than Demirjian's method using French-Canadian weighted scores. Furthermore, if the French-Canadian weighted scores are used, we note an overestimation of age. Demirjian's method using Belgian weighted scores is more reliable and accurate than using ANOVA. These results demonstrate that the ANOVA analysis is less appropriate than the Goldstein's technique[11,19,37] for deriving the weighted scores in the studies of dental age estimation.

Sexual Dimorphism

Fig.5 represents the mean maturity score and standard deviation calculated with Belgian gender specific weighted score for each completed year. We observed an advance of dental maturation for girls from 5 to 15 years old, according with Demirjian's studies.[11,39] However there is a bias in these results because the weighted score, used in the calculation of maturity score, are gender-specific. Nyström[16] determined gender differences using the mean of these gender-specific weighted-scores to calculate a new maturity score equal to girls and boys. Thus, the gender is not taking into account and we can determine the true nature of the sexual dimorphism without bias. In this study, we calculated a new weighted score for all 2523 children and we determined the maturity score for girls and boys with this score.

Fig.6 shows the difference in dental age between girls and boys for each group, using gender-independent Belgian weighted scores and Demirjian's method. We note an advance of the dental maturity for girls for all age groups. The sexual dimorphism increases gradually until 10 years and from that age, which corresponds to the beginning of puberty in girls, accelerate until 12 years. The catch-up growth for boys begins at 12-13 years, beginning of their puberty, continues slowly until 14 years and accelerates strongly until 18 years.

DISCUSSION

The goal of this study was to present the development of dental maturity in Belgian children and to provide new dental maturity standards curves for clinicians. We compared different methods, Demirjian's percentile method using several weighted scores and polynomial functions, for a better comprehension of the specific advantages of each method.

The efficiency of these methods is higher when completed years are used, a close enough accuracy in forensic and anthropologic context. Thus, for age prediction, the results should be given in completed years in order to obtain a high reliability.

Table 5: *Cubic equations for girls and boys*

Girls: Age = 0.0000657 x (Maturity Score)^3 – 0.0117x(Maturity Score)^2 + 0.852 x Maturity Score – 11.0892 [± 2.06 yrs (95% CI), ± 2.36 yrs (97% CI), ± 2.61 yrs (99% CI), R^2 = 0.93]
Boys: Age = 0.0000517 x (Maturity Score)^3 – 0.0092x(Maturity Score)^2 + 0.6514 x Maturity Score – 8.8209 [± 1.89 yrs (95% CI), ± 2.15 yrs (97% CI), ± 2.35 yrs (99% CI), R^2 = 0.95]

Table 6: *Predicted age at 95, 97 and 99% CI per maturity score in Belgian girls, polynomial function*

Score	1%	3%	5%	50%	95%	97%	99%
20,0	0,00	0,00	0,00	0,44	2,51	2,84	3,17
22,5	0,00	0,00	0,00	1,38	3,45	3,78	4,10
25,0	0,00	0,08	0,15	2,22	4,29	4,62	4,95
27,5	0,26	0,59	0,91	2,98	5,05	5,38	5,70
30,0	0,95	1,27	1,60	3,66	5,73	6,06	6,38
32,5	1,56	1,88	2,21	4,27	6,34	6,66	6,99
35,0	2,10	2,42	2,75	4,82	6,88	7,21	7,53
37,5	2,58	2,91	3,23	5,30	7,36	7,69	8,01
40,0	3,01	3,33	3,66	5,72	7,79	8,11	8,44
42,5	3,39	3,71	4,04	6,10	8,16	8,49	8,81
45,0	3,73	4,05	4,38	6,44	8,50	8,82	9,15
47,5	4,03	4,35	4,68	6,74	8,80	9,12	9,45
50,0	4,30	4,62	4,95	7,01	9,07	9,39	9,72
52,5	4,55	4,87	5,19	7,26	9,32	9,64	9,97
55,0	4,78	5,10	5,42	7,49	9,54	9,87	10,20
57,5	5,00	5,32	5,64	7,70	9,76	10,09	10,41
60,0	5,21	5,53	5,86	7,92	9,98	10,30	10,63
62,5	5,42	5,75	6,07	8,13	10,19	10,52	10,84
65,0	5,64	5,97	6,29	8,35	10,41	10,74	11,06
67,5	5,88	6,20	6,53	8,59	10,65	10,97	11,30
70,0	6,13	6,46	6,78	8,84	10,90	11,23	11,55
72,5	6,41	6,74	7,06	9,12	11,18	11,51	11,83
75,0	6,73	7,05	7,37	9,44	11,49	11,82	12,14
77,5	7,08	7,40	7,72	9,79	11,84	12,17	12,50
80,0	7,47	7,79	8,12	10,18	12,24	12,56	12,89
82,5	7,91	8,24	8,56	10,62	12,68	13,01	13,33
85,0	8,42	8,74	9,06	11,13	13,18	13,51	13,84
87,5	8,98	9,30	9,63	11,69	13,75	14,07	14,40
90,0	9,61	9,94	10,26	12,32	14,38	14,71	15,03
92,5	10,32	10,64	10,97	13,03	15,09	15,41	15,74
95,0	11,11	11,43	11,75	13,82	15,88	16,20	16,53
96,0	11,45	11,77	12,09	14,16	16,22	16,54	16,87
97,0	11,80	12,13	12,45	14,51	16,57	16,90	17,22
98,0	12,17	12,49	12,82	14,88	16,94	17,27	17,59
98,5	12,36	12,69	13,01	15,07	17,13	17,46	17,78
99,0	12,56	12,88	13,20	15,27	17,32	17,65	17,98
99,5	12,75	13,08	13,40	15,46	17,52	17,85	18,18
100,0	12,96	13,28	13,60	15,67	17,72	18,05	18,38

Table 7*: Predicted age at 95, 97 and 99% CI per maturity score in Belgian boys, polynomial function.*

Score	1%	3%	5%	50%	95%	97%	99%
20,0	0,00	0,00	0,00	0,93	2,83	3,13	3,43
22,5	0,00	0,00	0,00	1,76	3,65	3,95	4,25
25,0	0,01	0,31	0,61	2,51	4,41	4,71	5,00
27,5	0,70	1,00	1,30	3,19	5,09	5,39	5,69
30,0	1,33	1,62	1,92	3,82	5,71	6,01	6,31
32,5	1,89	2,19	2,49	4,39	6,28	6,58	6,88
35,0	2,41	2,71	3,00	4,90	6,79	7,09	7,39
37,5	2,88	3,17	3,47	5,37	7,26	7,56	7,86
40,0	3,30	3,60	3,90	5,79	7,69	7,98	8,28
42,5	3,69	3,99	4,28	6,18	8,07	8,37	8,67
45,0	4,04	4,34	4,64	6,53	8,43	8,72	9,02
47,5	4,37	4,67	4,97	6,86	8,75	9,05	9,35
50,0	4,67	4,97	5,27	7,16	9,05	9,35	9,65
52,5	4,96	5,26	5,55	7,45	9,34	9,64	9,94
55,0	5,23	5,53	5,83	7,72	9,61	9,91	10,21
57,5	5,49	5,79	6,09	7,98	9,87	10,17	10,47
60,0	5,75	6,05	6,35	8,24	10,13	10,43	10,73
62,5	6,01	6,31	6,61	8,50	10,39	10,69	10,99
65,0	6,28	6,58	6,88	8,77	10,66	10,96	11,26
67,5	6,56	6,85	7,15	9,05	10,94	11,24	11,53
70,0	6,85	7,15	7,45	9,34	11,23	11,53	11,83
72,5	7,16	7,46	7,76	9,65	11,55	11,84	12,14
75,0	7,50	7,80	8,10	9,99	11,88	12,18	12,48
77,5	7,87	8,17	8,47	10,36	12,25	12,55	12,85
80,0	8,28	8,57	8,87	10,77	12,66	12,96	13,25
82,5	8,72	9,02	9,32	11,21	13,10	13,40	13,70
85,0	9,21	9,51	9,80	11,70	13,59	13,89	14,19
87,5	9,75	10,05	10,34	12,24	14,13	14,43	14,73
90,0	10,34	10,64	10,94	12,84	14,73	15,02	15,32
92,5	11,00	11,29	11,59	13,49	15,38	15,68	15,97
95,0	11,71	12,01	12,31	14,21	16,10	16,39	16,69
96,0	12,02	12,32	12,61	14,51	16,40	16,70	17,00
97,0	12,34	12,63	12,93	14,83	16,72	17,02	17,31
98,0	12,67	12,96	13,26	15,16	17,05	17,34	17,64
98,5	12,83	13,13	13,43	15,33	17,22	17,51	17,81
99,0	13,01	13,30	13,60	15,50	17,39	17,69	17,98
99,5	13,18	13,48	13,78	15,67	17,56	17,86	18,16
100,0	13,36	13,66	13,95	15,85	17,74	18,04	18,34

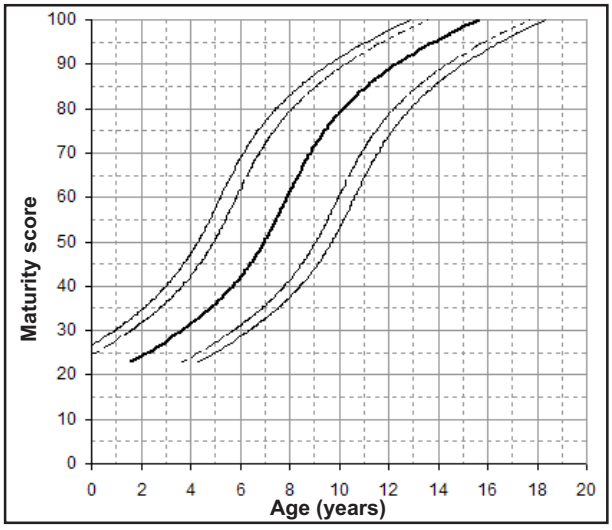

Fig.3: *Age as a function of maturity score in Belgian girls, Dental maturity, 95 and 99% CI*

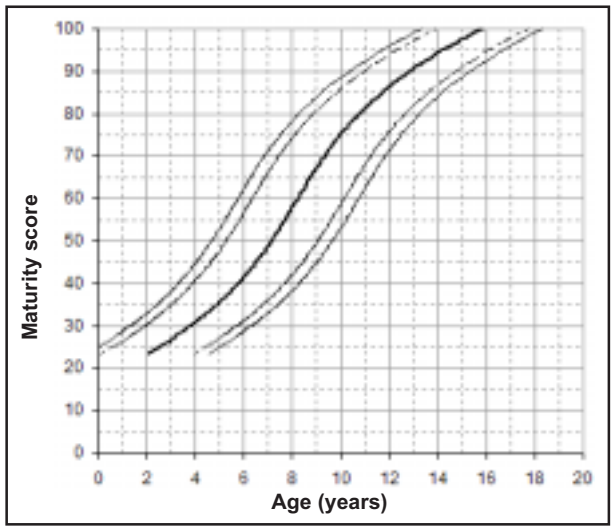

Fig.4: *Age as a function of maturity score in Belgian boys, Dental maturity, 95 and 99% CI*

The Demirjian method using French-Canadian weighted scores gives a high degree of accuracy but a poor reliability (7.07% age prediction error), showing the necessity to adapt the weighted score system to the studied population. Since accuracy and reliability are linked, the variation of each one changes the second; thus, the aim is to balance these two factors using the appropriated method and the most adapted biological indicators. With the Belgian weighted scores according to Goldstein[19,36], the reliability is multiplied by 9 (0.79% misclassified) but the mean accuracy (from 2 to 16 years) decreases by approximately 6 months. The high gain of reliability explains the diminution of the accuracy. In the determination of the maturity score, the ANOVA system for deriving the weighted scores is less reliable than Belgian weighted scores, leading one to think that Demirjian's method is a more robust approach if new standards are calculated for each population.

The polynomial regression shows a high reliability but is less accurate than Demirjian's method using Belgian weighted scores. The polynomial's accuracy decrease of approximately 2.6 months shows the best reliability (0.21% errors). The polynomial functions give the same confidence interval for all age groups explaining the low accuracy compared to percentile methods. In this study, we observed an inverse gradient of reliability and accuracy between the polynomial and percentile methods. Polynomial functions are more reliable than Demirjian's method using Belgian

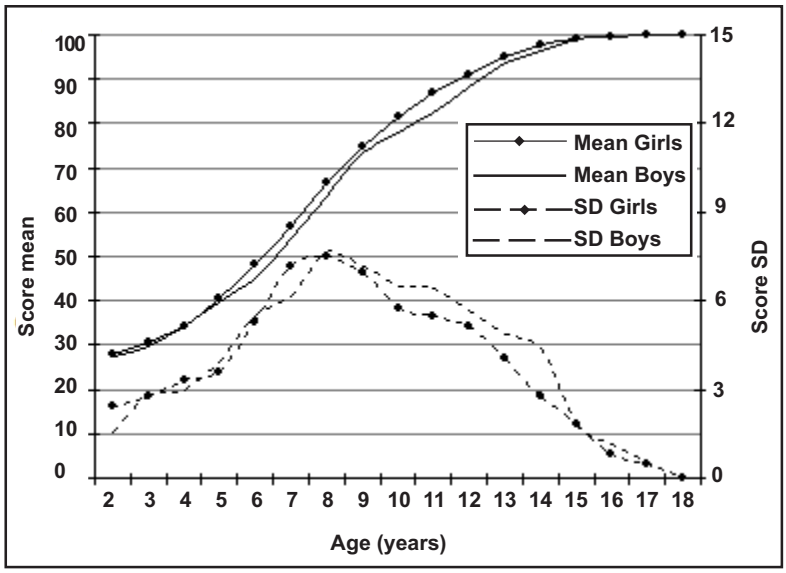

Fig.5: *Means and SD of maturity scores in girls and boys, using weighted scores for Belgian, Demirjian's method*

Fig.6: *Differences in dental age between girls and boys from the age of 2 to 18 years*

Table 8*: Comparison of the percentage of individual misclassified in age prediction and of the accuracy* between Demirjian's method using differently weighted scores and polynomial regressions*

Methods	Misclassified % (Decimal years)	Mean accuracy (Decimal years)	Misclassified % (End years)	Mean accuracy (End years)
Demirjian French-Canadian Scores 97% CI	15,13%	3,25	7,07%	3,22
Demirjian ANOVA Scores 99% CI (40)	2,78%	4,26	1,16%	4,32
Demirjian Belgian Scores 99% CI	2,54%	4,12	0,79%	4,16
Polynomial regression 97% CI	2,29%	4,57	1,12%	4,60
Polynomial regression 99% CI	1,12%	4,96	0,21%	4,98

* Mean accuracy represents the mean of the residues minimum and maximum in years (ex: 4.03 represent ± 2.15 years from 2 to 16 years) and Misclassified represents the number of individuals out of the confidence interval for the 2406 children from the age of 2 to 16 years. End years represent the same determination of the efficiency of these methods with the age in completed years

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weighted scores, but the difference is low (0.21% versus 0.79%). Nevertheless, the polynomial interpolations (age as a function of score) are advised for age prediction studies, in particular in forensic sciences, because the aim is reliability.

The percentile curves (score as a function of age) are most adapted for clinicians who want to detect advanced or delayed dental maturity for one individual compared with reference subjects of the same age. For this use we advise the use of Demirjian's method with scores adapted to the study population.

These methods have limitations. For example, if a tooth is missing on the left side, Demirjian proposed 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 teeth bilaterally missing teeth must still be aged. Moreover, dental maturity does not follow a linear progression[17] and the polynomial functions are recommended because the dental development is curvilinear with accelerations and stops. It has been shown that the cubic functions give the best correlations with dental maturity. To resolve the problem of missing data, Nyström[16] proposed a method based on a set of linear regressions for predicting the developmental stage of a missing tooth. Another solution could be a probabilistic method, like the Bayesian approach[40] that takes into account missing data.

In conclusion, for dental indicators, it is preferable to use Demirjian's method with population specific scores when the goal is the prediction of maturity score, and polynomial functions when the goal is age prediction.

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