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# Diagnostic performance of the Third Molar Maturity Index (I3M) for forensic age estimation at the 18-year threshold in a Surabaya population, Indonesia \*

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## Abstract

Third molar development is widely used in forensic age estimation because it continues to mature after most permanent teeth have erupted, extending into late adolescence and early adulthood. Cameriere's Third Molar Maturity Index (I3M) has been proposed as a reliable method for determining whether an individual has reached the legal age threshold of 18 years. This study aimed to evaluate the diagnostic performance of the I3M method for estimating legal age using panoramic radiographs in a population from Surabaya, Indonesia. A total of 100 digital panoramic radiographs of individuals aged 16–23 years were retrospectively analyzed. I3M values were calculated based on measurements of the apical openings of the lower left mandibular third molar using ImageJ software. The diagnostic performance of the established cut-off value of 0.08 was evaluated using sensitivity, specificity, accuracy, positive predictive value (PPV), and negative predictive value (NPV). The relationship between chronological age and I3M values was analyzed using Spearman's correlation coefficient. The I3M method demonstrated an overall accuracy of 91%, with sensitivity of 90.1% and specificity of 100% in distinguishing individuals aged  $\geq 18$  years from minors. The positive predictive value was 100%, whereas the negative predictive value was 50%. A strong negative correlation was observed between chronological age and I3M values ( $\rho = -0.871$ ,  $P < 0.001$ ). These findings suggest that the I3M method shows promising diagnostic performance for estimating whether an individual has reached the legal age of 18 years in the studied population. However, the results should be interpreted with caution due to the limited number of individuals under 18 years. Further studies involving larger and more balanced samples are required to confirm the applicability of the method in Indonesian populations.

**Keywords:** third molar; I3M; forensic age estimation; legal identity; Indonesian population

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## Introduction

In both clinical dentistry and forensic science, age estimation plays a crucial role, especially when reliable documentation of an individual's age is unavailable or disputed. Determining whether a person has reached the legal age of eighteen is crucial because it carries significant ethical and legal implications in matters such as criminal responsibility, asylum procedures, and civil identification (1). Since teeth are highly resistant to environmental influences and postmortem changes, dental maturity has long been recognized as one of the most reliable biological indicators for age estimation. In late adolescence, when the development of most teeth has already been completed, the evaluation of third molar (wisdom tooth) development becomes particularly useful among dental age estimation methods (2,3).

One of the most widely recognized approaches for dental age estimation is the Cameriere method, which has gained considerable attention due to its reliability and accuracy (4–6). This method evaluates tooth development by measuring the width of open apices in developing teeth on panoramic radiographs. It has been widely applied to estimate chronological age in children and adolescents (6,7). A specific application of this method is the Third Molar Maturity Index ( $I_3M$ ), which is used to determine whether an individual is above or below the legal age of 18 years (8–10). The  $I_3M$  method measures the maturity of the mandibular third molar and applies a cut-off value, commonly 0.08 to distinguish between minors and adults (10,11). However, the accuracy of dental age estimation methods may vary considerably among different populations. Dental development can be influenced by genetic, environmental, and socioeconomic factors, which contribute to population variability. For example, variations in dental maturation timing may be associated with genetic background, dietary patterns, and socioeconomic conditions. Therefore, population-specific validation studies are essential to ensure the accuracy and reliability of these age estimation methods when applied to different demographic groups (12–14).

The Cameriere method has been successfully validated in several populations, including European populations (15,16), Middle Eastern populations (14,17), and other international groups (18–20). In Indonesia, however, studies investigating the applicability of this method remain limited (21,22). Previous findings have suggested that third molar development among

Indonesian juveniles may occur at a slower rate compared with populations from other countries. Nevertheless, there is still limited comparative data across different Indonesian populations, highlighting the need for further population-based validation studies.

Therefore, this study aimed to evaluate the diagnostic performance of the Third Molar Maturity Index ( $I_3M$ ) using a cut-off value of 0.08 for determining whether an individual has reached the legal age of 18 years. Specifically, this research assessed the accuracy, sensitivity, and specificity of  $I_3M$  measurements obtained from panoramic radiographs in an Indonesian population sample from Surabaya, thereby evaluating its clinical applicability and forensic reliability as an age estimation tool.

## Materials and methods

### Sample

This study analysed 100 digital panoramic radiographs obtained from the radiographic archive of the Faculty of Dental Medicine at Universitas Airlangga in Surabaya, Indonesia, from individuals aged 16–23 years (36 males and 64 females). The dataset was retrospectively collected from an institutional clinical archive; therefore, an a priori sample size calculation was not performed. The final sample size was determined by the availability of radiographs that fulfilled the inclusion criteria.

Inclusion criteria were panoramic radiographs showing a mandibular third molar with identifiable crown and root morphology and sufficient image quality for measurement. Only intact mandibular third molars without previous dental treatment were included in the analysis. Both impacted and non-impacted mandibular third molars were included, provided that the root morphology and apical openings could be clearly identified on the panoramic radiographs. The eruption status of the third molar was not analyzed separately, as the objective of the study was to evaluate the diagnostic performance of the  $I_3M$  cut-off value regardless of impaction status.

Chronological age was calculated as the difference between the date of radiographic exposure and the subject's date of birth. Ethical approval was granted by the Institutional Ethics Committee (No.25/UN3.9.3/Etik/PT/2024).

### Measurements

Digital panoramic radiographs were imported and analyzed using ImageJ software. Measurements were performed on the lower left mandibular third molar following the procedure described by

Cameriere et al. (23). All measurements were performed by a trained examiner with experience in forensic dental age estimation using the I3M method. To evaluate intra observer reliability, the same observer repeated all I3M measurements after a one week interval. The third molar maturity index (I3M) was calculated based on the degree of root development of the mandibular third molar.

A value of I3M = 0 was assigned when root development was complete and both apices were fully closed. When the apices remained open, the widths of the inner sides of the open apices were measured. If two apical openings were present, the index was calculated using  $(A81 + A82)/YZ$ , where A81 and A82 represent the widths of the apical openings and YZ denotes the tooth length. In cases where only a single open apex was observed, the index was calculated using  $A8/YZ$  (see Figure 1).

#### Statistical analysis

Both descriptive and inferential statistical analyses were performed. Subjects were categorized into minors (16–17.99 years) and adults ( $\geq 18$  years) according to the legal age threshold. Descriptive statistics, including mean, median, and standard deviation, were calculated for chronological age and I3M values.

Normality of the I3M values was assessed using the Kolmogorov–Smirnov test. Since the data were not normally distributed ( $P < 0.001$ ), the relationship between chronological age and I3M values was analyzed using Spearman's rank correlation coefficient ( $\rho$ ). All statistical analyses were performed using IBM SPSS Statistics version 23.0 (IBM Corp., Armonk, NY, USA). A P-value  $< 0.05$  was considered statistically significant.

#### Intra-observer reliability

To evaluate the consistency of the I3M measurements, intra-observer reliability analysis was performed. One observer repeated the I3M measurements for all panoramic radiographs after a one-week interval. The intraclass correlation coefficient (ICC) was calculated using a two-way mixed-effects model with absolute agreement. An ICC value above 0.75 was considered to indicate good reliability, whereas values above 0.90 were interpreted as excellent reliability.

#### Diagnostic performance evaluation

The diagnostic performance of the I3M cut-off value of 0.08 was evaluated for determining

whether an individual had reached the legal age of 18 years. Classification results were defined as follows:

- True Positive (TP): individuals aged  $\geq 18$  years with  $I3M < 0.08$
- True Negative (TN): individuals aged  $< 18$  years with  $I3M \geq 0.08$
- False Positive (FP): individuals aged  $< 18$  years with  $I3M < 0.08$
- False Negative (FN): individuals aged  $\geq 18$  years with  $I3M \geq 0.08$

Based on these classifications, the following diagnostic parameters were calculated:

- Sensitivity, representing the proportion of individuals aged  $\geq 18$  years correctly classified as adults
- Specificity, representing the proportion of individuals aged  $< 18$  years correctly classified as minors
- Accuracy, representing the overall proportion of correctly classified individuals

In addition, positive predictive value (PPV) and negative predictive value (NPV) were calculated. To provide a more robust interpretation of diagnostic performance, 95% confidence intervals (CI) were also estimated for sensitivity, specificity, and accuracy.

#### Results

A total of 100 panoramic radiographs were included in this study. The age and sex distribution of the study population is presented in Table 1, showing that the sample consisted of 36 males and 64 females distributed across the age range of 16.00 to 23.99 years. Descriptive statistics for chronological age and I3M values are summarized in Table 2. The mean chronological age of the participants was  $20.88 \pm 2.01$  years, while the mean I3M value was  $0.06 \pm 0.06$ , with a median value of 0.05.

Intra-observer reliability analysis yielded an intraclass correlation coefficient (ICC) of 0.975, indicating excellent repeatability of the I3M measurements. This result confirms the consistency of the examiner's measurements and supports the methodological reliability of the I3M assessment in this study. The correlation analysis between chronological age and I3M value demonstrated a strong negative association, as shown in Table 3. Spearman's rank correlation coefficient was  $-0.871$  ( $P < 0.001$ ), indicating that the I3M value decreases as chronological age increases. This analysis describes the continuous relationship between dental maturation and chronological age but does not directly reflect the diagnostic performance of

the I3M cut-off for classification at the legal age threshold of 18 years.

For the diagnostic performance analysis, the I3M cut-off value of 0.08 was used to classify individuals as either  $\geq 18$  years or  $< 18$  years, as presented in Table 4. Among the 91 individuals aged  $\geq 18$  years, 82 were correctly classified as adults, while 9 individuals were misclassified as being younger than 18 years. All 9 individuals aged  $< 18$  years were correctly classified, and no false-positive cases were observed.

The overall diagnostic performance of the I3M method is summarized in Table 5. The method demonstrated an accuracy of 91% (95% CI: 83.6–95.8%), sensitivity of 90.1% (95% CI: 82.1–95.0%), and specificity of 100% (95% CI: 66.4–100%). The positive predictive value (PPV) was 100% (95% CI: 95.6–100%), whereas the negative predictive value (NPV) was 50% (95% CI: 26.0–74.0%).

## Discussion

Age estimation represents one of the most important aspects of forensic odontology, particularly in legal situations where determining whether an individual has reached the age of majority is required (24). In the present study, the diagnostic performance of Cameriere's Third Molar Maturity Index (I3M) was evaluated for determining whether an individual has attained the legal age of 18 years using panoramic radiographs in an Indonesian population from Surabaya.

The I3M method applied in this study was originally developed by Cameriere and colleagues based on research conducted in a Caucasian population, specifically the Italian population in Europe (23). This method uses the measurement of open apices in mandibular third molars to estimate dental maturity and has been demonstrated to be effective and reliable for determining legal age without significant differences between sexes. Since its introduction, the method has been validated and applied in several populations worldwide (25).

In the present study, the established I3M cut-off value of 0.08 was used to classify individuals as either minors or adults. Previous studies have demonstrated that the I3M cut-off value of 0.08 provides reliable discrimination between individuals younger and older than 18 years of age (10,11). Using this threshold, the present study obtained an overall classification accuracy of 91%, indicating that the I3M method correctly classified the majority of individuals according to the legal age threshold. The sensitivity of 90.1%

indicates that the method effectively identifies individuals aged 18 years or older, while the specificity of 100% indicates that all individuals younger than 18 years in the present sample were correctly classified. However, this estimate should be interpreted with caution because the number of participants under 18 years was limited.

The combination of high sensitivity and high specificity is important in forensic contexts, particularly when distinguishing individuals who may be below the legal age threshold. Misclassifying a minor as an adult may have significant legal and ethical consequences; therefore, methods that minimize such errors are highly desirable in forensic practice (26,27). These findings are consistent with previous studies that have evaluated the accuracy and applicability of the I3M method in various populations.

Several studies conducted in different populations, including South Indian, Egyptian, and French samples, have also reported high diagnostic performance using the I3M cut-off value of 0.08 (10,28,29). These studies demonstrated similar levels of accuracy and specificity, supporting the applicability of the I3M method across diverse demographic groups. Previous studies conducted in Indonesian populations have also evaluated the applicability of the I3M method. For example, Boedi et al. (21) applied the I3M approach to assess the minimum legal age of marriage in Indonesia and reported good discriminatory performance, although slightly different threshold values were observed between males and females. More recently, Keshena et al. (22) investigated the optimization of the I3M cut-off value for determining the age of majority in Indonesian juveniles and suggested that population-specific thresholds may improve classification accuracy. These findings further support the need for population-specific validation studies in different regions of Indonesia.

In contrast, other dental age estimation techniques, such as the Demirjian method, have shown more variable accuracy across populations. Although widely used, the Demirjian method has been reported to frequently overestimate chronological age and may demonstrate lower specificity compared with the I3M method (29–31). Therefore, the favorable diagnostic performance observed for the I3M method suggests that it may serve as a useful supportive tool for legal age determination in forensic settings.

The present study included both impacted and non-impacted mandibular third molars, provided that the apical morphology could be clearly visualized for I3M measurement. Previous studies have suggested that impaction may influence the maturation of third molars, with some reports indicating slightly delayed mineralization in impacted teeth compared with non-impacted teeth (32). However, the eruption status of the third molars was not analyzed separately in the present study. Therefore, the potential influence of impaction on I3M values should be considered when interpreting the results and may represent a topic for future research.

A further methodological consideration relates to cases where the apices of the third molars are completely closed. In such cases, the I3M value is recorded as 0, because no open apex can be measured. Although this condition reflects complete root maturation, it also limits the applicability of the method for differentiating older individuals because measurements cannot provide additional maturation information (22,33). Dental age estimation methods may vary across populations due to multiple biological and environmental influences on dental development. Factors such as hormonal regulation (34), genetic background (35), biological maturation processes (34), dental morphology (36), environmental influences including nutrition and lifestyle (37), and socioeconomic conditions (38) may all affect the timing of third molar development and eruption. Because of these influences, dental age estimation methods should ideally be validated in specific populations before being applied in forensic practice.

Another consideration relates to the sex distribution of the sample, which showed a predominance of female participants. Previous studies have suggested that dental maturation may occur slightly earlier in females than in males due to biological and hormonal differences influencing growth and development (34, 35). However, sex-specific analyses were not performed in the present study because of the limited number of minor participants and the uneven distribution between sexes. Therefore, the potential influence of sex on I3M values could not be fully evaluated and should be explored in future studies with more balanced samples.

Indonesia represents a highly heterogeneous population with considerable ethnic and regional diversity (39, 40). Since the present study was based on panoramic radiographs obtained from a single institutional archive in Surabaya, the

results should be interpreted as representative of a regional population rather than the entire Indonesian population. Therefore, multicenter studies involving diverse Indonesian regions would be valuable to further confirm the applicability of the I3M method nationwide (22). Another important consideration is that dental age estimation methods should ideally be combined with other biological indicators to increase accuracy. Because I3M is based solely on dental maturation, combining dental methods with skeletal age estimation techniques may improve the reliability of age assessment in forensic cases (33).

Several limitations of this study should be acknowledged. First, the sample size was limited to 100 panoramic radiographs, which may not fully represent the broader Indonesian population. Second, the distribution of the sample was relatively imbalanced, with a smaller number of individuals younger than 18 years. Consequently, the estimate of specificity was derived from a limited subgroup and should therefore be interpreted cautiously. Third, the sample was obtained from a single institutional archive, which may limit the generalizability of the findings to other Indonesian populations. Finally, although intra-observer reliability demonstrated excellent repeatability, inter-observer reproducibility was not evaluated.

Future studies involving larger and more diverse samples are recommended to further validate these findings. In addition, future research may explore the development of population-specific cut-off values using ROC-based analyses to determine whether alternative thresholds could improve diagnostic performance in Indonesian populations.

## Conclusion

The Third Molar Maturity Index (I3M) showed promising diagnostic performance for distinguishing individuals aged 18 years or older in the studied population. These findings suggest that the I3M method may serve as a useful supportive tool for forensic age estimation in legal and clinical contexts. However, the results should be interpreted with caution due to the limited number of individuals under 18 years and the imbalance in the sample distribution. Further multicenter studies involving larger and more balanced Indonesian populations are necessary to confirm the diagnostic performance of the method and to explore potential population-specific variations.

**Declarations of interest**

none

analysis, methodology, writing original draft, review &amp; editing, supervision.

**Author contributions**

MIM: conceptualization, formal analysis, methodology, writing original draft, review & editing; MK, MSA: formal analysis, methodology, writing original draft; MSM: formal analysis, methodology, writing original draft; AK, AA, BNR: writing original draft, methodology; AC: formal

**Statement on the use of artificial intelligence in manuscript preparation**

Artificial intelligence tools were used exclusively for language editing and did not influence the scientific content. The authors retain full responsibility for the manuscript.

**Table 1. Age and sex distribution of the study population**

Age Group (Years)	Male (n)	Female (n)	Total (N)
16.00-16.99	4	0	4
17.00-17.99	3	2	5
18.00-18.99	7	7	14
19.00-19.99	4	5	9
20.00-20.99	5	11	16
21.00-21.99	3	14	17
22.00-22.99	6	10	16
23.00-23.99	4	15	19
Total	36	64	100

n = number of individuals per sex group; N = total number of participants.

**Table 2. Descriptive Statistics of Chronological Age and I<sub>3</sub>M Values**

Variable	N	Mean	Median
Chronological Age (years)	100	20.88	21.08
I <sub>3</sub> M value	100	0.06	0.05

I<sub>3</sub>M = Third Molar Maturity Index; N = total number of participants.

**Table 3. Spearman Correlation Between Chronological Age and I<sub>3</sub>M Values**

Variables	Significance (2-tailed)	Correlation Coefficient ( $\rho$ )
Chronological age and I <sub>3</sub> M value	< 0.001	- 0.871

$\rho$  = Spearman's rank correlation coefficient; I<sub>3</sub>M = Third Molar Maturity Index.

**Table 4. Classification for Sensitivity and Specificity Analysis Using I<sub>3</sub>M Cut-off 0.08**

I <sub>3</sub> M	≥ 18 years	< 18 years	Total (N)
<0.08	82 (TP)	0 (FP)	82
≥0.08	9 (FN)	9 (TN)	18
Total	91	9	100

TP: True Positive (≥ 18 years correctly classified with I<sub>3</sub>M < 0.08); FP: False Positive (< 18 years incorrectly classified with I<sub>3</sub>M < 0.08); FN: False Negative (≥ 18 years incorrectly classified with I<sub>3</sub>M ≥ 0.08); TN: True Negative (< 18 years correctly classified with I<sub>3</sub>M ≥ 0.08); I<sub>3</sub>M cutoff value used for classification: 0.08.

Table 5. Diagnostic Performance of the I<sub>3</sub>M Method

Parameter	Value (%)	95% Confidence Interval
Sensitivity	90.1	82.1-95.0
Specificity	100	66.4-100
Accuracy	91	83.6-95.8
PPV	100	95.6-100
NPV	50	26.0-74.0

Sensitivity = proportion of individuals aged  $\geq 18$  years correctly classified using the I<sub>3</sub>M cut-off value of 0.08; specificity = proportion of individuals aged  $< 18$  years correctly classified. Positive predictive value (PPV) indicates the probability that individuals classified as  $\geq 18$  years are truly  $\geq 18$  years, whereas negative predictive value (NPV) indicates the probability that individuals classified as  $< 18$  years are truly  $< 18$  years. Accuracy represents the overall proportion of correctly classified individuals. CI = confidence interval; I<sub>3</sub>M = Third Molar Maturity Index.

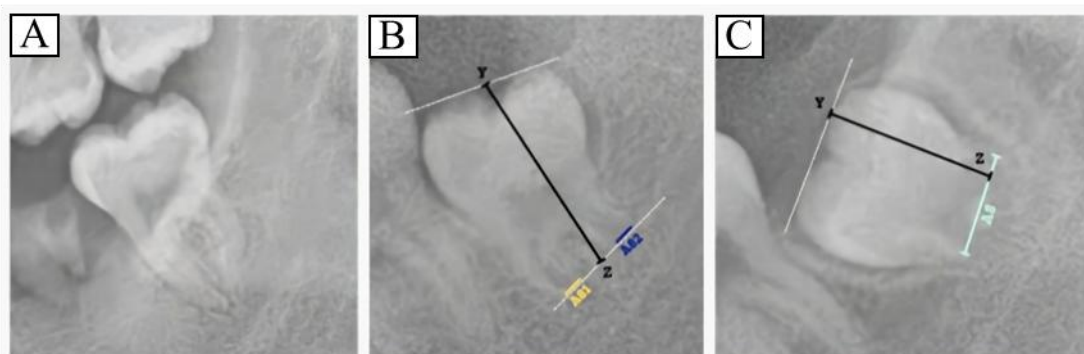


Figure 1. Calculation of the Cameriere's I<sub>3</sub>M. (a) I<sub>3</sub>M = 0 (closed apices); (b) I<sub>3</sub>M = (A81 + A82)/YZ (bifurcation present); (c) I<sub>3</sub>M = A8/YZ (bifurcation absent). A8, A81, and A82 indicate apical opening widths; YZ denotes tooth length.

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