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ScienceDirect
Forensic Science International 178 (2008) 125–131
Forensic Science International
www.elsevier.com/locate/forsciint

Age estimation of Korean children based on dental maturity

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Received 2 June 2007; received in revised form 25 September 2007; accepted 7 December 2007
Available online 23 April 2008

Abstract

The aim of this study was to evaluate the relationship between age and dental maturity and to establish the standard database of dental maturity based on the Demirjian's stages, which can be used for the age estimation of Korean children. For this purpose, dental maturity was measured by the Demirjian's stages on a randomly selected sample of panoramic radiographs taken from 2706 patients between 1 and 20 years of age and analyzed by multiple linear regression analysis based on the method of least squares. The results showed that, except for the third molars, the development of permanent teeth in Korean children was more advanced in females. The Demirjian's stage G of the second molar appeared last in both male and female subjects by age 18, showing 95th percentile at age in the male and female subjects between 16.7–17.4 years and 17.1–17.3 years, respectively. Coefficients of determination (r^2) of the Demirjian's stages relative to age in regression analysis were 0.9721 in male and 0.9740 in female subjects. The standard error was 0.63 years in male and 0.62 years in female subjects. The estimated age according to regression analysis was within ±1.0 year of the actual age in 92.0% of male and 92.5% of female subjects. Collectively, the data of the present study can be used as a reference for dental maturity and a standard for age estimation of Korean children.

Keywords: Age estimation; Dental maturity; Development of tooth; Demirjian's method

1. Introduction

Age estimation is an important characteristic for the identification of individuals, for which dental information, if available, can be the most valuable aid. There have been numerous studies using dental features for age estimation of deceased or living individuals. While several degenerative changes of teeth such as attrition, secondary dentin formation, and color change have been used for the age estimation of adults [1–13], dental maturity is generally accepted as the most reliable method to estimate the chronological age of children. The most frequently used techniques are based on dental maturity measured from radiographs, especially panoramic radiographs, due to the advantage of their being noninvasive and easy to use [14,15]. To date, there have been several methods introduced to estimate dental maturity based on radiographs [16–21].

Currently, the most frequently used method is the Demirjian's method based on eight calcification stages that represent the crown and root calcification to the apex closure. A score for each stage of each tooth is allocated, and the scores are summed to give a dental maturity score which can be converted directly into a dental age by using available tables and percentile curves [16]. Demirjian's study was based on the data from subjects who were French Canadian boys and girls. Thereafter, several studies have shown that the estimation of dental age of another population using Demirjian's standards based on French Canadian subjects was less accurate and ethnic differences of dental maturity had to be taken into account [22–27].

In addition, the Demirjian's method to estimate dental maturity based on percentile charts was shown to be more suitable in determining if the dental maturity of a subject with a known age is advanced or delayed rather than to predict an unknown age [12,15,25]. Several studies using polynomial or

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doi:10.1016/j.forsciint.2007.12.010

Table 1
Distribution of subjects according to gender and age

Age (year)	Male	Female	Total
1	4	6	10
2	38	43	81
3	84	63	147
4	74	62	136
5	71	71	142
6	71	69	140
7	79	71	150
8	73	72	145
9	76	74	150
10	76	71	147
11	81	83	164
12	69	68	137
13	71	73	144
14	55	73	128
15	72	103	175
16	70	115	185
17	59	58	117
18	66	64	130
19	67	72	139
20	67	72	139
Total	1323	1383	2706

multiple regression to predict age with the confidence interval as a function of the maturity score have been reported [12,15,28,29]. However, in the process of such analysis, each stage of the tooth has to be converted to a dental maturity score, which comprises the biological inter-ethnic differences. In the present study, a multiple linear regression analysis based on the method of least squares was adopted to predict age directly from the Demirjian's stages.

Based on the Demirjian's stages, which can be used for the age estimation of Korean children, the aim of this study was to establish a standard database of dental maturity, to evaluate the relationship between age and dental maturity and to design the calculating tables for age estimation.

2. Materials and methods

2.1. Materials

The present study was performed on a randomly selected sample of panoramic radiographs taken of 2706 patients (1323 males and 1383 females) between the ages of 1 and 20 years who visited the Seoul National University Dental Hospital from 2004 to 2005. The gender and age distributions of the subjects are presented in Table 1. Radiographs of patients who had any deformity or disturbance of growth including development of teeth were excluded. The research protocol was approved by the Institutional Review Board of the University Hospital (#CRI07003).

2.2. Methods

Dental maturity of all permanent teeth except the third molars was estimated by the method proposed by Demirjian et al. [16] which divides the process of tooth development into eight stages from A to H. Two well-trained examiners read radiographs after a period of a mutual calibration procedure. To test intra- and inter-examiner reliability, two different examiners staged the development of teeth on 100 radiographs selected randomly. Each examiner repeated the reading of the radiographs after a 2-week period (intra-examiner) and data from each examiner were compared (inter-examiner) to assess reliability.

2.3. Statistical analysis

To assess intra- and inter-examiner reliabilities, the intra-class correlation coefficient (ICC) was used. An independent sample *t*-test was done to evaluate the gender difference between the mean age of each Demirjian's stage. Multiple linear regression analysis based on the method of least squares was performed to evaluate the relationship between age and dental maturity and to design the calculating tables for age estimation. In the regression process, each stage of each tooth was treated as an independent variable. All statistical analysis was performed using SPSS software 11.0 for Windows.

3. Results

The ICC value for the intra- and inter-reliability was as high as 0.99 ($P < 0.001$) and 0.98 ($P < 0.001$), respectively, indicating excellent reliability. In 2706 subjects, the stage G of the second molar was last observed at age 18 in both male

Table 2
Means and standard deviations of age by the Demirjian's stage of maxillary and mandibular teeth

Tooth no.[a]	Gender	A			B			C			D			E			F			G		
		N	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.
(A) Maxillary teeth																						
11	Male				3	2.9	0.6	116	*3.3*	0.7	90	4.2	0.7	139	*6.2*	0.8	136	*7.9*	0.9	72	*9.6*	1.1
	Female							103	*3.0*	0.7	74	4.3	0.6	128	*6.0*	0.8	111	*7.6*	0.8	58	*9.1*	1.1
12	Male	1	2.5		27	*2.6*	0.4	159	3.9	0.7	49	5.0	0.7	166	*6.8*	0.8	120	*8.7*	0.9	86	*10.1*	0.9
	Female	2	2.3	0.2	22	*2.3*	0.4	122	3.8	0.7	50	4.9	0.6	142	*6.5*	0.8	104	*8.2*	0.8	82	*9.7*	1.1
13	Male	1	2.2		28	2.6	0.4	149	*3.8*	0.7	68	*5.1*	0.8	219	*7.2*	1.0	271	*10.4*	1.3	58	*12.7*	1.1
	Female				23	2.3	0.4	104	*3.5*	0.6	70	*4.9*	0.7	180	*6.6*	0.9	242	*9.7*	1.2	76	*11.6*	1.1
14	Male	41	3.2	0.5	96	3.8	0.5	69	4.9	0.6	155	*6.7*	0.8	107	*8.3*	0.8	215	*10.6*	1.1	60	12.2	1.1
	Female	24	3.0	0.5	63	3.7	0.6	78	4.7	0.6	138	*6.4*	0.8	109	*8.1*	0.9	193	*10.2*	1.0	58	11.8	0.9
15	Male	78	3.9	0.5	33	4.4	0.7	66	5.6	0.5	147	7.0	0.9	113	8.8	1.0	220	10.9	1.2	54	12.7	1.2
	Female	47	4.0	0.6	30	4.5	0.5	65	5.4	0.5	132	6.9	0.8	122	8.6	1.0	185	10.8	1.1	66	12.3	1.1
16	Male							25	2.5	0.4	131	3.5	0.6	114	5.2	0.8	141	*6.9*	0.8	117	*8.8*	1.1
	Female							26	2.4	0.4	99	3.5	0.7	103	5.0	0.7	133	*6.7*	0.8	100	*8.4*	0.8

Table 2 (*Continued*)

Tooth no.[a]	Gender	A			B			C			D			E			F			G		
		N	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.	*N*	Mean	S.D.
17	Male	69	4.2	0.5	28	4.8	0.5	96	6.0	0.8	159	7.6	0.9	149	9.7	1.1	139	*11.6*	1.1	114	13.5	1.6
	Female	41	4.2	0.4	30	4.9	0.5	87	5.8	0.9	154	7.4	0.9	136	9.5	1.1	138	*11.3*	1.2	151	13.8	1.8
21	Male				3	2.9	0.6	114	*3.3*	0.7	92	4.1	0.7	140	*6.2*	0.8	137	*7.9*	0.9	73	*9.6*	1.1
	Female				1	1.4	.	102	*3.1*	0.7	74	4.3	0.6	128	*6.0*	0.8	111	*7.6*	0.8	57	*9.0*	1.0
22	Male				27	*2.6*	0.4	159	3.9	0.7	49	5.0	0.7	165	*6.8*	0.8	120	*8.7*	0.9	85	*10.1*	1.0
	Female	2	2.3	0.2	22	*2.3*	0.4	122	3.8	0.7	50	4.9	0.6	141	*6.4*	0.7	104	*8.2*	0.8	87	*9.8*	1.1
23	Male				27	*2.6*	0.4	150	*3.7*	0.7	69	*5.1*	0.8	218	*7.2*	1.0	270	*10.4*	1.3	58	*12.6*	1.1
	Female				24	*2.3*	0.4	105	*3.5*	0.7	71	*4.8*	0.7	180	*6.6*	0.9	243	*9.7*	1.2	74	*11.6*	1.1
24	Male	42	3.2	0.5	94	3.8	0.5	70	4.9	0.6	155	*6.7*	0.8	108	*8.3*	0.8	216	*10.6*	1.1	58	12.2	1.1
	Female	28	3.0	0.4	61	3.7	0.6	77	4.7	0.6	138	*6.4*	0.8	111	*8.1*	0.9	190	*10.2*	1.0	65	12.0	1.1
25	Male	78	3.9	0.5	32	4.4	0.7	66	5.6	0.5	148	7.0	1.0	109	8.7	0.9	227	10.9	1.3	49	12.9	1.0
	Female	49	3.9	0.6	30	4.5	0.5	66	5.4	0.6	133	6.9	0.8	121	8.6	1.0	183	10.8	1.1	72	12.5	1.3
26	Male				1	3.0		24	2.5	0.4	130	3.5	0.6	114	5.2	0.8	146	*6.9*	0.9	114	*8.7*	0.9
	Female				1	2.9		26	2.4	0.4	97	3.5	0.7	103	5.0	0.7	135	*6.7*	0.8	101	*8.5*	0.9
27	Male	66	4.2	0.5	29	4.9	0.5	96	*6.0*	0.9	160	7.6	0.9	145	9.7	1.1	142	*11.5*	1.1	114	13.5	1.6
	Female	43	4.2	0.4	31	4.9	0.5	87	*5.7*	0.7	156	7.5	1.0	134	9.6	1.2	136	*11.2*	1.0	148	13.7	1.8
(B) Mandibular teeth																						
31	Male				1	3.2		93	3.2	0.7	104	4.0	0.7	81	*5.6*	0.7	107	6.8	0.7	75	8.2	1.2
	Female				1	1.4		76	3.0	0.7	80	3.9	0.7	79	*5.3*	0.5	108	6.7	0.8	69	7.9	0.7
32	Male				13	2.2	0.4	140	*3.6*	0.7	63	4.4	0.7	111	*6.2*	0.7	117	*7.5*	0.7	86	*9.3*	1.3
	Female				10	2.2	0.5	104	*3.4*	0.8	65	4.4	0.7	99	*5.9*	0.7	108	*7.2*	0.8	76	*8.9*	1.3
33	Male				15	2.2	0.4	159	*3.7*	0.7	61	4.8	1.0	218	*7.0*	1.0	274	*10.3*	1.3	61	*12.5*	1.3
	Female				10	2.1	0.4	125	*3.4*	0.8	58	4.7	0.7	168	*6.5*	0.9	236	*9.3*	1.2	79	*11.5*	1.0
34	Male	38	2.9	0.4	79	*3.7*	0.5	86	4.6	0.6	115	*6.3*	0.8	152	*7.9*	1.0	228	*10.5*	1.2	60	*12.4*	1.1
	Female	19	2.9	0.4	54	*3.4*	0.5	87	4.5	0.6	95	*6.0*	0.7	151	*7.6*	0.9	201	*10.1*	1.1	71	*11.8*	0.9
35	Male	65	3.9	0.5	37	4.5	0.5	52	5.5	0.8	142	6.9	1.0	114	*8.6*	1.1	238	*10.9*	1.3	56	*12.9*	1.3
	Female	49	3.9	0.6	33	4.6	0.6	63	5.3	0.6	110	6.7	0.8	122	*8.2*	1.0	209	*10.6*	1.2	80	*12.5*	1.1
36	Male							18	2.4	0.4	121	3.4	0.6	79	4.6	0.6	193	*6.6*	1.0	146	8.9	1.2
	Female				1	1.9		20	2.2	0.4	84	3.3	0.7	79	4.5	0.7	176	*6.3*	0.9	125	8.8	1.3
37	Male	76	4.1	0.5	41	4.9	0.5	98	6.1	0.7	151	7.7	1.0	119	*9.7*	1.0	172	*11.3*	1.2	137	14.1	1.7
	Female	47	4.2	0.5	42	4.9	0.5	91	5.9	0.7	142	7.6	1.0	98	*9.2*	1.0	168	*11.0*	1.1	198	14.0	1.8
41	Male				1	3.2		94	*3.2*	0.7	103	3.9	0.7	81	*5.6*	0.7	107	6.8	0.7	77	8.2	1.2
	Female				1	1.4		77	*3.0*	0.7	79	3.9	0.7	79	*5.3*	0.5	107	6.7	0.8	70	7.9	0.9
42	Male				13	2.2	0.4	141	*3.6*	0.7	62	4.4	0.7	111	*6.2*	0.7	117	*7.5*	0.7	84	9.3	1.3
	Female				10	2.2	0.5	103	*3.4*	0.8	65	4.4	0.8	100	*5.9*	0.7	107	*7.3*	0.8	76	8.9	1.3
43	Male				15	2.2	0.4	158	*3.7*	0.7	62	4.8	1.0	220	*7.0*	1.0	273	*10.3*	1.3	61	*12.4*	1.2
	Female				11	2.1	0.4	125	*3.4*	0.8	60	4.8	0.8	165	*6.5*	0.9	236	*9.3*	1.2	81	*11.5*	1.0
44	Male	40	3.0	0.4	78	*3.6*	0.5	86	4.6	0.6	118	*6.3*	0.8	153	*7.9*	1.1	227	*10.5*	1.2	63	*12.4*	1.1
	Female	20	2.9	0.4	54	*3.4*	0.5	85	4.5	0.6	97	*6.0*	0.7	148	*7.6*	0.9	205	*10.1*	1.1	78	*11.9*	0.9
45	Male	63	4.0	0.6	41	4.6	0.6	50	5.4	0.5	142	6.9	1.0	119	*8.6*	1.1	235	*10.9*	1.3	54	*13.0*	1.0
	Female	50	3.9	0.6	28	4.6	0.6	66	5.3	0.6	110	6.7	0.8	122	*8.2*	1.0	214	*10.6*	1.2	74	*12.5*	1.1
46	Male							20	2.9	2.2	120	3.4	0.6	79	4.6	0.6	194	*6.6*	1.0	145	*8.9*	1.2
	Female							22	2.3	0.4	83	3.3	0.7	76	4.5	0.7	178	*6.3*	0.9	118	*8.6*	1.0
47	Male	79	4.1	0.5	41	4.9	0.5	101	*6.1*	0.7	151	*7.8*	1.0	116	*9.6*	1.1	172	*11.3*	1.1	137	14.0	1.7
	Female	50	4.2	0.7	41	4.9	0.4	92	*5.9*	0.7	139	*7.5*	0.9	98	*9.2*	1.0	169	*11.0*	1.1	199	14.0	1.8

N: Number of subjects, S.D.: standard deviation, italicized characters mean statistically significant differences between genders at 95% confidence interval.

[a] Two-digit system was used for the numbering of teeth (e.g. 14 denotes the right maxillary first premolar).

Table 3
Percentiles of the subjects' age at stage G of the second molar

Gender	Tooth no.[a]	Percentiles						
Male		5	10	25	50	75	90	95
	17	11.1	11.6	12.4	13.4	14.8	15.7	16.9
	27	11.1	11.6	12.4	13.4	14.8	15.9	16.7
	37	11.6	12.1	12.8	13.7	15.2	16.5	17.4
	47	11.6	12.1	12.8	13.7	15.2	16.5	17.2
Female	17	11.5	11.7	12.3	13.5	15.3	16.4	17.2
	27	11.4	11.7	12.2	13.3	15.1	16.2	17.1
	37	11.5	11.8	12.5	13.8	15.4	16.6	17.2
	47	11.5	11.7	12.6	13.8	15.4	17.0	17.3

[a] Two-digit system was used for the numbering of teeth (e.g. 14 denotes the right maxillary first premolar).

and female subjects. The mean age of the Demirjian's stages and gender differences are shown in Table 2. The Demirjian's stage H was omitted because the upper limit of the age range of subjects could not be determined. Table 3 shows the percentile distributions of the subjects' ages at stage G of the second molar. Fiftieth percentiles of the subjects' ages were from 13.4 to 13.7 years in male and 13.3 to 13.8 years in female subjects. After this age, the correlation between the Demirjian's stages and the subjects' ages would decrease and the error of regression would increase because once the second molars, which develop last, reach stage H, no change in stages occurs with an age increase. Therefore, radiographs of 1693 patients (867 males and 826 females whose mean age was 8.1 ± 3.4 years and 8.2 ± 3.4 years, respectively) younger than 14 years old were included for regression analysis.

Multiple linear regression analysis was done separately for male and female subjects due to gender differences, as shown in Table 2. Coefficients of determination (r^2) of the Demirjian's stages relative to age were as high as 0.9721 in male and 0.9740 in female subjects, and the standard errors were 0.63 and 0.62 years in male and female subjects, respectively. Based on the results of the regression analysis, the calculation tables for age estimation were designed (Tables 4 and 5). The estimated age can be calculated by adding the constant to the sum of numerical values obtained from the calculation tables (Tables 4 and 5). The accuracy of estimation was evaluated by calculating the differences between the estimated and actual age. The results showed that the estimated age was within ± 1.0 year of the actual age in 92.0% of male and 92.5% of female subjects (Table 6).

Table 7 shows how to estimate age using the calculation table. First, a numerical value for each tooth is obtained and then the constant is added to the sum of numerical values. The result shows the difference between the estimated and actual age is only 0.14 years.

Table 4
Calculation table for age estimation of male subjects

Tooth no.[a]	Demirjian's stages							
	A	B	C	D	E	F	G	H
11			−0.56	−0.01	−0.40	−0.06	0.37	
12	−0.58	−0.29		0.80	2.41	2.48	2.18	2.91
13	−0.65	0.08	0.06	−0.22	−0.26		0.82	0.26
14	0.24	0.20	1.01	0.18	−0.39	0.15	0.84	0.16
15	0.14	0.07	0.69	0.10	0.51	0.79	0.22	−0.40
16				−0.62		0.05	0.33	
17	0.30	0.25	0.28		1.09	1.35	1.24	
21		0.22		−0.46	0.00	−0.33	−0.45	
22		0.69	0.83	−0.04	−1.36	−1.41	−1.08	−1.07
23		−0.22	−0.28		−0.09	−0.04	−0.45	0.33
24	−0.29		−0.90		0.72	0.26	−0.06	0.65
25	−0.21	0.02	−0.53	0.34	0.10	−0.05	0.42	0.98
26		−1.29	−1.19	−0.44	−0.87	−0.80	−0.62	
27	−0.04	0.06	0.38	0.94	−0.15	0.44	0.52	1.91
31			−1.07		−0.41		−0.08	
32				0.14		2.02	1.42	1.17
33				0.18	1.92	1.68	2.61	2.13
34	−0.36	0.47	0.33	−0.60	−1.11	−1.04	−0.70	−0.41
35	0.09	−0.40	−0.40	−0.54	0.01	−0.04	−0.42	−0.49
36			−1.28	−1.27	−1.33	−0.05	−0.62	−0.19
37	0.34		1.32	1.67	2.12	2.01	2.08	1.92
41		0.72	0.51	−0.54		−0.26	0.25	0.55
42		−0.34	0.00	−0.28	0.30	−1.44	−0.77	−0.40
43		1.35	1.58	1.45	−0.36		−0.83	−0.23
44	0.19	−0.52	−0.18	0.60	1.03	0.77	0.34	0.14
45	−0.10	0.30	0.31	0.35	−0.37	−0.25	0.57	0.57
46			0.84	0.98	1.30	0.04	0.36	
47	−0.19	0.23	−0.91	−0.83	−1.13	−1.18	−1.11	−0.74

Constant = 3.62, r^2 (coefficient of determination) = 0.9721, S.E. = 0.63.
[a] Two-digit system was used for the numbering of teeth (e.g. 14 denotes the right maxillary first premolar).

Table 5
Calculation table for age estimation of female subjects

Tooth no.[a]	Demirjian's stages							
	A	B	C	D	E	F	G	H
11			−1.64				0.13	−0.38
12	−1.36		0.56	0.64	0.57	0.65	0.70	1.12
13		−1.14	0.48	1.46	0.78	0.30	−0.14	0.49
14	0.04	−0.05	1.84	1.96	1.90	1.76	1.50	1.32
15	0.48	0.24	−0.25	1.22	−0.30	−0.27	0.00	1.36
16				−0.39	0.23	0.32	−1.18	−0.79
17	−0.49	−0.52	−1.48	−4.16	−2.45	−1.88	−1.46	
21			0.72	−0.82	−0.51	−0.41	−0.58	
22	1.02	0.09			0.23	0.33	0.43	
23		1.52	−0.17	−0.65	0.02	0.84	0.87	0.83
24	−0.28	−0.02	−1.96	−1.98	−1.91	−1.56	−0.80	−0.53
25	−0.30		0.50	−0.79	0.81	1.12	0.66	−0.25
26		1.67	1.64	2.18	1.68	1.70	3.45	3.37
27	0.39	0.59	1.72	4.65	3.12	3.05	2.55	0.78
31			−1.19	−1.15		−0.39	−1.92	
32		0.31	−0.37	−0.74	−0.76	−0.50	−0.13	−0.18
33		−0.08	−0.22	−0.61		0.57	0.31	0.31
34	3.25	2.98	2.57	2.52	1.93	1.77	1.77	2.05
35	0.20	0.04	0.29	−1.43	−0.81	−0.24	−0.08	0.00
36		−0.83	−0.57		−0.38	−0.35	0.60	0.14
37	0.25	0.73	1.36	1.11	0.54	0.54	0.40	1.44
41		−1.43	−0.10		−1.03	−0.32	1.41	
42			0.47	0.34	0.59	0.48	−0.09	
43		−0.62	−0.23	0.36	−0.17	−0.73	0.27	0.36
44	−3.09	−2.86	−2.19	−2.27	−1.58	−1.24	−1.09	−0.86
45	−0.16	−0.21	−0.39	1.31	0.79	0.16	−0.12	−0.51
46			−0.25	−0.48	0.20	0.16	−0.47	
47	−0.01	−0.63	−1.47	−1.04	−0.77	−0.46	0.09	−0.28

Constant = 3.56, r^2 (coefficient of determination) = 0.9740, S.E. = 0.62.
[a] Two-digit system was used for the numbering of teeth (e.g. 14 denotes the right maxillary first premolar).

Table 6
Accuracy of age estimation

Gender	Range of error (years)				
	Within ±0.2	Within ±0.3	Within ±0.5	Within ±1.0	Within ±2.5
Male (%)	38.3	50.6	70.1	92.0	100.0
Female (%)	38.0	50.2	70.0	92.5	100.0

4. Discussion

Age estimation of children may be necessary for school attendance, identification of missing children, or young deceased victims. Dental and skeletal maturity can be used to estimate the age of individuals in childhood [30]. Although there have been numerous studies attempting to determine whether there is a relationship between the dental and skeletal maturity, results are inconsistent [31–36]. The lack of agreement among the results of previous studies may partially be attributed to the different methods used for assessing dental and skeletal maturity [31].

Several methods to evaluate dental maturity based on the morphological changes or size of tooth have been presented [17–21]. Recent studies show the methods based on the size of tooth or fractions of crown and root growth can make the assessment more difficult, thus resulting in less precision. Conversely, the Demirjian's stages based on the morphological changes of tooth have been recommended for assessing the dental maturity because of the detailed description of the stages and good reproducibility [37,38].

In the present study, the mean age of the Demirjian's stages was likely to be lower in female than in male subjects with the differences being significant mainly at stages E, F and G, as shown in Table 2. These results indicate that the development of permanent teeth in Korean females is more advanced than in males, which is in agreement with the results from previous studies [14,15,17]. The Demirjian's stage H was omitted in the analysis of the mean age of the stages because once the development of a tooth reaches stage H, no change occurs with an age increase. This causes difficulty in determining the upper age range limit of the subjects. For this reason, the Demirjian's

Table 7
A practical example of age estimation for a male subject

Tooth no.[a]	Demirjian's stages	Coefficients[b]
11	H	
12	G	2.18
13	F	
14	F	0.15
15	F	0.79
16	H	
17	F	1.35
21	H	
22	G	−1.08
23	F	−0.04
24	F	0.26
25	F	−0.05
26	H	
27	C	0.38
31	H	
32	H	1.17
33	G	2.61
34	F	−1.04
35	F	−0.04
36	H	−0.19
37	F	2.01
41	H	0.55
42	H	−0.40
43	G	−0.83
44	F	0.77
45	F	−0.25
46	H	
47	F	−1.18

Sum of numerical values = 7.14, constant = 3.62, estimated age = 10.76, actual age = 10.9, difference of ages = 0.14.

[a] Two-digit system was used for the numbering of teeth (e.g. 14 denotes the right maxillary first premolar).

[b] Numerical values and the constant are pertinent values from Table 4.

stage G of the second molar, which develops last, was used to determine the time when the development of permanent teeth is completed. The Demirjian's stage G of the second molars showed 95th percentiles at age from 16.7 to 17.4 years in male and from 17.1 to 17.3 years in female subjects (Table 3) and was last observed at age 18 in both male and female subjects. The results show that the development of permanent teeth in Korean children, except for the third molar, would be nearly complete by the age of 19 years.

In the present study, to evaluate the relationship between age and dental maturity, instead of the original method used in Demirjian's study, multiple linear regression analysis based on the method of least squares, a widely used and more accessible modeling method, was performed. Each stage of each tooth was treated as an independent variable in the regression process. As a result, a constant and one coefficient for each pertinent valuable stage of a tooth were given, and calculation tables were composed of those coefficients. The estimated age can be calculated by adding the constant to the sum of coefficients of each tooth.

From the results of regression, age estimation was more accurate under 14 years of age. When the subjects older than 14 years were included in the regression process, standard and absolute errors between estimated and actual age increased. One reason for this increase was that the coefficient of each variable, each stage of each tooth in this study, are determined in the regression process to explain the relationship between age and variables with a minimum amount of error in as many samples as possible. As shown in the results, the stage G of the second molars showed 50th percentiles at age from 13.4 to 13.7 years in males and 13.3 to 13.8 years in females. Increasing the frequency of the older subjects with completely developed permanent teeth after 14 years of age would increase the error of regression.

The accuracy of age estimation in the present study was shown by the percentage of subjects whose age was estimated within certain ranges. Age could be estimated, as a result, within ±1.0 year of the actual age in 92.0% of male and 92.5% of female subjects. In previous studies using the Demirjian's stages for age estimation, the accuracy of estimation was calculated differently. In a recent study comparing the accuracy of several methods of age estimation using dental maturity [37], the mean difference between actual age and estimated age was used to evaluate the accuracy. The study showed Demirjian's method revised by Willems et al. [22] was the most accurate. The accuracy, the mean difference between actual and estimated age, was -0.05 ± 0.81 years and -0.20 ± 0.89 years in Caucasian boys and girls, respectively. In addition, for boys, the estimated age using Willems was not statistically different from the chronological age, but it was for girls ($P < 0.01$). When the accuracy of our results is re-evaluated in the same manner, the mean differences between actual and estimated age were 0.00 ± 0.56 years in male and 0.00 ± 0.54 years in female subjects, and the estimated age was not statistically different from actual age in both male and female subjects. Another way of calculating accuracy presented in the studies is to use the Demirjian's stages and polynomial functions for age estimation [14,15]. Calculated as the mean of the residues minimum and maximum in years, the accuracy was 3.95 years [14] and 4.71 years [15]. In a similar manner, the mean of the residues of our results was 0.80 years. Although a direct comparison is not possible due to the different statistical methods, the different age range of the samples, and ethnic differences, the age estimation using the Demirjian's stages and multiple linear regression based on the method of least squares with the data from Korean children can be proposed as sufficiently accurate for application in the field as well as in the clinic.

Overall, the Demirjian's stages were determined to be very reliable and reproducible. In addition, the Demirjian's stages and multiple linear regression analysis based on the method of least squares can provide a more accessible and accurate system to estimate the age of children.

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