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Correlation of chronological age with dental age estimated using modified Cameriere's method and UT-age estimation software — a cross-sectional study

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Abstract

Background Estimating age is essential in both the analysis of human skeletal remains and assessing live persons. The third molar develops over a longer period and is hence used in age estimation for subadults. Since dental age correlates with chronological age better than other growth markers, this study aims to assess the reliability of dental age assessed using the University of Texas (UT) age estimation method and modified Cameriere's method.

Methods It is a retrospective cross-sectional study in which the development and maturation of mandibular third molars were examined in 600 orthopantomograms (264 males and 336 females) of South Indian individuals (16–23 years). Dental age was estimated by using an Indian-specific formula based on maturity index value and the UT-age estimation software program. The results were evaluated using the Student's *t*-test for both methods and Pearson's correlation test to compare chronological age with estimated dental age.

Results Positive correlation was noted between chronological age and estimated dental age for males, females, and the total sample with highly statistically significant differences ($p = 0.000$). Modified Cameriere's method underestimated dental age in samples ranging from less than 1 year to more than 2 years. UT-age estimation method underestimated age in samples above 20 years and overestimated age in samples below 20 years. The predictive classification of utilizing the maturity index was 79.17% accurate.

Conclusions Dental age was negligibly over and underestimated in UT software method whereas it was overestimated in the modified Cameriere's method. To evaluate the reliability of these two methods, studies with larger sample sizes and population-specific data sets should be performed.

Keywords Age determination by teeth, Forensic dentistry, Radiography, panoramic, Age estimation, Dental age, Chronological age, Third molar, UT-age estimation software, Cameriere method

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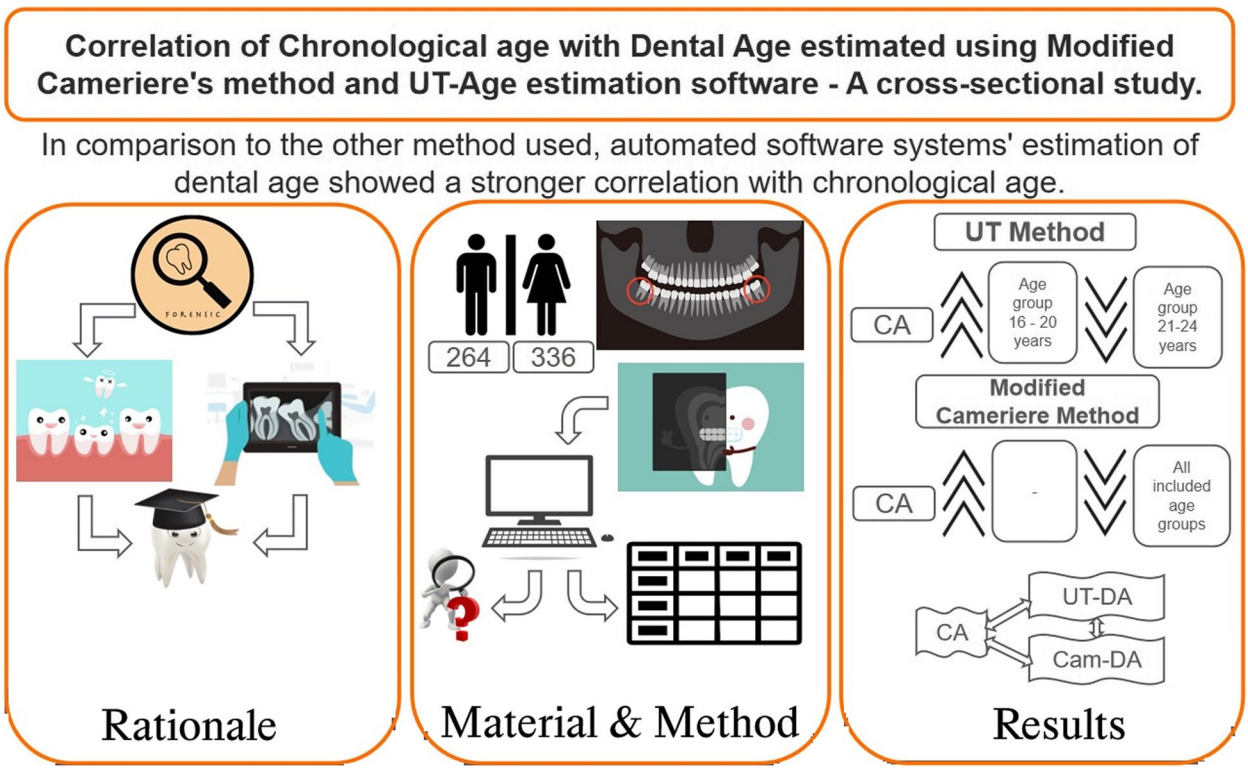
Graphical Abstract



Background

Forensic age assessment aids in the identification of both living and deceased individuals. In situations involving the deceased, age can be used to create a biological profile that can be compared to missing persons. If a person is still alive, estimating their age can help resolve legal issues involving minors and adults, such as adoption, imputability, and false identification documents (Cunha et al. 2009). Biological age is calculated using skeletal or dental components, despite how much it differs from chronological age. To estimate an individual's age in adolescents considering delicate legal and ethical consequences, the Study Group on Forensic Age Diagnostics (AGFAD) and the Forensic Anthropology Society of Europe (FASE) developed a three-step procedure (Schmeling et al. 2008). The following are the three steps:

1. A physical examination that includes documenting anthropometric data and evaluating sexual maturational signs
2. Orthopantomogram (OPG) that evaluates dental development based on tooth maturation
3. Skeletal growth examination through a hand-wrist radiograph and, if necessary, clavicle (Schulz et al. 2008).

When estimating a child or adolescent's age, dental maturity is crucial since the third molar, post-formational alterations, and pattern of tooth eruption all contribute to age (Kurniawan et al. 2022). Teeth are the strongest and most resilient part of the body, resistant to undergoing changes brought on by external forces, and hereditary factors control their growth and development. Teeth, due to their distinct traits, provide vital insights regarding an individual's identity, regardless of age, sex, race, or socioeconomic status (Shah et al. 2019). Although age estimated (dental age) based on dentition is closely related to chronological age, there may be slight variations depending on the method employed for assessment, which can be clinical, radiographic, histological, or biochemical (Limdiwala and Shah 2013).

Examining changes in tooth structure and the development of the third molar can help one to determine their age in a subadult population. Between the ages of 14 and 23, which correlate from late adolescence to

early adulthood, they are a solitary tooth that experiences developmental alterations (Thevissen et al. 2010). Radiographs (OPGs or periapical radiographs) can be used to assess the mineralization of the crown and root of the third molar since they are simple to obtain and non-invasive. When performing a radiographic examination of the third molar, orthopantomograms provides a reliable standardization and acceptable reproducibility (Donni et al. 2018).

When Olze et al. (2005) analyzed the validity of five classification systems that assessed the mineralization of third molars, Demirjian (Gustafson and Koch 1974) classification system was estimated to be the best approach due to its association with real age when compared to others. Solari and Abramovich (2002) and Kasper et al. (2009) further extended this to incorporate subgroups in later phases of development with radiographic evidence of each step.

The third molar maturity index (I_{3M}) was used by Cameriere et al. (2008) to define a way of identifying adults and minors. A cutoff value of 0.08 was established above which the age was found to be higher or equivalent to 18 years. The maturity index (I_{3M}) is defined as the ratio of the distance between two apical widths to the total tooth length (Galić et al. 2015). Comparing this technique to Demirjian's stage H, it was discovered to have higher sensitivity when categorizing people under the age of 18 (Cameriere et al. 2008). In 2010, Lewis, Silvaggi, and Senn developed the UT-age computer program, which generates template reports and estimates the mean age and age range of the individual with two standard deviations and the empirical probability that the individual has reached the age of majority based on the gender and ethnicity that are chosen (Lewis and Senn 2010).

Population-specific methods or data should be employed to compare the validity of applying third molar mineralization for estimating chronological age and increasing the dependability of the same. Although the effect of ethnicity on tooth development is not entirely understood, age estimates based on tooth growth among different races or populations produce comparable findings. In a sample of the South Indian population, SB Balla (Balla et al. 2019) developed a novel regression model in 2019 to estimate age using the third molar maturity index. In comparison to an earlier Indian-specific formula offered by Acharya (2011) that made use of Demirjian's technique, it was estimated that SB Balla's formula generated more accurate age estimations.

Hence, this study aims to evaluate the association between chronological age and dental age as estimated by two different methods: the University of Texas (UT) age estimation software approach and modified Cameriere's third molar maturity index method.

Methods

The third molars of 600 South Indians (264 males and 334 females) aged 16 to 23 were radiographically assessed using orthopantomograms in this retrospective cross-sectional study (OPG). Scan records were obtained from Department of Oral Medicine and Radiology between November 2021 and May 2022. Digital OPGs were captured using a Planmeca ProMax 2D® machine that was programmed to operate at 66 kVp and 8 mA and a scan duration of 15.8 s at the time of exposure. OPGs were performed as a routine radiological examination for which patients provided written consent in advance. This study was carried out with the approval of the institutional ethical committee (Registration no: 1529; Dated 29 November 2021) by the ethical standards established by the Declaration of Helsinki (Finland) (World Medical Association Declaration of Helsinki 2013).

The following were the inclusion criteria:

1. OPGs of known age and sex that do not have indications of a systemic disease or disorders that impact tooth growth at an accelerated or delayed rate
2. High-quality OPGs (preferably showing both mandibular third molars)

The following conditions were excluded:

1. Individuals with any kind of bone or dental disease or abnormal tooth development
2. Patients whose orthodontic treatment may have influenced the rate of development of third molars
3. Third molars with no distinct roots, three roots, or missing roots (congenital or surgical extraction)
4. OPGs indicating the Demirjian stage A to C of the third molar's development.

The sex, date of birth, date of exposure, and identifying number of each patient were all recorded. The chronological age (CA) in decimal years of each person was then calculated by subtracting their date of birth from the date of radiation exposure. The age and sex of the individuals were concealed. The distribution of the included individuals by sex and age is depicted in Fig. 1. The subjects' demographic information was obscured, and the pictures were exported in Joint Photographic Experts Group (JPEG) format before analysis to preserve anonymity. The images were randomly generated by a third observer (MS), who also gathered the data from the other two observers (JP and VK) and

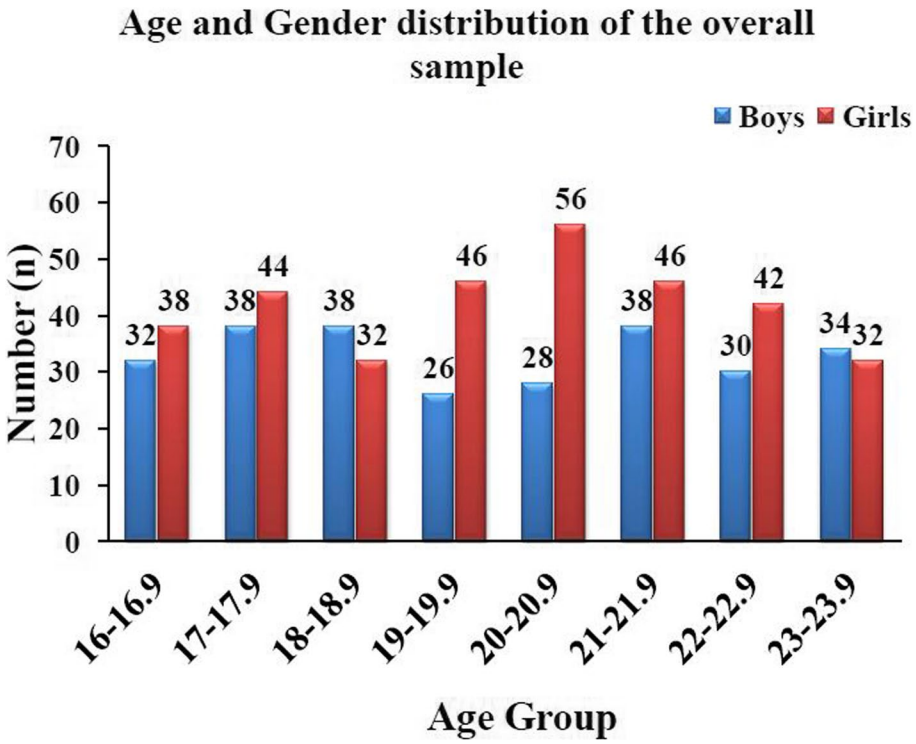


Fig. 1 The overall distribution of included samples according to the sex and age group of the individual

inputted the information post-analysis about the blinded images to correlate with the chronological age of the corresponding individual.

Cameriere's method

Cameriere et al. (2008) method was used to examine left-sided third molars. In cases where the left molars cannot be analyzed or missing, the right-side third molar was examined because the development of third molars on both sides is related (Schmeling et al. 2008). The third molar maturity index is calculated as the sum of the distances between the inner surfaces of the mesial and distal roots divided by the total length (I_{3M}). Photopea version 5.1 was used to estimate the distances between the apices of the mesial root (a), distal root (b), and overall length (c), as shown in Fig. 2. I_{3M} was calculated using the following formula: $I_{3M}=\frac{a+b}{c}$. The I_{3M} score is zero ($I_{3M}=0.0$) if the root development is finished. Following the calculation of the maturity index score, a population-specific formula developed by Balla et al. (2019) is used to estimate dental age (DA) separately for males and females.

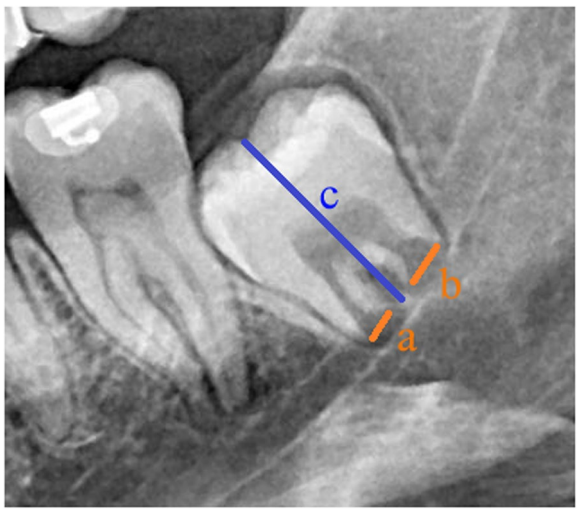


Fig. 2 The third molar maturity index evaluation method is depicted in this image. The orange lines (**a** and **b**) depict the distance between the root apices, whereas the blue line represents the whole length of the tooth (**c**)

$$\text{Males}: \text{Age} = 18.766 - (8.058 \times I_{3M}) + (3.171 \times I_{3M^2}) - (0.441 \times I_{3M^3})$$
$$\text{Females}: \text{Age} = 19.063 - (8.412 \times I_{3M}) + (3.136 \times I_{3M^2}) - (0.415 \times I_{3M^3})$$

UT-age estimation method

The UT-age estimation program v. 2.2.23, developed by Lewis, Silvaggi, and Senn, calculates dental age in terms of estimated mean age and the empirical probability that the individual has attained at the age of 18 and therefore makes it easier to record and maintain age estimates (Lewis and Senn 2010). A new case option is selected, and the person's details including name, sex, ancestry, and date of exposure are entered into the case information page. Once submitted, third molar staging from D to H is selected for the field available, with the option to upload a panoramic radiograph, which however is not mandatory.

In case there are any issues, the staging suggested by Kasper et al. (2009) is depicted in the help option. All the included OPGs were assessed by one observer (JP), and a second observer (VK) examined 300 OPGs to determine repeatability and inter-observer agreement. After a month, one observer (JP) observed 300 OPGs in a random sequence to determine intra-observer agreement. A third observer (MSM) enters the estimated dental ages of the two observers for both procedures into Microsoft Office Excel 2016 before doing statistical analysis.

Statistical analysis

The statistical analysis was carried out using the Statistical Package for the Social Sciences (SPSS) 21.0 for Windows (SPSS Inc., Chicago, IL, USA). The significance level for analysis was set at 5% ($p < 0.05$). Descriptive statistical analysis with mean and standard deviation for estimated dental age (DA) was done separately for males and females using Cameriere's method and the UT-age estimation method. A paired *t*-test was used to compare the means of chronological age (CA) and estimated dental age (DA) derived using Cameriere's method and the UT-age estimation method for both men and females in the included sample. Pearson's correlation test was used to assess the relationship between the DA and CA estimated using modified Cameriere's approach and the UT-age estimation method. The use of kappa statistics was done to evaluate intra- and inter-observer reliability. The contingency table was used to calculate the sensitivity, specificity, and accuracy of classification of whether an individual has reached major age based on the maturity index. The mean absolute error, as well as age under- or overestimation, was calculated for the differences between the actual chronological age and the estimated dental age using the abovementioned two approaches.

Results

Only 600 of the 876 OPGs observed matched our inclusion and exclusion criteria, with 264 males and 336 females ranging in age from 16 to 23 years. They were divided into eight age groups ranging from 16–16.9 to 23–23.9 years. Figure 1 illustrates the sample's general age and sex distribution. The discrepancy in estimated dental age was described in terms of underestimation or overestimation. Underestimation (negative value) occurs when the estimated dental age is less than the actual chronological age. Overestimation (positive value) occurs when the estimated dental age is larger than the actual chronological age.

The intra-class correlation coefficient for the intra-observer agreement was 86.2% (95% *CI*, 82.8–89.6%), while for the inter-observer agreement, it was 87.6% (95% *CI*, 84.8–90.3%). This demonstrates that I_{3M} evaluation by the same observer or two observers may be done with very good repeatability.

Modified Cameriere's method

Overestimation in chronological age was noted in males belonging to the 17–17.9 age group by around 1 year, which was statistically insignificant ($p = 0.486$). Except for individuals aged 17 to 17.9 years, all age groups showed an underestimation of chronological age, which was highly statistically significant ($p = 0.000$). Highly significant differences ($p < 0.001$) in underestimation were seen, ranging from less than 1 year (19–19.9 years) to more than 4 years (23–23.9 years). The differences between CA and estimated DA calculated using the modified Cameriere's approach are displayed in Table 1.

UT-age software method

In the age ranges of 16–16.9, 17–17.9, and 19–19.9-year age groups, dental age was overestimated in females and the overall sample, with a highly statistically significant difference ($p = 0.000$). Underestimation of chronological age was seen with statistically significant differences ($p = 0.001$) in the age ranges of 21–21.9- to 23–23.9-year age group for males, females, and overall. The differences between the CA and the estimated DA obtained using the UT-age estimation method are displayed in Table 2.

Table 3 demonstrates the overall underestimation and overestimation of chronological age using the UT-age method and Cameriere's method in terms of less than, more than, greater than 1 year, and greater than 2 years.

Correlation of estimated DA and CA

A moderate correlation between chronological age and estimated dental age was found using Pearson's correlation test. According to the UT-age method and Cameriere's method, the differences between males, females, and both groups were highly statistically significant ($p = 0.000$), as shown in Table 4. Additionally, a very strong correlation between the estimated dental age estimated by the UT-age technique and Cameriere's method

Table 1 The paired *t*-test was used to compare the differences between the chronological age and the dental age calculated using the modified Cameriere technique (SB Balla formula adaption) *Denotes statistically significant differences ($p \leq 0.05$), whereas ** denotes highly statistically significant differences ($p \leq 0.001$)

Age group	Gender	*N*	Chronological age (CA) (mean ± SD)	Dental age (DA) (mean ± SD)	CA–DA (mean ± SD)	*p*-value
16–16.9	**Male**	32	16.46 ± 0.26	17.14 ± 1.03	− 0.69 ± 0.92	0.000**
	Female	38	16.51 ± 0.32	17.8 9 ± 0.84	− 1.38 ± 0.82	0.000**
	Total	70	16.49 ± 0.29	17.55 ± 1.00	− 1.06 ± 0.93	0.000**
17–17.9	**Male**	38	17.46 ± 0.30	19.67 ± 2.15	− 2.20 ± 2.26	0.000**
	Female	44	17.50 ± 0.26	18.99 ± 1.86	− 1.48 ± 1.85	0.000**
	Total	82	17.49 ± 0.28	19.30 ± 2.02	− 1.82 ± 2.07	0.000**
18–18.9	**Male**	38	18.57 ± 0.24	19.10 ± 2.05	− 0.52 ± 2.05	0.122
	Female	32	18.59 ± 0.31	18.98 ± 1.54	− 0.38 ± 1.54	0.174
	Total	70	18.58 ± 0.28	19.04 ± 1.82	− 0.46 ± 1.82	0.039*
19–19.9	**Male**	26	19.41 ± 0.28	19.56 ± 1.34	− 0.15 ± 1.33	0.572
	Female	46	19.56 ± 0.30	20.27 ± 1.49	− 0.70 ± 1.52	0.003*
	Total	72	19.51 ± 0.30	20.01 ± 1.47	− 0.50 ± 1.48	0.005*
20–20.9	**Male**	28	20.55 ± 0.27	20.04 ± 1.78	− 0.51 ± 1.76	0.135
	Female	56	20.53 ± 0.29	19.23 ± 1.69	1.30 ± 1.65	0.000**
	Total	84	20.54 ± 0.29	19.50 ± 1.76	1.03 ± 1.72	0.000**
21–21.9	**Male**	38	21.47 ± 0.29	20.76 ± 1.24	0.70 ± 1.17	0.001**
	Female	46	21.48 ± 0.33	20.76 ± 1.28	0.71 ± 1.19	0.000**
	Total	84	21.47 ± 0.31	20.77 ± 1.25	0.71 ± 1.18	0.000**
22–22.9	**Male**	30	22.50 ± 0.24	21.07 ± 1.06	1.43 ± 0.96	0.000**
	Female	42	22.63 ± 0.24	21.19 ± 1.14	1.44 ± 1.23	0.000**
	Total	72	22.58 ± 0.24	21.14 ± 1.10	1.44 ± 1.13	0.000**
23–23.9	**Male**	34	23.43 ± 0.29	21.52 ± 0.24	1.91 ± 0.29	0.000**
	Female	32	23.43 ± 0.32	21.56 ± 0.59	1.86 ± 0.66	0.000**
	Total	66	23.43 ± 0.30	23.54 ± 0.45	1.89 ± 0.50	0.000**

was noted among males, females, and both groups with highly statistically significant differences ($p = 0.000$) as shown in Table 4.

Predictive classification using I_{3M} value

The identification of an individual's majority status based on the I_{3M} value was evaluated using a contingency table. I_3M value greater than or equal to 0.08 indicates age less than 18 years, and values less than 0.08 indicate age more than 18 years. A total of 75.59% of 264 men (158/209) were accurately categorized as majors, while 92.73% (51/55) were classified as minors. Among 336 females, 65.01% (171/263) were classified as majors and 100% (73/73) were classified as minors. The overall accuracy of applying I_{3M} to validate the legal threshold of 18 years was estimated to be 79.17%, demonstrating that this is a reliable predictor. Table 5 shows the contingency table describing the discrimination performance of the cut-off value of the third molar maturity index in males and females.

Predictive classification according to age group using UT-age estimation

Predictive classification of individuals' majority status is not possible using this method because the cutoff value for classifying individuals above or below 18 years of age, which is similar to Cameriere's method, cannot be established. As a result, individuals were classified based on their chronological age group versus dental age estimated using UT-age estimation. Out of 600 people, only 98 were classified according to their age group, with the majority of those classified falling into the 16, 17, 19, and 21 age ranges. This explains both the underestimation and the overestimation recorded by the age estimation software method as previously shown in Tables 2 and 3.

Discussion

Estimating a person's age is crucial in the field of forensics since it helps with the identification process. Applications for age estimation include identifying missing

Table 2 The paired *t*-test was used to compare the differences between chronological age and dental age calculated using UT-age estimation software

Age group	Gender	*N*	Chronological age (CA) (mean ± SD)	Dental age (DA) (mean ± SD)	CA–DA (mean ± SD)	*p*-value
16–16.9	**Male**	32	16.46 ± 0.26	15.39 ± 1.43	1.07 ± 1.32	0.000**
	Female	38	16.51 ± 0.32	15.70 ± 1.32	0.81 ± 1.29	0.000**
	Total	70	16.49 ± 0.29	15.56 ± 1.37	0.93 ± 1.30	0.000**
17–17.9	**Male**	38	17.46 ± 0.30	17.65 ± 1.48	− 0.18 ± 1.60	0.486
	Female	44	17.50 ± 0.26	16.71 ± 1.61	0.78 ± 1.59	0.002*
	Total	82	17.49 ± 0.28	17.15 ± 1.62	0.34 ± 1.66	0.068
18–18.9	**Male**	38	18.57 ± 0.24	17.60 ± 1.47	0.97 ± 1.50	0.000**
	Female	32	18.59 ± 0.31	17.13 ± 1.74	1.47 ± 1.67	0.000**
	Total	70	18.58 ± 0.28	17.39 ± 1.61	0.19 ± 1.59	0.000**
19–19.9	**Male**	26	19.41 ± 0.28	17.73 ± 0.67	1.68 ± 0.65	0.000**
	Female	46	19.56 ± 0.30	17.99 ± 1.40	1.58 ± 1.50	0.000**
	Total	72	19.51 ± 0.30	17.89 ± 1.19	1.61 ± 1.26	0.000**
20–20.9	**Male**	28	20.55 ± 0.27	18.06 ± 1.15	2.49 ± 1.05	0.000**
	Female	56	20.53 ± 0.29	17.32 ± 1.42	3.21 ± 1.36	0.000**
	Total	84	20.54 ± 0.29	17.57 ± 1.38	2.97 ± 1.30	0.000**
21–21.9	**Male**	38	21.47 ± 0.29	18.46 ± 0.56	3.00 ± 0.59	0.000**
	Female	46	21.48 ± 0.33	18.63 ± 0.58	2.85 ± 0.59	0.000**
	Total	84	21.47 ± 0.31	18.55 ± 0.57	2.92 ± 0.59	0.000**
22–22.9	**Male**	30	22.50 ± 0.24	18.71 ± 0.13	3.82 ± 0.23	0.000**
	Female	42	22.63 ± 0.24	18.72 ± 0.89	3.91 ± 1.01	0.000**
	Total	72	22.58 ± 0.24	18.71 ± 0.68	3.87 ± 0.79	0.000**
23–23.9	**Male**	34	23.43 ± 0.29	18.68 ± 0.25	4.76 ± 0.30	0.000**
	Female	32	23.43 ± 0.32	18.97 ± 0.27	4.46 ± 0.43	0.000**
	Total	66	23.43 ± 0.30	18.82 ± 0.29	4.61 ± 0.39	0.000**

* Denotes statistically significant differences ($p \leq 0.05$), whereas ** denotes highly statistically significant differences ($p \leq 0.001$)

people, and unknown victims, categorizing immigrants, and estimating whether someone is eligible for social benefits (Cunha et al. 2009; Schmeling et al. 2008). This can be accomplished by assessing skeletal, dental, morphological, and sexual development.

Dental age is estimated by evaluating tooth eruption or tooth formation, which provides a suggestion about dental maturity. Third molars take a long time to develop, and the various stages of their development may be linked to age estimation in the age range below 20 years; it is the sole approach of its sort (Ramisetty Sabitha Devi et al. 2017). Legal age can be established by observation and measurement of the third molar maturation process (Liversidge 2008; Galić et al. 2013; Cameriere et al. 2008).

OPG is a minimally intrusive method that has been recommended by ABFO and SGFAD as a standard investigative process in dental-based identification. OPGs are frequently employed to give forensic authorities important information on the dental development of individuals because of the unexpected increase in demand for the assessment of minors' ages in many forensic and medicolegal processes (Angelakopoulos et al. 2018).

The association between the chronological age and the third molar maturity index (I_{3M}) was found by Cameriere et al. in 2008 (Cameriere et al. 2008 Nov). He developed a threshold ($I_{3M} < 0.08$) that could be used to classify individuals as major or minor based on the measurement of the apices of the third molar. Additionally, he concluded that the individual's majority status was significantly impacted by insufficient mineralization stages of the Demirjian staging system (Cameriere et al. 2008). Variabilities are identified due to tooth mineralization or maturation timelines; genetic, biological, and geographical factors; and diet, socioeconomic level, and ethnicity (Elamin and Liversidge 2013; Black et al. 2011).

Many research has been conducted on various populations to determine the efficacy of the third molar maturity index in identifying the legal age of persons. In a sample of 339 French people, Tafrount et al. (2019) reported an overall accuracy of 90.65%, with sensitivity for males and females of 87.1% and 95.3%, respectively,

Table 3 Overestimation and underestimating of chronological age calculated using the modified Cameriere's approach and the UT-age estimation method in terms of less than a year, more than a year, and 2 years

Method	Population	Overestimation (in years)			Underestimation (in years)		
		< 1	> 1	> 2	< 1	> 1	> 2
UT age	**Males**	16–16.9 18–18.9 19–19.9 20–20.9	-	17–17.9	21–21.9	22–22.9 23–23.9	-
	Females	18–18.9 19–19.9	16–16.9 17–17.9	-	21–21.9	20–20.9 22–22.9 23–23.9	-
	Overall	18–18.9 19–19.9	16–16.9 17–17.9		21–21.9	20–20.9 22–22.9 23–23.9	-
Modified Cameriere	**Males**	17–17.9	-	-	18–18.9	16–16.9 19–19.9	20–20.9 21–21.9 22–22.9 23–23.9
	Females	-	-	-	16–16.9 17–17.9	18–18.9 19–19.9	20–20.9 21–21.9 22–22.9 23–23.9
	Overall	-	-	-	16–16.9 17–17.9 18–18.9	19–19.9	20–20.9 21–21.9 22–22.9 23–23.9

Table 4 Pearson's correlation coefficient test between chronological age and estimated dental age using two methods (males, female, and total)

Category	Comparison group	*r*-value	*p*-value
Males	CA vs. DA (modified Cameriere's method)	0.588	0.000**
	CA vs. DA (UT-age method)	0.598	0.000**
	DA (modified Cameriere's method vs. UT-age method)	0.835	0.000**
Females	CA vs. DA (modified Cameriere's method)	0.598	0.000**
	CA vs. DA (UT-age method)	0.588	0.000**
	DA (modified Cameriere's method vs. UT-age method)	0.890	0.000**
Total	CA vs. DA (modified Cameriere's method)	0.590	0.000**
	CA vs. DA (UT-age method)	0.592	0.000**
	DA (modified Cameriere's method vs. UT-age method)	0.861	0.000**

** Refers to highly statistically significant differences ($p \leq 0.001$)

Table 5 Contingency table for predictive classification utilizing I_{3M} value of 0.08 for categorizing people over or under the age of 18. True positive is represented by letter *a*, false positive by letter *b*, false negative by letter *c*, and true negative by letter *d*

Test	Males		Total males	Females		Total females
	Age (years)			Age (years)		
	≥ 18	< 18		≥ 18	< 18	
I_{3M} < 0.08	158[a]	4[b]	162	171[a]	0[b]	171
$I_{3M} \geq 0.08$	51[c]	51[d]	102	92[c]	73[d]	165
Total	209	55	264	263	73	336

and specificity for males and females of 81.3% and 96.2%. According to Kumagai et al. (2019), 276 Koreans had an accuracy rate of 89%, and the results for sensitivity (89% for males and 84% for females) and specificity (96% for males and 93% for females) indicated a good prediction of legal age. According to Angelakopoulos et al. (2018), the sensitivity was 80%, and specificity was 95% in 833 South African people. Chu et al. (2018) found an accuracy of 94.8%, a sensitivity of 90.7%, and a specificity of 100% in 840 Chinese people.

In our study, the overall accuracy of utilizing the third molar maturity index in the classification of 18 years or older was found to be 75.90% (79.17% for males and 72.62% for females). Sensitivity was 75.60% for males and 65.02% for females, while specificity was 92.73% for males and 100% for females. This was consistent with research carried out in an Indian population by Balla et al. (2017), where the sensitivity was found to be 86.7%, 96.7% specificity, and overall accuracy to be 92.15% (93.1% for males and 91.2% for females). According to research by Sharma et al. (2017), the sensitivity was found to be 74.7% for males and 66.66% for females, while the specificity was 83.6% for males and 79.6% for females. Thilak et al. (2021) discovered similar results in a study of the Goan population, where the sensitivity was 89.9% for males and 85.4% for females, while the specificity appeared to be 90.9% for males and 93.1% for females.

Research on forensic age estimates has recently tended to focus on developing population-specific formulas that may be used to lower mistakes and enhance the accuracy of the age estimation approach (Scendoni et al. 2020). Errors in estimating age can result from either underestimating or overestimating the chronological age, as well as the mean absolute error (MAE). This was further investigated in our study, where the application of the third molar maturity index in estimating a dental age was examined using a population-specific formula provided by Balla et al. (2019), making our study the first of its type in enhancing the utility of the maturity index.

In our study, the MAE was found to be 2.15 years for males, 2.39 years for females, and 2.29 years for overall sample when modified cameriere's method was used. Similar results were found in the research by Balla et al. (2019), where the MAE was 1.59 years for males, 1.53 years for females, and 1.54 years overall. In addition, the chronological age was overestimated by 0.2 years in males and 0.13 years in females in their research. In contrast to their findings, our study overestimated the age of males between 17 and 17.9 years by less than 1 year. A 1-year underestimation was seen in the age group under 19 years.

The UT-age estimate approach used data from numerous population studies. To determine the chronological age and empirical probability that a person has reached the age of 18, Blankenship et al. (2007) compared American Blacks with whites. In his analysis, the MAE for males was estimated to be 0.44 years and 0.97 years for females, and the overall MAE was 0.70 years. These results were comparable to those of research by Kasper et al. (2009) in the Hispanic population of Texas, where the MAE was 0.67 years, 0.91 years, and 0.79 years for males, females, and the total population, respectively. According to Arthanari et al. (2021), who studied the reliability of the UT-age estimate technique in the Indian population, the MAE for males was 0.52 years, for females was 0.78 years, and the MAE overall was 0.65 years. Similarly, in our study, MAE was estimated to be 0.07 years in males, 0.19 in females, and 0.14 in the total population, which is smaller than all the prior studies reported.

Limitations

The presence and position of the third molar are one of the key constraints of using it in age estimation. In patients with horizontal impaction, it is challenging to evaluate the third molar for the maturity index. Additionally, there is variation in the maturation of third molars (stage H) in individuals between the ages of 16 and 25, which can result in an under- or overestimation of age when the software approach or maturity index method is used. In the forensic context, third molars can be intentionally extracted to forge the true age; as a result, this should be taken into account when estimating legal age in relation to dental age estimate methodologies.

Underestimation of age was observed in nearly all groups, to varying degrees of year, when the regression model was used to calculate age based on the maturity index. This might be explained by the fact that those above the age of 18 had a maturity score of 0 when the root apices were closed. As a result, substituting this value into a sex-specific formula yields a fixed age (18.766 years for males and 19.063 years for females) that varies with actual chronological age.

Suggestions

When UT-age estimating software was applied, our study found a slight age underestimation. Third molar evaluation can be used in population-specific investigations to create a data set that can be compared to other age estimation methods. Age estimation can be modified for individuals above the age of 18 by substituting the maturity index in the regression calculation, as these groups were more prone to underestimating. Additionally, all

third molars, or at least bilateral mandibular molars, can be used to compare side disparities. Expanded research should be conducted on the Indian population to evaluate its validity with larger sample size.

Conclusions

According to the findings of our study, Cameriere's method is a reliable indicator for identifying people 18 years or older. Regardless of age group, an underestimation was found when the applicability of an Indian-specific formula for age estimation was examined. On the other hand, UT-age estimation software generated dental age estimations with the least amount of absolute error, making it a dependable approach for age estimation that is more effective without compromising diagnostic accuracy.

Abbreviations

CI	Confidence interval
UT	University of Texas
OPG	Orthopantomogram
kVp	Kilovoltage peak
mA	Milliampere
I_{3M}	Third molar maturity index
DA	Dental age
CA	Chronological age
MAE	Mean absolute error
ABFO	American Board of Forensic Odontology
SGFAD	Study Group on Forensic Age Diagnostics

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Authors' contributions

Dr. JP—conceptualization, data curation, formal analysis, methodology, and writing—original draft; Dr. VK — data curation, formal analysis, and writing review and editing; Dr. MS — conceptualization, data curation, formal analysis, methodology, and writing—original draft; Dr. LKS — supervision, validation, visualization, and writing—review and editing; and Dr. AF — supervision, validation, and visualization. The authors read and approved the final manuscript.

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Availability of data and materials

The data sets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval was obtained from the institutional ethical committee with registration number 1529 dated 29 November 2021. This study is an observational study that does not involve any intervention made on human participants. Informed consent was obtained from the patients during the radiographic procedure.

Consent for publication

Informed consent was obtained from the patients for publication at the time of the radiographic procedure.

Competing interests

The authors declare that they have no competing interests.

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