ACTA
STOMATOLOGICA
CROATICA
www.ascro.hr

Acta stomatol Croat. 2024;58(3):194-208.
DOI: 10.15644/asc58/3/1

ORIGINAL SCIENTIFIC PAPER
IZVORNI ZNANSTVENI RAD

Lei Shi[1], Luka Banjšak[1], Sandra Anić-Milošević[2], Ivan Galić[3]

Legal Age Thresholds Estimation in Croatian Children and Adolescents: Accuracy of the Olze, Haavikko, and Demirjian Methods

Dentalna procjena zakonskog dobnog praga u djece i adolescenata u Hrvatskoj: točnost Olzeove, Haavikkove i Demirjianove metode

[1] Department of Dental Anthropology, University of Zagreb School of Dental Medicine, Zagreb 10000, Croatia
Zavod za dentalnu antropologiju Stomatološkog fakulteta Sveučilišta u Zagrebu, Hrvatska
[2] Department of Orthodontics, University of Zagreb School of Dental Medicine, Zagreb 10000, Croatia
Zavod za ortodonciju Stomatološkog fakulteta Sveučilišta u Zagrebu, Hrvatska
[3] University of Split School of Medicine, Split 21000, Croatia
Medicinski fakultet Sveučilišta u Splitu, Hrvatska

Abstract

Objective: This study aimed to explore the accuracy of three established approaches for legal age threshold estimation in a Croatian sample. **Materials and methods:** Olze's third molar eruption stages, Haavikko stages, and Demirjian stages were applied in 583 orthopantomograms of Croatian children and adolescents aged 10.00-20.99 years old. The left mandibular second and third molar were assessed. Tooth formation and eruption chronology were established. Receiver operating characteristic (ROC) curves were performed to assess the classification ability of predictive variables for estimating 16- and 18-year-old thresholds. **Results:** Havikko stage, Demirjian stage and eruption stages in tooth 37 performed poorly for 16-year-old and 18-year-old thresholds. Tooth 38 provides valuable information for these two age thresholds estimation. For 16-year-old threshold, Haavikko Stage Rc and Demirjian Stage G both yielded Sp over 98% and Bayes PTP over 95% in both sexes. . Eruption stage C yielded Sp over 98%, Bayes PTP over 96% in males, and lower in females (Sp 96.7%, Bayes PTP 88.2%). For 18-year-old threshold, Haavikko stage Ac and Demirjian stage H both yielded 100% Sp and Bayes PTP. Eruption stage D yielded Sp over 96%, Bayes PTP over 90% in both sexes, slightly higehr in females than males. Mean age of tooth 37 at Haavikko stage Ac, Demirjian stage F, H and eruption stage D was statistically lower in females ($p<0,05$). **Conclusion:** Croatian population-based data on dental maturity were presented. Haavikko stage Rc, Demirjian stage G, eruption stage C and respective advanced stages in tooth 38 are effective for 16-year-old threshold classification. Haavikko stage Ac, Demirjian stage H and eruption stage D are effective for 18-year-old threshold classification.

Received: May 3, 2024
Accepted: August 10, 2024

Address for correspondence
Lei Shi, PhD
University of Zagreb
School of Dental Medicine
Department of Dental Anthropology
Chair of Forensic Dentistry
Gundulićeva 5, 10000 Zagreb, Croatia

MeSH Terms: Tooth Eruption; Third Molar; Age Determination by Teeth; Jurisprudence; Croatia
Author Keywords: Dental age; Third molars; Forensic odontology; Croatia Legal Age Tresholds

Lei Shi https://orcid.org/0000-0002-1402-7154
Luka Banjšak https://orcid.org/0000-0002-3939-8402
Sandra Anić-Milošević https://orcid.org/0000-0003-2641-2364
Ivan Galić https://orcid.org/0000-0003-0387-9535

Introduction

Forensic age estimation, a vital component of forensic odontology, holds substantial significance in legal and investigative scenarios where estimating an individual's age is imperative. Accurate age estimation aids in establishing identities, thus resolving legal disputes, and contributing crucial information to forensic investigations (1–3). Despite its importance, the accuracy of age estimation methods is contingent on their applicability to specific populations, necessitating continuous research and validation, especially in populations with limited data (4,5).

Uvod

Forenzička procjena dobi, vitalna komponenta forenzičke odontologije, iznimno je važna u pravnim i istražnim postupcima kada je imperativ procjena starosti pojedinca. Točna procjena dobi pomaže u utvrđivanju identiteta, rješavanju pravnih sporova i pridonošenju ključnih informacija forenzičkim istragama (1 – 3). Unatoč važnosti, točnost metoda procjene dobi ovisi o njihovoj primjenjivosti na određene populacije, što zahtijeva kontinuirano istraživanje i validaciju, osobito u populacijama s ograničenim podatcima (4, 5).

Age estimation in children and young adults is a critical facet of forensic odontology, playing a pivotal role in legal and investigative contexts where establishing an individual's age is essential. Various age estimation scoring systems have been developed based on tooth morphology changes during dental maturation. These methods encompass a range of approaches, from morphological assessments, such as the method by Nolla 1960, Moorrees et al. 1963, Haavikko et al. 1970, and Demirjian et al. 1973, to metric-based methods such as measurement of open apices which was established by Cameriere (1,6–11). Tooth mineralization methods are rooted in the morphological characteristics of developing permanent teeth, yielding an estimated age point by reference to the age medians for each tooth formation stage given in the original research or by referring to scores and age conversion tables. Underestimation by the Haavikko method was observed in most populations, ranging from 0.09-1.95 years (12–24). Conversely, the Demirjian method overestimates age in most populations (21,25–28). The Cameriere third molar index I_{3M}, measured as the ratio between the two apical pulp widths and the total tooth length, is often employed to differentiate age threshold of legal significance. In Croatian samples, the I_{3M} cut-off value of 0.08 for the 18-year threshold proved reliable with high sensitivity, specificity, and accuracy (29). Previous studies have emphasized its value in various populations (30–32).

The third molar eruption is another significant age indicator. Olze and Schmeling divided third molar eruption into four stages and provided reference data on wisdom tooth eruption for Caucasian, Asian, and African subjects (5). In some populations, this method proved reliable in estimating the most probable ages according to the chronology of eruption stages (33). Reportedly, stage D may exclude those under the age of eighteen, but results were inconsistent among populations (34,35). In late adolescence and early adulthood, most permanent teeth have reached maturity apart from second and third molars, which play a crucial role in age assessment during this phase and in determining attainment of age of legal significance.

In the context of the Croatian population, there remains a notable gap in comprehensive studies addressing dental age assessment, prompting a comprehensive investigation into the efficacy of established and novel approaches. It has been established that dental development varies among populations, thus emphasizing the need for population-specific validation.

This study addresses this gap by encompassing all three age estimation methods in a diverse sample of Croatian adolescents and young adults. By applying Haavikko, Demirjian, and Olze's third molar eruption stages, this study aimed to capture the full spectrum of molars formation and eruption in Croatian adolescents and young adults. Besides, it aimed to refine age assessment practices in the Croatian context.

Procjena dobi djece i mladih odraslih kritičan je aspekt forenzičke odontologije i ključna je u pravnim i istražnim kontekstima pri čemu je utvrđivanje dobi pojedinca iznimno važno. Razvijeni su različiti sustavi bodovanja za procjenu dobi koji se temelje na promjenama morfologije zuba tijekom njihova sazrijevanja. Te metode obuhvaćaju niz pristupa – od morfoloških procjena, kao što je metoda prema Nolli (1960.), zatim Moorreesa i suradnika (1963.), Haavikka i suradnika (1970.) te Demirjiana i suradnika (1973.) do metričkih metoda kao što je mjerenje otvorenih vrhova zubnih korjenova koje je uspostavio Cameriere (1,6 – 11). Metode mineralizacije zuba ukorijenjene su u morfološkim karakteristikama razvoja trajnih kutnjaka i daju procijenjenu dobnu točku referencijom na srednje dobi za svaku fazu formiranja zuba danu u izvornom istraživanju ili referencijom na rezultate i tablice pretvorbe dobi. Podcjenjivanje metodom Haavikka primijećeno je u većini populacija, u rasponu od 0,09 – 1,95 godina (12 – 24). Nasuprot tomu, Demirjianova metoda precjenjuje dob u većini populacija (21, 25 – 28). Camerieereov indeks trećeg molara I3M, mjeren kao omjer između dviju širina apikalne pulpe i ukupne duljine zuba, često se koristi za razlikovanje dobnoga praga od zakonskog značenja. U hrvatskim uzorcima granična vrijednost I3M-a od 0,08 za 18-godišnji prag pokazala se pouzdanom uz visoku osjetljivost, specifičnost i točnost (29). Prethodne studije isticale su njegovu vrijednost u različitim populacijama (30 – 32).

Nicanje trećeg kutnjaka još je jedan važan pokazatelj starosti. Olze i Schmeling podijelili su njegovo nicanje u četiri faze i pružili referentne podatke o nicanju umnjaka za kavkazoide, azijske i afričke etničke skupine (5). U nekim se populacijama ta metoda pokazala pouzdanom u procjeni najvjerojatnije starosti prema kronologiji stadija erupcije (33). Navodno stadij D može isključiti one mlađe od osamnaest godina, ali rezultati su bili nedosljedni među populacijama (34, 35). U kasnoj adolescenciji i ranoj odrasloj dobi većina trajnih zuba dosegnula je zrelost, osim drugoga i trećega kutnjaka koji su ključni u procjeni dobi tijekom te faze i u određivanju dostizanja dobi od zakonskog značenja.

U kontekstu hrvatske populacije ostaje vidljiv nedostatak u sveobuhvatnim studijama koje se bave procjenom dentalne dobi, što potiče temeljito istraživanje učinkovitosti utvrđenih i novih pristupa. Utvrđeno je da dentalni razvoj varira među populacijama te se ističe potreba za populacijski specifičnom validacijom.

Ovo istraživanje rješava taj nedostatak tako što obuhvaća sve tri metode procjene dobi na različitom uzorku hrvatskih adolescenata i mladih odraslih osoba. Primjenom Haavikkovih, Demirjianovih i Olzeovih faza erupcije trećeg molara, ova studija ima za cilj obuhvatiti cijeli spektar formiranja i nicanja molara kod hrvatskih adolescenata i mladih odraslih osoba te poboljšati praksu procjene dobi u hrvatskom kontekstu.

Materials and methods

Materials

A total of 583 samples were collected retrospectively at University Hospital Centre Zagreb between January 2019 and February 2024. Samples were divided into eleven age groups (Table 1). Orthopantomograms (OPGs) were retrospectively imported from the medical imaging system along with individual birth, sex, and acquisition date. No identifiable personal information was retrieved. Each sample's chronological age (CA) was calculated in Microsoft Excel (Microsoft Corporation, Redmond, WA) by the formula CA= (acquisition date of OPG- date of birth)/ 365.25 days. The Ethics Committee of the University of Zagreb School of Dental Medicine and University Hospital Center Zagreb granted the ethics approval for this study.

The inclusion criteria included Croatian ethnic origin; aged between 10.00 and 21.99; the presence of left mandibular second and third molars; no apparent mandibular lesions; no history of disease, medication, trauma, or surgery that potentially influence the development of left mandibular permanent teeth; no history of orthodontic treatment. The exclusion criteria included incomplete individual information; poor image quality or left mandibular molars were not clearly visualized; absence of molars 37 and 38; and dental anomalies.

Materijali i metode

Materijali

U KBC-u Zagreb retrospektivno su prikupljena 583 uzorka od siječnja 2019. do veljače 2024. te su podijeljeni u jedanaest dobnih skupina (tablica 1.). Ortopantomogrami (OPG) su retrospektivno uvezeni iz medicinskog sustava snimanja zajedno s pojedinačnim rođenjem, spolom i datumom stjecanja. Nisu pronađeni osobni podatci koji se mogu identificirati. Kronološka starost (CA) svakog uzorka izračunata je u programu Microsoft Excel (Microsoft Corporation, Redmond, WA) prema formuli CA = (datum nabave OPG – datum rođenja)/ 365,25 dana. Etička povjerenstva Stomatološkog fakulteta Sveučilišta u Zagrebu i KBC-a Zagreb dala su suglasnost za ovu studiju.

Kriteriji za uključivanje bili su hrvatsko etničko podrijetlo, dob između 10,00 i 21,99 godina, prisutnost drugoga i trećega kutnjaka lijeve mandibule, bez vidljivih mandibularnih lezija, bez povijesti bolesti, lijekova, trauma ili operacija koje potencijalno utječu na razvoj trajnih zuba lijeve čeljusti i bez povijesti ortodontskog liječenja. Kriteriji za isključivanje obuhvaćali su nepotpune pojedinačne informacije, slijede loša kvaliteta slike ili ako lijevi molari donje čeljusti nisu jasno vizualizirani, odsutnost kutnjaka 37 i 38 i dentalne anomalije.

Table 1 Sample distribution by sexes and age
Tablica 1. Distribucija uzorka prema spolu i dobi

Age Group	Females	Males	Total
10-11	14	10	24
11-12	21	24	45
12-13	46	35	81
13-14	45	28	73
14-15	47	34	81
15-16	38	48	86
16-17	32	31	63
17-18	29	38	67
18-19	14	10	24
19-20	7	17	24
20-21	7	8	15
Total	300	283	583

Methods

Haavikko, Demirjian, and Olze's third molar eruption staging method was used to evaluate the formation and eruption of the left mandibular second and third molars, similar to prior study (36). According to the Haavikko scoring system, the formation of permanent molars was divided into twelve stages: six stages for crown formation and six stages for root formation (Figure 1). Demirjian scoring system, permanent molars were divided into eight stages (A-H) (Figure 2). According to Olze's third molar eruption staging method, the third molar eruption was divided into four stages (A - D) (Figure 3).

OPGs were evaluated by two well-skilled observers using children's age estimation methods. One month after the first observer evaluated all samples, about 10% of samples were

Metode

Haavikkova, Demirjianova i Olzeova metoda određivanja stupnjeva erupcije trećega molara korištena je za procjenu formiranja i erupcije drugoga i trećega molara lijeve donje čeljusti, slično kao u prethodnoj studiji (36). Prema Haavikkovu sustavu bodovanja, formiranje trajnih kutnjaka podijeljeno je u dvanaest faza: šest za formiranje krunica i šest za formiranje korijena (slika 1.). U Demirjianovu sustavu bodovanja trajni kutnjaci podijeljeni su u osam stupnjeva (A – H) (slika 2.). Prema Olzeovoj metodi određivanja stadija erupcije trećeg molara, erupcija toga zuba podijeljena je u četiri stadija (A – D) (slika 3.).

OPG-ove su ocjenjivala dva vješta promatrača koristeći se metodama za procjenu dobi djece. Mjesec dana nakon što je prvi promatrač procijenio sve uzorke, njih oko 10 % nasu-

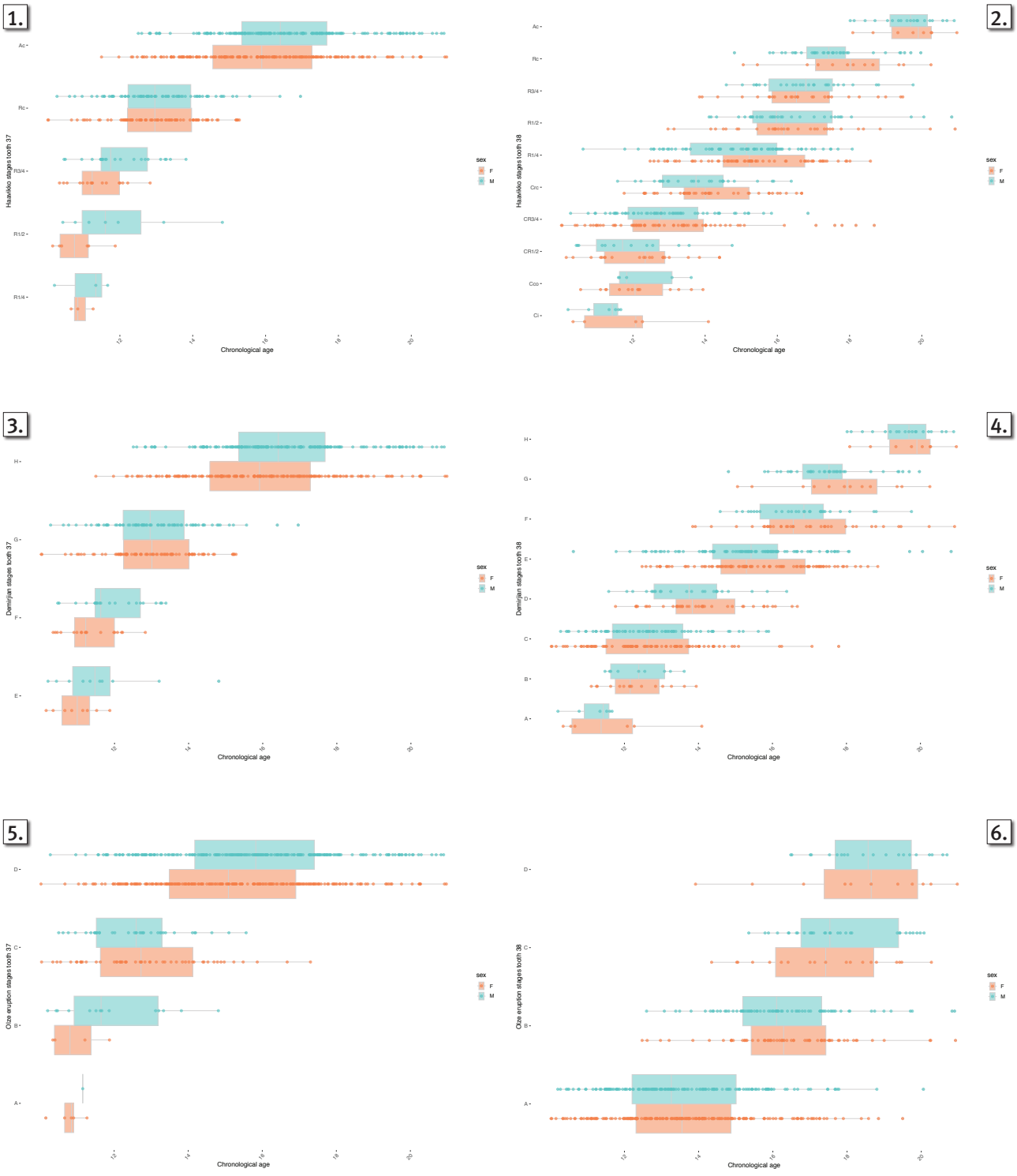

Figure 1 Boxplot of age distribution by Haavikko stages in tooth 37
Slika 1. Okvirni prikaz distribucije starosti po Haavikko stadijima zuba 37
Figure 2 Boxplot of age distribution by Haavikko stages in tooth 38
Slika 2. Okvirni prikaz distribucije starosti po Haavikko stadijima zuba 38
Figure 3 Boxplot of age distribution by Demirjian stages in tooth 37
Slika 3. Okvirni prikaz distribucije starosti po Demirjianovim stadijima zuba 37
Figure 4 Boxplot of age distribution by Demirjian stages in tooth 38
Slika 4. Okvirni prikaz distribucije starosti prema Demirjianovim stadijima zuba 38
Figure 5 Boxplot of age distribution by eruption stages in tooth 37
Slika 5. Boksplot distribucije starosti prema stadijima nicanja zuba 37
Figure 6 Boxplot of age distribution by eruption stages in tooth 38
Slika 6. Boksplot distribucije starosti po stadijima nicanja zuba 38

randomly selected and reevaluated by the first and second observers, respectively.

Statistical analysis

Statistical analysis was performed using R version 4.3.2 (R Core Team, Vienna, Austria). The significance level was set at 0.05. Cohen's kappa measured the intra- and interobserver agreement.

A receiver operating characteristic (ROC) curve analysis was performed to assess the classification ability of predictive variables. The areas under the ROC curve (AUC), accuracy (Acc), sensitivity (Se), specificity (Sp), and likelihood ratios, Positive Likelihood Ratio (LR+), Negative Likelihood Ratio (LR-), negative precision (NP), positive precision (PP) and Bayes post-test probability (Bayes PTP) were calculated to evaluate classification performance. Youden's index (J) was used to determine the optimal cut-off value or stage. Performance measures were calculated by 2×2 contingency table by each cut-off. In this study, sensitivity represents the proportion of true positives, indicating the individuals at the optimal cut-off stage who were correctly classified as being 16 years of age or 18 years of age, or older. As for specificity, it represents the proportion of true negatives. In this context, it would indicate the individuals correctly classified as below the age thresholds (16 or 18 years). AUC represents the overall performance of the logistic model in discriminating between individuals above the age thresholds and those below. A higher AUC indicates better discriminatory ability, with 0.5 indicating no discriminatory ability (random guessing) and 1 indicating perfect discrimination. An AUC between 0.7~0.8 represents acceptable discrimination ability. An AUC between 0.8~0.9 represents good discrimination ability, while an AUC above 0.9 indicates excellent discrimination ability. LR+ measures how much more likely a positive result (classifying an individual as above the age threshold) is in individuals who are above the threshold compared to those below. A higher LR+ indicates stronger evidence for correctly identifying individuals above the threshold. LR- measures how much less likely a negative result (classifying an individual as below the age threshold) is in individuals who are above the threshold compared to those below. A lower LR- indicates stronger evidence for correctly identifying individuals below the threshold. The Bayes post-test probability (p) of being 16 or 18 years of age or older was calculated using Bayes' theorem:

$$p = \frac{Se \times p0}{Se \times p0 + (1 - Sp) \times (1 - p0)}$$

Probability p0 was calculated as the proportion of 18.00~20.99 years population to 15.00~20.99 years population for 18-year-old threshold, and 16.00~20.99 years population to 11.00~20.99 years population for 16-year-old threshold with data from the Census of Population, Households, and Dwellings in 2021 - Population of Republic of Croatia on 31 August 2021.

Age distribution of tooth 37 and tooth 38 by stages by each method was characterized by the median, mean, interquartile range (IQR), standard deviation (SD), maximum,

mično je odabrano i ponovno ih je procijenio prvi, pa drugi promatrač.

Statistička analiza

Statistička analiza provedena je s pomoću R verzije 4.3.2 (R Core Team, Beč, Austrija). Razina značajnosti postavljena je na 0,05. Cohenovom kappom izmjereno je slaganje unutar promatrača i između njih.

Obavljena je analiza krivulje radnih karakteristika prijamnika (ROC) kako bi se procijenila mogućnost klasifikacije prediktivnih varijabli. Površine ispod ROC krivulje (AUC), točnost (Acc), osjetljivost (Se), specifičnost (Sp) i omjeri vjerojatnosti, omjer pozitivne vjerojatnosti (LR+), omjer negativne vjerojatnosti (LR-), negativna preciznost (NP), pozitivna preciznost (PP) i Bayesova vjerojatnost nakon testa (Bayes PTP) izračunate su za procjenu učinkovitosti klasifikacije. Youdenov indeks (J) korišten je za određivanje optimalne granične vrijednosti ili stadija. Mjere učinka izračunate su prema tablici nepredviđenih slučajeva 2 × 2 za svako granično razdoblje. U ovoj studiji osjetljivost predstavlja udio istinskih pozitivnih rezultata, upućujući na pojedince u optimalnoj graničnoj fazi koji su ispravno klasificirani kao osobe od 16 ili 18 godina ili više. Kad je riječ specifičnosti, ona je zapravo udio istinskih negativa. U ovom kontekstu to bi označavalo pojedince koji su ispravno klasificirani kao ispod dobnih pragova (16 ili 18 godina). AUC je, pak, ukupna izvedba logističkog modela u razlikovanju pojedinaca iznad dobnih pragova od onih ispod. Veći AUC upućuje na bolju diskriminatornu sposobnost, pri čemu 0,5 upozorava na nepostojanje diskriminatorne sposobnosti (nasumično pogađanje), a 1 na savršenu diskriminaciju. AUC između 0,7 – 0,8 pokazuje prihvatljivu sposobnost razlikovanja. AUC između 0,8 – 0,9 pokazuje dobru sposobnost razlikovanja, a AUC iznad 0,9 upućuje na izvrsnu sposobnost razlikovanja. LR+ mjeri koliko je vjerojatniji pozitivan rezultat (klasificiranje pojedinca kao iznad dobnoga praga) kod pojedinaca koji su iznad praga u usporedbi s onima ispod. Viši LR+ upućuje na jače dokaze za točnu identifikaciju pojedinaca iznad praga. LR- mjeri koliko je manja vjerojatnost negativnog rezultata (klasificiranje pojedinca kao ispod dobnoga praga) kod pojedinaca koji su iznad praga u usporedbi s onima ispod. Niži LR- upućuje na jače dokaze za točnu identifikaciju pojedinaca ispod praga. Bayesova post-testna vjerojatnost (p) da imate 16 ili 18 godina ili više izračunata je s pomoću Bayesova teorema.

$$p = \frac{Se \times p0}{Se \times p0 + (1 - Sp) \times (1 - p0)}$$

Vjerojatnost p0 izračunata je kao udio 18.00 – 20.99 godina populacije prema 15.00 – 20.99 godina populacije za prag od 18 godina, i 16.00 – 20,99 godina populacije prema 11,00 – 20,99 godina populacije za 16-godišnji prag s podatcima iz Popisa stanovništva, kućanstava i stanova 2021. (Stanovništvo Republike Hrvatske na dan 31. kolovoza 2021.).

Dobna distribucija zuba 37 i 38 prema stadijima svake metode karakterizirana je medijanom, prosjekom, interkvartilnim rasponom (IQR), standardnom devijacijom (SD), maksimumom i minimumom. Proveden je neovisni t-test za

and minimum. An independent t test was used to compare the difference between sexes. Box plots with points were generated to visualize the distribution.

Results

The intra-rater and inter-rater agreements are shown in Table 2. Fleiss' Kappa points to almost perfect agreement for both intra- and inter-rater by three methods in tooth 37 and 38.

Chronology of tooth 37 by Haavikko method and age threshold estimation

At stage Ac, mean age is statistically lower in females ($p<0,05$) (Table 3). In the boxplot, most stages were distributed before the 16-year-old line except for a few cases at stage Ac; a range of IQR is wider in advanced stages (Figure 1).

ROC curve analysis showed that the Haavikko stage in tooth 37 performs poorly for the 16-year-old threshold, exhibiting very low classification metrics (Table 4). Additionally, it is even less effective for the 18-year-old threshold, with lower classification metrics for both sexes.

usporedbu razlika između spolova. Okvirni dijagrami s točkama generirani su za vizualizaciju distribucije.

Rezultati

Podudarnost mjerenja između dvaju mjeritelja te jednoga mjeritelja u dvama razdobljima prikazana je u tablici 2. Fleissova kappa pokazuje gotovo savršenu podudarnost mjerenja između dvaju mjeritelja te jednog mjeritelja tijekom dvaju razdoblja za sve tri metode korištene na zubima 37 i 38.

Kronologija zuba 37 prema Haavikkovoj metodi i klasifikacija dobnoga praga

U stadiju Ac srednja dob statistički je niža kod žena ($p < 0,05$) (tablica 3.). U kutijastom dijagramu (boxplot) većina stadija bila je raspoređena prije 16-godišnje linije, osim u nekoliko slučajeva u fazi Ac; raspon IQR-a širi je u uznapredovalim stadijima (slika 1.).

Analiza ROC krivulje pokazala je da Haavikkov stadij u zubu 37 postiže loše rezultate za 16-godišnji prag i pokazuje vrlo nisku klasifikacijsku metrike (tablica 4.). Dodatno, još je manje učinkovit za prag od 18 godina, s nižom klasifikacijskom metrikom za oba spola.

Table 2 Intra-observer and inter-observer agreement of three methods in tooth 37 and 38 by Fleiss' Kappa
Tablica 2. Mjerenje dva promatrača tri metode zubi 37 i 38 prema Fleiss' Kappa

	Intra-rater			Inter-rater		
Tooth	Haavikko	Demirjian	Eruption	Haavikko	Demirjian	Eruption
37	0.894	1.000	0.976	0.899	0.951	0.957
38	0.833	0.967	0.963	0.832	0.908	0.823

Table 3 Age distribution by Haavikko stages in Tooth 37
Tablica 3. Dobna distribucija po Haavikko stadijima zuba 37

Stages	Female								Male								P*
	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	N	Median	Mean (SD)	IQR	Q1	Q2	Min	Max	
R1/4	3	10.84	10.92(0.31)	0.30	10.75	11.06	10.66	11.27	3	11.34	11.07(0.77)	0.73	10.77	11.50	10.20	11.67	0.7825
R1/2	6	10.75	10.84(0.65)	0.78	10.36	11.13	10.15	11.87	7	11.60	11.99(1.54)	1.62	10.96	12.58	10.43	14.81	0.1074
R3/4	16	11.24	11.39(0.70)	1.02	10.96	11.99	10.34	12.83	22	11.75	12.05(0.95)	1.27	11.48	12.76	10.47	13.82	0.0192
Rc	87	12.96	12.98(1.19)	1.76	12.21	13.97	10.02	15.28	73	12.96	13.09(1.30)	1.72	12.22	13.95	10.28	16.96	0.58
Ac	188	15.89	15.94(1.98)	2.72	14.55	17.27	11.50	20.97	178	16.40	16.57(1.89)	2.34	15.35	17.68	12.51	20.90	0.0019**

Note: N, number of individuals within specific stage; IQR, intraquartile range; Q1,first quartile; Q3, third quartile; Min, minimal; Max, maximal; SD, standard deviation, *Independent t-test. ** P<0.05

Table 4 Measures of classification ability of Haavikko stage in tooth 37 for 16-year threshold
Tablica 4. Mjere sposobnosti klasifikacije Haavikkovog stadija zuba 37 za 16-godišnji prag

Threshold	16-year-old	
Sex	Females	Males
Stage	Ac	
AUC	0.765(0.732-0.799)	0.778(0.739-0.778)
Accurarcy	67.0% (61.4%-72.3%)	72.4% (66.8%-77.6%)
Sensitivity	100.0% (95.9%-100.0%)	98.1% (93.2%-99.8%)
Specificity	53.1% (46.1%-60.0%)	57.5% (49.9%-64.9%)
LR+	2.13 (0.97-1)	2.31 (0.94-1)
LR-	0 (0-0.53)	0.03 (0-0.49)
Precision (Positive)	47.3% (40.0%-54.7%)	57.3% (49.7%-64.7%)
Precision (Negative)	100.0% (96.8%-100.0%)	98.1% (93.3%-99.8%)
Post-test Probability	67.2% (61.7%-72.6%)	68.9% (63.2%-74.3%)

Note: Values are reported with 95% confidence intervals in the parenthesis.

Chronology of tooth 38 by Haavikko method and age threshold classification

No statistical difference was observed beween females and males (Table 5). In the boxplot, the middle 50% of Crc, R1/4 and Rc in females, as well as the means, is distributed more to the right (older age) (Figure 2). In stage R1/4 - R3/4, the boxes were wider than in other stages in both sexes.

ROC curve analysis showed that, for 16-year-old threshold, Stage Rc yielded Sp over 98% and Bayes PTP over 95% in both sexes (Table 6). These values were even higher at the more advanced stage, Ac. For 18-year-old threshold, stage Ac yielded 100% Sp and Bayes PTP. However, Se were generally low by these stages, due to high propotion of false negative cases (Table 14).

Chronology of tooth 37 by Demirjian method and age threshold classification

At stage F and H, mean age is statistically lower in females (p<0,05) (Table 7). ROC curve analysis showed that, similar to the finding by Havikko stage, Demirjian stage in tooth 37 performed poorly for 16-year-old and 18-year-old thresholds (Table 8).

Kronologija zuba 38 prema Haavikkovoj metodi i klasifikacija dobnoga praga

Nije uočena statistička razlika između žena i muškaraca (tablica 5.). U kutijastom dijagramu, srednjih 50 % Crc-a i R1/4, Rc-a kod žena te srednja vrijednost, raspoređeni su više udesno (veća dob) (slika 2.). U stadiju R1/4 – R3/4 kutije su bile šire od ostalih stadija kod oba spola.

Analiza ROC krivulje pokazala je da, za prag od 16 godina, stadij Rc daje Sp veći od 98 %, a Bayesov PTP veći od 95 % u oba spola (tablica 6). Te su vrijednosti čak i veće u naprednijoj fazi, u Ac-u. Za prag od 18 godina, stupanj Ac daje 100 % Sp-a i Bayesov PTP. No Se je u tim fazama općenito nizak zbog velikoga udjela lažno negativnih slučajeva (tablica 14.).

Kronologija zuba 37 prema Demirjianovoj metodi i klasifikacija dobnoga praga

U stadiju F i H srednja dob statistički je niža kod žena (p < 0,05) (tablica 7.). Analiza ROC krivulje pokazala je da, slično nalazu u Havikkovu stadiju, Demirjianov stadij u zubu 37 daje loše rezultate za 16-godišnje i 18-godišnje pragove (tablica 8.).

Table 5 Age distribution by Haavikko stages in Tooth 38
Tablica 5. Dobna distribucija po Haavikko stadijima zuba 38

Stages	Females								Males								p*
	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	
Ci	5	12.08	11.89(1.49)	1.60	10.66	12.27	10.34	14.09	6	11.43	11.19(0.58)	0.67	10.92	11.58	10.20	11.67	0.3665
Cco	14	12.06	12.14(1.00)	1.47	11.36	12.82	10.55	13.94	5	11.83	12.35(0.94)	1.46	11.63	13.08	11.60	13.62	0.6874
CR1/2	21	12.34	12.24(1.24)	1.67	11.21	12.88	10.15	14.40	12	11.71	11.98(1.37)	1.74	10.99	12.73	10.43	14.75	0.5905
CR3/4	68	12.73	13.07(1.90)	1.96	12.00	13.95	10.02	18.68	57	12.77	12.97(1.40)	1.93	11.87	13.80	10.28	16.85	0.7322
Crc	43	14.01	14.16(1.34)	1.79	13.42	15.21	11.76	16.67	26	13.75	13.81(1.26)	1.68	12.82	14.50	11.58	16.39	0.288
R1/4	68	15.23	15.33(1.51)	2.27	14.49	16.76	12.48	18.58	65	15.15	14.91(1.61)	2.40	13.59	15.99	10.62	18.08	0.1289
R1/2	33	16.18	16.39(1.78)	1.94	15.44	17.38	12.97	20.92	32	15.97	16.45(1.64)	2.20	15.32	17.52	14.11	20.83	0.8962
R3/4	28	16.53	16.69(1.50)	1.59	15.85	17.44	13.85	19.47	26	16.79	16.81(1.26)	1.75	15.77	17.52	14.59	19.76	0.7486
Rc	12	18.02	17.85(1.57)	1.77	17.05	18.83	15.06	20.25	35	17.42	17.50(1.19)	1.07	16.81	17.89	14.81	19.97	0.485
Ac	8	19.90	19.67(0.94)	1.10	19.17	20.26	18.09	20.97	19	19.69	19.57(0.83)	1.03	19.12	20.15	18.02	20.90	0.7955

Note:N, number of individuals within specific stage; IQR, intraquartile range; Q1,first quartile; Q3, third quartile; Min, minimal; Max, maximal; SD, standard deviation, * independent t-test.

Table 6 Measures of classification ability of Haavikko stages in tooth 38 for 16-year and 18-year-old thresholds.
Tablica 6. Mjere sposobnosti klasifikacije Haavikko stadija zuba 38 za 16-godišnje i 18-godišnje pragove

Threshold	16-year-old		18-year-old	
Sex	Females	Males	Females	Males
Stage	Rc		Ac	
AUC	0.596(0.554-0.596)	0.737 (0.688-0.737)	0.643 (0.558-0.643)	0.771(0.688-0.771)
Accurarcy	75.7% (70.4%-80.4%)	80.2% (75.1%-84.7%)	93.3% (89.9%-95.9%)	94.3% (91.0%-96.7%)
Sensitivity	20.2% (12.4%-30.1%)	49.0% (39.1%-59.0%)	28.6% (13.2%-48.7%)	54.3% (36.6%-71.2%)
Specificity	99.1% (96.6%-99.9%)	98.3% (95.2%-99.7%)	100% (98.7%-100%)	100.0% (98.5%-100%)
LR+	21.34 (0.13-1.00)	29.26 (0.41-1)	0.23(0.15-1)	0.53 (0.39-1)
LR-	0.81 (0.13-1.00)	0.52 (0-0.04)	0.71 (0-0.80)	0.46 (0-0.01)
Precision (Positive)	90.0% (68.3%-98.8%)	94.4% (84.6%-98.8%)	100% (63.1%-100%)	100.0% (82.4%-100%)
Precision (Negative)	74.6% (69.1%-79.6%)	76.9% (70.8%-82.2%)	93.2% (89.6%-95.8%)	93.9% (90.3%-96.5%)
Post-test Probability	95.3% (92.3%-97.4%)	96.6% (93.6%-98.3%)	100% (98.8%-100%)	100.0% (98.7%-100%)

Note: Values are reported with 95% confidence intervals in the parenthesis.

Chronology of tooth 38 by Demirjian method and age threshold classification

Similarly, no statistical difference was observed beween females and males (Table 9). In the boxplot, the middle 50% of Demirjian E and G stages in females were wider and more to the right than in males. In stage C, E-F, the boxes were wider than other stages in both sexes (Figure 4).

ROC curve analysis showed identical results by Haavikko stages. For 16-year-old threshold, Stage G yielded Sp over 98% and Bayes PTP over 95% in both sexes. These values are even higher at the more advanced stage, H (Table 10). For 18-year-old threshold, stage H yielded 100% Sp and Bayes PTP. However, Se were generally low by these stages, due to high propotion of false negative cases (Table 14).

Chronology of tooth 37 by Olze eruption stage and age threshold classification

In both females and males, stage D exhibited the largest IQR and SD. Mean age at stage D was statistically lower in females (p<0,05) (Table 11). In both females and males, stage D exhibited the widest IQR (Figure 5). ROC curve analysis showed that eruption stages in tooth 37 were not effective for either age thresholds with very low classification metrics.

Chronology of tooth 38 by Olze eruption stage and age threshold classification

No statistical difference was observed beween females and males (Table 9). The age distribution of tooth 38 eruption stage was mainly wide (Figure 6). ROC curve analysis showed that stage C yielded Sp over 98%, Bayes PTP over 96% in males, these values were lower in females (Sp 96.7%,

Kronologija zuba 38 prema Demirjianovoj metodi i klasifikacija dobnoga praga

Slično tomu, nije uočena statistička razlika između žena i muškaraca (tablica 9.). U dijagramu je srednjih 50 % Demirjianova E i G stadija kod žena šire i više udesno nego kod muškaraca. U stadiju C, E – F kutije su bile šire od ostalih stadija u oba spola (slika 4.).

Analiza ROC krivulje pokazala je identične rezultate prema Haavikkovim stupnjevima. Za prag od 16 godina stadij G daje Sp veći od 98 % i Bayesov PTP veći od 95 % u oba spola. Te su vrijednosti čak i veće u naprednijoj fazi H (tablica 10.). Za prag od 18 godina stupanj H daje 100 % Sp-a i Bayesov PTP. No Se je općenito nizak u tim fazama zbog velikoga udjela lažno negativnih slučajeva (tablica 14.).

Kronologija zuba 37 prema Olzeovu stupnju nicanja i klasifikaciji dobnoga praga

I kod žena i kod muškaraca stadij D pokazuje najveći IQR i SD. Prosječna dob u stadiju D statistički je niža kod žena (p < 0,05) (tablica 11.). I kod žena i kod muškaraca stadij D pokazuje najširi IQR (slika 5). Analiza ROC krivulje pokazala je da stadiji nicanja zuba 37 nisu bili učinkoviti ni za jedan dobni prag s vrlo niskim klasifikacijskim metrikama.

Kronologija zuba 38 prema Olzeovu stupnju nicanja i klasifikaciji dobnoga praga

Nije uočena statistička razlika između žena i muškaraca (tablica 9.). Dobna distribucija stadija nicanja zuba 38 bila je uglavnom široka (slika 6.). Analiza ROC krivulje pokazala je da stupanj C daje Sp veći od 98 % i Bayesov PTP veći od 96 % kod muškaraca, a te su vrijednosti niže kod žena (Sp 96,7

Table 7 Age distribution by Demirjian stages in Tooth 37
Tablica 7. Dobna distribucija po Demirijanovim stadijima zuba 37

Stages	Female								Male								p*
	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	
E	8	10.99	10.98(0.59)	0.75	10.58	11.33	10.15	11.87	10	11.47	11.71(1.38)	1.01	10.87	11.88	10.20	14.81	0.1508
F	18	11.22	11.36(0.72)	1.07	10.92	12.00	10.34	12.83	21	11.63	11.96(0.89)	1.22	11.47	12.70	10.47	13.39	0.0247**
G	87	13.01	13.00(1.19)	1.77	12.24	14.01	10.02	15.28	75	12.96	13.09(1.29)	1.65	12.23	13.88	10.28	16.96	0.6313
H	187	15.92	15.95(1.98)	2.71	14.57	17.28	11.50	20.97	177	16.42	16.59(1.87)	2.33	15.35	17.68	12.51	20.90	0.0015**

Note: N, number of individuals within a specific stage; IQR, intraquartile range; Q1, first quartile; Q3, third quartile; Min, minimal; Max, maximal; SD, standard deviation, *independent t-test, **P<0.05

Table 8 Measures of classification ability of Demirjian stage in tooth 37 for 16-year threshold.
Tablica 8. Mjere sposobnosti klasifikacije Demirjianovih stadija zuba 37 za 16-godišnji prag

Threshold	16-year-old	
Sex	Females	Males
Stage	H	
AUC	0.768(0.734-0.768)	0.778(0.739-0.817)
Accurarcy	67.3% (61.7%-72.6%)	72.8% (67.2%-77.9%)
Sensitivity	100.0% (95.9%-100.0%)	98.1% (93.2%-99.8%)
Specificity	53.6% (46.6%-60.4%)	58.1% (50.5%-65.4%)
LR+	2.2(0.9-1)	2.3 (0.9-1)
LR-	2.2 (0.9-1)	0 (0-0.5)
Precision (Positive)	47.6% (40.3%-55.0%)	57.6% (50.0%-65.0%)
Precision (Negative)	100.0% (96.8%-100.0%)	98.1% (93.4%-99.8%)
Post-test Probability	67.4% (61.7%-72.6%)	69.2% (63.5%-74.6%)

Note: Values are reported with 95% confidence intervals in the parenthesis.

Table 9 Age distribution by Demirjian stages in Tooth 38
Tablica 9. Dobna distribucija po demirjianskim stadijima zuba 38

	Female								Male							P*
Stages	N	Median	Mean (SD)	IQR	Q_1	Q_3	Min	Max	N	Median	Mean (SD)	IQR	Q_1	Q_3	Min	Max	
A	6	11.37	11.67(1.44)	1.64	10.58	12.22	10.34	14.09	6	11.43	11.19(0.58)	0.67	10.92	11.58	10.20	11.67	0.4753
B	15	12.16	12.32(0.87)	1.19	11.75	12.94	11.10	13.94	9	12.39	12.38(0.80)	1.46	11.63	13.08	11.47	13.62	0.8618
C	86	12.61	12.75(1.58)	2.23	11.50	13.74	10.02	17.79	64	12.68	12.75(1.39)	1.90	11.68	13.57	10.28	15.90	0.9992
D	40	13.84	14.05(1.28)	1.60	13.39	14.99	11.76	16.67	24	13.75	13.74(1.23)	1.70	12.80	14.49	11.58	16.39	0.3407
E	96	15.30	15.56(1.55)	2.28	14.61	16.89	12.48	18.85	97	15.42	15.39(1.76)	1.76	14.38	16.14	10.62	20.83	0.57
F	37	16.56	16.97(1.64)	2.06	15.92	17.98	13.85	20.92	29	16.85	16.77(1.22)	1.71	15.66	17.38	14.59	19.76	0.6887
G	12	18.02	17.85(1.57)	1.77	17.05	18.83	15.06	20.25	35	17.53	17.51(1.19)	1.07	16.81	17.89	14.81	19.97	0.4986
H	8								19	19.69	19.57(0.83)	1.03	19.12	20.15	18.02	20.90	0.7955

Note: N, number of individuals within a specific stage; IQR, intraquartile range; Q1, first quartile; Q3, third quartile; Min, minimal; Max, maximal; SD, standard deviation; * independent t-test.

Table 10 Measures of classification ability of Demirjian stage in tooth 38 for 16-year and 18-year-old thresholds.
Tablica 10. Mjere sposobnosti klasifikacije Demirjianovog stadija zuba 38 za 16-godišnje i 18-godišnje pragove

Threshold	16-year-old		18-year-old	
Sex	Females	Males	Females	Males
Stage	G		H	
AUC	0.596 (0.554-0.596)	0.737 (0.688-0.737)	0.643 (0.558-0.643)	0.771 (0.688-0.771)
Accurarcy	75.7% (70.4%-80.4%)	80.2% (75.1%-84.7%)	93.3% (89.9%-95.9%)	94.3% (91.0%-96.7%)
Sensitivity	20.2% (12.4%-30.1%)	49.0% (39.1%-59.0%)	28.6% (13.2%-48.7%)	54.3% (36.6%-71.2%)
Specificity	99.1% (96.6%-99.9%)	98.3% (95.2%-99.7%)	100% (98.7%-100%)	100% (98.5%-100%)
LR+	21.34 (0.13-1)	29.26 (0.41-1)	Inf (0.2-1)	Inf (0.4-1)
LR-	0.81 (0-0.03)	0.52 (0-0.04)	0.7 (0-0.8)	0.5(0-0.01)
Precision (Positive)	90.0% (68.3%-98.8%)	94.4% (84.6%-98.8%)	100% (63.1%-100%)	100% (82.4%-100%)
Precision (Negative)	74.6% (69.1%-79.6%)	76.9% (70.8%-82.2%)	93.2% (89.6%-95.8%)	93.9% (90.3%-96.5%)
Post-test Probability	95.3% (92.3%-97.4%)	96.6% (93.6%-98.3%)	100% (98.8%-100%)	100% (98.7%-100%)

Note: Values are reported with 95% confidence intervals in the parenthesis.

Table 11 Age distribution by eruption stages in tooth 37
Tablica 11. Dobna distribucija po stadijima nicanja zuba 37

	Female								Male							P
Stages	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	
A	5	10.84	10.77(0.41)	0.24	10.66	10.90	10.15	11.27	1	11.15	11.15(-)	0.00	11.15	11.15	11.15	11.15	-
B	4	10.81	10.96(0.73)	0.99	10.39	11.38	10.34	11.87	14	11.65	12.01(1.42)	2.27	10.92	13.18	10.20	14.81	0.0718
C	53	12.73	12.92(1.68)	2.49	11.63	14.12	10.04	17.30	36	12.60	12.56(1.27)	1.77	11.52	13.29	10.50	15.56	0.2524
D	238	15.09	15.22(2.25)	3.42	13.49	16.91	10.02	20.97	232	15.82	15.76(2.3)	3.23	14.18	17.40	10.28	20.90	0.0112

Note: N, number of individuals within a specific stage; IQR, intraquartile range; Q1, first quartile; Q3, third quartile; Min, minimal; Max, maximal; SD, standard deviation; * independent t-test; ** P<0.05

Table 12 Age distribution by eruption stages in tooth 38
Tablica 12. Dobna distribucija po stadijima nicanja zuba 38

	Females								Males							p*
Stages	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	N	Median	Mean (SD)	IQR	Q1	Q3	Min	Max	
A	206	13.55	13.70(1.93)	2.56	12.31	14.87	10.02	19.50	156	13.26	13.64(1.93)	2.81	12.21	15.01	10.20	20.06	0.751
B	64	16.29	16.43(1.68)	2.01	15.41	17.43	12.48	20.92	76	16.10	16.27(1.68)	2.13	15.19	17.31	12.60	20.90	0.583
C	19	17.42	17.39(1.74)	2.65	16.07	18.72	14.35	20.27	31	17.54	17.78(1.41)	2.63	16.76	19.39	15.35	20.08	0.4161
D	11	18.65	18.30(2.17)	2.52	17.39	19.90	13.92	20.97	20	18.57	18.63(1.36)	2.05	17.68	19.73	16.48	20.70	0.6568

Note:N, number of individuals within specific stage; IQR, intraquartile range; Q1,first quartile; Q3, third quartile; Min, minimal; Max, maximal; SD, standard deviation; * independent t test.

Bayes PTP 88.2%). At stage D, these values were higher for the same age threshold. For 18-year-old threshold, stage D yielded Sp over 96%, Bayes PTP over 90% in both sexes, slightly higehr in females than males. Se were generally lower by any of the stages for either threshold due to high propotion of false negative cases (Table 13; Table 14).

Discussion

In forensic age estimation contexts, where the presence or absence of specific developmental changes occurred during formation and eruption stages, can help differentiate legal age thresholds. This study investigated the chronological sequence of formation and eruption of the left mandibular second and third molars in Croatian populations using multiple methodologies, aiming to distinguish individuals around the

%, Bayesov PTP 88,2 %). U fazi D te su vrijednosti više za isti dobni prag. Za prag od 18 godina stadij D daje Sp veći od 96 % i Bayesov PTP veći od 90 % u oba spola, malo viši kod žena nego kod muškaraca. Se je općenito niži za bilo koji stupanj za bilo koji prag zbog velikoga udjela lažno negativnih slučajeva (tablice 13. i 14.).

Rasprava

U kontekstu forenzičke procjene dobi, prisutnost ili odsutnost specifičnih razvojnih promjena koje su se dogodile tijekom formiranja i erupcije može pomoći u razlikovanju zakonskih dobnih pragova. Ova studija istražuje kronološki slijed formiranja i nicanja drugoga i trećega molara lijeve donje čeljusti u hrvatskoj populaciji korištenjem više metodologija, sa svrhom razlikovanja pojedinaca kad je riječ o

Table 13 Measures of classification ability of Olze eruption stages in tooth 38 for 16-year and 18-year thresholds
Tablica 13. Mjere sposobnosti klasifikacije Olzeovih stadija erupcije zuba 38 za 16-godišnje i 18-godišnje pragove

Threshold	16-year-old		18-year-old	
Sex	Females	Males	Females	Males
Stage	C		D	
AUC	0.613 (0.565-0.613)	0.722 (0.673-0.722)	0.618 (0.536-0.618)	0.655 (0.575-0.655)
Accuracy	75.7% (70.4%-80.4%)	79.2% (73.9%-83.7%)	91.7% (87.9%-94.5%)	89.0% (84.8%-92.4%)
Sensitivity	25.8% (17.1%-36.2%)	46.2% (36.3%-56.2%)	25.0% (10.7%-44.9%)	34.3% (19.1%-52.2%)
Specificity	96.7% (93.3%-98.7%)	98.3% (95.2%-99.7%)	98.5% (96.3%-99.6%)	96.8% (93.7%-98.6%)
LR+	7.79 (0.18-1)	27.54 (0.38-1)	17.00 (0.12-1)	10.63 (0.21-1)
LR-	0.77 (0-0.06)	0.55 (0-0.04)	0.76 (0-0.03)	0.68 (0-0.06)
Precision (Positive)	76.7% (57.7%-90.1%)	94.1% (83.8%-98.8%)	63.6% (30.8%-89.1%)	60.0% (36.1%-80.9%)
Precision (Negative)	75.6% (70.0%-80.6%)	75.9% (69.8%-81.2%)	92.7% (89.1%-95.4%)	91.3% (87.2%-94.4%)
Post-test Probability	88.2% (84.1%-91.7%)	96.4% (93.6%-98.3%)	94.2% (91.1%-96.7%)	91.1% (87.2%-94.2%)

Note: Values are reported with 95% confidence intervals in the parenthesis.

Table 14 Confusion matrix of cut-off stages in classifying 16- and 18-year-old thresholds
Tablica 14. Matrica zabune graničnih vrijednosti u klasifikaciji pragova od 14 i 16 godina

	Test	Age		Test	Age	
		≥16	<16		≥18	<18
Females	HM2 stage Ac	89	99	-	-	-
	earlier stages	0	112	-	-	-
	HM3 stage Rc	18	2	HM3 stage Ac	8	0
	earlier stages	71	209	earlier stages	20	272
	DM2 stage H	89	98	-	-	-
	earlier stages	0	113	-	-	-
	DM3 stage G	18	2	DM3 stage H	8	0
	earlier stages	71	209	earlier stages	20	272
	OM3 stage C	23	7	OM3 stage D	7	4
	earlier stages	66	204	earlier stages	21	268
Males	HM2 stage Ac	102	76	-	-	-
	Other stages	2	102	-	-	-
	HM3 stage Rc	51	3	HM3 stage Ac	19	0
	earlier stages	53	176	earlier stages	16	248
	DM2 stage H	102	75	-	-	-
	Other stages	2	104	-	-	-
	DM3 stage G	51	3	DM3 stage H	19	0
	earlier stages	53	176	earlier stages	16	248
	OM3 stage C	48	3	OM3 stage D	12	8
	earlier stages	56	176	earlier stages	23	240

pivotal age thresholds of those who were from 16 years of age to 18 years of age. Within the Croatian legal framework, individuals attain adulthood and assume full criminal responsibility at age 18. However, individuals aged 16 do not carry the same legal status as adults but can still face prosecution and sentencing for serious criminal offenses, including violent crimes or property crimes.

Our findings have revealed that tooth 37 is not effective for either age thresholds by any of the methods. Tooth 38, on the other hand, provided valuable information for these two age thresholds estimation. For 16-year-old threshold classification, in both sexes, Haavikko stage Rc, Demirjian stage G and eruption stage C in tooth 38 are effective with high Sp and Bayes PTP except for low Se due to high propotioon of false negative cases (Table 14). At advanced stage by either of the method, Sp and Bayes PTP are expected to be higher when classifying 16-year-old threshold.

For 18-year-old threshold classification, in both sexes, Haavikko stage Ac and Demirjian stage H in tooth 38 were highly effective with 100% Sp and 100% Bayes PTP. Eruption stage D was also effective with Sp over 96% and Bayes PTP over 90%. However, all Se were low due to high propotioon of false negative cases (Table 14). With very high Sp and Bayes PTP, it is most likely that an individual at Haavikko stage Ac, Demirjian stage H, or eruption stage D is over 18 years old. However, if an individual is at earlier stages than any of the abovementioned, it is inaccurate to conclude that he or she is younger than 18 with low Se.

Previous research found that Demirjian stage H is a reliable indicator for age of majority estimation across diverse populations (35,37–42). In a study in Austrian males, for each of the four third molars at stage H, the likelihood to be over 18 years showed 98–100% probability; the probability was about 93% for eruption stage D(35). This study has confirmed the reliability of Demirjian stage H in classifying age of majority. Moreover, Haavikko stage Ac, Demirjian stage H, and eruption stage D in tooth 38 are all highly effective in both sexes. High Sp is critical for ensuring low false positive in forensic context. Compared with the third molar index, Haavikko stage Ac, Demirjian stage H displayed similar classification ability to the third molar index cut-off value 0.08(29). Contrary to earlier studies, which suggested limited utility(35), this study demonstrates that eruption stage D is effective for the 18-year-old threshold.

Demirjian and Haavikko methods proved valuable and reliable in assessing the age of Croatian children with a strong correlation between dental age and chronological age (43). In a previous study by Brkić et al., Demirjian method demonstrated greater accuracy in estimating the age of Croatian children aged between 6 and 13.9 compared to the Haavikko method (13). However, regarding legal age threshold estimation, both methods yielded strikingly similar outcomes at optimal stages characterized by the completion of crown and root formation and the closure of the apex. Similar finding was reported in Portuguese population in estimating 18-year old threshold by these two methods in tooth 38 (44). This consistency is to be expected, given the substantial overlap in the staging criteria employed by these two methods.

ključnim dobnim pragovima od 16 i 18 godina. Unutar hrvatskoga pravnog okvira pojedinci postaju punoljetni i preuzimaju punu kaznenu odgovornost s navršenih 18 godina. Međutim, pojedinci sa 16 godina nemaju isti pravni status kao odrasli, ali još se uvijek mogu suočiti s kaznenim progonom i kaznom za teška nedjela, uključujući nasilne zločine ili imovinsku štetu.

Naši nalazi otkrivaju da zub 37 nije učinkovit ni za jedan dobni prag ni po jednoj od metoda. Zub 38, s druge strane, pruža informacije o vrijednosti za procjenu tih dvaju dobnih pragova. Za klasifikaciju praga od 16 godina, u oba spola, Haavikkov stadij Rc, Demirjianov stadij G i stadij erupcije C u zubu 38 učinkoviti su s visokim Sp-om i Bayesovim PTP-om, osim niskoga Se-a zbog velikog udjela lažno negativnih slučajeva (tablica 14.). U uznapredovalom stadiju bilo kojom metodom, očekuje se da će Sp i Bayesov PTP biti viši pri klasificiranju praga od 16 godina.

Za klasifikaciju praga od 18 godina, kod oba spola, Haavikkov stadij Ac, Demirjianov stadij H i kod zuba 38 vrlo su učinkoviti sa 100 % Sp-a i 100 % Bayesova PTP. Stadij erupcije D također je učinkovit sa specifičnošću većom od 96 % i Bayesovim PTP-om većim od 90 %. Međutim, svi Se-i su niski zbog velikog udjela lažno negativnih slučajeva (tablica 14.). S vrlo visokim Sp-om i Bayesovim PTP-om vrlo je sigurno da je osoba na Haavikkovu stupnju Ac, Demirjianovu stupnju H ili stupnju erupcije D starija od 18 godina. No ako je pojedinac u ranijim fazama od bilo koje od gore navedenih, netočno je zaključiti da je on ili ona mlađi od 18 godina s niskim Se-om.

Prethodno istraživanje pokazalo je da je Demirjianov stadij H pouzdan pokazatelj za procjenu punoljetnosti u različitim populacijama (35, 37 – 42). U studiji na austrijskim muškarcima, za svaki od četiri treća kutnjaka u stadiju H, vjerojatnost da će biti stariji od 18 godina pokazala je od 98 do 100 % vjerojatnosti; vjerojatnost je bila oko 93 % za stupanj erupcije D (35). Ova studija potvrđuje pouzdanost Demirjianova stupnja H u klasifikaciji punoljetnosti. Štoviše, Haavikkov stadij Ac, Demirjianov stadij H i stadij erupcije D u zubu 38 vrlo su učinkoviti u oba spola. Visoki Sp kritičan je za osiguravanje niskoga lažno pozitivnoga u forenzičkom kontekstu. U usporedbi s trećim molarnim indeksom, Haavikkovim stupnjem Ac, Demirjianov stupanj H pokazao je slično svojstvo klasifikacije kao granična vrijednost trećega molarnoga indeksa od 0,08 (29). Suprotno ranijim studijama koje su sugerirale ograničenu korisnost (35), ova studija pokazuje da je stadij erupcije D učinkovit za 18-godišnji prag.

Metode Demirjiana i Haavikka pokazale su se vrijednima i pouzdanima u procjeni dobi hrvatske djece s jakom korelacijom između dentalne i kronološke dobi (43). U prethodnoj studiji Brkića i suradnika, Demirjianova metoda pokazala je veću točnost u procjeni dobi hrvatske djece u dobi od 6 do 13,9 godina u odnosu na Haavikkovu metodu (13). Međutim, kad je riječ o procjeni zakonske starosne granice, obje metode daju nevjerojatno slične rezultate u optimalnim fazama koje karakterizira završetak formiranja krunice i korijena te zatvaranje vrha. Sličan nalaz zabilježen je u portugalskoj populaciji u procjeni 18-godišnjega praga tim dvjema metodama u zubu 38 (44). Ta dosljednost je očeki-

The timing of formation and eruption stages of third molars exhibits variability across different populations and ethnic groups, influenced by a combination of genetic, environmental, and dietary factors (5). In addition, study samples size and age structure have direct impact on the age distribution by stages (45). In comparison with central southern and southwestern Han populations (38,46), German population (47), and Portuguese population (48), on average, tooth 38 reached stage H 1-2 years earlier in Croatian population. Compared with a latest study in Portuguese population (44), Croatian samples tooth 38 in this study reached most stages 1-2 years earlier by both Haavikko and Demirjian method, except for samples at stage E and females at stage R1/4. This finding suggests potential advanced maturation in tooth 38. However, it is crucial to interpret this finding cautiously. Aside from ethnic differences, factors such as sample sizes, age ranges, and age structures must be considered when comparing. These factors significantly impact the comparability and generalizability of the results.

In this study sample, second molar completes formation and fully erupt earlier in females than males ($p<0.05$). Third molar formation and eruption pattern is similar for both sexes. The age at which third molar eruption stages C-D occur was observed to be 1-3 years earlier in both sexes compared to a previous study involving Croatian children and adolescents spanning ages 10 to 25 years, thus suggesting advanced gingival and complete emergence in the present Croatian population (49). In comparison with other populations, the timing of gingival and complete emergence is generally advanced in present population, although not for alveolar emergency; alveolar emergency is delayed for 1-2 years, but 2-3 years earlier in gingival and complete emergence in present population than northern Chinese population (50); complete emergence was 1-3 years earlier in comparison to third molar eruption in first nations people of Canada (33); 1-3 years earlier for alveolar, gingival and complete emergency compared with Austrian males (35); Alveolar emergency was 1.1 years earlier in Portuguese females and 2.4 years earlier in Portuguese males, but gingival emergency was 1.1 years and 0.5 years delayed respectively(51). The findings suggest significant variations in the timing of third molar eruption across different populations. These differences underscore the importance of considering population-specific norms when using third molar eruption stages for age estimation or other forensic purposes. Furthermore, this study uncovered significant variability in the timing of molar eruption compared to formation stages within the same population. This pattern has been noted in other populations as well (35,49,51). Such variability could potentially compromise the reliability of eruption stage assessments when estimating age thresholds. A previous study compared staging method of Olze et al. with five stages (52), method of Willmot et al. (53)with four stages and a new classification with six stages, and results showed very similar values for correlation with age and reliability among these three methods (34). However, it is worth noting that the original Olze staging method, which includes four stages, was not compared with these three methods. Therefore, it remains uncertain whether revana, s obzirom na značajno preklapanje u kriterijima stadija kojima se koriste te dvije metode.

Vrijeme formiranja i faza nicanja trećih kutnjaka pokazuje varijabilnost među različitim populacijama i etničkim skupinama, pod utjecajem kombinacije genetskih, okolišnih i prehrambenih čimbenika (5). Uz to, veličina ispitivanih uzoraka i dobna struktura izravno utječu na dobnu distribuciju po stadijima (45). U usporedbi s populacijom središnjega južnoga i jugozapadnoga Hana (38, 46), s njemačkom populacijom (47) i s portugalskom populacijom (48), u našem istraživanju u prosjeku je zub 38 dosegnuo stadij H godinu do dvije ranije u hrvatskoj populaciji. U usporedbi s najnovijom studijom u portugalskoj populaciji (44), hrvatski uzorci zuba 38 u ovoj studiji dostigli su većinu stadija godinu do dvije ranije i prema Haavikkovoj i prema Demirjianovoj metodi, osim uzoraka u stadiju E i žena u stadiju R1/4. Ovaj nalaz upućuje na potencijalno uznapredovalo sazrijevanje u zubu 38. No ključno je oprezno tumačiti ovaj nalaz. Uz etničke razlike, pri usporedbi moraju se uzeti u obzir čimbenici kao što su veličina uzorka, dobni rasponi i dobne strukture. Ti čimbenici značajno utječu na usporedivost i mogućnost generalizacije rezultata.

U ovom ispitivanom uzorku drugi kutnjak završava formiranje i potpuno izbija ranije kod žena nego kod muškaraca. Način formiranja i nicanja trećeg kutnjaka sličan je u oba spola. Uočeno je da je dob u kojoj se pojavljuju stupnjevi erupcije trećeg molara C-D godinu do tri godine ranije u oba spola u usporedbi s prethodnom studijom koja je obuhvaćala hrvatsku djecu i adolescente u dobi od 10 do 25 godina, što upućuje na nicanje u sadašnjoj hrvatskoj populaciji (49). U usporedbi s drugim populacijama, vrijeme gingivalnoga i potpunoga nicanja općenito je naprednije u sadašnjoj populaciji, iako ne i za alveolarno nicanje – alveolarna resorpcija kasni godinu do dvije, ali dvije do tri godine ranije u gingivi i potpunom nicanju u sadašnjoj populaciji nego u populaciji sjeverne Kine (50); potpuno nicanje bilo je godinu do 3 godine ranije u usporedbi s erupcijom trećeg kutnjaka među prvim narodima Kanade (33); godinu do tri godine ranije za alveolarnu, gingivnu i potpuni završetak rasta u usporedbi s austrijskim muškarcima (35). Alveolarna erupcija bila je 1,1 godinu ranije kod portugalskih žena i 2,4 godine ranije kod portugalskih muškaraca, ali gingivalni eruptivni stadij kasnio je 1,1 godinu, odnosno 0,5 godina (51). Rezultati sugeriraju značajne varijacije u vremenu nicanja trećeg kutnjaka među različitim populacijama. Te razlike ističu važnost razmatranja normi specifičnih za populaciju kada se koriste stupnjevi erupcije trećeg molara za procjenu dobi ili u druge forenzičke svrhe. Nadalje, ova je studija otkrila značajnu varijabilnost u vremenu nicanja molara u usporedbi sa stadijima formiranja unutar iste populacije. To je uočeno i u drugim populacijama (35, 49, 51). Takva varijabilnost mogla bi ugroziti pouzdanost procjene stadija erupcije pri procjeni pragova starosti. Prethodno istraživanje usporedilo je metodu stadija Olzea i suradnika s pet stupnjeva (52) i metoda Willmota i suradnika (53) s četiri stupnja i novom klasifikacijom od šest stupnjeva, a rezultati su pokazali vrlo slične vrijednosti korelacije s dobi i pouzdanosti između triju metoda (34). Međutim, potrebno je napomenuti da izvorna Ol-

fining the staging system would improve its performance in age estimation.

This study is mainly limited due to the uneven distribution of samples and age structure. Future study should explore the effectiveness of these methods with more balanced samples. Also, it is important to note that this conclusion is drawn from population-based data, and its applicability may not be universal due to variability in dental development and potential inaccuracies in age assessment methods that could affect the reliability of estimating age thresholds.

Conclusion

This study presented population-based data on dental maturity and offered a robust foundation for age threshold estimation in Croatian legal and investigative settings. Formation and eruption of left mandibular third molar provide valuable information for age thresholds estimation. Haavikko stage Rc, Demirjian stage G, eruption stage C and respective advanced stages in tooth 38 are effective for 16-year-old threshold estimation. Haavikko stage Ac, Demirjian stage H and eruption stage D are effective for 18-year-old threshold estimation. Left mandibular second molar completes formation and fully erupts earlier in females. The use of formation and eruption of second molar for age threshold estimation is limited.

Conflict of interest: None declared.

Acknowledgement: We extend our gratitude to Prof. Hrvoje Brkić for his contribution to this study, and colleagues from Department of Dental Anthropology, University of Zagreb School of Dental Medicine. This work is presented in the Jubilee 10th International Congress of the School of Dental Medicine University of Zagreb.

Funding: This work was supported by Croatian Science Foundation-project (IP-2020-02-9423).

Ethics approval: The Ethics Committee of the University of Zagreb School of Dental Medicine approved this research at the 18th regular session held on June 4th, 2020, decision number: 05-PA30-XVIII-6/2020. The Ethical Committee of University Hospital Center Zagreb at its 272nd regular session also approved this research. The study was carried out following the ethical standards of the Declaration of Helsinki (Finland).

Author's contribution: **L. S.** - Conceptualization, Methodology, Formal Analysis, Investigation, Validation, Writing - Original Draft, Review and Editing; **S. A. M.** - Data curation, Resources, Writing - Review & Editing; **I. G.** - Methodology, Investigation, Validation, Writing - Review & Editing; **L. B.** - Methodology, Validation, Writing - Review & Editing.

zeova metoda, koja uključuje četiri faze, nije uspoređivana s tim trima metodama. Stoga ostaje neizvjesno hoće li usavršavanje sustava stupnjevanja poboljšati njegovu izvedbu u procjeni dobi.

Ovo istraživanje uglavnom je ograničeno zbog neravnomjerne distribucije uzoraka i dobne strukture. Autori budućih studija trebali bi istražiti učinkovitost tih metoda s uravnoteženijim uzorcima. Također je važno napomenuti da je ovaj zaključak izveden iz podataka temeljenih na populaciji, a njegova primjenjivost možda nije univerzalna zbog varijabilnosti u dentalnom razvoju i potencijalnih netočnosti u metodama procjene dobi koje bi mogle utjecati na pouzdanost procjene dobnih pragova.

Zaključak

Ova studija predstavila je populacijske podatke o dentalnoj zrelosti i ponudila robusnu osnovu za procjenu dobnoga praga u hrvatskom pravnom i istražnom sustavu. Formiranje i nicanje lijevoga donjeg trećeg kutnjaka pružaju vrijedne informacije za klasifikaciju dobnih pragova. Haavikkov stadij Rc, Demirjianov stadij G, stadij erupcije C i odgovarajući uznapredovali stadiji u zubu 38, učinkoviti su za klasifikaciju praga od 16 godina. Haavikkov stadij Ac, Demirjianov stadij H i erupcijski stadij D učinkoviti su za 18-godišnju klasifikaciju praga. Drugi kutnjak lijeve donje čeljusti završava formiranje i potpuno izbija ranije kod žena. Istraživanje je pokazalo da je korištenje formiranja i erupcije drugoga donjeg kutnjaka za procjenu praga starosti ograničeno.

Sukob interesa: Autori nisu bili u sukobu interesa.

Zahvala: Zahvaljujemo prof. dr. sc. Hrvoju Brkiću na doprinosu ovoj studiji i kolegama iz Zavoda za dentalnu antropologiju Stomatološkog fakulteta Sveučilišta u Zagrebu. Rad je prezentiran na jubilarnom 10. Međunarodnom kongresu Stomatološkog fakulteta Sveučilišta u Zagrebu.

Financiranje: Ovaj rad poduprla je Hrvatska zaklada za znanost (projekt IP-2020-02-9423).

Etička odobrenja: Etičko povjerenstvo Stomatološkog fakulteta Sveučilišta u Zagrebu odobrilo je ovo istraživanje na 18. redovitoj sjednici održanoj 4. lipnja 2020. godine – broj odluke: 05-PA30-XVIII-6/2020. Etičko povjerenstvo KBC-a Zagreb na svojoj 272. redovitoj sjednici također je odobrilo ovo istraživanje. Studija je provedena u skladu s etičkim standardima Helsinške deklaracije (Finska).

Doprinos autora: **L. S.** - Konceptualizacija, metodologija, formalna analiza, istraživanje, validacija, pisanje - izvorni nacrt, pregled i uređivanje; **S. A. M.** - Sređivanje podataka, resursi, pisanje - pregled i uređivanje; **I. G.** - Metodologija, istraživanje, provjera valjanosti, pisanje - pregled i uređivanje; **L. B.** - Metodologija, provjera valjanosti, pisanje - pregled i uređivanje.

Sažetak

Cilj: Istraživala se točnost triju utvrđenih pristupa za procjenu zakonskoga dobnoga praga u hrvatskom uzorku. **Materijali i metode:** Olzeovi stadiji nicanja trećeg kutnjaka, Haavikkovi stadiji i Demirjianovi stadiji primijenjeni su na 583 ortopantomograma hrvatske djece i adolescenata u dobi od 10 do 20,99 godina. Procijenjeni su drugi i treći molar lijeve donje čeljusti. Utvrđena je kronologija nastanka i nicanja zuba. Krivulje radnih karakteristika (ROC) izvedene su da bi se procijenila sposobnost klasifikacije prediktivnih varijabli za procjenu 16-godošnjih i 18-godišnjih pragova. **Rezultati:** Havikkov stadij, Demirjianov stadij i stadiji erupcije u zubu 37 pokazuju loše rezultate za pragove od 16 i 18 godina. Zub 38 pruža informacije o vrijednosti za ta dva praga starosti. Za 16-godišnji prag Haavikkov stadij Rc i Demirjianov stadij G daju Sp veći od 98 % i Bayesov PTP veći od 95 % za oba spola. Stadij erupcije C daje Sp veći od 98 %, Bayesov PTP veći od 96 % kod muškaraca, a kod žena je niži (Sp 96,7 %, Bayesov PTP 88,2 %). Za 18-godišnji prag Haavikkov stadij Ac i Demirjianov stadij H daju 100-postotni Sp i Bayesov PTP. Stadij erupcije D daje Sp veći od 96 %, Bayesov PTP veći od 90 % u oba spola, a malo je veći kod žena nego kod muškaraca. Prosječna starost zuba 37 u Haavikkovu stadiju Ac, Demirjianovu stadiju F, H i stadiju nicanja D, statistički je niža kod žena ($p < 0,05$). **Zaključak:** Prikazani su podatci o zrelosti zuba u Hrvatskoj. Haavikkov stadij Rc, Demirjianov stadij G, stadij erupcije C i odgovarajući uznapredovali stadiji u zubu 38, učinkoviti su za klasifikaciju praga od 16 godina. Haavikkov stadij Ac, Demirjianov stadij H i erupcijski stadij D, učinkoviti su za 18-godišnju klasifikaciju praga.

Zaprimljen: 3. svibnja 2024.
Prihvaćen: 10. kolovoza 2024.

Adresa za dopisivanje
dr. sc. Lei Shi
Sveučilište u Zagrebu
Stomatološki fakultet
Zavod za dentalnu antropologiju
Katedra za forenzičnu stomatologiju
Gundulićeva 5, 10 000 Zagreb,
Hrvatska

MeSH pojmovi: nicanje zuba; umnjak; određivanje dobi pomoću zubi; zakonski status; Hrvatska
Autorske ključne riječi: dentalna dob, treći kutnjaci, forenzička odontologija, hrvatska zakonska starosna granica

References

1. 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(3):256–62.
2. Schmeling A, Grundmann C, Fuhrmann A, Kaatsch HJ, Knell B, Ramsthaler F, et al. Criteria for age estimation in living individuals. Int J Legal Med. 2008 Nov;122(6):457-60.
3. Soomer H, Ranta H, Lincoln MJ, Penttila A, Leibur E. Reliability and Validity of Eight Dental Age Estimation Methods for Adults. J Forensic Sci. 2003 Jan;48(1):149-52.
4. Esan TA, Yengopal V, Schepartz LA. The Demirjian versus the Willems method for dental age estimation in different populations: A meta-analysis of published studies. PLoS One. 2017 Nov 8;12(11):e0186682.
5. 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(6):445–8.
6. Haavikko K. The formation and the alveolar and clinical eruption of the permanent teeth. An orthopantomographic study. Suomen Hammaslaakariseuran Toimituksia. 1970;66(3):103-170.
7. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. 1973;45(2):211-227.
8. Nolla CA. The development of the permanent teeth. Journal of dentistry for children. 1960; Fourth Qua:254–66.
9. Moorrees CFA, Fanning EA, Hunt EE. Formation and resorption of three deciduous teeth in children. Am J Phys Anthropol. 1963; 21(2):205-213. doi:10.1002/ajpa.1330210212
10. Çelik Güler Ö, Deniz Y, Arslan S. Comparison of Dental and Skeletal Age Estimating Methods in Children. Acta Stomatol Croat. 2023 Mar;57(1):2-11.
11. 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.
12. Galić I, Vodanović M, Cameriere R, Nakaš E, Galić E, Selimović E, et al. Accuracy of Cameriere, Haavikko, and Willems radiographic methods on age estimation on Bosnian–Herzegovian children age groups 6–13. Int J Legal Med. 2011 Mar;125(2):315-21.
13. Brkić H, Galić I, Vodanović M, Dumančić J, Mehdi F, Anić Milošević S. The Cameriere, Haavikko, Demirjian, and Willems methods for the assessment of dental age in Croatian children. Int J Legal Med. 2022 Nov;136(6):1685-1696.
14. Wang Y, Huang S, Liu H. Use of Haavikko's method to assess dental age in Chinese children. Community Dent Health. 2011;28(2):160-164.
15. Kırzıoğlu Z, Ceyhan D. Accuracy of different dental age estimation methods on Turkish children. Forensic Science International. 2012;216(1–3):61–7.
16. Pinchi V, Norelli GA, Pradella F, Vitale G, Rugo D, Nieri M. Comparison of the applicability of four odontological methods for age estimation of the 14 years legal threshold in a sample of Italian adolescents. J Forensic Odontostomatol. 2012 Dec 1;30(2):17-25.
17. Ruiz-Mealin EV, Parekh S, Jones SP, Moles DR, Gill DS. Radiographic study of delayed tooth development in patients with dental agenesis. Am J Orthod Dentofacial Orthop. 2012 Mar;141(3):307-314.
18. Patnana AK, Vabbalareddy RS, V Vanga NR. Evaluating the reliability of three different dental age estimation methods in Visakhapatnam Children. Int J Clin Pediatr Dent. 2014 Sep-Dec;7(3):186-91.
19. Kumaresan R, Cugati N, Chandrasekaran B, Karthikeyan P. Reliability and validity of five radiographic dental-age estimation methods in a population of Malaysian children. J Investig Clin Dent. 2016;7(1):102-109.
20. Mohammed RB, Sanghvi P, Perumalla KK, Srinivasaraju D, Srinivas J, Siva Kalyan U, et al. Accuracy of four dental age estimation methods in Southern Indian children. J Clin Diagn Res. 2015 Jan;9(1): HC01-8.
21. Hegde S, Patodia A, Dixit U. A comparison of the validity of the Demirjian, Willems, Nolla and Häävikko methods in determination of chronological age of 5–15 year-old Indian children. J Forensic Leg Med. 2017 Aug: 50:49-57.
22. Chaudhry K, Talwar M, Vanga NR, Lehl GK, Choudhary A, Patnana AK. A Comparative Evaluation of Three Different Dental Age Estimation Methods in India: A Test of Ethnic Variability. Int J Clin Pediatr Dent. 2020 Jan-Feb;13(1):16-20.
23. Maber M, Liversidge HM, Hector MP. Accuracy of age estimation of radiographic methods using developing teeth. Forensic Science International. 2006;159(1):68–73.
24. Sezer B, Çarıkçıoğlu B. Accuracy of the London Atlas, Haavikko's Method and Cameriere's European Formula of dental age estimation in Turkish children. Leg Med (Tokyo). 2022 Feb: 54:101991.
25. Lopes LJ, Nascimento HAR, Lima GP, Santos LAN dos, Queluz D de P, Freitas DQ. Dental age assessment: Which is the most applicable method? Forensic Sci Int. 2018 Mar: 284:97-100.
26. Jayaraman J, King NM, Roberts GJ, Wong HM. Dental age assessment: are Demirjian's standards appropriate for southern Chinese children? J Forensic Odontostomatol. 2011;29(2):22-28..
27. Shi L, Yu L, Fan F, Lu T, Lin Y, Cheng Z, et al. Multi-regional age estimation study in Han Chinese children: validation of modified Tibetan method and comparative analysis between regions and ethnicities. Australian J Forensic Sci. 2023 Feb 21;0(0):1–12.
28. Erken Gungor O, Kale B, Celikoglu M, Gungor AY, Sari Z. Validity of the Demirjian method for dental age estimation for Southern Turkish children. Niger J Clin Pract. 2015 Sep-Oct;18(5):616-9.
29. Galić I, Lauc T, Brkić H, Vodanović M, Galić E, Biazevic MGH, et al. Cameriere's third molar maturity index in assessing age of majority. Forensic Sci Int. 2015 Jul;252:191.e1-5.
30. 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.
31. Angelakopoulos N, Galić I, Balla SB, Kiş HC, Gómez Jiménez L, Zolotenkova G, et al. Comparison of the third molar maturity index (I3M) between left and right lower third molars to assess the age of majority: a multi-ethnic study sample. Int J Legal Med. 2021 Nov;135(6):2423-2436.

32. Różyło-Kalinowska I, Kalinowski P, Kozek M, Galić I, Cameriere R. Validity of the third molar maturity index I3M for indicating the adult age in the Polish population. Forensic Sci Int. 2018 Sep: 290:352. e1-352.e6.
33. Olze A, Pynn B, Kraul V, Schulz R, Heinecke A, Pfeiffer H, et al. Dental age estimation based on third molar eruption in first nations people of Canada. J Forensic Odontostomatol. 2010 Dec 1;28(1):32-8. PMID: 21239860.
34. Timme M, Viktorov J, Steffens L, Streeter A, Karch A, Schmeling A. Third molar eruption in orthopantomograms as a feature for forensic age assessment—a comparison study of different classification systems. Int J Legal Med. 2023 May;137(3):765-772.
35. Widek T, Genet P, Merkens H, Boldt J, Petrovic A, Vallis J, et al. Dental age estimation: The chronology of mineralization and eruption of male third molars with 3T MRI. Forensic Sci Int. 2019;297:228–35.
36. Shi L, Galić I, Anić-Milošević S, Banjšak L, Brkić H. Accuracy of second and third molar maturity indices, Olze, Haavikko, and Demirjian methods for 14- and 16-year-old age thresholds assessment in Croatian children and adolescents. Int J Legal Med. 2024 Jul 11.
37. 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 Sep 10;201(1-3):79-83.
38. Liu Y, Geng K, Chu Y, Xu M, Zha L. Third molar mineralization in relation to chronologic age estimation of the Han in central southern China. Int J Legal Med. 2018 Sep;132(5):1427-1435.
39. Khosronejad A, Navabi M, Sakhdari S, Rakhshan V. Correlation between chronological age and third molar developmental stages in an Iranian population (Demirjian method). Dental Res J. 2017;14(2):143–9.
40. Márquez-Ruiz AB, Treviño-Tijerina MC, González-Herrera L, Sánchez B, González-Ramírez AR, Valenzuela A. Three-dimensional analysis of third molar development to estimate age of majority. Science & Justice. 2017;57(5):376–83.
41. 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 May;54(3):651-7.
42. Li G, Ren J, Zhao S, Liu Y, Li N, Wu W, et al. Dental age estimation from the developmental stage of the third molars in western Chinese population. Forensic Sci Int. 2012;219(1):158–64.
43. Čuković Bagić I, Sever N, Brkić H, Kern J. Dental Age Estimation in Children Using Orthopantomograms. Acta stomatol Croat. 2008;42(1):11–8.
44. Pereira CP, Rodrigues A, Augusto D, Santos A, Nushic V, Santos R. Dental age assessment and dental scoring systems: combined different statistical methods. Int J Legal Med. 2024;138(4):1533-1557.
45. Gelbrich B, Lessig R, Lehmann M, Dannhauer KH, Gelbrich G. Altersselektion in Referenzstichproben. Rechtsmedizin. 2010;20(6):459–63.
46. Qing M, Qiu L, Gao Z, Bhandari K. The chronological age estimation of third molar mineralization of Han population in southwestern China. J Forensic Leg Med. 2014 May;24:24-7. doi: 10.1016/j.jflm.2014.03.004.
47. Guo Y, Olze A, Ottow C, Schmidt S, Schulz R, Heindel W, et al. Dental age estimation in living individuals using 3.0 T MRI of lower third molars. Int J Legal Med. 2015;129(6):1265–70.
48. Silva Branco M, Pestana D. Medico-Legal Age Estimation in Living Individual from a Portuguese Population: Third Molar Mineralization. J Forensic Res [Internet]. 2012 [cited 2024 Mar 17];03(05). Available from: https://www.omicsonline.org/medico-legal-age-estimation-in-living-individual-from-a-portuguese-population-third-molar-mineralization-2157-7145.1000149.php?aid=6501
49. Brkić H, Vodanović M, Dumančić J, Petrovecki M. The Chronology of Third Molar Eruption in the Croatian Population. Coll Antropol. 2011 Jun;35(2):353-7.
50. Guo Y cheng, Yan C xia, Lin X wei, Zhou H, Pan F, Wei L, et al. Studies of the chronological course of third molars eruption in a northern Chinese population. Arch Oral Biol. 2014 Sep;59(9):906-11.
51. Caldas IM, Carneiro JL, Teixeira A, Matos E, Afonso A, Magalhães T. Chronological course of third molar eruption in a Portuguese population. Int J Legal Med. 2012;126(1):107–12.
52. Olze A, Peschke C, Schulz R, Schmeling A. Application of a modified stage classification in evaluating wisdom tooth eruption in a German population. Arch Kriminol. 2012 May-Jun;229(5-6):145-53.
53. Willmot SE, Hector MP, Liversidge HM. Accuracy of estimating age from eruption levels of mandibular teeth. Indian J Dent Res. 2009 Jan-Mar;20(1):26-30.