Modified radiographic age estimation criteria based on third molar eruption and mineralization status

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KEYWORDS

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ABSTRACT

Background: Radiographic assessment of the eruption and maturation status of third molars is widely used for age estimation.

Aim: This study compared the effectiveness of radiographic age estimation based on the eruption and mineralization status of third molars and proposed a new regression equation that combined both factors.

Methodology: Eruption and mineralization status of 995 third molars from 269 individuals (North-Indian Subpopulation) were assessed using panoramic radiographs (OPGs) of individuals aged 12-25 years. The Olze et al. (2007) criterion was applied to evaluate eruption levels, whereas a new simplified criterion was proposed to assess mineralization status. 71 additional OPGs were used to validate the proposed regression equations.

Results: A significant correlation was observed between chronological age and the stages of both methods; however, this correlation was slightly stronger for the mineralization method than for the eruption method. Regression Equation 1 (status of all four third molars was determined) consistently showed lower mean absolute difference (MAD) (females: 1.89 years; males: 1.22 years) and root mean square error (RMSE) (females: 2.22 years; males: 1.57 years), indicating smaller prediction errors and greater precision. Equation 2 (applied in cases where any third molar was impacted) exhibited higher MAD (females: 2.35 years; males: 1.90 years) and RMSE (females: 3.13 years; males: 3.09 years), reflecting comparatively larger deviations between estimated dental and chronological ages.

Conclusion: The mineralization method provides a more balanced and diagnostically reliable approach for age estimation, with a higher area under the curve, sensitivity, better overall accuracy, and superior discriminative ability for the estimation of 18 years. In contrast, Olze's eruption method demonstrated higher specificity, making it more useful when minimizing false-positive classification is a priority. Although Regression Equation 1 could estimate dental age more accurately, in cases where third molars are impacted, Regression Equation 2 could be useful.

INTRODUCTION

The assessment of dental age (DA) during the mid-teens to early twenties is based mainly on the development and

eruption status of the third molars, as they are the only teeth that develop and erupt during this period.[1-3] Numerous radiographic studies have been conducted in the last few decades in various ethnic groups to corroborate the role of third molars in age estimation. However, the majority of them evaluated mineralization status, while a few studies considered the eruption stages.[4-5] Although tooth eruption appears to follow a predictable pattern and timing, it is governed by a complex interaction of biological (gender, ethnicity, physical and sexual development), genetic, environmental (socioeconomic status), local (infection, premature loss of primary teeth, lack of space, impaction, crowding of permanent teeth, decayed teeth), craniofacial morphology and systemic (hormonal, nutritional factors and systemic diseases) factors, each contributing to the normal or pathological progression of tooth emergence. [6-9] On the contrary, tooth mineralization is a continuous process largely driven by genetic factors with less influence from other factors and can be assessed radiographically over a long period, using different stages of tooth formation as a criterion.[10-13]

Numerous classification systems have been proposed to categorize the mineralization status of the tooth based on crown and root development status, featuring a variable number of stages.[10,14] The most commonly employed criteria were Demirjian et al. 1973 and Nolla 1960, which have 8 and 10 developmental stages, respectively.[15-16] However, evaluating the large number of stages in available systems limits their reliability for accurate stage determination.[5,17] The relative morphological comparison (crown height/root length) is also inevitable in most staging techniques.[14] Therefore, researchers proposed modifications and adaptations of these criteria, including fewer stages.[18-20] Sant Anna et al. 2010 modified Nolla's criteria and proposed five stages to assess dental maturity.[21] Olze et al. in 2005 examined the validity of five different stage-based systems to assess the mineralization of third molars and found that the Harris and Nortje criteria (five stages) yielded results comparable to those of Demirjian et al. criteria. However, the Gustafson and Koch criteria (which involved four stages, commencement of mineralization; completion of crown; eruption when cusp(s) penetrate gingiva; completion of the root) have slightly lower accuracy than the Demirjian et al. criteria.[22] Moreover, determining apex closure, one of the major criteria, is particularly difficult, especially in maxillary molars, due to the superimposition of surrounding structures and compromised radiographic quality. In addition, literature reports the delayed closure of the apices due to poor socioeconomic status.[4,14,23] After considering the modifications and limitations of established criteria and the fact that Nolla's criteria has been developed to be applied to third molars, this study adapted and modified his criteria and proposed a newer classification system to determine the mineralization status of a tooth with four stages, without considering the comparison of crown height: root length and assessment of apex closure.

Moreover, most studies available in the literature present population-specific data independently based on either the eruption or mineralization status of the third molars. Thus, the present study was designed to compare the effectiveness of radiographic criteria for age estimation based on the eruption and mineralization status of third molars and to amalgamate these two independent elements by formulating a regression equation to improve the accuracy and reliability of DA estimation among individuals reporting to our institute, catering primarily to the North-Indian subpopulation.

METHODOLOGY

Study design and settings:

This retrospective institution-based observational study was conducted among individuals who reported to the Department of Oral and Maxillofacial Radiology, Post Graduate Institute of Dental Sciences, Rohtak, Haryana, catering primarily to the North-Indian subpopulation for routine radiographic examinations. Ethical approval was obtained from the institutional Biomedical Health and Research Committee (PGIDS/BHRC/23/35 dated 27.06.2023).

Sample size calculation:

After deciding on a timeframe of six months, the Raosoft sample size calculator was used to determine the sample size with 600 as the

number of eligible OPGs at a 95% confidence level, 5% margin of error and 50% response distribution rate. The minimum sample size was calculated as 235. The following formula was used to calculate the sample size:

$$x = Z(c/100)^2 r(100-r)$$

$$n = Nx/((N-1)E^2 + x)$$

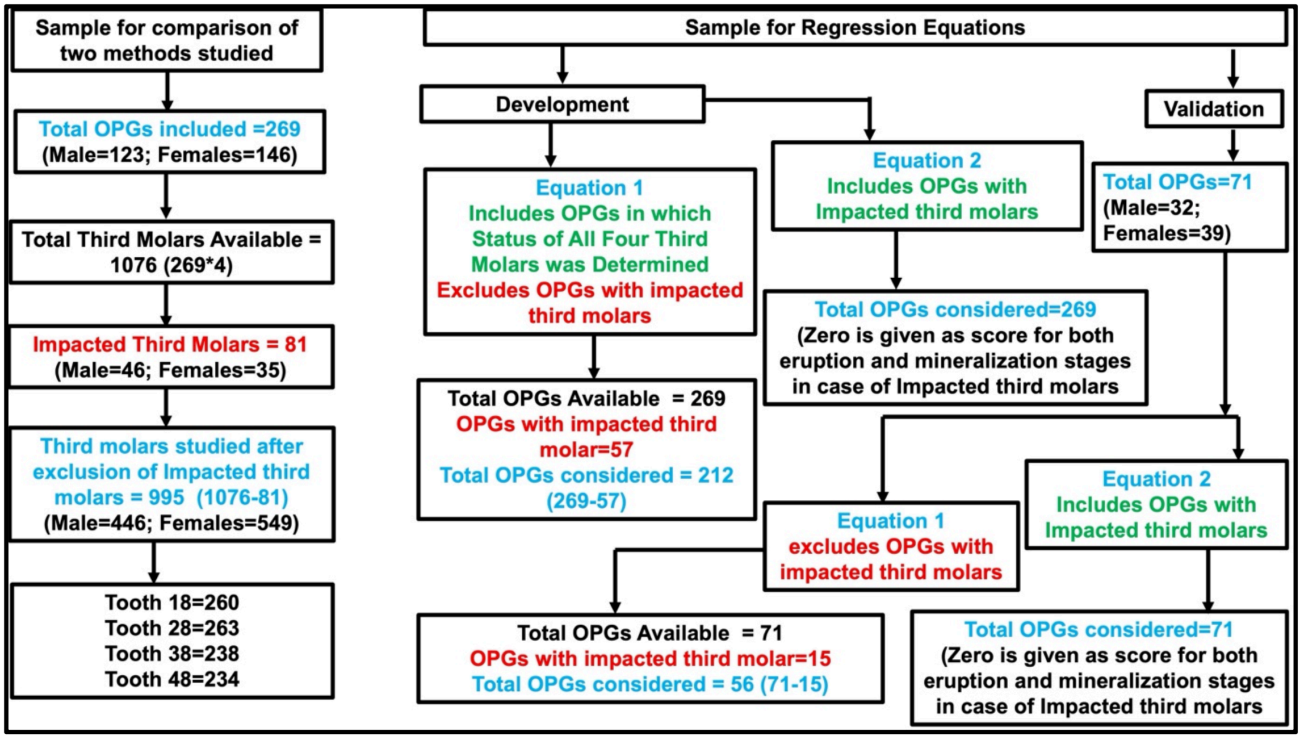
$$E = \mathrm{Sqrt}[(N - n)x/n(N-1)]$$

where N is the population size, r is the fraction of responses, Z(c/100) is the critical value for the confidence level c, n is the sample size, and E is the margin of error.[24]

Participants:

Panoramic radiographs (OPGs) from 350 individuals aged between 12 and 25 years who reported in the past six months were retrieved from the archives of the department. Radiographs were obtained using an orthopantomography machine (Papaya Plus, M/s Genoray Co. Limited, South Korea), and all scans were evaluated on a desktop monitor with an 8-bit depth and a resolution of 1920×1080. A total of 269 OPGs from the retrieved sample that showed all four third molars (developing or developed) were included in the study. OPGs showing developmental anomalies, trauma, orthodontic treatment or distortion were excluded from the study. Individual third molars that were impacted or had indiscernible root structures were also excluded. Thus, this study evaluated a total of 995 third molars, of which the maxillary right (18), maxillary left (28), mandibular left (38) and mandibular right (48) were 260, 263, 238 and 234, respectively. The FDI tooth-numbering system was used to represent third molars. Presents a detailed outline of the sample distribution for comparison of the two methods, formulation, and validation of regression equations.

Figure 1. Detailed Outline of Sample Distribution



Data Collection:
One investigator retrieved and assigned a unique identification number to each OPG. The date of birth and the date on which the radiograph was taken were recorded, and the chronological age (CA) was calculated by subtracting the date of birth from the date of the radiograph. Two examiners blinded to the CA reviewed the radiographs and recorded the eruption and mineralization status of the tooth. In the case of disagreement, the least developed stage was chosen.[15,25]
Olze et al.'s (2007)[26] criterion was used to appraise the eruption status, which is as follows: Stage A: The occlusal plane is covered with alveolar bone; Stage B: Alveolar emergence; complete resorption of alveolar bone over the occlusal plane; Stage C: Gingival emergence; penetration of gingiva by at least one dental cusp; and Stage D: Complete emergence in the occlusal plane.
The mineralization status of third molars was assessed using the newly proposed mineralization criteria, as follows:
Stage A- Crown formation completed
Stage B- 1/3rd of root formation completed
Stage C- 2/3rd of root formation completed
Stage D- Complete root formation without considering apex closure

Statistical Analysis:
The data collected were subjected to statistical analysis using SPSS Software version 23.0 (IBM Corp., Armonk, NY) and Jamovi Software version 2.6.0. Parametric data are expressed as mean and standard deviation, and categorical data are presented as frequencies and percentages. To assess inter- and intra-observer reliability, Cohen's kappa and intraclass correlation coefficients were applied. Pearson's chi-square test was used to compare categorical data. Pearson's correlation test was used to correlate the two variables. Paired t-tests and one-way ANOVA were used to compare the means between groups. The receiver operator characteristic (ROC) curve was plotted to compare the efficacy of the two methods in estimating 18 years of age. DeLong's test was employed to compare the area under the curve (AUC) of the two methods. In addition, diagnostic test parameters (sensitivity, specificity, positive likelihood ratio (LR+), negative likelihood ratio (LR-), positive predictive value (PPV), negative predictive value (NPV), accuracy and Youden's index) were used to compare the efficacy of the stages for two methods. Regression analysis was performed to formulate an equation to predict DA using the combined eruption and mineralization status of the third molars. The predictive accuracy of the formulas for estimating DA was established based on the mean absolute difference (MAD) and root mean square error (RMSE) values. $p<0.05$ was considered significant.

RESULTS

Inter- and Intra-observer reliability:
Cohen's kappa was computed from 995 third molars to assess the inter-observer reliability, which was 0.799 and 0.973 for Olze's eruption and new mineralization criteria, respectively, indicating good and very good inter-observer agreement, respectively.[27] The intraclass correlation coefficient was applied to randomly selected 100 third molars to assess intra-observer reliability, which was 0.987 and 0.998 for Olze's eruption and the new mineralization method, representing excellent reliability.[28]

Demographic Details:
Of 269 subjects, 146 were female, and 123 were male. The mean CA of the 269 included participants was 17.57±3.32. The mean CA for females and males was 17.97±3.33 and 17.10 ±3.25 years, respectively.
Of the 995 third molars assessed, 446 were from males, and 549 from females. The difference in the mean CA between males (16.878 ± 3.202) and females (17.839 ± 3.322) was found to be statistically significant ($p<0.001$). (Table S1) A statistically significant difference was observed in the mean CA between different stages of Olze's eruption (Stage A: 15.204 ± 2.080; Stage B: 17.466 ± 2.613; Stage C: 19.636 ± 2.872; Stage D: 21.171 ± 2.315; $p<0.001$) and the new mineralization (Stage A: 14.729 ± 1.799; Stage B: 16.438 ± 1.973; Stage C: 17.494 ± 2.415; Stage D: 20.787 ± 2.382; $p<0.001$) method. (Table S2) However, no significant difference was observed in the mean CA for individual third molars ($p=0.871$) and arch-

wise (p=0.449) comparisons. (Table S3 and S4).

Comparison of Olze's eruption and the newer mineralization method:

A statistically significant correlation was observed between CA and stages of both methods for all four third molars combined, individual third molars, sex and arch. However, the correlation coefficient was higher for the mineralization method than for Olze's eruption method for all the evaluated parameters. (Table 1) When all four third molars were considered together, the difference between the mean CA of the two methods was statistically significant for stages A, B and C; however, this difference was not significant for stage D. (Table 2) The stage-wise comparison of the mean CA of the two methods regarding individual third molars, sex and arches are presented in Table S5-S7.

A statistically significant difference was observed in the number of third molars in different stages of the two methods for all four third molars combined, individual third molars, sex and arches. (Table 3, S8-10)

When all four third molars were considered together, the ROC curve revealed that the AUC was statistically significantly higher for the mineralization method than for the eruption method for the estimation of 18 years of age. (Figure 2) Considering stage D as the cut-off stage, the new mineralization method had higher sensitivity, NPV, accuracy and Youden's index compared to Olze's eruption method. However, a higher LR+ of 15.50 for stage D of Olze's eruption method suggests that there is a greater likelihood of an individual being ≥18 years for stage D of Olze's eruption. (Table 4)

Table 5 shows the stage-wise percentage probability of an individual being ≥18 years for all four third molars together, individual third molars, arches and sex for both methods.

Table 1. Correlation of chronological age and stages of both methods

Parameters		CA-Olze's Eruption Method			CA-New Mineralization Method			Olze's Eruption- New Mineralization Method		
		n	r	p-value	n	r	p-value	n	r	p-value
Combined all four third molars		995	0.695	<0.001	995	0.758	<0.001	995	0.847	<0.001
Individual Tooth-wise	Tooth 18	260	0.655	<0.001	260	0.704	<0.001	260	0.850	<0.001
	Tooth 28	263	0.677	<0.001	263	0.726	<0.001	263	0.855	<0.001
	Tooth 38	238	0.732	<0.001	238	0.803	<0.001	238	0.840	<0.001
	Tooth 48	234	0.727	<0.001	234	0.815	<0.001	234	0.845	<0.001
Sex-wise	Male	446	0.738	<0.001	446	0.817	<0.001	446	0.854	<0.001
	Female	549	0.672	<0.001	549	0.718	<0.001	549	0.842	<0.001
Arch-wise	Maxillary	523	0.666	<0.001	523	0.715	<0.001	523	0.852	<0.001
	Mandibular	472	0.729	<0.001	472	0.809	<0.001	472	0.842	<0.001

Pearson's Correlation Test

CA-Chronological age; n-Number of third molars; r- Pearson Correlation Coefficient

For the maxillary arch, Tooth 18 and 28 were considered together

For the mandibular arch, Tooth 38 and 48 were considered together

Table 2. Stage-wise comparison of chronological age between the two methods concerning all four third molars together

Stage	Method	n	Mean	St. Deviation	Minimum	Maximum	p-value
A	Olze's Eruption	434	15.204	2.080	12.08	23.89	0.001
	New Mineralization	342	14.729	1.799	12.08	23.89	
B	Olze's Eruption	263	17.466	2.613	12.58	24.32	<0.001
	New Mineralization	208	16.438	1.973	12.90	23.22	
C	Olze's Eruption	117	19.636	2.872	12.96	24.62	<0.001
	New Mineralization	117	17.494	2.415	14.00	24.32	
D	Olze's Eruption	181	21.171	2.315	12.96	24.62	0.079
	New Mineralization	328	20.787	2.382	12.96	24.62	

One-way ANOVA
n-Number of third molars

Table 3. Distribution of third molars in different stages of two methods concerning all four third molars together

Olze's Eruption Method Stages	New Mineralization Method Stages					p-value
	A	B	C	D	Total	
A	326	88	16	4	434	<0.001
B	16	118	70	59	263	
C	0	2	28	87	117	
D	0	0	3	178	181	
Total	342	208	117	328	995	

Pearson's Chi-Square Test

Table 4. Diagnostic test parameters to predict the efficacy of stages to determine ≥18 years

Method	Cut-off Stages	*n*	*Sensitivity (%) (95% CI) (%)*	*Specificity (%) (95% CI (%)*	*PPV (%) (95% CI) (%)*	*NPV (%) (95% CI) (%)*	*Accuracy (%) (95% CI) (%)*	*LR+ (95% CI)*	*LR- (95% CI)*	*Youden's Index (95% CI)*
Olze's Eruption	C	995	64.85% (59.72%, 69.73%)	90.45% (87.87%, 92.63%)	79.87% (75.51%, 83.62%)	81.49% (79.27%, 83.53%)	81.01% (78.43%, 83.40%)	6.79 (5.27, 8.73)	0.39 (0.34, 0.45)	0.55 (0.48, 0.62)
	D	995	44.41% (39.26%, 49.66%)	97.13% (95.51%, 98.29%)	90.06% (84.99%, 93.54%)	74.94% (73.16%, 76.63%)	77.69% (74.97%, 80.24%)	15.50 (9.69, 24.78)	0.57 (0.52, 0.63)	0.42 (0.35, 0.48)
New Mineralization	C	995	85.29% (81.24%, 88.75%)	78.98% (75.58%, 82.10%)	70.34% (66.95%, 73.51%)	90.18% (87.74%, 92.18%)	81.31% (78.74%, 83.68%)	4.06 (3.47, 4.75)	0.19 (0.15, 0.24)	0.64 (0.57, 0.71)
	D	995	75.2% (70.46%, 79.54%)	91.72% (89.28%, 93.75%)	84.15% (80.25%, 87.39%)	86.36% (84.10%, 88.34%)	85.63% (83.29, 87.75%)	9.08 (6.96, 11.86)	0.27 (0.23, 0.32)	0.67 (0.60, 0.73)

CI: Confidence Interval; LR+: Positive Likelihood Ratio; LR-: Negative Likelihood Ratio; NPV: Negative Predictive Value; PPV: Positive Predictive Value; n: Number of third molars evaluated; Bracketed values represent Lower Bound, Upper Bound for 95% Confidence Interval

Figure 2. ROC curve depicting the Area Under the Curve (AUC) comparing the accuracy of Olze's Eruption and New Mineralization methods for estimation of 18 years when all third molars were considered together. The difference between AUCs was calculated by subtracting the AUC of the New Mineralization method from the AUC of Olze's Eruption method; Bracketed values represent Lower Bound, Upper Bound for 95% Confidence Interval

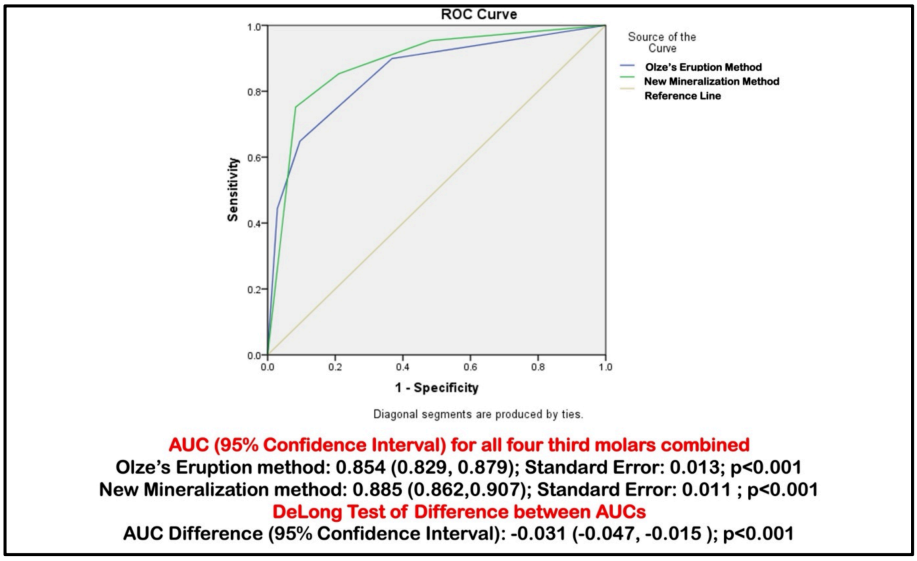


Table 5. Percentage probability of an individual being ≥18 years

Parameters		Age (years)	n	Olze's Eruption Method				New Mineralization Method			
				A	B	C	D	A	B	C	D
Combined all four third molar		<18	628	91.5%	65.0%	35.9%	9.9%	95.0%	82.2%	68.4%	15.9%
		≥18	367	8.5%	35.0%	64.1%	90.1%	5.0%	17.8%	31.6%	84.1%
Tooth-wise	Tooth 18	<18	162	87.7%	60.0%	55.0%	9.4%	91.3%	74.1%	71.4%	18.3%
		≥18	98	12.3%	40.0%	45.0%	90.6%	8.7%	25.9%	28.6%	81.7%
	Tooth 28	<18	163	87.9%	61.8%	60.0%	7.4%	92.6%	75.5%	68.8%	16.7%
		≥18	100	12.1%	38.2%	40.0%	92.6%	7.4%	24.5%	31.3%	83.3%
	Tooth 38	<18	152	96.0%	67.7%	23.1%	11.4%	98.7%	88.2%	72.4%	13.4%
		≥18	86	4.0%	32.3%	76.9%	88.6%	1.3%	11.8%	27.6%	86.6%
	Tooth 48	<18	151	95.9%	70.8%	21.2%	12.8%	98.8%	93.5%	60.7%	15.0%
		≥18	83	4.1%	29.2%	78.8%	87.2%	1.3%	6.5%	39.3%	85.0%
Arch-wise	Maxillary	<18	325	87.8%	60.9%	57.8%	8.4%	91.9%	74.8%	70.0%	17.5%
		≥18	198	12.2%	39.1%	42.2%	91.6%	8.1%	25.2%	30.0%	82.5%
	Mandibular	<18	303	95.9%	69.2%	22.2%	12.2%	98.7%	90.7%	66.7%	14.2%
		≥18	169	4.1%	30.8%	77.8%	87.8%	1.3%	9.3%	33.3%	85.8%
Sex-wise	Male	<18	304	94.9%	73.7%	44.0%	9.9%	98.8%	89.1%	82.8%	8.5%
		≥18	142	5.1%	26.3%	56.0%	90.1%	1.3%	10.9%	17.2%	91.5%
	Female	<18	324	88.6%	57.9%	29.9%	10.0%	91.8%	76.7%	50.9%	20.7%
		≥18	225	11.4%	42.1%	70.1%	90.0%	8.2%	23.3%	49.1%	79.3%

n - Number of third molars
For the maxillary arch, Tooth 18 and 28 were considered together
For the mandibular arch, Tooth 38 and 48 were considered together

Regression analysis

Development of the regression equation: The current study proposed two regression equations using the combined eruption and mineralization statuses of the third molars. To formulate a regression equation, numerical values were assigned to the stages of both methods: stage A=1, stage B=2, stage C=3 and stage D=4.

Regression Equation 1:
This was developed from 212 subjects, including only OPGs, where the status of all four third molars was determined (i.e. excluding OPGs with any of the impacted third molars). (Figure 1)

	Regression Equation -1	**R square**
Female	12.445 + 0.674 (T18 O) + 0.055 (T18 M) - 0.810 (T28 O) – 0.043 (T28 M) + 1.328 (T38 O) + 0.169 (T38 M) – 0.522 (T48 O) + 1.337 (T48 M)	0.660
Male	11.513 + 1.015 (T18 O) + 1.227 (T18 M) - 0.586 (T28 O) – 1.204 (T28 M) - 0.331 (T38 O) + 0.967 (T38 M) + 0.532 (T48 O) + 0.573 (T48 M)	0.746

Regression Equation 2:
It was derived from OPGs of all 269 included participants, with a score of zero for both the eruption and mineralization stages for the impacted third molar. (Figure 1)

In the regression equations, O represents Olze's eruption stage, and M represents the mineralization stage of the tooth. T18, T28, T38 and T48 represent the maxillary right, maxillary left, mandibular left and mandibular right third molars, respectively.

	Regression Equation -2	**R square**
Female	13.328 + 0.758 (T18 O) + 0.031 (T18 M) + 0.048 (T28 O) + 0.361 (T28 M) + 1.164 (T38 O) - 0.142 (T38 M) – 1.385 (T48 O) + 1.225 (T48 M)	0.507
Male	12.169 – 0.499 (T18 O) + 0.134 (T18 M) + 0.950 (T28 O) + 1.369 (T28 M) – 1.199 (T38 O) + 0.804 (T38 M) + 0.460 (T48 O) - 0.020 (T48 M)	0.676

Tooth-wise predictors for regression equations:
The analyses of individual third molar eruption and mineralization stages revealed variable contributions to age estimation, with noticeable sex-specific differences between the equations. In Regression Equation 1, females showed significant positive associations for T38 eruption (B = 1.328, p = 0.014) and T48 mineralization (B = 1.337, p = 0.015), with T48 mineralization being the most influential (β = 0.531). In males, only T18 mineralization was statistically significant (B = 1.227, p = 0.048). Most other parameters in Equation 1 were not significant, indicating limited predictive contribution. In contrast, Regression Equation 2 demonstrated a greater number of significant predictors. Among females, T38 eruption (B = 1.164, p = 0.022), T48 eruption (B = -1.385, p = 0.009), and T48 mineralization (B = 1.225, p = 0.005) significantly contributed to age estimation, with T48 mineralization again showing the strongest positive influence (β = 0.529). Among males, significant predictors included T28 eruption (B = 0.950, p = 0.036), T28 mineralization (B = 1.369, p = 0.003), T38 eruption (B = -1.199, p = 0.008), and T38 mineralization (B = 0.804, p = 0.027). (Table S11 and S12)

Validation of proposed regression equations:
To validate the proposed regression equations, an additional 71 OPGs from individuals aged 12-25 years were retrieved from the departmental archives of our institute. Regression Equation 1 was validated using 56 OPGs, whereas all 71 OPGs were used to validate Regression Equation 2. (Figure 1) For both sexes, statistically significant correlations were observed between CA and estimated DA using Regression Equations 1 and 2. In addition, no statistically significant difference was observed between the estimated DA and CA for either regression equation. Among females, the MAD and RMSE for Equation 1 were 1.89 ± 1.20 years and 2.22 years, and for Equation 2, 2.35 ±

2.09 years and 3.13 years, respectively. Among males, Regression Equation 1 yielded the lowest MAD (1.22 ± 1.01 years) and RMSE (1.57 years), indicating the highest predictive accuracy among all evaluated equations. In contrast, Regression Equation 2 showed a higher MAD (1.90 ± 2.48 years) and RMSE (3.09 years). The MAD values, ranging from 1.22 to 2.35 years, suggest that the estimated DA was reasonably close to the CA in both males and females, with relatively small average prediction errors. The RMSE values, ranging from 1.57 to 3.13 years, indicate the presence of occasional larger prediction errors. (Table 6) Thus, the proposed regression equations provide reasonably reliable estimates, albeit with some variability across cases, demonstrating that individual-level prediction errors remain clinically relevant.

Table 6. Relationship between chronological age and estimated dental age using regression equations

Sex	Regression Formula	Paired Samples Statistics			Paired Differences (Chronological Age-Estimated Dental Age)		Absolute Difference		RMSE	p-value
		n	Chronological Age	Estimated Dental Age						
			Mean± SD	Mean± SD	Mean± SD	95% Confidence Interval of the Difference (Lower, Upper)	Mean± SD	Range		
Female	Regression equation 1	29	18.49±3.78	18.56±3.03	-0.07±2.26	-0.93, 0.79	1.89±1.20	0.05-4.25	2.22	0.868
	Regression equation 2	39	19.45±3.79	18.52±2.59	0.93±3.03	-0.06, 1.91	2.35±2.09	0.05-9.03	3.13	0.064
Male	Regression equation 1	27	16.49 ±3.07	16.59±2.69	-0.10±1.60	-0.73, 0.53	1.22±1.01	0.02-3.76	1.57	0.747
	Regression equation 2	32	17.17±3.33	16.78±2.86	0.39±3.12	-0.73, 1.52	1.90±2.48	0.04-11.36	3.09	0.475

Paired Samples Correlations				
Sex	**Regression Formula**	n	**Correlation**	**p-value**
Female	Regression equation 1	29	0.801	<0.001
	Regression equation 2	39	0.607	<0.001
Male	Regression equation 1	27	0.854	<0.001
	Regression equation 2	32	0.501	0.003

Paired T-test

n-Number of OPGs evaluated; SD- Standard Deviation; RMSE – Root Mean Square Error

Regression Equation 1 was applied in cases where the status of all four third molars was determined (i.e. excluding OPGs with any of the impacted third molars)

Regression Equation 2 included OPGs with impacted third molars.

Comparison of two regression equations:

A comparative evaluation of the two regression equations revealed that Regression Equation 1 had a higher predictive ability (R^2 = 0.660 and 0.746 for females and males, respectively) than Regression Equation 2 (R^2 = 0.507 and 0.676 for females and males, respectively). Regression Equation 1 demonstrated greater consistency, with fewer but more stable predictors. However, Regression Equation 2 identified a greater number of statistically significant predictors in both sexes, suggesting that it captures a broader range of developmental indicators contributing to age estimation. (Table S11 and S12) In addition,

Equation 1 showed minimal mean differences between CA and estimated DA, lower MADs and RMSE values, indicating greater accuracy and precision. Moreover, Equation 1 exhibited stronger correlations with CA in both females (r = 0.801) and males (r = 0.854) than Equation 2, which showed comparatively weaker correlations (r = 0.607 in females and r = 0.501 in males). Neither equation showed statistically significant differences between CA and estimated DA. Thus, the findings indicate that while Regression Equation 2 may offer broader insights into multiple developmental variables, Regression Equation 1 demonstrates better overall predictive performance and reliability.

DISCUSSION

Third molar eruption and maturation status play vital roles in age estimation. Various qualitative and categorical tooth staging techniques that utilize dental radiographs have been employed for this purpose. However, the precision of these techniques is influenced by certain factors, such as biological variability, sample quality, and correct radiographic interpretation.[14]

One of the most commonly used radiographic criteria for determining the eruption status of third molars for age estimation was proposed by Olze et al. in 2007. It has the advantage of being able to identify both missing and impacted teeth, thus providing a better age estimate than clinical eruption techniques.[29] In addition, this method shows a good assessment of DA in young adults and is suggested to be clinically acceptable in terms of accuracy and ease of assessment.[1] The tooth emergence process is directly affected by several factors; hence, eruption methods are prone to errors and inaccuracies.[30] A few shortcomings of Olze's criteria that were comprehended during this study include discrepancies in the determination of stages following positional changes due to missing first and second molars, which may hasten the eruption of third molars, the presence of bony hindrance in the path of eruption and buccolingual eruption of third molars, which can radiographically appear below the occlusal plane. Moreover, delayed calcification could affect the accuracy of age estimation.

Radiographic interpretation of tooth development is complex, subjective and less reliable as it is affected by rater characteristics such as knowledge, experience, and expertise.[14] The inter-observer variability noted during the determination of eruption status in this study could be attributed to the inherent difficulty in distinguishing developmental stages B and C. Moreover, radiographic interpretation of gingival eruption was difficult or often impossible because of the gingiva being partially radiolucent, which could also introduce error.[29-31] Considering this fact, Olze et al. (2012)[32] modified their criteria to determine stage C based on the eruption of the third molar according to the length of the crown of the adjacent second molar. However, the varied directions of eruption, impaction of third molars and absence or positional variability of second molars could further complicate the stage assessment. This signifies a higher chance of imprecision if radiographs alone are used to determine eruption status.

A comparison of the findings of the present study with those of other studies regarding the eruption and mineralization patterns and timings of third molars is presented in the tables S13[1-3,5,26,29,33-42] and S14[5,10,17,20,36,39-40,43-50]. The diagnostic accuracy findings of this study were not associated with those reported by Shi et al.[40], except for specificity, LR+, and LR- for stage D of Olze's eruption method in determining 18 years of age. The likelihood of an individual being ≥18 years of age in this study was consistent with stage D of Widek et al.'s study but not with stage C. [39] Our findings for stage D of the newly proposed mineralization methods corresponded to the diagnostic accuracy findings (specificity, PPV, NPV, accuracy, LR+, and LR -) of stage G of Demirjian et al.'s method in determining 18 years as reported by Costa et al.[25] Regarding the likelihood of an individual being ≥18 years, the findings of this study (stage D of the new mineralization method) were in agreement with those of Widek et al.'s study (stage G of the Demirjian et al.'s method).[39] Our findings for LR- were in line with those of Liversidge and Masden (2010) for root stages combined $R_{3/4}$ and Rc in determining 18 years; however, sensitivity, specificity and LR+ were in contrast.[51] As this study did not consider apex closure as a separate stage, the findings of stage H of Demirjian et al.'s method are not applicable for comparison, as most studies used stage H as a cut-off to determine 18 years. The differences between the findings of this study and those of other studies could be due to variations in ethnicity, geographical regions, age groups, and the number

of participants. The classification systems referenced, types of third molars evaluated (mandibular, maxillary, or both), and subjectivity in assessing the developmental stage could also contribute to the varied findings.

In the present study, inter-observer variability was lower with the mineralization method than with the eruption technique. A higher correlation coefficient was observed between CA and the stages of the mineralization method than with the eruption stages. In addition, the AUC was higher for the mineralization method than for the eruption method when estimating 18 years. Considering stage D as the cut-off stage, the new mineralization method had considerably higher sensitivity (75.2%) than Olze's eruption method (44.41%), while maintaining high specificity (91.72%). In contrast, Olze's eruption method exhibited extremely high specificity (97.13%) but poor sensitivity, indicating accurate exclusion of non-target individuals while failing to detect a substantial proportion of true positive individuals. The new mineralization method also achieved higher accuracy (85.63% vs. 77.69%) and a superior Youden's index (0.67 vs. 0.42), indicating stronger overall discriminatory performance. Furthermore, the lower LR- value of the new mineralization method (0.27) compared with Olze's eruption method (0.57) suggests better exclusion capability. However, higher LR+ and the probability of an individual being ≥18 years old for stage D of Olze's eruption method suggest that there is a greater likelihood of an individual being ≥18 years old for stage D of Olze's eruption. Literature suggests that all available third molars should be considered in DA estimation as mineralization and eruption differ between quadrants within the same individual. [39] Therefore, this study proposes two regression equations: one considering the status of all four third molars and the other applicable in cases where third molars are impacted. The rationale for including impacted third molars in Regression Equation 2 is that third molars are the most commonly impacted teeth.[52] Although Regression Equation 2 demonstrated lower predictive performance and greater estimation variability than Regression Equation 1, it could still provide clinically useful age estimates. However, a major drawback of Regression Equation 2 is that it interprets age as 12.169 and 13.328 for males and females, respectively, if all third molars are impacted, which could also be one of the reasons for the higher RMSE. Although the mineralization stage could be evaluated in the case of impacted third molars, when formulating and validating Regression Equation 2, both the eruption and mineralization stages were scored zero because existing studies reported that impacted third molars exhibit slower mineralization and that impaction is a consequence of late maturation. [52-53]

Although the third molar is the only tooth that develops and erupts during the mid-teens to early twenties and is thus widely used as a dental indicator to differentiate juveniles from adults, it shows a large variation in the time of emergence and development.[54] This study also reported a wide variation in CA for stage D of eruption (12.96-24.62 years) and mineralization (12.96-24.62 years) methods, similar to previous studies.[17,29] The present study observed a statistically significant correlation between the stages of eruption and mineralization method, consistent with literature reporting a strong correlation between eruption time and dental maturity. Furthermore, literature documented a weak correlation between CA and eruption time, suggesting that the increasing maturity of the teeth and eruption proceed independently.[52] In the present study, third molars attained all mineralization stages earlier than the corresponding eruption stages. In addition, when all four third molars were considered together, stage D (root completion) was observed in 328 third molars. However, among these, stage D of Olze's eruption (complete emergence) was observed in only 178 third molars, followed by third molars in stage C (87), B (59), and A (04). The mandibular arch has been reported to have a higher tendency for impacted third molars.[53] The difference between the number of third molars which achieved stage D of mineralization and eruption was higher for the mandibular arch (74) than for the maxillary arch (59). These findings highlight the importance of clinical correlation with radiological evaluation to determine eruption status, as relying only on radiographic criteria makes the interpretation of impaction difficult. Thus, the third molar alone may not be an ideal developmental marker. Nonetheless, in the absence of other biological age indicators in late teens and early adulthood, third molar maturation and eruption status should be used cautiously alongside other skeletal factors to estimate age. [37]

One of the main limitations of this study was its retrospective design, as medical records were unavailable for assessment. Another limitation involved determining the mineralization stage when the distal root exhibited a lower developmental level than the mesial root. However, as suggested by the literature, whenever such a situation was encountered, a lower stage was assigned. Furthermore, assessment of the eruption status of the tooth radiographically alone has inherent reliability limitations. Another limitation is the lack of validation of the newly proposed mineralization stages, requiring comparison of the accuracy of this criterion with that of previously established methods across different population groups. The regression equations proposed in this study are population-specific and therefore cannot be generalized universally. Consequently, prospective studies in different populations with combined clinico-radiological evaluations of third molars are warranted.

CONCLUSION

The mineralization approach offers a more balanced and diagnostically robust method for age estimation, demonstrating higher accuracy and better discriminative power than the eruption method. A statistically significant correlation was observed between the stages of eruption and the mineralization method. This study introduced regression equations that integrate the eruption and mineralization stages of third molars. Both equations effectively estimated age in the study population; however, Equation 1 showed improved predictions based on the MAD and RMSE metrics.

REFERENCES

1. Akki S, Gugwad RS, Javali R. Dental age estimation based on third molar eruption in Indian population. IOSR Journal of Dental and Medical Sciences 2016;15 (VIII):29-32.
2. Angelakopoulos N, Sharma S, Balla SB, Zolotenkova G, De Luca S. Assessing the accuracy of the third molar eruption as an indicator of adulthood: findings from a black South African sample using the Gambier method. Int J Legal Med 2025;139(5):2313-22. doi: 10.1007/s00414-025-03505-2.
3. Vadivel MK, Pydi HS, Gurugubelli S, Pedada RK, Varma MR. Study on clinical staging of third molar eruption as an aid in age estimation. Int J Acad Med Pharm 2025; 7 (4); 1063-6. doi: 10.47009/jamp.2025.7.4.203.
4. Selmanagić A, Ajanović M, Kamber-Ćesir A, Redžepagić-Vražalica L, Jelešković A, Nakaš E. Radiological evaluation of dental age assessment based on the development of third molars in Population of Bosnia and Herzegovina. Acta Stomatol Croat 2020;54(2):161-7. doi: 10.15644/asc54/2/6.
5. Karadayi B, Kaya A, Kolusayın MO, Karadayi S, Afsin H, Ozaslan A. Radiological age estimation: based on third molar mineralization and eruption in Turkish children and young adults. Int J Legal Med 2012;126(6):933-42. doi: 10.1007/s00414-012-0773-8.
6. Ahmed NM, Alzahrani NS, Asali AS, Khormi NH, Abulsaud HA, Alqahtani SA et al. Dental eruption patterns and their relationship to systemic health conditions in children. Int J Community Med Public Health 2025; 12(2):1049–53. https://doi.org/10.18203/2394-6040.ijcmph20250047.
7. Hegde RJ, Khare SS, Saraf TA, Trivedi S, Naidu S. Evaluation of the accuracy of Demirjian method for estimation of dental age among 6-12 years of children in Navi Mumbai: a radiographic study. J Indian Soc Pedod Prev Dent 2015;33:319-23. doi: 10.4103/0970-4388.165693.
8. Dogaroiu C, Cosma A, Gherghe EV, Morosanu G, Avramoiu M. Age estimation in subadults using teeth eruption examination. Rom J Leg Med 2015;23: 49-56. doi: 10.4323/rjlm.2015.49.
9. Buenaventura C, Lago R, Fernandez A, Alvarez-Vaz R, Picapedrs A. Age estimation according to the degree of dental mineralization: Demirjian method. Odontoestomatología. 2022, 24:1-9. doi: 10.22592 / ode2022n40e225
10. Arumugam V, Doggali N. A simpler way of medico-legal age estimation for Indian population using Mincer third molar method. Saudi J Oral Dent Res 2020; 5(8):379-386.
11. Putri AS, Soedarsono N, Nehemia B, Atmadja DS, Ubelaker DH. Age estimation of individuals aged 5-23 years based on dental development of the Indonesian population. Forensic Sci Res 2021;7(2):115-123. doi: 10.1080/20961790.2021. 1886648.
12. Skanchy TL, Maness H, Al Dayesh A, Harris EF. A comparison of two dental age estimation techniques in contemporary American Whites: the Moorrees and Demirjian approaches. Int J of Forensic Sci Pathol 2016; 4(5):243-8.
13. Branco MS, Pestana D, Pereira CP. Medico-legal age estimation in living individual from a Portuguese Population: third molar mineralization. J Forensic Res 2012; 3:149. doi:10.4172/2157-7145.1000149
14. Abdul Rahim AH, Davies JA, Liversidge HM. Reliability and limitations of permanent tooth staging techniques. Forensic Sci Int 2023;346:111654. doi: 10.1016/j.forsciint.2023.111654.
15. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol 1973;45(2):211-27.
16. Nolla CM. The development of permanent teeth. Journal of Dentistry for Children 1960; 254:60.
17. Sisman Y, Uysal T, Yagmur F, Ramoglu SI. Third-molar development in relation to chronologic age in Turkish children and young adults. Angle Orthod 2007;77(6):1040-5. doi: 10.2319/101906-430.1.
18. Gustafson G, Koch G. Age estimation up to 16 years of age based on dental development. Odontol Revy 1974;25(3):297-306.

19. Gat H, Sarnat H, Bioratn K, Dayan D. Dental age evaluation: a new 6-development stage method. Clin Prev Dent 1984;6:18-22.
20. Sarnat H, Kaffe I, Porat J, Amir E. Developmental stages of the third molar in Israeli children. Pediatr Dent 2003;25(4):373-7.
21. Sant Anna EF, Cury-Saramago AA, Figueroa AA, Polley JW. Evaluation of maxillary permanent molars in patients with syndromic craniosynostosis after monobloc osteotomy and midface advancement with rigid external distraction (RED). Cleft-Palate Craniofacial Journal 2010; 47 (2): 109-15.
22. Olze A, Bilang D, Schmidt S, Wernecke KD, Geserick G, Schmeling A. Validation of common classification systems for assessing the mineralization of third molars. Int J Legal Med 2005;119(1):22-6. doi: 10.1007/s00414-004-0489-5.
23. Manjrekar S, Deshpande S, Katge F, Jain R, Ghorpade T. Age estimation in children by the measurement of open apices in teeth: a study in the Western Indian Population. Int J Dent 2022;2022:9513501. doi: 10.1155/2022/9513501.
24. Raosoft sample size calculator. © 2004 by Raosoft, Inc. Available at: http://www.raosoft.com/. (Last accessed on 18.11.2025).
25. Costa J, Montero J, Serrano S, Albaladejo A, López-Valverde A, Bica I. Accuracy in the legal age estimation according to the third molars mineralization among Mexicans and Columbians. Aten Primaria 2014;46 (Suppl 5):165-75.doi: 10.1016/S0212-6567(14)70086-1.
26. Olze A, van Niekerk P, Ishikawa T, Zhu BL, Schulz R, Maeda H, et al. Comparative study on the effect of ethnicity on wisdom tooth eruption. Int J Legal Med 2007;121(6):445-8. doi: 10.1007/s00414-007-0171-9.
27. Landis JR, Koch GG, The measurement of observer agreement for categorical data. Biometrics 1977; 33:159–74.
28. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 2016;15(2):155-63. doi: 10.1016/j.jcm.2016.02.012.
29. Kutesa AM, Rwenyonyi CM, Mwesigwa CL, Muhammad M, Nabaggala GS, Kalyango J. Dental age estimation using radiographic assessment of third molar eruption among 10–20-year-old Ugandan population. J Forensic Dent Sci 2019;11:16-21.
30. Kutesa AM, Ndagire B, Nabaggala GS, Mwesigwa CL, Kalyango J, Rwenyonyi CM. Socioeconomic and nutritional factors associated with age of eruption of third molar tooth among Ugandan adolescents. J Forensic Dent Sci 2019;11:22-7.
31. Timme M, Viktorov J, Steffens L, Streeter A, Karch A, Schmeling A. Third molar eruption in orthopantomograms as a feature for forensic age assessment-a comparison study of different classification systems. Int J Legal Med 2023;137(3):765-72. doi: 10.1007/s00414-023-02982-7.
32. Olze A, Peschke C, Schulz R, Schmeling A. Application of a modified stage classification in evaluating wisdom tooth eruption in a German population. Arch Kriminol 2012;229(5-6):145-53.
33. Olze A, Ishikawa T, Zhu BL, Schulz R, Heinecke A, Maeda H, Schmeling A. Studies of the chronological course of wisdom tooth eruption in a Japanese population. Forensic Sci Int 2008;174(2-3):203-6. doi: 10.1016/j.forsciint.2007.04.218.
34. Olze A, Peschke C, Schulz R, Schmeling A. Studies of the chronological course of wisdom tooth eruption in a German population. J Forensic Leg Med 2008;15(7):426-9. doi: 10.1016/j.jflm.2008.02.008.
35. Olze A, Pynn BR, Kraul V, Schulz R, Heinecke A, Pfeiffer H, Schmeling A,. Dental age estimation based on third molar eruption in First Nation people of Canada. J Forensic Odontostomatol. 2010;28(1):32-8.
36. Scheurer E, Quehenberger F, Mund MT, Merkens H, Yen K. Validation of reference data on wisdom tooth mineralization and eruption for forensic age estimation in living persons. Int J Legal Med 2011;125(5):707-15. doi: 10.1007/s00414-011-0587-0.
37. Tuteja M, Bahirwani S, Balaji P. An evaluation of third molar eruption for assessment of chronologic age: a panoramic study. J Forensic Dent Sci 2012;4:13-8.
38. Raj N, Shenai P, Chatra L, Veena KM, Rao PK, Prabhu RV, *et al*. Age estimation of an individual by using Olze's method in South Indian population. Arch Med Health Sci 2014;2:173-7. DOI: 10.4103/2321-4848.144330.
39. Widek T, Genet P, Merkens H, Boldt J, Petrovic A, Vallis J et al. Dental age estimation: the chronology of mineralization and eruption of male third molars with 3T MRI. Forensic Sci Int 2019; 297:228-35. doi: 10.1016/j.forsciint.2019.02.019.
40. Shi L, Anić-Milošević S, Galić I. Legal dental age thresholds estimation in Croatian children and adolescents: accuracy of the Olze, Haavikko, and Demirjian Methods. Acta Stomatol Croat 2024;58(3):194-208. doi: 10.15644/asc58/3/1.
41. Timme M, Viktorov J, Steffens L, Streeter A, Karch A, Schmeling A. Third molar eruption in dental panoramic radiographs as a feature for forensic age assessment - new reference data from a German population. Head Face Med 2024;20(1):29. doi: 10.1186/s13005-024-00431-3.
42. De Luca S, Paladugu S, Balla SB, Moukarzel M, Angelakopoulos N. Accuracy of third molar eruption for legal age estimation using the Gambier method in Lebanese subadults. Odontology 2025. doi: 10.1007/s10266-025-01229-8.
43. Ajmal M, Assiri KI, Al-Ameer KY, Assiri AM, Luqman M. Age estimation using third molar teeth: a study on southern Saudi population. J Forensic Dent Sci 2012;4(2):63-5. doi: 10.4103/0975-1475.109886.
44. Jung YH, Cho BH. Radiographic evaluation of third molar development in 6- to 24-year-olds. Imaging Sci Dent 2014;44(3):185-91. doi: 10.5624/isd.2014.44.3.185.
45. Mathew AL, Cherian SA, Mathew R. Chronological age estimation based on mandibular third molar development from digital panoramic radiograph in a south kerala population. j ora med 2017; 1(1):12.
46. Firdaus RP, Nehemia B. Age estimation of 8- to 25-year-olds based on third molar calcification using the Demirjian method in an Indonesian population. J Phys: Conf Ser 2018; 1073 022005. doi :10.1088/1742-6596/1073/2/022005
47. Ramaswami TB, da Rosa GC, Fernandes MM, de Oliveira RN, Ribeiro Tinoco RL. Third molar development by Demirjian's stages and age estimation among Brazilians. Forensic Imaging 2020; 20: 200353. doi: 10.1016/j.fri.2020.200353
48. Sindi MA, Al-Sebaei MO, Bamashmous MS. Radiographic assessment of third molar development and its relation to dental and chronological age in the Saudi Arabian

population. Egypt J Forensic Sci 2023;13:23. doi: https://doi.org /10.1186/s41935-023-00342-5.
49. Sadan N, Aderet N, Tagger-Green N, Ratson T, Laviv A. Age assessment through third molar teeth developmental stage in children. Applied Sciences 2023;13(4):2069. https://doi.org/10.3390/app13042069
50. Sharma S, Garg N, Gupta P, Naik SR, Roy S, Anand A et al. Age estimation of children and young adults of Jharkhand using mineralization of third molars and its relation to chronological age: a retrospective analysis. Cureus 2024; 16(5): e60431. doi:10.7759/cureus.60431.
51. Liversidge HM, Marsden PH. Estimating age and the likelihood of having attained 18 years of age using mandibular third molars. Br Dent J 2010;209(8): E13. doi: 10.1038/sj.bdj.2010.976.
52. Kjær I. Mechanism of human tooth eruption: review article including a new theory for future studies on the eruption process. Scientifica (Cairo) 2014;2014:341905. doi: 10.1155/2014/341905.
53. Angelakopoulos N, Franco A, Mula AP, Moukarzel M, Sharma S, Balla SB. Effect of impaction on third molar development and age estimation-a study in a Lebanese population. Morphologie 2023;107(359):100607. doi: 10.1016/j.morpho.2023.06.002.
54. Priyadharshini KI, Idiculla JJ, Sivapathasundaram B, Mohanbabu V, Augustine D, Patil S. Age estimation using development of third molars in South Indian population: A radiological study. J Int Soc Prevent Communit Dent 2015;5:32-8. Doi: 10.4103/2231-0762.156522.

SUPPLEMENTARY MATERIAL

Table S1. Relationship of chronological age concerning sex

Sex	n	Mean	Standard Deviation	Minimum	Maximum	p-value
Female	549	17.839	3.322	12.29	24.59	<0.001
Male	446	16.878	3.202	12.08	24.62	
Total	995	17.408	3.302	12.08	24.62	

One-way ANOVA
n-Number of third molars

Table S2. Relationship of chronological age concerning stages of Olze's eruption method and new mineralization method

Method	Stage	n	Mean	Standard Deviation	Minimum	Maximum	p-value
Olze's Eruption Method	A	434	15.204	2.080	12.08	23.89	<0.001
	B	263	17.466	2.613	12.58	24.32	
	C	117	19.636	2.872	12.96	24.62	
	D	181	21.171	2.315	12.96	24.62	
	Total	995	17.408	3.302	12.08	24.62	
New Mineralization Method	A	342	14.729	1.799	12.08	23.89	<0.001
	B	208	16.438	1.973	12.90	23.22	
	C	117	17.494	2.415	14.00	24.32	
	D	328	20.787	2.382	12.96	24.62	
	Total	995	17.408	3.302	12.08	24.62	

One-way ANOVA
n-Number of third molars

Table S3. Relationship of chronological age concerning individual third molars

Tooth	n	Mean	Standard Deviation	Minimum	Maximum	p-value
18	260	17.443	3.245	12.08	24.62	0.871
28	263	17.524	3.322	12.08	24.62	
38	238	17.361	3.338	12.08	24.59	
48	234	17.288	3.321	12.08	24.62	
Total	995	17.408	3.302	12.08	24.62	

One-way ANOVA
n-Number of third molars

Table S4. Relationship of chronological age concerning arches

Arch	n	Mean	Standard Deviation	Minimum	Maximum	p-value
Maxillary	523	17.484	3.281	12.08	24.62	0.449
Mandibular	472	17.325	3.326	12.08	24.62	
Total	995	17.408	3.302	12.08	24.62	

One-way ANOVA
n-Number of third molars
For the maxillary arch, Tooth 18 and 28 were considered together
For the mandibular arch, Tooth 38 and 48 were considered together

Table S5. Stage-wise comparison of chronological age between the two methods concerning individual third molars

Stage	Tooth	Method	n	Mean	Standard Deviation	Minimum	Maximum	p-value
A	18	Olze's Eruption	122	15.498	2.254	12.08	23.89	0.110
		New Mineralization	92	15.015	2.080	12.08	23.89	
	28	Olze's Eruption	116	15.457	2.361	12.08	23.89	0.084
		New Mineralization	94	14.925	1.996	12.08	23.89	
	38	Olze's Eruption	99	14.873	1.747	12.08	20.97	0.087
		New Mineralization	76	14.447	1.443	12.08	18.83	
	48	Olze's Eruption	97	14.868	1.702	12.08	19.43	0.072
		New Mineralization	80	14.436	1.419	12.08	18.83	
B	18	Olze's Eruption	65	17.805	2.811	12.80	24.32	0.029
		New Mineralization	58	16.781	2.242	13.14	22.09	
	28	Olze's Eruption	68	17.558	2.617	13.14	24.32	0.120
		New Mineralization	53	16.864	2.141	13.14	23.22	
	38	Olze's Eruption	65	17.320	2.398	12.58	23.30	0.002
		New Mineralization	51	16.037	1.706	12.90	19.86	
	48	Olze's Eruption	65	17.178	2.627	12.58	24.32	0.005
		New Mineralization	46	15.961	1.492	12.90	19.86	
C	18	Olze's Eruption	20	18.475	2.402	14.71	23.30	0.201
		New Mineralization	28	17.526	2.570	14.16	24.32	
	28	Olze's Eruption	25	18.640	2.461	14.71	23.30	0.164
		New Mineralization	32	17.652	2.748	14.16	24.32	
	38	Olze's Eruption	39	20.388	3.033	12.96	24.59	<0.001
		New Mineralization	29	17.366	2.262	14.00	23.30	
	48	Olze's Eruption	33	20.204	2.894	12.96	24.62	<0.001
		New Mineralization	28	17.415	2.103	14.16	23.30	
D	18	Olze's Eruption	53	21.085	2.416	12.96	24.62	0.265
		New Mineralization	82	20.606	2.437	12.96	24.62	
	28	Olze's Eruption	54	21.407	2.401	12.96	24.62	0.153
		New Mineralization	84	20.802	2.423	12.96	24.62	
	38	Olze's Eruption	35	21.105	2.191	16.17	24.18	0.635
		New Mineralization	82	20.884	2.341	12.96	24.59	
	48	Olze's Eruption	39	21.023	2.225	15.90	24.18	0.716
		New Mineralization	80	20.858	2.358	12.96	24.62	

One-way ANOVA
n-Number of third molars

Table S6. Stage-wise comparison of chronological age between the two methods concerning arches

Stage	Arch	Method	n	Mean	Standard Deviation	Minimum	Maximum	p-value
A	Maxillary	Olze's Eruption	238	15.478	2.302	12.08	23.89	0.018
		New Mineralization	186	14.969	2.033	12.08	23.89	
	Mandibular	Olze's Eruption	196	14.870	1.721	12.08	20.97	0.013
		New Mineralization	156	14.442	1.427	12.08	18.83	
B	Maxillary	Olze's Eruption	133	17.679	2.706	12.80	24.32	0.008
		New Mineralization	111	16.821	2.185	13.14	23.22	
	Mandibular	Olze's Eruption	130	17.249	2.507	12.58	24.32	<0.001
		New Mineralization	97	16.001	1.600	12.90	19.86	
C	Maxillary	Olze's Eruption	45	18.567	2.409	14.71	23.30	0.055
		New Mineralization	60	17.593	2.645	14.16	24.32	
	Mandibular	Olze's Eruption	72	20.304	2.951	12.96	24.62	<0.001
		New Mineralization	57	17.390	2.166	14.00	23.30	
D	Maxillary	Olze's Eruption	107	21.247	2.402	12.96	24.62	0.071
		New Mineralization	166	20.705	2.425	12.96	24.62	
	Mandibular	Olze's Eruption	74	21.062	2.194	15.90	24.18	0.555
		New Mineralization	162	20.871	2.342	12.96	24.62	

One-way ANOVA
n-Number of third molars
For the maxillary arch, Tooth 18 and 28 were considered together
For the mandibular arch, Tooth 38 and 48 were considered together

Table S7. Stage-wise comparison of chronological age between the two methods concerning the sex of an individual

Stage	Sex	Method	n	Mean	Standard Deviation	Minimum	Maximum	p-value
A	Female	Olze's Eruption	237	15.565	2.117	12.29	23.89	0.060
		New Mineralization	182	15.179	2.033	12.29	23.89	
	Male	Olze's Eruption	197	14.769	1.953	12.08	23.22	0.002
		New Mineralization	160	14.217	1.320	12.08	18.71	
B	Female	Olze's Eruption	145	18.118	2.838	12.58	24.32	<0.001
		New Mineralization	116	16.752	2.024	13.14	22.09	
	Male	Olze's Eruption	118	16.666	2.051	12.80	23.22	0.023
		New Mineralization	92	16.043	1.841	12.90	23.22	
C	Female	Olze's Eruption	67	20.098	2.924	12.96	24.59	0.003
		New Mineralization	53	18.444	3.012	14.00	24.32	
	Male	Olze's Eruption	50	19.015	2.708	14.88	24.62	<0.001
		New Mineralization	64	16.708	1.365	14.51	21.19	
D	Female	Olze's Eruption	100	21.311	2.210	12.96	24.59	0.062
		New Mineralization	198	20.759	2.493	12.96	24.59	
	Male	Olze's Eruption	81	20.999	2.442	15.62	24.62	0.602
		New Mineralization	130	20.829	2.210	16.00	24.62	

One-way ANOVA
n-Number of third molars

Table S8. Tooth-wise distribution of third molars in different stages of two methods

Tooth	Olze's Eruption Method Stages	New Mineralization Method Stages					p-value
		A	B	C	D	Total	
Tooth 18	A	89	28	4	1	122	<0.001
	B	3	29	16	17	65	
	C	0	1	8	11	20	
	D	0	0	0	53	53	
	Total	92	58	28	82	260	
Tooth 28	A	89	21	4	2	116	<0.001
	B	5	32	19	12	68	
	C	0	0	8	17	25	
	D	0	0	1	53	54	
	Total	94	53	32	84	263	
Tooth 38	A	73	20	5	1	99	<0.001
	B	3	31	17	14	65	
	C	0	0	6	33	39	
	D	0	0	1	34	35	
	Total	76	51	29	82	238	
Tooth 48	A	75	19	3	0	97	<0.001
	B	5	26	18	16	65	
	C	0	1	6	26	33	
	D	0	0	1	38	39	
	Total	80	46	28	80	234	

Pearson's Chi-Square Test

Table S9. Arch-wise distribution of third molars in different stages of two methods

Arch	Olze's Eruption Method Stages	New Mineralization Method Stages					p-value
		A	B	C	D	Total	
Maxillary	A	178	49	8	3	238	<0.001
	B	8	61	35	29	133	
	C	0	1	16	28	45	
	D	0	0	1	106	107	
	Total	186	111	60	166	523	
Mandibular	A	148	39	8	1	196	<0.001
	B	8	57	35	30	130	
	C	0	1	12	59	72	
	D	0	0	2	72	74	
	Total	156	97	57	162	472	

Pearson's Chi-Square Test
For the maxillary arch, Tooth 18 and 28 were considered together
For the mandibular arch, Tooth 38 and 48 were considered together

Table S10. Sex-Wise distribution of third molars in different stages of two methods

Sex	Olze's Eruption Method Stages	New Mineralization Method Stages					p-value
		A	B	C	D	Total	
Female	A	172	54	11	0	237	<0.001
	B	10	61	32	42	145	
	C	0	1	10	56	67	
	D	0	0	0	100	100	
	Total	182	116	53	198	549	
Male	A	154	34	5	4	197	<0.001
	B	6	57	38	17	118	
	C	0	1	18	31	50	
	D	0	0	3	78	81	
	Total	160	92	64	130	446	

Pearson's Chi-Square Test

Table S11. Tooth-wise Parameters for Formulating Regression Equation 1

Sex		Unstandardized Coefficients		Standardized Coefficients	p-value	95.0% Confidence Interval for B	
		B	Standard Error	Beta		Lower Bound	Upper Bound
Females	(Constant)	12.445	0.400		<0.001	11.652	13.237
	T18 (Olze's eruption)	0.674	0.438	0.239	0.127	-0.194	1.542
	T18 (New Mineralization)	0.055	0.561	0.022	0.922	-1.056	1.166
	T28 (Olze's eruption)	-0.810	0.465	-0.282	0.084	-1.732	0.112
	T28 (New Mineralization)	-0.043	0.611	-0.017	0.945	-1.253	1.168
	T38 (Olze's eruption)	1.328	0.535	0.451	0.014	0.269	2.388
	T38 (New Mineralization)	0.169	0.570	0.066	0.767	-0.960	1.298
	T48 (Olze's eruption)	-0.522	0.540	-0.175	0.336	-1.593	0.548
	T48 (New Mineralization)	1.337	0.544	0.531	0.015	0.259	2.414
Males	(Constant)	11.513	0.347		<0.001	10.823	12.204
	T18 (Olze's eruption)	1.015	0.561	0.395	0.074	-0.102	2.132
	T18 (New Mineralization)	1.227	0.610	0.514	0.048	0.014	2.440
	T28 (Olze's eruption)	-0.586	0.627	-0.232	0.353	-1.834	0.663
	T28 (New Mineralization)	-1.204	0.673	-0.500	0.077	-2.544	0.136
	T38 (Olze's eruption)	-0.331	0.516	-0.118	0.523	-1.358	0.695
	T38 (New Mineralization)	0.967	0.705	0.394	0.174	-0.436	2.369
	T48 (Olze's eruption)	0.532	0.455	0.196	0.246	-0.373	1.437
	T48 (New Mineralization)	0.573	0.646	0.236	0.377	-0.712	1.859

Table S12. Tooth-wise parameters for formulating regression equation 2

Sex		Unstandardized Coefficients		Standardized Coefficients	p-value	95.0% Confidence Interval for B	
		B	Standard Error	Beta		Lower Bound	Upper Bound
	(Constant)	13.328	0.456		<0.001	12.425	14.231
	T18 (Olze's eruption)	0.758	0.444	0.278	0.090	-0.121	1.637
	T18 (New Mineralization)	0.031	0.436	0.012	0.944	-0.832	0.894

Females	T28 (Olze's eruption)	0.048	0.476	0.017	0.920	-0.894	0.990
	T28 (New Mineralization)	0.361	0.442	0.145	0.415	-0.512	1.234
	T38 (Olze's eruption)	1.164	0.503	0.420	0.022	0.170	2.158
	T38 (New Mineralization)	-0.142	0.430	-0.060	0.741	-0.992	0.708
	T48 (Olze's eruption)	-1.385	0.519	-0.499	0.009	-2.412	-0.358
	T48 (New Mineralization)	1.225	0.426	0.529	0.005	0.384	2.067
Males	(Constant)	12.169	0.398		<0.001	11.381	12.957
	T18 (Olze's eruption)	-0.499	0.429	-0.183	0.248	-1.349	0.352
	T18 (New Mineralization)	0.134	0.434	0.053	0.759	-0.726	0.994
	T28 (Olze's eruption)	0.950	0.448	0.350	0.036	0.063	1.837
	T28 (New Mineralization)	1.369	0.451	0.531	0.003	0.476	2.261
	T38 (Olze's eruption)	-1.199	0.445	-0.446	0.008	-2.080	-0.318
	T38 (New Mineralization)	0.804	0.359	0.354	0.027	0.093	1.514
	T48 (Olze's eruption)	0.460	0.449	0.183	0.308	-0.430	1.350
	T48 (New Mineralization)	-0.020	0.378	-0.009	0.958	-0.769	0.729

Table S13. Comparison of findings of our study with other studies concerning the eruption status of third molars

Study	Population	Number of OPGs included (M:F)	Age (years)	Method	Inference
Olze et al., 2007 [26]	German, Japanese Black South African	2,482 **German:** 666(144:522) **Japanese:** 1300 (549:751) **Black South African:**519 (410:106)	12-26	Olze et al., 2007	**Tooth 18 Mean Age (years) M:F** **German** Stage A:18.9:16.6; Stage B: 20.8:18.9; Stage C: 22.1:20.3; Stage D: 23.4:24.0 **Japanese** Stage A: 19.9:19.9; Stage B: 20.9: 20.6; Stage C: 21.5: 21.2; Stage D: 22.4: 22.3; **Black South African** Stage A: 15.7: 14.8; Stage B: 17.8: 18.0; Stage C: 20.7: 18.7; Stage D: 22.7: 22.0
Olze et al., 2008 [33]	Japanese	1300 (549:751)	14-26	Olze et al., 2007	**Range (years) M:F** Stage A: 14.6-25.4:14.2-25.8; Stage B: 15.1-26.8:15.2-26.2; Stage C: 15.9-25.9: 16.1-26.3; Stage D: 17.5-26.6: 17.6-26.2 **Mean Age (years) M:F** **Tooth 18:** Stage A-19.9:19.9; Stage B- 20.9:20.6; Stage C: 21.5:21.2; Stage D: 22.4:22.3 **Tooth 28:** Stage A-19.2:20.0; Stage B- 21.0:20.5; Stage C: 21.3:21.2; Stage D: 22.5:22.3 **Tooth 38:** Stage A-19.2:19.5; Stage B- 21.7:20.9; Stage C: 21.6:21.6; Stage D: 22.5:22.2 **Tooth 48:** Stage A-18.9:18.4; Stage B- 22.1:21.2; Stage C: 21.3:21.2; Stage D: 22.5:22.2 No statistically significant difference was observed in the study population concerning side or jaw With regard to sex of an individual, statistically significant differences were only observed for tooth 48 in stage A

Olze et al., 2008 [34]	German	666 (144:522)	12-26	Olze et al., 2007	**Range (years) M:F** Stage A: 14.7-26.1:12.0-25.4; Stage B: 14.7-26.6:12.0-25.4; Stage C: 18.7-26.6: 13.7-25.4; Stage D: 19.0-26.9: 17.4-25.8 **Mean Age (years) M:F** **Tooth 18:** Stage A-18.9:16.6; Stage B- 20.8:18.9; Stage C: 22.1:20.3; Stage D: 23.4:24.0 **Tooth 28:** Stage A-18.8:16.6; Stage B- 21.2:18.6; Stage C: 21.4:20.6; Stage D: 23.7: 22.0 **Tooth 38:** Stage A-18.6:15.5; Stage B- 22.4:18.9; Stage C: 22.8:20.2; Stage D: 23.6:21.9 **Tooth 48:** Stage A-19.9:15.5; Stage B- 21.3:18.7; Stage C: 22.7:20.3; Stage D: 23.7:22.0 Depending on the tooth, the males were between 1.7 and 4.4 years older than the females at the different eruption stages Concerning sex, statistically significant differences were observed for tooth 18 at eruption stages A and B, for tooth 28 at stages A, B and D, and for teeth 38 and 48 at all eruption stages.
Olze et al., 2010 [35]	First Nations people of Canada	605 (258:347)	11-29	Olze et al., 2007	**Range (years) M:F** Stage A: 11.7-18.9:11.0-25.5; Stage B: 13.0-26.7:12.4-27.5; Stage C: 13.6-29.8:13.7-27.4; Stage D: 14.5-29.8: 15.9-29.4 **Mean Age (years) M:F** **Tooth 18:** Stage A-14.9:15.1; Stage B- 17.8:18.2; Stage C: 21.6:20.2; Stage D: 22.2:22.3 **Tooth 28:** Stage A-14.6:14.8; Stage B- 18.1:18.4; Stage C: 20.6:20.0; Stage D: 22.8:22.2 **Tooth 38:** Stage A-12.8:13.3; Stage B- 15.9:17.3; Stage C: 18.1:17.5; Stage D: 21.6:20.6 **Tooth 48:** Stage A-13.6:13.7; Stage B- 16.2:16.7; Stage C: 17.2:18.5; Stage D: 20.5:21.3 A good correlation was observed between the stages and the chronological ages of the subjects for both sexes.
Scheuer et al., 2011 [36]	Central European individuals living in Switzerland	307 (139:168)	17.5 and 18.5 years	Olze et al., 2007	All men and 75% of the women were overestimated by up to 7 years. **Number of Third Molars in each stage (M:F)** **Tooth 18:** Stage A- 18:41; Stage B-78:84; Stage C- 14:16; Stage D- 19:13 **Tooth 28**: Stage A- 14:37; Stage B-83:91; Stage C- 12:15; Stage D- 21:12 **Tooth 38**: Stage A- 17:27; Stage B-48:70; Stage C- 22:22; Stage D- 11:12 **Tooth 48**: Stage A- 12:36; Stage B-46:59; Stage C- 22:17; Stage D- 12:14
Karadayi et al., 2012 [5]	Turkish Caucasian origin and Turkish nationality	768 (374:394)	8-22	Olze et al., 2007	**Range (years) M:F** Stage A: 7.67-19.94:7.54-20.96; Stage B: 12.42-22.49:12.67-22.22; Stage C: 14.17-22.45:13.64-22.02; Stage D: 15.47-22.43:15.89-22.48 **Mean Age (years) M:F** **Tooth 28:** Stage A-11.37:11.93; Stage B- 17.27:18.22; Stage C: 17.75: 18.44; Stage D: 20.14:20.02 **Tooth 38:** Stage A-11.37:11.83; Stage B- 16.79:17.64; Stage C: 17.92 :18.33; Stage D: 20.04:20.27 No statistical difference with respect to eruption was found among the jaws Concerning sex of an individual, Statistically significant were only observed for tooth 28 at eruption stage B

Tuteja et al., 2012 [37]	Indian	150 (77:73)	12-26	Olze et al., 2007	**Range (years) M:F** Stage A: 11.50-15.91:12.16-23.25; Stage B: 15.16-25.33: 14.66-23.66 years; Stage C: 19.58-25.16: 14.66-25.50; Stage D: 16.58-26.25: 14.66-26.58 **Mean Age (years) M:F** **Tooth 18:** Stage A-13.65:14.55; Stage B- 21.75:16.93; Stage C: 21.58:21.56; Stage D: 22.60:22.60 **Tooth 28:** Stage A-13.65:14.55; Stage B- 21.54:17.58; Stage C: 24.21:20.41; Stage D: 22.50:22.67 **Tooth 38:** Stage A-13.39:13.14; Stage B- 19.07:18.12; Stage C: 25.16:21.98; Stage D: 22.52:22.41 **Tooth 48:** Stage A-13.39:13.29; Stage B- 19.61:19.06; Stage C:x:17.61; Stage D: 22.51:22.58 Although, the females were approximately 1.3–3.6 years ahead of the males at the different eruption stages of the third molar, however this difference was non-significant suggesting that this method of age estimation using third molar cannot be used to differentiate gender.
Raj et al., 2014 [38]	Kerala, South India Moderate to High Socioeconomic Status	25 (10:15)	12-26	Olze et al., 2007	**Mean estimated age (years) Whole Sample:M:F** 16.05:15.76:16.25 (no statistically significant difference between mean estimated age and mean CA) **Mean Age (years) M:F** **Tooth 18:** Stage A-14.9:15.1; Stage B- 17.8:18.2; Stage C: 21.6:20.2; Stage D: 22.2:22.3 **Tooth 28:** Stage A-14.6:14.8; Stage B- 18.1:18.4; Stage C: 20.6:20.0; Stage D: 21.6:22.2 **Tooth 38:** Stage A-12.8:13.3; Stage B- 15.9:17.3; Stage C: 18.1:17.5; Stage D: 21.6:20.6 **Tooth 48:** Stage A-13.6:13.7; Stage B- 16.2:16.7; Stage C: 17.2:18.5; Stage D: 20.5:21.3
Akki et al., 2016 [1]	Indian	349 (180:169)	12-25	Olze et al., 2007	**Range (years) M:F** **Stage A:** 12-17:12-18**; Stage B:** 12-19:13-23; **Stage C:** 17-24:14-24**; Stage D:** 18-25:16-25 **Mean Age (years) M:F** **Tooth 18:** Stage A-12.8:14.4; Stage B-16.8: 17.5; Stage C:19.8: 19.3; Stage D-22.3: 22.6 **Tooth 28:** Stage A-12.5: 13.4; Stage B-16.7:16.9; Stage C:19.4: 21.8; Stage D-22.3: 22.7 **Tooth 38:** Stage A-12.3:12.6; Stage B-:15.1:15.9; Stage C:19.7: 19.5; Stage D-22.2: 22.4 **Tooth 48:** Stage A-12.1:12.6; Stage B-14.9:15.7; Stage C:19.5: 18.9; Stage D- 22: 22.2
Kutesa et al., 2019 [29]	Ugandan	1012	10-20	Olze et al., 2007	**Mean Age (years) M:F** **Tooth 18:** Stage A-13.1:12.6; Stage B- 15.8:15.2; Stage C: 16.8:16.6; Stage D: 18.6:18.0 **Tooth 28:** Stage A-13.1:12.6; Stage B- 15.7:15.3; Stage C: 17.2:16.5; Stage D: 18.6: 18.0 **Tooth 38:** Stage A-12.3:12.0; Stage B- 15.7:14.8; Stage C: 16.5:15.8; Stage D: 18.2:17.5 **Tooth 48:** Stage A-12.3:12.0; Stage B- 15.4:14.9; Stage C: 16.8:15.2; Stage D: 18.2:17.6 **Range (years) M:F:** Stage A:10-19: 10-19; Stage B:11-19:10-19; Stage C: 12-20: 10-19; Stage D: 13-20: 13-20 Significantly higher mean age in males as compared to females with regard to stage D. No significant difference in the mean age between the homologous pairs of third molar teeth.

Widek et al. 2019 [39]	Austrian	316; all males	13-25	Olze et al., 2007	**Mean Age (years)** **Tooth 18:** Stage A-16.65; Stage B-20.01; Stage C: 20.94; Stage D: 21.67 **Tooth 28:** Stage A-16.92; Stage B- 19.82; Stage C: 20.28; Stage D: 21.87 **Tooth 38:** Stage A- 15.49; Stage B-18.94; Stage C: 20.56; Stage D: 21.54 **Tooth 48:** Stage A-15.50; Stage B- 18.61; Stage C: 19.82; Stage D:21.65 **Range (years):** Stage A:13.01-24.77; Stage B:13.84-24.98; Stage C:14.92-24.63; Stage D: 16.59-24.96
Shi et al., 2024 [40]	Croatian	583 (283:300)	10-21.99	Olze et al. 2007	**Tooth 38** **Range (years) M:F** Stage A: 10.20-20.06:10.02-19.50; Stage B: 12.60-20.90:12.48-20.92; Stage C: 15.35-20.08:14.35-20.27; Stage D: 16.48-20.70:13.92-20.97 **Mean Age (years) M:F** Stage A: 13.64:13.70; Stage B:16.27:16.43; Stage C:17.78:17.39; Stage D: 18.63:18.30
Timme et al., 2024 [41]	German	605 (303:302)	15-26	Olze et al. (2012) (Modification: Stage C: At least half the crown length of the second molar has been reached, the occlusal plane has not been reached.)	**Range (years) M:F** Stage A: 15.07-25.64:15.04-25.92-; Stage B: 15.27-25.72:15.09-25.93; Stage C: 17.03-25.99:15.43-25.92; Stage D: 17.10-25.95: 16.11-25.98 **Mean Age M:F** **Tooth 38**: Stage A: 16.94:17.59; Stage B: 18.91:19.66; Stage C: 20.35:20.97; Stage D: 22.29: 22.60 **Tooth 48**: Stage A: 16.78:17.49; Stage B: 19.77:19.43; Stage C: 20.21: 21.34; Stage D: 22.08: 22.27
Angelakopoulos et al., 2025 [2]	black South African	877 (357:520)	14-24	Gambier et al., 2019	**Range (years) M:F** Stage 1: 14.01-23.39:14-23.27; Stage 2: 14.07-23.73:14.13-23.99; Stage 3: 14.30-23.85:14.28-23.99 **Mean Age (years) M:F** **Tooth 18:** Stage 1-16.19:16.38; Stage 2- 17.97:17.82; Stage 3: 19.59:19.84 **Tooth 28:** Stage 1-16.17:16.35; Stage 2- 17.88:17.92; Stage 3: 19.57:19.71 **Tooth 38:** Stage 1-15.74:16.12; Stage 2- 17.66:17.73; Stage 3: 19.29:19.66 **Tooth 48:** Stage 1-15.72:16.19; Stage 2- 17.88:17.71; Stage 3: 19.15:19.71
De Luca et al., 2025 [42]	Lebanese	537 (298:239)	15-24	Gambier et al., 2019	**Range (years) M:F** Stage 1: 15.02-23.38:15.01-23.29; Stage 2: 15.05-23.57:15.02-23.45; Stage 3: 15.14-23.57:15.34-23.61 **Mean Age (years) M:F** **Tooth 18:** Stage 1:17.37:17.51; Stage 2- 19.16:19.54; Stage 3: 21.01:21.11 **Tooth 28:** Stage 1:17.35:17.57; Stage 2: 19.46:19.21; Stage 3: 20.92:21.14 **Tooth 38:** Stage 1-16.94:17.41; Stage 2: 19.18:19.15; Stage 3: 20.60:20.48 **Tooth 48:** Stage 1:17.06:17.26; Stage 2: 19.13:19.34; Stage 3: 20.50:20.58

Vadivel et al., 2025 [3]	Srikakulam, Andhra Pradesh, India	400 (200:200) 800 Mandibular Third molars	18-25	Modified Olze's et al. criteria (Modifications: Level A: Retromolar space is much less than the width of the 2nd molar. Level B: Retromolar space is almost equal to that of the 2nd molar.)	**Number of Third Molars in each Level M:F** Level A: 16:22; Level B: 92:139; Level C: 188:184; Level 4:104:55
Our Study	North-Indian	269 OPGs (123:146) 995 Third molars	12-25	Olze's et al. 2007	**Range (years) M:F** Stage A: 12.08-23.22: 12.29-23.89; Stage B: 12.80-23.22:12.58-24.32; Stage C: 14.88-24.62:12.96-24.59; Stage D: 15.62-24.62: 12.96-24.59 **Mean Age (years) (all four third molars combined)** Stage A: 15.204; Stage B: 17.466; Stage C: 19.636; Stage D: 21.171 **Tooth -Wise Mean Age (years)** **Tooth 18:** Stage A: 15.498; Stage B: 17.805; Stage C: 18.475; Stage D: 21.085 **Tooth 28:** Stage A: 15.457; Stage B: 17.558; Stage C: 18.640; Stage D: 21.407 **Tooth 38:** Stage A: 14.873; Stage B: 17.320; Stage C: 20.388; Stage D: 21.105 **Tooth 48:** Stage A: 14.868; Stage B: 17.178; Stage C: 20.204; Stage D:21.023

Table S14: Comparison of Findings of Our Study with Other Studies Concerning the Mineralization Status of Third Molars

Study	Population	Number of OPGs included (M:F)	Age (years)	Method	Inference
Sarnat et al., 2003 [20]	Israel	674 Third molars evaluated =2696	7-16	Modified Gat et. al criteria with addition of Stage 0	**Age wise number of third molars in each stage** 7 years: Stage 3: 0; Stage 4: 0; Stage 5: 0; Stage 6: 0 8 years: Stage 3: 10; Stage 4: 4; Stage 5: 0; Stage 6: 0 9 years: Stage 3: 27; Stage 4: 0; Stage 5: 0; Stage 6: 0 10 years: Stage 3: 112; Stage 4: 4; Stage 5: 1; Stage 6: 0 11 years: Stage 3: 167; Stage 4: 19; Stage 5: 0; Stage 6: 0 12 years: Stage 3: 168; Stage 4: 43; Stage 5: 0; Stage 6: 0 13 years: Stage 3: 134; Stage 4: 95; Stage 5: 6; Stage 6: 0 14 years: Stage 3: 79; Stage 4: 111; Stage 5: 8; Stage 6: 0 15 years: Stage 3: 24; Stage 4: 99; Stage 5: 24; Stage 6: 2
Sisman et al., 2007 [17]	Turkish	900 (380:520)	8-25	Demirjian et al.	**Tooth 48 (in case 48 not present than 38 was considered) Mean Age(M:F)** Stage D: 12.90:13.60; Stage E: 14.42:15.42; Stage F: 16.90: 16.84; Stage G: 18.08:19.29; Stage H: 22.10:22.66 **Range (years): M:F** Stage D: 10.00-17.00:8.00-22.00; Stage E: 10.00-18.00:10.00-18.00; Stage F: 12.00-22.00; 14.00-24.00; Stage G: 10.00-22.00: 14.00-24.00; Stage H: 10.00-25.00: 15.00-25.00
Scheurer et al., 2011 [36]	Central European individuals living in Switzerland	307 (139:168)	17.5 and 18.5 years	Demirjian and Mincer et al.	**Number of Third Molars in each stage (M:F)** **Tooth 18**: Stage D- 4:7; Stage E-9:8; Stage F- 23:30; Stage G- 39:52; Stage H: 29:21 **Tooth 28:** Stage D- 2:8; Stage E-9:8; Stage F- 19:28; Stage G- 40:43; Stage H: 37:19 **Tooth 38:** Stage D- 3:14; Stage E-14:13; Stage F- 27:51; Stage G- 61:62; Stage H: 11:8 **Tooth 48**: Stage D- 4:8; Stage E-12:25; Stage F- 28:44; Stage G- 61:54; Stage H: 10:9 Overestimations was observed in 76% and 82% of the males and females respectively with average differences of 2years between estimated and chronological age

Ajmal et al., 2012[43]	Southern region of the Kingdom of Saudi Arabia.	360 All males	13-23	Demirjian's chart modified by Kasper	**Mandibular Third Molars** **Mean Age (Years)** Stage 4: 15.50; Stage 5: 16.52; Stage 6: 17.96; Stage 7: 19.52; Stage 8:22.02 **Range (years)** Stage 4: 13-19; Stage 5: 13-20; Stage 6: 15-22; Stage 7: 15-23; Stage 8:16-24
Karadayi et al., 2012 [5]	Turkish Caucasian origin and Turkish nationality	768 (374:394)	8-22	Nolla et al.	**Mean Age (years) M:F** **Tooth 28:** Stage 6:14.61:14.49; Stage 7: 16.46:16.40; Stage 8: 17.43: 17.87; Stage 9: 19.21:19.23; Stage 10: 20.90:21.02 **Tooth 38:** Stage 6:14.89:14.72; Stage 7: 15.93:16.43; Stage 8: 17.03: 17.68; Stage 9: 19.06:19.16; Stage 10: 20.91:21.06 **Range (Years) M:F** Stage 6:12.45-19.10:11.64-19.81; Stage 7:12.42-19.94:12.57-21.90; Stage 8: 14.16-22.21:14.56-21.25; Stage 9: 15.47-22.49:16.10-22.22; Stage 10: 19.30-22.45:19.27:22.48 No statistically significant jaw differences was observed
Jung & Cho 2014 [44]	Korea	2490 (1273:1217) Third molar evaluated: 7081 (3562:3519)	6-24	Modified Demirjian's	**Mean Age (years)** Stage D: 14.77; Stage E: 16.25; Stage F: 17.58; Stage G: 19.00; Stage H: 21.96 **Mean Age (years) M:F** Stage D: 14.58:14.87; Stage E: 16.06:16.39; Stage F: 17.17:17.83; Stage G: 18.70:19.35; Stage H: 21.85:22.10
Mathew et al., 2017 [45]	Kerala, South India	160	9-25	Demirjian et al.	**Tooth 38** **Mean Age (years) M:F** Stage D: 13.2:13.5; Stage E: 13.6:14.6; Stage F: 16.0: 16.0; Stage G: 16.5:17.5; Stage H: 21.2:21.4 **Range (years) M:F** Stage D: 12-15:12-17; Stage E: 10-17:12-17; Stage F: 14-19:14-19; Stage G: 14-18: 14-22; Stage H: 16-25: 17-25
Firdaus et al., 2018 [46]	Indonesian	407 (185:222)	8-25	Demirjian et al.	**All four Third Molars** **Mean Age (years)** Stage D: 12.26; Stage E: 14.0; Stage F: 16.92; Stage G: 19.61; Stage H: 23.25 **Range (years)** Stage D: 10.12-16.22; Stage E:11.32-18.43; Stage F:14.10-20.94 ; Stage G: 15.77-23.04; Stage H: 20.04-25.73
Branco et al., 2012 [13]	Portuguese	329 (133:196)	14.0-22.8	Demirjian et al.	**Mean Age (Years) M:F** **Tooth 18**: Stage D: 15.1:15.5; Stage E: 15.4:16.3; Stage F: 16.0:17.6; Stage G: 17.6:18.5; Stage H: 19.9:20.0 **Tooth 28:** Stage D: 15.1:15.3; Stage E: 15.8:16.3; Stage F: 16.0:17.5; Stage G: 17.5:18.9; Stage H: 20.1:20.2 **Tooth 38**: Stage D: 14.9:15.6; Stage E: 15.6:16.9; Stage F: 17.0:18.1; Stage G: 18.8:19.5; Stage H: 20.3:20.4 **Tooth 48**: Stage D: 14.7:15.6; Stage E: 15.7:16.2; Stage F: 16.8:18.1; Stage G: 18.5:19.4; Stage H: 20.3:20.5
Widek et al., 2019 [39]	Austrian	316; all males	13-25	Demirjian et al. , modified by Mincer et al.	**Mean Age (years)** **Tooth 18**: Stage D: 13.95; Stage E: 16.03; Stage F: 17.56; Stage G: 20.22; Stage H: 22.39 **Tooth 28:** Stage D: 13.92; Stage E: 15.81; Stage F: 17.47; Stage G: 20.28; Stage H: 22.36 **Tooth 38**: Stage D: 14.13; Stage E: 15.8; Stage F: 17.53; Stage G: 20.62; Stage H: 22.15 **Tooth 48**: Stage D:14.35; Stage E: 15.89; Stage F: 17.59; Stage G: 20.48; Stage H: 22.61 **Range (years)** Stage D:13.01-17.71; Stage E: 13.01-20.96; Stage F: 13.11-23.78; Stage G: 16.19-24.98; Stage H: 17.3-24.96
Ramaswami et al., 2020 [47]	South Brazilians	1,013 (369:644)	15-23	Demirjian et al.	**Mean Age (years) M:F** **Maxillary Third Molars:** Stage D: 16.2:16.2; Stage E: 16.0: 17.2; Stage F: 16.4:17.3; Stage G: 17.0:17.8; Stage H: 20.2:20.5 **Mandibular Third Molars:** Stage D: 16.0:17.0; Stage E: 16.5:17.8; Stage F:16.6:17.3; Stage G: 17.3:18.4; Stage H: 20.3:20.7
Arumugam and Doggalli 2020 [10]	Indian	400 (200:200)	14-22	Mincer et al. adapted from Demirjian et al.	**All four Third Molars** **Mean Age (years) M:F** Stage D: 14.7:14.8; Stage E: 15.5: 15.8; Stage F: 17:17.1; Stage G: 18.6:18.9; Stage H: 20.7:20.7

Sindi et al., 2023 [48]	Saudi Arabian	508 (229:279)	6–24	Demirjian's classification modified by Kasper; Moorrees'	**All four Third Molars** **Mean Age ((Range) years** **Modified Demirjian:** Stage D: 13.99 (9-19); Stage E: 15.80 (10-20); Stage F: 16.58 (12-23); Stage G: 17.89 (14-24); Stage H: 20.21 (16-24) **Moorrees:** Stage 6: 13.20 (9-19); Stage 7:13.70 (9-19); Stage 8: 14.32 (10-21); Stage 9: 15.57(10-20); Stage 10: 17.06 (12-23); Stage 11: 17.06 (13-22); Stage 12: 18.27 (12-24); Stage 13: 19.43 (16-21); Stage 14: 20.42 (17-24)
Sadan et al., 2023 [49]	Israel	324 (179:145)	8-21	Demirjian et al.	**Mean Age (years)** **Maxillary Third Molars:** Stage D: 12.65; Stage E:14.92; Stage F:17.13; Stage G & H:18.28 **Mandibular Third Molars:** Stage D: 12.90; Stage E:14.77; Stage F:17.49; Stage G & H: 18.23
Shi et al., 2024 [40]	Croatian	583 (283:300)	10-21.99	Haavikko et al. Demirjian et al.	**Tooth 38** **Mean Age (years) M:F** **Haavikko et al. :** Crc:13.81:14.16; R1/4: 14.91:15.33; R1/2: 16.45:16.39; R3/4: 16.81:16.69; Rc: 17.50:17.85; Ac: 19.57:19.67 **Demirjian et al.:** Stage D: 13.74:14.05; Stage E: 15.39:15.56; Stage F: 16.77:16.97; Stage G: 17.51:17.85; Stage H: 19.57:x **Range (years) M:F** **Haavikko et al. :** Crc:11.58-16.39:11.76-16.67; R1/4: 10.62-18.08:12.48-18.58; R1/2: 14.11-20.83:12.97-20.92; R3/4: 14.59-19.76:13.85-19.47; Rc: 14.81-19.97:15.06-20.25; Ac: 18.02-20.90:18.09-20.97 **Demirjian et al. :** Stage D: 11.58-16.39:11.76-16.67; Stage E: 10.62-20.83:12.48-18.85; Stage F: 14.59-19.76:13.85-20.92; Stage G: 14.81-19.97:15.06-20.25; Stage H: 18.02-20.90:x
Sharma et al., 2024 [50]	Jharkhand, India	720 (370:350)	6-22	Demirjian et al.	**All four third molars** **Mean Age (years) M:F** Stage D: 19.00:19.56; Stage E: 19.40:19.63; Stage F: 19.36:20.26; Stage G: 20.45:20.70; Stage H: 21.37:21.69
Present Study	North-Indian	269 (123:146) 995 Third Molars	12-25	Newly proposed method	**Mean Age (years) (All four third molars combined)** Stage A: 14.729, Stage B: 16.438; Stage C: 17.494; Stage D: 20.787 **Tooth-Wise Mean Age (years)** **Tooth 18:** Stage A: 15.015; Stage B: 16.781; Stage C: 17.526; Stage D: 20.606 **Tooth 28:** Stage A: 14.925; Stage B: 16.864; Stage C: 17.652; Stage D: 20.802 **Tooth 38:** Stage A: 14.447; Stage B: 16.037; Stage C: 17.366; Stage D: 20.884 **Tooth 48:** Stage A: 14.436; Stage B: 15.961; Stage C: 17.415; Stage D:20.858 **Range (years) M:F** Stage A: 12.08-18.71:12.29-23.89, Stage B: 12.90-23.22: 13.14-22.09; Stage C: 14.51-21.19:14.00-24.32; Stage D: 16.00-24.62:12.96-24.59