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ORIGINAL ARTICLE

New models for age estimation and assessment of their accuracy using developing mandibular third molar teeth in a Thai population

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Abstract Age estimation using developing third molar teeth is considered an important and accurate technique for both clinical and forensic practices. The aims of this study were to establish population-specific reference data, to develop age prediction models using mandibular third molar development, to test the accuracy of the resulting models, and to find the probability of persons being at the age thresholds of legal relevance in a Thai population. A total of 1867 digital panoramic radiographs of Thai individuals aged between 8 and 23 years was selected to assess dental age. The mandibular third molar development was divided into nine stages. The stages were evaluated and each stage was transformed into a development score. Quadratic regression was employed to develop age prediction models. Our results show that males reached mandibular third molar root formation stages earlier than females. The models revealed a high correlation coefficient for both left and right mandibular third molar teeth in both sexes ($R = 0.945$ and 0.944 in males, $R = 0.922$ and 0.923 in females, respectively). Furthermore, the accuracy of the resulting models was tested in randomly selected 374 cases and showed low error values between the predicted dental age and the chronological age for both left and right mandibular third molar teeth in both sexes (−0.13 and −0.17 years in males, 0.01 and 0.03 years in females, respectively). In Thai samples, when the mandibular third molar teeth reached stage H, the probability of the person being over 18 years was 100 % in both sexes.

Keywords Dental age estimation · Third molar development · Demirjian method · Thailand · Forensic odontology

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Introduction

Forensic age estimation plays an essential role in biological identification to predict the chronological age for dead victims or living persons for legal purposes [1]. In Thailand, the Criminal Code states that "A child not yet over ten years of age shall not be punished (section 73)"; "A child over ten years of age but not yet over fifteen years of age, he/she shall not be punished, but the Court shall have the power to control the behavior of the child (section 74)"; "For any person over fifteen years of age but not yet eighteen years of age, it shall reduce the scale of punishment as provided for such offence by one-half (section 75)"; "For any person aged eighteen years but not over twenty years of age, the Court shall reduce the scale of punishment as provided for such offence by one-third or a half (section 76)"; and "Whoever has sexual intercourse with a child who is not over thirteen years old yet, the offender shall be punished (section 277)." According to the Criminal Code as excerpted above, the legally important age limits in Thailand are 10, 13, 15, 18, and 20 years. Therefore, accuracy of age estimation methods for suspects with unknown chronological age is needed in the interest of justice [2].

Currently, there are several methods for age estimation, including a physical examination, hand bone development using radiographic examination, and dental development using panoramic radiographic examination [3]. Hand bone development is completed at about 18 years of age, which is earlier than third molar development that continues until the early twenties [4]. Moreover, skeletal development is highly influenced by nutritional and environmental factors, whereas tooth development is more affected by genetic factors [5]. In addition, teeth are the strongest structures in the human body, are protected by the soft and hard tissues of the face, and are highly resistant to external factors, such as decomposition processes and extreme temperatures [6]. Therefore, teeth are a good biological indicator for age estimation.

Third molar development is a major approach for age estimation, especially in adolescents and young adults because all other permanent teeth have already completed their development in these periods except the third molar teeth. Several dental developmental classification methods have been developed to estimate the chronological age, such as the Gleiser and Hunt method [7], the Moorrees et al. method [8], the Demirjian et al. method [9], the Kullman et al. method [10], and the Gat et al. method [11]; however, the Demirjian et al. classification method [9] has been commonly used to assess the age from third molar teeth in several studies [12–19]. Demirjian et al. employed changes in tooth developmental stages to describe the dental maturity classification from crown formation to closure of the root apices [9]. Several researchers have provided population-specific reference data for age estimation based on third molar development according to the Demirjian et al. classification method; however, there are differences in developmental timing of third molar teeth between populations [12–19]. Therefore, it is important to use population-specific reference data for age estimation in each population.

Previously, researchers have described age estimation using third molar development in a Thai population; however, those earlier studies did not use the Demirjian et al. classification method [20–23]. Therefore, the aims of this study were to establish population-specific reference data, to develop prediction models for age estimation using the mandibular third molar development according to the Demirjian et al. classification method, to test the accuracy of age estimation of the resulting models in a Thai population, and to find the probability of persons being at the age thresholds of legal relevance in Thailand.

Materials and methods

This study was approved by the Human Experimentation Committee of the Faculty of Dentistry, Chiang Mai University, Thailand. This study was a retrospective study of digital panoramic radiographs produced using the Orthophos XG 3D® (Sirona, Bensheim, Germany) or Kodak 9000C 3D® (Carestream, Rochester, NY, USA) machines. The selected radiographs were obtained from the patients' radiographic databases at the Dental Hospital, Faculty of Dentistry, Chiang Mai University, Chiang Mai, Thailand (from August 2012 to December 2014). The patients' demographic data, including patients' names, sexes, dates of birth, and the dates of the radiographs, were recorded confidentially.

A total of 1867 digital panoramic radiographs of Thai individuals aged between 8 and 23 years was randomly selected using the simple random sampling approach and divided into two groups. The training sample was used to establish population-specific reference data and to develop the prediction models for age estimation based on mandibular third molar development according to the Demirjian et al. classification method. The test sample was used to construct age prediction ranges with a 95 % predictive interval for age estimation and to test the accuracy of age estimation of the resulting models. Moreover, all of the samples were used to find the probability of persons being at the age thresholds of legal relevance in Thailand. The chronological age was calculated from the birth date and the digital panoramic radiograph date and expressed as years with two decimal places. Exclusion criteria included the following: non-Thai individuals, unclear radiograph, systemic diseases, missing mandibular third molar teeth, supernumerary teeth, macrodontia, microdontia, or jaw cysts/tumors.

This study was separated into three main parts: (1) establishing population-specific reference data and developing the age prediction models, (2) testing the accuracy of the resulting age prediction models, and (3) finding the probability of persons being at the age thresholds of legal relevance in Thailand. First, the developmental stages of the mandibular third molar teeth were assessed according to the Demirjian et al. classification method, by which tooth development was divided into nine stages. Briefly, stage 1 indicates the radiolucent bud. Stages A to D and E to H show the crown development and root formation stages, respectively. Then, each development stage was transformed into a development score using a scale of nine scores (stage 1 = 1, stage A = 2, stage B = 3, stage C = 4, stage D = 5, stage E = 6, stage F = 7, stage G = 8, and stage H = 9). The development score and the chronological age were used to establish population-specific reference data and to develop age prediction models from quadratic regression analysis.

Second, the validation of the resulting age prediction models was analyzed in the test sample of digital panoramic radiographs by evaluating the mean difference between the predicted dental age and the chronological age, the standard error of prediction (SEP) and a 95 % predictive interval (95 % PI). Moreover, the percentage of accuracy in age estimation within the difference values between the predicted dental age and the chronological age from ±0.50 to ±4.00 years was

presented. Third, finding the probability of persons being at the age thresholds of legal relevance in Thailand was calculated using the Bayesian approach [24].

A month after the first assessment of all samples by the first observer, 100 digital panoramic radiographs were randomly selected using simple random sampling from the total samples by the first observer and set aside for another month, when intra- and inter-observer agreement were tested. The 100 selected radiographs were assessed without the information of age and sex by the first observer to test for intra-observer agreement and by the second observer to test for inter-observer agreement. Cohen's kappa test was used to evaluate the intra- and inter-observer agreements.

Descriptive statistics with the mean, standard deviation, minimum, and maximum values of the chronological age in males and females were calculated. Moreover, the frequency and the probability of the Demirjian et al. stages in each age group were calculated. The Wilcoxon signed ranks test was used to compare the developmental stages between the left and right mandibular third molar teeth. The independent sample *t* test and Mann-Whitney *U* test were used to compare the mean age between males and females when normality was available and unavailable, respectively. All statistical analyses were performed using the SPSS software package (SPSS for Windows, version 15, Chicago, IL, USA).

Results

Digital panoramic radiographs of 1867 Thai samples (877 males, 990 females) were separated into two groups: (1) the training sample was 79.97 % of the total (702 males and 791 females) and (2) the test sample was 20.03 % of the total (175 males and 199 females). The results showed that there were no significant differences between teeth 38 and 48 in either males ($p = 0.857$) or females ($p = 0.059$).

The Kappa values were 0.967 (tooth 38) and 0.956 (tooth 48) for intra-observer agreement and 0.922 (tooth 38) and 0.933 (tooth 48) for inter-observer agreement. These values represent almost perfect agreement according to the Landis and Koch guidelines [25].

Tables 1 and 2 show the descriptive statistics data for the chronological age for each development score according to the Demirjian et al. classification method for teeth 38 and 48 for both sexes in a Thai population. Our results show that the mean values of the chronological age in the initial cusp formation stage (score 2) were 9.37 years for tooth 38 and 9.49 years for tooth 48 in males and 9.23 years for tooth 38 and 9.24 years for tooth 48 in females. Moreover, the mean values of the chronological age in the completed crown formation stage (score 5) were 13.77 years for tooth 38 and 13.59 years for tooth 48 in males and 14.66 years for tooth 38 and 14.68 years for tooth 48 in females.

In tooth 38, the independent sample *t* test or Mann-Whitney *U* test results revealed that the development scores 5, 7, and 8 had significant differences between males and females ($p = 0.019$, 0.001, and 0.029, respectively); males reached the tooth developmental stages earlier than did females, 1.09, 0.64, and 0.33 years earlier for development scores 5, 7, and 8, respectively (Table 1). In tooth 48, the results indicate that development scores 5, 6, 7, and 8 had significant differences between males and females ($p = 0.023$, 0.037, 0.008, and 0.026, respectively); males reached the tooth developmental stages earlier than did females, 0.89, 0.40, 0.61, and 0.35 years earlier for development scores 5, 6, 7, and 8, respectively (Table 2).

The age prediction models in this study showed a strong correlation between the development score and the chronological age for both teeth in both males and females ($R = 0.945$ for tooth 38 and $R = 0.944$ for tooth 48 in males, $R = 0.922$ for tooth 38 and $R = 0.923$ for tooth 48 in females). In addition, the standard error values from the resulting models were 1.29 years for tooth 38 and 1.30 years for tooth 48 in males and 1.48 years for tooth 38 and 1.47 years for tooth 48 in females. The prediction models for dental age estimation in this study are shown in Table 3.

Furthermore, the accuracy of age estimation of the resulting prediction models were tested in the test sample (374 cases) using the error values and the absolute difference values between the predicted dental age and the chronological age. The results show that the error values were −0.13 years for tooth 38 and −0.17 years for tooth 48 in males and 0.01 years for tooth 38 and 0.03 years for tooth 48 in females. In addition, the age predictive ranges with a 95 % predictive interval for dental age estimation and the standard error of prediction values are shown in Tables 4 and 5. Table 6 shows the percentage of accuracy in age estimation, within the difference values between the predicted dental age and the chronological age from ±0.50 to ±4.00 years of the resulting models of teeth 38 and 48 in males and females using the absolute difference values.

Tables 7 and 8 show the frequency of the Demirjian et al. stages in each age group for the left and right mandibular third molar teeth in both sexes, respectively. Moreover, Tables 9 and 10 show the probability of persons being over ages 10, 13, 15, 18, and 20, which are the age thresholds of legal relevance in Thailand, at each Demirjian et al. stage for the left and right mandibular third molar teeth in both sexes, respectively.

Discussion

The maxillary third molar teeth on radiographic images are superimposed by related anatomical structures, such as the posterior wall of the maxillary sinus, the zygomatic arch, and the innominate line of the zygomatic process [26].

Table 1 Descriptive statistics of the chronological age and the comparison of average age between male and female in each development score for tooth 38

Score	Male ($n = 702$)					Female ($n = 791$)					p value
	$n_{\geq 18}/n$	Mean	SD	Min	Max	$n_{\geq 18}/n$	Mean	SD	Min	Max	
1	0/3	8.59	0.55	8.08	9.17	0/4	8.50	0.10	8.41	8.64	0.724 MW
2	0/15	9.49	0.99	8.13	10.63	0/13	9.24	0.75	8.12	10.51	0.461
3	0/54	10.62	1.34	8.59	13.20	0/38	10.28	1.20	8.26	12.60	0.213
4	0/29	12.61	1.07	10.38	14.68	0/42	12.33	1.22	10.01	14.96	0.321
5	0/10	13.59	1.52	12.08	16.36	0/52	14.68	1.28	11.63	17.19	0.019[a]
6	5/111	15.49	1.34	12.28	18.93	17/160	15.82	1.68	11.56	20.21	0.073
7	28/88	17.18	1.27	14.78	19.88	71/152	17.82	1.60	14.98	22.17	0.001[a]
8	172/190	19.75	1.36	16.51	23.37	151/171	20.08	1.58	16.50	22.99	0.029 MW[a]
9	202/202	N/A	N/A	18.28	23.92	159/159	N/A	N/A	19.34	23.89	N/A

$n_{\geq 18}$ number of samples being ≥18 years of age, n number of samples, *Mean* mean age, *SD* standard deviation, *Min* minimum age, *Max* maximum age, *MW* Mann-Whitney U test to compare the mean age between males and females

[a] Statistically significant difference using the independent sample t test or Mann-Whitney U test ($p < 0.05$)

Therefore, the mandibular third molar teeth were selected in this study because its evaluation is clearer than that of the maxillary third molar teeth on panoramic radiographs.

In this study, the mean values of the chronological age in the cusp formation stage (stage A) of the mandibular third molar teeth in a Thai population were around 9 years of age. Compared with other populations, our findings are similar to those in Western Chinese [27] and Turkish [28] populations, but the development timing of this Thai population were earlier than those in Southwestern Chinese [4] and Korean [29] populations and later than those in a Brazilian [26] population. The mean values of the chronological age in the crown formation stage (stage D) in Thai samples were about 13–14 years. Our results are consistent with findings in Southwestern Chinese [4], Western Chinese [27], Korean [29], and black African [30] populations, but the development timing of Thai samples was earlier than that in Austrian [31], Japanese [32], German [32], and one specific Turkish [33] populations and later than in Brazilian [26] and another specific Turkish [28] populations. In addition, the mean values of the chronological age in the completed root formation stage (stage H) in our samples were about 21–22 years of age. Our results are consistent with those in Southwestern Chinese [4], Brazilian [26], Western Chinese [27], and Korean [29] populations, but the development timing of Thai samples was earlier than in black African [30], Austrian [31], Japanese [32], and German [32] populations and later than in one of the earlier quoted Turkish [33] populations (Table 11). Moreover, Olze et al. [14] compared the timing of third molar

Table 2 Descriptive statistics of the chronological age and the comparison of average age between male and female in each development score for tooth 48

Score	Male ($n = 702$)					Female ($n = 791$)					p value
	$n_{\geq 18}/n$	Mean	SD	Min	Max	$n_{\geq 18}/n$	Mean	SD	Min	Max	
1	0/3	8.59	0.55	8.08	9.17	0/5	8.75	0.57	8.41	9.76	0.881 MW
2	0/16	9.37	0.96	8.13	10.63	0/13	9.23	0.85	8.12	10.51	0.687
3	0/53	10.63	1.27	8.59	13.20	0/38	10.37	1.25	8.26	12.97	0.328
4	0/28	12.63	0.94	11.03	14.68	0/41	12.26	1.16	10.01	14.40	0.165
5	0/13	13.77	1.46	12.28	16.36	0/57	14.66	1.19	11.63	17.19	0.023[a]
6	4/108	15.48	1.30	12.08	18.93	17/156	15.88	1.67	11.56	20.21	0.037[a]
7	30/87	17.23	1.29	14.78	19.88	72/153	17.84	1.61	14.98	22.17	0.008 MW[a]
8	171/192	19.73	1.41	16.51	23.37	149/168	20.08	1.58	16.50	22.99	0.026[a]
9	202/202	N/A	N/A	18.28	23.92	160/160	N/A	N/A	19.34	23.89	N/A

$n_{\geq 18}$ number of samples being ≥18 years of age, n number of samples, *Mean*: mean age, *SD* standard deviation, *Min* minimum age, *Max* maximum age, *MW* Mann-Whitney U test to compare the mean age between males and females

[a] Statistically significant difference using the independent sample t test or Mann-Whitney U test ($p < 0.05$)

Table 3 Age prediction models using quadratic regression analyses in both sexes

Sex	Tooth	Model	R	R^2	SE
Male	38	$y = 7.648 + 0.753x_1 + 0.093{x_1}^2$	0.945	0.892	1.29
	48	$y = 7.535 + 0.799x_2 + 0.088{x_2}^2$	0.944	0.892	1.30
Female	38	$y = 6.421 + 1.256x_1 + 0.055{x_1}^2$	0.922	0.850	1.48
	48	$y = 6.522 + 1.243x_2 + 0.055{x_2}^2$	0.923	0.852	1.47

y the dental age, x_1 the development score for tooth 38, x_2 the development score for tooth 48, R correlation coefficient, R^2 coefficient of determination, *SE* standard error (in years)

development in three ethnic groups (Caucasoid, Mongoloid, and African populations). They found that the developmental timing of the Caucasian population was earlier than that of the Mongoloid population but later than that of the African population. The possible reasons for the unrelated findings may be the differences in ethnic, environmental, and habit causes in tooth development between populations [14, 17].

The development of mandibular third molar teeth was earlier in males than in females in both teeth 38 and 48. Especially, root formation stages showed significantly older (between 0.28 and 1.09 years; $p < 0.05$) mean ages in females than in males. Our findings are consistent with those of earlier studies, in that there were differences between the sexes in the development timing of mandibular third molar teeth, particularly in root formation stages, that were earlier in males than in females [12, 28, 31, 34, 35]. Harris [34] found that mineralization of the mandibular third molar has been faster in males than females, which is unique for this tooth. He suggested two possible factors affecting this finding; either the X chromosome slows down third molar formation in females or the Y chromosome enhances third molar mineralization rate in males. However, some studies have reported no differences between males and females in the timing of third molar development [18, 26, 28, 33]. Therefore, the future studies are needed to explain this discrepancy.

Previously, Thevissen et al. [22] established population-specific age estimation equations using third molar development based on the Gleiser and Hunt classification in a Thai population. They used the panoramic radiographs of 1199 cases (613 males and 586 females) aged between 15 and 24 years. Although Thevissen et al. have provided the equations for age estimation from third molar development in a Thai population, these equations cannot be applied before the beginning of the root formation stage, whereas our age prediction models are applicable from the initial mineralization stage to the tooth completion stage. In addition, the resulting age prediction models in this study had a high percentage of accuracy in Thai samples, in that the percentages of the absolute error values between the predicted dental age and the chronological age within 1 and 2 years were about 50 and 85 %, respectively. Our findings are consistent with those of Verochana et al. [23], especially the percentage of the absolute error values within 1 year. However, our models showed higher values for the percentage of accuracy within two years than those of Verochana et al. [23]. Possible reasons for the discrepant findings may be differences in research design, statistical analysis, sample size, or age categories between the two studies.

Currently, there are several dental age estimation studies using third molar teeth according to the Demirjian et al. classification method [12–19, 26–33]. However, most studies did not test the accuracy of age estimation methods in the test sample and did not report the prediction interval values,

Table 4 Error values between the dental age and the chronological age and age ranges with 95 % predictive interval using the age prediction model for tooth 38 and 48 for males

Stage	Score	Tooth 38						Tooth 48					
		Dental age	n	Error	SEP	95 % PI		Dental age	n	Error	SEP	95 % PI	
						Lower	Upper					Lower	Upper
1	1	8.49	2	−0.55	0.56	7.39	9.59	8.42	2	−0.62	0.63	7.19	9.65
A	2	9.53	6	−0.22	1.11	7.35	11.71	9.49	6	−0.26	1.12	7.29	11.69
B	3	10.74	10	−0.39	1.19	8.41	13.07	10.72	10	−0.36	1.11	8.54	12.90
C	4	12.15	8	−0.45	1.14	9.92	14.38	12.14	8	−0.52	1.18	9.83	14.45
D	5	13.74	5	−0.84	1.56	10.68	16.80	13.73	4	−0.32	1.06	11.65	15.81
E	6	15.51	30	−0.25	1.29	12.98	18.04	15.50	31	−0.29	1.28	12.99	18.01
F	7	17.48	20	−0.15	1.20	15.13	19.83	17.44	20	−0.19	1.21	15.07	19.81
G	8	19.62	39	−0.13	1.28	17.11	22.13	19.56	39	−0.19	1.29	17.03	22.09
H	9	N/A	55	0.14	1.20	19.61	24.31	N/A	55	0.03	1.19	19.52	24.18
Total		–	175	−0.13	1.24	–	–	–	175	-0.17	1.22	–	–

Score the development score, *n* number of samples, *Error* mean difference values between the predicted dental age and the chronological age, *Dental age* the predicted dental age from age prediction model, *SEP* the standard error of prediction, *95 % PI* 95 % of predictive interval of predicted dental age

Table 5 Error values between the dental age and the chronological age and age ranges with 95 % predictive interval using the age prediction model for tooth 38 and 48 for females

Stage	Score	Tooth 38						Tooth 48					
		Dental age	*n*	Error	SEP	95 % PI		Dental age	*n*	Error	SEP	95 % PI	
						Lower	Upper					Lower	Upper
1	1	7.73	3	−1.51	1.61	4.57	10.89	7.82	4	−1.52	1.60	4.68	10.96
A	2	9.15	4	0.16	0.54	8.09	10.21	9.23	3	0.45	0.62	8.01	10.45
B	3	10.68	6	0.25	1.08	8.56	12.80	10.75	6	0.32	1.10	8.59	12.91
C	4	12.33	12	−0.21	1.30	9.78	14.88	12.37	14	−0.13	1.21	10.00	14.74
D	5	14.08	10	−0.05	1.38	11.38	16.78	14.11	7	−0.50	1.30	11.56	16.66
E	6	15.94	41	0.16	1.64	12.73	19.15	15.96	41	0.19	1.66	12.71	19.21
F	7	17.91	40	0.33	1.30	15.36	20.46	17.92	38	0.51	1.36	15.25	20.59
G	8	19.99	42	−0.49	1.59	16.87	23.11	19.99	46	−0.50	1.65	16.76	23.22
H	9	N/A	41	0.19	1.32	19.59	24.77	N/A	40	0.27	1.41	19.40	24.92
Total		–	199	0.01	1.44	–	–	–	199	0.03	1.48	–	–

Score the development score, *n* number of samples, *Error*: mean difference values between the predicted dental age and the chronological age, *Dental age* the predicted dental age from age prediction model, *SEP* the standard error of prediction, *95 % PI* 95 % of predictive interval of predicted dental age

whereas our study has developed the age prediction models and tested the accuracy of resulting models to confirm the correctness of the findings. Moreover, some age estimation studies using third molar teeth were focused on samples aged over 14 years, whereas the young child samples were included in our study because Liversidge et al. [36] reported that the initial mineralization of third molar teeth was observed on panoramic radiographs in samples as young as 8 years of age. Additionally, there was a need, according to the Thai criminal law, to identify an age threshold as low as 10 years. However, there are other age estimation methods that can be used to classify children in the 10 years age threshold such as the Demirjian's method using seven teeth [37]. It is, therefore, advisable that multiple methods may be needed to increase the accuracy of age estimation, especially in legal cases of children.

It was the aim of our study to develop tooth-specific models for estimating the age because there is a possibility that a person of interest may have only one mandibular third molar tooth, either on the left or on the right side. Although there is no significant difference in the tooth developmental stages between the left and right mandibular third molar teeth, when estimating the age of a person who has both left and right mandibular third molars, we recommend using the left side, since the left side provided a more accurate age estimation in our study.

In terms of age prediction ranges with a 95 % predictive interval in our study, we found that the development scores 1–4 (stages 1–C) and 7–9 (stages F–H) should represent ages <15 and >15 years, respectively. Moreover, the development scores 1–5 (stages 1–D) and 9 (stage H) should represent ages <18 and >18 years, respectively. Although

Table 6 The percentage of accuracy in age estimation within the difference values between the predicted dental age and the chronological age from ±0.50 to ±4.00 years of the resulting models of teeth 38 and 48 in males and females

Difference value (years)	Male (*n* = 175)				Female (*n* = 199)			
	Tooth 38		Tooth 48		Tooth 38		Tooth 48	
	n	%	*n*	%	*n*	%	*n*	%
±0.50	47	26.86	46	26.29	46	23.12	43	21.61
±1.00	94	53.71	93	53.14	93	46.73	84	42.21
±1.50	133	76.00	134	76.57	133	66.83	129	64.82
±2.00	158	90.29	161	92.00	168	84.42	165	82.91
±2.50	168	96.00	169	96.57	187	93.97	184	92.46
±3.00	175	100.00	175	100.00	195	97.99	195	97.99
±3.50					197	98.99	197	98.99
±4.00					199	100.00	199	100.00

n number of samples, % percentage of accuracy

Table 7 Frequency of the Demirjian et al. stages in each age group of tooth 38 in both sexes

Age	Tooth 38																			
	Male									Total	Female									Total
	1	A	B	C	D	E	F	G	H		1	A	B	C	D	E	F	G	H	
8	3	7	5							15	5	6	7							18
9	2	4	17							23	2	9	10							21
10		9	17	2						28		2	12	8						22
11		1	12	8						21			11	13	2	1				27
12			9	14	6	5				34			4	16	6	5				31
13			4	8	2	10				24				13	14	25				52
14				5	3	33	4			45				4	14	38	1			57
15					1	42	13			56					17	39	21			77
16					3	29	31	2		65					8	48	45	3		104
17						15	22	20		57					1	24	39	19		83
18						7	31	48	3	89						13	43	31		87
19							7	70	16	93						5	27	45	12	89
20								46	45	91						3	12	44	29	88
21								32	61	93							3	44	38	85
22								10	82	92							1	26	60	87
23								1	50	51								1	61	62
Total	5	21	64	37	15	141	108	229	257	877	7	17	44	54	62	201	192	213	200	990

Table 8 Frequency of the Demirjian et al. stages in each age group of tooth 48 in both sexes

Age	Tooth 48																			
	Male									Total	Female									Total
	1	A	B	C	D	E	F	G	H		1	A	B	C	D	E	F	G	H	
8	3	8	4							15	5	7	6							18
9	2	5	16							23	4	6	11							21
10		8	19	1						28		3	11	8						22
11		1	12	8						21			11	14	1	1				27
12			9	14	7	4				34			5	17	4	5				31
13			3	9	2	10				24				13	16	23				52
14				4	4	33	4			45				3	16	37	1			57
15					2	40	14			56					20	35	22			77
16					2	32	27	4		65					6	50	45	3		104
17						14	22	21		57					1	25	39	18		83
18						6	33	47	3	89						13	41	33		87
19							7	69	17	93						5	27	44	13	89
20								46	45	91						3	12	44	29	88
21								32	61	93							3	42	40	85
22								11	81	92							1	29	57	87
23								1	50	51								1	61	62
Total	5	22	63	36	17	139	107	231	257	877	9	16	44	55	64	197	191	214	200	990

Table 9 Probability of being over the important legal ages for tooth 38

Stage	Tooth 38									
	Male					Female				
	10	13	15	18	20	10	13	15	18	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A	47.62	0.00	0.00	0.00	0.00	11.76	0.00	0.00	0.00	0.00
B	65.63	6.25	0.00	0.00	0.00	61.36	0.00	0.00	0.00	0.00
C	100.00	35.14	0.00	0.00	0.00	100.00	31.48	0.00	0.00	0.00
D	100.00	60.00	26.67	0.00	0.00	100.00	87.10	41.94	0.00	0.00
E	100.00	96.45	65.96	4.96	0.00	100.00	97.01	65.67	10.45	1.49
F	100.00	100.00	96.30	35.19	0.00	100.00	100.00	99.48	44.79	8.33
G	100.00	100.00	100.00	90.39	38.86	100.00	100.00	100.00	89.67	53.99
H	100.00	100.00	100.00	100.00	92.61	100.00	100.00	100.00	100.00	94.00

the percentages of about 90 % accuracy in age estimation fell into the age range of ±2 years for males and ±2.5 years for females according to Table 7 in our study, which may not be favorable results for judicial or administrative proceedings, similar findings were also reported in a recent study [23]. In addition, this approach for dental age estimation with tested groups has rarely been previously studied. Taken together, these findings may reflect that we need to combine multiple approaches for age estimation, for example, an age estimation method using the development of the other seven teeth in the quadrant [37] and other methods using the development of various bones [38, 39]. The probabilities of persons being over the important legal age thresholds in Thailand (10, 13, 15, 18, and 20 years of age) are presented in Tables 9 and 10. However, these probabilities are descriptive findings and derived from 1867 Thai samples. Therefore, the probability tables should be used with caution and cannot be directly inferred to predict the exact chronological age in a Thai population.

In our study, the number of cases in the test sample was quite small in the first six age categories (8 to 13 years) because of the limitation that the patients who seek dental treatment in our institution are predominantly adolescents and adults (age >13 years), together with the fact that the pediatric dentists prescribe panoramic radiographs for only some patients, when necessary, in the interest of radiation safety. Therefore, we have a limited number of panoramic radiographs of younger patients.

Although the panoramic radiograph is needed to estimate the dental age in children, it would be inappropriate to prescribe such a radiograph solely for administrative or legal purposes. In general, prior to prescribing any radiographs for children, a clinical examination should be performed to evaluate their dental status so that a radiographic prescription is justified. Therefore, if a panoramic radiograph is required for clinical reasons, the panoramic radiograph can be used to evaluate both the dental status and dental age estimation. A treatment plan followed by proper dental treatments should be also provided to the children according to their needs.

Table 10 Probability of being over the important legal ages for tooth 48

Stage	Tooth 48									
	Male					Female				
	10	13	15	18	20	10	13	15	18	20
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A	40.91	0.00	0.00	0.00	0.00	18.75	0.00	0.00	0.00	0.00
B	68.25	4.76	0.00	0.00	0.00	61.36	0.00	0.00	0.00	0.00
C	100.00	36.11	0.00	0.00	0.00	100.00	29.09	0.00	0.00	0.00
D	100.00	58.82	23.53	0.00	0.00	100.00	92.19	42.19	0.00	0.00
E	100.00	97.12	66.19	4.32	0.00	100.00	96.95	66.50	10.66	1.52
F	100.00	100.00	96.26	37.38	0.00	100.00	100.00	99.48	43.98	8.38
G	100.00	100.00	100.00	89.18	38.96	100.00	100.00	100.00	90.19	54.21
H	100.00	100.00	100.00	100.00	92.22	100.00	100.00	100.00	100.00	93.50

Table 11 Comparison of mean values (in years) of the chronological age in tooth development stages according to the Demirjian et al. classification method in this study with those in other populations in teeth 38 and 48 in both sexes

Population	Cusp formation (stage A)				Crown completed (stage D)				Tooth completed (stage H)			
	Male		Female		Male		Female		Male		Female	
	38	48	38	48	38	48	38	48	38	48	38	48
Thai (this study)	9.49	9.37	9.24	9.23	13.59	13.77	14.68	14.66	N/A	N/A	N/A	N/A
Southwestern Chinese [4]	10.63	10.67	10.44	10.50	14.30	14.41	14.81	14.84	21.92	21.87	21.89	21.92
Brazilian [26]	8.50	8.50	8.20	8.40	12.90	13.00	13.20	13.20	21.70	21.70	21.60	21.60
Western Chinese [27]	9.40	9.80	10.30	10.00	14.30	14.20	14.40	14.60	21.30	21.20	21.60	21.70
Southwest Eastern Turkish [28]	8.97	9.14	9.30	9.31	12.89	12.86	13.27	13.17	–	–	–	–
Korean [29]	10.10	10.10	10.10	10.30	14.60	14.80	15.00	14.90	21.10	21.10	22.40	22.30
Black African [30]	–	–	–	–	13.40	14.80	13.60	14.00	22.90	22.90	22.50	22.80
Austrian [31]	–	–	–	–	16.10	15.30	15.40	15.50	22.40	22.50	22.90	22.80
Japanese [32]	–	–	–	–	18.20	18.10	18.00	18.20	22.70	22.60	22.40	22.40
German [32]	–	–	–	–	16.30	16.70	15.50	15.70	22.70	22.70	23.00	23.10
Turkish [33]	–	–	–	–	14.50	14.50	15.20	15.10	20.10	20.00	20.00	20.00

It would be interesting to test the accuracy of these equations in samples from different regions of Thailand as well as other ethnic samples from Southeast Asian countries. As now the Asian Economic Community (AEC) has started, it will affect a free flow of migration among this community and human trafficking is still a widespread problem in these regions. Collaboration with other researchers in the Asian countries would be beneficial to find a new information and knowledge for predicting age in this part of the world.

Conclusions

The findings in this study provide accurate population-specific reference data for dental age estimation using mandibular third molar development according to the Demirjian et al. classification system for a Thai population. Moreover, we present age prediction models and age prediction ranges with a 95 % predictive interval for age estimation with low error values in Thai samples. In Thai samples, when the mandibular third molar teeth reached stage H, the probability of the person being over 18 years was 100 % in both sexes. Therefore, the overall results of this study should be useful for forensic age estimation and clinical dentistry, particularly in Thai children, adolescents, and young adults.

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