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Dental Age Assessment by I_{2M} and I_{3M}: Portuguese Legal Age Thresholds of 12 and 14 Year Olds

Dentalna procjena dobi s pomoću I_{2M} i I_{3M}: prema portugalskom zakonu za dob od 12 do 14 godina

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Abstract

Objective: Better understanding of dental age assessment may help in cases of age estimation in Forensic Clinics. The first aim was to provide essential information on method reliability for upcoming studies using dental age assessment by second molar index (I_{2M}), and third molar index (I_{3M}) for age estimation on legal ages of 12 - 14 years. The second aim was to document forensic method outcomes of the Demirjian method which has already been used in forensic clinic. **Material and methods:** Two samples were used for this purpose: for I_{2M}, 633 orthopantomographs (270 females / 363 males), the age range from 7 to 17 years and for I_{3M}, 471 orthopantomographs (253 females / 218 males), the age range from 10 to 23 years, from the database population of Lisbon North University Hospital Center, approved by the Ethic Committee. **Results:** The I_{3M} cut-off point (1.133) for 12- year-olds obtained better results than the cut-off point stated by the I_{2M} (0.135). Besides, I_{2M} cut-off point (0.001) for 14- year- olds showed better results when compared with the cut-off point (0.705) established by the I_{3M}. Both methods are reliable for the legal age thresholds of 12 and 14 years. However, using I_{2M} and I_{3M} allows us to vary the cut-off value to privilege sensitivities or specificity, depending on which is more appropriate to the intended application. **Conclusions:** The accuracy (88.94%) of I_{3M} obtained better results for the 12- year- old cut-off point (1.133) and the accuracy (90.21%) of the I_{2M} performed better for the 14- year- old cut-off point (0.001).

Introduction

Forensic Odontology is a discipline of Forensic Sciences. The main purpose consists of proper observation, handling, examination and technical-scientific evaluation of oral evidence, which will be presented in the major interest of the justice (1). The judicial system faces several difficulties regarding the identification of individuals without reliable identification, often categorizing them by physical appearance, which leads to errors and lack of equity when presented to the court (2). In children and adolescents, there are several forensic issues such as minimal age for criminal responsibility and the threshold age for civil adulthood where the biological age assessment through dental evidence can help (3-5).

In Portugal, the legal ages, between the ages of 12 and 14 years, are covered by the Portuguese penal code which promotes the protection of juvenile individuals, giving priority to healing and prevention over individual measures of punishment. For the application of criminal law, we assume the practice of a fact qualified as a crime by a minor less than 16 years of age is not imputable. This is valid for ages between 12 and 16 years. A child below the age of 16 years cannot be held criminally liable. Children aged between 12 and 16 years can be subject to penalties under the Guardianship and Education Law, which allows for detention of children in closed educational centers. Also, this allows the application of preventing educational measures when crimes are committed by children from 12 to 16 years of age, referred to as juvenile delinquency (6,7).

Within Section II of Chapter V, Book II of the Portuguese Penal Code, we are faced with the intervention area of crimes against sexual self-determination, that is, the classification of the crime, in undocumented victims, in order to blame the assailant through the action of the age estimate. According to Article 171º (Child sexual abuse), all children and young people less than 14 years of age are considered victims. In addition to this crime, article 173 refers to sexual acts with adolescents, where the victims are all children or young people between 14 and 16 years of age. If the victim is between 14 and 18 years of age, without documents, article 174 acts, resorting to the prostitution of minors. If the victim is under 18, articles 175 and 176 cover sexual exploitation of children and pornography of minors, respectively (8).

Since age estimation must be as precise as possible when applied to the medico-legal field, in the best interest of justice, the use of radiographic techniques, namely orthopantomography, is preferred over any other indirect method. It is a process that is relatively time-efficient, showing to be more accurate than skeletal development for estimating chronological age (9-12).

Several methods, using orthopantomographs, have been introduced to estimate age through dental observation. They have been commonly used in studies of dental maturity and for age estimation (13). Demirjian method is one of them, which consists in assigning one out of eight stages according to the mineralization state of the tooth (14,15). However, this system is highly subjective since it depends on the stage that the observer attributes to it.

Uvod

Forenzička dentalna medicina disciplina je sudskih znanosti. Njezina je glavna svrha pravilno opažanje, rukovanje, pregledavanje te tehnička i znanstvena procjena oralnih dokaza koji se zahtijevaju uglavnom u interesu pravde (1). Pravni sustav suočava se s nekoliko poteškoća kad je riječ o identifikaciji osoba bez pouzdanog identiteta te se one često kategoriziraju prema fizičkom izgledu, što nerijetko završava pogreškama i nedostatkom jednakosti pred sudom. Kod djece i adolescenata nekoliko je forenzičkih točaka, kao što su najmanja dob za kriminalnu odgovornost te razina dobi za civilnu odraslost, kada dentalni dokazi mogu pomoći pri procjeni biološke dobi (3 – 5).

U Portugalu je dob od 12 do 14 godina regulirana Kaznenim zakonom koji promiče zaštitu mladih osoba te daje prednost oporavku i prevenciji, a ne individualnim kaznenim mjerama. Pri primjeni kaznenoga zakona pretpostavlja se da nema kaznene odgovornosti ako je čin koji se smatra kaznenim djelom učinio maloljetnik. To vrijedi za dob od 12 do 16 godina. Dakle, dijete mlađe od 16 godina ne može kazneno odgovarati. Djeca u toj dobi mogu biti kažnjena prema Zakonu o skrbi i edukaciji koji omogućuje njihovo upućivanje u odgojne centre zatvorenog tipa. Tako se mogu primijeniti preventivne odgojne mjere u slučaju kada su djeca u dobi od 12 do 16 godina učinila kazneno djelo, što se naziva juvenilnom delinkvencijom (6, 7).

U drugom dijelu 5. poglavlja, u drugoj knjizi portugalskoga Kaznenog zakona, govori se o intervencijama u slučaju kaznenih djela protiv vlastite seksualne orijentacije, odnosno o klasifikaciji kaznenoga djela nad nedokumentiranim žrtvama kako bi se počinitelj kaznio s obzirom na procijenjenu dob. Prema članku 171. (seksualno zlostavljanje djece) sva djeca i osobe mlađe od 14 godina smatraju se žrtvama. Članak 173. dodatno govori o seksualnom činu s adolescentima u kojem su žrtve sva djeca i mlade osobe u dobi od 14 do 16 godina. Ako žrtva ima od 14 do 18 godina, a nema dokumentacije, članak 174. definira zločin kao prostituiranje maloljetnika. Ako žrtva ima manje od 18 godina, članci 175. i 176. govore o seksualnom iskorištavanju djece te o maloljetničkoj pornografiji (8).

Budući da procjena dobi mora biti što je moguće točnija kada se primjenjuje u medicinsko-pravnom području u najboljem interesu pravde, upotreba rendgenskih tehnika, ponajprije ortopantomografije, najprihvatljivija je od svih neizravnih metoda. To je razmjerno brz postupak koji se pokazao točnijim od skeletalnog razvoja pri procjenjivanju kronološke dobi (9 – 12).

Za procjenjivanje kronološke dobi s pomoću dentalnog pregleda koristi se nekoliko metoda, uključujući i ortopantomografiju. Njihova upotreba uobičajena je u istraživanjima dentalne zrelosti i pri procjeni dobi (13). Jedna od metoda jest Demirjianova koja se sastoji od određivanja jednoga od osam stupnjeva prema stanju mineralizacije zuba (14, 15). No, taj je sustav visoko subjektivan, zato što ovisi o stupnju koji određuje osoba koja procjenjuje.

S druge strane, Cameriereova metoda s regresivnom formulom prema kojoj se određuje dob s pomoću omjera koji se

On the other hand, there is Cameriere's method with a regressive formula in which it is established that the ratio given by the sum of the distances from the inner sides of the open apices and the height of the developing of second and third molars (second molar maturity index – I_{2M} and third molar maturity index - I_{3M}) is a reliable method to discriminate, regardless of geographic origin and socio-economic status (16,17).

The aim of this study was to assess the cut-off points for the Portuguese legal ages of 12 and 14 years, important according to the Portuguese Penal Code, through the second molar maturity index (I_{2M}) and third molar maturity index (I_{3M}) and to compare this method to the Demirjian's stages already applied in the forensic community for dental age assessment.

Material and methods

Sample

To assess the cut-off points through the I_{2M}, 633 orthopantomographs (270 females and 363 males) were selected between 7 and 17 year olds and to assess the cut off points through the I_{3M}. We selected 471 orthopantomographs (253 females and 218 males) between 10 and 23 years old (Table 1). The samples were taken as a random basis from the X-ray database of the Stomatology Department at Hospital Santa Maria, targeting patients from the Lisbon North University Hospital Center.

Selection criteria were healthy subjects of Portuguese origin, presence of the second and third molar in all lower quadrants, absence of congenital dental anomalies in shape or/and position, including root canal treatment, caries or restorations in the left mandibular permanent teeth. Heavily rotated, impacted, and unclear orthopantomographs were excluded from the analysis.

dobije zbrajanjem udaljenosti od unutarnje strane otvorenih apeksa i visine drugoga i trećega molara u razvoju (indeks zrelosti drugog molara – I_{2M}, indeks zrelosti trećeg molara – I_{3M}) pouzdana je metoda za diskriminaciju, bez obzira na geografsko podrijetlo i socijalno-ekonomski status (16, 17).

Svrha ovog istraživanja bila je procijeniti granične točke za portugalsku zakonsku dob od 12 i 14 godina, važne točke u portugalskome kaznenom zakonodavstvu, s pomoću indeksa zrelosti drugog kutnjaka (I_{2M}) i indeksa zrelosti trećeg kutnjaka (I_{3M}) te usporediti tu metodu s Demirjianovim stupnjevima koji se već primjenjuju u forenzičkoj zajednici za dentalno određivanje dobi.

Materijal i metode

Uzorak

Da bismo odredili granične točke s pomoću I_{2M}, odabrali smo 633 ortopantomograma (270 uzetih od djevojčica i djevojaka i 363 od dječaka i mladića) u dobi od 7 do 17 godina, a da bismo odredili granične točke s pomoću I_{3M} odabrali smo 471 ortopantomogram (253 od djevojčica i djevojaka i 218 od dječaka i mladića) u dobi od 10 do 23 godine (tablica 1.). Uzorak je prikupljen slučajnim odabirom iz baze rendgenskih snimki Odjela za dentalnu medicinu Bolnice Santa Maria koja prima pacijente u sklopu Sveučilišnoga bolničkog centra Lisabon – Sjever.

Kriteriji za odabir bili su zdrave osobe portugalskog podrijetla koje imaju drugi i treći kutnjak u oba donja kvadranta, bez kongenitalnih dentalnih anomalija kad je riječ o obliku i/ili položaju zuba, uključujući endodontsko liječenje, karijes i ispune na donjim lijevim zubima. Jako rotirani, impaktirani zubi te mutni i nejasni ortopantomogrami bili su isključeni.

Table 1   Age distribution by sex
Tablica 1.   Distribucija dobi prema spolu

Age (years) • Dob (godine)	Sample for I_{2M} • Uzorak za I_{2M}			Sample for I_{3M} • Uzorak za I_{3M}		
	Sex • Spol		Total • Ukupno	Sex • Spol		Total • Ukupno
	Male • Muški	Female • Ženski		Male • Muški	Female • Ženski	
7	38	25	63	-	-	-
8	48	36	84	-	-	-
9	60	41	101	-	-	-
10	54	39	93	26	35	61
11	45	29	74	23	37	60
12	35	38	73	22	30	52
13	28	22	50	27	19	46
14	23	17	40	23	24	47
15	7	6	13	16	13	29
16	8	10	18	13	13	26
17	17	7	24	8	22	30
18	-	-	-	10	9	19
19	-	-	-	15	13	28
20	-	-	-	11	5	16
21	-	-	-	10	10	20
22	-	-	-	8	13	21
23	-	-	-	6	10	16
Total	363	270	633	218	253	471

The subject's sex, date of birth, and the date of the ortho-pantomography were recorded. The chronological age (CA) for each subject was computed by subtracting the date of the X-rays from the date of birth.

The study was performed in accordance with the ethical standards laid down by Faculty of Dental Medicine, University of Lisbon Health Ethics Committee, under the number 911105 and 911106.

Measurements

As proposed by Cameriere *et al.* in the original study, the maturity index was assessed as follows: a ratio between the sum of the inner side's width of the open apices (A1 and A2) in the left and right lower third molar and the tooth's length (L) when more than one root were presented, or a ratio between the width of the open apex (A) and the tooth's length (L1) when a single root was present (18).

X-ray images in JPG format were analyzed by a software program, *ImageJ*®. The orthopantomographs were scaled at 400% and afterwards the measurement was changed from pixels to millimeters.

Mineralization of permanent teeth on the lower left mandible was also assessed according to the Demirjian (14) classification for later comparison with Cameriere's molar maturity index.

Statistical analysis

The intra-class correlation coefficient (ICC) was applied to quantify intra- and inter-observer agreement. Weighted Cohen's kappa was used to evaluate intra and inter-observer agreement in Demirjian's stages classification. Spearman ρ rank correlation was also used to evaluate the order relation between two measurements. For this purpose, 10% of the sample was randomly selected 3 months following the initial scoring process to determine percentage of agreement, for both intra- and inter-observer agreement analyses.

Apart from the accuracy, the sensitivity and the specificity, other measures to assess misclassification were computed, such as the positive predictive value (PPV), the negative predictive value (NPV), and the positive and negative likelihood ratios (LR+ and LR–). Moreover, the post-test probabilities (Bayes PTP) were computed using Bayes's theorem in order to generalize the results of the Portuguese population, using data extracted from the Statistics Portugal data base (https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main), (11).

Finally, the Receiver Operating Characteristic (ROC) curves were obtained and the areas under the ROC curves (AUC) were computed.

Results

The results of Cohen's kappa and ICC for second molar are showed in Tables 2 and 3. Intra-observer validation for I_{2M} varies between 0.608 and 0.943. The weighted Cohen's kappa for intra-observer validation of Demirjian stadiums is equal to 0.834. In terms of inter-observer validation, kappa coefficients were equal to 0.834 and to 1.000. The computed Spearman correlations have values greater than 0.95. Thus,

Bilježili su se spol, datum rođenja te datum snimke. Kronološka dob (CA) svakog ispitanika izračunata je oduzimanjem datuma rođenja od datuma snimke.

Istraživanje je provedeno u skladu sa standardima Etičkoga povjerenstva Fakulteta dentalne medicine Sveučilišta u Lisabonu (pod brojevima 911105 i 911106).

Mjerenja

Kao što su predložili Cameriere i suradnici u izvornom istraživanju, indeks zrelosti procjenjuje se na sljedeći način: ako zub ima više od jednog korijena, mjeri se omjer između zbroja dužina unutarnjih strana otvorenih apeksa (A1 i A2) na lijevom i desnom donjem trećem molaru i dužine zuba (L), a ako postoji samo jedan korijen, mjeri se omjer između širine otvorenog apeksa (A) i dužine zuba (L1) (18).

Rendgenske snimke u JPG formatu analizirane su u programu ImageJ®. Ortopantomogrami su povećani na 400 % te su mjerenja poslije izmijenjena iz piksela u milimetre.

Mineralizacija trajnih zuba u lijevom dijelu donje čeljusti procijenjena je Demirjianovom (14) klasifikacijom za kasniju usporedbu s Cameriereovim indeksom zrelosti molara.

Statistička analiza

Intraklasni koeficijent korelacije (ICC) primijenjen je da bi se kvantificiralo podudaranje mjerenja i mjeritelja. Cohenov kappa korišten je za mjerenje podudaranja kod klasifikacije Demirjianovih stupnjeva. Korelacija Spearmanova ρ ranga upotrijebljena je za procjenu reda odnosa između dvaju mjerenja. U tu svrhu je 10 % uzorka ponovno izmjereno nakon tri mjeseca kako bi se odredio postotak podudaranja unutar ispitivača i između ispitivača.

Osim točnosti, osjetljivosti i specifičnosti izračunate su i druge vrijednosti procjene pogrešne klasifikacije kao što su pozitivna predviđena vrijednost (PPV), negativna predviđena vrijednost (NPV) te pozitivni i negativni omjer sličnosti (LR+ i LR-). Nadalje, vjerojatnosti post-testa (Bayes PTP) izračunate su s pomoću Bayesova teorema (11) kako bi se generalizirali rezultati za portugalsku populaciju korištenjem podataka iz statističke baze podataka Portugala (https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_main).

Na kraju su dobivene krivulje karakteristika operativnog primatelja (ROC) te je izračunata vrijednost područja ispod ROC-a (AUC).

Rezultati

Rezultati Cohenova kappa indeksa i ICC za drugi molar prikazani su u tablicama 2 i 3. Validacija vrijednosti za ispitivača za I_{2M} varira od 0,608 do 0,943. Cohenov kappa za validaciju između mjerenja Demirjianovih stupnjeva iznosio je 0,834. Kad je riječ o validaciji između mjeritelja, kappa koeficijenti iznosili su 0,834 i 1,000. Izračunate Spearmanove korelacije imale su vrijednosti veće od 0,95. Zato nam po-

Table 2 CCI values of intra-observer validation (I_{2M})
Tablica 2. CCI vrijednosti validacije između mjera (I_{2M})

	Measure • Mjera	Intra Observer 1 • Mjeritelj 1
37	A1	0.922
	A2	0.918
	L	0.926
	A	0.810
	L1	0.608
47	A1	0.927
	A2	0.918
	L	0.943
	A	0.793
	L1	0.653

Notes: A1, Width of the mesial open apex of the multiradicular tooth; A2, Width of the distal open apex of the multiradicular tooth; L, Maximum tooth length; A, Width of the open apex of the monoradicular tooth; L1, Maximum monoradicular tooth length
Bilješka: A1 – širina mezijalnog otvora apeksa višekorijenskih zuba; A2 – širina distalnog otvora apeksa višekorijenskih zuba; L– maksimalna duljina zuba; A – širina otvora apeksa jednokorijenskih zuba; L1 – maksimalna duljina jednokorijenskoga zuba

Table 3 Weighted Cohen's kappa coefficient values of intra and inter-observer validation (Demirjian)
Tablica 3. Cohenov kappa koeficijent validacije između mjerenja i mjeritelja (Demirjian)

Method • Metoda	Validation • Validacija	κ	ρ
Demirjian	Intra	0.834	0.953
	Inter 1	0.834	0.953
	Inter 2	1.000	1.000

Table 4 CCI values of Intra-observer validation (I_{3M})
Tablice 4. CCI vrijednosti validacije između mjerenja (I_{3M})

	Measure • Mjera	Intra Observer 1 • Mjeritelj 1	Observer 2 • Mjeritelj 2	Inter
38	A1	0.978	0.978	0.996
	A2	0.985	0.966	0.996
	L	0.852	0.994	0.985
	A	0.991	0.996	0.998
	L1	0.998	0.993	0.998
48	A1	0.991	0.992	0.964
	A2	0.989	0.991	0.998
	L	0.985	0.994	0.997
	A	0.980	0.993	0.999
	L1	0.981	0.988	0.993

Notes: A1, Width of the mesial open apex of the multiradicular tooth; A2, Width of the distal open apex of the multiradicular tooth; L, Maximum tooth length; A, Width of the open apex of the monoradicular tooth; L1, Maximum monoradicular tooth length
Bilješka: A1 – širina mezijalnog otvora apeksa višekorijenskih zuba, A2 – širina distalnog otvora apeksa višekorijenskih zuba, L – maksimalna duljina zuba; A – širina otvora apeksa jednokorijenskih zuba; L1 – maksimalna duljina jednokorijenskoga zuba

Table 5 Weighted Cohen's kappa coefficient values of Intra and Inter-observer validation (Demirjian)
Tablica 5. Cohenov kappa koeficijent validacije između mjerenja i mjeritelja (Demirjian)

Method • Metoda	Validation • Validacija	κ	P
Demirjian	Intra	0.969	0.990
	Inter 1	0.919	0.980
	Inter 2	0.930	0.986

the obtained values denote, in most cases, excellent results both in precision and in reproducibility.

On the other hand, for the third molars, the results of Cohen's kappa and ICC are showed in Tables 4 and 5. The intra-observer validation for I_{3M} varies between 0.852 and 0.998 for observer 1 and between 0.966 and 0.996 for observer 2. The inter observer validation varies between 0.964 and 0.999. The weighted Cohen's kappa for intra-observer validation of Demirjian stadiums was 0.969, while intra-observer varies between 0.919 and 0.930. All values showed excellent results regarding precision and repeatability.

The Spearman's correlation was used to understand the relationship between chronological age and I_{2M} and Demir-

datci pokazuju da imamo odlične rezultate za preciznost i ponovljivost.

Vrijednosti Cohenova kappa indeksa i ICC za treći molar nalaze se u tablicama 4 i 5. Validacija vrijednosti za ispitivača za I_{3M} varira između 0,852 i 0,998 za ispitivača 1 i između 0,966 i 0,996 za ispitivača 2. Validacija između ispitivača iznosi između 0,964 i 0,999. Cohenov kappa za validaciju između mjerenja Demirjianovih stupnjeva iznosio je 0,969, a između mjerenja bio je od 0,919 do 0,930. Sve vrijednosti pokazuju odlične rezultate kad je riječ o preciznosti i ponovljivosti.

Spearmanova korelacija korištena je za razumijevanje odnosa između kronološke dobi i I_{2M} te Demirjianovih stup-
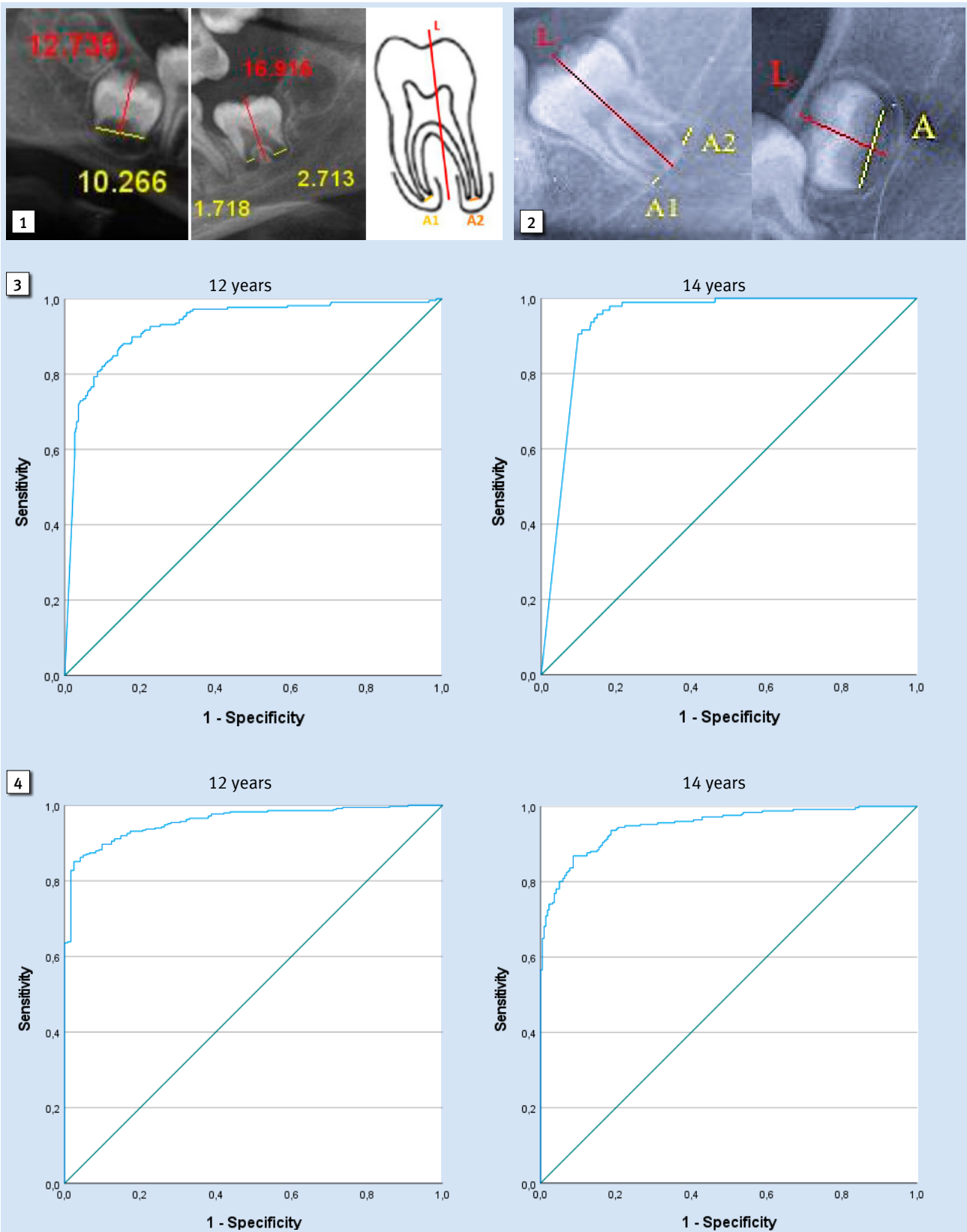
Figure 1 Measurement of second molar index, according to the molar index proposed by Cameriere
Slika 1.   Mjerenje indeksa drugog molara prema molarnom indeksu koji je predložio Cameriere
Figure 2 Measurement of the third molar index, according to de third molar index proposed by Cameriere
Slika 2.   Mjerenje indeksa trećeg molara prema molarnom indesku koji je predložio Cameriere
Figure 3 ROC curves for I_{2M}
Slika 3.   ROC krivulje za I_{2M} (osjetljivost, 1 − specifičnost)
Figure 4 ROC curves for I_{3M}
Slika 4.   ROC krivulje za I_{3M} (osjetljivost, 1 − specifičnost)

jian stadiums. The correlation between the real age and the I$_{2M}$ was 0.875, whereas with the Demirjian stadiums it was 0.861. Thus, both reveal a significant order relationship with chronological age. For the third molar, the Spearman correlation between real age and I$_{3M}$ was 0.902, and the correlation between chronological age and Demirjian stadiums was 0.902, showing that both methods are equally reliable.

Based on the maturity indices and Demirjian stages, it was intended to classify a person as under 12- year- old or at least 12 year- old, as well as classify him/her as under 14- year- old or at least 14- year- old. To perform these classifications, the cut-off points for I$_{2M}$ and for the I$_{3M}$ were computed us-

njeva. Korelacija između stvarne dobi i I$_{2M}$ bila je 0,875, a s Demirjianovim stupnjevima 0,861. Oba mjerenja pokazuju uredan odnos s kronološkom dobi. Za treći molar je Spearmanova korelacija između stvarne dobi i I$_{3M}$ bila 0,902, a između stvarne dobi i Demirjianovih stupnjeva 0,902, što pokazuje da su oba mjerenja jednako pouzdana.

Na temelju indeksa zrelosti i Demirjianovih stupnjeva namjeravali smo klasificirati osobe u skupinu s mlađima od 12 godina i s najmanje 12 godina, te s mlađima od 14 godina i one s najmanje 14 godina. Da bismo proveli tu klasifikaciju, izračunali smo granične točke za I$_{2M}$ i I$_{3M}$ s pomoću binarne logističke regresije, minimalizirajući pojavu pogrešne klasifi-

Table 6 Reliability Measures for the cut-off points for the ages of 12 and 14 (I$_{2M}$ and Demirjian) **Tablica 6.** Pouzdanost mjerenja za granične točke za dob od 12 i 14 godina (I$_{2M}$ i Demirjian)		
12 years • 12 godina	**I$_{2M}$ <0.135**	**Demirjian (G, H)**
Sensitivity • Osjetljivost	81.19%	88.53%
Specificity • Specifičnost	90.36%	85.30%
Accuracy • Točnost	87.20%	86.41%
PPV	81.57%	75.98%
NPV	90.14%	93.40%
LR+	8.42	6.02
LR-	0.21	0.13
Bayes PTP	91.57%	88.60%
AUC	0.93	-
14 years • 14 godina	**I$_{2M}$ <0.001**	**Demirjian (H)**
Sensitivity • Osjetljivost	90.53%	90.53%
Specificity • Specifičnost	90.15%	90.15%
Accuracy • Točnost	90.21%	90.21%
PPV	61.87%	61.87%
NPV	98.18%	98.18%
LR+	9.19	9.19
LR-	0.11	0.11
Bayes PTP	85.07%	85.07%
AUC	0.938	-

Table 7 Reliability Measures for the cut-off points for the ages of 12 and 14 (I$_{3M}$ and Demirjian) **Tablica 7.** Pouzdanost mjerenja za granične točke za dob od 12 i 14 godina (I$_{3M}$ i Demirjian)		
12 years • 12 godina	**I$_{3M}$ <1.133**	**Demirjian (D, E, F, G, H)**
Sensitivity • Osjetljivost	93.98%	94.56%
Specificity • Specifičnost	74.38%	80.99%
Accuracy • Točnost	88.94%	91.06%
PPV	91.36%	93.48%
NPV	81.08%	83.76%
LR+	3.67	4.97
LR-	0.08	0.07
Bayes PTP	96.00%	97.02%
AUC	0.959	-
14 years • 14 godina	**I$_{3M}$ <0.705**	**Demirjian (E, F, G, H)**
Sensitivity • Osjetljivost	86.85%	88.25%
Specificity • Specifičnost	88.13%	92.69%
Accuracy • Točnost	87.45%	89.96%
PPV	89.34%	95.06%
NPV	85.40%	83.20%
LR+	7.32	12.08
LR-	0.15	0.13
Bayes PTP	95.26%	97.07%
AUC	0.95	-

ing binary logistic regression, minimizing the occurrence of misclassifications. For the Demirjian stadiums, the individuals were classified using the most similar age group for each stage since all individuals in the same stadium are classified in the same age group. In these procedures, the sex variable was used as an explanatory variable, but Wald's test shows that this explanatory variable should be removed from the model (in all cases the p-value was greater than 0.05). Therefore, all results obtained measured the entire sample without distinguishing males from females.

The reliability measures of these classifications are shown in Table 6 for the second molar and in Table 7 for the third molar. Figure 3 shows the ROC curves for I_{2M}, and Figure 4 shows the ROC curves for I_{3M}.

Discussion

Over the years, estimating age through dental methods has become crucial in the juvenile criminal justice. For that same reason, several studies have been conducted over the years to estimate the age accurately, mainly by considering the population affinity.

In this present study, the first one for the Portuguese legal age thresholds of 12 and 14 year-olds, we tested the discriminatory potential of a specific cut-off value of I_{2M} and I_{3M} in discriminating children aged 12 and 14. Secondly, we compared those quantitative dental age assessment methods with the qualitative dental age assessment method, the Demirjian classification, which has already been used in the Portuguese population.

The intra and inter-observer results (Tables 2 to 5) mostly represent excellent results both on precision and on reproducibility for the I_{2M}, I_{3M} and Demirjian's stadiums, which is consistent with the existing literature regarding both methods (1,19-22).

Spearman's correlation results show that all methods (I_{2M}, I_{3M} and Demirjian's stadiums from the second and the third molar) reveal significant correlation with real age, which is consistent with the available literature (2,23).

In Portugal, the legal ages of 12 and 14 years are covered in the Portuguese penal code which promotes the protection of the juvenile individuals, giving priority to healing and prevention over punishment. Consequently, the determination of the cut-off points is very important in order to determine if an individual is younger than 12 or 14 years, or at least if the individual is 12 or 14- year- old (6). Regarding the cut-off points for 12 year olds (I_{3M} = 1.133 and I_{2M} = 0.135), I_{3M} shows better sensitivity (93.98%) but lower specificity (74.38%) than I_{2M} (sensitivity = 81.19% and specificity = 90.36%). For the Portuguese cut-off points for 14- year- olds (I_{2M} = 0.001 and I_{3M} = 0.705), I_{2M} has higher values of sensitivity and specificity (90.53% and 90.15%) than I_{3M} (sensitivity = 86.85% and specificity = 88.13%). The results of our study are consistent with the results obtained by Cameriere in 2018 (13). Although, the area under the ROC curve of I_{3M} for both ages (AUC 12 years = 0.959 and AUC 14 years = 0.95) is greater than the area under the ROC curve of I_{2M} (AUC 12 years = 0.93 and AUC 14 years = 0.938), both

kacije. Za Demirjianove stupnjeve klasificirali smo pojedince s pomoću najsličnije dobne skupine za svaki stupanj, s obzirom na to da su svi pojedinci u stupnju klasificirani kao ista dobna skupina. U tim postupcima varijabla spola koristila se kao opisna varijabla, ali Waldov test pokazao je da ju je potrebno isključiti iz modela (u svim slučajevima je p vrijednosti bila veća od 0,05). Zato su se svi rezultati mjerili za cijeli uzorak, bez razlikovanja prema spolu.

Pouzdanost mjerenja u tim klasifikacijama vidi se u tablici 6. za drugi molar te u tablici 7. za treći molar. Na slici 3. su ROC krivulje za I_{2M}, a na slici 4. za I_{3M}.

Rasprava

Tijekom godina je procjenjivanje dobi dentalnim metodama postalo ključno u kaznenom pravu za mlade. Iz tog razloga provedeno je nekoliko istraživanja u kojima su autori pokušali što točnije odrediti dob, ponajprije uzimajući u obzir populaciju i njezinu pripadnost.

U ovom istraživanju, prvom provedenom u Portugalu za dob od 12 i 14 godina, ispitivali smo diskriminatorni potencijal specifičnih graničnih vrijednosti I_{2M} i I_{3M} kod djece rubne dobi od 12 i 14 godina. Nadalje, uspoređivali smo te kvantitativne procjene dentalne dobi s kvalitativnom metodom procjenjivanja dobi, Demirjianovom klasifikacijom koja je već korištena za portugalsku populaciju.

Rezultati, kad je riječ o ispitivačima i ponovljivosti (tablice 2 – 5), uglavnom su odlični za preciznost i ponovljivost za I_{2M}, I_{3M} i Demirjianove stupnjeve, što je u skladu s do sada objavljenom literaturom koja se odnosi na obje metode (1, 19 – 22).

Spearmanova korelacija pokazuje da su sve metode (I_{2M}, I_{3M} i Demirjianovi stupnjevi za drugi i treći molar) pokazale značajnu korelaciju sa stvarnom dobi, što je u skladu s objavljenom literaturom (2, 23).

U Portugalu je dob od 12 i 14 godina obuhvaćena Kaznenim zakonom koji promiče zaštitu mladih osoba i daje prednost prevenciji, a ne kažnjavanju. Posljedično, određivanje krajnjih točaka veoma je važno da bi se odredilo je li dob pojedinca 12 ili manje godina ili 14 ili manje godina (6). U vezi s graničnom točkom za 12-godišnjake (I_{3M} = 1,133, I_{2M} = 0,135), I_{3M} pokazuje bolju osjetljivost (93,98 %), ali manju specifičnost (74,38 %) od I_{2M} (osjetljivost = 81,19 %, specifičnost = 90,36 %). Za portugalske granične vrijednosti za 14-godišnjake (I_{2M} = 0,001, I3M = 0,705) I_{2M} ima više vrijednosti osjetljivosti i specifičnosti (90,53 % i 90,15 %) od I_{3M} (osjetljivost = 86,85 %, specifičnost = 88,13 %). Rezultati ovog istraživanja u skladu su s rezultatima istraživanja Camerierea i suradnika iz 2018. godine (13). No, područje ispod krivulje ROC za I_{3M} za obje dobi (AUC 12 godina = 0,959 i AUC 14 godina = 0,95) veće je od područja ispod krivulje za I_{2M} (AUC 12 godina = 0,93, AUC 14 godina = 0,938), no oba indeksa daju izvrsne rezultate za područje ispod ROC krivulje (veće od 0,9) (24).

Točnost se mjeri ispod ROC krivulje. Područje vrijedno-

indexes obtain excellent results for the area under the ROC curve (greater than 0.9), (24).

The accuracy is measured under the ROC curve. The area of 1 represents a perfect method. The area measures discrimination, that is, the ability of the method to correctly classify those who are, or are not, 12 and 14- year- old (24). Hence, the areas under the ROC curves obtained in this study for 12- and 14-year- olds reveal that the use of I_{2M} and I_{3M} is a suitable methodology to classify the age of the analyzed individuals. However, when compared I_{2M} to I_{3M}, the latter shows better results regarding age estimation. The value of AUC obtained in this study is higher than in other studies (13,25).

The sensitivity obtained by Cameriere and Ferrante using dental age assessment by the 7 teeth regression, bone age assessment by hand-wrist bones or using the combination of both, biological indicators for the cut points of 12 and 14- year- olds were lower than the sensitivity obtained for the cut-points using only the dental parameters I_{2M} or I_{3M} for the Portuguese population (20). This means that it is better to use only dental age assessment for these Portuguese legal ages. The Bayes post-test probabilities with highest value were obtained using only the I_{3M} for the cut points determining for the legal age threshold 12- year- old (Bayes PTP = 96%) and 14 year- old (Bayes PTP = 95.26%). Bayes post-test probability of being 12 and 14- year- old is computed to discriminate between those who are not 12- year- old and 14- year-old or over 14. Accurate age estimation is crucial to ensure that children and adolescents are identified and treated adequately in the Portuguese criminal field.

For the I_{2M} results, there are no studies to sustain the results regarding the cut-off point for 12- year olds. Nevertheless, the obtained results are very reasonable. For the cut-off point for the 14- year-olds, some studies assume $I_{2M} = 0$ which is equal to the cut-off point obtained in this study by the binary logistic regression (the only cases in which $I_{2M} < 0.001$ were $I_{2M} = 0$). Thus, the reliability measures are similar to the ones obtained in those studies (2,13,26).

When comparing the Demirjian with Cameriere method, the results are quite similar. For 14- year-olds using the second molar, the results are identical because all individuals have obtained the same age classification in both methods since $I_{2M} = 0$ implies Demirjian stadium equals to H. However, Cameriere's method is better because the age group classification is based on a quantitative variable and, consequently, the cut-off point can be adjusted to improve one measure in relation to another (sensitivity or specificity), whereas this is not possible if Demirjian stadium is used.

Conclusions

This is the first study in Portugal to validate the reliability and the medico-legal application of I_{2M} and I_{3M} for the legal thresholds ages 12 and 14 years in the Portuguese population. Regarding our results for the cut-off points for Portuguese population for the 12 year-olds, I_{3M} is better and for 14- year- olds, I_{2M} has performed better. When comparing the age classification by I_{2M} or I_{3M} and the Demirjian stages, it is possible to conclude that there are no significant differenc-

sti 1 savršena je metoda. Mjeri diskriminaciju, odnosno mogućnost metode da ispravno klasificira one koji imaju ili nemaju 12, odnosno 14 godina (24). Zato područje ispod ROC krivulje u ovom istraživanju za 12-godišnjake i 14-godišnjake pokazuje da je upotreba I_{2M} i I_{3M} prikladna metodologija za klasifikaciju dobi analiziranih pojedinaca. No, ako se usporede I_{2M} i I_{3M}, ovaj posljednji pokazuje bolje rezultate kad je riječ o procjeni dobi. Vrijednost AUC-a dobivena u ovom istraživanju viša je negoli u ranijim istraživanjima (13, 25).

Osjetljivost koju su Cameriere i Ferrante dobili s pomoću dentalne procjene dobi regresijom 7 zuba na temelju koštane procjene kostiju ručnih zglobova ili kombinacijom bila je niža od one dobivene korištenjem samo dentalnih parametara I_{2M} i I_{3M} za granične točke 12-godišnjaka i 14-godišnjaka u portugalskoj populaciji (20). To znači da je u Portugalu bolje koristiti se samo dentalnom procjenom dobi za te razine. Bayesove post-testne vjerojatnosti s najvišim vrijednostima dobivene su korištenjem samo I_{3M} graničnih točaka za određivanje razine kod 12-godišnjaka (Bayes PTP = 96 %) i 14-godišnjaka (Bayes PTP = 95, 26%). Bayesova post-test vjerojatnost za dob od 12 i 14 godina računa se da bi se razlikovali oni koji nemaju 12 ili 14, godina, ili imaju više od 14 godina. Precizna procjena dobi ključna je za sigurnu identifikaciju djece i adolescenata koje je potrebno liječiti u sklopu portugalskog zakona.

Za rezultate I_{2M} nema istraživanja koja bi poduprla granične točke za 12-godišnjake. No, dobiveni rezultati bili su prihvatljivi. Za graničnu točku 14-godišnjaka u nekim se istraživanjima pretpostavlja da je $I_{2M} = 0$, što je jednako graničnoj točci dobivenoj u ovom istraživanju binarnom logističkom regresijom (jedini slučajevi kod kojih je $I_{2M} < 0,001$ bili su $I_{2M} = 0$). Zato je pouzdanost mjera slična onima koje su dobivene u drugim istraživanjima (2, 13, 26).

Uspoređujući Demirjianovu i Cameriereovu metodu, rezultati su bili prilično slični. Za 14-godišnjake je upotreba drugog molara dala identične rezultate jer su svi pojedinci dobili istu dobnu klasifikaciju u objema metodama, zato što $I_{2M} = 0$ implicira Demirjianov stupanj H. No, Cameriereova metoda je bolja jer je grupna klasifikacija dobi utemeljena na kvantitativnoj varijabli, a posljedično granična točka može biti prilagođena kako bi poboljšala jedno mjerenje u odnosu prema drugom (osjetljivost ili specifičnost), no to nije moguće pri primjeni Demirjianove metode stupnjeva.

Zaključak

Ovo je prvo istraživanje u Portugalu kojim se potvrđuje pouzdanost i medicinsko-pravna primjena I_{2M} i I_{3M} razina za dobi od 12 i 14 godina. Kad je riječ o našim rezultatima i graničnim točkama za portugalsku populaciju, čini se da je I_{3M} bolji za određivanje granične točke 12-godišnjaka, a I_{2M} za 14-godišnjake. U uspoređivanju dobne klasifikacije I_{2M} i I_{3M} i Demirjianovih stupnjeva, može se zaključiti da između tih metoda nema značajnih razlika u preciznosti. No, upotre-

es between the precision obtained by these methods. However, the use of I_{2M} and I_{3M} allows us to vary the cut-off value to privilege sensitivities or specificity, depending on which is more appropriate to the intended application. Thus, the I_{2M} and I_{3M} indexes provide reliable classification by each Portuguese legal age threshold of 12 and 14 year-olds. In medico-legal circumstances, a successful discrimination method must produce a smaller number of false positives than false negatives in order to legally protect the children's rights.

ba I_{2M} i I_{3M} omogućuje prilagođavanje graničnih točaka zbog specifičnosti i osjetljivosti, ovisno o tome što je prikladnije za ispitivanu populaciju. Zato I_{2M} i I_{3M} indeksi daju pouzdanu klasifikaciju za portugalsku zakonsku dob od 12 i 14 godina. U medicinsko-pravnim situacijama uspješna metoda razlikovanja mora dati manji broj lažno pozitivnih nalaza od lažno negativnih, kako bi se pravno zaštitila dječja prava.

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Conflict of Interest Statement

All authors declare no conflict of interest.

Izjava o sukobu interesa

Autori nisu bili u sukobu interesa.

Ethical approval

This study was performed, approved and realized in accordance with the ethical standards specified by the Health Ethics Committee of the Faculty of Dental Medicine, University of Lisbon, Lisbon, Portugal.

Etičko odobrenje

Istraživanje je provedeno, odobreno i realizirano u skladu s etičkim standardima Zdravstvenoga etičkog povjerenstva Fakulteta dentalne medicine Sveučilišta u Lisabonu, Portugal.

Informed Consent

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. No informed consent was obtained since this was a retrospective study based on anonymized clinical records.

Informirani pristanak

Svi provedeni postupci koji kao sudionike uključuju ljude bili su u skladu s etičkim standardima institucionalnih ili nacionalnih istraživačkih povjerenstava te s Helsinškom deklaracijom iz 1964. godine i njezinim kasnijim dodatcima, ili usporedivim etičkim standardima. Nisu traženi informirani pristanci zato što se radilo o retrospektivnom istraživanju na anonimnim kliničkim podatcima.

Author's contribution: C. P. P. - Supervision, Conceptualization, Project Administration, Methodology, Validation, Formal Analysis, Investigation, Data curation, Writing-Review and Editing, Visualization, Researcher of research center with support Grant from the government; **R. S. -** Methodology, Validation, Formal Analysis, Investigation, Data curation, Writing-Review and Editing, Visualization, Researcher of research center with support Grant from the government. F. S. - Investigation, Resources, Writing - Review & Editing; **R.C. -** Investigation, Methodology, Writing - Review & Editing; **D. A. -** Investigation, Validation, Writing - Original Draft. She is a master student of master's degree of Faculty of Dental Medicine, University of Lisbon; **A.R. -** Investigation, Validation, Writing - Original Draft. She is a master student of master's degree of Faculty of Dental Medicine, University of Lisbon.

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Sažetak

Cilj: Bolje razumijevanje dentalne procjene dobi moglo bi pomoći pri procjeni dobi u kliničkoj forenzici. Prvi cilj bio je osigurati ključne informacije o pouzdanosti metode za buduća istraživanja koja bi se koristila dentalnom procjenom s pomoću indeksa drugog molara (I_{2M}) te indeksa trećeg molara (I_{3M}) za procjenu legalne dobi od 12 do 14 godina. Drugi cilj bio je dokumentirati forenzičke ishode Demirjianove metode koja se već primjenjuje u kliničkoj forenzici. **Materijal i metode:** Za ovu svrhu korištena su dva uzorka – za I_{2M} 633 ortopantomograma (270 od djevojčica i djevojaka i 363 od dječaka i mladića u dobi od 7 do 17 godina), a za I_{3M} 471 ortopantomogram (253 od djevojčica i djevojaka i 218 od dječaka i mladića u dobi od 10 do 23 godine). Svi su uzeti iz baze podataka Sveučilišnoga bolničkog centra Lisabon – Sjever, a njihovu upotrebu odobrilo je Etičko povjerenstvo. **Rezultati:** Granična točka I_{3M} za 12-godišnjake (1,133) dala je bolje rezultate od one za I_{2M}. Nadalje, granična točka I_{2M} za 14-godišnjake (0,001) pokazala je bolje rezultate od granične točke I_{3M} (0,705). Obje su metode pouzdane za određivanje dobi od 12 i 14 godina prema zakonu. No, korištenje I_{3M} i I_{2M} omogućuje pomicanje granične vrijednosti zbog osjetljivosti ili specifičnosti, ovisno o adekvatnoj primjeni. **Zaključak:** Točnost I_{3M} (88,94 %) davala je bolje rezultate kada se određivala granična vrijednost 12-godišnjaka (1,133), a točnost I_{2M} (90,21 %) bila je bolja u slučaju 14-godišnjaka (0,001).

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References

1. Schrader BA. History and Scope of Forensic Odontology. Elsevier Inc; 2018.
2. Balla SB, Reddy T, Galic I, Naishadham PP. Validation of Cameriere's third molar maturity index alone and in combination with apical maturity of permanent mandibular second molar for indicating legal age of 14 years in a sample of South Indian children. Forensic Sci Int. 2019 Apr;297:243-248.
3. Juliana R, Lizarbe Q, Solís C, Quezada-márquez MM, Cameriere R, Galic I. Demirjian's stages and Cameriere's third molar maturity index to estimate legal adult age in Peruvian population, Leg Med (Tokyo). 2017 Mar;25:59-65.
4. Santiago BM, Almeida L, Cavalcanti YW, Magno MMB, Maia LC. Accuracy of the third molar maturity index in assessing the legal age of 18 years : a systematic review and meta-analysis. Int J Legal Med. 2018 Jul;132(4):1167-1184.
5. Pereira CP, Russell LM, De Pádua Fernandes M, Da Silva RH, De Sousa Santos RF. Dental age estimation based on development dental atlas assessment in a child/adolescent population with systemic diseases. Acta Stomatol Croat. 2019 Dec;53(4):307-317.
6. Decreto Lei nº 166/99 de 14 de Setembro. Diário da República nº215/1999 – I Série A. Assembleia da República. Lisboa, n.d.
7. Decreto Lei nº 147/99 de 1 de Setembro. Diário da República nº204/1999 – I Série A. Assembleia da República. Lisboa, n.d.
8. Decreto Lei nº 48 de 15 de Março, Diário da República: I-A Série, No 63 (1995) – artigos 171-176, n.d.
9. Ranasinghe S, Perera J, Taylor JA, Tennakoon A, Pallewatte A. Dental age estimation using radiographs : Towards the best method for Sri Lankan children. Forensic Sci Int. 2019 May;298:64-70.
10. Kelmendi J, Cameriere R, Koçani F, Galic I. The third molar maturity index in indicating the legal adult age in Kosovar population. Int J Legal Med. 2018 Jul;132(4):1151-1159.
11. Balla SB, Chinni SS, Galic I, Mohan A, Machani P, Cameriere R. A cut-off value of third molar maturity index for indicating a minimum age of criminal responsibility : Older or younger than 16 years ? J J Forensic Leg Med. 2019 Jul;65:108-112.
12. Sever N, Čuković Bagić I, Kern J, Brkić H. Dental Age Estimation in Children Using Orthopantomograms, Acta Stomatol Croat. 2008;42:11–18.
13. R. Cameriere, L.A. Velandia Palacio, J. Pinares, F. Bestetti, R. Paba, E. Coccia, L. Ferrante, Assessment of second (I2M) and third (I3M) molar indices for establishing 14 and 16 legal ages and validation of the Cameriere's I3M cut-off for 18 years old in Chilean population, Forensic. Sci. Int. 285 (2018) 205.e1-205.e5. https://doi.org/10.1016/j.forsciint.2017.12.043.
14. Demirjian A, Goldstein H, Tanner JM, Demirjian A. A new system of dental age assessment. Hum Biol. 1973 May;45(2):211-27.
15. Galić I, Nakaš E, Prohić S, Selimović E, Obradović B, Petrovečki M. Dental age estimation among children aged 5-14 years using the demirjian method in Bosnia-Herzegovina. Acta Stomatol Croat. 2010;44:17–25.
16. Cameriere R, Ferrante L, Cingolani M. Age estimation in children by measurement of open apices in teeth. Int J Legal Med. 2006 Jan;120(1):49-52.
17. Cameriere R, Ferrante L, Scarpino F, Ermenc B, Bejtulla Z. Dental Age Estimation of Growing Children: Comparison Among Various European Countries. Acta Stomatol Croat. 2006;40:256–262.
18. Cameriere R, Ferrante L, De Angelis D, Scarpino F, Galli F. The comparison between measurement of open apices of third molars and Demirjian stages to test chronological age of over 18 year olds in living subjects. Int J Legal Med. 2008 Nov;122(6):493-7.
19. Balla SB, Chinni SS, Galic I, Alwala AM, Machani P, Cameriere R. A cut-off value of third molar maturity index for indicating a minimum age of criminal responsibility: Older or younger than 16 years? J Forensic Leg Med. 2019 Jul;65:108-112.
20. Tafrount C, Galić I, Franchi A, Fanton L, Cameriere R. Third molar maturity index for indicating the legal adult age in southeastern France. Forensic Sci Int. 2019 Jan;294:218.e1-218.e6.
21. Bagherpour A, Imanimoghadda M, Bagherpour M, Einolghozati M. Dental age assessment among Iranian children aged 6-13 years using the Demirjian method. Forensic Sci Int. 2010 Apr 15;197(1-3):121.e1-4.
22. Spinas E, De Luca S, De Luca S. Is the third molar maturity index (I 3M) useful for a genetic isolate population ? Study of a Sardinian sample of children and young adults, Int J Legal Med. 2018 Nov;132(6):1787-1794.
23. Boaz K, Nagesh K, Srikant N, Gupta N, Nandita K, Manaktala N, Lewis A. Demirjian's method in the estimation of age: A study on human third molars. J Forensic Dent Sci. May-Aug 2015;7(2):153-7.
24. Santos, R., Martins, J., Felgueiras, M., and Ferreira, L. Accuracy Measures for Binary Classification Based on a Quantitative Variable, REVSTAT - Statistical Journal 2019;17(2): 223-244.
25. Cameriere R, De Luca S, Cingolani M, Ferrante L. Measurements of developing teeth, and carpals and epiphyses of the ulna and radius for assessing new cut-offs at the age thresholds of 10, 11, 12, 13 and 14 years. J Forensic Leg Med. 2015 Aug;34:50-4.
26. Albernaz Neves J, Antunes-Ferreira N, Machado V, Botelho J, Proença L Quintas. Validation of the Third Molar Maturation Index (I3M) to assess the legal adult age in the Portuguese population. Sci Rep. 2020 Oct 28;10(1):18466.