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SHORT COMMUNICATION

The chronology of second and third molar development in Koreans and its application to forensic age estimation

Sang-Seob Lee · Young-Sub Byun · Myung Jin Park · Jong-Hoon Choi · Chang-Lyuk Yoon · Kyoung-Jin Shin

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Abstract The accuracy of forensic age estimation based on the chronology of second (M2) and third molar (M3) development was investigated using 2,087 orthopantomograms of Korean men and women aged between 3 and 23 years. The developmental stages of M2s and M3s in these subjects were classified using the criteria of Demirjian. Inter-observer reliability and statistical data on each stage of mineralization of M2s and M3s were evaluated. The left–right symmetries of the maturation degrees in the M2s and M3s were observed in both sexes, between which no arch differences were found, but statistically significant sex-specific differences were observed in some stages of M2 and M3 development. In multiple regression analysis, a strong positive relationship was observed between age and mineralization of M2s and M3s. The regression formulas for estimating the age of Koreans were presented based on sex and combination of teeth. These results suggest that the developments of second and third molars can be considered as valuable age indicators in Korean adolescents and young adults.

Keywords Koreans · Age estimation · Second molar · Third molar · Regression formula

Introduction

Age estimation is an important step in the identification of unknown human remains [1]. Because of its greater accuracy compared with other age indicators in the body, age estimation with teeth has been widely employed in human identification. However, accurate age estimation for late teens and young adults still has some difficulties even when teeth were used. This is because the development of almost permanent teeth may be completed, and regressive changes in teeth with increasing age may not yet appear at that age. For the estimation of the transition zone age between non-adults and adults, third molars (M3s) have been most widely used [2–15], but it was shown that the development of the teeth varies according to the population; Thevissen et al. [7] insisted that dental age estimation especially for young individuals should be based on the data collected from the appropriate population group. Therefore, the establishment of population-specific standards of M3s was considered to be important for enhancing the accuracy of age estimation based on the development of these teeth.

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S.-S. Lee
Division of Forensic Medicine, National Forensic Service,
331-1 Shinwol 7-Dong, Yangcheon-Gu,
Seoul 158-707, South Korea

Y.-S. Byun · J.-H. Choi
Department of Oral Diagnosis and Oral Medicine,
Yonsei University College of Dentistry,
250 Seongsanno, Seodaemun-Gu,
Seoul 120-752, South Korea

M. J. Park · K.-J. Shin (✉)
Department of Forensic Medicine,
Yonsei University College of Medicine,
250 Seongsanno, Seodaemun-Gu,
Seoul 120-752, South Korea
e-mail: kjshin@yuhs.ac

C.-L. Yoon
Department of Oral Medicine and Forensic Odontology,
Chosun University College of Dentistry,
421 Seosuk-Dong, Dong-Gu,
Gwangju 501-717, South Korea

However, M3s are often missing congenitally or have been extracted, thereby making them not always available as an age indicator. Moreover, if M3s are malformed or malpositioned, the age estimation may be difficult. To overcome these limitations, the combined evaluation of the second molar (M2) with the third molar was suggested in the Korean population [16, 17]. However, these reports did not employ the criteria of Demirjian [18], and therefore, it is difficult to compare the patterns of the development of M2s and M3s in the Korean population with those of other populations. In this regard, the chronology of M2 and M3 development was investigated in 2,087 Koreans using Demirjian's classification system, and multiple regression formulas between age and mineralization of these teeth were calculated to apply it to the forensic age estimation of Korean adolescents and young adults.

Materials and methods

A total of 2,087 digital orthopantomograms were randomly selected from the Dental Hospital of Yonsei University in Seoul, Korea. They consisted of 1,030 males and 1,057 females in the age range of 3 to 23 years (see the Electronic supplementary Table S1). Radiographs that showed malformed, largely decayed, and endodontically treated teeth and those of patients with gross pathologic lesions in the jaw bones and systemic endocrinal disorders were excluded from the study. The chronological age of the radiograph was determined based on the difference between the date of birth and the time of capture of the radiograph. This study was carried out according to the protocols approved by the Severance Hospital Institutional Review Board (no. 4-2009-0175).

The stages of maturity of the M2s and M3s in both the left and right sides of both the maxillary and mandibular arches were classified according to the eight-stage scheme presented by Demirjian et al. [18]. The two examiners observed all radiographs after a preliminary training session. The examiners were blinded to the sexes and ages of the subjects during all phases of the study. Inter-observer reliability was determined using Kappa statistics, based on the data from each examiner. Statistical data including means and standard deviations of the ages were obtained for each stage of mineralization in both sexes. For the average of a final stage H which depends on the age maximum of the investigated reference population, 50% probability values were calculated. The left–right symmetries and arch differences for the degrees of maturation in all four M2s and M3s in both sexes were evaluated using a Chi-square test. The relationships between the chronological age and the degrees of calcification of the M2s and M3s were evaluated using multiple linear regression analysis. To perform the regression analysis, data from one side of each jaw were used to avoid unnecessary duplication of mineralization data. Regression analyses were performed in two ways, i.e., treating the developmental stage of each tooth as discrete data and continuous data, respectively. All statistical analyses were performed using SAS 9.1 (SAS Institute Inc., Cary, NC, USA).

Results

The statistical data for all the eight developmental stages of M2s and M3s are presented in the Electronic supplementary Tables S2–S5 and Figs. S1–S4. The mean age for the stage H of M2s and M3s in both sexes is shown in the Electronic supplementary Table S6, where the probability for tooth stage H is 50%. Inter-observer reliability was very excellent in all stages of the M2s and M3s in both jaws and both sexes (kappa value=0.905–0.948). No significant differences were found between the degrees of maturation of the left and right M2s and M3s in either males or females ($p<0.001$). No significant differences were also found between the upper and lower M2s and M3s ($p<0.001$). However, statistically significant sex-specific differences were observed in some stages of development of the upper and lower M2s and M3s; upper right at stages C, D, and E, the upper left at stages D and E, and the lower right and left at stages D and G of M2 (Tables S2 and S3); and upper right at stages A, F, and G, the upper left at stages C, F, and G, and the lower right and left at stages C, F, G, and H of M3 (Tables S4 and S5). M3 formation was slightly advanced in early stages of females, but the rate of formation was reversed after stage E in the maxilla and stage D in the mandible (Figs. S3 and S4). On the other hand, the development of M2 was faster in females at all stages. In the stage H where 50% probability values were calculated, the maxillary M3s of Korean males reach point H approximately 2 years before females, whereas the mandibular M3s of males are 1 years ahead of females (Table S6). In multiple regression analysis, a strong positive relationship was observed between the chronological age and developmental stages of M2s and M3s (Tables 1, 2, 3, and 4). The lowest coefficient of correlation (r^2) was 0.776 when regression analysis was performed for the upper M3 alone in continuous data form, and the highest was 0.947 for the upper and lower M2s in discrete data form.

Discussion

The criteria of Demirjian, which is for evaluating the maturation degree of teeth [18], have been widely employed in many researches on M3s because of its

Table 1 Intercepts and coefficients of regression treating the developmental stage of each tooth as discrete data based on the number of teeth and their locations in the Korean males

Male		Single tooth				Two teeth				Four teeth
		Mx M2	Mx M3	Mn M2	Mn M3	Mx M2+ Mn M2	Mx M3+ Mn M3	Mx M2+ Mx M3	Mn M2+ Mn M3	Mx M2 and M3+ Mn M2 and M3
Intercept		19.63	20.87	19.65	20.83	19.78	21.02	20.87	20.83	21.02
Mx M2	A	−15.78				−9.06				
	B	−14.63				−8.30				
	C	−13.54				−7.97				
	D	−11.68				−7.09		−7.08		−3.93
	E	−9.48				−6.18		−5.79		−3.35
	F	−6.40				−3.95		−3.78		−2.34
	G	−3.40				−2.20		−2.13		−1.38
	H	0.00				0.00		0.00		0.00
Mx M3	A		−10.88				−4.76	−5.14		−2.71
	B		−10.12				−4.87	−4.88		−2.68
	C		−8.69				−5.22	−4.61		−3.34
	D		−6.94				−4.26	−3.74		−2.62
	E		−4.04				−2.47	−2.40		−1.81
	F		−2.60				−1.56	−2.01		−1.36
	G		−1.48				−0.97	−1.36		−0.98
	H		0.00				0.00	0.00		0.00
Mn M2	A			−15.71		−6.91				
	B			−14.75		−6.53				
	C			−13.59		−5.88				
	D			−11.84		−4.81			−5.84	−3.14
	E			−9.91		−3.73			−4.48	−2.17
	F			−6.95		−2.73			−3.52	−1.46
	G			−3.29		−1.60			−1.69	−0.87
	H			0.00		0.00			0.00	0.00
Mn M3	A				−10.95		−6.36		−6.56	−3.08
	B				−10.13		−5.56		−6.24	−2.75
	C				−7.67		−3.44		−4.45	−1.53
	D				−6.09		−2.77		−3.55	−1.07
	E				−4.00		−2.09		−2.84	−0.89
	F				−2.72		−1.34		−1.96	−0.77
	G				−1.12		−0.41		−1.05	−0.42
	H				0.00		0.00		0.00	0.00
r^2		0.94	0.83	0.93	0.84	0.95	0.86	0.90	0.88	0.91

The estimated age can be calculated by adding an intercept to the sum of the numerical values corresponding to the developmental stage of each tooth on each column

Mx maxilla, *Mn* mandible, *M2* second molar, *M3* third molar, (+) combined data, *A–H* developmental stages presented by Demirjian et al. [18]

increased objectiveness by using only anatomical features without including measurements predicting crown and root length. Olze et al. [19] validated five common classification systems for assessing the mineralization of M3s and concluded that Demirjian's stages should be used to evaluate M3s. Dhanjan et al. [20] also reported excellent reproducibility of Demirjian's classification system compared with the systems of Moorrees and Haavikko. For these reasons, the criteria of Demirjian were selected to evaluate the developmental stages of M2s and M3s in the present study, and very excellent inter-observer reliability was observed in all stages of the teeth.

A lot of studies reported on the tendency for more advanced mineralization of the maxillary M3 than of the

Table 2 Intercepts and coefficients of regression treating the developmental stage of each tooth as discrete data based on the number of teeth and their locations in the Korean females

Female		Single tooth				Two teeth				Four teeth
		Mx M2	Mx M3	Mn M2	Mn M3	Mx M2+ Mn M2	Mx M3+ Mn M3	Mx M2+ Mx M3	Mn M2+ Mn M3	Mx M2 and M3+ Mn M2 and M3
Intercept		19.72	21.10	19.71	21.61	19.79	21.84	21.09	21.61	21.82
Mx M2	A	−15.59				−7.86				
	B	−15.04				−7.86				
	C	−13.88				−7.31				
	D	−12.07				−6.42		−8.40		−8.54
	E	−10.00				−5.77		−6.95		−3.72
	F	−6.77				−3.56		−5.14		−2.44
	G	−3.80				−1.83		−2.94		−1.25
	H	0.00				0.00		0.00		0.00
Mx M3	A		−11.98				−5.80	−5.12		−2.44
	B		−10.77				−4.99	−4.52		−2.09
	C		−9.59				−4.39	−4.07		−1.64
	D		−7.30				−4.08	−2.89		−1.18
	E		−4.17				−2.14	−2.18		−0.87
	F		−1.86				−0.79	−1.64		−0.60
	G		−0.98				−0.57	−0.98		−0.52
	H		0.00				0.00	0.00		0.00
Mn M2	A			−15.73		−7.84				
	B			−14.83		−7.19				
	C			−13.80		−6.68			−9.56	
	D			−12.20		−5.86			−7.76	
	E			−10.27		−4.52			−5.90	−3.36
	F			−7.09		−3.49			−4.53	−2.86
	G			−3.80		−2.03			−2.70	−1.78
	H			0.00		0.00			0.00	0.00
Mn M3	A				−12.12		−7.05		−6.37	−3.27
	B				−10.89		−6.52		−5.82	−3.25
	C				−9.49		−5.67		−5.05	−3.06
	D				−6.69		−3.84		−3.38	−2.19
	E				−4.29		−2.88		−2.77	−1.99
	F				−2.25		−1.65		−2.08	−1.71
	G				−1.30		−1.04		−1.29	−1.12
	H				0.00		0.00		0.00	0.00
r^2		0.94	0.81	0.94	0.82	0.95	0.84	0.90	0.90	0.92

The estimated age can be calculated by adding an intercept to the sum of the numerical values corresponding to the developmental stage of each tooth on each column

Mx maxilla, *Mn* mandible, *M2* second molar, *M3* third molar, (+) combined data, *A–H* developmental stages presented by Demirjian et al. [18]

mandibular M3 [2, 3, 9–11, 14]. However, Olze et al. [21] reported no statistically significant differences in chronological M3 mineralization between maxilla and mandible in a Japanese population. In previous reports on Koreans [6, 16, 17], no mention was made of arch differences. Therefore, further study was needed to conclude whether this observation is unique to the Korean population or not. In the present study, the arch differences between maxillary M2s and M3s and their mandibular counterparts were not observed. In addition, side differences between upper and lower M2s and M3s in Koreans were not observed in either sex. This result was similar to those of other population-based reports [2–5, 9, 11, 13–15].

On the other hand, the sexual dimorphism of M3s was found in this study, with significant differences found at stages C, F, and G in the maxilla and at stages C, F, G, and H in the

Table 3 Coefficients of regression treating the developmental stage of each tooth as continuous data based on the number of teeth and their locations in the Korean males

Male	Single tooth				Two teeth				Four teeth
	Mx M2	Mx M3	Mn M2	Mn M3	Mx M2+ Mn M2	Mx M3+ Mn M3	Mx M2+ Mx M3	Mn M2+ Mn M3	Mx M2 and M3+ Mn M2 and M3
Intercept	−2.27	7.65	−2.40	8.09	−2.61	7.38	−0.70	0.42	−0.76
Mx M2	2.68				1.87		1.86		1.04
Mx M3		1.70				0.80	0.79		0.50
Mn M2			2.68		0.86			1.60	0.76
Mn M3				1.65		0.96		0.95	0.38
r^2	0.92	0.81	0.90	0.83	0.92	0.85	0.89	0.88	0.90

The estimated age can be calculated by adding an intercept to the product of the developmental stage of each tooth (A, 1 ~ H, 8) and the numerical value on each column

Mx maxilla, *Mn* mandible, *M2* second molar, *M3* third molar, (+) combined data

mandible. Meinl et al. [4] revealed that in individuals of an Austrian population, root formation stages (E–H) occurred earlier in males than in females. Prieto et al. [13] also reported significant sexual dimorphism in stages E, F, and G, with males reaching the stages earlier than females. In a study based on a Japanese population, significant differences in M3s were revealed in stages D, E, and G [11]. Lee et al. [6] also found significant gender differences at stages C, F, G, and H in a previous population study of Koreans, which is very analogous to our findings. By integrating these findings, it can be concluded that M3s of Korean males develop faster than those of females after stage D or E.

This study also revealed a strong positive correlation between the developmental degrees of M2s and M3s and chronological age in Koreans. In performing multiple regression analysis, the developmental stages of one, two, or four teeth were used as variables to enhance the practicality. As the jaw bones of dead remains were often recovered in parts or fragments, the estimation of age should be performed with one side of the jaw or one jaw bone only, in some cases. In certain forensic conditions, periapical dental radiographs should be used in age estimation instead of orthopantomograms, which have proven to be valuable in human identification [22]. In addition, when estimating the ages of living individuals, one or more M3s were often congenitally missing or had been extracted. In these circumstances, the calculated regression formulas which use the developmental stages of one or two teeth may be useful. The correlation coefficients of regression analysis with combined data from the stages of M2 and M3 were observed to be higher than those only with M3. These results may be due to the reduced variability in M2s compared with that in M3s. In addition, by using combined data for M2 and M3, the span of age estimates can be wider than using data only for M3 (Tables 1, 2, 3, and 4). Meanwhile, the coefficients between stages of M3 and age were much higher than those of previous non-Korean-based studies [8–10], but were similar

Table 4 Coefficients of regression treating the developmental stage of each tooth as continuous data based on the number of teeth and their locations in the Korean females

Female	Single tooth				Two teeth				Four teeth
	Mx M2	Mx M3	Mn M2	Mn M3	Mx M2+ Mn M2	Mx M3+ Mn M3	Mx M2+ Mx M3	Mn M2+ Mn M3	Mx M2 and M3+ Mn M2 and M3
Intercept	−2.74	6.37	−2.79	7.09	−3.10	6.14	−4.44	−2.89	−4.84
Mx M2	2.74				1.71		2.46		1.26
Mx M3		2.04				0.93	0.69		0.31
Mn M2			2.74		1.08			2.14	1.24
Mn M3				1.97		1.18		0.87	0.43
r^2	0.91	0.78	0.90	0.80	0.92	0.82	0.90	0.89	0.91

The estimated age can be calculated by adding an intercept to the product of the developmental stage of each tooth (A, 1 ~ H, 8) and the numerical value on each column

Mx maxilla, *Mn* mandible, *M2* second molar, *M3* third molar, (+) combined data

to those in a previous study of M3s in Koreans [6]. Although it is impossible to compare coefficients directly, the higher value will be able to be explained by differences in samples. In this study, images of digital panoramic radiographs were used, and digital images might be much clearer and more accurate than the conventional images for evaluating the stages of tooth development. In addition, the size of the samples was much larger than those in previous studies. Lee et al. [6] explained that the difference in the coefficients was due to the differences in statistical processing and that asserted stages of tooth development should be treated as an independent and discrete variable. However, some reports [8, 17, 23, 24] presented regression formulas that were deduced by treating stages of tooth development as a continuous variable. The two different statistical approaches were employed in the multiple regression analysis of this study. As a result, the coefficients of regression analysis using the discrete data were observed to be slightly higher than those using the continuous data. However, the difference was so small (0.01–0.03) that it was impossible to conclude that the statistical approach classifying stages of teeth as discrete variables is more accurate than that classifying stages of teeth as continuous variable classification.

For the age estimations of transition zones between non-adults and adults in living individuals, Schmeling et al. [25] recommended combined investigation methods involving physical examinations, inspection of signs of sexual maturation, X-ray examination of the left hand and medial clavicular epiphysis, and dental examinations including the development of third molars. Some reported about the importance of additional features of the ossification status of the medial clavicular epiphysis, and both the visibility of the periodontal ligament and the root pulp for the diagnosis of the important age threshold of 18 years [26–28]. Knell et al. also concluded that the third molar as a sole criterion cannot be considered reliable for attained age of 18 years [29]. In this study, only tooth mineralization was assessed for age estimation of living Koreans. Therefore, to satisfy the international criteria for age estimation in living individuals, future researches about combined investigation of different characteristics of Korean population will be needed.

Conclusions

This study presented Korean population data and regression formulas for forensic age estimation based on the developmental stages of M2s and M3s. These results suggest that the developments of M2s and M3s can be considered valuable age indicators in Korean adolescents and young adults.

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