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Comparison of Dental Maturity in Children of Different Ethnic Origins: International Maturity Curves for Clinicians

ABSTRACT: Dental maturity was studied with 9577 dental panoramic tomograms of healthy subjects from 8 countries, aged between 2 and 25 years of age. Demirjian's method based on 7 teeth was used for determining dental maturity scores, establishing gender-specific tables of maturity scores and development graphs. The aim of this study was to give dental maturity standards when the ethnic origin is unknown and to compare the efficiency and applicability of this method to forensic sciences and dental clinicians. The second aim was to compare the dental maturity of these different populations. We noted an high efficiency for International Demirjian's method at 99%CI (0.85% of misclassified and a mean accuracy between 2 to 18 years ± 2.15 years), which makes it useful for forensic purposes. Nevertheless, this international method is less accurate than Demirjian's method developed for a specific country, because of the inter-ethnic variability obtained by the addition of 8 countries in the dental database. There are inter-ethnic differences classified in three major groups. Australians have the fastest dental maturation and Koreans have the slowest.

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

Age estimation studies play a great role in forensic science and for dental clinicians. Several authors show that dental material is suitable for predicting the age of children (9,15,16, 27,28,33,34,44). The most frequently used method is Demirjian's method, based on dental panoramic radiographs and development curves for both genders. Age is expressed in percentiles for French-Canadian children. Demirjian's method (8,9) uses 8 calcification stages, which span from crown and root calcification to the closure of the apex, for the 7 left permanent mandibular teeth. Demirjian and Goldstein (8) have excluded the third molar because this tooth is frequently 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 using available tables and percentile curves based on a large French-Canadian sample.

Studies made for other populations have shown a great variability in the dental maturation process for different populations. Several authors (7,15,16,21,30,32,41,45) showed that the results are less accurate if another population is computed with Demirjian's standards. This shows the necessity to create representative databases for each population in order to reach a better comprehension of human dental maturation. A problem exists when ethnic origin of a particular child is not available or ethnicity is unreliable. The solution for age estimation is to create international dental development curves from different databases collected in several populations.

We collected a database of 9577 dental panoramic radiographs from 8 different countries, Australia (26), Belgium (45), England (21), Finland (33), France (3), French Canada (8,9), South Korea (43) and Sweden (43). Demirjian's method was then used to establish international dental development. For more reliability the 99th and the 99.99th percentiles to dental maturity curves were added.

The main aim of this study was to calculate an international weighted score in order to give new dental maturity curves for the children when the ethnic origin is unknown, using Demirjian's method. At the same time, the efficiency of this age prediction method, concerning the accuracy and the reliability of predictions was determined. The second aim was to compare the dental maturity of these different populations in order to give the best estimation for the human dental variability in the maturity processes.

Materials and Methods

Dental Data Base

The sample was collected in 8 countries by several authors working with Demirjian's method. The database consisted of 4742 girls' and 4835 boys' radiographs for a total of 9577 dental panoramic radiographs of healthy Australians (26), Belgians (45), English (21), Finns (33), French (3), French-Canadians (8,9), South Koreans (43) and Swedes (43) aged between 2 and 25 years of age. There were 614 radiographs from Australia, 2527 from Belgium, 521 from England, 2283 from Finland, 1049 from France, 1822 from French-Canada, 311 from South Korea and 450 from Sweden. Subjects with missing teeth were excluded. These panoramic radiographs were collected from Dental Clinics, University Institute of Dentistry, Dental Hospitals, Orthodontic Clinics and private orthodontic practices from these 8 countries. The distribution of dental panoramic radiographs by age and gender is given in Table 1.

Dental Maturation and Methods

Dental age estimation was performed according to a revised version of Demirjian's method (8,9). The 7 left mandibular teeth were

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TABLE 1—*Age and gender distribution of dental panoramic tomograms.*

Age (years)	Girls	Boys	Total
2	17	23	40
3	85	88	173
4	181	244	425
5	249	277	526
6	293	333	626
7	416	391	807
8	460	456	916
9	457	454	911
10	486	446	932
11	400	343	743
12	408	398	806
13	354	335	689
14	270	319	589
15	214	247	461
16	191	169	360
17	155	171	326
18	41	63	104
19	34	36	70
20–25	31	42	73
Total	4742	4835	9577

rated on an 8-stage scale from A to H. Intra-observer agreement was tested by the observers of each country and it did not show significant differences (3,8,9,21,26,33,43,45). To construct mathematical models, the 8-stages scale (A to H) was converted in a numerical scale (2 to 9). For increased accuracy, we added the stage 0 when the dental calcification has not yet begun and the stage 1, or crypt stage, represented the period when the bone crypt was visible without the dental germ inside it. Thus, each tooth was rated on 10-stage scale from 0 to 9. For each stage and for each tooth, we calculated a biologically weighted score for girls and boys. A method for deriving the score was described in Goldstein (14) and Tanner (42). Each score for the 7 teeth was added in order to obtain the dental maturity score, rescaled linearly to 100. This score was converted to dental age using appropriate tables of percentiles 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 (13). The percentiles curves were calculated for 0.01th, 1st, 5th, 16th, 50th, 84th, 95th, 99th and 99.99th percentiles.

To determine the efficiency of this multi ethnic database, we took into account the accuracy and the reliability of the prediction. The accuracy represents the mean of each minimum and maximum residue (in years) for all girls and boys. The minimum residue, for one individual, is represented by the difference between the inferior limit of the predicted age and the real age, and the maximum residue is represented by the difference between the upper limit 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 confidence interval.

The real age was considered in decimal years in order to obtain accuracy in months to establish dental profiles. The results were expressed separately using predicted age in decimal age and predicted age in completed years. Completed years (1-year age groups) 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, 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 consider a larger range using completed years, this prediction becomes correct. We note that the reliability, with completed years, is higher for almost the same accuracy compared to the method taking into account the decimal age. Only the result is expressed in completed years with all the calculations made considering decimal age.

To compare dental maturity, we calculated specific weighted score for each country. With these specific scores we determined the estimate age for the 50th percentile for each 1-year age group between 5 to 16 years of age separately for each country. This was needed because we did not have data for all the age groups represented for each country. However, we had to leave England out of the comparisons because the oldest children in the British sample were 9 years of age. The described procedure made it possible to compare timing of dental development between countries. A paired T-test was used to assess the differences in timing between each pair of countries. Thus, for each 1-year age group, between 5 to 16 years of age, we obtained an estimated age for each country using Demirjian's method for the 50th percentile in order to compare the differences of predictions between each country. In order to compare the whole of the biological variation of each country, the estimated ages of each country for each age group were calculated with the same multi-ethnic weighed scores. This method is used by Nyström (33) to compare gender differences and has been adapted to inter-ethnic comparison in this study. Thus, the mean estimated age represent the age variation for all the children of one country for each age group.

The same method is used to give gender dimorphism of the multi-ethnic sample. A unique gender independent multi-ethnic weighted score, considering both genders together, was performed to know the dental development for girls and boys. Girls' age estimate minus Boys' age estimate for each age group gave a gender dimorphism curve.

To conserve a maximum of children in the reference database we used the method called n-1 technique, following a Jackknife Re-sampling Strategy (11). One-by-one, each individual in the database was extracted, tested and replaced, allowing to obtain an evaluation sample of n children and to conserve a reference sample of n-1 children. SPSS Software 11.0 for Windows (SPSS Inc., Chicago, Illinois) was used along with software developed with visual basic macro (Microsoft® Excel 2002, PC) for the calculation and application of the n-1 strategy.

Results

Dental Maturity

In order to obtain the dental maturity score, a gender-weighted score was calculated for each stage of the 7 teeth specific of multi-ethnic sample. These scores (Table 2) have been linearly rescaled to 100 to allow the calculation of the final dental maturity score in accordance with Demirjian and Goldstein's method (8,9,13,14). The dental maturity score is obtained by the sum of all weighted scores corresponding to each development stages of the 7 teeth. This maturation score can then be compared with the appropriate developmental tables expressed in percentiles.

Dental maturity score as a function of age with Demirjian's method using multi-ethnic weighted scores was presented for girls and boys in Table 3 and 4 and developmental curves are expressed in percentiles in Figs. 1 and 2. The predicted ages as a function of maturity score are presented in Table 5 and 6. In this case, when the score 100 is reached, all the teeth are calcified and the predicted ages at 95, 99 and 99.99% of confidence interval must be read like minimum ages, from the indicated value until the end of life, because this last result depends of the age distribution of the studied sample. This approach is appropriate for clinicians to detect if the

TABLE 2—*Specific weighted scores standardized to 100, for 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				2.57	3.81		3.42
Crypt/1					4.10		3.52
A/2				2.82	4.18		4.41
B/3			2.16	3.56	4.88		4.74
C/4	2.70	3.46	4.22	4.83	6.03	3.04	6.13
D/5	4.12	4.50	5.47	6.40	7.44	3.73	7.78
E/6	5.26	5.84	7.22	8.07	8.65	4.97	9.51
F/7	6.46	7.20	8.94	9.93	10.68	6.17	11.06
G/8	7.79	8.43	11.05	11.67	12.60	8.34	13.20
H/9	12.35	12.87	14.61	14.96	15.61	13.15	16.44
Boys	31	32	33	34	35	36	37
No sign/0				2.13	3.62		3.34
Crypt/1					3.73		3.87
A/2				2.97	4.25		4.24
B/3		2.90	2.44	3.70	4.78		4.71
C/4	3.49	3.77	4.47	4.92	5.92	2.85	6.04
D/5	4.14	4.60	5.74	6.53	7.33	3.70	7.78
E/6	5.30	5.93	7.62	8.20	8.84	4.94	9.54
F/7	6.52	7.38	9.61	10.12	10.77	6.29	11.14
G/8	7.84	8.64	11.83	11.91	12.73	8.45	13.29
H/9	12.28	12.87	15.06	14.94	15.51	13.15	16.18

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

†No sign, crypt stage and Demirjian's scale (9)/new numerical stage (0 to 9).

dental maturity of a subject is "advanced" or "delayed" in comparison with subjects of the same age. Moreover, in forensic sciences the reliability is an important criterion and must be improved. Thus, in order to obtain an increase in reliability, we have added the 99th and 99.99th percentile. These international developmental curves suit for predictions when no maturity tables or charts are available for the ethnic group concerned.

The efficiency of this method depends on the percentiles considered. The results taking into account the accuracy and the reliability are given in Table 7. Moreover we gave the specific efficiency of the two largest samples of the database: Belgium and Finland. These specific efficiencies were calculated with Demirjian's method using Belgian (5) and Finnish (4) weighted scores. In the multi-ethnic database, the higher the considered percentile level the stronger is the reliability. On the contrary, the accuracy decreases when the reliability increases. Mean accuracy is lower for the multi-ethnic population using multi-ethnic weighed scores with the 99th percentile than for Finns using Finnish weighed scores and for Belgians using Belgian weighed scores (Table 7). These results show us the increase of the dental variability when several populations are considered. However, with the 99th percentile level the reliability with multi-ethnic scores is higher than in Finns with Finnish weighed scores and about the same as in Belgians with their weighed scores (Table 7). Thus the reliability with multi-ethnic scores is higher, or almost the same, than the specific scores of one country. This high reliability is explained by the great number of individuals considered in multi-ethnic database and proves the efficiency of the Demirjian's method. Moreover, the efficiency is always the best when the completed years are used. Completed years were taken into account only for the result and not for the calculation of predictions. Furthermore, the predictive interval is tighter for the young children and increases at the beginning of the puberty. Thus, the predictions are very accurate before 12 years of age (Table 5 and 6).

Gender Dimorphism

Figure 3 represents the mean maturity score and the standard deviation (SD) calculated with gender independent multi-ethnic weighted score. Dental maturation of girls from 5 to 16 years old

FIG. 1—*Dental maturity percentiles for girls using multi-ethnic weighted scores, Demirjian's method with 0.01th, 1st, 5th, 16th, 50th, 84th, 95th, 99th and 99.99th percentiles.*

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

Age	0.01%	1%	5%	16%	50%	84%	95%	99%	99.99%
2.50	23.60	23.94	24.48	24.68	26.65	28.62	29.40	30.13	30.14
2.75	23.89	24.30	24.91	25.07	27.08	29.03	30.03	31.05	31.13
3.00	24.24	24.72	25.44	25.62	27.69	29.69	30.94	32.24	32.43
3.25	24.66	25.20	26.06	26.31	28.48	30.60	32.11	33.67	34.00
3.50	25.14	25.76	26.76	27.14	29.42	31.73	33.50	35.31	35.81
3.75	25.70	26.39	27.56	28.11	30.51	33.06	35.09	37.13	37.81
4.00	26.34	27.10	28.44	29.18	31.74	34.57	36.86	39.12	39.99
4.25	27.04	27.88	29.41	30.37	33.10	36.23	38.77	41.24	42.32
4.50	27.82	28.74	30.46	31.67	34.57	38.03	40.82	43.48	44.76
4.75	28.67	29.68	31.60	33.05	36.15	39.95	42.98	45.82	47.29
5.00	29.59	30.69	32.81	34.52	37.83	41.98	45.22	48.22	49.89
5.25	30.58	31.78	34.10	36.07	39.59	44.09	47.54	50.68	52.53
5.50	31.64	32.94	35.47	37.69	41.44	46.27	49.91	53.18	55.21
5.75	32.76	34.18	36.90	39.37	43.35	48.51	52.32	55.71	57.89
6.00	33.95	35.48	38.40	41.11	45.32	50.79	54.75	58.24	60.56
6.25	35.21	36.85	39.95	42.89	47.34	53.10	57.19	60.76	63.21
6.50	36.52	38.29	41.57	44.71	49.41	55.43	59.63	63.27	65.82
6.75	37.89	39.79	43.24	46.57	51.50	57.76	62.05	65.74	68.38
7.00	39.31	41.34	44.95	48.46	53.63	60.09	64.45	68.17	70.87
7.25	40.78	42.95	46.70	50.37	55.76	62.40	66.80	70.55	73.30
7.50	42.30	44.60	48.50	52.29	57.91	64.69	69.11	72.87	75.64
7.75	43.86	46.30	50.32	54.22	60.06	66.94	71.37	75.12	77.89
8.00	45.46	48.04	52.17	56.16	62.20	69.16	73.56	77.29	80.04
8.25	47.10	49.81	54.04	58.10	64.33	71.32	75.69	79.39	82.10
8.50	48.76	51.61	55.93	60.03	66.43	73.43	77.74	81.39	84.05
8.75	50.45	53.44	57.83	61.95	68.51	75.47	79.71	83.30	85.88
9.00	52.17	55.28	59.73	63.85	70.56	77.45	81.59	85.12	87.61
9.25	53.90	57.14	61.62	65.73	72.57	79.36	83.39	86.84	89.22
9.50	55.64	59.01	63.52	67.59	74.53	81.19	85.09	88.46	90.71
9.75	57.39	60.88	65.40	69.41	76.44	82.94	86.71	89.97	92.09
10.00	59.14	62.74	67.26	71.21	78.30	84.61	88.22	91.38	93.36
10.25	60.89	64.60	69.10	72.97	80.10	86.19	89.65	92.69	94.52
10.50	62.64	66.44	70.91	74.68	81.83	87.69	90.97	93.89	95.56
10.75	64.38	68.26	72.69	76.36	83.50	89.10	92.20	94.99	96.49
11.00	66.10	70.06	74.43	77.99	85.09	90.41	93.33	95.99	97.32
11.25	67.81	71.83	76.13	79.57	86.61	91.64	94.37	96.89	98.05
11.50	69.49	73.57	77.78	81.10	88.05	92.78	95.32	97.69	98.69
11.75	71.15	75.26	79.38	82.57	89.41	93.83	96.17	98.40	99.23
12.00	72.77	76.91	80.93	83.99	90.69	94.79	96.94	99.02	99.68
12.25	74.36	78.51	82.42	85.35	91.89	95.66	97.62	99.54	100
12.50	75.92	80.07	83.85	86.66	93.00	96.45	98.21	99.99	100
12.75	77.43	81.56	85.21	87.90	94.03	97.15	98.73	100	100
13.00	78.90	83.00	86.51	89.08	94.97	97.77	99.17	100	100
13.25	80.32	84.37	87.74	90.20	95.82	98.31	99.54	100	100
13.50	81.70	85.68	88.89	91.26	96.59	98.78	99.85	100	100
13.75	83.02	86.92	89.98	92.25	97.28	99.18	100	100	100
14.00	84.29	88.09	90.99	93.18	97.88	99.50	100	100	100
14.25	85.50	89.19	91.92	94.04	98.40	99.77	100	100	100
14.50	86.66	90.22	92.79	94.84	98.84	99.97	100	100	100
14.75	87.75	91.17	93.58	95.58	99.21	100	100	100	100
15.00	88.79	92.06	94.30	96.26	99.51	100	100	100	100
15.25	89.78	92.87	94.95	96.88	99.74	100	100	100	100
15.50	90.70	93.61	95.53	97.43	99.91	100	100	100	100
15.75	91.56	94.29	96.04	97.93	100	100	100	100	100
16.00	92.37	94.90	96.49	98.37	100	100	100	100	100
16.25	93.13	95.44	96.89	98.75	100	100	100	100	100
16.50	93.83	95.93	97.23	99.09	100	100	100	100	100
16.75	94.48	96.37	97.53	99.37	100	100	100	100	100
17.00	95.08	96.75	97.78	99.60	100	100	100	100	100
17.25	95.65	97.09	98.00	99.79	100	100	100	100	100
17.50	96.17	97.40	98.19	99.94	100	100	100	100	100
17.75	96.65	97.67	98.36	100	100	100	100	100	100
18.00	97.11	97.93	98.53	100	100	100	100	100	100
18.25	97.55	98.18	98.69	100	100	100	100	100	100
18.50	97.96	98.42	98.87	100	100	100	100	100	100
18.75	98.37	98.68	99.08	100	100	100	100	100	100
19.00	98.78	98.96	99.31	100	100	100	100	100	100
19.25	99.20	99.28	99.60	100	100	100	100	100	100
19.50	99.43	99.65	99.96	100	100	100	100	100	100
19.75	99.87	100	100	100	100	100	100	100	100
20.00	100	100	100	100	100	100	100	100	100

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

Age	0.01%	1%	5%	16%	50%	84%	95%	99%	99.99%
2.50	24.51	24.91	24.93	25.68	27.40	28.41	29.48	30.51	31.19
2.75	24.68	25.00	25.01	25.85	27.65	28.86	30.01	31.27	32.36
3.00	24.73	25.18	25.24	26.17	28.08	29.51	30.76	32.28	33.76
3.25	24.87	25.45	25.59	26.64	28.67	30.35	31.71	33.51	35.37
3.50	25.11	25.82	26.08	27.24	29.42	31.36	32.86	34.95	37.16
3.75	25.42	26.28	26.67	27.98	30.32	32.54	34.17	36.57	39.10
4.00	25.83	26.82	27.38	28.83	31.35	33.86	35.64	38.35	41.17
4.25	26.31	27.44	28.18	29.80	32.51	35.31	37.25	40.26	43.35
4.50	26.87	28.15	29.09	30.87	33.79	36.88	38.98	42.29	45.63
4.75	27.51	28.93	30.08	32.04	35.17	38.56	40.81	44.42	47.98
5.00	28.23	29.79	31.15	33.29	36.65	40.33	42.75	46.63	50.37
5.25	29.02	30.71	32.29	34.63	38.22	42.19	44.76	48.91	52.81
5.50	29.88	31.71	33.51	36.04	39.86	44.12	46.84	51.23	55.27
5.75	30.81	32.76	34.79	37.52	41.58	46.10	48.97	53.58	57.73
6.00	31.80	33.88	36.13	39.06	43.36	48.14	51.15	55.96	60.19
6.25	32.86	35.06	37.53	40.65	45.19	50.22	53.35	58.34	62.63
6.50	33.97	36.29	38.97	42.29	47.07	52.32	55.58	60.71	65.04
6.75	35.14	37.58	40.46	43.98	48.98	54.45	57.82	63.07	67.41
7.00	36.37	38.91	41.99	45.70	50.93	56.59	60.06	65.40	69.73
7.25	37.65	40.29	43.55	47.46	52.90	58.73	62.29	67.69	71.99
7.50	38.97	41.71	45.15	49.24	54.88	60.87	64.50	69.94	74.18
7.75	40.34	43.17	46.77	51.04	56.88	62.99	66.69	72.13	76.31
8.00	41.76	44.66	48.41	52.85	58.88	65.10	68.85	74.27	78.35
8.25	43.21	46.19	50.08	54.68	60.87	67.18	70.96	76.34	80.31
8.50	44.70	47.75	51.76	56.52	62.86	69.23	73.03	78.33	82.19
8.75	46.22	49.33	53.45	58.35	64.83	71.24	75.05	80.25	83.97
9.00	47.77	50.93	55.16	60.19	66.78	73.20	77.01	82.08	85.66
9.25	49.34	52.56	56.87	62.01	68.70	75.12	78.90	83.84	87.25
9.50	50.94	54.20	58.58	63.83	70.60	76.98	80.73	85.50	88.75
9.75	52.57	55.86	60.30	65.64	72.46	78.79	82.49	87.07	90.15
10.00	54.20	57.52	62.01	67.42	74.28	80.53	84.17	88.55	91.45
10.25	55.85	59.19	63.72	69.19	76.06	82.21	85.77	89.94	92.65
10.50	57.52	60.87	65.42	70.93	77.79	83.82	87.29	91.23	93.76
10.75	59.18	62.54	67.11	72.64	79.47	85.36	88.73	92.43	94.77
11.00	60.86	64.22	68.78	74.32	81.10	86.83	90.08	93.54	95.68
11.25	62.53	65.88	70.44	75.97	82.67	88.22	91.35	94.55	96.51
11.50	64.20	67.54	72.09	77.59	84.18	89.53	92.53	95.47	97.24
11.75	65.87	69.19	73.71	79.16	85.63	90.77	93.62	96.30	97.89
12.00	67.53	70.82	75.31	80.69	87.01	91.92	94.62	97.05	98.46
12.25	69.18	72.44	76.89	82.18	88.33	93.00	95.54	97.71	98.95
12.50	70.81	74.03	78.44	83.63	89.58	93.99	96.37	98.29	99.37
12.75	72.43	75.61	79.95	85.03	90.76	94.91	97.12	98.79	99.71
13.00	74.02	77.15	81.44	86.37	91.88	95.75	97.78	99.21	99.99
13.25	75.59	78.67	82.89	87.67	92.92	96.50	98.36	99.57	100
13.50	77.14	80.15	84.31	88.91	93.89	97.19	98.87	99.86	100
13.75	78.66	81.61	85.68	90.09	94.78	97.79	99.29	100	100
14.00	80.14	83.02	87.02	91.22	95.61	98.33	99.65	100	100
14.25	81.59	84.39	88.31	92.30	96.37	98.79	99.94	100	100
14.50	83.01	85.73	89.55	93.31	97.05	99.19	100	100	100
14.75	84.38	87.01	90.74	94.26	97.67	99.52	100	100	100
15.00	85.71	88.25	91.88	95.15	98.21	99.79	100	100	100
15.25	87.00	89.44	92.97	95.97	98.70	100	100	100	100
15.50	88.24	90.58	93.99	96.73	99.11	100	100	100	100
15.75	89.43	91.66	94.96	97.43	99.47	100	100	100	100
16.00	90.57	92.69	95.86	98.05	99.76	100	100	100	100
16.25	91.66	93.66	96.69	98.62	100	100	100	100	100
16.50	92.69	94.57	97.46	99.11	100	100	100	100	100
16.75	93.67	95.41	98.14	99.53	100	100	100	100	100
17.00	94.58	96.19	98.75	99.89	100	100	100	100	100
17.25	95.44	96.91	99.28	100	100	100	100	100	100
17.50	96.23	97.55	99.72	100	100	100	100	100	100
17.75	96.96	98.13	100	100	100	100	100	100	100
18.00	97.62	98.63	100	100	100	100	100	100	100
18.25	98.22	99.06	100	100	100	100	100	100	100
18.50	98.75	99.41	100	100	100	100	100	100	100
18.75	99.22	99.69	100	100	100	100	100	100	100
19.00	99.61	99.89	100	100	100	100	100	100	100
19.25	99.94	100	100	100	100	100	100	100	100
19.50	100	100	100	100	100	100	100	100	100
19.75	100	100	100	100	100	100	100	100	100
20.00	100	100	100	100	100	100	100	100	100

FIG. 2—*Dental maturity percentiles for boys using multi-ethnic weighted scores, Demirjian's method with 0.01th, 1st, 5th, 16th, 50th, 84th, 95th, 99th and 99.99th percentiles.*

TABLE 5—*Predicted age at 50th, 95th, 99th and 99.99th percentile per maturity score in girls, Demirjian's method.*

Score	0.01%	1%	5%	50%	95%	99%	99.99%
27.50	2.00	2.00	2.00	2.94	3.75	4.15	4.43
30.00	2.09	2.40	2.78	3.65	4.41	4.84	5.12
32.50	2.95	3.08	3.35	4.16	4.95	5.41	5.70
35.00	3.37	3.49	3.75	4.58	5.42	5.91	6.21
37.50	3.71	3.83	4.10	4.96	5.85	6.36	6.68
40.00	4.00	4.13	4.41	5.31	6.26	6.78	7.12
42.50	4.27	4.41	4.70	5.64	6.64	7.18	7.53
45.00	4.53	4.68	4.98	5.96	7.00	7.56	7.93
47.50	4.77	4.94	5.25	6.27	7.36	7.92	8.31
50.00	5.01	5.19	5.51	6.57	7.70	8.27	8.68
52.50	5.25	5.43	5.77	6.86	8.04	8.62	9.05
55.00	5.48	5.68	6.02	7.15	8.37	8.96	9.41
57.50	5.71	5.92	6.27	7.44	8.70	9.30	9.77
60.00	5.94	6.16	6.53	7.74	9.03	9.63	10.12
62.50	6.18	6.41	6.79	8.03	9.36	9.97	10.48
65.00	6.41	6.65	7.05	8.32	9.69	10.30	10.84
67.50	6.65	6.91	7.31	8.62	10.03	10.65	11.21
70.00	6.90	7.17	7.59	8.93	10.37	10.99	11.58
72.50	7.15	7.43	7.87	9.24	10.73	11.35	11.96
75.00	7.42	7.71	8.16	9.56	11.09	11.71	12.35
77.50	7.69	8.00	8.46	9.89	11.46	12.09	12.76
80.00	7.98	8.30	8.78	10.24	11.86	12.49	13.19
82.50	8.29	8.62	9.12	10.61	12.28	12.92	13.65
85.00	8.62	8.97	9.48	10.99	12.72	13.37	14.14
87.50	8.98	9.34	9.88	11.42	13.22	13.88	14.68
90.00	9.38	9.76	10.32	11.88	13.77	14.45	15.30
92.50	9.84	10.24	10.83	12.41	14.42	15.13	16.04
93.00	9.94	10.35	10.95	12.52	14.57	15.29	16.21
94.00	10.16	10.57	11.19	12.77	14.89	15.63	16.58
95.00	10.40	10.82	11.45	13.03	15.26	16.03	17.00
96.00	10.67	11.10	11.75	13.33	15.69	16.51	17.49
97.00	10.98	11.42	12.09	13.67	16.24	17.15	18.09
100.00	12.64	13.03	13.92	15.49	(19.64)	(19.83)	(20.27)

(Value): predicted age must be read like minimum age, from the indicated value until the end of life.

TABLE 6—*Predicted age at 50th, 95th, 99th and 99.99th percentile per maturity score in boys, Demirjian's method.*

Score	0.01%	1%	5%	50%	95%	99%	99.99%
27.50	2.00	2.00	2.00	2.68	3.95	4.29	4.75
30.00	2.00	2.09	2.76	3.65	4.68	5.06	5.52
32.50	2.75	3.07	3.45	4.24	5.27	5.69	6.15
35.00	3.20	3.53	3.91	4.71	5.78	6.24	6.71
37.50	3.56	3.90	4.30	5.13	6.25	6.73	7.21
40.00	3.88	4.23	4.65	5.52	6.68	7.20	7.68
42.50	4.17	4.54	4.98	5.88	7.10	7.64	8.13
45.00	4.45	4.82	5.28	6.23	7.49	8.06	8.55
47.50	4.71	5.10	5.58	6.56	7.88	8.46	8.96
50.00	4.97	5.37	5.87	6.89	8.26	8.86	9.36
52.50	5.23	5.63	6.15	7.21	8.63	9.24	9.75
55.00	5.48	5.90	6.43	7.52	8.99	9.62	10.13
57.50	5.73	6.16	6.71	7.83	9.35	10.00	10.51
60.00	5.98	6.42	6.98	8.15	9.71	10.37	10.88
62.50	6.23	6.68	7.26	8.46	10.08	10.74	11.25
65.00	6.49	6.95	7.54	8.78	10.44	11.12	11.63
67.50	6.75	7.22	7.83	9.10	10.80	11.49	12.00
70.00	7.02	7.49	8.12	9.42	11.17	11.87	12.38
72.50	7.29	7.78	8.42	9.76	11.55	12.26	12.76
75.00	7.58	8.07	8.73	10.10	11.93	12.65	13.16
77.50	7.88	8.38	9.06	10.45	12.33	13.06	13.56
80.00	8.19	8.71	9.39	10.82	12.74	13.47	13.97
82.50	8.53	9.05	9.75	11.21	13.16	13.91	14.40
85.00	8.89	9.42	10.13	11.63	13.61	14.36	14.86
87.50	9.28	9.82	10.54	12.08	14.08	14.85	15.34
90.00	9.72	10.27	11.00	12.57	14.59	15.37	15.86
92.50	10.23	10.79	11.52	13.14	15.15	15.95	16.44
93.00	10.34	10.90	11.64	13.26	15.27	16.08	16.57
94.00	10.58	11.15	11.88	13.52	15.53	16.34	16.83
95.00	10.84	11.41	12.15	13.81	15.80	16.63	17.11
96.00	11.14	11.71	12.44	14.13	16.09	16.94	17.42
97.00	11.48	12.06	12.78	14.50	16.42	17.29	17.77
100.00	13.39	13.90	14.49	16.59	(17.89)	(19.21)	(19.53)

(Value): predicted age must be read like minimum age, from the indicated value until the end of life.

TABLE 7—*Comparison of the percentage of individual misclassified in age prediction and of the accuracy* * *of the Demirjian's method using multi-ethnic weighted scores and Demirjian's method using Finnish and Belgian weighted scores.*

Methods	Misclassifies %	Mean Accuracy	Misclassifies % (End Years)	Mean Accuracy (End Years)
Demirjian multi-ethnic Scores 95% CI	11.03%	3.14	4.23%	3.13
Demirjian multi-ethnic Scores 99% CI	2.40%	4.36	0.85%	4.31
Demirjian multi-ethnic Scores 99.99% CI	0.55%	5.28	0.14%	5.29
(4) Demirjian Finnish Scores 99% CI	3.75%	3.86	1.07%	3.90
(5) Demirjian Belgian Scores 99% CI	2.54%	4.12	0.79%	4.16

* Mean accuracy represents the mean of the residues minimum and maximum in years (ex: 3.14 represent ± 1.57 years from 2 to 18 years) and Misclassifies represent the number of individuals out of the confidence interval for the 9434 children from the age of 2 to 18 years. End years represent the same determination of the efficiency of these methods with the age in completed years.

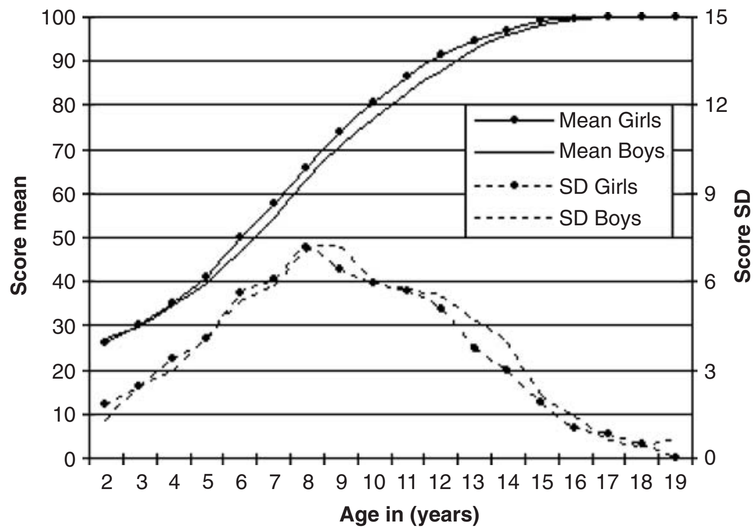

FIG. 3—*Means and SD of maturity scores in girls and boys, modified from Nyström (33), using multi-ethnic weighted scores, Demirjian's method.*

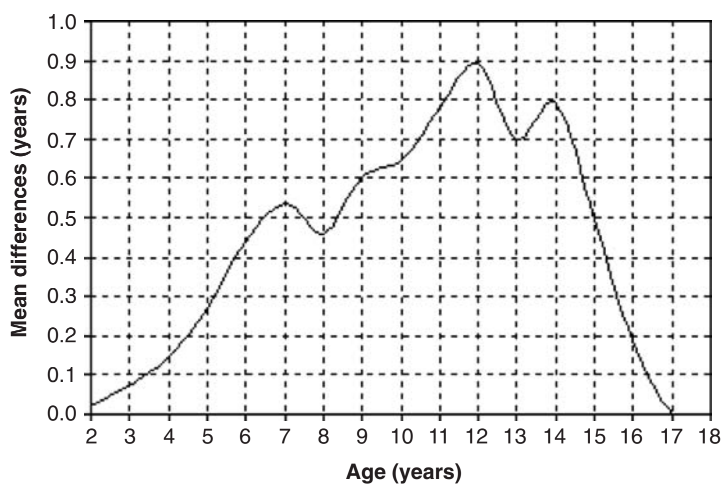

FIG. 4—*Differences in dental age between girls and boys from the age of 2 to 18 years. Girls' age estimate minus boys' age estimate, modified from Nyström (33), using gender independent multi-ethnic weighted scores, Demirjian's method.*

is more advanced than boys, according with Demirjian studies (10). 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 (33) proposed to calculate the mean of 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 gender from the original data, and we determined the maturity score for all of the 9577 radiographs (Fig. 4).

The results obtained with gender independent scores show that dental maturity is always advanced for the girls. Girls are advanced already at 2 years of age until 12 years of age. The catch-up growth in boys begins at 12–13 years, at the beginning of their puberty, and continues strongly until 18 years of age.

TABLE 8—*T-test paired for each pair of country, Mean represents the mean estimated age difference (years) for each age group of 5 to 16 years of age. Bilateral Significativity > 0.3 and t < 1.088.*

Pairs #	Mean	SD	t	dof	Significativity
FIN - BEL	0.07	0.21	1.094	11	0.297
FIN - FRA	−0.08	0.31	−0.909	11	*0.383**
FIN - CAN	0.20	0.34	2.043	11	0.066
FIN - SWE	0.10	0.27	1.296	11	0.221
FIN - KOR	0.21	0.45	1.648	11	0.128
FIN - AUS	−0.09	0.28	−1.077	11	*0.305**
BEL - FRA	−0.15	0.30	−1.708	11	0.116
BEL - CAN	0.14	0.26	1.806	11	0.098
BEL - SWE	0.04	0.25	0.487	11	*0.636**
BEL - KOR	0.15	0.36	1.425	11	0.182
BEL - AUS	−0.15	0.19	−2.736	11	0.019
FRA - CAN	0.28	0.26	3.796	11	0.003
FRA - SWE	0.18	0.21	3.050	11	0.011
FRA - KOR	0.30	0.25	4.157	11	0.002
FRA - AUS	−0.01	0.26	−0.067	11	*0.947***
CAN - SWE	−0.10	0.29	−1.224	11	0.246
CAN - KOR	0.01	0.27	0.139	11	*0.892***
CAN - AUS	−0.29	0.29	−3.493	11	0.005
SWE - KOR	0.11	0.29	1.330	11	0.210
SWE - AUS	−0.19	0.26	−2.502	11	0.029
KOR - AUS	−0.30	0.34	−3.056	11	0.011

Fin: Finland, Bel: Belgium, Fra: France, Can: French-Canadian, Swe: Sweden, Kor: Korea and Aus: Australia.
*Signification level > 0.300.
**Highly significant, tested samples are similar with Alpha risk = 0.01.

TABLE 9—*T-test paired for each pair of country, Mean represents the mean estimated age difference (years) for each age group of 5 to 11 years of age. Bilateral Significativity > 0.3 and t < 1.134.*

Pairs #	Mean	SD	t	dof	Significativity
FIN - BEL	0.17	0.06	7.518	6	0.000
FIN - FRA	−0.01	0.27	−0.140	6	*0.893***
FIN - CAN	0.31	0.36	2.292	6	0.062
FIN - SWE	0.17	0.15	3.003	6	0.024
FIN - KOR	0.31	0.31	2.632	6	0.039
FIN - AUS	0.08	0.15	1.045	6	*0.336**
BEL - FRA	−0.19	0.29	−1.732	6	0.134
BEL - CAN	0.14	0.34	1.408	6	0.209
BEL - SWE	−0.01	0.11	−0.176	6	*0.866***
BEL - KOR	0.13	0.31	1.141	6	0.297
BEL - AUS	−0.09	0.18	−1.358	6	0.223
FRA - CAN	0.32	0.22	3.877	6	0.008
FRA - SWE	0.18	0.24	1.986	6	0.094
FRA - KOR	0.32	0.22	3.883	6	0.008
FRA - AUS	0.09	0.22	1.132	6	*0.301**
CAN - SWE	−0.14	0.26	−1.452	6	0.197
CAN - KOR	0.00	0.17	−0.023	6	*0.983***
CAN - AUS	−0.23	0.33	−1.829	6	0.117
SWE - KOR	0.14	0.26	1.435	6	0.201
SWE - AUS	−0.09	0.20	−1.158	6	0.291
KOR - AUS	−0.23	0.26	−2.323	6	0.059

Fin: Finland, Bel: Belgium, Fra: France, Can: French-Canadian, Swe: Sweden, Kor: Korea and Aus: Australia.
*Signification level > 0.300.
**Highly significant, tested samples are similar with Alpha risk = 0.01.

TABLE 10—*T-test paired for each pair of country, Mean represents the mean estimated age difference (years) for each age group of 12 to 16 years of age. Bilateral Significativity > 0.3 and t < 1.190.*

Pairs #	Mean	SD	t	dof	Significativity
FIN - BEL	−0.09	0.25	−0.799	4	*0.469**
FIN - FRA	−0.18	0.38	−1.052	4	*0.352**
FIN - CAN	0.05	0.28	0.394	4	*0.713**
FIN - SWE	0.01	0.39	0.046	4	*0.965***
FIN - KOR	0.08	0.60	0.288	4	*0.787**
FIN - AUS	−0.32	0.26	−2.801	4	0.049
BEL - FRA	−0.09	0.34	−0.595	4	*0.584**
BEL - CAN	0.14	0.11	2.826	4	0.048
BEL - SWE	0.10	0.39	0.548	4	0.613*
BEL - KOR	0.17	0.45	0.820	4	0.458*
BEL - AUS	−0.23	0.19	−2.694	4	0.054
FRA - CAN	0.23	0.32	1.575	4	0.190
FRA - SWE	0.19	0.18	2.340	4	0.079
FRA - KOR	0.26	0.30	1.904	4	0.130
FRA - AUS	−0.14	0.26	−1.235	4	0.284
CAN - SWE	−0.04	0.34	−0.277	4	*0.795**
CAN - KOR	0.03	0.40	0.157	4	*0.883***
CAN - AUS	−0.37	0.21	−3.907	4	0.017
SWE - KOR	0.07	0.36	0.439	4	*0.683**
SWE - AUS	−0.33	0.29	−2.538	4	0.064
KOR - AUS	−0.40	0.44	−2.025	4	0.113

Fin: Finland, Bel: Belgium, Fra: France, Can: French-Canadian, Swe: Sweden, Kor: Korea and Aus: Australia.
*Signification level > 0.300.
**Highly significant, tested samples are similar with Alpha risk = 0.01.

Inter-ethnic Comparison

In order to compare the dental maturity of different countries, we calculated gender independent multi-ethnic weighted scores. With these scores we determined the mean predictive age for each one-year age group from 5 to 16 years of age and for each country using Demirjian's method (8,9). For example, for the 10 years old age group, the mean predictive age of Finland is 10.58 and 10.36 for Belgium. A paired T-test was performed for each pair of country (Tables 8, 9 and 10) in order to detect a significant difference in dental maturity between two countries to compare the differences between the mean predicted ages of all one-year age groups for each country.

In the Table 8, we note the same dental maturity for France/Australia and French-Canada/Korea with alpha risk = 0.01. Seven other pairs of countries present significant differences (bilateral significativity < 0.05): Belgium/Australia; France/Canada, Sweden, Korea; and Australia/Canada, Sweden, Korea. In many cases, Finland/Belgium for example, the difference is small and normally non significative (bilateral significativity of 0.297). To catch these small differences and to allow the separation between these countries for classification, a bilateral significativity level superior at 0.3 was used, in Table 8, in order to accept the similarity of two countries (20,38,39). Thus, in this case, the Finish dental maturity is faster than Belgians (mean age difference between Finland and Belgium = 0.07 years). The comparison in Table 8 also shows that Australians have the most advanced maturation closely followed by France and Finland (bilateral significativity > 0.3). We noted the existence of three groups between 5 to 16 years of age for girls and boys: Australia, France and Finland; Belgium and Sweden; French-Canada and Korea with a bilateral significativity level of 0.3; with a mean age difference between Australia and Korea of almost 4 months. If we consider a 0.05 significativity level, there are 4 groups with intra group liaisons: Australia, France and Finland as the first group; France, Finland and Belgium as the second group; Finland, Belgium and Sweden as the third group; and Sweden, French-Canada and Korea as the final group. The Australians are always the most advanced in dental maturation.

To get the best comprehension of international differences, dental maturity was compared separately in two age subgroups: 5 to 11 years (Table 9) and 12 to 16 years (Table 10). The former group represents the time before female puberty, and the later groups the adolescent period. Between 5 to 11 years of age, with a bilateral significativity level of 0.3, the French are most advanced in dental maturation, but in the same group as Australians. The classification is: France, Finland and Australia; Belgium and Sweden; French-Canada and Korea. Finland and France have the same dental maturity, and so have Belgium and Sweden, and also French-Canada and Korea (Highly significant, alpha risk = 0.01). The maximum mean age difference is almost 4 months between French and French-Canadians (Age difference = 0.329 years, 3.95 months, Table 9). With 0.05 significativity level, there are three groups: France, Finland and Australia, is the first; Australia, Belgium, Sweden and French-Canada, is the second; and last is Belgium, Sweden, French-Canada and Korea.

Between 12 to 16 years of age (Table 10), there are three groups for 0.05 significativity level: Australia, France and Belgium; France, Belgium, Finland and Sweden; Finland, Sweden, French-Canada and Korea. For 0.3 significativity level there are three groups: Australia as the first group; France, Belgium as the second group; and Finland, Sweden, French-Canada and Korea, as the third group. The maximum mean age difference is almost 5 months between Australia and Korea. In all the age groups studied, French-Canadians were inside the slowest dental maturation group, as could be expected on the basis of previous literature (4,7,19,21,45).

Discussion

The first aim of this present study was to present international dental maturity and to provide new dental developmental tables and curves when the ethnic origin is unknown. 99.99th percentile is used in order to capture the entire dental variability for forensic and clinical applications. Multi-ethnic dental standards allow a high reliability and accuracy. There are variations in function of the confidence interval; the choice of the best confidence interval will be determined by the aim of the age prediction, reliability for forensic sciences and accuracy for clinicians. The 99% level constitutes an appropriate compromise with reliability less than 1% and a mean accuracy of ± 2.15 years. The decimal ages must be used in the calculation, but the result can be expressed in completed years in order to increase the reliability for forensic sciences (Table 7). However, a limit exists with the Demirjian's method; only one tooth is able to predict age for the oldest children, the mandibular second molar. Thus, addition of third molar in calculation is advised, in order to improve accuracy of the age prediction until 18 years of age. Beyond 18 years of age, Demirjian's method becomes inappropriate to predict age with accuracy.

In many cases, the ethnic origin is unknown which makes it difficult to choose the appropriate ethnic standard. This study gives clinicians an alternative. Compared with other results in the literature (3,4,5,8,9,33,45) using Demirjian's method, the dental variability is higher in the present study consisting of several populations because of inter-ethnic variability effect. Since Demirjian's method considers multi-ethnic scores, the accuracy of the age prediction decreases because of an increase in variation; but the reliability of the age prediction is higher or equal than the methods considering specific population scores. This effect is particularly interesting for forensic applications, when the ethnic origin is unknown.

Dental maturity for girls is always advanced until 18 years of age, but there is catch up growth for boys at the age of 12–13. However, because of inter-population variability, girls' maturity acceleration and boys' catch up growth are less visible. Here the dimorphism is not really conforming to the adolescent period because inter-population variability is higher than the gender variability. The maximum dental maturity difference is 11 months between girls and boys at 12 years of age.

Teivens (43) used correlation between maturity scores and age to compare populations, but the high correlations masked the small inter-ethnics differences. Two countries can obtain a high correlation level between the age and the maturity score, but present different stages of maturity. The maturity scores are dependant of the age composition of each sample. But, if the first population is composed of older children, the maturity score will increase and there will be differences between these two same populations. This problem can be resolved by the standardization of the maturity score to 100. T-test using estimated age is a more suitable approach because inter-ethnic differences and timing can be directly compared. Two age groups, separated at 12 years of age witch corresponds to the beginning of the puberty (10,29,31,35,37), were defined in order to observe the effects of the puberty on the inter-ethnics variation. Multi-ethnic timing analysis of dental maturity (Tables 8, 9 and 10) showed three major groups: Australia (with the fastest dental maturity), France and Finland were the first; Belgium and Sweden were the second; and French-Canada and Korea were the third. There are small modifications for these groups according to the significativity level and age group considerations. But every time French-Canadians and Koreans have the lowest dental maturity. The maximum mean age difference was 5 months between 12 to 16 years of age, and 4 months between 5 to 16 and 5 to 11 years of age. During the adolescent period, we noted a maximum mean age difference larger than during the juvenile period (4 vs. 5 months). Thus, maximum inter-ethnic variability is smaller before the puberty optimum level. Passed this stage, the dental maturity acceleration at the puberty increases the maximum inter-ethnic variability (10) and produces changes in the inter-ethnics classification, because of the high level of intra-specific dental variability at this developmental period. However, inter-ethnic differences present a tendency to become non-significative passed 12 years of age between several counties, because the acceleration of the dental maturity is more variable between countries, and can generate differential catch-up-growth which reduces or enhances the differences between countries. For example, France and French-Canada present a significant difference between 5 to 11 years of age; this difference becomes non-significant passed 12 years of age with a small bilateral significativity of 0.19 (with alpha risk = 0.05, at 0.3 level the difference is always significant), but the difference between Finland and France was enhanced beyond 12 years of age.

All these ethnic groups live in cities with an occidental economic level type. Thus, it is difficult to take this factor into account when explaining dental maturity differences, and the systematic late maturity of French-Canadians. However, there are two major groups of factors that exercise an influence on the human growth: The genetic and ecologic factors. The French-Canadian population is a special case, because it is a melting pot between native Amerindians and European immigrants. Moreover, there is a strong Amerindians genetic contribution in Canada with Gordon's and Vautrin's colonization plan between 1932 and 1937 (2). This example shows the necessity to study the dental maturity of sub groups for each population, as soon as possible, in order to understand the origin of dental maturity differences.

Also, there is a relation between ecological factors and human dental growth timing. Ecological factors modify timing of development, and the specific biological adaptations, which contribute to preserve the developmental homeostasis (22), and generate ethnic growth variations. Indeed, physical factors such as temperature and humidity present an influence on growth by adaptive responses to the environment (1,40). These conditions influence animal growth (6,36), parasite growth (24) and induce changes in human metabolism and growth (12,17,18,23). Physical factors induce human biological adaptations and adjustments, and enhance the biological variation developing structural and physiological aptitudes in response to the environment (1,25). These adjustments or biological reactions play a role on the growth timing, generating late maturity if the ecological conditions are not optimum. A preliminary study on the relations between dental growth and ecological factors, such as nutrition, biological stress, gestation time, humidity, temperature and other physical and behavioural factors, is in preparation. The first partial results, based on climatic factors, show a positive gradient and high correlation between humid environment conditions and dental maturity timing.

In this study, the dental developmental tables are very reliable but less accurate than tables calculated for a specific country, and must be used when the ethnic origin is unknown. In order to obtain an optimal accuracy, the clinician must use appropriate specific tables (3,4,5,8,9,26). It is possible to use the same ethnic dental reference for Australia, France and Finland, or for Belgium and Sweden, in order to analyse dental maturity, but the efficiency will be lower than specific tables. However, for Korea there are no available specific maturity standards, but the results have showed a similarity between French-Canadians and Koreans maturity. Thus, clinicians can use the French-Canadians dental standards, developed by Demirjian (8,9), in order to analyze Korean maturity.

International dental maturity standards present a high interest in forensic science in order to help to obtain an positive body identification, when ethnic origin is unknown, by a reliable age estimation. This method is particularly useful in a context of natural catastrophe. In the future, addition of other countries, like Russia, USA, India, Africa and first nations like Amerindians and Australian aborigines will lead to a better representation of the human dental variability. The full dental database is now available for data exchange based on Demirjian's method, in order to upgrade the actual dental database with more countries and to approach the full human dental variability.

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