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Original Research Article

FORENSIC VALIDITY OF CAMERIERE'S THIRD MOLAR METHOD FOR LEGAL AGE DETERMINATION IN THE MUMBAI METROPOLITAN REGION: A MEDICO-LEGAL PERSPECTIVE

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ABSTRACT

Background: Age determination at the threshold of 18 years holds paramount significance in the Indian legal system, influencing criminal culpability under the Indian Penal Code, protection under the Juvenile Justice (Care and Protection of Children) Act, 2015, applicability of the Protection of Children from Sexual Offences Act, 2012, and numerous civil rights. Dental age estimation using third molar development has emerged as a valuable forensic tool, with Cameriere's method offering a quantitative approach using the 0.08 cut-off for legal age determination. **Objectives:** To evaluate the forensic validity and diagnostic accuracy of Cameriere's third molar maturity index with the 0.08 cut-off for determining legal age (18 years) in the Mumbai Metropolitan Region population.

Materials and Methods: A retrospective cross-sectional study was conducted on 196 orthopantomographs (94 males, 102 females) aged 15-20.83 years. Binary classification was performed using the 0.08 cut-off (estimated age ≥18 years = adult; <18 years = minor). Diagnostic metrics including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated with 95% confidence intervals.

Results: The method demonstrated accuracy of 71.43% (95% CI: 64.74-77.29%), sensitivity of 72.02%, and specificity of 67.86%. The PPV was notably high at 93.08% (95% CI: 87.37-96.32%), while NPV was low at 28.79%. Nine false positives (minors misclassified as adults) and 47 false negatives (adults misclassified as minors) were identified.

Conclusion: The high PPV indicates reliability when the method classifies an individual as an adult. However, the low NPV and presence of false positives (potential human rights violations) necessitate that the Cameriere method be used only as one component within a multi-factorial forensic age assessment, never as a standalone determinant of legal age.

Keywords: Forensic age estimation; Legal age determination; Cameriere method; Third molar; Juvenile Justice Act.

INTRODUCTION

Age estimation occupies a pivotal position in forensic medicine, with the determination of whether an individual has attained the age of 18 years bearing profound legal consequences across multiple domains of the Indian judicial system.[1] The legal significance of this threshold age permeates virtually

every aspect of law enforcement, criminal prosecution, and civil rights administration in India.[2]

Under the Indian Penal Code (IPC), 1860, and the Bharatiya Nyaya Sanhita (BNS), 2023, an individual aged 18 years or above is subject to full criminal liability and adult sentencing provisions, including imprisonment and, in heinous cases, capital punishment.[3] The Juvenile Justice (Care and Protection of Children) Act, 2015, defines a child as any person below the age of 18 years, entitling such individuals to special protection, rehabilitation-focused interventions, and exemption from adult criminal proceedings.[4] The Protection of Children from Sexual Offences (POCSO) Act, 2012, extends its protective umbrella exclusively to individuals below 18 years of age, and the determination of victim or perpetrator age fundamentally alters the nature of charges and sentencing.[5]

Beyond criminal law, the 18-year threshold determines eligibility for voting under the Representation of the People Act, 1951, capacity to enter legally binding contracts under the Indian Contract Act, 1872, validity of marriage under personal laws, eligibility for employment under the Child Labour (Prohibition and Regulation) Amendment Act, 2016, and entitlement to various government benefits and welfare schemes.[6,7] In an era of increased migration and asylum applications, age determination also holds significance for immigration proceedings and deportation decisions.[8]

Forensic age estimation employs multiple methodologies, including documentation review, physical examination, skeletal radiography, and dental assessment.[9] Among these, dental age estimation has gained prominence due to the relative resistance of teeth to environmental influences, the standardized nature of dental development, and the non-invasive acquisition of orthopantomographs.[10] Third molar development assumes particular importance for legal age determination as it represents the only dental structure still undergoing development around the 18-year threshold in most individuals.[11]

Cameriere and colleagues developed a quantitative method for age estimation based on the relationship between chronological age and the ratio of open apex width to tooth length in developing third molars.[12,13] The method employs a normalized measurement (I3M) representing the sum of normalized open apices of the lower third molars. Critically, a cut-off value of 0.08 has been established corresponding to an estimated age of 18 years, providing a practical threshold for legal age determination.[14] When I3M $\leq$ 0.08, the individual is estimated to be 18 years or older (adult); when I3M> 0.08, the individual is estimated to be below 18 years (minor).

The validation of any forensic age estimation method on specific populations is imperative given documented variations in dental development across ethnic, geographical, and socioeconomic groups.[15] The Mumbai Metropolitan Region, with its diverse population representing multiple ethnic backgrounds and socioeconomic strata, provides an ideal setting for such validation. The present study aims to evaluate the forensic validity and diagnostic accuracy of Cameriere's third molar method with the 0.08 cut-off for legal age determination in this population, with specific emphasis on the medico-legal implications of classification errors.

MATERIALS AND METHODS

Study Design and Ethical Considerations

This retrospective cross-sectional study was conducted at the Department of Forensic Medicine, Topiwala National Medical College (TNMC), Mumbai. The study utilized orthopantomographs (OPGs) collected from a previous research project that had obtained appropriate ethical approval from the Institutional Ethics Committee, TNMC, and written informed consent from all participants. The present analysis was performed in accordance with the Declaration of Helsinki guidelines for ethical research involving human subjects.

Study Population and Sample Selection

The study sample comprised 196 individuals (94 males, 102 females) residing in the Mumbai Metropolitan Region. The age range was 15 to 20.83 years, capturing the critical period around the legal age threshold of 18 years.

Inclusion Criteria

1. Residents of Mumbai Metropolitan Region
2. Age between 15 and 21 years with documented date of birth
3. Presence of at least one mandibular third molar with visible root development
4. Good quality OPG with clear visualization of third molar apices.

Exclusion Criteria

1. Congenitally absent mandibular third molars
2. History of dental trauma or pathology affecting third molar development
3. Systemic conditions known to affect dental development
4. Poor quality radiographs precluding accurate measurements.

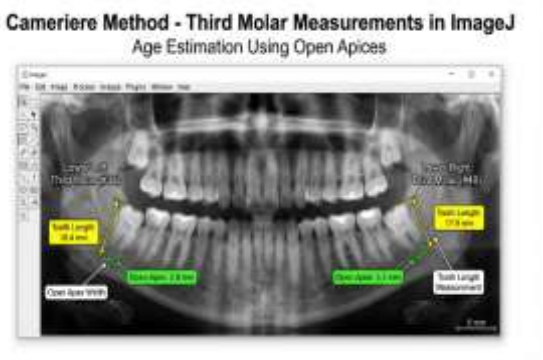

Figure 1: Cameriere's Third Molar Method

Digital OPGs were analyzed using ImageJ software, a validated tool for dental morphometric analysis. Measurements were performed on digital OPGs according to the standardized Cameriere protocol.[12,13] For each mandibular third molar, the following measurements were recorded: (a) tooth length from apex to occlusal surface; (b) open apex width(s). The normalized measurement (I_{3M}) was calculated as the sum of the ratios of open apex widths to tooth length for available mandibular third molars. Age was estimated using the Cameriere regression formula, incorporating the I_{3M} value, gender, and interaction terms.

Legal Age Classification Protocol

Binary classification for legal age determination was performed using the established 0.08 cut-off:[14]

Predicted Adult (≥18 years): Estimated age ≥18 years (corresponding to $I_{3M} \leq 0.08$)

Predicted Minor (<18 years): Estimated age <18 years (corresponding to $I_{3M} > 0.08$)

The chronological age, calculated from documented date of birth to date of radiograph, served as the ground truth for classification accuracy assessment.

Statistical Analysis

A 2×2 confusion matrix was constructed comparing predicted classification (adult vs. minor) against actual chronological age status. The following diagnostic metrics were calculated:

- Sensitivity (True Positive Rate): TP/(TP+FN) – proportion of actual adults correctly identified
- Specificity (True Negative Rate): TN/(TN+FP) – proportion of actual minors correctly identified
- Positive Predictive Value (PPV): TP/(TP+FP) – probability of being adult when classified as adult
- Negative Predictive Value (NPV): TN/(TN+FN) – probability of being minor when classified as minor
- Accuracy: (TP+TN)/Total – overall proportion of correct classifications
- False Positive Rate (FPR): FP/(FP+TN) – proportion of minors incorrectly classified as adults
- False Negative Rate (FNR): FN/(FN+TP) – proportion of adults incorrectly classified as minors

Wilson score 95% confidence intervals were calculated for all proportions. Analysis was performed using Python v3.9.

RESULTS

The study sample comprised 196 participants with a mean chronological age of 18.51 years (range: 15.0–20.83 years). Of these, 94 participants were males (48.0%) and 102 were females (52.0%). Based on legal age classification, 168 participants (85.7%) were adults (chronological age ≥18 years), while 28 participants (14.3%) were minors (chronological age <18 years). The sex-wise age distribution of the study population is shown in Table 1, while detailed sample characteristics stratified by legal age status are presented in Table 2.

Table 1: Sex-wise Age Distribution of Study Participants

Age Group (years)	Male (n)	Female (n)	Total (n)
15–17	6	10	16
>17–19	44	47	91
>19–21	44	45	89
Total	94	102	196

Table 2: Sample Characteristics by Legal Age Status

Characteristic	Overall (n=196)	Adults ≥18 (n=168)	Minors <18 (n=28)
Sex - Male, n (%)	94 (48.0%)	80 (47.6%)	14 (50.0%)
Sex - Female, n (%)	102 (52.0%)	88 (52.4%)	14 (50.0%)
Mean Age (years)	18.51	18.91	16.92
Age Range (years)	15.0 - 20.83	18.0 - 20.83	15.0 - 17.83
Proportion of Total	100%	85.7%	14.3%

Classification Results and Confusion Matrix

Application of the Cameriere method with the 0.08 cut-off resulted in 130 participants (66.3%) being classified as adults and 66 participants (33.7%) being classified as minors. The complete confusion matrix is presented in Table 3.

Of the 168 actual adults, 121 were correctly classified as adults (True Positives, 61.7% of total sample), while 47 were incorrectly classified as minors (False Negatives, 24.0% of total). Of the 28 actual minors, 19 were correctly classified as minors (True Negatives, 9.7% of total), while 9 were incorrectly classified as adults (False Positives, 4.6% of total).

Table 3: Confusion Matrix for Legal Age Classification

	Actual Adult (≥18)	Actual Minor (<18)	Total
Predicted Adult (≥18)	121 (TP)	9 (FP)	130
Predicted Minor (<18)	47 (FN)	19 (TN)	66
Total	168	28	196

TP = True Positive; FP = False Positive; TN = True Negative; FN = False Negative. Classification based on 0.08 cut-off corresponding to estimated age 18 years.

Diagnostic Performance Metrics

The diagnostic performance metrics are summarized in Table 4. The overall accuracy of the Cameriere method for legal age classification was 71.43% (95% CI: 64.74-77.29%). The sensitivity (ability to correctly identify adults) was 72.02% (95% CI: 64.80-78.26%), while the specificity (ability to correctly identify minors) was 67.86% (95% CI: 49.34-82.07%).

The Positive Predictive Value (PPV) was notably high at 93.08% (95% CI: 87.37-96.32%), indicating that when the method classified an individual as an adult, this classification was correct in approximately 93 out of 100 cases. In contrast, the Negative Predictive Value (NPV) was markedly low at 28.79% (95% CI: 19.27-40.64%), indicating that when the method classified an individual as a minor, this classification was correct in only approximately 29 out of 100 cases.

The False Positive Rate was 32.14% (95% CI: 17.93-50.66%), meaning that approximately one-third of actual minors were incorrectly classified as adults. The False Negative Rate was 27.98% (95% CI: 21.74-35.20%), indicating that approximately 28% of actual adults were incorrectly classified as minors.

Table 4: Diagnostic Performance Metrics for Legal Age Determination

Metric	Value (%)	95% Confidence Interval
Accuracy	71.43	64.74 - 77.29
Sensitivity	72.02	64.80 - 78.26
Specificity	67.86	49.34 - 82.07
Positive Predictive Value (PPV)	93.08	87.37 - 96.32
Negative Predictive Value (NPV)	28.79	19.27 - 40.64
False Positive Rate	32.14	17.93 - 50.66
False Negative Rate	27.98	21.74 - 35.20

Characterization of Classification Errors

False Positive Cases (Minors Classified as Adults): Nine minors were incorrectly classified as adults. The mean chronological age of these individuals was 17.22 years (range: 16.33-17.83 years), with a mean estimated age of 18.53 years, representing an overestimation of approximately 1.3 years. These 9 false positive cases constituted 32.14% of all minors in the study sample. Notably, all false positive cases were individuals aged 16-18 years, representing the vulnerable borderline zone closest to the legal threshold.

False Negative Cases (Adults Classified as Minors): Forty-seven adults were incorrectly classified as minors. The mean chronological age was 18.58 years (range: 18.0-20.0 years), with a mean estimated age of 17.39 years, representing an underestimation of approximately 1.2 years. These false negative cases constituted 27.98% of all adults. The majority were young adults within 2 years of the 18-year threshold, indicating a conservative bias in the method for this age group.

DISCUSSION

The determination of legal age in forensic practice carries consequences of profound magnitude that extend far beyond the immediate clinical setting into the realms of criminal justice, human rights, and social welfare.[16] The present study evaluated the Cameriere third molar method using the 0.08 cut-off for discriminating between adults and minors in the Mumbai Metropolitan Region population, yielding findings with significant medico-legal implications.

The high PPV of 93.08% represents the most forensically valuable finding of this study. This metric indicates that when the Cameriere method classifies an individual as an adult (estimated age ≥18 years), this prediction is correct in approximately 93 out of 100 cases. From a legal evidentiary standpoint, this provides substantial support for adult classification with a reasonable degree of medical certainty. In criminal proceedings where the prosecution bears the burden of proving the accused has attained adult status, a PPV exceeding 90% offers robust medical evidence.[17]

The corresponding sensitivity of 72.02% indicates that the method successfully identifies approximately 72% of actual adults as adults. While this represents a meaningful proportion of true identifications, it also implies that nearly 28% of adults are misclassified as minors—a conservative error that, while legally problematic, does not carry the same gravity of human rights implications as false positive classifications.

The strikingly low NPV of 28.79% represents a critical limitation that must be explicitly communicated in forensic reports and court testimony. When the Cameriere method classifies an individual as a minor (estimated age <18 years), this classification is correct in only approximately 29 out of 100 cases. Conversely, 71% of those classified as minors by this method are actually adults. This finding has profound implications for defense cases where establishing minor status would confer legal protections.[18]

The low NPV reflects the inherent conservative bias of the Cameriere method in this age range, consistently underestimating chronological age in young adults. While this bias provides a 'safety margin' from a precautionary perspective, it severely limits the method's utility for confirming minor status and necessitates the employment of additional assessment modalities when a minor classification is obtained.

The identification of 9 false positive cases—minors incorrectly classified as adults—represents the most

concerning finding from a human rights perspective. Each false positive classification carries the potential for serious violations of the individual's fundamental rights and protections.[19]

Under the Indian criminal justice system, a minor incorrectly classified as an adult may faceimprisonment in adult facilities rather than juvenile rehabilitation, exposure to adult sentencing including life imprisonment, and in extreme cases, potential capital punishment for heinous offences.4 He/she may be denied rehabilitation-focused interventions, special procedures before Juvenile Justice Boards, and identity protection provisions mandated under the JJ Act, 2015.[4] If the misclassified minor is a victim, age determination affects the applicability of stringent penalties under POCSO; if a perpetrator, misclassification denies age-appropriate handling of the case.[5] He/she may be removed from child protection services, ineligibility for educational and social welfare benefits designated for minors, and potential deportation in immigration cases where minor status would confer protection.[8]

The mean chronological age of false positive cases (17.22 years) and the range (16.33-17.83 years) indicate that these individuals are clustered in the immediate pre-threshold zone. This borderline period of 16-18 years emerges as a zone of heightened vulnerability requiring extraordinary caution in forensic assessment.

The 47 false negative cases—adults incorrectly classified as minors—present a different set of legal and administrative challenges. While less grave than false positives from a human rights perspective, these errors permit adult individuals to potentially escape adult criminal liability and face only juvenile proceedings. There might be access for resources and protections intended exclusively for minors. In POCSO cases involving adult perpetrators, potentially receive reduced sentences through misapplication of juvenile provisions

The concentration of false negatives among young adults aged 18-20 years reflects the inherent biological variability in third molar development and the conservative nature of the Cameriere method near the threshold age. From a precautionary standpoint, this conservative bias aligns with the principle of 'benefit of the doubt' advocated in international forensic age estimation guidelines.[20]

Our findings are consistent with previous validation studies of the Cameriere method in Indian populations, which have generally demonstrated similar patterns of moderate overall accuracy with higher PPV than NPV.[15] Studies from South Indian,[21] and North Indian,[22] populations have reported comparable performance metrics, suggesting that the observed diagnostic characteristics may be generalizable across Indian subpopulations. However, subtle variations attributable to regional, ethnic, and socioeconomic factors warrant continued population-specific validation.

Limitations

This study has several limitations that warrant acknowledgment. The sample was drawn from a single institution in the Mumbai Metropolitan Region, potentially limiting generalizability to other regions of India. The unequal distribution of adults (85.7%) and minors (14.3%) reflects the age range studied but may influence some diagnostic metrics. The retrospective design precluded standardization of radiographic technique and conditions. Furthermore, the study could not account for all potential confounding factors such as nutritional status, genetic variations, and socioeconomic influences on dental development.

CONCLUSION

The Cameriere third molar method with the 0.08 cut-off demonstrates moderate overall accuracy (71.43%) for legal age determination in the Mumbai Metropolitan Region population. The high positive predictive value (93.08%) indicates substantial reliability when the method classifies an individual as an adult, providing useful supportive evidence for adult status in legal proceedings. However, the low negative predictive value (28.79%) and the presence of 9 false positive cases (minors misclassified as adults) underscore critical limitations with serious human rights implications.

The method should be employed exclusively as one component within a multi-factorial forensic age assessment framework, never as a standalone determinant of legal age. In borderline cases and whenever doubt exists, the precautionary principle mandates presumption of minor status to protect fundamental rights. Forensic practitioners must communicate limitations transparently, and legal professionals must understand the probabilistic rather than deterministic nature of biological age estimation.

Adherence to these principles will ensure that forensic age estimation serves justice while safeguarding the rights and welfare of vulnerable individuals at the critical threshold of legal adulthood.

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