Aten Primaria. 2014;46(Espec Cong 1):165-175

Atención Primaria

www.elsevier.es/ap

SCIENTIFIC ARTICLE

Accuracy in the legal age estimation according to the third molars mineralization among Mexicans and Columbians

José Costa[a,*], Javier Montero[b], Sarai Serrano[b], Alberto Albaladejo[b], Antonio López-Valverde[b], Isabel Bica[a]

[a] *Instituto Politécnico de Viseu, Escola Superior de Saúde, Viseu, Portugal*
[b] *Departamento de Cirugía, Universidad de Salamanca, Salamanca, Spain*

KEYWORDS
Forensic science;
Age estimation;
Third molar development;
Accuracy;
Forensic odontology

Abstract
Objectives: This study aims to assess the accuracy of age estimation according to two cut-off points of Demirjian's developmental stages (G and H) in the wisdom teeth, using panoramic radiographs from Colombian and Mexican teenagers.
Study design: The degree of maturation of the third molars was classified according to Demirjian in 8 stages (from A to H) by a blinded trained assessor. The sensitivity, specificity and efficacy of two cut-off points (G and H) were calculated for both samples.
Results: The orthopantomographies of 316 subjects, 171 Colombians (54.1%) and 145 Mexicans (45.9%), were analyzed. The stage H was found to be the best threshold for detecting juveniles (because the high specificity) in all the third molars assessed. The specificity was higher for lower third molars than for upper third molars, but no asymmetrical discrepancy was noted.
Conclusions: The stage H is the best cut-off point for detecting the adulthood when a high-specificity test is required.

Introduction

In current society the need to develop techniques for the estimation of the age of human cadavers or of illegal immigrants has increased. Owing to the actions of terrorist groups, high levels of violence, the presence of undocumented immigrants and abandoned children, child abuse and sexual crimes, the number of people, corpses and unidentified human remains has risen in recent years.

Dental mineralization is a highly valuable tool for the estimation of age. The development and formation of the teeth occur in a constant and gradual manner over a period of time, starting in the foetal stage and lasting up to the beginning of the second decade of life. It is a constant and universal process among populations of different origins, although there may be cross-population variations in the progress or delay of the mineralization process.[1,2] Thus, the analysis of third molars within populations with different

*Corresponding author.
E-mail: jsc.costa@gmail.com (J. Costa).

geographic and ethnic origins in an age range close to the age of legal maturity is of paramount importance.

Third molars are the teeth that provide the greatest amount of information with regards to dental maturity in people who have already concluded their dental mineralization of the second molars. However, since of the complete human dentition third molars have the most variable morphology, processes of formation and time of eruption, they are frequently found in incorrect positions, are malformed, or impacted (…), which can lead to errors when they are used as legal age estimators.[1,3]

For different reasons, age estimation in living individuals is performed worldwide every day, and this is why the forensic estimation of age is necessary to determine whether a person has achieved sufficient age to take responsibility for actions contravening the law, which results in the application of criminal legislation as applied to adults. In terms of the penal code, the diagnostic ages of forensic medical interest will thus deem that anyone of 14 years or younger is unfit to plead; anyone of 18 years or younger will be dealt with as a minor, and anyone of 21 or younger may benefit from a reduction in imputability.

In recent years, the demands of the legal and social systems to establish an efficient, dependable and safe process, one able to guarantee the correct estimation of age when there are no documents available to confirm dates of birth, have encouraged the development of research based on the mineralization of the third molar as a reliable indicator of age.[2,3]

The bibliographical references to the rating of the degree of mineralization and development of the third molars as a predictive element of age are numerous,[1,2,4] and most of them are based on the developmental stages proposed by Demirjian[5] in 1973. However, there are no studies that have focused on the validation of this method in Latin-American populations.

The present study aimed to assess the accuracy of age estimation according to two cut-off points of Demirjian's developmental stages of the wisdom teeth using panoramic radiographs from Colombian and Mexican teenagers.

Material and methods

We collected panoramic radiographs from teenagers belonging to two different geographic populations (Columbians and Mexicans). In both populations, the study only included teenagers with known chronological ages, ranging between 8 and 25 years. The first sample comprised patients needing dental care, who received attention at a Medical Centre of the City of Bogotá (Columbia). The second sample consisted of patients requiring dental care at the Private University of Chihuahua, Mexico. A panoramic radiograph (PR) was prescribed for all participants, after which images were randomly selected (following the consecutive order of dental attendance) from the radiographic database for analysis of the maturation of the third molars. Also, the chronological age and sex of all patients were retrieved from the same database.

The grades of maturation of the third molars (Fig. 1) were estimated using the diagrams of mineralization proposed by Demirjian,[5] in which the mineralization stages start with the calcification of certain oclusal points of the dental crown and finish with the closure of the apical orifice. For all third molars, depending on their grade of development, a value on a scale from A to H was assigned; this was performed using direct comparison of the radiographic appearance of each third molar with the chart shown in Figure 1. In cases where there was doubt between two stages of mineralization, we chose the least developed stage. We consider that the target periods for assessing legal age (up to 18 years) are between stages A and G. Since the G stage (formation of the root without apical closure) is borderline between individuals younger and older than 18 years, we only focused on stage H as an indicator of presumable adulthood. After the X-ray analysis, a global dataset was generated using both the real and the tooth-estimated age for the assessment of the accuracy of this classification method. The stage of mineralization was assessed for each third molar, and an aggregated value was computed by recording the higher developed stage of every wisdom teeth.

Figure 1 Developmental Stages of the permanent molars according to Demirjian's article.[5] A) Calcification of certain occlusal points without fusion. B) Fusion of the oclusal points of mineralization. C) End of the formation of enamel and beginning of the deposition of dentine. D) Formation of the crown to the enamel-cement junction. E) The longitude of the root is shorter than the latitude of the crown. F) The longitude of the root is equal to or greater than that of the crown. G) The growth of the root has ended; the apical orifice remains open. H) Closure of the apical orifice.

Ethics

This research was conducted according to the last Declaration of Helsinki, ensuring the protection of such clinical data. All the panoramic radiographs were sent to the Forensic Dental Section of the University of Granada for a blind recoding. A numerical code was assigned to each panoramic radiograph to maintain the anonymity of the origin of each of them, storing them in a separate database from the relative information about the age and gender of each patient.

Statistics

We used descriptive analysis to assess the sensitivity and specificity of the method within both samples (Columbians and Mexicans). As there was only one observer, we only calculated the intraclass correlation coefficients (Kappa's coefficient) by re-evaluating 100 panoramic radiographs (50 from the Mexicans and 50 from the Columbians). The sensitivity and specificity of the Demirjian age estimation method (up to the G stage) were studied for both samples (Specificity: true negative/true negative + false positive; Sensitivity: true positive/true positive + false negative). In

our case the sensitivity measures how well the Demirjian's age estimation method correctly detects individuals older than 18 years when stage G or H are used as cut off points. The specificity is the probability that using this test and the selected threshold G or H, we correctly identified a former stage of such threshold in an individual younger than 18. For each threshold a combination of sensitivity and specificity can be combined in the ROC (Receiver operator characteristic) plot reflecting the performance of the test. The area under curve indicates the probability of having an advanced maturation stage in a randomly selected individual from the older category, or *vice versa*. The positive and negative likelihood ratios (LR+ and LR−, respectively) were also calculated for the G and H threshold. For each threshold the LR+ gives the ratio of having at least this mineralization stage in older subjects compared to younger individuals whereas the LR− shows the ratio of having an early matured stage in the older subjects compared to one in the younger category. The positive (PPV) and negative (NPV) predictive values reflect the probability of being adult or juvenile when the test is positive or negative respectively. The accuracy of the test shows the proportion of true results (true positive + true negative/all results). All these parameters were calculated for every third molar among Mexicans and Columbians but also for the whole sample.All the analyses were made using the SPSS v.18 (Statistical Package for the Social Sciences, Chicago, ILL).

Results

The sample comprised 316 subjects of whom 171 were Colombians (54.1%) and 145 Mexicans (45.9%). Within the Colombians, 50.9% were male with a mean age of 16.0 ± 5.2 years and a range from 7 to 25 years. The Mexican sample mostly comprised males (54.5%) with a mean age of 16.3 ± 2.6 years and a range from 13 to 22 years.

The intra class-correlation coefficients (Kappa) were 0.91 for the Mexican sample and 0.82 for the Columbians, supporting the intra-observer consistency for both populations.

In general, we found that the mineralization of the upper third molars occurred earlier than in the lower third molars (Tables 1-4), and also earlier in the males than in the females. The sensitivity/ specificity values, the positive and negative predictive value, the likelihood ratio for positive and negative results as well as the efficacy for the H and G stages among each wisdom teeth are shown in Table 5.

The Tables 1 to 4 show the distribution of the real age and the stages of each third molar mineralization for males and females within the Columbian and Mexican samples. We did not find any clear trend in the distribution of the mineralization stages regarding gender for none wisdom teeth, although the percentage of subjects between A-F stages is higher for Columbian males and Mexican females than counterparts, for every wisdom teeth. However, such differences depend on the distinct distribution of sex within distinct age ranges for Columbians and Mexicans (Tables 1-4). The right lower third molar (tooth #48) is the less matured in our setting for both samples.

For the Columbian sample (n = 171 subjects) we evaluated 559 third molars and found that 60.3 % of these molars (n = 361) were between stages A and F and hence presumably belonged to minors (see Material and methods). Of those, 337 (93.4%) were properly assigned by the Demirjian age estimation method, but 24 (6.6%) were found in subjects aged 18 years or older. Within the G stage 60.5% were older than 18 years and 39.5% were minors. In the same way the stage H indicator of adulthood was properly assigned to 96.1% of the sample. From the above findings it was possible to conclude that most third molars having an H classification of mineralization were from individuals of legal age; the subjects classified in stages A-F were minors, while G represented the limit stage between minor status and adulthood.

In the sample of Mexicans (n = 145 subjects), 507 third molars were assessed and classified according to the stages of mineralization proposed by Demirjian.[5] We found that 60.3 % of the Mexican third molars (n = 354 cases) were in stages A to F and hence presumably belonged to minors. Of them, 303 (85.6%) were properly assigned by the Demirjian age estimation method, but 51 subjects (14.4%) were 18 years or older (Tables 1-4). Within the G stage, 69.5% of the subjects were older than 18 years and 30.5% were minors. The adulthood indicator (stage H) was properly assigned to 100.0% (n = 71) of the sample. Thus, using the aggregated molar estimation for Mexicans, the sensitivity of stage H for detecting adulthood was 39.7% and sensitivity was 100%. However, the sensitivity and specificity of stage G for detecting adulthood were 71.5% and 92.4% respectively. The specificity is higher for lower third molars than for upper third molars.

In the whole sample, for both Mexican and Columbian aggregated third molar estimation, the Demirjian Stage H had 58.2% sensitivity and 99.1% specificity (Table 5), whereas Stage G had 80.2% sensitivity and 93.0% specificity in detecting adulthood (Table 5). For the whole sample the lower third molars afford the highest specificity and the subsequent higher LR+. In the whole sample the mean age within the stage G and H was 18.1 ± 1.7 years and 21.4 ± 2.5 years respectively. There were not significant differences regarding sex, although females tended to be older within the stages G (18.3 ± 1.9 years) and H (21.6 ± 2.7 years), than males (17.8 ± 1.4 years and 21.2 ± 2.4 years years respectively). According to our results (Table 5) the stage H is the best threshold for detecting juveniles (because the high specificity) in all the third molars.

According to the aggregated estimation (the maximum maturation among all the present wisdom teeth) for the Columbians, the sensitivity of stage H for detecting adulthood was 74.9% and specificity was 95.3% (Table 5). Among this Columbian sample, the sensitivity and specificity of stage G were 87.9 and 93.6 respectively (Table 5). Regarding the aggregated estimation of the diagnostic performance it was found than among the whole sample the stage G (formation of the root without apical closure) is 10.2 times more likely to occur in an individual at least 18 as opposed to someone younger than 18 (LR+). In the same sense, the apex closure (Stage H) is 57.8 times more likely to be present in adults than in juveniles. Thus it is observed that the LR+ is for the stage H than for the stage G is four-fold more likely to occur in adults than in teenagers. The specificity and the corresponding LR+ are higher for lower third molars than for upper third molars using both

the G and H thresholds. However the accuracy was similar or even higher for the stage G, since the stage H has lower sensitivity (false negative results) whereas the stage G has a more balanced sensitivity/specificity values.

The ROC curves (Figs. 2 and 3) demonstrated that the Demirjian's method applied to all the third molars is able to discriminate properly adults from juveniles (area under curve ranging from 0.94 to 0.95).

Table 1 Distribution of the Demirjian Mineralization Stages in the right maxillary third molars (#18) among Columbians and Mexicans regarding gender

	Columbian males										Columbian females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8		1								1	1								1	2
9			2						1	3		1								1
10	1	1	3	2					4	11	3	1	2	1					2	9
11	1	1	2	3					1	8	1	1	2	3					1	8
12			3	4	1				1	9		1		2	1					4
13				4	1				2	7		1		4					2	7
14				3					2	5				5	2	1				8
15						2				2				3		1				4
16				3		2			1	6				1			1	1		3
17				1		1	1	1		4				1			2			3
18						1		3		4				1	2		1	3		7
19						1		1		2							1	1	1	3
20								3	1	4							1	1		2
21								3	1	4								2		2
22								3	1	4								2	1	3
23								2		2								3	3	6
24								4	2	6								3	3	6
25								4		4								5	2	7
Total	2	3	10	20	2	7	1	24	17	86	5	5	4	21	5	2	6	21	16	85
< 18 years	2	3	10	20	2	5	1	1	12	56	5	5	4	20	3	2	3	1	6	49
≥ 18 years	0	0	0	0	0	2	0	23	5	30	0	0	0	1	2	0	3	20	10	36

	Mexican males										Mexican females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8																				
9																				
10																				
11																				
12																				
13		1	2	5	1				1	10		2	8	7					2	19
14		1		10		2				13		1		5	1				2	9
15					2					2				1						1
16				3	2	3	4		2	14			1	6	5	1	1		4	18
17					1		2			3			1	1	1	1				4
18						1	1		1	3							1	1		2
19					3	1	4	8	3	19				1		7	5	6	1	20
20															1		1	1		3
21																				
22								1		1								2	2	4
23																				
24																				
25																				
Total		2	2	18	9	7	11	9	7	65		3	10	21	8	9	8	10	11	80
< 18 years		2	2	18	6	5	6	0	3	42		3	10	20	7	2	1	1	8	52
≥ 18 years		0	0	0	3	2	5	9	4	23		0	0	1	1	7	7	9	3	28

NR: not recorded (missing tooth).

Discussion

In recent years, owing to the need to protect the rights recognized for minors the legal and social demands to set up an efficient and safe procedure that will guarantee the correct estimation of age when documentation certifying the date of birth is not available have promoted research based on the degree of mineralization of third molars.[6] These are the only teeth expected to be still undergoing the process of mineralization during ages close to that of the legal age.[1,7,8]

Table 2 Distribution of the Demirjian Mineralization Stages in the left maxillary third molars (#28) among Columbians and Mexicans regarding gender

	Columbian males										Columbian females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8		1								1	1								1	2
9			2						1	3		1								1
10		1	3	2					5	11	3		2	1					2	8
11	1	1	2	3					1	8	1		2	3					2	8
12			4	3	2					9			1	2					1	4
13				4	1				2	7	1		1	4					2	8
14				3					2	5				4	2	1			1	8
15						2				2				2	1	1				4
16				3		1	2			6				1			1	1		3
17					1	1	1	1		4				1		1	1			3
18						1		3		4				1	2		1	3		7
19								1	1	2							1	1		2
20		1						2	1	3							1	1	1	3
21								1	2	3								2		2
22								3	1	4								3		3
23								3		3						1		3	1	5
24								3	3	6								5	2	7
25								3	1	4								5	2	7
Total	1	4	11	18	4	5	3	20	20	86	6	1	6	19	5	4	5	24	15	85
< 18 years	1	3	11	18	4	4	3	1	11	56	6	1	6	18	3	3	2	1	9	49
≥ 18 years	0	1	0	0	0	1	0	19	9	30	0	0	0	1	2	1	3	23	6	36

	Mexican males										Mexican females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8																				
9																				
10																				
11																				
12																				
13		1	1	6	1				1	10		2	8	7					2	19
14		1		9	1	2				13				5	1				3	9
15					2					2				1						1
16			1	1	3	3	4		2	14				5	6	1	1		5	18
17					1		2			3			1	1	1	1				4
18						1	1		1	3							1	1		2
19					2	1	4	9	3	19				2		7	5	5	1	20
20																		1	2	3
21																				
22								1		1								3	1	4
23																				
24																				
25																				
Total	0	2	2	16	10	7	11	10	7	65	0	2	9	21	8	9	7	10	14	80
< 18 years	0	2	2	16	8	5	6	0	3	42	0	2	9	19	8	2	1	0	10	51
≥ 18 years	0	0	0	0	2	2	5	10	4	23	0	0	0	2	0	7	6	10	4	29

NR: not recorded (missing tooth).

This cross-sectional study aimed at the analysis of the performance of a well-established method[5,9-11] but in populations other than those in which it was originally validated. The sample sizes seem to be sufficient to support preliminary conclusions about the goodness of this method using the proposed cut-off points for detecting adult thood.[1,2,5] The wide age range of the sample, including early and late maturing individuals, offer an optimal scenario in which to explore the consistency of the test over the entire age range. However since the distribution of gender across

Table 3 Distribution of the Demirjian Mineralization Stages in the left lower third molars (#38) among Columbians and Mexicans regarding the gender

	Columbian males										Columbian females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8		1								1	2									2
9	1		2							3	1									1
10	3	1	4	1					2	11		2	1	1					5	9
11	1	1	3	2					1	8		2	3	2	1					8
12			3	5	1					9	1	1	2							4
13		1	2	3					1	7		1	3	2					1	7
14			1	3					1	5			2	3	3					8
15				1	1					2			1	2	1					4
16			1	1	1	2	1			6					1		2			3
17			1		1	1		1		4						1	1		1	3
18				1			1	2		4				1	2		2	2		7
19						1	1			2					1		1		1	3
20	1						1	2		4							1	1		2
21								2	2	4							1	1		2
22								3	1	4								2	1	2
23								2		2							1	1	4	3
24								4	2	6							2	3	2	6
25								3	1	4								3	3	7
Total	6	4	17	17	4	4	4	19	11	86	4	6	12	11	9	1	11	13	18	85
< 18 years	5	4	17	16	4	3	1	1	5	56	4	6	12	10	6	1	3	0	7	49
≥ 18 years	1	0	0	1	0	1	3	18	6	30	0	0	0	1	3	0	8	13	11	36

	Mexican males										Mexican females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8																				
9																				
10																				
11																				
12																				
13			4	4	1				1	10	1	1	11	2					4	19
14			4	6	2				1	13		1	3	2	2				1	9
15				1	1					2			1							1
16					7	2	3		2	14		2		8	4		1		3	18
17						1	1		1	3				1	2	1				4
18					1		2			3							1	1		2
19					1	2	6	6	4	19			1	1	3	2	8	4	1	20
20																1	1	1		3
21																				
22								1		1								3	1	4
23																				
24																				
25																				
Total	0	0	8	11	13	5	12	7	9	65	1	4	16	14	11	4	11	9	10	80
< 18 years	0	0	8	11	11	3	4	0	5	42	1	4	15	13	8	1	1	0	8	51
≥ 18 years	0	0	0	0	2	2	8	7	4	23	0	0	1	1	3	3	10	9	2	29

NR: not recorded (missing tooth).

ages is not uniform (Tables 1-4), the effect of such variable could not have been properly evaluated in this study, and thus the performance of the tests was only estimated by combining both genders. However there is enough evidence supporting that the degree of third development is higher in males compared to females.[2,8,12-16] In any case, we believe that since the main diagnostic value of the Demirjian's method may be related to living individuals with known sex, it was not relevant to determine possible faults made by exchanging the gender.It should be also acknowledged that

Table 4 Distribution of the Demirjian Mineralization Stages in the right lower third molars (#48) among Columbians and Mexicans regarding gender

	Columbian males										Columbian females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8		1								1	2									2
9	1		2							3	1									1
10	3		6						2	11	1	1	2	1					4	9
11	1	1	3	2					1	8		1	4	2	1					8
12			3	6						9	1	1	2							4
13		1	2	3					1	7		1	2	2					2	7
14			3						2	5			2	3	3					8
15					2					2			1	2	1					4
16				2	2	1	1			6				1			2			3
17			1		1	1		1		4				1	1		1			3
18				1				3		4					2		2	2	1	7
19							2			2				1	1		1			3
20	1							3		4							1	1		2
21								2	2	4							1	1		2
22								3	1	4								3		3
23							1	1		2							1	1	4	6
24								4	2	6							1	3	2	6
25								3	1	4								2	5	7
Total	6	3	20	14	5	2	4	20	12	86	5	4	13	13	9	0	10	13	18	85
< 18 years	5	3	20	13	5	2	1	1	6	56	5	4	13	12	6	0	3	0	6	49
≥ 18 years	1	0	0	1	0	0	3	19	6	30	0	0	0	1	3	0	7	13	12	36

	Mexican males										Mexican females									
Age	A	B	C	D	E	F	G	H	NR	Total	A	B	C	D	E	F	G	H	NR	Total
8																				
9																				
10																				
11																				
12																				
13			4	3	2				1	10	2	1	9	4					3	19
14	1		3	7	2					13		1	4	2	2					9
15			1	1						2			1							1
16			1	1	7	2	3			14	1		2	8	4		1		2	18
17					1		1		1	3					3	1				4
18					1		1		1	3							1	1		2
19				2	1	1	4	7	4	19				1	5	1	8	3	2	20
20																1	1	1		3
21																				
22								1		1								3	1	4
23																				
24																				
25																				
Total	1	0	9	14	14	3	9	8	7	65	3	2	16	15	14	3	11	8	8	80
< 18 years	1	0	9	12	12	2	4	0	2	42	3	2	16	14	9	1	1	0	5	51
≥ 18 years	0	0	0	2	2	1	5	8	5	23	0	0	0	1	5	2	10	8	3	29

NR: not recorded (missing tooth).

the selection of radiographs on a consecutive sampling from archived collection is not an ideal way to recruited balanced data regarding sex and age.

To date, researchers who have analyzed the maturity of third molars for the establishment of dental age have reported a considerable corpus of data, but unequal results. The latter stems from the intrinsic characteristics of the samples studied, but is also derived from the different methodologies used, sample sizes, age ranges, etc.[1,2,7,8,12-14] Most of the methods tended consistently to overestimate the younger individuals and underestimate the older individuals, because of the extremely high variability of maturation of third molars, mainly between 16 and 22 years old.[11] Our considerably smaller sample also showed this pattern. Age in individuals who are dentally advanced will be over-estimated and in those dentally delayed will be under-estimated (Table 1-4). This occurred mainly among Mexicans, and future research should be directed towards giving plausible explanations for

Table 5 Diagnostic accuracy for legal age determination using both the H and the G mineralization stages as the cut-off points in all the third molars among Mexicans and Columbians

	Columbians		Mexicans		Global	
	H	G	H	G	H	G
Aggregated estimation						
Sensitivity	74.9	87.9	39.7	71.5	58.2	80.2
Specificity	95.3	93.6	100.0	92.4	99.1	93.0
PPV	96.1	85.3	100.0	86.1	97.1	85.0
NPV	89.7	91.8	74.4	87.5	81.6	89.6
LR+	40.0	9.4	–	11.3	57.8	10.2
LR–	0.19	0.15	0.63	0.26	0.39	0.21
Accuracy	91.8	89.2	77.7	87.1	86.4	88.1
Estimation for #18						
Sensitivity	84.3	90.2	31.6	63.2	61.8	78.7
Specificity	97.7	94.3	92.1	84.3	94.9	88.7
PPV	95.6	88.5	63.2	63.2	85.9	77.8
NPV	91.5	95.2	75.9	84.3	83.2	89.2
LR+	37.1	15.8	4.0	4.0	12.2	7.0
LR–	0.16	0.10	0.74	0.44	0.40	0.24
Accuracy	92.8	92.9	74.0	78.0	83.8	85.3
Estimation for #28						
Sensitivity	82.4	88.2	45.5	70.5	65.3	80.0
Specificity	97.7	91.9	100.0	90.1	98.8	91.0
PPV	95.5	86.5	100.0	79.5	96.9	83.5
NPV	90.3	92.9	77.1	84.9	83.3	88.9
LR+	35.4	10.8	–	7.1	54.5	8.9
LR–	0.18	0.13	0.55	0.33	0.25	0.22
Accuracy	92.0	90.5	80.8	83.2	86.6	87.0
Estimation for #38						
Sensitivity	62.0	86.0	34.8	73.9	49.0	80.2
Specificity	98.9	95.7	100.0	93.7	99.4	94.7
PPV	96.9	91.5	100.0	87.2	97.9	89.5
NPV	82.7	92.6	72.5	86.1	77.6	89.5
LR+	57.0	19.8	–	11.7	83.7	15.2
LR–	0.38	0.15	0.65	0.28	0.51	0.21
Accuracy	85.9	92.3	76.0	86.4	81.3	89.5
Estimation for #48						
Sensitivity	68.8	87.5	36.4	72.7	53.3	80.4
Specificity	98.9	94.6	100.0	94.1	99.4	94.4
PPV	97.1	89.4	100.0	86.5	98.0	88.1
NPV	86.0	93.6	75.2	87.0	80.5	90.3
LR+	63.9	16.3	–	12.4	94.8	14.3
LR–	0.32	0.13	0.64	0.29	0.47	0.21
Accuracy	88.7	92.2	78.3	86.8	83.7	89.6

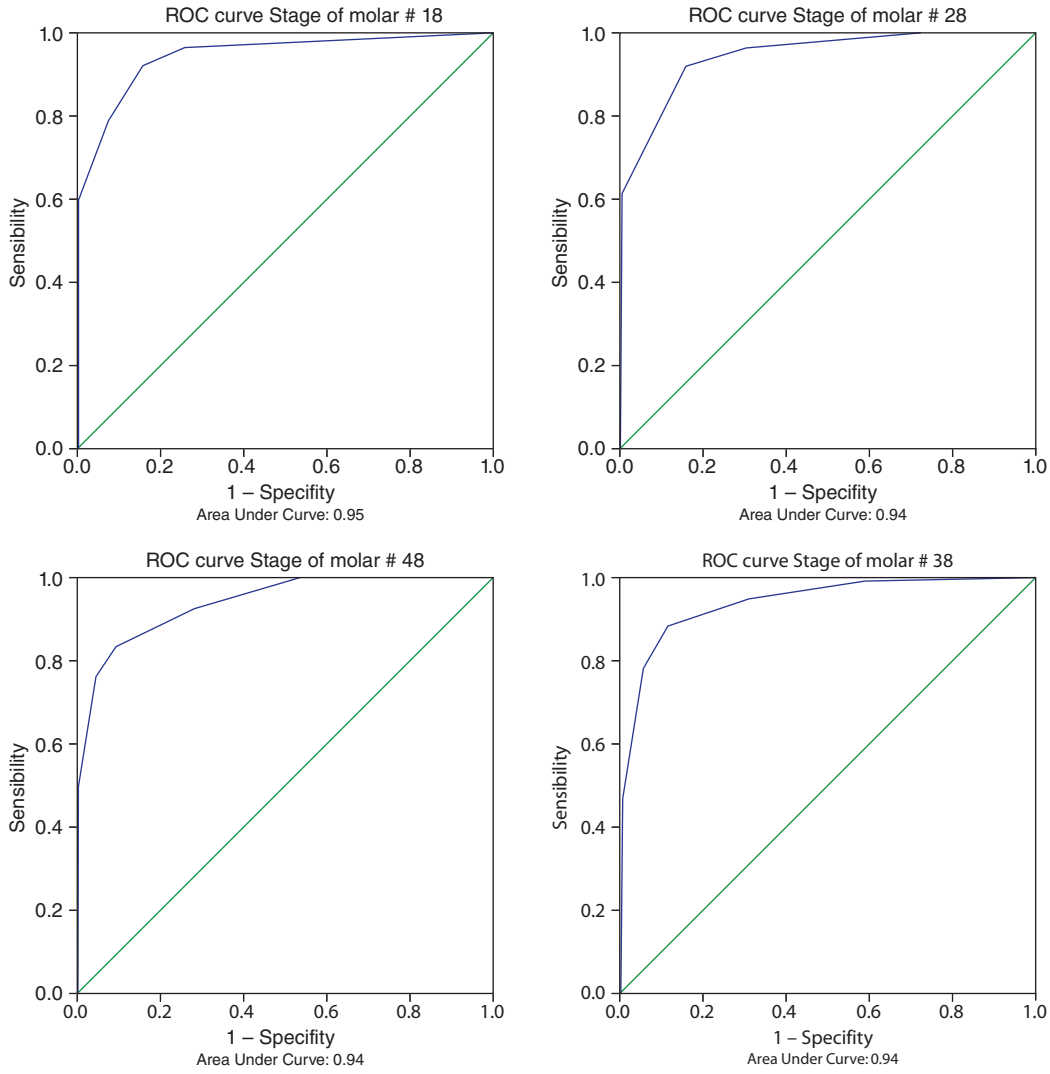

Figure 2 ROC curve according to Demirjian's stages in the upper and lower, right and left third molars (#18) (#28) (#38) (#48).

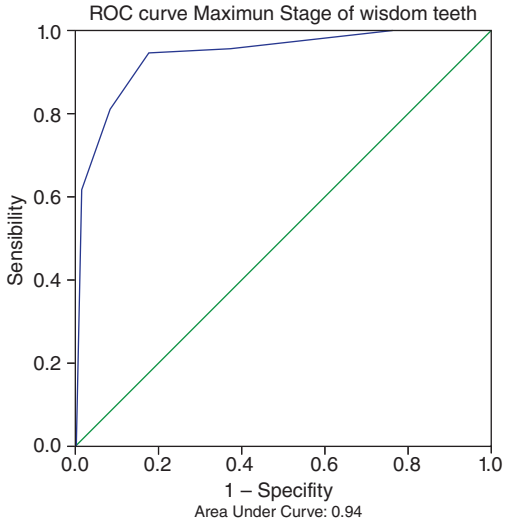

Figure 3 ROC curve according to Demirjian's stages in all the third molars (aggregated estimation).

such population-related discrepancy. The reference populations of this study are heterogeneous (Columbians and Mexicans), because although both populations are Latin Americans living in mountainous regions, they are from different geographic latitudes (distance to the equator), and hence differences in solar exposure could impinge on nutritional patterns, which may in turn lead to changes in the patterns of growth and development of both the osseous and dental structures.[12] Future research should address the issue of the pattern of mineralization according to the type of diet in ecological and epidemiological studies.

Since differences in physiological maturity and dental development exist not only between nations[4,7,13-17] but also between groups from the same populations, we expected to find such variability in our samples. This was the rationale for performing an analysis of the validity of the classification using the suggested cut-off points between the G and H stages.[1,2,5] Several authors have confirmed that ethnic and racial characteristics modify the chronology of dental mineralization.[2,4,8,19-21]

In 2008 Martin de lasHeras et al[2] conducted a comparative study of the development of the third molar in three populations from different ethnic and socio- geographic groups: Spanish subjects from Galicia; Spanish subjects from Ceuta, and Maghribians from Ceuta. They found significant statistical differences between the Maghribian population of Ceuta and the Spanish population of Galicia (a slower mineralization). However, the difference between the Spanish and Maghribian subjects from the town of Ceuta (North of Africa) did not reach statistical significance. Those authors concluded that in general there is a positive association between the age of the individual and the degree of mineralization according to Demirjian.[5] Some geographic and nutritional factors could underlie the discrepant mineralization of third molars among Spanish subjects.

Although a significant ethnic-related difference has been shown in several studies,[4,7,13-17] this is at the group level, and actually it has no consequences when estimating age at the individual level because of the magnitude of the standard deviation within groups. Future works should consider the influence of geographic, nutritional and genetic influences in order to establish adjusted standard cut off points for the particular population studied, but taking into account that such population specific reference study will not be necessary to estimate the age at the individual level, because of the worldwide similarity in third molars maturity.[11,22]

Our results concerning sensitivity and specificity are fairly similar to those obtained in similar studies carried out in North American[1] and European populations.[8,22-25] Other authors have found that the passage from stage G to H occurs at lower ages,[4,20] while still others have reported that this stage change occurs at older ages.[15-17,20] The mean age within the stages G and H for the whole sample match with that expected from large cross-sectional studies carried out in White Caucasian and Black Africans.[23,24]

The area under ROC curves demonstrated that this method discriminated almost perfectly older from younger of 18 years, for every third molar assessed and also for the aggregated estimation of molars. This area is clearly higher than that reported in similar studies.[2,11,14,25] In the same sense, the likelihood ratio of being at least 18 if the third molar is mature (Stage H) is clearly higher than that reported elsewhere (LR+ = 13.61)[11] which means that in our setting was very uncommon the presence of apical closure in juveniles (Tables 1-4). This finding may be in disagreement with Kasper who concluded that the third molar development is faster in Hispanic than American Caucasians.[16]

Although no clear conclusion could be drawn regarding the left-right asymmetry in the developmental formation stages of the wisdom teeth as found elsewhere,[8,21] we found that upper third molars are more advanced than counterparts, in agreement with several authors.[1,4,21-23,26-28] As a consequence the lower wisdom teeth afford higher specificity values (Table 5).

In light of our results, it seems that Demirjian's method[5] is a reliable and valid method for the estimation of legal age among Mexicans and Columbians, and that stage H would be selected as the cut-off point if a high-specificity test were required in order to minimize the risk of assigning legal age to teenagers (false-positives).Future efforts should compare these data with those collected from other Hispanic populations and should evaluate the potential association with diet and other possible enviromental factors (i.e. disease, medical treatments, habits, etc.).

What we know about the theme

Dental mineralization is a highly valuable tool for the estimation of age. Several studies based on the Demirjian's developmental stages have demonstrated good accuracy. However there may be cross-population variations in the progress or delay of the mineralization process and the Latin-American populations has not been evaluated by this approach.

What we get out the study

We have demonstrated that determining the Demirjian's stages in the wisdom teeth is a reliable and valid method for the estimation of legal age among Mexicans and Columbians, being the stage H the preferable cut-off point if a high-specificity test is required.

Acknowledgments

Authors want to thank the technical support shared by the Legal Medicine Department of the University of Granada, (Spain) specially to Prof. Aurora Valenzuela's research team.

Conflicts of interest

The authors declare that there are no conflicts of interest.

References

1. Mincer HH, Harris EF, Berryman HE. The ABFO study of third molar development and its use as an estimator of chronological age. J Forensic Sci. 1993;38:379-90.
2. Martin-de las Heras S, García-Fortea P, Ortega A, Zodocovich S, Valenzuela A. Third molar development according to chronological age in populations from Spanish and Magrebian origin. Forensic Sci Int. 2008;174:47-53.
3. Bolaños MV, Moussa H, Manrique MC, Bolaños MJ. Radiographic evaluation of third molar development in Spanish children and young people. Forensic Sci Int. 2003;133:212-9.
4. Solari AC, Abramovitch K. The accuracy and precision of third molar development as an indicator of chronological age in Hispanics. J Forensic Sci. 2002;47:531-5.
5. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. 1973;45:211-27.
6. Corradi F, Pinchi V, Barsanti I, Garatti S. Probabilistic classification of age by third molar development: The use of soft evidence. J Forensic Sci. 2013;58:51-9.
7. Kullman L, Johanson G, Akesson L. Root development of the lower third molar and its relation to chronological age. Swed Dent J. 1992;16:161-7.
8. Prieto JL, Barbería E, Ortega R, Magaña C. Evaluation of chronological age based on third molar development in the Spanish population. Int J Legal Med. 2005;119:349-54.

9. Olze A, Bilang D, Schmidt S, Wernecke KD, Geserick G, Schmeling A. Validation of common classification systems for assessing the mineralization of third molars. Int J Legal Med. 2005;119:22-6.
10. Caldas IM, Júlio P, Simões RJ, Matos E, Afonso A, Magalhães. Chronological age estimation based on third molar development in a Portuguese population. Int J Legal Med. 2011;125:235-43.
11. Liversidge HM, Marsden PH. Estimating age and the likelihood of having attained 18 years of age using mandibular third molars. Br Dent J. 2010;209:E13.
12. Chaillet N, Nyström M, Demirjian A. Comparison of dental maturity in children of different ethnic origins: international maturity curves for clinicians. J Forensic Sci. 2005;50:1164-74.
13. Robetti I, Iorio M, DalleMolle M. Orthopantomography and the determination of majority age. Panminerva Med. 1993;35: 170-2.
14. Garamendi PM, Landa MI, Ballesteros J, Solano MA. Reliability of the methods applied to assess age minority in living subjects around 18 years old. A survey on a Moroccan origin population. Forensic Sci Int. 2005;154:3-12.
15. Meinl A, Tangl S, Huber C, Maurer B, Watzek G. The chronology of third molar mineralization in the Austrian population a contribution to forensic age estimation. Forensic Sci Int. 2007; 169:161-7.
16. Kasper KA, Austin D, Kvanli AH, Rios TR, Senn DR. Reliability of third molar development for age estimation in a Texas Hispanic population: a comparison study. J Forensic Sci. 2009;54:651-7.
17. Olze A, Schmeling A, Taniguchi M, Maeda H, Van Niekerk P, Wernecke KD, et al. Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization. Int J Legal Med. 2004;118:170-3.
18. Maber M, Liversidge HM, Hector MP. Accuracy of age estimation of radiographic methods using developing teeth. Forensic Sci Int. 2006;159 Suppl 1:S68-73.
19. Bolanos MV, Manrique MC, Bolanos MJ, Briones MT. Approaches to chronological age assessment based on dental calcification. Forensic Sci Int. 2000;110:97-106.
20. Orhan K, Ozer L, Orhan AI, Dogan S, Paksoy CS. Radiographic evaluation of third molar development in relation to chronological age among Turkish children and youth. Forensic Sci Int. 2007;165:46-51.
21. Arany S, Iino M, Yoshioka N. Radiographic survey of third molar development in relation to chronological age among Japanese juveniles. J Forensic Sci. 2004;49:534-8.
22. De Salvia A, Calzetta C, Orrico M, De Leo D. Third mandibular molar radiological development as an indicator of chronological age in a European population. Forensic Sci Int. 2004;146 Suppl: S9-12.
23. Liversidge HM. Timing of human mandibular third molar formation. Ann Hum Biol. 2008;35:294-321.
24. Blankenship JA, Mincer HH, Anderson KM, Woods MA, Burton EL. Third molar development in the estimation of chronologic age in American blacks as compared with whites. J Forensic Sci. 2007;52:428-33.
25. Thevissen PW, Fieuws S, Willems G. Human dental age estimation using third molar developmental stages: does a Bayesian approach outperform regression models to discriminate between juveniles and adults? Int J Legal Med. 2010;124:35-42.
26. Lewis JM, Senn DR. Dental age estimation utilizing third molar development: A review of principles, methods, and population studies used in the United States. Forensic Sci Int. 2010;201:79-83.
27. Thevissen PW, Fieuws S, Willems G. Human third molars development: Comparison of 9 country specific populations. Forensic Sci Int. 2010;201:102-5.
28. Olze A, Van Niekerk P, Ishikawa T, Zhu BL, Schulz R, Maeda H, et al. Comparative study on the effect of ethnicity on wisdom tooth eruption. Int J Legal Med. 2007;121:445-8.