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ORIGINAL ARTICLE

Radiological age estimation: based on third molar mineralization and eruption in Turkish children and young adults

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Abstract Radiographic evaluation of mineralization and eruption stages of third molars using dental panoramic radiographies can be an efficient tool for chronological age estimation in both forensic sciences and legal medicine. The third molar tooth is utilized for dental age estimation about the age span of 15–23 years because it represents the only tooth still in development. The aim of this study is to obtain and analyze data regarding third molar development and eruption in Turkish population for dental age estimation. A total of 744 dental panoramic radiographies of 394 female and 350 male subjects aged between 8 and 22 years were examined. Third molar development was determined according to the Nolla classification system, and eruption was assessed relative to the alveolar bone level. Mandibular and maxillary third molars were generally found at similar stages of development on both sides. Nolla stage 6 (completed crown calcification) was reached at around the age of 15 in both maxillary and mandibular third molars in both sexes. Alveolar emergence was at around the age of 16 in males and around age of 17 in females. Although third molars' eruption shows greater variability than development of third molars, data which were obtained from this study about eruption of these teeth can be supportive to development data for age estimation.

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Introduction

Age estimation is proving valuable when birth data are lacking or doubted in the management of immigration to help determine chronological age [1]. In addition, the age of living persons is to be applied for purposes of differentiation between juvenile and adult status in criminal law cases [2]. The Turkish Penal Code defines three legally relevant age limits: 12, 15, and 18 years. Correlatively, the legally relevant age thresholds in several European countries range from 14 to 18 years of age [3].

Dental age can be assessed among young children with greater accuracy because many teeth are undergoing development and mineralization simultaneously [4]. About in the age span of 14–23 years, the wisdom teeth represent the only teeth still in development [5, 6]. Because of this, while the accuracy rate of the dental age estimation in young child is very high [7], this rate is lowered [8] in adolescent. But the use of third molars for age estimation is one of the few tools for age assessing undocumented juvenile suspects or refugees, and no better dental indicators are yet available [9].

Up to now, several studies have been undertaken to estimate dental age according to third molars and provided reference data of different populations for comparative studies and age estimation of juveniles and adolescents [10–18]. These studies show that dental development varies between different populations, making population-specific studies necessary. Most of these studies are based on tooth mineralization and a few of them are based on tooth eruption because eruption, when used alone, is not a good age indicator due to factors like interindividual variation or the elapsed time without changes in tooth emergence [19]. In spite of that fact, assessment of

third molars' eruption provides assistive data for the estimation of the forensic dental age in living individuals [20].

The aim of this study is to obtain and analyze data regarding third molar development and eruption in Turkish population for dental age estimation and for comparing with other populations.

Materials and methods

A total of 768 dental panoramic radiographies (DPRs) of 394 female and 374 male subjects aged between 8 and 22 years were examined (Table 1). As a result of statistical evaluation for the determination of sample numbers, it was considered that at least 10 X-rays were needed to be studied for each sex in each age group. All the subjects were of Turkish Caucasian origin and had Turkish nationality also having no history of medical disease or surgical intervention that could affect the presence and development of third molars. Radiographs were obtained for clinical purposes from consecutive patients, with known dates of birth and who have attended the Istanbul Hospital, Osmaniye Dental Unit in Istanbul (Turkey) between June 2009 and January 2010. Radiographs that were unclear or that showed hypodontia, gross pathology, failure of eruption, and previous orthodontic treatment were excluded. The chronological age, converting to a decimal age, was based on the date of the panoramic radiograph and the date of birth. All the DPRs were divided into 15 groups. In age group 8, the patients of ages ranging from 7.50 to 8.49 were involved and so on.

Table 1 DPG distribution according to age and sex

Age groups[a]	Male	Female	Total
8 years	40	38	78
9 years	51	32	83
10 years	48	37	85
11 years	23	22	45
12 years	21	20	41
13 years	22	33	55
14 years	21	20	41
15 years	20	16	36
16 years	23	21	44
17 years	22	26	48
18 years	20	35	55
19 years	17	23	40
20 years	13	20	33
21 years	16	30	46
22 years	17	21	38
Total	374	394	768

[a]In age group 8, the patients of ages ranging from 7.50 to 8.49 were involved and so on

All assessments on DPRs were performed with appropriate magnification and contrast adjustment by the first author (BK, 6 years of experience in assessing mineralization and eruption stages) on left maxillary and mandibular third molars. The mineralization status of the third molars was evaluated using the formation stages described by Nolla [21], which divides the developmental process of the tooth into 10 stages from 1 to 10. The eruption stages were evaluated using the classification of stages by Olze et al. [22] in four positions:

Stage A— occlusal plane covered with alveolar bone,
Stage B— alveolar eruption, complete resorption of alveolar bone over occlusal plane,
Stage C— gingival emergence, penetration of gingiva by at least one dental cusp,
Stage D— complete emergence in occlusal plane.

After assessing the developmental and eruptional stages, the mean and standard deviation were identified for each stage and for maxillary and mandibular third molars on the left side.

Mann–Whitney *U* test was performed to evaluate the difference in the prevalence of third molars between sex groups and the mean age of each Nolla's and Olze's stage. Then, Wilcoxon test was performed to test developmental and eruptional differences between the upper and lower arches. All statistical analyses were calculated using SPSS 14.0 (SPSS Inc., Chicago, IL) for Windows.

Intra- and interobserver reliabilities were tested by reexamining 70 radiographs after 2 weeks. The DPRs were chosen at random from the total sample and reevaluated under blinded conditions by the first observer (BK). The same radiographs were rated by a second observer (AK, 3 years of experience in assessing mineralization and eruption stages), and Cohen's kappa test was performed to calculate the intra- and interobserver agreements.

Results

Cohen's kappa measuring intraobserver reliability for mineralization stages was 0.75, for eruption stages was 0.79, and interobserver reliability for mineralization stages was 0.67, for eruption stages was 0.76, indicating substantial agreement.

Tables 2 and 3 show the means and standard deviations of age of the Nolla's stages. Mann–Whitney *U* test results demonstrated that the third molars 28 in stage 2 and 38 in stage 1 showed significantly younger average age in females than in males. But third molars 38 in stage 8 showed significantly older average age in females than in males. Nolla stage 6 (completed crown calcification) was reached at

Table 2 Mean and standard deviation (SD) of age of the Nolla's stages from 1 to 10 of tooth 28

Stage	Male					Female					*P* value
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	
1	33	8.75	0.86	7.67	11.10	22	8.89	1.04	7.54	11.06	0.686
2	15	9.51	0.63	8.43	10.89	17	9.02	0.69	7.88	10.24	0.037*
3	42	10.33	0.93	8.55	12.29	18	10.43	1.27	7.67	12.84	0.687
4	27	11.40	1.72	8.78	14.31	28	11.27	1.41	7.99	14.32	0.880
5	15	12.44	0.87	10.90	13.46	25	12.48	1.14	9.91	14.39	0.847
6	28	14.61	1.24	12.45	17.49	31	14.49	1.87	1.64	19.81	0.434
7	38	16.46	1.85	12.42	19.94	39	16.40	2.38	12.58	21.90	0.835
8	38	17.43	1.98	14.16	22.21	43	17.87	1.78	14.56	21.22	0.192
9	22	19.21	1.98	15.47	22.49	39	19.23	1.69	16.10	22.22	0.988
10	26	20.90	0.97	19.30	22.43	32	21.02	0.88	19.27	22.48	0.628

*$P<0.05$

around the age of 15 in both maxillary and mandibular third molars in both sexes.

Table 4 shows the number of cases and the minimum, maximum, and mean values with standard deviations for the age of eruption of teeth 28 and 38 according to eruption stage for males and females. The mean age of alveolar emergence ranged from 16.79 to 17.27 years in males and from 17.64 to 18.22 years in females. Statistically significant sex differences were only observed for tooth 28 at eruption stage B ($P=0.039$).

The minimum age for alveolar emergence in this study was 12 in males and 13 in females. Also, the minimum age for complete emergence of the wisdom teeth in the occlusal plane was 15 in males and 16 in females (Table 5).

Tables 6 and 7 show the prevalence of third molars 28 and 38 mineralization stages. It was seen that third molars reached complete crown calcification at around the age of 15 in males and 14 in females on both jaws.

Statistically significant jaw differences for mineralization and eruption stages were not observed in this study population.

Discussion

Dental maturation and emergence (tooth eruption) have long been recognized as a useful parameter for estimating age. Two methods of age evaluation are available for juveniles: the morphologic and radiologic examination of skeletal features and radiologic examination of third molars [23].

On the forensic application, varied classification systems for the establishment of degree of third molar maturation have been selected in most of scientific papers. Some studies suggest that using fewer stages increases intra- and interobserver repeatability [1, 11, 24]. This approach

Table 3 Mean and standard deviation (SD) of age of the Nolla's stages from 1 to 10 of tooth 38

Stage	Male					Female					*P* value
	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	
1	31	9.22	0.99	7.69	11.40	34	8.61	0.79	7.57	10.37	0.010*
2	22	9.45	0.82	7.81	10.89	21	9.44	0.95	8.08	11.88	0.789
3	40	10.23	1.07	7.87	12.83	23	10.67	1.52	7.67	13.96	0.180
4	27	11.59	1.25	9.96	14.31	27	11.45	1.33	9.68	14.74	0.622
5	14	13.13	0.80	12.03	15.28	20	12.64	1.01	10.39	14.15	0.204
6	27	14.89	1.55	12.81	19.10	34	14.72	1.93	11.64	19.81	0.500
7	33	15.93	2.05	12.42	19.71	40	16.43	2.59	12.57	21.90	0.475
8	39	17.03	1.79	14.16	22.21	47	17.68	1.71	14.56	21.25	0.039*
9	26	19.06	1.92	15.47	22.49	43	19.16	1.78	16.10	22.22	0.710
10	27	20.91	1.06	19.30	22.45	35	21.06	0.88	19.27	22.48	0.634

*$P<0.05$

Table 4 Mean and standard deviation (SD) of age of the eruption stages from 1 to 4 of teeth 28 and 38

Tooth	Eruption stage	Male					Female					*P* value
		N	Mean	SD	Min	Max	N	Mean	SD	Min	Max	
28	Stage A	168	11.37	2.60	7.67	19.94	159	11.93	2.70	7.54	19.94	0.490
	Stage B	59	17.27	2.34	12.42	22.49	51	18.22	2.21	13.54	12.22	0.039*
	Stage C	19	17.75	2.14	15.39	22.24	34	18.44	2.04	14.56	21.90	0.148
	Stage D	37	20.14	1.58	15.47	22.43	49	20.02	1.76	15.89	22.48	0.955
38	Stage A	167	11.37	2.47	7.69	19.10	179	11.83	2.94	7.57	20.96	0.248
	Stage B	48	16.79	2.58	12.42	22.49	47	17.64	2.46	12.67	22.22	0.069
	Stage C	36	17.92	2.08	14.17	22.45	48	18.33	1.85	13.64	22.02	0.105
	Stage D	35	20.04	1.73	15.47	22.43	51	20.27	1.76	15.89	22.48	0.289

*$P<0.05$

unquestionably is true, but increased repeatability occurs at the decrease of precision. Repeatability is not in itself adequate. If there are numerous stages, each defining a narrow, specific developmental interval, there would be more accurate age estimation [25]. This is why it is believed that when the classification system for age estimation is preferred, using increasing stage number, which is not to create a problem for repeatability should be an appropriate approach. In addition to this, some authors claim that intermediate stages in classification systems cause a decrease in repeatability [1]. Thus, Nolla's classification system (not including intermediate stages) was selected as the most suitable one for this study. In this study and in previous studies using the Nolla classification system, it was shown that there exists no problem considering inter- and intraobserver agreement [13, 26].

It is possible to compare peculiar studies of different populations in which third molar development and eruption are examined. But the mean age of stages or the probability of being a certain age can be directly affected by the age interval of subjects [12]. Especially, means and standard deviations of initial calcification and root completed stages are affected by the age interval determined randomly for each study. For example, in this study, if the age interval was chosen as 8–26 instead of 8–22, probably, the mean values of third molar's root completed and eruption completed would be higher. This is why the age intervals should be taken into consideration while evaluating third molar maturation in different ethnic populations in order to make a correct comparison.

A number of studies have reported about a range of different classifications for evaluating tooth mineralization on the forensic and clinical application of dental age estimation. A comparison of these systems is difficult because of different number and range of evaluated stages. However, studies made using different classification systems can be compared with respect to their stages at certain level of tooth maturation (initial calcification, crown completed, and root completed). For instance, the stage of crown completed was defined as "stage D" in the Demirjian system, "stage 6" in the Nolla system, and "stage Cr_c" in the Moorrees system. In this study, the age reaching complete crown calcification of Turkish population is around 15 years old. Comparing with the other populations, it is similar to Korean [12], Spanish [13], and American Hispanics [27] populations in the third molars 38; 1.5 years earlier than the Australian population [28]; 1 year later than the Southern Chinese population [11]; and approximately 2 years later than the Brazilian population [29]. For Turkish population, the apical ends of the third molar roots are completely closed in around 21 years old, about 1 year earlier than the Australian population [28], and 0.7 years earlier than the Japanese population [14], but 1 year later than the American Hispanic population [27]. These results show that there are different levels of variations among ethnic populations in terms of tooth development as it was pointed out in so many studies [11, 13, 16, 17, 27–35]. Therefore, standards should be special to populations (Table 8).

In the present study, alveolar emergence is at around the age of 16 in males and at around the age of 17 in females. The third molars do not emerge before the 17th year of life in some European populations [20, 36, 37] and Japanese population [38] (Table 9) but may emerge as early as age 13 in Indian [39] and East African [40] populations.

No statistical differences were in the mineralization rate between maxilla and mandible. This finding is consistent with many other studies in the area [31, 33, 34]. Also, no statistical difference with respect to eruption was found among jaws alike in the study made on the Japanese population by Olze et al. [38].

In this study, sexual dimorphism was determined at tooth 38 in two stages and at tooth 28 at one stage statistically. There has been no consensus in the literature on this issue. In some studies, there were no statistical differences in the mean degree of third molar development between males and

Table 5 Frequency of the Nolla's stage of tooth 28

Age groups[a]	Male												Female											
	0	1	2	3	4	5	6	7	8	9	10	Total	0	1	2	3	4	5	6	7	8	9	10	Total
8	24	15	1									40	22	10	4	1	1							38
9	19	14	6	9	3							51	14	6	9	3								32
10	13	2	6	18	9							48	13	5	4	6	7	2						37
11	4	2	2	8	4	3						23	5	1		5	9	2						22
12	7			7	1	4	1	1				21	1			2	7	9	1					20
13	2				5	8	6	1				22	7			1	1	8	11	5				33
14	2				5		6	4	4			21	1				3	4	7	5				20
15	5						8	4	2	1		20	3						3	4	6			16
16	2						6	9	5	1		23	4						6	5	3	3		21
17	2						1	8	8	3		22	6						1	7	9	3		26
18	2							5	10	3		20	9							6	12	8		35
19	1							5	3	6	2	17	3						1	4	3	11	1	23
20								1	3	2	7	13	1						1	1	7	3	7	20
21	4								1	2	9	16	6							1	3	7	13	30
22	3								2	4	8	17	5							1		4	11	21
Total	90	33	15	42	27	15	28	38	38	22	26	374	100	22	17	18	28	25	31	39	43	39	32	394

[a] In age group 8, the patients of ages ranging from 7.50 to 8.49 were involved and so on

Table 6 Frequency of the Nolla's stage of tooth 38

Age groups[a]	Male												Female											
	0	1	2	3	4	5	6	7	8	9	10	Total	0	1	2	3	4	5	6	7	8	9	10	Total
8	27	9	3	1								40	16	16	4	2								38
9	22	11	9	9								51	10	13	8	1								32
10	11	7	8	17	5							48	8	5	7	9	7	1						37
11	1	4	2	7	9							23	4		1	7	9	1						22
12	4			5	8	2		2				21	3		1	1	7	7	1					20
13	3			1	1	9	6	2				22	5			2	1	7	12	6				33
14	1				4	2	6	4	4			21	2			1	2	4	6	5				20
15	2					1	7	6	3	1		20					1		3	5	7			16
16	3						5	7	6	2		23	4						6	4	3	4		21
17	1						2	4	12	3		22	3						2	7	10	4		26
18	4							4	7	5		20	3						3	3	14	12		35
19	1						1	3	5	4	3	17	5							4	6	7	1	23
20	2							1		3	7	13	2						1	3	4	3	7	20
21	3									6	7	16	3							2	3	8	14	30
22	3								2	2	10	17	2							1		5	13	21
Total	88	31	22	40	27	14	27	33	39	26	27	374	70	34	21	23	27	20	34	40	47	43	35	394

[a] In age group 8, the patients of ages ranging from 7.50 to 8.49 were involved and so on

Table 7 Frequency of the Olze et al.'s stage [22] of tooth 38

Age Groups[a]	Tooth 28								Tooth 38							
	Male				Female				Male				Female			
	Stage A	Stage B	Stage C	Stage D	Stage A	Stage B	Stage C	Stage D	Stage A	Stage B	Stage C	Stage D	Stage A	Stage B	Stage C	Stage D
8	16				16				13				22			
9	32				18				29				22			
10	34				23				37				29			
11	19				17				22				18			
12	13	1			19				15	2			18			
13	20				26				17	2			26	2		
14	10	9			15	4			12	6	2		14	3	1	
15	9	4	1	1	7	2	4		10	5	2	1	8	5	3	
16	10	8	3		9	1	4	3	7	9	3	1	8	2	4	3
17	2	8	9	1	3	13	1	3	2	7	9	3	4	13	2	4
18	2	10	2	4	3	10	8	5	2	5	9		5	6	18	3
19		10	1	5	2	7	5	6	1	6	4	5	2	5	9	2
20	1	4		8	1	5	6	7		1		10	2	3	6	7
21		2		10		5	5	14		2	3	8	1	5	2	19
22		3	3	8		4	1	11		3	4	7		3	3	13
Total	168	59	19	37	159	51	34	49	167	48	36	35	179	47	48	51

[a] In age group 8, the patients of ages ranging from 7.50 to 8.49 were involved and so on

Table 8 Mean, standard deviation (SD), and age interval in years in different populations, based on mineralization stages (initial calcification, crown completed, apex closed)

Mineralization stages						Classification system	Age interval (years)	Related studies (population)
Initial calcification		Crown completed		Apex closed				
Male Mean ± SD	Female Mean ± SD	Male Mean ± SD	Female Mean ± SD	Male Mean ± SD	Female Mean ± SD			
9.45±0.82	9.44±0.95	14.89±1.55	14.72±1.93	20.91±1.06	21.06±0.88	Nolla	8–22	Present study (Turkish)
11.53±3.44	12.64±4.48	12.90±1.50	13.60±2.24	22.10±2.87	22.66±2.18	Demirjian	8–25	Sisman et al.[23] (Turkish)
9.22±1.72	9.61±1.56	13.23±1.17	13.30±1.36	20.43±0.87	20.47±0.84	Demirjian	7–22	Cantekin et al. [30] (Eastern Turkish)
–	–	14.50±2.70	15.20±2.70	20.10±2.00	20.0±1.90	Demirjian	4–20	Orhan et al. [31] (Turkish)
8.65±−	9.02±−	12.67±−	12.08±−	20.56±−	21.10±−	Moorrees	5–25	Harris E.F. [25] (American Blacks)
9.82±1.47	10.55±1.82	13.47±1.48	13.73±1.73	22.72±2.27	23.42±2.02	Demirjian	4–27	Zeng et al. [11] (Southern China)
–	–	16.10±2.30	15.40±1.80	22.40±1.80	22.90±1.30	Demirjian	12–24	Meinl et al. [16] (Austrian)
–	–	16.40±1.53	16.65±1.46	22.00±2.15	22.08±2.28	Demirjian	15–25	Bassed et al. [28] (Australian)
–	–	15.50±1.59	16.00±1.64	20.50±1.97	20.90±2.01	Demirjian	14–24	Mincer et al. [18] (American Whites)
10.10±1.40	10.10±1.60	14.60±1.50	15.00±1.60	21.10±1.20	22.40±1.70	Demirjian	4–26	Lee et al. [12] (Korean)
–	–	15.40±−	16.0±−	21.60±−	21.80±−	Demirjian	14–24	Arany et al. [14] (Japanese)
–	–	15.08±1.04	15.11±1.00	19.74±1.09	19.66±0.98	Demirjian	14–21	Prieto et al. [9] (Spanish)
9.40±1.60	10.30±1.70	14.30±2.30	14.40±2.20	21.30±1.80	21.60±1.50	Demirjian	5–23	Li et al. [32] (Western Chinese)
8.50±1.00	8.20±1.00	12.90±1.30	13.20±1.60	21.70±2.20	21.60±2.20	Demirjian	6–25	Oliveria et al. [29] (Brazilian)
9.68±1.35[a]		13.52±1.93[a]		19.45±1.15[a]		Nolla	4–20	Bolanos et al. [13] (Spanish)
–	–	18.20±3.00	18.00±2.70	22.70±2.10	22.30±2.10	Demirjian	12–30	Olze et al. [33] (Japanese)
8.30±1.20	8.40±1.60	13.10±1.20	14.00±2.30	–	–	Demirjian	6–22	Caldas et al. [34] (Portuguese)
–	–	13.40±1.60	13.60±2.50	22.90±2.40	22.50±2.30	Demirjian	10–26	Olze et al. [17] (Black African)
–	–	16.40±1.30[a]		20.90±1.50[a]		Demirjian	15–22	Knell et al. [35] (Swiss and other European)
–	–	14.94±1.47	15.19±1.73	19.88±1.75	20.07±1.87	Demirjian	12–22	Kasper et al. [27] (American Hispanic)

[a] Both sex

females [13, 33]. However, in some previous studies [5, 14], sexual dimorphism was determined at some stages.

Third molars in the Turkish population were likely to appear at age 9 and develop completely by the age 21 in both males and females. These findings were showing similarity with the results of the study performed on Eastern Turkish population [30] with similar age range (age range 7 to 22). For both sexes, completion age of third molar development was seen to be 20 [31] in one study and 22 [23] in another study, both of which were made on the Turkish population. The diversity could be explained by the differences in the selected age range of the study populations.

Table 9 Mean and standard deviation (SD) in years in different populations, based on eruption stages of tooth 38

Eruption stage	Sex	Olze et al. [17] (Black African)			Olze et al. [20] (German)			Olze et al. [38] (Japanese)			Present study (Turkish)		
		N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
Stage A	Male	5	13.6	1.4	6	18.6	3.5	16	19.2	3.3	167	11.37	2.47
	Female	2	15.4	0.8	105	15.5	2.3	33	19.5	2.9	179	11.83	2.94
Stage B	Male	8	19.1	4.0	17	22.4	2.0	28	21.7	2.2	48	16.79	2.58
	Female	11	15.7	2.7	104	18.9	3.0	80	20.9	2.2	47	17.64	2.46
Stage C	Male	4	20.8	2.8	30	22.8	2.1	26	21.6	2.3	36	17.92	2.08
	Female	3	18.6	4.7	99	20.2	3.0	52	21.6	2.1	48	18.33	1.85
Stage D	Male	250	22.4	2.2	27	23.6	2.1	137	22.5	2.1	35	20.04	1.73
	Female	58	21.7	2.8	16	21.9	2.3	155	22.2	1.8	51	20.27	1.76

In many countries, the proof that an individual has reached 18 years of age may have a crucial importance for forensic age estimation in living individuals. In the present study, for only stage 10, an age below 18 years can be excluded. However, it is possible to prove with certainty that the age of 18 has been reached on the basis of new radiological criteria of third molars by studies of Olze et al. [41, 42].

Tooth development is affected from environmental factors less than tooth eruption. Therefore, the variation of third molar eruption is greater [43]. This information is confirmed with the comparison of this study's third molar development prevalence tables (Tables 6 and 7) and the eruption prevalence table (Table 5).

The present investigation provides reference data on third molar mineralization and eruption in the Turkish population. Although third molars' eruption shows greater variability than development of third molars, data which were obtained from this study about eruption of these teeth can be supportive to development data for age estimation.

References

1. Maber M, Liversidge HM, Hector MP (2006) Accuracy of age estimation of radiographic methods using developing teeth. Forensic Sci Int 159:68–73
2. Olze A, Taniguchi M, Schmeling A, Zhu BL, Yamada Y, Maeda YH, Geserick G (2003) Comparative study on the chronology of third molar mineralization in a Japanese and a German population. Leg Med 5:256–260
3. Dunkel F, Van Kalmthout A, Schuler-Springorum H (1997) Entwicklungstendenzen und Reformstrategien im Jugendstrafrecht im Europa ischen Vergleich. Forum, Monchengladbach
4. Demirjian A, Goldstein H, Tanner JM (1973) A new system of dental age assessment. Hum Biol 45:211–227
5. Mesotten K, Gunst K, Carbonez A, Willems G (2002) Dental age estimation and third molars: a preliminary study. Forensic Sci Int 129:110–115
6. Smith T, Brownless L (2011) Age assessment practices: A literature review & annotated bibliography. UNICEF, New York
7. Ardakani F, Bashardoust N, Sheikhha M (2007) The accuracy of dental panoramic radiography as an indicator of chronological age in Iranian individuals. J Forensic Odontostomatol 25:30–35
8. Thorson J, Hagg U (1991) The accuracy and precision of the third mandibular molar as an indicator of chronological age. Swed Dent J 15:15–22
9. Prieto JL, Barbería E, Ortega R, Magaña C (2005) Evaluation of chronological age based on third molar development in the Spanish population. Int J Legal Med 119:349–354
10. Schmeling A, Olze A, Pynn BR, Kraul V, Schulz R, Heinecke A, Pfeiffer H (2010) Dental age estimation based on third molar eruption in First Nation people of Canada. J Forensic Odontostomatol 28:32–38
11. Zeng D, Wu Z, Cui M (2010) Chronological age estimation of third molar mineralization of Han in Southern China. Int J Legal Med 124:119–123
12. Lee SH, Lee JY, Park HK, Kim YK (2009) Development of third molars in Korean juveniles and adolescents. Forensic Sci Int 188:107–111
13. Bolanos MV, Moussa H, Manrique MC, Bolanos MJ (2003) Radiographic evaluation of third molar development in Spanish children and young people. Forensic Sci Int 133:212–219
14. Arany S, Iino M, Yoshioka N (2004) Radiographic survey of third molar development in relation to chronological age among Japanese juveniles. J Forensic Sci 49:534–538
15. Rai B, Kaur J, Jafarzadeh H (2010) Dental age estimation from the developmental stage of the third molars in Iranian population. J Forensic Legal Med 17:309–311
16. Meinl A, Tangl S, Huber C, Maurer B, Watzek G (2007) The chronology of third molar mineralization in the Austrian population—a contribution to forensic age estimation. Forensic Sci Int 169:161–167
17. Olze A, van Niekerk P, Schulz R, Schmeling A (2007) Studies of the chronological course of wisdom tooth eruption in a Black African population. J Forensic Sci 52:1161–1163
18. Mincer HH, Harris EF, Berryman HE (1993) The A.B.F.O. study of third molar development and its use as an estimator of chronological age. J Forensic Sci 38:379–390
19. Ubelaker DH (1987) Estimating age at death from immature human skeletons: an overview. J Forensic Sci 32:1254–1263
20. Olze A, Peschke C, Schulz R, Schmeling A (2008) Studies of the chronological course of wisdom tooth eruption in a German population. J Forensic Leg Med 15:426–429
21. Nolla CM (1960) The development of permanent teeth. J Dent Child 27:254–266
22. Olze A, van Niekerk P, Ishikawa T, Zhu BL, Schulz R, Madea H, Schmeling A (2007) Comparative study on the effect of ethnicity on wisdom tooth eruption. Int J Legal Med 121:445–448
23. Sisman Y, Uysal T, Yagmur F, Ramoglu SI (2007) Third-molar development in relation to chronologic age in Turkish children and young adults. Angle Orthod 77:1040–1045
24. Dhanjal KS, Bhardwaj MK, Liversidge HM (2006) Reproducibility of radiographic stage assessment of third molars. Forensic Sci Int 159:74–77
25. Harris EF (2007) Mineralization of the mandibular third molar: a study of American blacks and whites. Am J Phys Anthropol 132:98–109
26. Golovcencu L, Scripcaru C, Zegan G (2009) Third molar development in relation to chronological age in Romanian children and young adults. Rom J Leg Med 17:277–282
27. Kasper KA, Austin D, Kvanli AH, Rios TR, Senn DR (2009) Reliability of third molar development for age in a North Texas Hispanic population: a comparison study. J Forensic Sci 54:651–657
28. Bassed RB, Briggs C, Drummer OH (2011) Age estimation and the developing third molar tooth: an analysis of an Australian population using computed tomography. J Forensic Sci 56:1185–1191
29. Oliveira FT, Capelozza ALA, Lauris JRP, Bullen IRFR (2012) Mineralization of mandibular third molars can estimate chronological age—Brazilian indices. Forensic Sci Int. doi:10.1016/j.forsciint.2011.12.013
30. Cantekin K, Yilmaz Y, Demirci T, Celikoglu M (2011) Morphologic analysis of third-molar mineralization for eastern Turkish children and youth. J Forensic Sci 57:531–534
31. Orhan K, Ozer L, Orhan AI, Dogan S, Paksoy CS (2007) Radiographic evaluation of third molar development in relation to chronological age among Turkish children and youth. Forensic Sci Int 165:46–51
32. Li G, Ren J, Zhao S, Liu Y, Li N, Wub NLW, Yuan S, Wang H (2012) Dental age estimation from the developmental stage of the third molars in western Chinese population. Forensic Sci Int. doi:10.1016/j.forsciint.2011.12.015
33. Olze A, Taniguchi M, Schmeling A, Zhu BL, Yamada Y, Maeda H, Geserick G (2004) Studies on the chronology of third molar mineralization in a Japanese population. Leg Med 6:73–79

34. Caldas IM, Julio P, Simoes RJ, Matos E, Afonso A, Magelhaes T (2011) Chronological age estimation based on third molar development in a Portuguese population. Int J Legal Med 125:235–243
35. Knell B, Ruhstaller P, Prieels F, Schmeling A (2009) Dental age diagnostics by means of radiographical evaluation of the growth stages of lower wisdom teeth. Int J Legal Med 123:465–469
36. Rantanen AV (1967) The age of eruption of the third molar teeth. Acta Odontol Scand 25:1–86
37. Muller HR (1983) Eine Studieuber die Inkonstanz des dritten Molaren. Fehlen, Anlage, Durchbruch, Diss Dresden
38. Olze A, Ishikawa T, Zhu BL, Schulz R, Heinecke A, Maeda H, Schmeling A (2008) Studies of the chronological course of wisdom tooth eruption in a Japanese population. Forensic Sci Int 174:203–206
39. Shourie KL (1946) Eruption age of teeth in India. Ind J Med Res 34:105–118
40. Chagula WK (1960) The age at eruption of third permanent molars in male East Africans. Am J Phys Anthropol 18:77–82
41. Olze A, Solheim T, Schulz R, Kupfer M, Pfeiffer H, Schmeling A (2010) Assessment of the radiographic visibility of the periodontal ligament in the lower third molars for the purpose of forensic age estimation in living individuals. Int J Legal Med 124:445–448
42. Olze A, Solheim T, Schulz R, Kupfer M, Schmeling A (2010) Evaluation of the radiographic visibility of the root pulp in the lower third molars for the purpose of forensic age estimation in living individuals. Int J Legal Med 124:183–186
43. Ciapparelli L (1992) The chronology of dental development and age assessment. In: Clark DH (ed) Practical forensic odontology. Wright, Oxford, pp 22–42