Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Accuracy of Cameriere's Third Molar Maturity Index (I3M) and Demirjian Staging in Impacted vs. Non-impacted Teeth for Legal Age Assessment

Maria Poletaeva
Sechenov First Moscow State Medical University
Rizky Merdietio Boedi
Diponegoro University
Nikolaos Angelakopoulos
University of Bern
Stefano De Luca
lucastefano@uniovi.es
University of Oviedo
Yuriy Pigolkin
Sechenov First Moscow State Medical University
Galina Zolotenkova
Sechenov First Moscow State Medical University

Method Article

Keywords: Age estimation, Cameriere Index, Dental age, Demirjian stages, Forensic Sciences, Impaction, Third molars

Posted Date: November 24th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11680662/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

This study evaluates the impact of third molar impaction on the accuracy of dental age estimation for legal adulthood (≥ 18 years) using the Cameriere third molar maturity index (I3M) and Demirjian staging. Orthopantomograms of 555 Russian individuals (353 females and 202 males) aged 14.02–22.98 years, obtained from an orthodontic clinical setting, were analysed retrospectively. Development and impaction were assessed for the mandibular third molars (FDI 38, or FDI 48 when FDI 38 was absent); 76.6% of teeth were impacted. A two-way ANOVA was used to test whether the effect of impaction differed between sexes, and diagnostic performance was evaluated with ROC curve analysis, Youden index cut-offs validated by 5-fold cross-validation, DeLong's test and logistic regression. The sex x impaction interaction was not significant (p = 0.803); therefore, all subsequent analyses were performed on the pooled sample. At the same age, impacted third molars showed a higher I3M (difference 0.056 [0.013; 0.098], p = 0.011), indicating a small delay in mineralisation, although this difference was absent at stages F–H (0.009 [-0.013; 0.031], p = 0.422); at the same Demirjian stage, the age difference was not significant (0.25 years [-0.08; 0.58], p = 0.134). Both methods showed excellent diagnostic accuracy (AUC 0.96 for the I3M and 0.94 for the Demirjian stages), with no difference in the I3M AUC between impacted and non-impacted teeth (p = 0.970). The Youden-optimal I3M cut-off was 0.08 overall, 0.085 for impacted and 0.08 for non-impacted teeth; in impacted teeth, 0.08 and 0.09 had similar accuracy (0.920 vs 0.925, p = 0.727), and under 5-fold cross-validation within each group the re-derived cut-off ranged from 0.079 to 0.089 in impacted and from 0.068 to 0.080 in non-impacted teeth (accuracy 0.92 in both). At 0.08, specificity was 0.98 in impacted and 0.91 in non-impacted teeth. In this sample, 86% of individuals at Demirjian stage G and 99% at stage H were ≥ 18 years. Both methods showed high accuracy in this single-centre orthodontic sample, and the 0.08 cut-off performed well in impacted teeth.

Introduction

Dental age estimation (DAE) in living individuals is part of contemporary forensic age assessments [1, 2] and of clinical dentistry [3], particularly orthodontics [4]. It is mainly applied, in medico-legal frameworks, to people without reliable identity documents, such as asylum seekers, undocumented migrant minors and victims of trafficking [5–8]. Moreover, DAE as part of a broader age estimation methodology assumes critical importance in judicial proceedings concerning sporting events[9], child labour [10], sexual abuse and exploitation [11], juvenile delinquency [12] and the recruitment or involvement of minors in armed conflict [13]. In such contexts, the outcome has direct legal consequences, since it determines whether a person is treated as a child, with the protections that this implies, or as an adult [14]. Age estimation is, however, inherently uncertain, and wrongly classifying a minor as an adult is generally regarded as the more critical error; results should therefore be interpreted within a decision framework that gives the benefit of the doubt to the individual [5].

According to the current scientific literature, tooth development is considered to be under stronger genetic control and less affected by nutritional, environmental, systemic diseases and hormonal

disorders than skeletal maturation [15] and it is widely used to estimate chronological age (CA) in forensic practice [16, 17]. Because the third molar is the last tooth to complete its development, its maturation is the main dental indicator used to assess whether the legal age of majority, set at 18 years in many countries, has been reached [5]. Third molar development can be evaluated using metric approaches, which relate the open apices to the tooth length [18] and/or with staging systems [19, 20].

The third molar is the most variable tooth in terms of its presence, structure and position within the dental arch [21]. Its impaction is common, with a worldwide pooled prevalence of 24.40% [22], and 36.9% per subject in a more recent meta-analysis [23]. A third molar is generally considered impacted when it fails to reach its normal position in the dental arch within the expected time because of an obstacle such as the second molar, bone or lack of space [24]. According to a recent systematic review and meta-analysis, third molar impaction is associated with a statistically significant but small delay in third molar mineralization, with a pooled mean difference 0.8 years, which appeared more pronounced in females than in males and varied across stages, potentially influencing DAE in legal settings [25].

The Demirjian staging method is one of the most widely adopted DAE techniques [19, 20] due to its clearly defined developmental stages [26]. Another widely used third molar assessment method, proposed by Cameriere et al. (2008), is the third molar maturity index (I3M), based on the ratio between the sum of the open apical widths and the tooth length; a value below 0.08 indicates an age of at least 18 years [18]. Both approaches have been validated in Russian samples [27–30], but the evidence on whether third molar impaction modifies their performance for the 18-year threshold is limited and inconsistent. This study therefore aimed to 1) assess whether impaction is associated with differences in third molar development, using the I3M and Demirjian staging; 2) compare their accuracy for age ≥ 18 years in impacted and non-impacted teeth; 3) evaluate whether the 0.08 I3M cut-off remains appropriate irrespective of impaction status.

Material and Methods

Study Design and Sample

This retrospective, single-centre, cross-sectional diagnostic accuracy study was approved by the Local Research Ethics Committee of Sechenov First Moscow State Medical University, Moscow, Russia (approval No. 4–24, 21.02.2024). All panoramic radiographs (PANs) had been taken as part of orthodontic pre-treatment planning, none was obtained solely for this research, and all images were fully anonymised before analysis. No new data collection, database access, or patient contact was involved. No subjects were exposed to radiation solely for the purpose of this research. This study was performed according to the ethical standards advocated by the Declaration of Helsinki [31].

The PANs were collected retrospectively at Sechenov University Dental Hospital, Moscow, Russia, and were acquired between 2015 and 2022 with a Pan eXam Plus system (KaVo Dental™, Biberach, Germany)

set at 66 kV, 2.5 mA and 17 s. Each PAN was fully anonymised, with sex, date of birth and date of radiograph recorded, and the CA of the subject was calculated as the difference between the date of radiograph and the date of birth, expressed in decimal years (days/365.25). The inclusion criteria were individuals of Russian nationality through hospital records aged 14.00–22.99 years with at least one mandibular third molar present. The exclusion criteria were: the absence of both Fédération Dentaire Internationale (FDI) 38 and FDI 48 [32], extensive decay, restorations or root canal treatment of FDI 38 or FDI 48, visible bone lesions associated with these teeth, surgical appliances in the mandible, deformation of the maxillofacial bones, visible third molar anomalies, poor image quality including distortion, motion artefacts or unclear apices, and missing data on the date of radiograph, date of birth or sex. The sample comprised 555 individuals (353 females and 202 males) aged 14.02–22.98 years (mean 18.41 ± 2.76 years), with no significant difference in age distribution between females and males ($p = 0.789$, Table 1).

Table 1
Sample distribution according to sex and age

Age range (years)	Female	Male	Total
14.00–14.99	47	21	68
15.00–15.99	38	25	63
16.00–16.99	39	33	72
17.00–17.99	39	18	57
18.00–18.99	35	17	52
19.00–19.99	29	15	44
20.00–20.99	39	27	66
21.00–21.99	41	25	66
22.00–22.99	46	21	67
Total	353	202	555
Radiographic Assessment			

Teeth FDI 38 and FDI 48 were selected following the I3M selection criteria. Images were assessed [18] in a darkened room on a personal computer (Vaio PCG-71911X, Sony Corp., Minato, Tokyo, Japan) equipped with a 15.6” LCD screen with a resolution of 1366 × 768, and Adobe Photoshop CS6 (Adobe Inc., San Jose, CA, USA) was used for image visualisation and analysis. The developmental status was assessed using the Demirjian staging system (stages A–H) [19, 20] and the I3M [18]. Impaction was considered when the tooth was tilted outside the normal path for the eruption in the dental arch [33]. The reference set to assess the type of impaction was the vertical (crown-apex) axis of the permanent mandibular second molar. In this context, the vertical axis of the third molar was compared with the vertical axis of the

second molar. Impaction could be associated with the mandibular ramus or against the second molar (Fig. 1). Impacted teeth were further classified by angulation as vertical, mesioangular, distoangular or horizontal according to Winter [24], where two axes compared visually.

The primary observation was performed by the first author (MP), with five years of experience in evaluating PAN images. To assess inter-observer agreement, a second examiner (RMB) independently evaluated 30 randomly selected radiographs. Both observers were blinded to the age and sex of the subjects. The intraclass correlation coefficient (ICC; two-way, absolute agreement) was calculated for the I3M, and the weighted Cohen's kappa for the Demirjian stages.

Statistical Analysis

Statistical analyses were performed in R version 4.5.2 (R Foundation for Statistical Computing, Vienna, Austria), and a p-value < 0.05 was considered statistically significant. Differences between FDI 38 and FDI 48 were assessed with the Wilcoxon signed-rank test for the I3M and the Demirjian stages in individuals with both third molars present, and agreement between sides was calculated as the ICC and the linearly weighted Cohen's kappa, respectively. When no significant difference was found between the sides, FDI 38 was used as the primary reference. Differences in age between impacted and non-impacted teeth within each Demirjian stage were tested with the Mann–Whitney U test, with Holm correction for the five stages.

To determine whether the effect of impaction on mineralisation differed between sexes, a two-way ANOVA with sex, impaction status and their interaction was fitted to the CA, adjusted for the Demirjian stage. A two-way ANCOVA with the same factors was fitted to the I3M, adjusted for the CA (natural cubic spline with three degrees of freedom).

To analyse the capability of each method for estimating the legal adult age of 18 years, a receiver operating characteristic (ROC) curve analysis was performed and the area under the curve (AUC) was calculated with its 95% CI [34]. The optimal I3M cut-off was determined using the Youden index for the overall sample and for impacted and non-impacted teeth, with its 95% CI from 1000 bootstrap resamples. Differences in the AUC between impacted and non-impacted teeth were compared using DeLong's test. Sensitivity, specificity, accuracy and the number of minors classified as adults were also calculated at the fixed cut-offs of 0.08 and 0.09 (I3M below the cut-off classified as ≥ 18 years). Because the classifications at the cut-offs of 0.08 and 0.09 concern the same individuals, they were compared with the exact McNemar test. To check the stability of the cut-off and to avoid overfitting to the training sample, a stratified 5-fold cross-validation was performed separately in the overall sample and in impacted and non-impacted teeth (set.seed = 33), with folds stratified by ≥ 18-year status and, in the overall sample, also by impaction status: the cut-off was re-derived in each training set and applied to the held-out fold.

For the Demirjian staging, the probability of being ≥ 18 years at each stage was calculated as the observed proportion with its exact Clopper–Pearson 95% CI. To test whether impaction was an independent predictor of being ≥ 18 years, logistic regression models including the Demirjian stage or the I3M, impaction status, sex and the tooth assessed were fitted.

Results

The inter-observer reliability was excellent. For the I3M, the ICC was 0.96, and for Demirjian staging, Cohen's kappa was 0.86. These results indicate high consistency between examiners. In individuals with both third molars, no significant differences were observed between the left (FDI 38) and right (FDI 48) sides for the I3M (480 pairs, $p = 0.790$) or the Demirjian stages (479 pairs, $p > 0.999$). Agreement between sides was high for the I3M (ICC = 0.955 [0.946; 0.962]) and the Demirjian stages (weighted kappa = 0.915 [0.894; 0.935]; identical stage in 87.3% of pairs). Impaction status was concordant in 81.0% of pairs, with FDI 38 more often the impacted tooth when the sides differed (McNemar's test, $p = 0.036$). Consequently, FDI 38 was used as the primary reference; when it was missing, data from FDI 48 were used (n = 38).

The sex × impaction interaction was not significant, either for the CA at a given Demirjian stage ($p = 0.803$) or for the I3M at a given CA ($p = 0.800$). The effect of impaction therefore did not differ between females and males, no sex-specific analysis was performed, and the following results are reported for the pooled sample. At the same CA, impacted teeth had a higher I3M than non-impacted teeth (difference 0.056 [0.013; 0.098], $p = 0.011$), indicating slightly slower mineralisation. When the analysis was restricted to stages F–H, this difference was no longer present (0.009 [− 0.013; 0.031], $p = 0.422$). At the same Demirjian stage, the mean age was 0.25 years [− 0.08; 0.58] higher in impacted teeth, which was not statistically significant ($p = 0.134$).

The descriptive statistics for CA and I3M values according to the Demirjian stages are summarised in Table 2. The mean age increased and the I3M values decreased progressively from stage D to stage H. Of the 555 third molars, 425 (76.6%) were impacted and 130 (23.4%) were non-impacted. The proportion of impacted teeth fell from 86.3% at stage D to 69.9% at stage H ($p = 0.002$).

Table 2

Descriptive statistics of chronological age and I3M values by Demirjian stage[19, 20]

Demirjian stage	n	Age min	Age mean ± SD	Age max	I3M mean ± SD
D	73	14.06	15.32 ± 1.07	18.22	0.82 ± 0.25
E	91	14.02	16.42 ± 1.98	22.65	0.49 ± 0.22
F	110	14.10	16.69 ± 1.93	22.86	0.26 ± 0.17
G	128	15.21	19.82 ± 1.71	22.98	0.06 ± 0.06
H	153	17.44	21.11 ± 1.31	22.98	0.00 ± 0.00
Demirjian Analysis					

The mean CA was higher in impacted than in non-impacted teeth at stages E to H, although the differences were small except at stage G (Table 3). The difference in mean age was largest at stage G (20.02 ± 1.68 vs 19.20 ± 1.70 years, p = 0.014, p = 0.072). In the logistic regression adjusted for sex and the tooth assessed, impaction status was not a significant predictor of being ≥ 18 years (OR = 1.82 [0.89; 3.86], p = 0.104). The Demirjian stage discriminated individuals ≥ 18 years with an AUC of 0.939 [0.920; 0.958] (cross-validated AUC 0.931 [0.909; 0.952]). The probability of being ≥ 18 years increased highly at stage G (0.86 [0.79; 0.91]) and was almost certain at stage H (0.99 [0.95; 1.00]) (Table 4).

Table 3

Comparison of chronological age between impacted and non-impacted teeth by Demirjian stage[19, 20]

Stage	Group	n	Min	Mean ± SD	Median [IQR]	Max	p
D	Impacted	63	14.09	15.31 ± 1.03	15.13 [14.26; 16.02]	18.22	0.860
	Non-impacted	10	14.06	15.37 ± 1.33	14.99 [14.20; 16.23]	17.57	
E	Impacted	75	14.02	16.45 ± 2.12	16.12 [14.77; 17.39]	22.65	0.802
	Non-impacted	16	14.25	16.27 ± 1.21	16.16 [15.36; 16.75]	18.79	
F	Impacted	84	14.10	16.76 ± 1.97	16.30 [15.45; 17.28]	22.86	0.499
	Non-impacted	26	14.12	16.49 ± 1.84	16.19 [15.58; 17.02]	21.54	
G	Impacted	96	15.21	20.02 ± 1.68	19.93 [18.99; 21.59]	22.98	0.014
	Non-impacted	32	16.56	19.20 ± 1.70	18.99 [18.17; 19.88]	22.64	
H	Impacted	107	17.44	21.13 ± 1.31	20.99 [20.34; 22.41]	22.98	0.959
	Non-impacted	46	17.59	21.08 ± 1.32	21.33 [20.54; 21.83]	22.86	

Table 4

Probability of being ≥ 18 years by Demirjian stage[19, 20] [exact 95% CI]

Demirjian stage	Overall	Impacted	Non-impacted
D	0.01 [0.00; 0.07]	0.02 [0.00; 0.09]	0.00 [0.00; 0.31]
E	0.20 [0.12; 0.29]	0.21 [0.13; 0.32]	0.12 [0.02; 0.38]
F	0.14 [0.08; 0.21]	0.14 [0.08; 0.24]	0.12 [0.02; 0.30]
G	0.86 [0.79; 0.91]	0.89 [0.80; 0.94]	0.78 [0.60; 0.91]
H	0.99 [0.95; 1.00]	0.99 [0.95; 1.00]	0.98 [0.88; 1.00]
Third Molar Maturity Index Analysis			

The diagnostic performance of the I3M for estimating the legal adult age of 18 years was high, with an AUC of 0.959 [0.943; 0.975] in the overall sample, 0.959 [0.941; 0.978] for impacted and 0.960 [0.928; 0.992] for non-impacted teeth (Table 5, Fig. 2). DeLong's test showed no significant difference between the AUCs of impacted and non-impacted teeth (p = 0.970). The optimal cut-off determined by the Youden index was 0.080 for the overall sample and for non-impacted teeth, and 0.085 for impacted teeth.

When the cut-off of 0.09 was applied to impacted teeth instead of 0.08, the sensitivity increased from 0.87 [0.82; 0.91] to 0.89 [0.84; 0.93] (p = 0.063) and the specificity decreased from 0.98 [0.94; 0.99] to 0.96 [0.92; 0.98] (p = 0.250), without a significant difference in accuracy (0.920 vs 0.925, p = 0.727). In impacted teeth, 5 of 205 minors were classified as adults at 0.08 and 8 of 205 at 0.09. In non-impacted teeth, the corresponding numbers were 5 of 55 and 9 of 55 (Table 6). At 0.08, the false-adult rate was 2.4% [0.8; 5.6] in impacted and 9.1% [3.0; 20.0] in non-impacted teeth (Fisher's exact test, post hoc, p = 0.038). Therefore, no separate cut-off was adopted for impacted teeth. In the logistic regression adjusted for sex and the tooth assessed, impacted teeth had higher odds of being ≥ 18 years at the same I3M (OR = 2.26 [1.03; 5.20], p = 0.042), but adding these covariates did not improve the cross-validated AUC (0.955 vs 0.956, p = 0.689).

In the 5-fold cross-validation (Table 7), the re-derived cut-off was 0.080 in all folds of the overall sample. In impacted teeth, it ranged from 0.079 to 0.089, with a held-out specificity of 0.93 to 1.00 across folds and 0.97 [0.93; 0.99] overall. In non-impacted teeth, it was 0.08 in four folds and 0.068 in one; each held-out fold contained only 11 minors, and specificity ranged from 0.82 to 1.00 across folds (0.91 [0.80; 0.97] overall). The cross-validated accuracy was 0.92 in all three analyses.

Table 5

ROC analysis of the I3M for age ≥ 18 years: optimal cut-off, AUC, sensitivity, specificity and accuracy for the overall sample and for impacted and non-impacted teeth at the Youden-optimal cut-off (I3M at or below the cut-off classified as ≥ 18 years)

Group	n (≥ 18 years)	Optimal cut-off [95% CI]	AUC [95% CI]	Sensitivity [95% CI]	Specificity [95% CI]	Accuracy [95% CI]
Overall	555 (295)	0.080 [0.079; 0.116]	0.959 [0.943; 0.975]	0.89 [0.85; 0.92]	0.96 [0.93; 0.98]	0.92 [0.90; 0.94]
Impacted	425 (220)	0.085 [0.080; 0.129]	0.959 [0.941; 0.978]	0.88 [0.83; 0.92]	0.98 [0.94; 0.99]	0.93 [0.90; 0.95]
Non-impacted	130 (75)	0.080 [0.046; 0.102]	0.960 [0.928; 0.992]	0.93 [0.85; 0.98]	0.91 [0.80; 0.97]	0.92 [0.86; 0.96]

Table 6

Performance of the fixed I3M cut-offs of 0.08 and 0.09 (I3M below the cut-off classified as ≥ 18 years); p values compare 0.09 with 0.08 (exact McNemar test)

Group	Cut-off	Sensitivity [95% CI]	Specificity [95% CI]	Accuracy [95% CI]	Minors classified as adults	p: sensitivity / specificity / accuracy
Overall	0.08	0.88 [0.84; 0.92]	0.96 [0.93; 0.98]	0.92 [0.89; 0.94]	10/260	
	0.09	0.90 [0.86; 0.93]	0.93 [0.90; 0.96]	0.92 [0.89; 0.94]	17/260	0.031 / 0.016 / > 0.999
Impacted	0.08	0.87 [0.82; 0.91]	0.98 [0.94; 0.99]	0.92 [0.89; 0.94]	5/205	
	0.09	0.89 [0.84; 0.93]	0.96 [0.92; 0.98]	0.92 [0.90; 0.95]	8/205	0.063 / 0.250 / 0.727
Non-impacted	0.08	0.92 [0.83; 0.97]	0.91 [0.80; 0.97]	0.92 [0.85; 0.96]	5/55	
	0.09	0.93 [0.85; 0.98]	0.84 [0.71; 0.92]	0.89 [0.83; 0.94]	9/55	> 0.999 / 0.125 / 0.375

Table 7
5-fold cross-validation of the Youden-optimal I3M cut-off within each group: cut-off derived in each training set, sensitivity and specificity in the held-out fold, and specificity of the fixed 0.08 in the same fold

Group	Fold	Held-out n (minors)	Cut-off	Sensitivity	Specificity	Specificity at 0.08
Impacted	1	85 (41)	0.079	0.86	0.95	0.95
	2	85 (41)	0.085	0.80	0.98	0.98
	3	85 (41)	0.089	0.95	0.93	0.98
	4	85 (41)	0.085	0.82	1.00	1.00
	5	85 (41)	0.085	0.91	0.98	0.98
Non-impacted	1	26 (11)	0.080	1.00	0.82	0.82
	2	26 (11)	0.080	1.00	1.00	1.00
	3	26 (11)	0.080	0.87	0.82	0.82
	4	26 (11)	0.068	0.80	0.91	0.91
	5	26 (11)	0.080	0.93	1.00	1.00
Impacted	Pooled	425 (205)	0.085 ± 0.004	0.87 [0.82; 0.91]	0.97 [0.93; 0.99]	0.98 [0.94; 0.99]
Non-impacted	Pooled	130 (55)	0.078 ± 0.006	0.92 [0.83; 0.97]	0.91 [0.80; 0.97]	0.91 [0.80; 0.97]
Overall	Pooled	555 (260)	0.080 ± 0.000	0.89 [0.85; 0.92]	0.96 [0.93; 0.98]	0.96 [0.93; 0.98]

Discussion

Since the third molar is the most commonly impacted tooth [23], researchers often question whether its impaction affects the rate of development [35]. Understanding the potential effect of impaction on the development of third molars is important for DAE in forensic practice, as third molar assessment is one of the main forensic odontological methods for age assessment [27]. In the Russian population itself, positional anomalies account for 18% of observed data [21, 36]. The impaction of the third molars in DAE practice therefore needs to be considered, as studies have reported mixed results [37–39] and recent meta-analysis conducted by Balla et al., (2026) has a high heterogeneity with I^2 reaching 81.5% [25]. In this study, although minor statistically significant differences in third molar development were observed, impaction did not change the discrimination of the 18-year threshold.

The present study demonstrated that the Cameriere I3M and the Demirjian staging method are highly accurate in this orthodontic Russian sample. A slower development of impacted third molars was observed compared with non-impacted teeth: at the same age, impacted teeth had a higher I3M (0.056), and at stages E to G the mean age of impacted teeth was higher. The most notable difference was recorded at stage G, where impacted teeth corresponded to a mean age of 20.02 years compared with 19.20 years for non-impacted teeth. This delay may be related to the mechanical obstruction by the second molar and the lack of retromolar space [39], whereas the mechanical compression may cause localized microvascular compromise in the developing periodontal tissues, reducing the metabolic supply to apical odontoblasts and consequently slowing down dentin deposition and apical closure [40]. These findings are consistent with those of studies in black South African males, in whom impacted mandibular third molars at stages F and G belonged to individuals 0.32–1.88 years older [37], and in a Lebanese sample, in which mean ages were higher in impacted teeth at most stages [33]. The effect of impaction did not differ between sexes, which justified the use of the pooled sample. This differs from the meta-analysis, in which the delay appeared more pronounced in females [25].

Importantly, despite the slight biological delay in the maturation of impacted third molars, this did not lead to a significant reduction in the accuracy of the age-of-majority assessment. The AUC of the I3M reached 0.96 for the total sample and for impacted and non-impacted teeth, corresponding to excellent diagnostic quality, and DeLong's test gives no significant difference between the AUCs. The optimal cut-off was 0.08 for the total sample and for non-impacted teeth and 0.085 for impacted teeth. In impacted teeth, 0.09 did not differ significantly from 0.08 in sensitivity ($p = 0.063$), specificity ($p = 0.250$) or accuracy ($p = 0.727$), and it classified three more minors as adults. Cross-validation within each group supported 0.08 in impacted teeth, where the re-derived cut-off ranged from 0.079 to 0.089 and the specificity from 0.93 to 1.00. In non-impacted teeth, the cut-off was 0.080 in four of five folds but 0.068 in one, and with only 11 minors per held-out fold, specificity ranged from 0.82 to 1.00. The 55 minors in this group are too few to confirm the cut-off, so the data support 0.08 in impacted teeth but cannot establish it in non-impacted teeth. This is consistent with the multi-ethnic study of Angelakopoulos et al., (2022) which found that 0.08 remains useful for discriminating individuals younger than 18 years [17]. The accuracy of the 0.08 cut-off (I3M < 0.08; sensitivity 0.88, specificity 0.96, accuracy 0.92) was comparable to that reported in an Italian sample (0.87, 0.96 and 0.91) [41] and in previous Russian samples, in which sensitivity ranged from 0.89 to 0.96 and specificity from 0.95 to 1.00 [27–29]. The presence of a biological delay without a reduction in diagnostic accuracy can be explained by the fact that the delay shifts the age distribution at each stage slightly but does not increase the overlap of the age distributions of individuals younger and older than 18 years.

The discrepancy or similarity with studies in which the effect of impaction was minimal or absent may be explained by specific methodological differences. First, the way the comparison is made may influence the result. For example, Olze et al., (2012) compared the mean age of impacted and non-impacted teeth separately within each stage and found differences of 0.32–1.88 years [37], whereas Saputri et al., (2021) analysed all stages in one model adjusted for stage and found no difference [39]. The

current study reproduced both findings. In stage-by-stage comparison, impacted teeth were 0.82 years older at stage G, but when all stages were analysed together, the difference was only 0.25 years and not significant (p = 0.134). In addition, the continuous I3M detected a delay (difference 0.056, p = 0.011) that the Demirjian stages could not, because a tooth can mineralise more slowly while remaining within the same stage. Secondly, the upper age limit differs between studies. The present study used an upper age limit of 23 years, whereas the South African study included individuals up to 26 years [37]. The younger upper age limit truncates the age distribution at stages G and H. Finally, sample composition plays a critical role, where samples drawn from orthodontic patients, as in this study, include more crowded dentitions and may accentuate root formation delays compared with outpatient or population-based samples [38].

At the same time, several limitations of the present study must be acknowledged. The most significant limitation is the selection of the sample from an orthodontic clinic. In this sample, 76.6% of the assessed third molars were impacted, which is about twice the worldwide pooled prevalence of 36.9% per subject and three times the European estimate of 24.5% [23]. This proportion of sample selection should be attributed carefully to the general Russian population. In addition, impaction was judged on developing teeth, some of which may erupt later. This may introduce a diagnostic bias in young adolescents (14–16 years, Demirjian stages D–E), in whom apparent impaction may reflect transient physiological crowding rather than true bony retention. Such early misclassification likely contributed to an overestimation of the impaction rate at the initial stages of mineralisation in our sample. Consistent with this, the proportion of impacted teeth fell from 86.3% at stage D to 69.9% at stage H, and the I3M difference between impacted and non-impacted teeth was not present at stages F–H. Therefore, impaction should be interpreted with caution in adolescents whose skeletal growth is not yet complete. The definition of impaction was also limited where it had no numerical angular threshold, did not record bone coverage, depth of inclusion or the relationship to the ramus, and agreement for the classification itself was not assessed. Moreover, the non-impacted group contained only 55 minors. Another limitation relates to the technical difficulty of measuring dilacerated roots, which are frequent in impacted teeth and complicate the determination of the long axis of the tooth, potentially introducing errors into the I3M. Furthermore, the retrospective design and the restriction of the sample to a single region (the Central Federal District of Russia) reduce the generalisability of the results, and data on socioeconomic status, which may influence the timing of tooth mineralisation, were not available.

Despite these limitations, the data allow some practical recommendations for forensic casework. The Cameriere and Demirjian methods can be used to assess the attainment of 18 years of age with high accuracy, and the current sample presents that no corrective coefficients need to be done for impacted third molars. From a medicolegal perspective, because third molar impaction tends to delay rather than accelerate mineralisation, the 0.08 cut-off in impacted teeth is conservative with respect to misclassifying a minor as an adult (specificity = 0.98; 5 of 205 minors classified as adults). However, in non-impacted teeth, the false-adult rate (minors classified as adults) was higher (5 of 55 minors, 9.1% [3.0; 20.0]), which should be considered in practice, in keeping with the principle of benefit of the doubt in

forensic age assessments as Raising the cut-off to 0.09 would increase this number in both groups (to 8 of 205 and 9 of 55).

Conclusion

In this single-centre sample of orthodontic patients, impacted lower third molars showed a small delay in mineralisation, detected with the continuous I3M at the early stages but not consistently with Demirjian staging, and with no evidence of a difference between sexes. This study demonstrates that both the I3M and Demirjian staging provide high diagnostic accuracy for legal age assessment in this Russian sample. In this sample, no statistically significant difference in I3M discrimination between impacted and non-impacted third molars was observed. Although the conventional 0.08 cut-off showed similar overall performance, further validation is required to establish its equivalence across impaction categories. Demirjian stage G indicated a high probability of being ≥ 18 years (86%), reaching 99% at stage H. Future external validation in population-based, non-orthodontic samples, using explicit criteria for impactions, is needed before these results can be generalised.

Declarations

Rizky Merdietio Boedi

Conceptualisation, Data curation, Writing, Critical review, Proofreading
rizkymerdietio@lecturer.undip.ac.id

Nikolaos Angelakopoulos

Writing, Critical review, nikolaos.angelakopoulos@unibe.ch

Stefano De Luca

Writing, Critical review and supervision, lucastefano@uniovi.es

Galina Zolotenkova

Administration, critical review, supervision, zolotenkova_g_v@staff.sechenov.ru

Declarations

Compliance with ethical standards:

The study was carried out following the ethical standards of the Declaration of Helsinki (Finland).

Informed consent:

Informed consent was waived by the relevant Ethics Committees due to the retrospective nature of the study and the use of fully anonymised data from an existing dataset. No direct involvement of human participants occurred in the study.

Ethical approval:

This study received ethical approval from the Ethics Committee of Sechenov First Moscow State Medical University, Moscow, Russian Federation (approval No. 4–24, 21.02.2024). The study used fully anonymised, retrospectively collected data from an existing dataset, with no direct involvement of human participants. Given the retrospective nature of the study and the use of fully anonymised data, the requirement for informed consent was waived by the relevant ethics committees.

Competing Interests:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding:

This work did not receive any specific funding from public, commercial, or not-for-profit organizations.

Author Contribution

Maria Poletaeva: Conception, data collection and curation, Writing, Critical review, poletaeva_m_p@staff.sechenov.ru Rizky Merdietio Boedi: Conceptualisation, Data curation, Writing, Critical review, Proofreading rizkymerdietio@lecturer.undip.ac.id Nikolaos Angelakopoulos: Writing, Critical review, nikolaos.angelakopoulos@unibe.ch Stefano De Luca: Writing, Critical review and supervision, lucastefano@uniovi.esYuriy Pigolkin: Writing and Critical review, pigolkin_yu_i@staff.sechenov.ru Galina Zolotenkova: Administration, critical review, supervision, zolotenkova_g_v@staff.sechenov.ru

Acknowledgments:

None

Data availability:

The data supporting this study's findings are available from the first and corresponding author upon reasonable request.

References

1. Kelmendi J, Merdietio Boedi R, Vodanovic M et al (2025) Modified Demirjian's method for dental age estimation in Kosovar children and adolescents. Forensic Sci Med Pathol 21:1743–1754. 10.1007/s12024-025-01061-0
2. Thicot F, Egger C, Castiglioni C et al (2024) Forensic age estimation at the University Center of Legal Medicine Lausanne-Geneva: a retrospective study over 12 years. Int J Legal Med 138:1881–1889. 10.1007/s00414-024-03254-8
3. Perinetti G, Sossi R, Primozic J et al (2017) Diagnostic reliability of mandibular second molar maturation in the identification of the mandibular growth peak: A longitudinal study. Angle Orthod 87:665–671. 10.2319/010417-12.1
4. Vila-Blanco N, Varas-Quintana P, Tomás I et al (2023) A systematic overview of dental methods for age assessment in living individuals: from traditional to artificial intelligence-based approaches. Int J Legal Med 137:1117–1146. 10.1007/s00414-023-02960-z
5. Cummaudo M, De Angelis D, Magli F et al (2021) Age estimation in the living: A scoping review of population data for skeletal and dental methods. Forensic Sci Int 320. 10.1016/j.forsciint.2021.110689
6. Rawat G, Kureel K (2018) Dental age estimation in children and adolescents. J Dent Health Oral Disorders Therapy 9. 10.15406/jdhodt.2018.09.00390
7. Corona Maioli S, Bhabha J, Wickramage K et al (2021) International migration of unaccompanied minors: trends, health risks, and legal protection. Lancet Child Adolesc Health 5:882–895. 10.1016/s2352-4642(21)00194-2
8. Heldring N, Rezaie A-R, Kvist O (2025) Developmental asymmetry of the clavicles and third molars and its implications for forensic age estimation. Sci Rep 15:41182. 10.1038/s41598-025-28730-y
9. Timme M, Steinacker JM, Schmeling A (2017) Age estimation in competitive sports. Int J Legal Med 131:225–233. 10.1007/s00414-016-1456-7
10. Abdullah A, Huynh I, Emery CR et al (2022) Social Norms and Family Child Labor: A Systematic Literature Review. Int J Environ Res Public Health 19. 10.3390/ijerph19074082
11. Campbell K (2018) Producing Knowledge in the Field of Sexual Violence in Armed Conflict Research: Objects, Methods, Politics, and Gender Justice Methodology. Social Politics: Int Stud Gend State Soc 25:469–495. 10.1093/sp/jxy025
12. Young S, Greer B, Church R (2018) Juvenile delinquency, welfare, justice and therapeutic interventions: a global perspective. BJPsych Bull 41:21–29. 10.1192/pb.bp.115.052274
13. Legassicke M, Johnson D, Gribbin C (2023) Definitions of Child Recruitment and Use in Armed Conflict: Challenges for Early Warning. Civil Wars 26:430–454. 10.1080/13698249.2023.2167042

14. Humphris R, Sigona N (2019) The Bureaucratic Capture of Child Migrants: Effects of In/visibility on Children On the Move. Antipode 51:1495–1514. 10.1111/anti.12548
15. Feijóo G, Barbería E, De Nova J et al (2012) Permanent teeth development in a Spanish sample. Application to dental age estimation. Forensic Sci Int 214:213e211–213e216. 10.1016/j.forsciint.2011.08.024
16. Lossois M, Cyteval C, Baccino E et al (2022) Forensic age assessments of alleged unaccompanied minors at the Medicolegal Institute of Montpellier: a 4-year retrospective study. Int J Legal Med 136:853–859. 10.1007/s00414-022-02813-1
17. Angelakopoulos N, De Luca S, Oliveira-Santos I et al (2022) Third molar maturity index (I3M) assessment according to different geographical zones: a large multi-ethnic study sample. Int J Legal Med 137:403–425. 10.1007/s00414-022-02930-x
18. Cameriere R, Ferrante L, De Angelis D et al (2008) The comparison between measurement of open apices of third molars and Demirjian stages to test chronological age of over 18 year olds in living subjects. Int J Legal Med 122:493–497. 10.1007/s00414-008-0279-6
19. Demirjian A, Goldstein H, Tanner JM (1973) A new system of dental age assessment. *Hum Biol* ;45:211–227. 1973
/05/01
. doi: 10.2307/41459864
20. Demirjian A, Goldstein H (1976) New systems for dental maturity based on seven and four teeth. Ann Hum Biol 3:411–421. 10.1080/03014467600001671
21. Arsenina OI, Shishkin KM, Shishkin MK et al (2016) The third permanent molars and their influence on the dentoalveolar arches. Rossiiskaya stomatologiya 9. 10.17116/rosstomat20169233-40
22. Carter K, Worthington S (2015) Predictors of Third Molar Impaction. J Dent Res 95:267–276. 10.1177/0022034515615857
23. Pinto AC, Francisco H, Marques D et al (2024) Worldwide Prevalence and Demographic Predictors of Impacted Third Molars—Systematic Review with Meta-Analysis. J Clin Med 13. 10.3390/jcm13247533
24. Varghese G (2021) Management of Impacted Third Molars. *Oral and Maxillofacial Surgery for the Clinician*. pp.299–328
25. Balla SB, Ali SH, Mula AP et al (2026) The effect of impaction on the mineralisation of third molars and forensic age estimation: A systematic review and meta-analysis. Forensic Sci Int 378. 10.1016/j.forsciint.2025.112650
26. Angelakopoulos N, Boedi RM, De Luca S et al (2026) Does increased staging complexity influence expert agreement in dental age estimation? Int J Legal Med. 10.1007/s00414-026-03946-3
27. Scendoni R, Zolotenkova GV, Vanin S et al (2020) Forensic Validity of the Third Molar Maturity Index (I3M) for Age Estimation in a Russian Population. *BioMed Research International* ;2020. 10.1155/2020/6670590

28. Poletaeva MP, Suvorov AY, Zolotenkov DD et al (2023) Forensic medical diagnostics of age by the Cameriere method. Forensic Med Expertise 66. 10.17116/sudmed20236604141
29. Zolotenkova GV, Poletaeva MP, Averianov SV et al (2024) Validation of method for estimation age of majority by the third molar maturity index on the sample of Ufa population. Forensic Med Expertise 67. 10.17116/sudmed20246704142
30. Poletaeva MP, Kamyshev VV, Tsvetanov MC et al (2025) Estimation of the age of majority by the Demirjian method in the Russian population. Forensic Med Expertise 68. 10.17116/sudmed2025680519
31. World Medical A (2025) World Medical Association Declaration of Helsinki. JAMA 333:71–74. 10.1001/jama.2024.21972
32. Leatherman G (2009) Two-digit system of designating teeth—FDI submission. Aust Dent J 16:394–394. 10.1111/j.1834-7819.1971.tb03438.x
33. Angelakopoulos N, Franco A, Mula AP et al (2023) Effect of impaction on third molar development and age estimation—A study in a Lebanese population. Morphologie 107. 10.1016/j.morpho.2023.06.002
34. DeLong ER, DeLong DM, Clarke-Pearson DL (1988) Comparing the Areas under Two or More Correlated Receiver Operating Characteristic Curves: A Nonparametric Approach. Biometrics 44. 10.2307/2531595
35. Balla SB, Nambi NK, Nambi S et al (2021) Legal age determined by a new threshold value of third molar maturity index in subjects with impacted mandibular third molars: An orthopantomographic study in south Indian adolescents. Int J Legal Med 136:251–259. 10.1007/s00414-021-02715-8
36. Morozov A, Romanova E, Kirichenko V et al (2020) X-Ray Analysis of the Position of the Rudiments of Abnormally Located Lower Third Molars during Their Formation and Growth. Actual Probl dentistry 16:108–113. 10.18481/2077-7566-20-16-1-108-113
37. Olze A, van Niekerk P, Schulz R et al (2012) The influence of impaction on the rate of third molar mineralisation in male black Africans. Int J Legal Med 126:869–874. 10.1007/s00414-012-0753-z
38. Friedrich RE, Ulbricht C, Baronesse von Maydell LA (2003) The influence of wisdom tooth impaction on root formation. Annals Anat - Anatomischer Anzeiger 185:481–492. 10.1016/s0940-9602(03)80112-7
39. Saputri RI, De Tobel J, Vranckx M et al (2021) Is third molar development affected by third molar impaction or impaction-related parameters? Clin Oral Invest 25:6681–6693. 10.1007/s00784-021-03955-z
40. Jin SS, He DQ, Wang Y et al (2020) Mechanical force modulates periodontal ligament stem cell characteristics during bone remodelling via TRPV4. Cell Prolif 53. 10.1111/cpr.12912
41. De Luca S, Biagi R, Begnoni G et al (2014) Accuracy of Cameriere's cut-off value for third molar in assessing 18 years of age. Forensic Sci Int 235:102e101–102e106. 10.1016/j.forsciint.2013.10.036

Figures

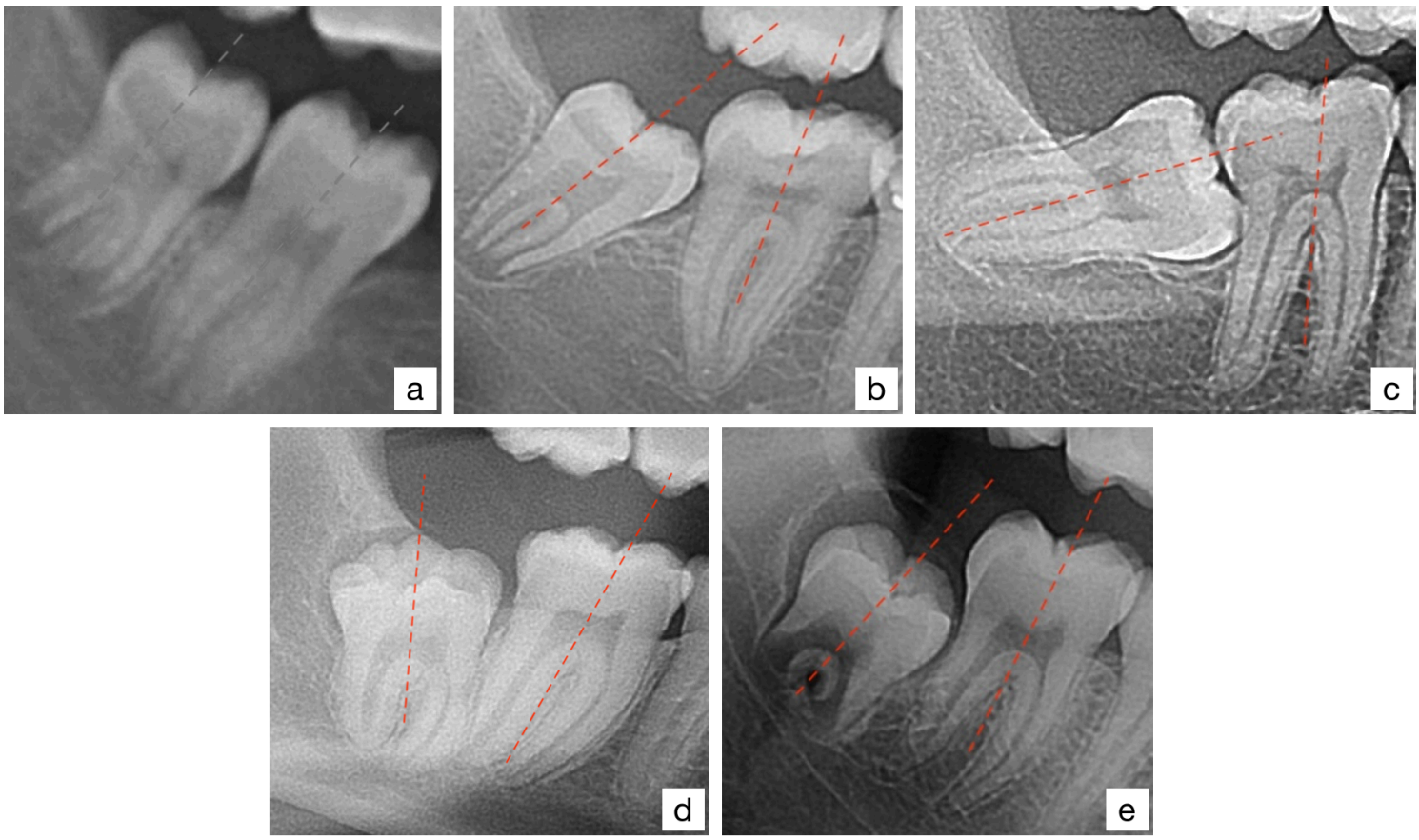


Figure 1

Assignment of third molar impaction: a-“non-impacted”, b-e -“impacted” (b, mesioangular; c, horizontal; d, distoangular; e, vertical).

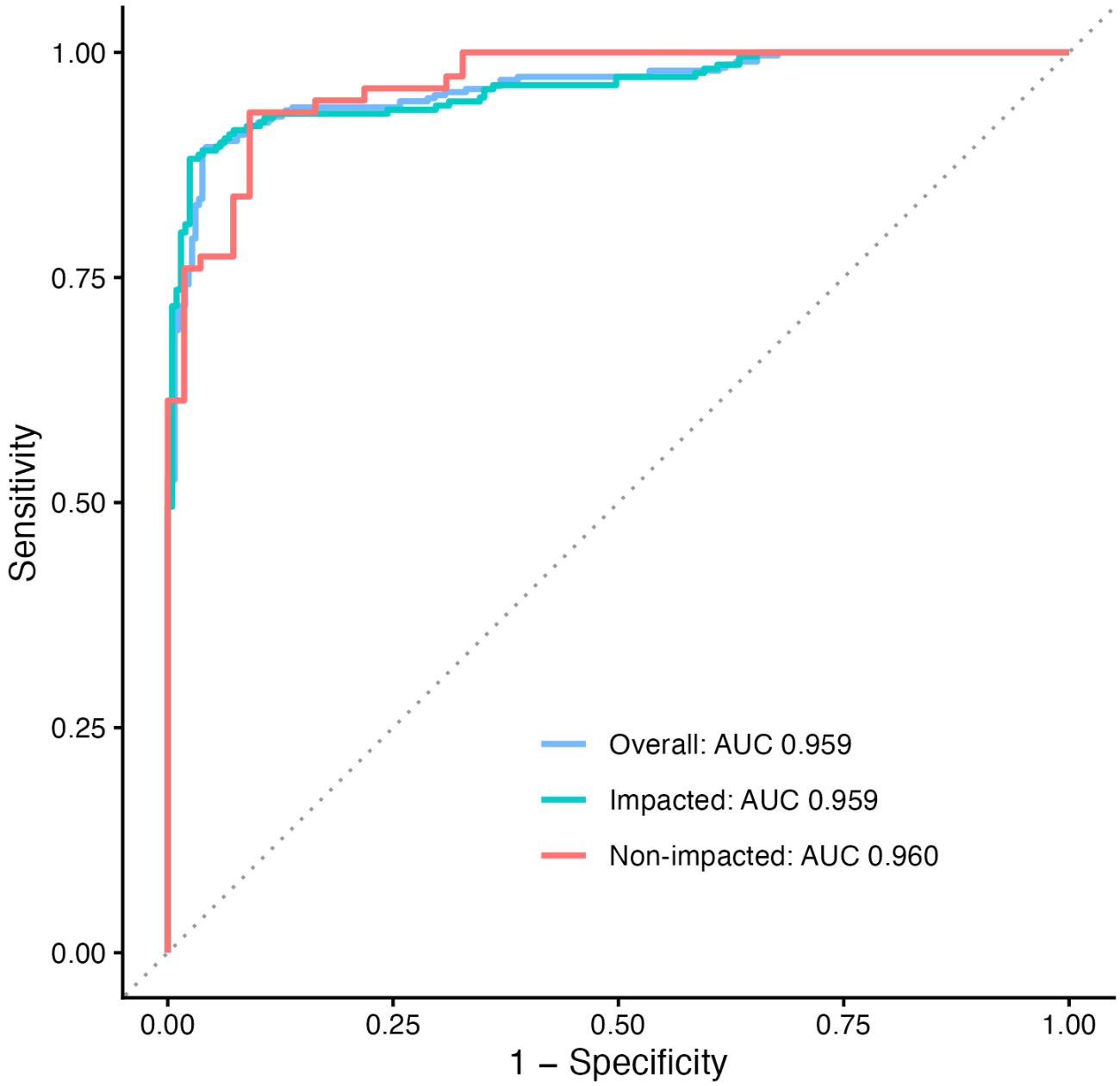


Figure 2

ROC curve analysis for age ≥ 18 years using the I3M for the overall sample and for impacted and non-impacted teeth.