

Accuracy of four dental age estimation methods in determining the legal age threshold of 18 years among South Indian adolescents and young

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KEYWORDS

Dental age estimation;
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ABSTRACT

The aim of this study was to compare the accuracy, specificity and sensitivity of four commonly used methods of dental age estimation in a sample of south Indian adolescents and young adults aged between 14 and 30 years, with an age threshold of 18 years, using receiver operating characteristic curves (ROC) and the area under the curve (AUC). A total of 1070 orthopantomograms (535 males and 535 females) of adolescents and young adults of south Indian origin were collected retrospectively and interpreted. The effectiveness of each method was evaluated by using sensitivity (Se), specificity (Sp), likelihood ratios (LR+ and LR-) and AUC. Among all methods, I3M < 0.08 resulted in better values of AUC, Se and Sp which were 0.950, 91.5%, 97.8% and 0.950, 88.5% and 98.6% in males and females, respectively. For “stage H” of Demirjian’s system, the AUC, Se and Sp were 0.940, 84.9%, 97.7% and 0.930, 79.9% and 98.5% in males and females, respectively. The use of the Olze et al “stage 1 (or higher)” root pulp visibility and “stage D” of third molar eruption were not recommended in the studied population due to the greater percentage of third molars with incomplete mineralization in younger age groups and impaction. Taking into account the values of Se, Sp, both positive and negative LRs, we recommend the use of the cut-off value of I3M < 0.08 to discriminate adults and minors in south Indian adolescents and young adults.

INTRODUCTION

Selection of an appropriate method of age estimation is crucial in forensic and medico-legal settings. It depends on what parameters are present and what general age is represented. Many parameters were examined for age assessment in children and adolescents including the skull bones, long bones, pubic symphysis, hand-wrist bones and permanent dentition. According to the forensic literature, the rate of tooth formation is the better indicator of chronological age than skeletal development, as it is less affected by malnutrition and other factors.¹⁻³ In most countries, the legal age is 18 years.⁴ Forensic experts are often confronted with the conceptually simple medico-legal question of whether an individual is a juvenile (below 18 years) or an adult (18 years or above). This is due to the varied legal consequences in penal and criminal law if a subject of unknown age is judged to be a juvenile or an adult.

Age assessment by dental examination methods is today either the evaluation of the clinical emergence of the teeth or the radiographic evaluation of the mineralization of the crown and

root portions of the developing teeth. To answer the legal question pertaining to the attainment of 18 years, one has to rely on the developing third molars. It has been emphasized in the forensic literature for the use of qualified personnel in age assessment who have a clear understanding of the methods in use, who must apply an appropriate method or a proven scientific technique(s) with a known rate of error.⁵ Considering the mandibular third molars, their mineralization (Cameriere's third molar maturity index (I₃M) and Demirjian's staging system),^{6, 7} clinical emergence (Olze et al stages of tooth eruption)⁸ and secondary changes (Olze et al stages of root pulp visibility RPV),⁹ were extensively studied in the literature to estimate the probability that an individual is over 18 years. All these methods were validated independently in various populations for the evaluation of 18 years of age for forensic purposes.

However, there were no studies that compared these four methods in discriminating adults and minors in south Indian individuals. Therefore, the aim of the present study was to compare the accuracy, specificity and sensitivity of four commonly used methods of dental age estimation i.e. Cameriere's third molar maturity index (I₃M < 0.08), Demirjian stages of tooth development (Stage H), Olze's stages of root pulp visibility (stage 1) and Olze's eruption stages of third molars (stage D) in a sample of south Indian adolescents and young adults aged between 14 and 30 years, with an age threshold of 18 years, using receiver operating characteristic curves (ROC) and the area under the curve (AUC).

MATERIAL AND METHODS

Sample

A total of 1070 orthopantomograms (OPGs) of south Indian adolescents and young adults aged between 14 and 30 years were selected retrospectively from the archives of the Department of Radiology, Panineeya Dental College and from Private Dental Clinics in south India. The inclusion criteria were: OPGs from individuals aged between 14 and 30 years, south Indian nationality and good quality images with at least one mandibular third molar. Exclusion criteria were: distorted OPGs, gross pathology affecting the region of interest, rotated third molars that impede the measurements and bilateral absence of the mandibular third molars. Data on the sex, date of birth and the date on which the radiograph was taken were recorded. The chronological age was obtained by calculating the difference between the

date of birth and the date the radiograph was taken. All OPGs were initially allotted with consecutive numbers in order to ensure blinding of the examiner to the subjects' details.

Methods

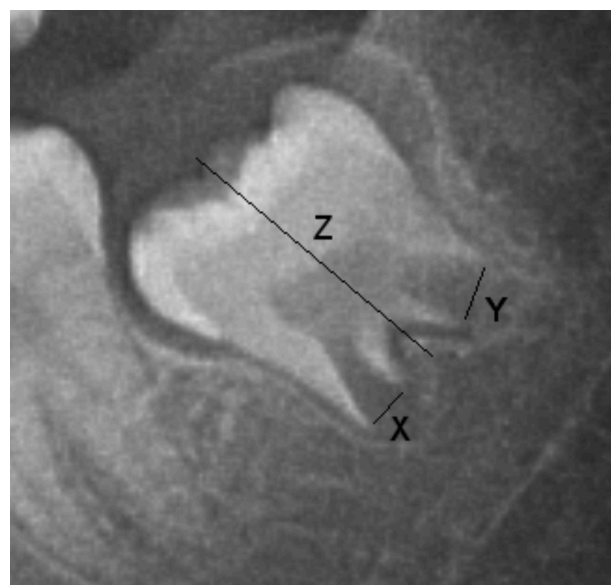
Four methods were adopted to provide the legal age threshold of 18 years, two methods took the maturation of the mandibular third molars into consideration^{6, 7}, a third method considered eruption of the mandibular third molars⁸ and the fourth method studied the changes in the root pulp visibility in the fully formed mandibular third molars⁹.

Cameriere et al. third molar maturity index (I₃M)

The mineralisation status of the mandibular third molar was calculated using the Cameriere's third molar maturity index (I₃M).⁶ I₃M is evaluated as the sum of the distances between the inner sides of the two open apices (X+Y) divided by the tooth length (Z) (Figure 1). A score of "0" is allocated when the development of the third molar is complete. In the present study, the recommended value of I₃M < 0.08 was tested to discriminate adults from minors in both sexes.

The tooth length and apical width measurements of mesial and distal roots of mandibular third molars were performed using Image J software (version 1.48, National Institute of Health, USA). All the measurements were carried out by a single examiner.

Figure 1. Measurements of the mandibular third molar for the calculation of the third molar maturity index (I₃M)⁶; I₃M is evaluated as the sum of the distances between the inner sides of the two open apices (X+Y) divided by tooth length (Z)



Demirjian's stages of tooth development

The mineralisation status of the mandibular third molar was evaluated by using Demirjian's system of tooth development.⁷ The discrimination of adults and minors was studied using the Demirjian's final stages of root mineralisation i.e., "stages E to H" (Figure 2). Mincer et al¹⁰ for the first time studied Demirjian's stages of tooth development to answer the medico-legal question pertaining to the legal age threshold of at least 18 years. In the present study, Stage "H" (completed mineralization) was used as a cut-off point to estimate adulthood.

Olze et al stages of third molar eruption

The eruption status of the mandibular third molar was studied using the staging system reported by Olze et al⁸ that includes no emergence (stage A), alveolar emergence (stage B), gingival emergence (stage C) and complete emergence (stage D) (Figure 4). Impacted mandibular third molars were excluded from the analysis. In the present study, Stage "D" was used as a cut-off point to predict the attainment of legal age threshold of 18 years.

Olze et al stages of root pulp visibility (RPV)

The prediction of legal age threshold 18 years was also determined using Olze et al⁹ stages of RPV that includes stages 0, 1, 2 and 3 where stage "0" has mandibular third molars with root canals visible all the way to apex, while stage "3" has mandibular third molars with the lumen of two root canals virtually invisible for the full length (Figure 3). In this study, we have verified stage "0" of RPV for indicating the major/ minor status.

Analysis of the images by the examiners

Each radiograph was given a unique identification number and was randomly selected for evaluation by the examiner. All the evaluations were made independently by two examiners (A1 and B1), in order to evaluate the inter-examiner variability. Later 50 OPGs were selected randomly and were rescored again by the first examiner (A2) after one month interval to measure the intra-examiner variability.

Figure 2. Demirjian stages of root development of permanent teeth (Stages E to H)

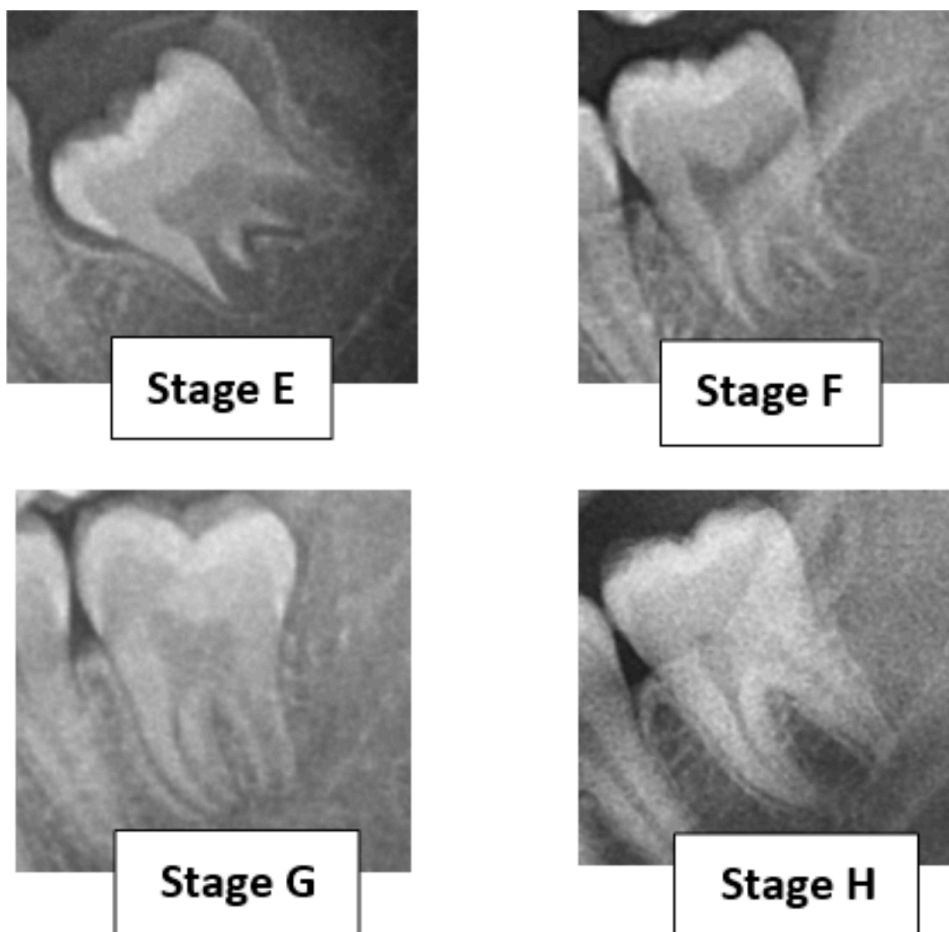


Figure 3. Radiographic images of Olze et al stages of radiographic visibility of root pulp in mandibular third molars

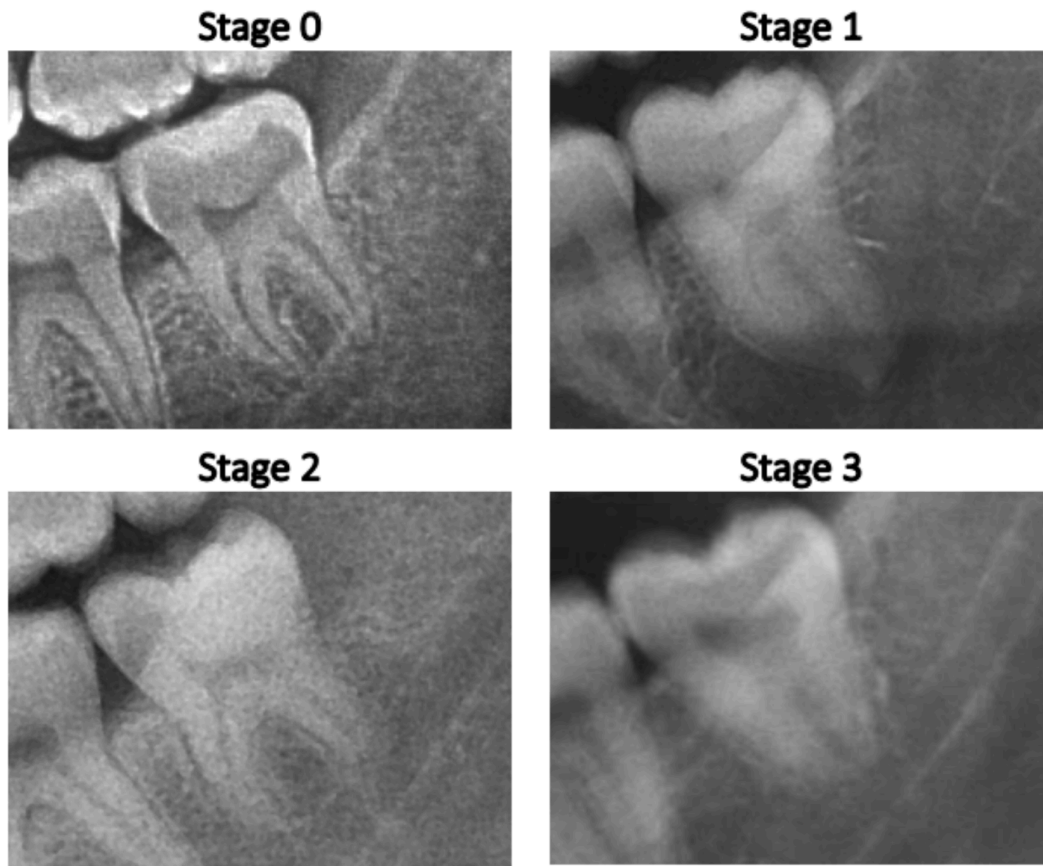
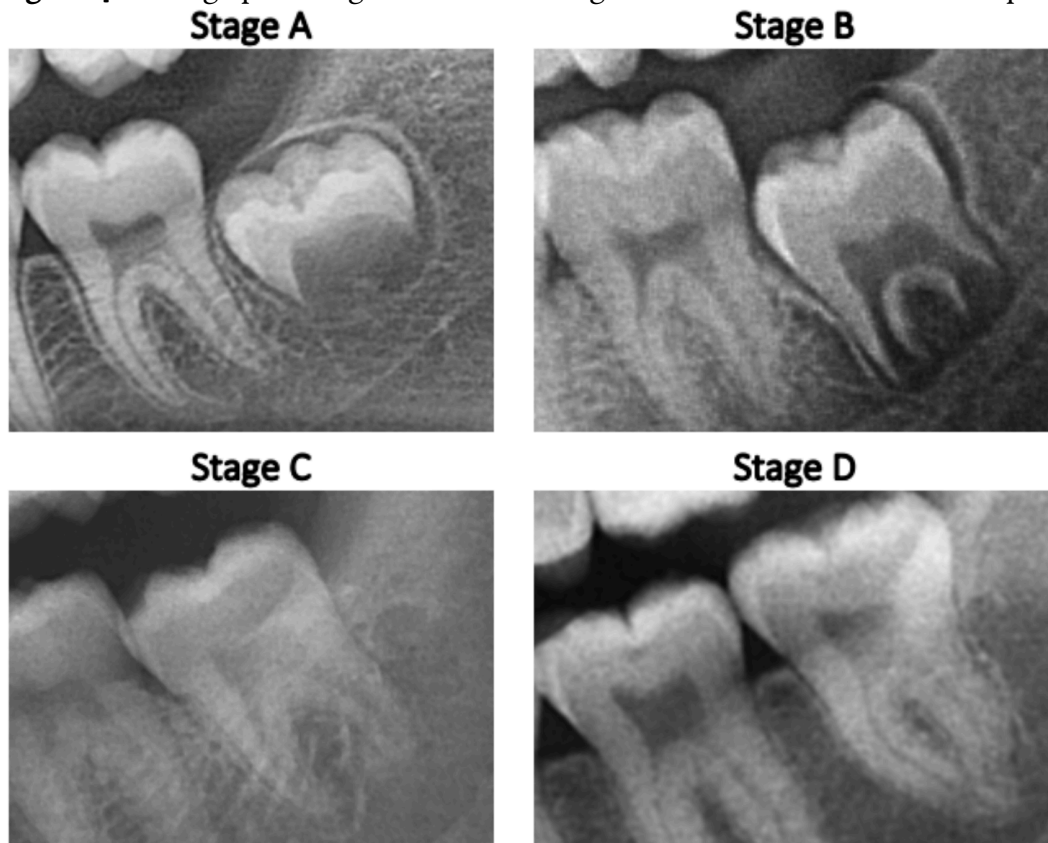


Figure 4. Radiographic images of Olze et al stages of mandibular third molar eruption



Statistical analysis

Statistical analysis was performed using SPSS 22.0 for Windows (IBM Corp, Chicago, IL, USA). The significance level for the analysis was set at 5%. Intra-examiner agreement was calculated for each method using the intra-class correlation coefficient, rescoring 50 OPGs one month after the initial evaluation. Inter-examiner agreement was calculated using another examiner using the intra-class correlation coefficient for each method.

The overall effectiveness of all four methods of age estimation were evaluated by plotting the ROC curve. Using the age threshold of 18 years, the area under the ROC curve (AUC) was calculated for each method and both sexes.¹¹ Additionally, the performance of all the methods was tested by 2x2 contingency table. A 2x2 contingency table is a tabular representation of categorical data used to summarize the relationship between two categorical variables. It generally displays the number of participants, who are true positives (TP), true negatives (TN), false positives (FP) and false negatives (FN) in the overall sample. The performance of each method was further evaluated by; accuracies (Ac), sensitivities (Se), specificities (Sp) and positive and negative likelihood ratios (LR+, LR-). Accuracy represents the overall performance of the method in terms of discriminating between minors and adults. The sensitivity (Se) represents the proportion of individuals aged 18 years and older who had $I_3M < 0.08$ or those who attained the stage "H" of DSS or stage "1" or above (\geq stage 1) of RPV or those who reached the stage "D" of eruption of mandibular third molars. The specificity (Sp) represents the proportion of individuals aged 18 years and older who had $I_3M \geq 0.08$ or those who were ranked as stage "G" or below of DSS or stage "0" of RPV or those who ranked as stage "C" or below of mandibular third molar eruption. Both LR+ and LR- ratios indicate how many times more or less likely the individuals to be a major or a minor based on the cut-off value used. They in turn help rule in or rule out diagnoses respectively in most situations. An LR+ value of above 10 increases the likelihood of being an adult, while an LR- value under 0.1 decreased the likelihood of being adult.¹²

RESULTS

Age and sex distribution of the individuals who took part in this study were presented in table 1. The mean chronological age of males and females was 21.1 ± 4.44 and 21.09 ± 4.49 years, respectively. Tables 2 and 3 present the total number of evaluated samples in both sexes using the Olze et al methods of root pulp visibility and mandibular third molar eruption. Olze et al RPV method could not be applied to a sample of 32.5% males and 35.9% females due to incomplete mineralization (open apices) of the mandibular third molars examined. On the other hand, in 23.6% of males and 26.7% of females, the Olze et al method of mandibular third molar eruption could not be applied due to the impacted third molars. Both intra- and inter-examiner agreement values were presented in table 4.

Table 1. Age and Sex distribution of the overall sample

Age groups	Male n (%)	Female n (%)
14- 14.9	40 (7.5)	40 (7.5)
15- 15.9	40 (7.5)	40 (7.5)
16- 16.9	40 (7.5)	40 (7.5)
17- 17.9	40 (7.5)	40 (7.5)
18- 18.9	40 (7.5)	40 (7.5)
19- 19.9	40 (7.5)	40 (7.5)
20- 20.9	40 (7.5)	40 (7.5)
21- 21.9	40 (7.5)	40 (7.5)
22- 22.9	40 (7.5)	40 (7.5)
23- 23.9	25 (4.7)	25 (4.7)
24- 24.9	25 (4.7)	25 (4.7)
25- 25.9	25 (4.7)	25 (4.7)
26- 26.9	25 (4.7)	25 (4.7)
27- 27.9	25 (4.7)	25 (4.7)
28- 28.9	25 (4.7)	25 (4.7)
29- 29.9	25 (4.7)	25 (4.7)
Total	535 (100)	535 (100)

Table 2. Descriptive table of the total sample according to each stage of Olze et al root pulp visibility in both sexes

Stages of Root pulp visibility	Males n (%)	Females n (%)
Stage 0	22 (4.1)	20 (3.7)
Stage 1	142 (26.5)	124 (23.2)
Stage 2	158 (29.5)	147 (27.5)
Stage 3	39 (7.3)	52 (9.7)
Incomplete mineralization*	174 (32.5)	192 (35.9)
Total	535 (100)	535 (100)

*Indicates third molars with incomplete mineralization which were excluded from analysis.

Table 3. Descriptive table of the total sample according to each stage of Olze et al tooth eruption in both sexes

Eruption Stages	Males n (%)	Females n (%)
Stage A	29 (5.4)	23 (4.3)
Stage B	80 (15)	81 (15.1)
Stage C	18 (3.4)	27 (5)
Stage D	282 (52.7)	261 (48.8)
Impacted*	126 (23.6)	143 (26.7)
Total	535 (100)	535 (100)

*Indicates impacted third molars which were excluded from analysis.

Table 4. Intra-class correlation coefficients (ICC) for intra- and inter-examiner agreements

Method	ICC	95% Confidence Interval	
		Lower limit	Upper limit
Intra-examiner agreement			
Cameriere’s method of I3M	0.931	0.878	0.962
Demirjian’s staging system	0.895	0.853	0.921
Olze’s Root pulp visibility	0.815	0.776	0.838
Olze’s stages of tooth eruption	0.846	0.808	0.869
Inter-examiner agreement			
Cameriere’s method of I3M	0.887	0.824	0.926
Demirjian’s staging system	0.847	0.811	0.883
Olze’s Root pulp visibility	0.792	0.767	0.829
Olze’s stages of tooth eruption	0.828	0.793	0.844

Intra-class correlation coefficient values of approximately 0.8 and higher were recorded for all methods in both sexes indicating good agreement between the repeated measurements for within and between examiners. Figures 5 to 7 presented the best performance for discrimination between adults and minors using the area under the curve for different methods of age assessment in both sexes.

Tables 5 to 8 present the contingency data showing the discrimination performance of all

the methods, according to the sex. Overall performance measures of the cut-off values for all the methods used in our sample are presented in table 9 for both sexes, separately.

DISCUSSION

Assessing the probability of at least 18 years of age is the commonest practise of medico-legal physicians and forensic odontologists. They are often under pressure (for legal reasons) by police personnel to quickly estimate the age of a young

person in conflict with the law. Therefore, it is common for them to rely on the simple and reproducible methods to assess dental age. Various authors have used different perspectives of dental age assessment using third molars that mainly involves development/maturation of third molars and their stages of eruption. It has been stated in previous studies that it is easier to learn the few stages of eruption than to study the eight stages of the Demirjian et al,⁷ that allows medico-legal experts to quickly provide an answer for legal reasons.¹³ However, we believe that it is important to choose an age estimation method based on their specificity index (rate of false positives), especially in a criminal context where

an age misclassification could result in significant legal and ethical consequences.¹⁴ In 2012, Pinchi et al¹⁵ tested the accuracy of four methods of dental age estimation to predict the legal age threshold of 14 years in an Italian population. To the best of our knowledge, no study is available in the literature testing the accuracy of four different methods of dental age estimation to predict the legal age threshold of 18 years. In the present study, we compared the accuracy, sensitivity and specificity of the commonly used methods of dental age estimation in forensic practice in estimating the legal age of 18 years in a sample of south Indian adolescents and young adults.

Figure 5. Receiver Operating Characteristic curves for Cameriere’s I3M < 0.08 & Stage H of Demirjian’s method for discriminating adults and minors in both sexes

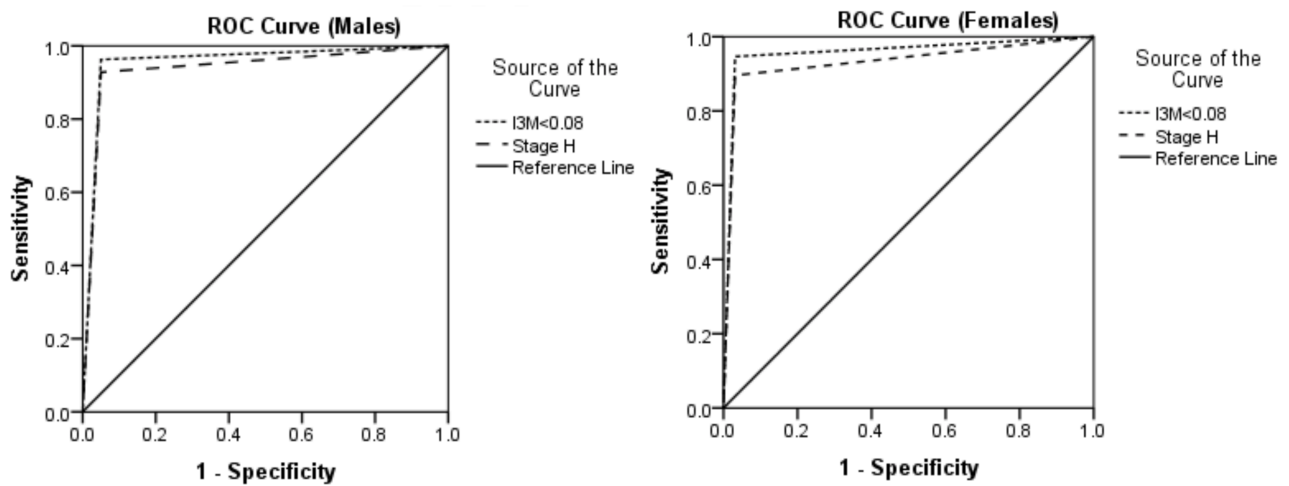


Figure 6. Receiver Operating Characteristic curves for Stage I of Olze et al root pulp visibility for discriminating adults and minors in both sexes

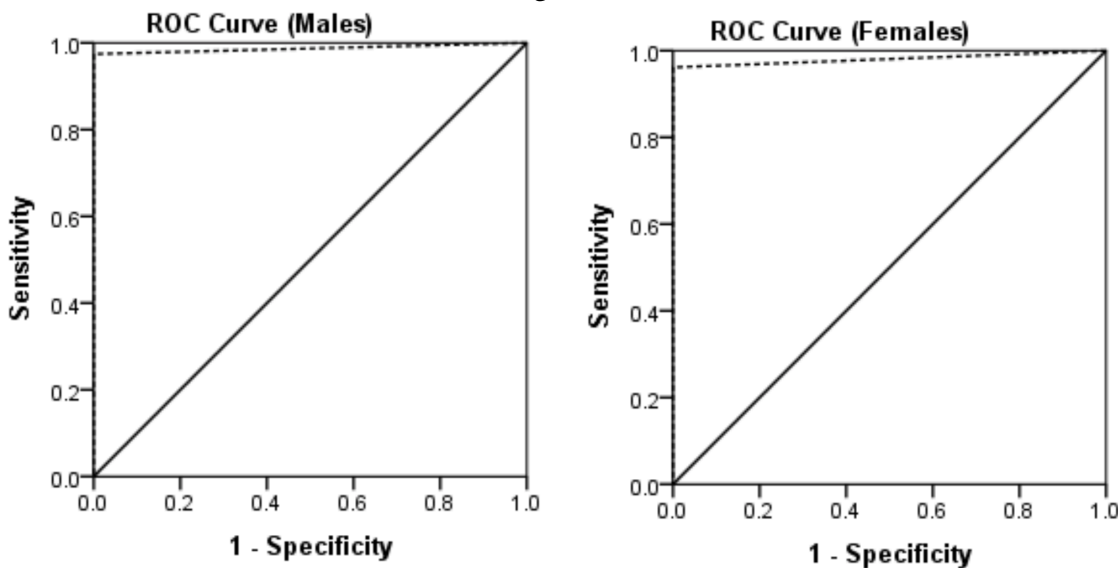


Figure 7. Receiver Operating Characteristic curves for Stage D of Olze et al third molar eruption for discriminating adults and minors in both sexes

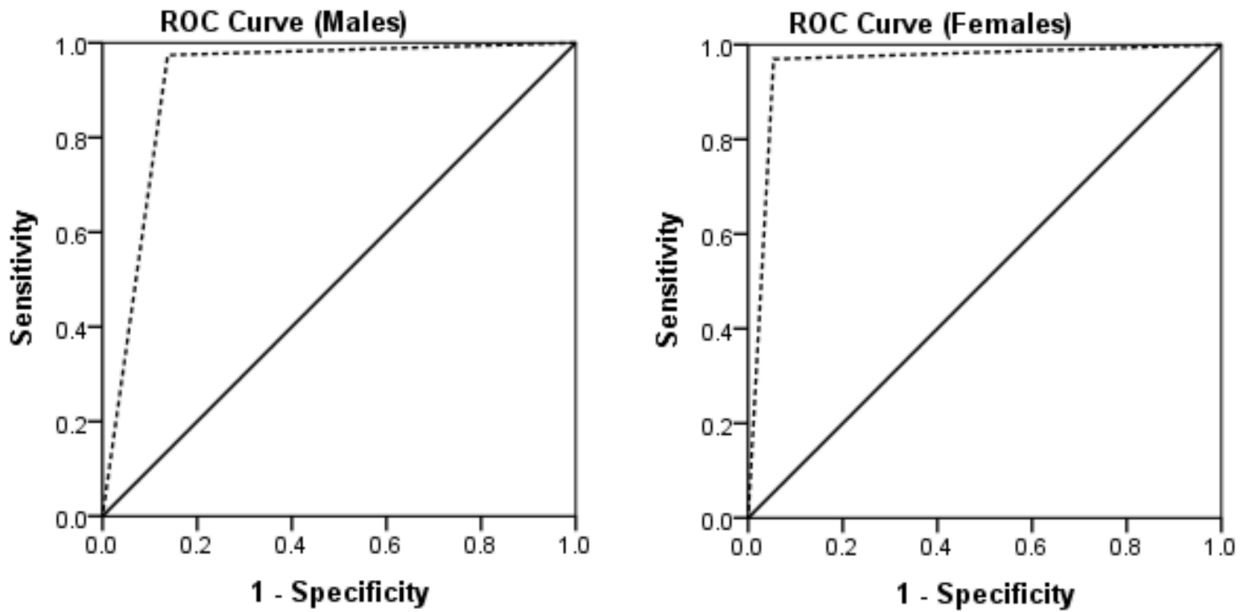


Table 5. Contingency tables describing discrimination performance of the test on being adult (≥ 18) or minor (< 18) for third molar maturity index ($I_3M < 0.08$)

Males			
	Age status		Total
	<18 years	≥ 18 years	
≥ 0.08	152 ^{TP} (95)	14 ^{FN} (3.7)	166 (31)
< 0.08	8 ^{FP} (5)	361 ^{TN} (96.3)	369 (69)
Total	160 (100)	375 (100)	535 (100)
Females			
	Age status		Total
	<18 years	≥ 18 years	
≥ 0.08	155 ^{TP} (96.9)	20 ^{FN} (5.3)	175 (32.7)
< 0.08	5 ^{FP} (3.1)	355 ^{TN} (94.7)	360 (67.3)
Total	160 (100)	375 (100)	535 (100)

Note: TP; True positive, FP; False positive, TN; True negative, FN; False negative

Table 6. Contingency tables describing discrimination performance of the test on being adult (≥ 18) or minor (< 18) for “stage H” of Demirjian’s method

Males			
	Age status		Total
	<18 years	≥ 18 years	
\leq Stage G	152 ^{TP} (95)	27 ^{FN} (7.2)	179 (33.5)
Stage H	8 ^{FP} (5)	348 ^{TN} (92.8)	356 (66.5)
Total	160 (100)	375 (100)	535 (100)
Females			
	Age status		Total
	<18 years	≥ 18 years	
\leq Stage G	155 ^{TP} (96.9)	39 ^{FN} (10.4)	194 (36.3)
Stage H	5 ^{FP} (3.1)	336 ^{TN} (89.6)	341 (63.7)
Total	160 (100)	375 (100)	535 (100)

Note: TP; True positive, FP; False positive, TN; True negative, FN; False negative

Table 7. Contingency tables describing discrimination performance of the test on being adult (≥ 18) or minor (< 18) for “stage D” of Olze et al third molar eruption

Males			
	Age status		Total
	<18 years	≥ 18 years	
\leq Stage C	119 ^{TP} (86.2)	7 ^{FN} (2.6)	126 (30.8)
Stage D	19 ^{FP} (13.8)	264 ^{TN} (97.4)	283 (69.2)
Total	138 (100)	271 (100)	409 (100)
Females			
	Age status		Total
	<18 years	≥ 18 years	
\leq Stage C	123 ^{TP} (94.6)	8 ^{FN} (3.1)	131 (33.4)
Stage D	7 ^{FP} (5.4)	254 ^{TN} (96.9)	261 (66.6)
Total	130 (100)	262 (100)	392 (100)

Note: TP; True positive, FP; False positive, TN; True negative, FN; False negative

Table 8. Contingency tables describing discrimination performance of the test on being adult (≥ 18) or minor (< 18) for “stage 1” of Olze et al radiographic visibility of root pulp

Males			
	Age status		Total
	<18 years	≥ 18 years	
Stage 0	13 ^{TP} (100)	9 ^{FN} (2.6)	22 (6.1)
\geq Stage 1	0 ^{FP} (0.0)	339 ^{TN} (97.4)	339 (93.9)
Total	13 (100)	348 (100)	361 (100)
Females			
	Age status		Total
	<18 years	≥ 18 years	
Stage 0	7 ^{TP} (100)	13 ^{FN} (3.9)	20 (5.8)
\geq Stage 1	0 ^{FP} (0.0)	323 ^{TN} (96.1)	323 (94.2)
Total	7 (100)	336 (100)	343 (100)

Note: TP; True positive, FP; False positive, TN; True negative, FN; False negative

Table 9. Output measures from 2x2 contingency tables (95% confidence interval) to test the performance of cut-off value of $I_3M < 0.08$, Demirjian “stage H”, “Stage 1 (or higher)” of root pulp visibility (RPV) and “stage D” of third molar eruption to discriminate subjects as ≥ 18 years and < 18 years of age in males and females.

Males	$I_3M < 0.08$	Stage H	Stage 1 (or higher) of RPV	Stage D of eruption
Accuracy	95.8 (93.8- 97.4)	93.4 (91.1- 95.4)	97.5 (95.3- 98.8)	93.6 (90.8- 95.8)
Sensitivity	91.5 (86.2- 95.3)	84.9 (78.8- 89.8)	59.1 (36.3- 79.2)	94.4 (88.9- 97.7)
Specificity	97.8 (95.7- 99.1)	97.7 (95.6- 99.1)	100 (98.9- 100)	93.2 (89.7- 95.9)
LR+	42.23 (21.25- 83.95)	37.79 (18.99- 75.18)	--	14.07 (9.09- 21.76)
LR-	0.09 (0.05- 0.14)	0.15 (0.11- 0.22)	0.41 (0.25- 0.68)	0.06 (0.03- 0.12)
AUC	0.95 (0.93- 0.97)	0.94 (0.91- 0.96)	0.98 (0.97- 0.99)	0.92 (0.88- 0.95)
Females	$I_3M < 0.08$	Stage H	Stage 1 (or higher) of RPV	Stage D of eruption
Accuracy	95.3 (93.1- 96.9)	91.7 (89.1- 93.9)	96.2 (93.6- 97.9)	96.2 (93.7- 97.8)
Sensitivity	88.5 (82.9- 92.8)	79.9 (73.5- 85.3)	35 (15.3- 59.2)	93.9 (88.3- 97.3)
Specificity	98.6 (96.7- 99.5)	98.5 (96.6- 99.5)	100 (98.8- 100)	97.3 (94.5- 98.9)
LR+	63.77 (26.6- 152.5)	54.49 (22.76- 130.4)	--	35.01 (16.84- 72.8)
LR-	0.12 (0.08- 0.18)	0.20 (0.15- 0.27)	0.65 (0.47- 0.9)	0.06 (0.03- 0.12)
AUC	0.95 (0.93- 0.97)	0.93 (0.91- 0.95)	0.98 (0.96- 0.99)	0.96 (0.93- 0.98)

Note: LR+, positive likelihood ratio; LR-, negative likelihood ratio; PPV, positive predictive value; NPV, negative predictive value; Bayes PTP, Bayes post-test probability; AUC, Area under the curve; RPV, Root pulp visibility

Cameriere's third molar maturity index ($I_3M < 0.08$)

Cameriere's method of third molar maturity index ($I_3M < 0.08$)⁶ is a widely used method in recent times for estimating adult age. When tested in various populations, it showed different results with varying accuracy, Se and Sp values. The results of the present study showed that the $I_3M < 0.08$ provides the AUC value of 0.95 both for males and females. This indicates that a randomly selected individual (either male or female) from the older age category (≥ 18 years) will have I_3M index less than 0.08 compared to a randomly chosen individual from the younger category (< 18 years) approximately 95% of the time. The Se and Sp of this test was 91.5% and 97.8% for males and 88.5% and 98.6% for females. The proportion of the correctly classified individuals was 95.8% and 95.3% in males and females. These results were in line with the conclusions of the previous studies where higher Se and Sp values of greater than 90% were reported.¹⁶⁻²⁸ When these results were compared with studies within the same country, results differed.²⁹ Our study showed better accuracy, Se and Sp compared to the findings of Sharma et al.²⁹ The possible differences might be due to the age range studied, the sample size and the variation in the third molar development even within the same country.

As regards the results of likelihood ratio are concerned, the diagnostic test of $I_3M < 0.08$ has a significant contribution to the prediction of legal age threshold of 18 years, due to the balanced values of LR+ and LR-. The cut-off value of 0.08 provided higher LR+ values (42.23 in males and 63.77 in females) meaning that there was excellent prediction of the probability of majority; and lower LR- (0.09 in males and 0.12 in females), indicating that the test is very good at identifying subjects younger than 18 years of age. As for the obtained results, the cut-off value of $I_3M < 0.08$ successfully predicted age over 18 years in 96.3% of the males and in 94.7% of the females. In addition, 95% and 96.9% of predictions were accurate for the group younger than 18 years, for males and females respectively. This means that the cut-off value of $I_3M < 0.08$ is suitable as an age marker for 18 years and it resulted in 5% and 3.1% of ethically unacceptable errors in males and females.

Demirjian's staging system

Unlike Cameriere's method, Demirjian's staging system is a subjective method of assessment that allows the examiner to determine the stage of tooth development. In this method, the mineralization of the root portion was categorised into four stages (E to H), where the last stage (stage H) indicated the closed apex or finished maturation of the tooth.⁷ The more advanced the stage or final phase of the root development, the better it was for the discrimination between adults and minors.³⁰ From our study findings, we observed that the "stage H" of root maturity as a reliable marker to indicate that an individual was quite likely to be at least 18 years of age. The values of Se for "stage H" were 84.9% and 79.9% respectively, while the values of Sp were 97.7% and 98.5% in males and females, respectively. In the original study⁶, the authors also obtained lower Se values (58%) and higher Sp values (98%) when "stage H" was used as a marker for adult age. In order to increase the Se of the test, they recommended the use of "stage G". However, it resulted in a significant decrease of the specificity to 90% and also the probability that the individual has reached 18 years. In another study by Quispe-Lizarbe et al²¹, the authors reported a significant decrease of the specificity i.e., from 98% to 85% in males and 98% to 93% in females when "stage G" was used instead of "stage H" for indicating the age of majority. Similar results were reported by Costa et al³¹ in Mexicans and Columbians and Sharma P et al in Indians.³² According to Meinel et al³³ when "stage H" was determined in an Austrian individual, it was 99% certain that the individual was an adult. Our results concerning Se and Sp are fairly similar to those obtained in above-mentioned studies.^{6, 21, 31} One difference between these studies and our study findings was better "Se" values when "stage H" was used as a cut-off value, which we believe is due to the extension of upper age limit to 30 years.

In the present study, the "stage H" showed 5% and 3.1% incorrect classifications (false positives) in males and females, with a better specificity, which is ethically mandatory for criminal proceedings. However, it has resulted in increased false negatives/ technically unacceptable errors (7.2% in males and 10.4% in females). The ROC curves demonstrated that "stage H" of Demirjian's method is able to

properly discriminate adults from minors with AUC values of 0.94 and 0.93 in males and females, respectively. Regarding the aggregated estimation of the diagnostic performance, it is 37.79 times in males and 54.49 times in females, that “stage H” is more likely to occur in an individual at least 18 as opposed to someone younger than 18 (LR+).

In 2001, Solari and Abramovitch³⁴ added intermediate sub-stages (F1 and G1) to the later stages of root development of third molars in order to improve the accuracy of third molars to calculate the probability of an individual being under age 18. Future research should address the use of “stage G1” in the prediction of 18 years in the studied population.

Olze et al stages of root pulp visibility

From our study findings, stage 1” of RPV was chosen as a cut-off value for the 18 year old threshold of both sexes. The AUC, Se and Sp were 0.980, 59.1% and 100% in males; and 0.980, 35% and 100% in females, respectively. In the original study by Olze et al,⁹ the authors studied the RPV in the OPGs of individuals aged between 15 and 40 years. According to their results, an age under 18 years (being a minor) can easily be excluded when individuals were classified as stage 1 and above of RPV in mandibular third molars. In the present study, few individuals (2.6% males and 3.9% females) who were marked as “stage 0” were adults (≥ 18 years) resulting in false negatives. However, all minors with completely matured third molars were presented with “stage 0” of RPV, indicating 100% specificity.

The results from this study, especially the higher specificity values and lower sensitivity values of “stage 1 (or higher)” of root pulp visibility may be partially explained by different age distributions. It is to be noted that the samples were skewed towards the younger ages with a higher number of samples in the older age range in the studied population. This uneven age distribution among the samples resulted from the selection criteria that only the mandibular third molars showing complete root formation should be analyzed. In the present study, we have analyzed OPGs of individuals aged between 14 and 30 years, following the age criteria similar to that of the original study⁸ and the other studies³⁵⁻⁴¹ with age ranging from 15 to 40 years. It was reported in the literature that very few mature third molars

i.e., approximately 5% to 9% were from the 16 year old age group. In the present study, all third molars were not fully matured until 17 years, and only 25% of them exhibited fully matured mandibular third molars in the age group of 17 years. Unfortunately, other studies³⁵⁻⁴¹ on the radiographic visibility of root pulp did not report these statistics on the number of third molars with incomplete mineralization below 18 years.

Despite the higher specificity and AUC values, one significant limitation of this method was the skewed age distribution due to the lack of young individuals (<18 years) with fully matured mandibular third molars. Therefore, this method should not be used in the studied population, especially to predict whether a male or a female has reached 18 years of age. In future studies, the authors must locate and evaluate an additional sample of equal and possibly higher number of younger individuals with fully matured third molars.

Olze et al stages of mandibular third molar eruption

Studies on the chronology of the third molar eruption are scarce. Age assessment based on the eruption of the teeth are simple, reliable, can be performed easily by medico-legal physicians who are not experts in forensic odontology.^{42, 43} There is a need to understand the eruption of third molars and their use in forensic age assessment. Even though, it was mentioned in the literature that the emergence of third molars does not occur before the 17th year of life⁴⁴, few reports have indicated that they might emerge as early as 13 years,⁴⁵⁻⁴⁷ that raised concerns regarding their use for forensic age assessment in a court of law. Later Olze et al⁸ presented a classification comprised of four stages of third molar eruption, investigated and compared the chronological course of third molar eruption in Black South African⁸, Japanese⁴⁸, German⁴⁹ and Canadian^{50, 51} males and females. They concluded that the data based on the third stage of eruption can be utilized for forensic estimation of the minimum and most probable ages of investigated persons.

From our study findings, “stage D” of third molar eruption was chosen as a cut-off value for the 18 year old threshold of both sexes. The AUC, Se and Sp were 0.920, 94.4% and 93.2% in males; and 0.960, 93.9% and 97.3% in females, respectively. According to the likelihood ratio, it is 14.07 times in males and 35.01 times in females, that “stage D” of third molar eruption is more

likely to occur in an individual at least 18 as opposed to someone younger than 18 (LR+). Our study results showed that 100% of individuals older than 18 years of age had attained stages C and D of third molar eruption. However, stage C was reached by 7.5% and 12.5% of males and females younger than 18 years. On the other hand, stage D was attained by 12% and 4.3% of males and females younger than 18 years, respectively. Therefore, when "stage D" was used to predict the legal age threshold 18 years, it has resulted in 13.8% and 5.4% of false positives or ethically unacceptable errors in males and females, respectively.

Our study findings indicated that the prediction of the age of majority using the eruption of the mandibular third molars is possible in the studied population, however with some important limitations. Third molars are by far the most commonly impacted teeth in the oral cavity.⁵² It has been reported that 72% of a Swedish population and 68.8% of a Chinese population of young adults had at least one impacted wisdom tooth.^{53, 54} In our study, we have observed that the rate of mandibular third molar impaction was 23.6% and 26.7% in males and females, respectively. Due to the non-inclusion of the impacted teeth in the scoring system by Olze et al⁹ those teeth which were disturbed by impaction were excluded from the analysis, which further limited the use of this approach.

Influencing factors

Sex is considered to be one of the factors that influences the biological maturation of the skeletal and dental parameters. It is widely accepted that the maturation of skeletal parameters occurs earlier in females than their male counterparts. Concerning the dental maturation, unlike other teeth, third molar maturation occurs earlier in males than females. Our study results corroborated the findings of the literature.^{10, 34, 55} The second factor to consider is the difference in the maturation/development between the right and left sides. It was clearly highlighted in the literature that there were no side differences with respect to dental maturation.^{56, 57} No side differences were reported in the studied population from previous studies,^{22, 58} and therefore the maturation/eruption/secondary dentine formation of lower left mandibular third molars were studied. Another factor to consider is the

representativeness of the sample. In the present study, we could not take the socio-economic status into consideration due to the retrospective nature of the study. In forensic and legal scenarios, children are typically from impoverished environments with poor nutritional status during growth.⁵⁹ Therefore, we believe that these may not perform accurately, and would likely increase the number of false negatives (appear younger than they are) in individuals who were malnourished. However, considering the context of criminal proceedings, it is more important to avoid false positives (appear older than they are), these methods can perhaps be considered as a conservative approach to this age estimation problem. Considering secondary dentine formation, future research should investigate the influence of dietary habits and modern dental health care on the radiographic visibility of the root pulp in third molars.

CONCLUSIONS

According to our search of the forensic literature, this is first radiographic study to compare the accuracy of four dental age estimation methods to indicate the legal age over 18 years in south Indian adolescents and young adults. The following conclusions can be drawn from our study findings:

1. The specific cut-off value of I3M < 0.08 showed better accuracy, higher sensitivity and specificity values of >90% for discriminating adults from minors in the studied population.
2. "Stage H" of the Demirjian staging system could be useful in answering the medico-legal question on whether a subject is at least 18 years of age. However, it has resulted in decreased sensitivity values (false negatives).
3. "Stage 1(or higher)" of RPV has resulted in 100% specificity suggesting the strong possibility that the individuals are aged over 18 years. However, the skewed age distribution towards younger age groups and greater percentage of third molars with incomplete mineralization has limited the applicability of this method.
4. "Stage D" of tooth eruption i.e., complete emergence of the third molars in the occlusal plane could be useful in predicting the age equal to or over 18 years. Although, it is easy to use in a daily clinical context, increased percentage of third molar impactions has limited the use of this approach.

Despite the limitations, these determinations can be seen as preliminary and tentative attempts at improving age of majority (18 years) determinations in the living individuals of south

Indian origin from the maturation, eruption and the secondary dentine formation in mandibular third molars.

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