Forensic Science International 188 (2009) 107–111

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Development of third molars in Korean juveniles and adolescents

Soo-Hyun Lee, Jeong-Yun Lee, Hee-Kyung Park, Young-Ku Kim *

Department of Oral Medicine & Oral Diagnosis, School of Dentistry & Dental Research Institute, Seoul National University, Yeongeon-Dong 28, Jongno-Gu, Seoul 110-749, Republic of Korea

ARTICLE INFO

Article history:
Received 31 December 2008
Received in revised form 5 February 2009
Accepted 27 March 2009
Available online 1 May 2009

Keywords:
Age estimation
Third molar
Development of tooth
Demirjian's method

ABSTRACT

The aim of the present study was to provide reference data of the Korean population which is adequate to compare with other mongoloid populations and can be applied to the age estimation of Korean juveniles and adolescents. A cross-sectional study was performed on a randomly selected sample of 3301 orthopantomographs taken of patients aged from 4 to 26 years, and the developmental stages of the third molars were evaluated based on Demirjian's stages. The results showed that the development of third molars in the Korean population was likely to begin at age 7 in both males and females and be completed by age 22 in males and 24 in females at the latest, and the level of development of all four third molars correlated significantly with age in both genders. There were significantly more subjects without third molars in females than in males, however, subjects with all four third molars were significantly more common in males than in females. The Demirjian's stages C, F and G could be used as a reference stage to determine dichotomously whether a Korean is more likely to be under or above age 14, 18, or 20, respectively. These results will provide a reference for age estimation of Korean juveniles and adolescents and enable comparison with results from other ethnic populations.

1. Introduction

Age estimation of juveniles and adolescents is commonly required in most civilized countries, since age thresholds of social or legal relevance lie between age 14, 18 or 20. However, only limited information is available for the age estimation of this age group. Although the developmental process of teeth is one of the most valuable biomarkers for age estimation in childhood, the accuracy inevitably decreases in juveniles and adolescents during which period the development of teeth is nearly completed. The third molar is the only tooth of which the level of development can be used for age estimation of this age group. Even though age estimation based on the development of third molars has been reflected as an often-debated or questionable method in relevant literature, third molars are still at the center of medicolegal interest since except for skeletal examination there is no other precise method for estimating the age of adolescents [1]. In line with the recommendations of the Study Group on Forensic Age Diagnostics, age estimates should consist of a physical examination which also records anthropometric data, signs of sexual maturation, potential age-relevant developmental disorders, an X-ray of the left hand and a dental examination which records dentition status and evaluations of an orthopantomogram [2].

Although it is impossible to predict the exact chronological age, evaluating the development of third molars could provide some valuable information on the likelihood of being a certain age [3].

Recently, many studies concerning the development of third molars have been reported and provided reference data of different ethnic groups for comparative studies and age estimation of juveniles and adolescents [1,4–11]. Unfortunately until now the Japanese population has mainly been studied as a representative of the mongoloid population [1,7,9,10].The aim of the present study was to provide reference data of the Korean population which is adequate to compare with other mongoloid populations and can be applied to the age estimation of Korean juveniles and adolescents.

2. Materials and methods

2.1. Materials

A cross-sectional study was performed on a randomly selected sample of 3301 orthopantomographs taken of patients (1610 males and 1691 females whose age were 15.2 ± 6.7 and 15.5 ± 6.5, respectively) who visited the Seoul National University Dental Hospital from 2004 to 2005 and were aged from 4 to 26 years, which is a sufficient age range that allows the complete development of third molars. Table 1 shows the distribution of subjects according to gender and age. To accomplish even distribution of subjects throughout the age range and gender, we selected 5–10 subjects randomly from each pool of subjects with 0.1 year's interval of age and respective gender. Radiographs of patients were excluded that showed any deformity or disturbance of growth influencing the development of teeth or reflected a history of

* Corresponding author. Tel.: +82 2 2072 2615; fax: +82 2 744 9135.
E-mail address: ykkim1@snu.ac.kr (Y.-K. Kim).

0379-0738/$ – see front matter © 2008 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.forsciint.2009.03.033

Table 1
Distribution of subjects according to gender and age.

Age	Gender		Total
	Male	Female	
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
21	70	70	140
22	70	70	140
23	70	70	140
24	69	69	138
25	68	70	138
26	66	71	137
Total	1610	1691	3301

extraction of a third molar. The research protocol was approved by the Institutional Review Board of the University Hospital (#CRI07013).

2.2. Methods

The developmental level of third molars was estimated by the method proposed by Demirjian et al. [12], which divides the developmental process of the tooth into 8 stages from A to H. Two well trained examiners observed the radiographs after a period of mutual calibration. To test intra- and inter-examiner reliability, two different examiners staged the development of teeth on 100 randomly selected radiographs. Each examiner repeated the process after 2 weeks (intra-examiner), and data from each examiner were compared (inter-examiner) to assess reliability.

2.3. Statistical analysis

The intra-class correlation coefficient (ICC) was used to assess intra- and inter-examiner reliabilities. Chi-square test and independent sample *t*-test were performed to evaluate the difference in the prevalence of third molars between gender groups and the mean age of each Demirjian's stage, respectively. Relationship between age and the level of development of third molars was evaluated by multiple linear regression analysis. All statistical analyses were performed using SPSS 11.0 for Windows.

Table 2
Frequency of the Demirjian's stage of tooth 18.

Age	Demirjian's stage																	
	Male								Total	Female								Total
	A	B	C	D	E	F	G	H		A	B	C	D	E	F	G	H	
7										3	1							4
8	10	4	2						16	15								15
9	19	6	6						31	20	10	2						32
10	17	17	12	1					47	10	22	11						43
11	5	15	23	5	1	1			50	8	9	24	8	1				50
12	3	9	23	16					51	3	4	28	12	2				49
13		3	15	17	7				42		3	16	26	12				57
14		1	4	13	17	6	2		43			8	14	25	9	1		57
15			2	11	22	18	4		57			2	20	35	22	2		81
16			3	5	12	23	8	1	52			4	14	33	35	11		97
17				4	13	17	18	2	54				8	16	13	7	1	45
18			2	2	7	10	19	10	50				1	4	19	16	4	44
19					1	3	13	33	50					3	14	16	20	53
20					1		5	45	51					2	10	10	30	52
21						2	3	46	51					1	5	9	27	42
22							1	47	48						1	6	41	48
23																4	36	40
24																1	45	46
Total	54	55	92	74	81	80	73	184	693	59	49	95	103	134	128	83	204	855

Table 3
Frequency of the Demirjian's stage of tooth 28.

Age	Demirjian's stage																	
	Male								Total	Female								Total
	A	B	C	D	E	F	G	H		A	B	C	D	E	F	G	H	
7										3	1							4
8	11	4	2						17	18								18
9	17	7	7						31	20	10	3						33
10	18	15	15	1					49	14	19	14						47
11	11	19	24	5	1				60	7	14	24	8	1				54
12	2	11	27	16	1				57	3	3	32	12					50
13		1	15	19	7				42		1	18	27	12				58
14	1	2	3	11	18	5			40		2	5	18	22	10	1		58
15			2	10	19	19	4		54			4	13	36	23	2		78
16				6	17	22	9	2	56			3	14	34	33	9		93
17				4	13	19	17	1	54				7	14	14	7	2	44
18			1		6	11	18	12	48				1	6	21	13	5	46
19					4	4	14	34	56					3	13	18	18	52
20							6	44	50					3	12	10	28	53
21						2	3	49	54						6	11	29	46
22							1	48	49						1	3	43	47
23																2	41	43
24																1	45	46
Total	60	59	96	72	86	82	72	190	717	65	50	103	100	131	133	77	211	870

3. Results

Intra- and inter-examiner reliability in ICC value were as high as 0.99 ($P < 0.001$) and 0.98 ($P < 0.001$), respectively, indicating excellent reliability. Tables 2–5 show the frequency of each Demirjian's stages of third molars. The age range of subjects who had at least one third molar before the stage H was 7.0–22.9 years in males and 7.0–24.9 years in females. Further analyses were performed on subjects within these age ranges. Coefficients of determination (r^2) by multiple linear regression analysis were 0.8359 in males and 0.8120 in females with 95% confidence interval. The level of development of all four third molars correlated significantly with age in both genders. When investi-

Table 4
Frequency of the Demirjian's stage of tooth 38.

Age	Demirjian's stage																	
	Male								Total	Female								Total
	A	B	C	D	E	F	G	H		A	B	C	D	E	F	G	H	
7	1								1	5	1							6
8	11	1	2						14	14								14
9	21	8	4						33	22	7	1						30
10	22	20	13	1					56	12	19	16						47
11	5	19	37	2					63	10	11	36	3					60
12	2	5	41	8	1				57	6	10	33	10					59
13	1	4	25	21	5	1			57	2	1	32	21	8				64
14	1		11	20	10	5			47	1	1	10	31	21	4	1		69
15	1		2	13	13	27	5		61	1		4	23	38	17	1		84
16		1		12	18	24	9		64			3	26	33	36	8		106
17				5	11	22	18		56			2	11	16	10	11	1	51
18				1	7	15	25	6	54				3	16	13	17	4	53
19					3	3	17	32	55					6	17	19	20	62
20					1	1	7	47	56					3	9	13	31	56
21						1	5	51	57					1	4	15	30	50
22							4	51	55						1	7	42	50
23															1	3	47	51
24																1	51	52
Total	65	58	135	83	69	99	90	187	786	73	50	137	128	142	112	96	226	964

Table 5
Frequency of the Demirjian's stage of tooth 48.

Age	Demirjian's stage								
	Male								Total
	A	B	C	D	E	F	G	H	
7	1								1
8	11	1	2						14
9	23	8	5						36
10	16	22	12	1					51
11	11	13	35	3					62
12	4	7	41	8	1				61
13		4	30	18	6				58
14	1	1	12	17	10	6			47
15			2	13	17	28	3		63
16		1		11	16	26	8		62
17			1	9	6	24	16		56
18				1	6	20	21	5	53
19				1	1	5	16	33	56
20						2	7	46	55
21						2	4	50	56
22							4	52	56
23									
24									
Total	67	57	140	82	63	113	79	186	787

Age	Demirjian's stage								
	Female								Total
	A	B	C	D	E	F	G	H	
7	5	1							6
8	14								14
9	21	8	1						30
10	14	18	14						46
11	9	13	35	2	1				60
12	9	5	34	9	1				58
13	5		27	23	7				62
14	1		10	31	19	6	1		68
15			4	21	42	17	2		86
16			3	28	31	39	7		108
17			2	10	12	14	10	1	49
18				1	16	19	15	3	54
19					5	18	22	19	64
20					3	10	12	32	57
21						7	10	32	49
22						1	7	47	55
23						1	2	44	47
24									
Total	78	45	130	125	137	132	88	178	913

gating the prevalence of third molars, subjects aged less than 16 years were excluded to avoid mistaking subjects whose third molars had not begun to develop yet for ones without third molars, namely, agenesis, because the Demirjian's stage A, the beginning of development of the third molar, was observed by the age of 15 years in both males and females, as shown in Tables 2–5. The prevalence of third molars in 469 males from age 16 to 22 and 660 females from age 16 to 24 is shown in Table 6. Chi-square test results revealed that the left maxillary third molar showed significantly higher frequency in males than in females. Subjects without third molars were significantly more common in females than in males, and subjects with all four third molars were significantly more frequent in males than in females. Table 7 shows the means and standard deviations of age estimations according to the Demirjian staging and gender differences. The means and standard deviations were calculated with third molars of males aged under 23 years and females under 25 years old. Stages F and G showed significant differences by gender ($P < 0.01$). Table 8 shows the probability of being less than age 14, 18, or 20 which are age thresholds of social or legal relevance in Korea. The probabilities of being less than age 14, 18, or 20 decrease steeply to the lower half when passing the stages C to D, F to G, and G to H, respectively, indicating that stages C, F, and G can be used as reference stages to determine dichotomously the probability of being less or more than age thresholds of social or legal relevance.

Table 6
Prevalence of third molars.

		Male		Female		Total	
		N	Percentage	*N*	Percentage	*N*	Percentage
Tooth no.	18	356	75.9	467	70.8	823	72.9
	28**	367	78.3	470	71.2	837	74.1
	38	397	84.6	531	80.5	928	82.2
	48	394	84.0	527	79.8	921	81.6
Number of third molars	0*	26	6	59	9	85	8
	1	25	5	39	6	64	6
	2	65	14	95	14	160	14
	3	53	11	102	15	155	14
	4**	300	64	365	55	665	59
	Total	469	100	660	100	1129	100

Age ranges of male subjects were from age 16 to 22 and from age 16 to 24 for female. Significance of gender difference of prevalence of third molars was analyzed by Chi-square test.
* $P < 0.05$.
** $P < 0.01$.

Table 7
Mean and standard deviations of age of the Demirjian's stages from A to H.

Demirjian's stage	Tooth no.	Males			Females		
		Mean	SD	*N*	Mean	SD	*N*
A	18	9.9	1.1	54	9.7	1.3	59
	28*	10.1	1.3	60	9.7	1.3	65
	38	10.1	1.4	65	10.1	1.6	73
	48	10.1	1.3	67	10.3	1.7	78
B	18	11.0	1.3	55	10.7	1.2	49
	28	11.1	1.2	59	10.8	1.3	50
	38	11.1	1.3	58	11.0	1.2	50
	48*	11.2	1.5	57	10.7	1.0	45
C	18	12.2	1.8	92	12.5	1.5	95
	28*	11.9	1.6	96	12.4	1.4	103
	38*	12.2	1.3	135	12.6	1.5	137
	48	12.3	1.4	140	12.6	1.5	130
D	18	14.1	1.7	74	14.4	1.7	103
	28	14.0	1.6	72	14.3	1.7	100
	38	14.6	1.5	83	15.0	1.6	128
	48	14.8	1.8	82	14.9	1.5	125
E	18	15.8	1.6	81	15.9	1.6	134
	28	15.9	1.7	86	15.9	1.6	131
	38	16.2	1.7	69	16.4	1.7	142
	48	15.8	1.5	63	16.2	1.6	137
F	18**	16.7	1.5	80	17.5	1.9	128
	28**	16.8	1.4	82	17.5	1.9	133
	38***	16.7	1.4	99	17.6	1.9	112
	48***	16.9	1.5	113	17.7	1.9	132
G	18***	18.2	1.6	73	19.3	2.1	83
	28**	18.3	1.5	72	19.2	1.9	77
	38***	18.6	1.6	90	19.5	1.9	96
	48**	18.7	1.6	79	19.4	1.8	88
H	18	20.9	1.3	184	22.3	1.8	204
	28*	20.9	1.3	190	22.3	1.7	211
	38*	21.1	1.2	187	22.4	1.7	226
	48	21.1	1.2	186	22.3	1.7	222

SD: Standard deviation. *N*: number of subjects. The means and standard deviations were calculated with the third molars of males under age 23 and females under age 25, respectively.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

4. Discussion

There is no doubt that age estimation is one of the most important tools of forensic science used for individual identification. There have been many studies estimating chronological age based on several aspects of the degeneration of teeth, e.g. secondary dentin formation, attrition, color change of teeth, etc. [13–23]. Methods of age estimation using tooth wear and the development of permanent teeth were reported in 2000, 2007 and 2008 by our lab, and have been proved to be valuable and useful in the field [24–26].

For the age estimation of children, the level of development of permanent teeth is an excellent biomarker, but the accuracy inevitably decreases in juveniles and adolescents in whom the development of permanent teeth except for third molars is almost completed. Only limited information is available for the age estimation of these age groups, and radiographic examination of the development of third molars and skeletal development has been recommended [27]. Recently, many studies on the development of the third molar have become available. Ethnicity has been proved to play a role in the development of the third molar and

Table 8
Probabilities of being under age 14, 18, or 20.

Demirjian's stage	Tooth no.	Male			Female		
		14	18	20	14	18	20
A	18	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
	28	**99.9%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
	38	**99.8%**	**100.0%**	**100.0%**	**99.2%**	**100.0%**	**100.0%**
	48	**99.9%**	**100.0%**	**100.0%**	**98.6%**	**100.0%**	**100.0%**
B	18	**98.9%**	**100.0%**	**100.0%**	**99.6%**	**100.0%**	**100.0%**
	28	**99.0%**	**100.0%**	**100.0%**	**99.5%**	**100.0%**	**100.0%**
	38	**98.4%**	**100.0%**	**100.0%**	**99.3%**	**100.0%**	**100.0%**
	48	**97.2%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**
C	18	**83.8%**	**99.9%**	**100.0%**	**85.1%**	**100.0%**	**100.0%**
	28	**90.9%**	**100.0%**	**100.0%**	**87.4%**	**100.0%**	**100.0%**
	38	**90.9%**	**100.0%**	**100.0%**	**83.1%**	**100.0%**	**100.0%**
	48	**88.0%**	**100.0%**	**100.0%**	**82.8%**	**100.0%**	**100.0%**
D	18	47.1%	**98.9%**	**100.0%**	40.7%	**98.3%**	**100.0%**
	28	50.6%	**99.5%**	**100.0%**	42.4%	**98.5%**	**100.0%**
	38	35.4%	**98.8%**	**100.0%**	27.5%	**97.1%**	**99.9%**
	48	33.4%	**96.8%**	**99.9%**	27.5%	**97.8%**	**100.0%**
E	18	13.1%	**90.4%**	**99.4%**	12.5%	**90.9%**	**99.5%**
	28	12.9%	**89.0%**	**99.2%**	10.8%	**90.7%**	**99.5%**
	38	9.4%	**85.1%**	**98.7%**	7.7%	**83.6%**	**98.5%**
	48	11.7%	**92.4%**	**99.7%**	8.5%	**86.1%**	**99.0%**
F	18	3.8%	**80.3%**	**98.5%**	3.1%	**61.2%**	**91.3%**
	28	2.3%	**80.0%**	**98.8%**	3.3%	**60.3%**	**90.5%**
	38	2.6%	**83.0%**	**99.2%**	2.8%	**58.1%**	**89.6%**
	48	2.3%	**77.6%**	**98.4%**	2.7%	**56.9%**	**89.0%**
G	18	0.5%	45.5%	**87.2%**	0.6%	26.9%	**63.2%**
	28	0.2%	41.8%	**87.4%**	0.3%	26.0%	**65.3%**
	38	0.2%	36.0%	**81.0%**	0.2%	21.0%	**60.1%**
	48	0.2%	33.9%	**79.6%**	0.1%	22.4%	**63.8%**
H	18	0.0%	1.4%	25.1%	0.0%	0.7%	9.8%
	28	0.0%	1.6%	25.6%	0.0%	0.7%	9.6%
	38	0.0%	0.4%	18.0%	0.0%	0.6%	8.4%
	48	0.0%	0.4%	17.9%	0.0%	0.5%	8.3%

Figures in bold characters mean the probability of more than 50%.

Table 9
Means and standard deviations of age of the Demirjian's stages from D to H at different age ranges.

Demirjian's stage	Gender	Tooth no.	14–24 years			14–25 years			12–26 years		
			Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*
D	Male	18	15.6	1.2	35	15.6	1.2	35	14.4	1.6	68
		28	15.5	1.0	31	15.5	1.0	31	14.2	1.4	66
		38	15.5	1.1	51	15.5	1.1	51	14.7	1.4	80
		48	15.8	1.3	52	15.8	1.3	52	14.9	1.6	78
	Female	18	15.7	1.0	57	15.7	1.0	57	14.6	1.5	95
		28	15.6	1.1	53	15.6	1.1	53	14.6	1.5	92
		38	15.7	1.1	94	15.7	1.1	94	15.0	1.5	125
		48	15.6	1.1	91	15.6	1.1	91	15.0	1.5	123
E	Male	18	16.1	1.5	73	16.1	1.5	73	15.9	1.6	80
		28	16.2	1.5	77	16.2	1.5	77	16.0	1.6	85
		38	16.5	1.4	63	16.5	1.4	63	16.2	1.7	69
		48	16.2	1.2	56	16.2	1.2	56	15.8	1.5	63
	Female	18	16.2	1.4	119	16.2	1.4	119	15.9	1.6	133
		28	16.2	1.4	118	16.2	1.4	118	16.0	1.5	130
		38	16.5	1.6	134	16.5	1.6	134	16.4	1.7	142
		48	16.4	1.5	128	16.4	1.5	128	16.3	1.6	136
F	Male	18	16.8	1.4	79	16.8	1.4	79	16.8	1.4	79
		28	16.8	1.4	82	16.8	1.4	82	16.8	1.4	82
		38	16.7	1.3	98	16.7	1.3	98	16.7	1.4	99
		48	16.9	1.5	113	16.9	1.5	113	16.9	1.5	113
	Female	18	17.5	1.9	128	17.5	1.9	128	17.5	1.9	128
		28	17.5	1.9	133	17.5	1.9	133	17.5	1.9	133
		38	17.6	1.9	112	17.6	1.9	112	17.6	1.9	112
		48	17.7	1.9	132	17.7	1.9	132	17.7	1.9	132
G	Male	18	18.2	1.6	73	18.2	1.6	73	18.2	1.6	73
		28	18.3	1.5	72	18.3	1.5	72	18.3	1.5	72
		38	18.6	1.6	90	18.6	1.6	90	18.6	1.6	90
		48	18.7	1.6	79	18.7	1.6	79	18.7	1.6	79
	Female	18	19.2	2.0	82	19.3	2.1	83	19.3	2.1	83
		28	19.2	1.8	76	19.2	1.9	77	19.2	1.9	77
		38	19.5	1.8	95	19.5	1.9	96	19.5	1.9	96
		48	19.4	1.8	88	19.4	1.8	88	19.4	1.8	88
H	Male	18	21.4	1.6	235	21.9	1.8	281	22.4	2.1	326
		28	21.4	1.6	240	21.9	1.8	287	22.3	2.1	327
		38	21.6	1.4	238	22.1	1.7	291	22.5	2.0	336
		48	21.6	1.4	234	22.1	1.7	284	22.5	2.0	332
	Female	18	21.6	1.5	159	22.3	1.8	204	22.8	2.0	244
		28	21.7	1.5	166	22.3	1.7	211	22.8	2.0	250
		38	21.8	1.5	175	22.4	1.7	226	22.9	1.9	271
		48	21.8	1.4	178	22.3	1.7	222	22.8	1.9	260

Age ranges referred to the previous studies, 14–24 years in Arany et al. [1], 14–25 years in Solari and Abramovitch [5], and 12–26 years in Olze et al. [7,10].

invaluable reference data of various populations have been reported [1,4–11].

But it is strange that although the mean age of stages or the probability of being a certain age can be directly affected by the age range of subjects, the method of determining the age range of subjects has not been clearly described in most of the previous studies. If the range of age was determined arbitrarily, the mean ages of early and late stages could have been miscalculated and could be an inadequate reference for the entire population. Moreover, in most countries the ages mainly affected by such miscalculation such as age 14 and 18 are ages of social and legal relevance. The age range of subjects should be determined carefully to eliminate the possibility of including the subjects who should be excluded or vice versa. More practically, as it can be seen in Table 9, if the upper boundary of the age range of subjects of the present study had been determined at age 26 as in the previous study [10], the mean age of stage H third molars would have been calculated to be 0.5–1.5 years more than the actual results shown in Table 7 since the time to reach stage H for the third molar of 25- or 26-year-old subjects was unknown. In the same way, if the lower boundary of the age range of subjects had been determined at age 14 as in previous studies [1,5], the mean age of stage D third molars would have been calculated to be 0.7–1.5 years more than the actual results shown in Table 7 because of the subjects who had stage D third molars but were younger than age 14.

In the present study, the age range of subjects was determined from a preliminary survey on a randomly selected sample of 3301 orthopantomographs taken of patients aged from age 4 to 26. As results showed, the age range of subjects who had at least one third molar before stage H was from age 7.0 to 22.9 in males and 7.0 to 24.9 in females. The development of the third molars was likely to begin at age 7 in both Korean males and females and completed by age 22 in males and 24 in females at the latest. Subsequent analyses were done with the subjects aged within these ranges. To assess the development of the third molars, crypt stage has been taken into consideration in addition to the Demirjian's stages [11]. However, while the crypts of the mandibular third molars could be seen clearly, it could not be discriminated reliably for the maxillary teeth since adjacent structures on the orthpantomogram, e.g. floor or posterior wall of maxillary sinus, zygomatic arch, and innominate line of zygomatic process overlap the area. So the Demirjian's stage A was regarded as the sign of the beginning of development in this study.

Multiple linear regression analysis showed strong correlation between age and the level of development of third molars. Determination of coefficients in this study was much higher than those of previous studies [3,11]. This may be due to the difference of statistical processing. In the regression of the present study, each stage of each tooth was converted to a dummy variable and treated independently, because the Demirjian's stages are ordinal and not

an equal spacing scale. There is no need to calculate the maturity scores in this regression process, Demirjian's stages are used directly as variables, which makes the statistical process simpler with reduced possibility of statistical errors [26].

The prevalence of third molars after age 16 is shown in Table 6. The gender specific differences in frequencies of subjects without third molars or with all four third molars were observed. Prevalence can be changed according to the age range and distribution of subjects in the sample. In the present study, age range was determined based on the preliminary study. Considering the fact that stage A was observed in subjects as young as age 15, for subjects under age 16, it is difficult to reliably determine whether the third molars will develop later or are actually absent. So the subjects aged less than 16 years were excluded from the estimation of prevalence. In previous studies based on Spanish [8] and Turkish [11] populations the prevalence of the third molars between age 4 and 20 has been evaluated to be 37.1% and 14.2%, respectively. Even when the ethnic factor is considered, the 8% figure of our study is much lower than those of previous reports. Ethnicity could not be the sole factor to sufficiently explain this deviation. The difference might be brought about by the difference in age range, which was set between age 4 and 20 in both previous studies in contrast to age 16–22 in male and 16 and 24 in female subjects in this study. In addition, the large difference with the two previous studies might be due to the distribution of subjects according to age. When the prevalence of third molars with subjects aged between 4 and 20 years of our study, the proportion of subjects without third molars was calculated to be 34.9%, which reflects the fact that the subjects whose third molars could develop later are comprised. The large proportion of the subjects younger than the age when agenesis of third molars can be determined certainly could increase the proportion of the subjects without third molars by mistaking the subjects whose third molars will develop later for ones without third molars.

The results show that complete development of third molars is achieved earlier in males than in females and the gender differences were significant in stages F and G. This advancement of development of teeth of males observed in stages F and G is consistent with previous studies [1,4,27], though some studies have not found gender specific differences [8,9].

As shown in Table 9, when the development of third molars of the Korean population estimated from subjects within the age range previously described [1,5,10] are compared to that of Japanese population belonging to the same mongoloid ethnic group, although direct comparison is impossible, results of the present study were in more agreement with Arany's report [1] than Olze's [9].

Table 8 shows the probability of being under age thresholds of social or legal relevance in Korea. The age of 14 years is the legally relevant threshold for criminal responsibility and, the age of 20 years is the relevant age for adult in Korea, while age 18 is adapted in most European countries. As described before [3], only the likelihood of being a certain age could be derived from the results rather than being able to predict the exact age. Steep decrease to below half of the probabilities of being less than age 14, 18, or 20 was observed when passing the stages C to D, F to G, and G to H, respectively. If a Korean male subject has third molars of the Demirjian's stage G, it can be presumed that there would be a higher probability of he being more than age 18 than that of being less than age 18 and a higher probability of he being less than age 20 than that of being more than age 20.

Collectively, third molars in the Korean population were likely to appear at age 7 in both males and females, and develop completely by the age 22 in males and 24 in females, respectively, and the level of development of third molars shows strong correlation with age. There were significantly more subjects without third molars in females than in males, and significantly more subjects with all four third molars in males than females. The Demirjian's stages C, F and G can be used as a reference stage to determine dichotomously whether a Korean is more likely to be less or more than age 14, 18, or 20, respectively. These results of the present study will provide the reference for age estimation of Korean juveniles and adolescents and enable comparison with the results from other ethnic populations. Further, if the consensus on the sample selection criteria and the procedure of filing data will allow more reliable and valuable data on the development of the third molar.

References

[1] S. Arany, M. Iino, N. Yoshioka, Radiographic survey of third molar development in relation to chronological age among Japanese juveniles, J. Forensic Sci. 49 (2004) 534–538.
[2] A. Schmeling, W. Reisinger, G. Geserick, A. Olze, Age estimation of unaccompanied minors; Part I. General consideration, Forensic Sci. Int. 159 (2006) S61–S64.
[3] H.H. Mincer, E.F. Harris, H.E. Berryman, The A.B.F.O. study of dental age assessment, Hum. Biol. 45 (1973) 379–390.
[4] K. Mesotten, K. Gunst, A. Carbonez, G. Willems, Dental age estimation and third molars: a preliminary study, Forensic Sci. Int. 129 (2002) 110–115.
[5] A.C. Solari, K. Abramovitch, The accuracy and precision of third molar development as an indicator of chronological age in Hispanics, J. Forensic Sci. 47 (2002) 531–535.
[6] K. Mesotten, K. Gunst, A. Carbonez, G. Willems, Chronological age determination based on the root development of a single third molar: a retrospective study based on 2513 OPGs, J. Forensic Odontostomatol. 21 (2003) 31–35.
[7] A. Olze, M. Taniguchi, A. Schmeling, B. Zhu, Y. Yamada, H. Maeda, G. Geserick, Comparative study on the chronology of third molar mineralization in a Japanese and a German population, Legal Med. 5 (2003) S256–260.
[8] M.V. Bolaños, H. Moussa, M.C. Manrique, M.J. Bolaños, Radiographic evaluation of third molar development in Spanish children and young people, Forensic Sci. Int. 133 (2003) 212–219.
[9] A. Olze, M. Taniguchi, A. Schmeling, B. Zhu, Y. Yamada, H. Maeda, G. Geserick, Studies on the chronology of third molar mineralization in a Japanese population, Legal Med. 6 (2004) 73–79.
[10] A. Olze, A. Schmeling, M. Taniguchi, H. Maeda, P.V. Niekerk, K. Wernecke, G. Geserick, Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization, Int. J. Legal Med. 118 (2004) 170–173.
[11] K. Orhan, L. Ozer, A.I. Orhan, S. Dogan, C.S. Paksoy, Radiographic evaluation of third molar development in relation to chronological age among Turkish children and youth, Forensic Sci. Int. 165 (2007) 46–51.
[12] A. Demirjian, H. Goldstein, J.M. Tanner, A new system of age assessment, Hum. Biol. 45 (1973) 211–227.
[13] G. Gustafson, Age determinations on teeth, J. Am. Dent. Assoc. 41 (1950) 45–54.
[14] G. Johanson, Age determination from human teeth, Odontol. Rev. 22 (Suppl. 21) (1971) 40–126.
[15] G. Bang, E. Ramm, Determination of age in humans from root dentin transparency, Acta Odontol. Scand. 28 (1970) 3–35.
[16] G.D. Dalitz, Age determination of adult human remains by teeth examination, J. Forensic Sci. Soc. 2 (1962) 11–21.
[17] W.R. Maples, An improved technique using dental histology for estimation of adult age, J. Forensic Sci. 23 (1978) 764–770.
[18] T. Solheim, P.K. Sundnes, Dental age estimation of Norwegian adult-a comparison of differential methods, Forensic Sci. Int. 16 (1980) 7–17.
[19] G. Øilo, B.L. Dahl, G. Hatle, A.-L. Gad, An index for evaluating wear of teeth, Acta Odontol. Scand. 45 (1987) 361–365.
[20] B.L. Dahl, G. Øilo, A. Andersen, O. Bruaset, The suitability of a new index for the evaluation of dental wear, Acta Odontol. Scand. 47 (1989) 205–210.
[21] M.J. Roberts, K.M. Söderholm, Comparison of three techniques for measuring wear of dental restorations, Acta Odontol. Scand. 47 (1989) 367–374.
[22] M. Lopez-Nicolas, M. Canteras, A. Luna, Age estimation by IBAS image analysis of teeth, Forensic Sci. Int. 45 (1990) 143–150.
[23] V.K. Kashyap, N.R. Koteswara Rao, A modified Gustafson method of age estimation from teeth, Forensic Sci. Int. 47 (1990) 237–247.
[24] Y.K. Kim, H.S. Kho, K.H. Lee, Age estimation by occlusal tooth wear, J. Forensic Sci. 45 (2000) 303–309.
[25] J.I. Yun, J.Y. Lee, J.W. Chung, H.S. Kho, Y.K. Kim, Age estimation of Korean adults by occlusal tooth wear, J. Forensic Sci. 52 (2007) 678–683.
[26] S.E. Lee, S.H. Lee, J.Y. Lee, H.K. Park, Y.K. Kim, Age estimation of Korean children based on dental maturity, Forensic Sci. Int. 178 (2008) 125–131.
[27] S. Ritz-Timme, C. Cattaneo, M.J. Collins, E.R. Waite, H.W. Schütz, H.J. Kaatsch, H.I. Borrman, Age estimation: the state of the art in relation to the specific demands of forensic practice, Int. J. Legal Med. 113 (2000) 129–136.