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Interpreting group differences using Demirjian's dental maturity method

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ABSTRACT

Although Demirjian's method is designed to assess dental maturity at the individual level, significant differences between average dental age and real age for groups have been interpreted as population differences. The aim of this study was to describe the variation in maturity score for age and age for maturity score from a large collaborative database of children and discuss methods adapted for groups in light of this. Tooth stages from radiographs of 4710 males and 4661 females (age 2–18) were used and dental maturity scores calculated using Demirjian and Goldstein [2]. The mean, standard deviation, standard error and 95% confidence intervals of maturity score by age group (6 and 12 months groups) and age by maturity score (5 points) groups were calculated. Adapted maturity curves from 13 published studies of boys from Europe, Middle East, Africa, India, China and South America were compared to the database. Most adapted curves at the 50th percentile from world regions fell within the 95% confidence intervals. Those that did not, were hampered by small sample size or poorly fitting curves. This is complicates by the inclusion of mature individuals. Few studies adapting Demirjian's method provide sufficient or appropriate statistics to compare maturation of individual teeth. The wide 95% confidence intervals for maturity score by age, age by maturity score, age of individual tooth stages and large number of sequences suggest that the significant differences in dental maturity score do not reflect any biological difference in the timing of tooth formation stages at the population level. Demirjian's dental maturity method is inappropriate to assess population differences in dental maturity and adapting scores for age or age for scores for different groups of children is probably unnecessary.

1. Introduction

Demirjian's dental maturity method [1–3] is a useful tool to assess dental maturity for the individual child. Numerous researchers have applied this method to groups of children in various parts of the world and the significant differences between most groups and the reference have been interpreted as either a true population difference or a secular trend. Many authors have used this to justify the need for population specific dental maturity scores, however, there is growing evidence that this is probably unnecessary. The aim of this paper were to describe the variation in (1) dental maturity score by age groups and (2) age by maturity score categories using a large database [4,5] and discuss the adapted scores for boys from published studies from different world regions in the light of this variation.

2. Materials and methods

The data were from a large collaborative database of cross-sectional, retrospective dental radiographs set up by Chaillet et al. of children of European origin in Australia, Belgium, Canada, England, Finland, France, and Sweden with a small group from South Korea [4]. Dental maturity and the variation in age of individual tooth stages have been documented [5,6]. The sample for this study consisted of radiographic data of individuals aged 2–18 ($N = 4710$ males, $N = 4661$ females). For the first part of this study data were divided into 6- and 12-month age groups and 5-point maturity score categories; only dentally immature individuals were selected made up of 4081 males (mean 9.60, SD 3.20, age 2.10–18.51) and 3959 females (mean 9.59, SD 3.00, age 2.11–18.44). The mean, standard deviation, standard error and 95% confidence intervals (CI) of maturity score by age group and age by maturity score groups were calculated. Median tooth formation stage was calculated for 1-year age categories as well as the proportion of individuals with all seven left mandibular teeth in stage H by age category. This is used to illustrate the appropriate method to calculate average age of a single maturity event between groups: using the status quo method to calculate mean age, standard deviation (to calculate the 95% CI for an individual) and standard error (to calculate 95% CI for the group). One age group was selected (7-year olds, $N = 792$) to show the range of formation stages by tooth and most frequent sequences in tooth stage.

3. Results

The variation of dental maturity score and age is illustrated in Figs. 1–3. Mean maturity score, standard deviation, standard error of mean and 95% confidence interval (CI) by 6-month and 1-year age groups is shown in Figs. 2 and 3 and Tables 1 and 2. The age groups with the highest standard deviation are from 5 to 8 years of age in males and 4 to 7 in females. This corresponds to the section

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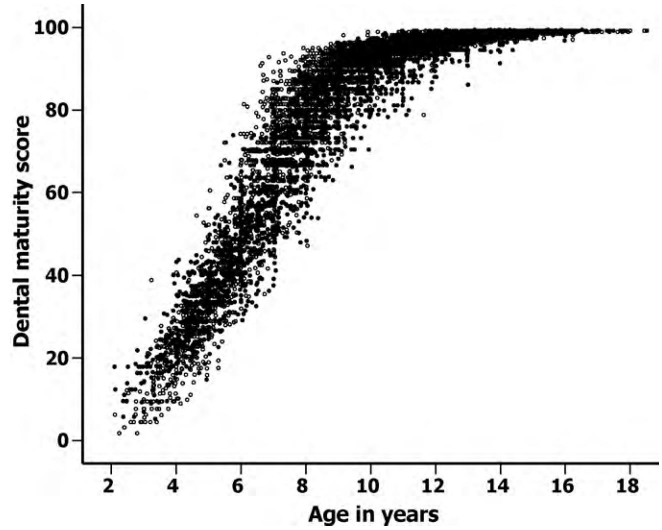

Fig. 1. Scatter plot of dental maturity score and age. Closed circles: boys; open circles: girls.

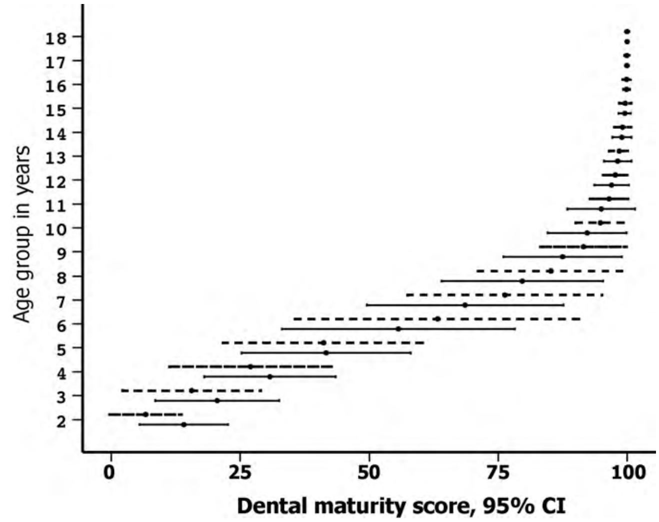

Fig. 3. Mean dental maturity score and 95% confidence interval by age category for an individual child. Males: solid line, closed circles; females, dashed line, open circles.

of the maturity curve with the steepest slope. For instance a boy aged from 7.00 to 7.49 years is likely to have a dental maturity score between 45.04 and 84.30. These confidence intervals are suitable for a single individual with developing teeth. Once all seven teeth have reached stage H (apex mature), dental maturity cannot be estimated using Demirjian's method.

Mean age, standard deviation, standard error of mean and 95% confidence interval (CI) by maturity score categories is shown in Table 3. This shows wide confidence intervals in age for most score categories. For example, a boy with a maturity score of 71 is likely to be between 6.26 and 9.37 years. Similarly, a boy with a score of 95 is likely to be between 10 and 16 years of age. Median tooth formation stage by 1-year age categories is shown in Table 4. The number of individuals with seven mature teeth is also detailed. The youngest individual with all seven teeth in stage H was 10 years old, while the oldest individual with an immature dentition was 18. The median stage for age category hides the number of possible tooth stages, evident from Table 5 showing the variation in tooth formation stage of individual teeth in 7-year olds. The central incisor median stage was G, however the range was from stage D to H. The median stage for most tooth types represents more than half the individuals, with the exception of the lateral incisor and second premolar where two stages have roughly similar proportions. The median tooth stages for 7-year olds were GGEEDGD for I_1, I_2, C, P_1, P_2, M_1 and M_2, respectively. Dental development in 792 seven-year olds (380 male, 412 female) from the database showed a wide range of tooth formation stages by tooth type and 228 different sequences. The most frequent sequence occurred in only 39 out of 792 individuals with 126 unique combinations occurring once only. The three most frequently occurring sequences and the percentage of the group they represent are shown in Table 5.

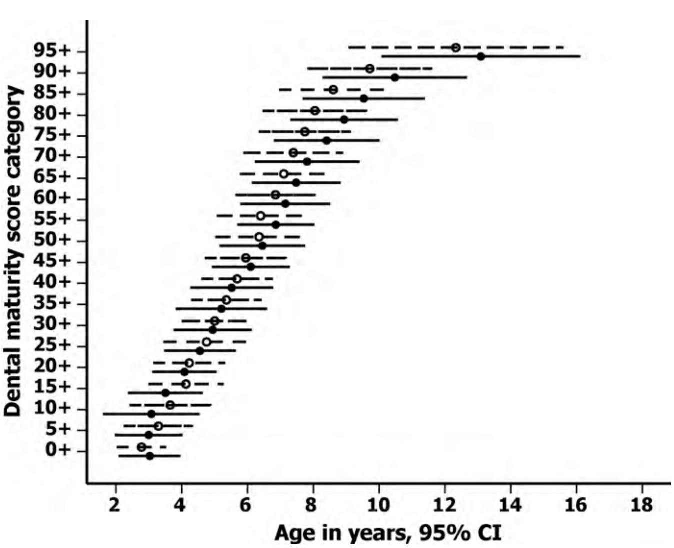

Fig. 2. Mean age and 95% confidence interval by dental maturity score categories for an individual child. Males: solid line, closed circles; females: dashed line, open circles.

4. Discussion

Demirjian's method is designed to assess the developing dentition of an individual child. The formation stages of the left mandibular teeth (excluding third molar) are assessed, the individual scores for each of the seven stages are summed and this is converted to a single dental age which represents the average age of a child for that score. The clinical interpretation of this indicates if the child is dentally advanced, average or delayed compared to the reference. It is clear from Figs. 1–3 that there is considerable variation in both scores for age and age for score. The variation in age and dental maturity score can be determined with some difficulty from the illustrations in Demirjian's publications [1,2]. The results from this study allow the clinician to compare the dental score of a single individual child with the 95% confidence interval (CI) from this large database. Similarly, the variation in dental score can be compared for a single age category.

Numerous studies of children from different regions have documented a significant difference between average dental and average real age for groups of children. This has resulted in some researchers (myself included) suggesting that population specific tooth data are required and questioning the validity of using Demirjian's dental maturity method to assess dental age in other world groups. This has been followed by numerous modifications of the method by changing the weighted scores or providing equations to either calculate age from score or score from age [7–25]. A comparison of adapted dental age for score or score for age for the average boy from studies that give equations/tables is illustrated in Fig. 4. Both types are illustrated here with age on the *x*-axis. The adaptions are for boys in Germany, Hungary, Netherlands, Poland, Spain, Kuwait, West Africa, India, Brazil, Venezuela

Table 1
Variation in dental maturity score by 6-month age group in dentally immature individuals. Mean: mean maturity score, SD: standard deviation, SE: standard error of mean, 95% CI: 95% confidence interval calculated for a single individual, age 2.0+ indicates 2.00–2.49, years, etc.

Age	Males						Females					
	N	Mean	SD	SE	95% CI		*N*	Mean	SD	SE	95% CI	
2.0+	7	11.47	3.817	1.443	3.99	18.95	5	6.60	4.315	1.930		15.06
2.5+	15	15.27	4.176	1.078	7.08	23.45	10	6.67	3.374	1.067	0.06	13.28
3.0+	28	16.33	5.367	1.014	5.81	26.84	36	13.05	6.956	1.159		26.69
3.5+	58	22.56	5.429	0.713	11.92	33.20	48	17.45	6.156	0.889	5.39	29.52
4.0+	109	28.90	6.138	0.588	16.87	40.93	91	23.78	6.326	0.663	11.38	36.17
4.5+	134	32.25	6.417	0.554	19.67	44.83	90	30.25	8.267	0.871	14.04	46.45
5.0+	134	37.77	7.329	0.633	23.40	52.13	124	37.85	8.588	0.771	21.02	54.69
5.5+	137	45.44	7.585	0.648	30.58	60.31	121	44.55	10.103	0.918	24.75	64.35
6.0+	161	50.61	9.968	0.786	31.08	70.15	120	55.30	11.203	1.023	33.34	77.25
6.5+	173	58.64	8.896	0.676	41.20	76.07	171	66.82	12.225	0.935	42.86	90.78
7.0+	174	64.67	10.018	0.759	45.04	84.30	179	72.91	10.289	0.769	52.74	93.07
7.5+	206	71.88	8.144	0.567	55.91	87.84	233	78.88	8.183	0.536	62.84	94.91
8.0+	221	76.31	7.851	0.528	60.92	91.70	240	83.12	7.902	0.510	67.63	98.60
8.5+	240	82.75	6.820	0.440	69.39	96.12	221	87.52	5.537	0.372	76.67	98.37
9.0+	227	86.33	6.137	0.407	74.30	98.36	241	90.50	4.722	0.304	81.25	99.76
9.5+	219	88.75	5.335	0.361	78.29	99.21	214	92.66	3.257	0.223	86.28	99.05
10.0+	195	91.31	4.077	0.292	83.32	99.31	220	94.18	2.654	0.179	88.98	99.38
10.5+	238	92.99	3.576	0.232	85.99	100.00	265	95.32	2.084	0.128	91.23	99.40
11.0+	145	93.99	4.180	0.347	85.80	100.00	187	96.29	1.666	0.122	93.02	99.56
11.5+	188	95.73	2.278	0.166	91.26	100.00	205	96.69	2.045	0.143	92.68	100.00
12.0+	197	96.79	1.768	0.126	93.32	100.00	222	97.45	1.142	0.077	95.21	99.69
12.5+	202	97.14	1.672	0.118	93.86	100.00	188	97.97	1.183	0.086	95.65	100.00
13.0+	129	97.90	1.572	0.138	94.81	100.00	153	98.27	1.098	0.089	96.12	100.00
13.5+	204	98.34	1.221	0.086	95.95	100.00	200	98.60	0.869	0.061	96.90	100.00
14.0+	146	98.71	1.047	0.087	96.66	100.00	118	99.02	0.837	0.077	97.37	100.00
14.5+	170	99.19	0.793	0.061	97.64	100.00	150	99.18	0.822	0.067	97.57	100.00
15.0+	133	99.50	0.599	0.052	98.32	100.00	122	99.49	0.661	0.060	98.19	100.00
15.5+	116	99.56	0.609	0.057	98.37	100.00	98	99.82	0.429	0.043	98.97	100.00
16.0+	78	99.75	0.475	0.054	98.82	100.00	89	99.84	0.483	0.051	98.89	100.00
16.5+	92	99.97	0.155	0.016	99.66	100.00	104	99.94	0.258	0.025	99.43	100.00
17.0+	95	99.94	0.207	0.021	99.54	100.00	78	99.96	0.196	0.022	99.58	100.00
17.5+	76	99.98	0.129	0.015	99.73	100.00	77	99.92	0.272	0.031	99.38	100.00

and China [7,11–13,17–25] and the 95% confidence interval from the present study is shown in grey. Most of the curves for the average age/score lie within the CI of this study or at the lower border. If the curve for the average boy lies close to this edge, it is likely that about half of boys have a greater maturity score than the reference but many studies do not illustrate raw data scores for age. Scrutiny of sample size and raw data used to construct these curves provide several possible explanations including small sample size and complex equations that do not reflect the raw data. The curve for French boys [7] is at the lower 95% CI for ages 4–7, however, only two boys represent the age group 2.5–3.5 and three boys for age group 3.5–4.5. The Hungarian boys [18] are made up of one 4-year old, four 6-year olds and five 7-year olds and the curve from age 4 to 8 is unrepresentative. The adaption of maturity for south Indian children [12] is not a curve but a line which extends below the lower CI from age 8; the number of 8–10-year olds is nine or ten for each age cohort. A sample of ten for a year of age is probably the minimum to estimate the mean while many more are required to accurately estimate standard deviation. The curve for Kuwaiti boys [23] also falls at or below the 95th CI. Few studies give standard deviation of dental maturity score by age category; two are illustrated in Fig. 5 showing the 95% CI of Chinese

Table 2
Variation in dental maturity score by 1-year age group for dentally immature individuals. Mean: mean maturity score, SD: standard deviation, SE: standard error of mean, 95% CI: 95% confidence interval calculated for a single individual, age 2.0+ indicates 2.00–2.99 years, etc.

Age	Males						Females					
	N	Mean	SD	SE	95% CI		*N*	Mean	SD	SE	95% CI	
2.0+	22	14.06	4.336	0.931	5.50	22.62	15	6.65	3.555	0.918	0.00	13.61
3.0+	86	20.53	6.127	0.661	8.52	32.54	84	15.57	6.831	0.745	2.18	28.95
4.0+	243	30.75	6.499	0.417	18.01	43.49	181	26.99	8.020	0.596	11.27	42.71
5.0+	271	41.65	8.380	0.509	25.22	58.07	245	41.16	9.932	0.635	21.59	60.63
6.0+	343	55.66	11.508	0.621	33.10	78.21	303	63.25	14.114	0.811	35.59	90.92
7.0+	380	68.58	9.726	0.499	49.51	87.64	412	76.28	9.613	0.474	57.44	95.12
8.0+	461	79.67	8.002	0.383	63.98	95.35	461	95.23	7.208	0.335	71.10	99.35
9.0+	437	87.50	5.868	0.281	75.99	99.00	443	91.51	4.260	0.202	83.16	99.85
10.0+	432	92.22	3.883	0.187	84.61	99.83	485	94.80	2.424	0.110	90.05	99.55
11.0+	333	94.97	3.353	0.184	88.40	100.00	385	96.44	1.839	0.094	92.83	100.00
12.0+	395	96.93	1.708	0.086	93.59	100.00	385	97.54	1.065	0.054	95.45	100.00
13.0+	310	98.03	1.336	0.076	95.41	100.00	299	98.18	0.802	0.046	96.61	100.00
14.0+	223	98.54	0.805	0.054	96.96	100.00	165	98.55	0.560	0.044	97.45	100.00
15.0+	112	98.95	0.449	0.042	98.07	100.00	66	98.78	0.337	0.041	98.12	100.00
16.0+	23	99.04	0.366	0.076	98.32	100.00	17	98.76	0.500	0.121	97.78	100.00
17.0+	9	99.21	0.033	0.011	99.15	100.00	10	99.05	0.158	0.050	98.74	100.00

Table 3
Variation in age (years) by 5-point dental maturity score group in dentally immature individuals ($N=8042$). Mean: mean age, SD: standard deviation, SE: standard error of mean, 95% CI: 95% confidence interval calculated for a single individual, 0+ indicates 0–4.9, etc.

Score	Males						Females					
	N	Mean	SD	SE	95th CI		*N*	Mean	SD	SE	95th CI	
0+	3	2.81	0.500	0.289	1.86	3.79	11	2.78	0.367	0.111	2.06	3.50
5+	8	3.07	0.477	0.169	2.14	4.01	26	3.29	0.521	0.102	2.27	4.31
10+	14	3.08	0.733	0.196	1.64	4.51	32	6.35	0.614	0.109	2.45	4.85
15+	44	3.50	0.561	0.085	2.40	4.60	44	4.12	0.565	0.085	3.02	5.23
20+	75	4.08	0.482	0.056	3.13	5.02	67	4.23	0.539	0.066	3.17	5.28
25+	96	4.55	0.537	0.055	3.50	5.60	73	4.75	0.652	0.076	3.47	6.03
30+	106	4.94	0.585	0.057	3.79	6.09	60	5.00	0.491	0.063	4.04	5.96
35+	113	5.20	0.689	0.065	3.85	6.55	95	5.36	0.530	0.054	4.32	6.40
40+	134	5.52	0.624	0.054	4.29	6.74	73	5.68	0.535	0.063	4.63	6.73
45+	116	6.10	0.587	0.054	4.95	7.25	63	5.95	0.615	0.077	4.74	7.15
50+	112	6.45	0.648	0.061	5.18	7.72	67	6.35	0.658	0.080	5.06	7.64
55+	88	6.86	0.579	0.062	5.72	7.99	60	6.40	0.662	0.085	5.10	7.70
60+	123	7.15	0.678	0.061	5.82	8.48	72	6.85	0.604	0.071	5.67	8.03
65+	128	7.48	0.669	0.059	6.17	8.79	84	7.10	0.659	0.072	5.81	8.39
70+	199	7.81	0.794	0.056	6.26	9.37	137	7.39	0.754	0.064	5.91	8.87
75+	235	8.40	0.801	0.052	6.83	9.97	170	7.74	0.696	0.053	6.38	9.11
80+	213	8.94	0.814	0.056	7.34	10.53	201	8.05	0.790	0.056	6.50	9.59
85+	329	9.53	0.931	0.051	7.71	11.36	368	8.61	0.817	0.043	7.00	10.21
90+	598	10.48	1.099	0.045	8.32	12.63	575	9.72	0.950	0.040	7.85	11.58
95+	1342	13.10	1.523	0.042	10.10	16.08	1681	12.33	1.349	0.404	9.10	15.56

Table 4
Median stage by year age groups. 2+ includes all individuals from 2.00 to 2.99 years, mature number of individuals with seven teeth in stage H divided by number of individuals in age category.

Age	*N*	I_1	I_2	C	P_1	P_2	M_1	M_2	Mature males	Mature females
2+	38	D	D	C	B	A	D	–		
3+	170	D	D	C	C	A	D	A		
4+	424	E	D	C	C	B	E	B		
5+	516	E	E	D	D	C	F	C		
6+	646	F	F	E	D	D	G	D		
7+	792	G	G	E	E	D	G	D		
8+	922	H	G	F	E	E	G	D		
9+	880	H	H	F	F	F	G	E		
10+	918	H	H	G	F	F	H	F	1/432	
11+	725	H	H	G	G	F	H	F		7/392
12+	809	H	H	H	G	G	H	G	4/399	25/410
13+	686	H	H	H	H	G	H	G	23/333	54/353
14+	583	H	H	H	H	H	H	G	93/316	102/267
15+	470	H	H	H	H	H	H	H	137/249	155/221
16+	363	H	H	H	H	H	H	H	147/170	176/193
17+	326	H	H	H	H	H	H	H	162/171	145/155
18+	104	H	H	H	H	H	H	H	62/63	39/41

and Polish boys, respectively [11,21] superimposed on the 95% CI of boys from this study. The upper edge of the CI for younger Polish boys is based on only 7 6-year old boys. In other respect, this suggests similar variation in these groups.

The relationship between dental maturity score and age forms a sigmoid curve. Finding the appropriate equation to describe maturity score and age from a small sample of children is complicated by the inclusion of individuals who are dentally mature. For example, a recent study shows cubic and compound

Table 5
The variation in tooth formation stage by tooth type in 7-year olds ($N=792$).

	Tooth						
	I_1	I_2	C	P_1	P_2	M_1	M_2
N in stage A					5		1
N in stage B					4		4
N in stage C			3	9	92		143
N in stage D	1	2	72	216	383		550
N in stage E	13	69	460	517	301	8	95
N in stage F	110	318	247	50	10	129	
N in stage G	433	344	10			625	
N in stage H	235	59				31	
Median stage	**G**	**G**	**E**	**E**	**D**	**G**	**D**
Sequence 1, 4.9%	G	G	F	E	E	G	D
Sequence 2, 4.2%	G	F	E	E	D	G	D
Sequence 3, 4.0%	G	F	E	E	E	G	D

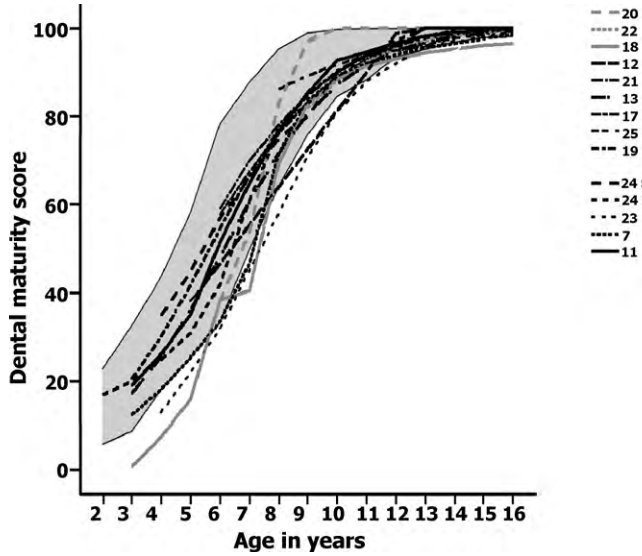

Fig. 4. Average adapted dental maturity scores for boys from published studies in Germany, Hungary, Netherlands, Poland, Spain, Saudi, Kuwait, Senegal, India, Brazil, Venezuela and China [7,11–13,17–25]. S: Spanish; V: Venezuela. Grey area represents 95% confidence interval for boys from the present study.

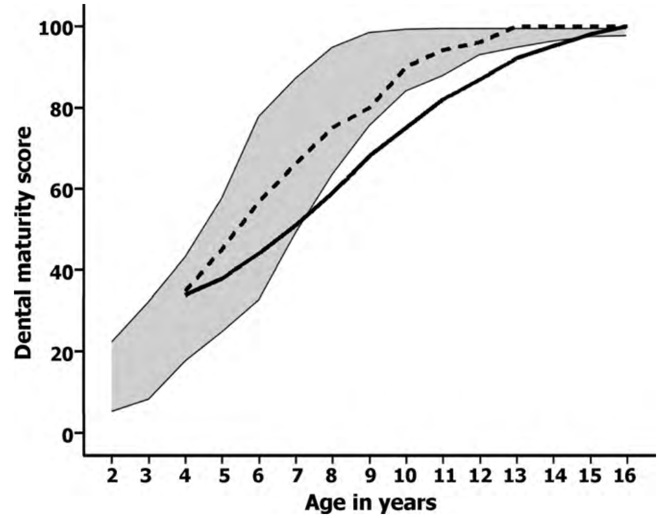

Fig. 6. Average dental maturity scores for Spanish boys calculated using cubic equation (solid line) and compound equation (dashed line) [24]. Grey area represents 95% confidence interval for boys from the present study.

functions of maturity score to predict dental age [24]. These curves are illustrated with the 95% CI of boys from the present study in Fig. 6. The adaption using cubic function (shown as a solid line) for Spanish boys from age 7 falls well below the CI of this study while the compound function (dashed line) for this group places it well within. This suggests that the choice of equation has a big impact on the average score for age. The sample size for this group is adequate, but examining the raw data from their illustration (Fig. 3a from Ref. [24]) the score range for all ages is within the 95% CI from this study. This suggests that despite a high R^2 value adapting Demirjian's method of dental maturity does not reflect how well the raw data fit the curve and questions the validity of adapting scores using complex equations.

The mechanism of how a population difference is possible in the developing dentition is unknown. Formation of enamel and dentine is highly regulated, evident from the incremental structure seen on any ground section of a tooth. Careful histological studies that count enamel increments to determine the duration of crown and root formation show similarities between groups. The duration of human molar crown formation is remarkably similar between maxilla and mandible, first, second, third molars, over time and across continents [26]. The first permanent mandibular molar begins to mineralise around birth, the second molar aged 3–4 and initial cups tips of the third molar can be seen as early as 6.2 or as late as 12.1 years [30]. This suggests that an earlier or later initiation of individual teeth is one plausible explanation of differences in tooth formation between individuals and/or between groups. Other tooth types show small differences in crown duration [27] but this is unlikely to be seen at the resolution of dental radiographs where tooth development is collapsed into eight radiographic stages that occur years apart.

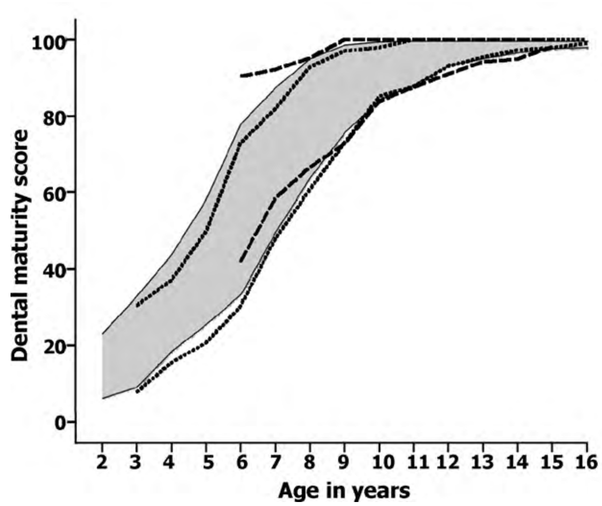

Fig. 5. Dental maturity score 95% confidence interval calculated for Chinese (short dash) [11] and Polish boys (long dash) [21]. Grey area represents 95% confidence interval for boys from the present study.

If a population difference was present, this would be evident at the individual tooth stage level and this has not been demonstrated for the seven teeth used in Demirjian's method. This is hampered by a general confusion of the appropriate measures of maturity of individual tooth formation stages and is briefly explained and illustrated below [see 28–30]. Average age of individuals within a stage does not measure maturity; cumulative frequency distribution methods are appropriate and although most studies of tooth eruption follow this approach, few studies of tooth formation employ these methods. No significant differences were seen in maturation of teeth (Demirjian stages) in two ethnic groups (Bangladeshi, White in London, UK) aged 4–9 years [31]. This was followed by a more thorough study from ages 2 to 22 years in these groups using fifteen tooth stages and also failed to show significant differences [32]. Further comparison of the database used in this study failed to show any consistent pattern of one tooth type or one region being significantly earlier or later than others [5]. There is clearly a need for a worldwide comparative study, which is underway [see 6].

The reason why Demirjian's dental maturity method has been adapted is unclear. A child's maturity score is calculated and if it does not correspond with the age of the average child of the reference, adapting the scores or conversion to age allows the clinician to 'solve the problem' by converting the score of a small sample to be average. In reality, the fact that the maturity score lies within a large age range is not taken into account, even though most clinicians are not surprised that dental maturity differs so much for any one age. The age variation of any tooth stage is large and describing tooth formation at the population level requires a large sample with a very wide age range to include sufficient advanced, normal and delayed children. This incongruity of adjusting the maturity score for small samples with varying age ranges has resulted in very little progress in understanding dental maturity despite a plethora of published studies.

Presumably, one of the reasons for adapting Demirjian's dental maturity method has been to improve the agreement between dental and known age for the group. Most studies fail to provide evidence from a separate target sample that adapting Demirjian's method decreases the average difference between dental and known age. Adjustment is unlikely to change the variation in either score by age or age by score. One exception is the study by Willems et al. [14] who simplified the method so that the scores add up directly to dental age and tested this on a separate sample. Willems et al. has been shown to be more accurate estimating known age than other methods in different world regions (England, India, Malaysia) [33–35], although comparisons are difficult when studies differ in the definition of 'accuracy', very small target sample of different age ranges are used and individuals with seven mature teeth are incorrectly included. The difficulties assessing accuracy of dental age and the nature of target samples are discussed elsewhere [29,36].

The reason why significant differences occur between average dental age and known age is unclear. It is prudent to remember that dental maturity score represents the sum of weighted scores of 43 individual tooth stages. These weighted scores were calculated using correspondence analysis with end point constraints. Some early stages have zero weight, while the tooth with the most weight is stage H of M_1 in boys and of I_1 in girls. Originally, each tooth had similar weight [1]. With the addition of younger and older individuals the weighted scores were changed, even though the additional early tooth formation stages have scores of zero. Additional constrains (changing the weight value for some tooth stages) produces a scale which is more sensitive to either the earlier or later period of development [37]. The weight values have little, if any biological meaning. It is possible that significant differences between the average dental age (maturity score converted to age) and average known age for a group of children also has little meaning. A single dental maturity measure such as dental age reflects a huge number of sequences of tooth stages. In this study, the sequences were counted in 792 seven-year olds and the most frequent sequence was found in less than five percent of children with over a hundred unique combinations. This large number of possible tooth stage sequences and the weight of individual tooth stages, might contribute to the frequent finding of significant differences between average dental age and average known age, and suggests that interpreting this as a population difference is incorrect.

Maturity is a process that we arbitrarily divide into maturity events. Traditionally in human biology, the average age when a child enters a stage is the age when half of children have reached or passed the individual formation stage and this is the appropriate method to assess and compare maturity events [29,38–40]. Measuring the age when a child enters a maturity event is done using the status quo method. This entails asking the question: has this individual attained seven mature teeth (or has the tooth reached or passed a specific stage)? The status quo method uses information from all individuals to calculate mean age including those who have not yet reached/passed the stage. Mean age, standard error and standard deviation can be obtained using probit or logistic regression. The mean age is also, confusingly described as the median age. It is not the middle child *in that stage* [see 6]; it is however, the age prior to which half children enter the stage.

For example, to calculate the average age of dental maturity, i.e. having seven teeth in stage H, the proportion of boys and girls in each age category is counted and plotted against the age interval (Fig. 7). This shows the age category with no dentally mature individuals up to the age category where *all* individuals have a maturity score of 100. Probit or logistic regression can be used to calculate the mean. For probit analysis, three columns of data are needed, the number of mature individuals is the response, *N* for the age category is total observed and the midpoint of the age category is the covariate. Fig. 7 shows the cumulative incidence curves for boys and girls with the earliest aged boy to reach this maturity state at ten (the most dentally advanced child) and the high proportion by age 18. The average age or median age is the age when half or 50% of individuals reach this stage. Mean age of attaining dental maturity can be estimated by plotting the curve of proportion or percentage of the age category by age midpoint or calculated using probit regression from raw data in Table 4. Mean age for boys is 15.28 (SD 1.27) for girls is 14.87 (SD 1.50). The 95% CI at the individual level is 12.79–17.77 for boys and 11.93–17.81 for girls (calculated using SD) while at the population level is 15.02–15.57 for boys and 14.61–15.15 for girls (calculated using SE).

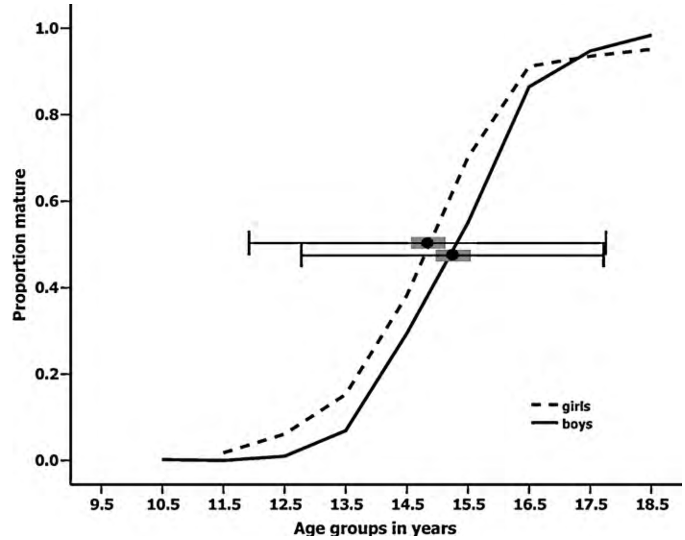

Fig. 7. Proportion of males and females who have reached maturity by age group. Solid line males, dashed line female. Mean age with 95% CI for an individual (grey bar) and for the group (whiskers). These should be at the 0.5 proportion but are separated for clarity.

Population reference data require a large sample size and a wide age range. It is clear from this example of calculating maturity, that an 8-year age range for one event is required to accurately describe the variation. Maturity data of permanent teeth is needed for world regions and can be presented as cross-tabulation of year age group and tooth stage. This would allow comparison and better understanding of the variation between groups. Demirjian et al. [1] end their landmark paper with a statement that it seems reasonable to assume that the pattern of development of the teeth will not vary very much in different populations. They recommend this method as a valid measuring instrument for universal use. However, they follow this with the speculation that the use of relatively small local samples, dental age equivalents could readily by estimated for different populations. With present knowledge of the similarity between groups and the difficulties discussed here, in my view, this is inappropriate and unnecessary.

5. Conclusions

The numerous significant differences in Demirjian's dental maturity method in different groups, interpreted incorrectly as population differences, are at odds with the available evidence of the similarity in maturity of individual tooth formation stages between world groups. Possible explanations for differences in average dental age and known age using Demirjian's method include the weighted scores, complex equations and the inclusion of mature individuals. Demirjian's method remains a useful, valid tool to assess maturity of the individual child patient and is probably applicable to any region. Willems et al. [14] scores are the best adaption and is the recommended method of choice to assess maturity or estimate age if all seven teeth are available [36]. Demirjian's method is unsuitable to compare dental maturation between regions or ethnic groups, particularly if these are of small sample size and of insufficient age range.

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