Third molar maturity index for discriminating between adults and minors: validation in an Iranian sample

Najmeh Movahhedian [1], Sara Nikmanesh [1], Amirreza Bazooband [1]

[1] *Department of Oral and Maxillofacial Radiology, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran.*

Corresponding author:
movahedian@sums.ac.ir

The authors declare that they have no conflict of interest.

KEYWORDS

Forensic dentistry,
Forensic Anthropology
Population Data,
Age determination by teeth,
Third molar,
Maturity index

J Forensic Odontostomatol
2024. Dec;(42): 3 -9:19
ISSN :2219-6749
DOI: doi.org/10.5281/zenodo.14561902

ABSTRACT

The life-altering effects of criminal trials necessitate providing reliable methods to distinguish adults (≥18) from minors (< 18). The present study aims to evaluate the accuracy of the third molar maturity index (I3M) introduced by Cameriere et al. (2008) in distinguishing adults from minors in the Iranian population. Panoramic radiographs of 800 Iranian individuals (400 males and 400 females) aged 14-23 were evaluated. The cut-off value of I3M=0.08 was analysed to determine whether the individual is younger or older than 18. All male or female subjects with I3M above 0.7 were below 18 years old. The cut-off value of 0.08 showed a sensitivity of 80.83% and 63.33% and a specificity of 88.12% and 93.12%, respectively, in males and females. The positive predictive values were 91.08% and 93.25%, and the negative predictive values were 75.40% and 62.87%, respectively, for males and females. The Bayes' post-test probability was 94% for females and 92% for males. 83.75% of males and 75.25% of females correctly classified as adults or minors. The most remarkable error rate occurred at 18 years old (67.5 % in females and 57.5% in males). By ROC curve analysis, the population-specific cut-off values of I3M 0.097 for males, 0.116 for females, and 0.099 regardless of sex, were acquired, which improved the sensitivity of discrimination between adults and minors (86.3%, 73.8%, and 78.1 %, respectively). The results showed that I3M is a reliable method for distinguishing between minors and adults in the Iranian population. This method provides a higher accuracy level in identifying individuals under 18 years old. Population-specific I3M cut-off values increased accuracy, sensitivity, and NPV, especially for females. The I3M method produced better results in diagnosing adult males than adult females and a higher accuracy level in identifying individuals under 18.

INTRODUCTION

Forensic age estimation has become a growing concern in criminal and civil cases involving young individuals, illegal immigration, and a variety of refugee status difficulties. It has been shown that half the refugees from Middle Eastern or African countries are children below 18 years of age. [1] In many countries, this age represents a legal cut-off to distinguish minors from adults. [2-6] Also, the International Criminal Court, founded in 1998 to investigate and prosecute those suspected of committing an offence, considered 18 years old, the age of

the legal majority. [7] The life-altering effects of criminal trials and the protection of minors' legal rights necessitate providing reliable, lawful, and non-invasive methods to distinguish adults from minors accurately.

Following the guidelines of the Study Group on Forensic Age Diagnostic (AGFAD), the age estimation of a living individual includes 1) Physical examination to record anthropometric data, sexual maturity signs, and age-appropriate developmental anomalies; 2) Radiography of the left hand or the clavicle (in case of completed wrist skeletal development); 3)X-ray analysis of the dentition to determine dental maturity. [8] Based on AGFAD recommendation, combining three independent developmental systems enhances the diagnostic accuracy of age estimation. [9]

Skeletal techniques have some disadvantages due to the substantial heterogeneity of bone growth, which is impacted by environmental variables. [10] However, dental development has less variability since it is under common control by genes rather than environmental factors. [11] It is indicated that socio-economic status is more pronounced in skeletal maturation than in dental development. [12] Cardoso [12] showed that age estimation in pre-adolescents using long bone development leads to biased, divergent results, especially in children with low socio-economic status. In contrast, dental age estimation is almost buffered against environmental factors. For dental age estimation of individuals between 14 and 23 years of age and to discriminate children from adults, analysis of third molar development is the most practical and appropriate indicator since these teeth are still developing at this age. [13, 14] Mincer et al. [15] pioneered applying Demirjian's staging system for age estimation based on third molar teeth. They showed that the majority of male and female subjects (90% and 92%, respectively) with fully developed third molars (those in stage H) were adults. However, this yields significant false negative results due to the high number of individuals over 18 years of age with unmatured third molar teeth. [16] More recently, Cameriere et al. [16] proposed the third molar maturity index (I3M), the ratio between the width of open apices and the third molar tooth length, as a method of age estimation based on third molar development. They provided a cut-off value of 0.08 to discriminate between adults (≥18) and minors (<18). This method was shown to have higher sensitivity, specificity, and lower frequency of false negative results.

Population affinity has been shown as a potential factor influencing the accuracy of anthropological methods, [5, 17] including age estimation derived from third molar development. [18] In this regard, several studies have evaluated the accuracy of the Cameriere cut-off value in different populations worldwide; however, the accuracy of the Cameriere cut-off value for discrimination of minors from adults has yet to be carefully addressed in the Iranian population. So, the main aim of the present study was to evaluate the cut-off value of I3M 0.08 to discriminate minors from adults in the evaluated sample.

MATERIALS AND METHODS

Samples

The institutional human ethics committee approved the research protocol for this cross-sectional study (#IR.Sums.Dental.REC.1399.088).

Digital panoramic radiographs of 1296 Iranian living subjects aged 14-23 years were evaluated. The images were retrieved from the Oral and Maxillofacial Radiology Department of Shiraz Dental School archive. The radiographs were taken for specific clinical indications other than the present study. All the patients or their guardians had signed a written informed consent for the possible use of their radiographic data, preserving their anonymity in research or publications.

The images with low quality (N=122), any pathological lesion in the area of interest (N=38), multiple dental anomalies (N=3), hypodontia(N=1), or congenitally missing mandibular third molar teeth (N=46) were excluded. Mandibular third molar teeth with an extensive carious lesion (N=24), endodontic treatment (N=1), coronal restoration (N=11), or severe rotation (N=223) were also eliminated from the study. Moreover, radiographs from individuals with a history of systemic disease or developmental abnormality and dental / maxillofacial trauma (N=27) were also excluded from the study. Finally, the study sample comprised 800 panoramic radiographs (400 males and 400 females), then divided into ten one-year age groups. Each group included 80 subjects evenly distributed according to sex (40 male and 40 female subjects). (Table 1)

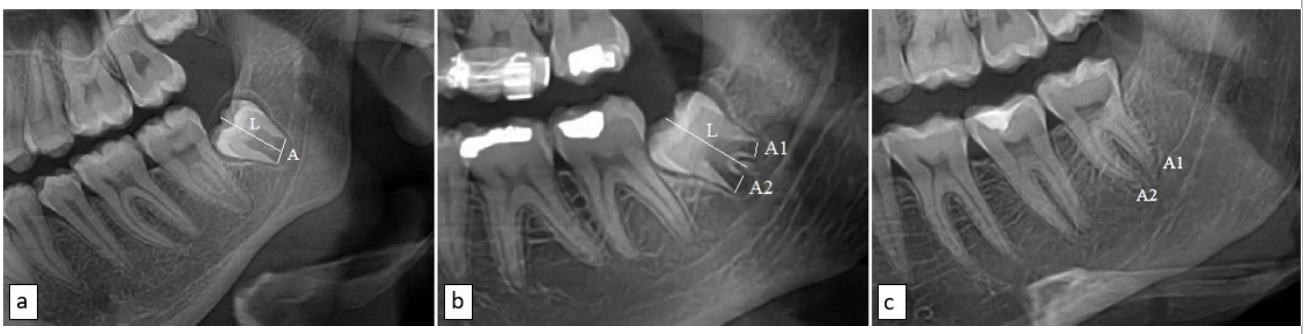
Table 1. Distribution of the subjects per age and sex groups (Female/Male). The numbers in the parenthesis show the subjects with completely developed left mandibular third molars (I3M=0.00).

Age categories	Males	Females	Total
14-14.9	40(0)	40(0)	80(0)
15-15.9	40(0)	40(2)	80(2)
16-16.9	40(2)	40(0)	80(2)
17-17.9	40(3)	40(1)	80(4)
18-18.9	40(6)	40(3)	80(9)
19-19.9	40(11)	40(7)	80(18)
20-20.9	40(18)	40(9)	80(27)
21-21.9	40(22)	40(9)	80(31)
22-22.9	40(32)	40(19)	80(51)
23-23.9	40(32)	40(27)	80(59)
Total	400(126)	400(77)	800(203)

Age is presented in years.

All panoramic radiographs were taken by the Vatech PaX-I panoramic X-ray unit (Vatech Co., Seoul, Republic of Korea). According to the Cameriere et al. [16] method, the I3M of each subject was calculated as the ratio of the distance between the inner margins of the third molar's open apex to the total tooth length to eliminate the effect of magnification differences in radiographs. In this regard, I3M is measured as zero in completely developed roots, and in third molar teeth with two or more roots, it is defined as the sum of the width of open apices to the tooth length (Fig. 1).

Figure 1. Calculation of I3M in third molar teeth with different numbers of roots and developmental stages. A1 and A2: width of the two open apices' inner margins; L: tooth length. a) A/L in a one-rooted third molar; b) (A1+A2+...)/L in a third molar with two (or more) roots; c) I3M is calculated as zero in a third molar tooth with closed root apices



The measurements were recorded on the left mandibular third molar teeth, either erupted or impacted, for standardisation. However, since a strong correlation has been shown between the development of the left and right third molar teeth, [19, 20] the measurements were recorded on the right counterpart whenever the left mandibular third molar did not meet the inclusion criteria. The radiographs were coded with an ID to obscure the subjects' demographic data and prevent observer bias.

For calculating the chronological age of the subjects, the birth date of the individuals was subtracted from the date of radiographic

acquisition and then rounded to one decimal place.

Radiographic images were evaluated by a well-trained and calibrated last-semester dental student using EzDent-i software (Vatech Co., Ltd., Hwaseong, Korea) on a 14-inch monitor in deemed environmental lighting. The observer adjusted image contrast, brightness, and sharpness or used a zoom-in option to better visualise tooth anatomy. The same observer randomly selected 200 radiographs of the study sample and examined them again after two weeks to assess the observer-intra agreement.

Statistical analysis

To examine intra-observer reliability for the evaluated panoramic radiographs, the intra-class correlation coefficient (ICC) was calculated. The cut-off value of 0.08 was applied to distinguish adults from minors, as described by Cameriere. [16] Subjects with an I3M less than 0.08 were considered adults (≥ 18), and subjects with an I3M greater than 0.08 were considered minors (<18).

The sensitivity (Se), the proportion of correctly determined adults out of all the subjects with the age of ≥18, and the specificity (Sp), the ratio of precisely defined minors out of all the subjects with ages below 18 years old, as well as accuracy (Ac), a proportion of correctly classified subjects among all the adult subjects were calculated.

The positive and negative likelihood ratios (LR+ and LR-) and predictive values (PPV and NPV) were computed. The LR+ determines how much more likely the positive result (I3M<0.08) is to occur in adults in comparison with minors, and the LR- determines how much less likely the negative result (I3M≥0.08) is to appear in adults compared to minors. LR+ values between 2-5 show a slight increase, and 5–10 and over 10, respectively, represent moderate and significant increases in the likelihood of being over 18 years old. LR- values of 0.5-0.2 demonstrate a small, 0.2-0.1 means a moderate decrease, while < 0.1 reflects a significant/almost definite reduction in the likelihood of being over 18 years old [21]. PPV represents a proportion of adults with positive test results (true positives) in total subjects with a positive result (I3M<0.08). In other words, PPV defines the probability of being an adult when I3M is <0.08. NPV represents a proportion of minors with a negative test result (true negative) in total subjects with negative test results (I3M ≥0.08). NPV determines the probability of being under 18 years old when I3M ≥0.08. [22]

The post-test probability, which can help to differentiate adults from minors, was also calculated, which according to Bayes' theorem (Bayes PTP), is defined as:

$$P = \frac{Se\ P_0}{Se\ P_0 + (1 - Sp)\ (1 - P0)}$$

P: the post-test probability, Se: Sensitivity, Sp: Specificity, P_0: the probability that the individual is ≥18 within the target population aged 14-23 years. In this study, P0 was calculated based on the Iranian Bureau of Statistics data and was considered 63% for females and 62% for males.

A receiver operating curve (ROC) analysis was conducted to determine whether there is an I3M value and a higher discriminant ability between adults and minors for the Iranian population according to the highest Youden index (J).

Data analysis was performed using PASW SPSS software for Windows version 18.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

ICC showed a perfect intra-observer agreement. Its value was 0.96 (95% CI 0.92, 1.00).

Table 2 shows the mean chronological age of the female and male subjects in different I3M classes. The values varied between the two sexes. The differences were statistically significant in I3M 0.04-0.5 (P value < 0.05). The mean age was greater in female than male subjects in all I3M classes except for the I3M 0.5-0.7 and 0.7-0.9. The data reveals that the I3M value had a general reverse relation with the mean chronological age. Additionally, all male or female subjects with I3M above 0.7 were below 18 years old.

Table 2. Descriptive statistics of the chronological age of the subjects based on ranges of I3M and sex

I3M	Female								Males								
	N	Mean	SD	Min	Q1	Med	Q3	Max	N	Mean	SD	Min	Q1	Med	Q3	Max	P value*
[0.0,0.0	122	20.95	1.89	15	20	21	23	23	164	20.96	1.73	16	20	21.0	22	23	0.976
[0.04,0.08	41	19.76	2.22	14	18	20	21.5	23	49	18.80	1.83	15	17.5	19	20	23	0.027
[0.08,0.3)	150	17.88	2.28	14	16	18	20	23	110	17.08	1.88	14	16	17	18	23	0.003
[0.3,0.5)	55	16.01	1.97	14	15	15	17	23	42	15.09	1.28	14	14	15	16	18	0.010
[0.5,0.7)	11	15	1.22	14	14	15	16	18	14	16	2.21	14	14	15.5	16.5	21	0.236
[0.7,0.9)	16	14.37	0.71	14	14	14	14.75	16	10	14.5	0.52	14	14	14.5	15	15	0.693
≥0.9	5	15	1	14	14	15	16	16	11	14.54	0.93	14	14	14	15	17	0.392

I3M: third molar maturity index; N: number of individuals; SD: standard deviation; Min: minimum value; Q1: 1st quartile; Med: median; Q3: 3rd quartile; Max: maximum value;

Table 3 reveals the association between the subject's age (adult≥18 and minor<18) and the positive or negative test results (I3M <0.08 and I3M ≥0.08, respectively), and Table 4 summarises the measures for Ac, Se, Sp, LR^+, LR^-, PPV, NPV, and Bayes PTP. The data shows that 335 of 400 male subjects were correctly diagnosed as adults or minors. So, the accuracy of the I3M of 0.08 in the male subjects has been 83.75% (95%CI, 79.76-87.23%). Moreover, 301 of 400 female subjects were correctly diagnosed, which resulted in an accuracy of 75.25% (95%CI, 70.72-79.40%). The data in Table 3 also shows that in male subjects, the proportion of correctly determined adults (194) out of all the adult male subjects (240), the sensitivity of the I3M 0.08 in males, has been 80.83% (95%CI, 75.28-85.61%). For female subjects, this proportion and sensitivity were 152/240 and 63.33% (95%CI, 56.89-69.44%). In other words, an I3M of 0.08 produced better results in diagnosing adult males than adult females. On the other hand, the specificity, the proportion of correctly diagnosed minors out of all the subjects below 18 years old, was better for females (93.12%; 95%CI, 88.03-96.52%; 149/160) compared to males (88.12%; 95%CI, 82.08-92.70%; 141/160). The LR^+ was 7.69 (95%CI, 5.44-10.86), showing that I3M < 0.08 is 7.69 more likely to be found in adult individuals (≥18) rather than minors (<18). The LR^- was 0.31 (95%CI, 0.27-0.36), showing that I3M ≥0.08 is 0.31 less likely to occur in adults (≥18) than minors (<18). In the current study, the PPV was 92.02% (93.25% for females and 91.08% for males), indicating a high probability of being an adult if I3M is < 0.08. Post-test probability was 94% (95% CI, 88.8-97.0%) in females and 92% (95% CI, 87.2-95.0%) in males, considered excellent in both sexes. (Table 4)

Table 3. Cross-tabulation reporting discriminant function of cut-off value of 0.08 for the male and female subjects (male and female)

Quantities	Females	Males	Total
AC	75.25% (95% CI, 70.72-79.40%)	83.75% (95% CI, 79.76-87.23%)	79.50% (95% CI, 76.53-82.25%)
Sensitivity	63.33% (95% CI, 56.89-69.44%)	80.83% (95% CI, 75.28-85.61%)	72.08% (95% CI, 67.84-76.05%)
Specificity	93.12% (95% CI, 88.03-96.52%)	88.12% (95% CI, 82.08-92.70%)	90.62% (95% CI, 86.89-93.59%)
LR+	9.21 (95% CI, 5.17-16.43)	6.81 (95% CI, 4.44-10.43)	7.69 (95% CI, 5.44-10.86)
LR-	0.39 (95% CI, 0.33-0.47)	0.22 (95% CI, 0.17-0.28)	0.31 (95% CI, 0.27-0.36)
PPV	93.25% (95% CI, 88.25-96.58%)	91.08% (95% CI, 86.42-94.54%)	92.02% (95% CI, 88.81-94.55%)
NPV	62.87% (95% CI, 56.38-59.04%)	75.40% (95% CI, 68.59-81.39%)	68.40% (95% CI, 63.74-72.80%)
Bayes PTP	94% (95% CI, 88.8-97.0%)	92% (95% CI, 87.2-95.0%)	93% (95% CI, 89.5-95.1%)

AC: accuracy; LR+: positive likelihood ratio; LR: negative likelihood ratio; PPV: positive predictive value; NPV: negative predictive value; Bayes PTP: Bayes post-test probability.

Table 4. The quantities from the cross-tabulation based on I3M of 0.08 for discrimination between adults (≥18) and minors (<18) in the sample of Iranian

	Test	Age		Total
		Adult≥18	Minor<18	
Males and females	I3M <0.08	346	30	376
	I3M ≥0.08	134	290	424
	Total	480	320	
Males	I3M <0.08	194	19	213
	I3M ≥0.08	46	141	187
	Total	240	160	
Females	I3M <0.08	152	11	163
	I3M ≥0.08	88	149	237
	Total	240	160	

Table 5 classifies the correct discrimination as an adult or minor based on age groups in both sexes. The data shows that the most remarkable error rate occurred in individuals with 18 years old (67.5 % in females and 57.5% in males), followed by females at 19 years old (47.5%).

Based on the ROC curve analysis, the population-specific cut-off value of I3M 0.099 was acquired. When the subjects' sex was considered, the cut-off value was defined as 0.097 for males and 0.116 for females. As shown in Table 6, the cut-off value of 0.099 increased the sensitivity of discriminating adults from minors (78.1 % vs. 72.08%). The increase in sensitivity was greater when the specific cut-off value for females was used (0.116), which improved the sensitivity from 63.33% to 73.8%. Specific cut-off value for males (0.097) also increased the sensitivity from 80.83% to 86.3%. The specific cut-off values similarly improved accuracy (81.9% vs. 79.50%) and NPV (72.7% vs. 68.40%). On the other hand, these specific cut-off values decreased the specificity, which was more significant in females (87.5% vs. 93.12%), LR+ (6.25 vs. 7.69), LR- (0.25 vs. 0.31), and PPV (90.4% vs. 92.02%). (Table 6)

Table 5. The number of correctly diagnosed subjects as adults or minors/total subjects according to age groups using I3M of 0.08. The percentage of correct diagnoses is presented in parentheses.

Age (years)	Females	Males
14	39/40 (97.5%)	40/40 (100%)
15	37/40 (92.5%)	39/40 (97.5%)
16	38/40 (95%)	33/40 (82.5%)
17	35/40 (87.5%)	29/40 (72.5%)
18	13/40 (32.5%)	17/40 (42.5%)
19	21/40 (52.5%)	29/40 (72.5%)
20	26/40 (65%)	37/40 (92.5%)
21	24/40 (60%)	34/40 (85%)
22	31/40 (77.5%)	38/40 (95%)
23	37/40 (92.5%)	39/40 (97.5%)

Table 6. The quantities are based on population-specific I3M cut-off values of 0.116 for females, 0.097 for males, and 0.099 regardless of sex. (Please compare the results with Table 4)

Quantities	Females' cut-off value*	Males' cut-off value	Total cut-off value
AC	79.3% (95% CI, 74.9-83.1%)	86.5% (95% CI, 82.8-89.7%)	81.9% (95% CI, 79.0-84.5%)
Sensitivity	73.8% (95% CI, 67.7-79.2%)	86.3% (95% CI, 81.2-90.3%)	78.1% (95% CI, 74.2-81.7%)
Specificity	87.5% (95% CI, 81.4-92.2%)	86.9% (95% CI, 80.6-91.7%)	87.5% (95% CI, 83.4-90.9%)
LR+	5.90 (95% CI, 3.89-8.95)	6.57 (95% CI, 4.40-9.82)	6.25 (95% CI, 4.66-8.38)
LR-	0.30(95% CI, 0.24-0.37)	0.16 (95% CI, 0.11-0.22)	0.25 (95% CI, 0.21-0.30)
PPV	89.9% (95% CI, 85.4-93.1%)	90.8% (95% CI, 86.8-93.6%)	90.4% (95% CI, 87.5-92.6%)
NPV	69.0% (95% CI, 64.1-73.5%)	80.8% (95% CI, 75.3-85.3%)	72.7% (95% CI, 69.1-76.0%)

AC: accuracy; LR+: positive likelihood ratio; LR: negative likelihood ratio; PPV: positive predictive value; NPV: negative predictive value.

DISCUSSION

Forensic age estimation is highly valued because of the effects the results would have on the individual's life. Lately, determining age has been one of the most common requests made by law enforcement and legal authorities, [23] mainly due to the increasing number of immigrants/refugees, unaccompanied minors, and individuals with missing or uncertain birth documents. Based on statistics, in 2015, over two hundred thousand Middle Eastern persons, most of whom do not have personal documents, traveled through Serbia, and this number is rising due to the challenging situations in developing countries. [24] The importance of age estimation stands out, especially in determining adults from minors. A child considered as an adult is at greater risk of improper conduct, precarious work, forced into early marriage, or the armed forces. [9] So, it is it is crucial to apply a reliable method for distinguishing minors from adults. Forensic dentistry works well in this regard by analysing the third molar maturity index introduced by Cameriere since third molars are still developing at 18 years old. [3, 5, 6, 25]

There are discrepancies in the literature regarding the effect of population affinity on the accuracy of age estimation. Some studies showed heterogeneity in dental development between different populations, [26] and reported more accurate results using population-specific references. [27] However, Sgheiza and Liversidge [28] explain these differences by discrepancies in methodology between the reference and follow-up studies. The effect of sample size [28, 29] and uneven age distribution [30, 31] on producing bias and increasing the error rate in age estimation methods have been discussed in the literature. Sgheiza [32] relates the population effects to the location-based factors instead of ancestry. On the other hand, multiple studies reported dissimilarities in the development, formation, and eruption of third molars between various populations. [14, 18, 26] Lewis and Senn [33] recommended that population-specific investigations are necessary for dental age estimation based on third molars due to variable developmental rates and sexual dimorphism of the third molar teeth between various population affinities. Based on such findings, some researchers also suggest validating Cameriere's method across different populations. [6, 17] So, this study verified the Cameriere third molar maturity index in an Iranian sample and provided population-specific cut-off values.

We evaluated the panoramic radiographs of individuals aged 14-23, during which the third molar mineralisation is in process in most healthy individuals. [13, 34] Extending the upper age limit to older ages, whose third molars have closed apices, influences the mean value of I3M and adversely affects the discriminant performance of the test. Previous studies on different populations also applied a similar upper age limit for assessing third molar development. [16, 26, 35-37] The complete development of mandibular third molars in the subjects of the current study started at age 15 for females and 16 for males. This finding suggests that individuals belonging to this particular demographic who exhibit signs of complete apex closure should be acknowledged as being at the

age of at least 15 for females or 16 for males. Some previous studies [36-38] also reported a comparable minimum age for apex closure of the mandibular third molar in males. However, the minimum age reported in these studies for females was higher: 16, [38] 17.63, [37] and 17.74. [36] Other studies [39, 40] reported a minimum age of 18-21 years for third molar apex closure in males and females.

Data from the present study demonstrates statistically significant (P value < 0.05) disparities in the mean ages of males and females within the range of I3M values from 0.04 to 0.5. The higher mean ages in females, with or without statistically significant difference, were evident in almost all the I3M values except for I3M 0.5-0.9. These results closely match those obtained by Deitos et al. [25] in the Brazilian population, which revealed a notable difference in sex and early development in males throughout most of the I3M ranges examined, except for the I3M range from 0.7 to 0.9. Galic' et al. [37] found comparable results in the Croatian population. They showed higher mean ages in female subjects in all the I3M ranges with statistically significant differences in I3M values between 0.00 and 0.3. A similar pattern was also noticed in the Albanian sample for the I3M range between 0.04 and 0.08. [41] On the other hand, some studies found no statistically significant difference in the timing of mandibular third molar teeth development between males and females across various I3M ranges. [3, 16, 36, 39]

Our findings also indicated that all individuals with I3M ≥ 0.7 were under 18 years old. This amount was different in other studies as it was ≥ 0.9 for Serbian 42 and Croatian [37] samples, ≥ 0.3 for the Libyan sample, [43] and ≥ 0.7 for South Indian females and ≥ 0.3 for South Indian males. [40] However, these differences should be interpreted with caution since the classification of I3M did not follow the same pattern in different studies.

This study employed the cut-off value of 0.08 for I3M, proposed by Cameriere et al., [16] to assess the efficacy of this technique in the Iranian population and to make the results comparable with those of similar studies. The test's sensitivity was 80.83% for males and 63.33% for females. The sensitivity is lower in both sexes than in most previous studies. [3, 5, 6, 36, 39-41, 44, 45] However, it is superior to that reported in Saudi Arabia (52.3% for males and 51.3% for females). [46] The current study also exhibited a higher sensitivity in males than females, indicating that the test identifies adults more accurately for males. Santiago et al. reported a similar pattern in a meta-analysis of multiple studies. [47]

Our results showed a relatively high specificity (90.62%, 93.12% for females, and 88.12% for males), better than the specificity reported by the studies on Brazilian, [25] Australian, [5] and Chilean [48] samples. Almost similar specificity, especially for females, was reported by Cameriere et al. [41], De Luca et al. [39], and Galić et al. [37], respectively, for the Albanian, Colombian, and Croatian populations. However, some previous studies reported higher specificities. [3, 6, 44, 46]

Based on the current study's findings, the specificity was higher than the sensitivity. Most previous studies also showed this pattern. [49] Only a few studies reported an inverse relation. [5, 39, 41] The tendency for higher specificity indicates that the examined index exhibits a higher accuracy level in identifying individuals under 18 years old compared to its effectiveness in detecting adults. The importance of prioritising specificity over sensitivity in age estimate methods has been emphasised from a forensic standpoint and adheres to the principles of medical ethics. [16] It is ethically unacceptable if an individual under 18 is incorrectly identified as an adult since it would breach their rights. [9] So, it is of vital importance to eliminate the false positive results (increase specificity).

In this survey, the PPV was 93.25% in females and 91.08% in males. PPV defines the probability of being an adult when the I3M is <0.08. This result shows that in the Iranian sample, when the I3M of an individual is < 0.08, the probability of that person being an adult is 93.25% for females and 91.08% for males. PPV was reported 87% and 92% for Japanese female and male subjects. [45] PPV was also reported in some previous studies as 94.6 to 98.1%. [3, 36, 42, 44] Previous studies also reported NPV between 87%-100%, [3, 36, 42, 44] while we found an NPV of 75.40% for males and 62.87% for females. The NPV defines the proportion of minors out of all the subjects with I3M ≥0.08. In the present study, the higher specificity compared to sensitivity and greater PPV than NPV, especially in female subjects, suggest relatively high false negative results (I3M ≥0.08 in adults) in females. In contrast, the false positive results (13M <0.08 in the subjects under 18 years old) are relatively low in our sample.

Most errors in classifying individuals as minors and adults by I3M 0.08 in the current survey occurred at 18 in both sexes (67.5 % incorrect classification in females and 57.5% in males). The greatest classification errors reported by the previous studies [42, 44, 50] were also at 18. The percentage of correctly classified subjects, *true* positive or negative, across all the adult subjects, or the general accuracy was around 80% (83.75% for males and 75.25% for females). Almost similar accuracy (83%) was reported by Cameriere et al.. [16] These accuracies are higher than those reported by AlQahtani et al. [46] in Saudi Arabia but are lower than other previous studies. [5, 25, 39, 45, 50-52] We should consider that the accuracy level for age estimation sufficient for criminal and civil cases is different. The threshold is usually considered higher in criminal cases compared to civil cases. However, accepted accuracies for criminal and civil cases vary among countries. [53] For example, in Germany, high accuracy in age estimation is needed, even in civil cases. Still, in Italy and numerous countries, [35] an accuracy rate of at least 51% might be considered adequate in civil cases. Additionally, the different types of age estimation errors are interpreted differently in the criminal and civil frameworks. For instance, in criminal cases, false adults (false positive results) are the least favorable errors, which were relatively low in the current investigation.

This study provided specific I3M cut-off values (0.116 for females, 0.097 for males, and 0.099 regardless of gender). Applying these values increased accuracy, sensitivity, and NPV, especially for females. On the other hand, they reduced specificity and PPV to a smaller degree. These data may indicate a decrease in false negative results (adults wrongly classified as minors) but, at the same time, an increase in false positive results (children wrongly classified as adults). So, although applying the population-specific cut-off values increased sensitivity due to the vital importance of the protection of the legal rights of minors, the authors suggest using Cameriere's I3M cut-off value of 0.08 in the Iranian population.

Age estimation using I3M exhibits limitations primarily associated with variability in third molars' position, morphology, and development. Considering these limitations in expert judgment is essential to prevent overestimation. [34, 54, 55] Moreover, this method is not applicable without a mandibular third molar tooth, which may be extracted due to malposition or other related complications.

In future studies, it is suggested that the I3M be accompanied by other age estimation methods to evaluate whether it would compensate for the lower sensitivity we found for the Iranian population.

CONCLUSION

The I3M of 0.08 is a suitable method for discriminating minors from adults in the Iranian population. This study also provided population-specific I3M cut-off values (0.116 for females, 0.097 for males, and 0.099 regardless of gender). These values increased accuracy, sensitivity, and NPV, especially for females. On the other hand, they reduced specificity and PPV to a smaller degree. Generally, the I3M method provides higher specificity than sensitivity, which implies a higher accuracy level in identifying individuals under 18 years old.

REFERENCES

1. De Micco F, Martino F, Campobasso CP (2020) Ethical issues in age assessment by the third molar development. Aust J Forensic Sci 54: 88-99. doi: 10.1080/00450618.2020.1789220
2. Cipriani D. (2016) Children's rights and the minimum age of criminal responsibility: a global perspective. Routledge.
3. Gulsahi A, De Luca S, Cehreli SB, Tirali RE, Cameriere R (2016) Accuracy of the third molar index for assessing the legal majority of 18 years in Turkish population. Forensic Sci Int 266: 584 e1- e6. doi: 10.1016/j.forsciint.2016.04.034
4. Deitos AR, Costa C, Michel-Crosato E, Galić I, Cameriere R, Biazevic MGH (2015) Age estimation among Brazilians: Younger or older than 18? Journal of Forensic and Legal Medicine 33: 111-5. doi: https://doi.org/10.1016/j.jflm.2015.04.016
5. Franklin D, Karkhanis S, Flavel A, Collini F, DeLuca S, Cameriere R (2016) Accuracy of a cut-off value based on the third molar index: Validation in an Australian population. Forensic Sci Int 266: 575 e1- e6. doi: 10.1016/j.forsciint.2016.06.032
6. Dardouri AAK, Cameriere R, De Luca S, Vanin S (2016) Third molar maturity index by measurements of open apices in a Libyan sample of living subjects. Forensic Sci Int 267: 230 e1- e6. doi: 10.1016/j.forsciint.2016.07.020

7. Schneider EM, Iglesias JR, Hallberg K, Kuperman MN (2014) Crimes against humanity: the role of international courts. PLoS One 9: e99064. doi: 10.1371/journal.pone.0099064
8. Schmeling A. Forensic age estimation. In: Houck MM (ed) Forensic anthropology. London: Academic Press, 2017, pp.120–145.
9. Schmeling A, Grundmann C, Fuhrmann A et al (2008) Criteria for age estimation in living individuals. Int J Legal Med 122: 457-60. doi: 10.1007/s00414-008-0254-2
10. Demirjian A. (1986) Dentition. In: Falkner F, Tanner JM, eds. Postnatal Growth Neurobiology. Springer US Boston, MA. pp. 269-98.
11. Nolla CM (1960) The development of the permanent teeth. J Dent Child (Chic) 27: 254-66.
12. Cardoso HF (2007) Environmental effects on skeletal versus dental development: Using a documented subadult skeletal sample to test a basic assumption in human osteological research. Am J Phys Anthropol 132: 223-33. doi: 10.1002/ajpa.20482
13. Thevissen PW, Fieuws S, Willems G (2010) Human third molars development: Comparison of 9 country specific populations. Forensic Sci Int 201: 102-5. doi: 10.1016/j.forsciint.2010.04.054
14. Thevissen PW, Fieuws S, Willems G (2013) Third molar development: evaluation of nine tooth development registration techniques for age estimations. J Forensic Sci 58: 393-7. doi: 10.1111/1556-4029.12063
15. Mincer HH, Harris EF, Berryman HE (1993) The A.B.F.O. study of third molar development and its use as an estimator of chronological age. J Forensic Sci 38: 379-90.
16. Cameriere R, Ferrante L, De Angelis D, Scarpino F, Galli F (2008) 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 122: 493-7. doi: 10.1007/s00414-008-0279-6
17. Yan J, Lou X, Xie L, Yu D, Shen G, Wang Y (2013) Assessment of dental age of children aged 3.5 to 16.9 years using Demirjian's method: a meta-analysis based on 26 studies. PLoS One 8: e84672. doi: 10.1371/journal.pone.0084672
18. Olze A, Schmeling A, Taniguchi M et al (2004) Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization. Int J Legal Med 118: 170-3. doi: 10.1007/s00414-004-0434-7
19. Thevissen PW, Galiti D, Willems G (2012) Human dental age estimation combining third molar(s) development and tooth morphological age predictors. Int J Legal Med 126: 883-7. doi: 10.1007/s00414-012-0755-x
20. Thevissen PW, Fieuws S, Willems G (2010) Human dental age estimation using third molar developmental stages: does a Bayesian approach outperform regression models to discriminate between juveniles and adults? Int J Legal Med 124: 35-42. doi: 10.1007/s00414-009-0329-8
21. Altman DG, Bland JM (1994) Statistics Notes: Diagnostic tests 2: predictive values. BMJ 309: 102. doi: 10.1136/bmj.309.6947.102
22. Šimundić AM (2009) Measures of Diagnostic Accuracy: Basic Definitions. Ejifcc 19: 203-11.
23. Boyacioglu Dogru H, Gulsahi A, Cehreli SB, Galic I, van der Stelt P, Cameriere R (2018) Age of majority assessment in Dutch individuals based on Cameriere's third molar maturity index. Forensic Sci Int 282: 231 e1-e6. doi: 10.1016/j.forsciint.2017.11.009
24. OECD MP. (2015) Is this humanitarian migration crisis different? Migration Policy Debates. pp. 1-15.
25. Deitos AR, Costa C, Michel-Crosato E, Galic I, Cameriere R, Biazevic MG (2015) Age estimation among Brazilians: Younger or older than 18? J Forensic Leg Med 33: 111-5. doi: 10.1016/j.jflm.2015.04.016
26. Liversidge HM (2008) Timing of human mandibular third molar formation. Ann Hum Biol 35: 294-321. doi: 10.1080/03014460801971445
27. Baghdadi ZD, Pani SC (2012) Accuracy of population-specific Demirjian curves in the estimation of dental age of Saudi children. Int J Paediatr Dent 22: 125-31. doi: 10.1111/j.1365-263X.2011.01179.x
28. Sgheiza V, Liversidge HM (2023) The effect of reference sample composition and size on dental age interval estimates. Am J Biol Anthropol 182: 82-92. doi: 10.1002/ajpa.24790
29. Lin L (2018) Bias caused by sampling error in meta-analysis with small sample sizes. PLoS One 13: e0204056. doi: 10.1371/journal.pone.0204056
30. Buckberry J (2015) The (mis)use of adult age estimates in osteology. Ann Hum Biol 42: 323-31. doi: 10.3109/03014460.2015.1046926
31. Vossoughi M, Movahhedian N, Ghafoori A (2022) The impact of age mimicry bias on the accuracy of methods for age estimation based on Kvaal's pulp/tooth ratios: a bootstrap study. Int J Legal Med 136: 269-78. doi: 10.1007/s00414-021-02651-7
32. Sgheiza V (2024) Sex and ancestry patterning of residual correlations in human dental development: Cooperative genetic interaction and phenotypic plasticity. Am J Biol Anthropol 184: e24908. doi: 10.1002/ajpa.24908
33. Lewis JM, Senn DR (2010) Dental age estimation utilizing third molar development: A review of principles, methods, and population studies used in the United States. Forensic Sci Int 201: 79-83. doi: 10.1016/j.forsciint.2010.04.042
34. AlQahtani SJ, Hector MP, Liversidge HM (2010) Brief communication: The London atlas of human tooth development and eruption. Am J Phys Anthropol 142: 481-90. doi: 10.1002/ajpa.21258
35. Liversidge HM, Marsden PH (2010) Estimating age and the likelihood of having attained 18 years of age using mandibular third molars. Br Dent J 209: E13. doi: 10.1038/sj.bdj.2010.976
36. Cavric J, Galic I, Vodanovic M et al (2016) Third molar maturity index (I3M) for assessing age of majority in a black African population in Botswana. Int J Legal Med 130: 1109-20. doi: 10.1007/s00414-016-1344-1
37. Galic I, Lauc T, Brkic H et al (2015) Cameriere's third molar maturity index in assessing age of majority. Forensic Sci Int 252: 191 e1-5. doi: 10.1016/j.forsciint.2015.04.030
38. Sharma P, Wadhwan V, Ravi Prakash SM, Aggarwal P, Sharma N (2017) Assessment of age of majority by measurement of open apices of the third molars using Cameriere's third molar maturity index. J Forensic Dent Sci 9: 96-101. doi: 10.4103/jfo.jfds_31_16
39. De Luca S, Aguilar L, Rivera M et al (2016) Accuracy of cut-off value by measurement of third molar index: Study

of a Colombian sample. Forensic Sci Int 261: 160 e1-5. doi: 10.1016/j.forsciint.2016.01.026
40. Balla SB, Galic I, P K, Vanin S, De Luca S, Cameriere R (2017) Validation of third molar maturity index (I(3M)) for discrimination of juvenile/adult status in South Indian population. J Forensic Leg Med 49: 2-7. doi: 10.1016/j.jflm.2017.05.003
41. Cameriere R, Santoro V, Roca R et al (2014) Assessment of legal adult age of 18 by measurement of open apices of the third molars: Study on the Albanian sample. Forensic Sci Int 245: 205 e1-5. doi: 10.1016/j.forsciint.2014.10.013
42. Zelic K, Galic I, Nedeljkovic N et al (2016) Accuracy of Cameriere's third molar maturity index in assessing legal adulthood on Serbian population. Forensic Sci Int 259: 127-32. doi: 10.1016/j.forsciint.2015.12.032
43. Dardouri AAK, Cameriere R, De Luca S, Vanin S (2016) Third molar maturity index by measurements of open apices in a Libyan sample of living subjects. Forensic Science International 267: 230.e1-.e6. doi: https://doi.org/10.1016/j.forsciint.2016.07.020
44. Kelmendi J, Cameriere R, Kocani F, Galic I, Mehmeti B, Vodanovic M (2018) The third molar maturity index in indicating the legal adult age in Kosovar population. Int J Legal Med 132: 1151-9. doi: 10.1007/s00414-017-1761-9
45. Kumagai A, Takahashi N, Palacio LAV, Giampieri A, Ferrante L, Cameriere R (2019) Accuracy of the third molar index cut-off value for estimating 18 years of age: Validation in a Japanese samples. Leg Med (Tokyo) 38: 5-9. doi: 10.1016/j.legalmed.2019.03.001
46. AlQahtani S, Kawthar A, AlAraik A, AlShalan A (2017) Third molar cut-off value in assessing the legal age of 18 in Saudi population. Forensic Sci Int 272: 64-7. doi: 10.1016/j.forsciint.2017.01.004
47. Santiago BM, Almeida L, Cavalcanti YW, Magno MB, Maia LC (2018) 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 132: 1167-84. doi: 10.1007/s00414-017-1766-4
48. Cameriere R, Velandia Palacio LA, Pinares J et al (2018) Assessment of second (I(2M)) and third (I(3M)) molar indices for establishing 14 and 16 legal ages and validation of the Cameriere's I(3M) cut-off for 18 years old in Chilean population. Forensic Sci Int 285: 205.e1-.e5. doi: 10.1016/j.forsciint.2017.12.043
49. De Micco F, Martino F, Velandia Palacio LA, Cingolani M, Campobasso CP (2021) Third molar maturity index and legal age in different ethnic populations: Accuracy of Cameriere's method. Med Sci Law 61: 105-12. doi: 10.1177/0025802419900686
50. Tafrount C, Galic I, Franchi A, Fanton L, Cameriere R (2019) Third molar maturity index for indicating the legal adult age in southeastern France. Forensic Sci Int 294: 218 e1- e6. doi: 10.1016/j.forsciint.2018.10.013
51. Albernaz Neves J, Antunes-Ferreira N, Machado V et al (2020) Validation of the Third Molar Maturation Index (I(3M)) to assess the legal adult age in the Portuguese population. Sci Rep 10: 18466. doi: 10.1038/s41598-020-75324-x
52. De Luca S, Pacifici A, Pacifici L et al (2016) Third molar development by measurements of open apices in an Italian sample of living subjects. J Forensic Leg Med 38: 36-42. doi: 10.1016/j.jflm.2015.11.007
53. Corradi F, Pinchi V, Barsanti I, Manca R, Garatti S (2013) Optimal age classification of young individuals based on dental evidence in civil and criminal proceedings. Int J Legal Med 127: 1157-64. doi: 10.1007/s00414-013-0919-3
54. Bennett KA (1989) Human skeletal remains, excavation, analysis, interpretation, 2nd ed. By Douglas H. Ubelaker. Washington, DC: Taraxacum. 1988. Am J Phys Anthropol 80: 264-5. doi: 10.1002/ajpa.1330800217
55. Anderson DL, Thompson GW, Popovich F (1976) Age of attainment of mineralization stages of the permanent dentition. J Forensic Sci 21: 191-200.