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Original Article

Association between mandibular third molar impaction pattern and mandibular crowding severity: a retrospective radiographic study

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Abstract: Objective: This study analyzed mandibular third molar (M3M) impaction and its link to mandibular crowding. Methods: This retrospective study included 351 M3M patients (Oct 2023-Oct 2024), with 320 analyzed after exclusion. Outcome measures included mandibular full dentition crowding (MFDC), retromolar space of the mandible (RSM), impaction angle of the mandibular third molar (IAM3M), crown width of the mandibular third molar (CW-M3), eruption height of the mandibular third molar (EH-M3), adjacent distance between the mandibular second and third molars (AD-M2M3), and root curvature of the mandibular third molar (RC-M3). Spearman correlation and linear regression identified risk factors for mandibular crowding. Receiver operating characteristic (ROC) analysis evaluated radiographic indicators' predictive value for severe crowding (>8 mm). Results: Among 320 subjects, 487 impacted M3M were identified, 53.39% mesial, 20.12% horizontal, 16.22% vertical, 5.75% distal, and 4.52% buccal/lingual. Crowding severity was mild (34.38%), moderate (44.06%), and severe (21.56%). Severe crowding was most frequent in mesial (60.9%) and horizontal (26.1%) impactions, with other types below 10%. One-way ANOVA showed MFDC, IAM3M, CW-M3, and EH-M3 decreased, mesial > horizontal > distal > vertical > buccal/lingual (all $P<0.05$); RSM, AD-M2M3, and RC-M3 increased in the same sequence (all $P<0.05$). Spearman analysis revealed positive correlations between impaction type and MFDC ($P<0.001$). Linear regression identified mesial impaction, horizontal impaction, IAM3M>30°, and RSM<2.5 mm as independent risk factors for crowding (all $P<0.05$). IAM3M had the best predictive value for severe crowding (AUC=0.749, 95% CI: 0.703-0.795), followed by RSM (AUC=0.719, 95% CI: 0.665-0.773). Conclusion: M3M impaction worsens mandibular crowding, which offers clinical guidance.

Keywords: Mandibular third molar, impaction type, mandibular dentition crowding, correlation, radiography

Introduction

Malocclusion represents one of the most prevalent disease spectra encountered in routine clinical dental practice. Among all forms of malocclusion, dental crowding stands out as the most frequently diagnosed subtype. This condition not only compromises patients' stomatognathic function and facial aesthetics, but also predisposes individuals to a cascade of secondary complications including dental caries, periodontitis, and occlusal trauma, thereby severely diminishing both oral health status and overall quality of life [1, 2]. In Chinese adolescents during the early permanent dentition stage, the prevalence of dental crowding reaches as high as 48.9%, meaning nearly half of young patients present a fundamental structural mismatch between tooth mass and basal bone volume. Even among adult populations, mandibular full dentition crowding (MFDC) remains highly prevalent, establishing it as one of the leading chief complaints prompting patients to seek orthodontic care [3].

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The pathogenesis underlying MFDC is multifactorial and highly complex. The academic community generally agrees that the core driving force lies in the disharmony between dental and skeletal dimensions. This imbalance is further modulated by an interplay of genetic predispositions, abnormal jaw growth, deleterious oral habits, and anomalous dental development. In particular, the association between aberrant eruption - namely impaction - of the mandibular third molar (M3M) and MFDC has long remained a heated research topic and a source of ongoing debate within the fields of orthodontics and alveolar surgery [4, 5].

As the last permanent tooth to erupt in the human dentition, M3M eruption is easily constrained by multiple factors including insufficient retromolar space, adjacent tooth resistance, and genetic influences, resulting in an exceptionally high rate of impaction [6]. An impacted M3M refers to a tooth that fails to erupt fully or becomes locked during eruption due to various obstacles, remaining either completely embedded within the jawbone or only partially exposed. Based on its spatial orientation relative to surrounding anatomical structures and the direction of impaction, such teeth can be categorized into several subtypes: mesial impaction, horizontal impaction, vertical impaction, distal impaction, and buccal or lingual impaction [7, 8]. The distribution of these impaction patterns varies considerably, with mesial and horizontal impaction being the most commonly observed forms in clinical settings. Impacted M3Ms not only carry risks of caries and pericoronitis for themselves, but also exert pressure on adjacent teeth, potentially triggering root resorption and tooth migration, which in turn destabilizes the entire mandibular dentition [9, 10]. Despite these well-documented effects, the exact mechanism linking impacted M3Ms to MFDC has yet to reach a universal consensus among researchers.

Regarding the relationship between M3M impaction and MFDC, some scholars propose that the anteriorly directed force generated during M3M eruption - especially the mesial horizontal thrust from mesially impacted molars - transmits to the anterior mandibular segment and exacerbates crowding. Furthermore, occupation of the retromolar space of the mandible (RSM) by impacted teeth worsens the existing tooth-bone discrepancy [11]. Supporting evidence from related studies [12] has confirmed a positive correlation between the impaction angle of the mandibular third molar (IAM3M) in mesially impacted teeth and crowding severity, as well as a negative correlation between RSM dimensions and crowding degree. These findings suggest that prophylactic extraction of impacted molars may alleviate crowding and reduce post-orthodontic relapse. However, other investigators challenge the existence of a significant association. They argue that MFDC primarily arises from insufficient jaw growth leading to tooth-bone disproportion, with M3M impaction merely representing an accompanying finding rather than a causal factor. Inconsistencies across studies have also been attributed to variations in sample selection, grouping criteria, and insufficient stratification of impaction types, all of which may introduce bias into analytical outcomes [13].

With rapid advances in imaging technology, radiographic modalities such as cone-beam computed tomography (CBCT) and panoramic radiography have become increasingly integrated into routine dental practice, offering robust support for the precise evaluation of M3M impaction [14]. Although several existing studies have used radiographic approaches to explore the relationship between M3M impaction patterns and mandibular crowding, most are limited by small sample size, narrow ranges of observed indicators, failure to clarify differential effects across impaction subtypes, and lack of adjustment for independent risk factors associated with crowding. Moreover, the predictive value of radiographic indicators remains underexplored, leaving a gap between current evidence and real-world clinical needs.

In clinical practice, treatment planning for MFDC must be individualized according to each patient's unique presentation. Decisions regarding the management of M3Ms - whether to retain or extract them - represent a particularly challenging dilemma in orthodontic therapy [15]. Clarifying how distinct M3M impaction patterns influence the severity of MFDC, identifying independent risk factors that worsen crowding, and defining the predictive capacity of relevant radiographic indices would provide valuable guidance for designing personalized orthodontic protocols and optimizing M3M management strategies. Such insights would be clinically meaningful for improving therapeutic outcomes and lowering the risk of post-treatment relapse [16]. In addition, establishing a clearer correlation between M3M impaction morphology and MFDC would help refine the theoretical framework of MFDC pathogenesis, offering new perspectives and directions for future research in orthodontics and dentoalveolar surgery.

Against this research background and clinical demand, the present study adopted a retrospective design. We systematically classified M3M impaction types and analyzed their distribution characteristics. Concurrently, we collected a series of radiographic indicators, including crown width of the mandibular third molar (CW-M3), eruption height of the mandibular third molar (EH-M3), adjacent distance between the mandibular third and second molars (AD-M2M3), and root curvature of the mandibular third molar (RC-M3), to explore their correlations with MFDC severity. We further identified independent risk factors associated with severe mandibular crowding and assessed the clinical predictive value of these radiographic indicators. This study aims to quantify the impact of different M3M impaction patterns on mandibular crowding, thereby providing scientifically sound evidence for clinical decision-making and individualized treatment, and ultimately promoting continued progress in orthodontic and alveolar surgery research.

Patients and methods

Study design

We retrospectively enrolled a total of 351 patients who visited the Department of Orthodontics at Affiliated Hospital of Stomatology, Nanjing Medical University between October 2023 and October 2024. All these subjects were diagnosed with M3M impaction by radiographic examinations, and complete relevant imaging data had been collected for each case. A total of 31 patients were excluded, including mandibular hypoplasia (n=3), prognathism (n=4), facial asymmetry (n=2), tooth fusion (n=4), dental malformation (n=5), history of orthodontic treatment (n=10), and previous extraction of mandibular third molars (n=3), 320 patients were ultimately included in the present study. The included subjects were then categorized based on the impaction orientation of their M3M, with classifications consisting of mesial impaction, horizontal impaction, vertical impaction, distal impaction, as well as buccal or lingual impaction (**Figures 1** and **2**).

Inclusion criteria

(1) Patients aged between 12 and 45 years, with no restrictions on gender; (2) A definitive diagnosis of impacted M3Ms (either unilateral or bilateral) confirmed by imaging examinations such as panoramic radiography and CBCT. The morphology and position of the impacted teeth should be clearly visualized, allowing for accurate classification of impaction types; (3) Complete and available clinical data; (4) Absence of severe jaw deformities (e.g., mandibular deficiency, maxillary protrusion) and temporomandibular disorders that may interfere with the assessment of mandibular dental crowding [17]; (5) No congenital tooth agenesis, supernumerary teeth, or developmental dental anomalies such as microdontia and fused teeth; (6) No prior history of M3M extraction or orthodontic treatment.

Exclusion criteria

(1) Cases where radiographic images of impacted M3M were indistinct, making it impossible to determine the exact impaction type or measure relevant observational indicators; also excluded were individuals with incomplete clinical or imaging records for which key data could not be retrieved or supplemented; (2) Presence of severe jaw deformities including mandibular hypoplasia, maxillary protrusion, and facial asymmetry, together with temporomandibular joint disorders and advanced periodontal disease characterized by periodontal pocket depths ≥5 mm; (3) Evidence of congenital tooth agenesis, supernumerary teeth, or dental developmental anomalies such as microdontia, fused teeth, and malformed teeth; individuals with a history of dental trauma or root canal therapy were also excluded; (4) Prior receipt of invasive or therapeutic interventions including M3M extraction, orthodontic treatment, and orthognathic surgery; (5) Coexistence of systemic conditions such as diabetes mellitus, immune system disorders, and endocrine disturbances, or long-term use of medications

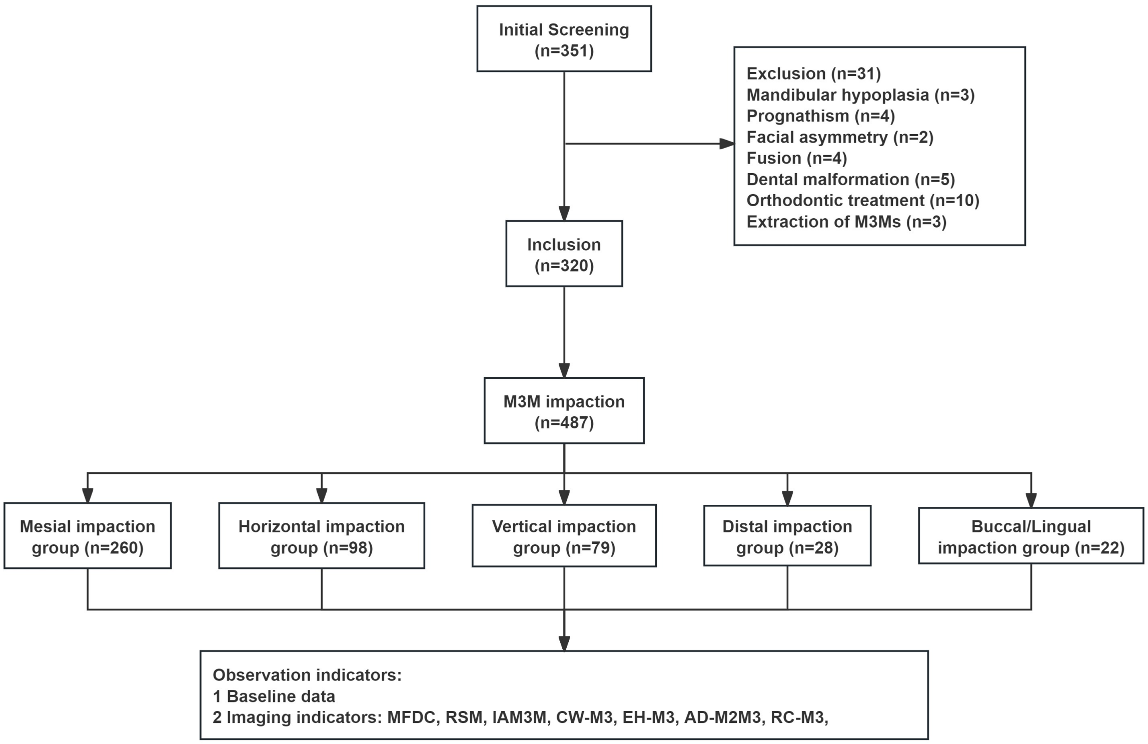

Figure 1. Flow chart. A total of 351 patients were initially screened in this study. After excluding 31 cases, 320 patients were finally included, with 487 impacted M3M in total. According to the direction of impaction, these teeth were divided into five groups: mesial impaction group (260 teeth), horizontal impaction group (98 teeth), vertical impaction group (79 teeth), distal impaction group (28 teeth), and buccal/lingual impaction group (22 teeth). Note: M3M: Mandibular third molar; MFDC: Mandibular full dentition crowding; RSM: Retromolar space of the mandible; IAM3M: Impaction angle of the mandibular third molar; CW-M3: Crown width of the mandibular third molar; EH-M3: Eruption height of the mandibular third molar; AD-M2M3: Adjacent distance between the mandibular third and second molars; RC-M3: Root curvature of the mandibular third molar.

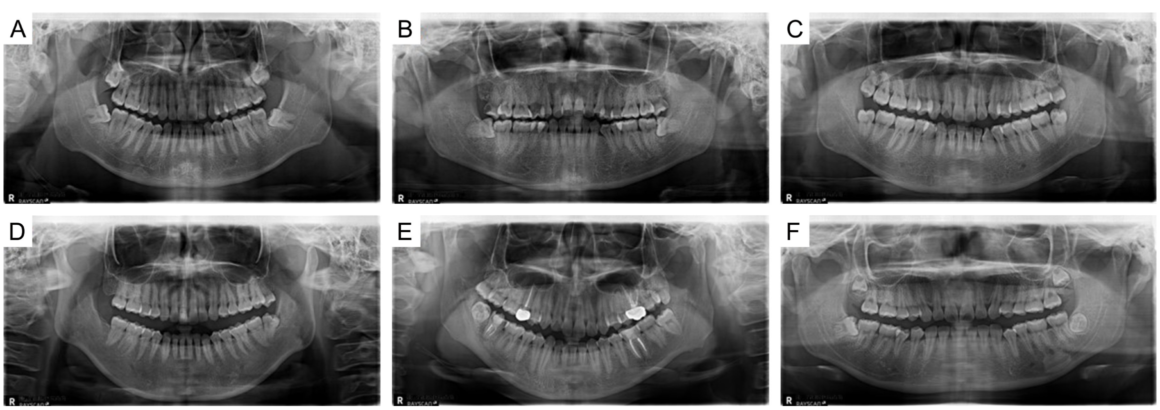

Figure 2. Images of different impaction directions. A. Mesial impaction; B. Horizontal impaction; C. Vertical impaction; D. Distal impaction; E. Buccal impaction; F. Lingual impaction.

known to affect dental development and jaw bone metabolism; (6) Pregnant or lactating females, as well as patients diagnosed with psychiatric disorders or cognitive impairment [18].

Data extraction

All data used in this study were extracted in a standard manner from clinical medical records and imaging documents. The entire extraction process was carried out independently by two orthodontists who had received systematic professional training. Information collected covered general demographic characteristics, M3M-related indicators including impaction type and angulation, as well as data associated with mandibular dental crowding. Upon completion of data collection, cross-verification was performed by the two investigators independently. Any inconsistencies or disagreements were resolved through arbitration by a senior orthodontic specialist. In addition, logical checks of the dataset were conducted, accompanied by dual-entry verification and anonymized encrypted management to ensure data accuracy and confidentiality.

Observational indicators

(1) MFDC: The degree of mandibular crowding was determined by calculating the difference between the total mesiodistal width of all teeth between bilateral mandibular canines and the intercanine arch length of the mandible. Measurements were performed using a specialized orthodontic caliper (Model: HJ-001; Manufacturer: Shanghai Haijie Medical Devices Co., Ltd., Shanghai, China), combined with panoramic radiographs and intraoral dental study casts. Crowding was graded as mild if the discrepancy was ≤4 mm, moderate at 4-8 mm, and severe when exceeding 8 mm [19].

(2) RSM: The shortest linear distance from the distal surface of the mandibular second molar to the anterior border of the mandibular ramus was measured on sagittal reconstructed CBCT images, using dedicated CBCT analysis software (Planmeca Romexis 5.0; Manufacturer: Planmeca Shanghai Co., Ltd., Finland) [20].

(3) IAM3M: Using the same Planmeca Romexis 5.0 software platform, the impaction angle was defined as the angular discrepancy between the long axis of the M3M and that of the adjacent mandibular second molar, assessed on both coronal and sagittal CBCT reconstructions [21].

(4) CW-M3: The maximum horizontal distance spanning the mesial and distal surfaces of the M3M crown was measured on panoramic radiographs by Kodak Dental Imaging Software 11.0 (Manufacturer: Kodak (China) Investment Co., Ltd., USA) [22].

(5) EH-M3: Vertical distance from the highest point of the M3M crown to the mandibular plane was quantified on sagittal CBCT sections with Planmeca Romexis 5.0 software [23].

(6) AD-M2M3: The shortest linear gap between the mesial surface of the M3M and the distal surface of the mandibular second molar was measured on panoramic radiographs using Kodak Dental Imaging Software 11.0 [24].

(7) RC-M3: RC-M3 was evaluated on sagittal CBCT images via Planmeca Romexis 5.0. Root curvature was recorded as the angle formed between the main long axis of the root and the long axis of its apical segment [25].

Ethical statement

This study was performed in strict accordance with the principles outlined in the Declaration of Helsinki. All research procedures were reviewed and approved by the Ethics Committee of Affiliated Hospital of Stomatology, Nanjing Medical University (Ethics Approval No.: PJ2023-180-001). According to the ethical approval document, the requirement for obtaining written informed consent from each patient was waived by the Ethics Committee.

Sample size calculation

Sample size estimation was performed with reference to a previous retrospective investigation exploring the correlation between impacted M3Ms and anterior mandibular dental crowding [26]. In that study, the mean crowding value was 4.26±4.88 mm in subjects without third molars, whereas the crowding measurement reached 6.79±5.45 mm in those presenting with third molars. Based on these values, Cohen's d was calculated as 0.49 using standard statistical formulae. Using G*Power 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Germany), the minimum required sample size was determined to be 220 participants. Accordingly, the present study enrolled a total of 320 patients, which exceeded the calculated threshold. Post-hoc power analysis was then conducted on the final 320 cases. Results indicated that, with a sample size of 320 and a type I error rate (α) set at 0.05, the statistical power for detecting differences in MFDC was no less than 80%. This outcome further verified that the sample size employed in this research was rational and robust, fully satisfying the statistical requirements for a retrospective observational study.

Statistical analysis

All statistical analyses were carried out using SPSS 26.0 software (IBM Corp., Armonk, NY, USA). First, normality of the data was assessed via the Kolmogorov-Smirnov test, while homogeneity of variances was evaluated using Levene's test. For measurement data that followed a normal distribution, between-group comparisons were performed using one-way analysis of variance (ANOVA), with results expressed as mean ± standard deviation (SD), and multiple comparisons were corrected by the Bonferroni method. In cases where data deviated from a normal distribution, values were presented as median (interquartile range) [M (Q1, Q3)], and the Kruskal-Wallis H test was adopted for intergroup comparisons. Categorical variables were described as case number (percentage) [n (%)], with the chi-square (χ^2) test or Fisher's exact test used for group comparisons. Spearman correlation analysis was applied to explore the relationship between M3M impaction-related indicators and the severity of MFDC. Buccal/lingual impaction was set as the reference group, and dummy variables were created for all other impaction types, including mesial impaction, horizontal impaction, vertical impaction, and distal impaction. Variables showing statistically significant differences in univariate analysis were introduced into a linear regression model with severe MFDC as the dependent variable, so as to identify independent risk factors affecting the severity of mandibular crowding. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the predictive value of relevant radiographic parameters for severe mandibular crowding, and the area under the curve (AUC) was calculated accordingly. All statistical tests were two-sided, and a *P*-value < 0.05 was considered significant.

Results

Baseline data of M3Ms

Baseline clinical characteristics of M3M with distinct impaction patterns were compared in **Table 1**. A total of 487 impacted M3M from 320 subjects were enrolled in this study. According to impaction orientation, these teeth were divided into five subgroups: mesial impaction group (260 teeth), horizontal impaction group (98 teeth), vertical impaction group (79 teeth), distal impaction group (28 teeth), and buccal/lingual impaction group (22 teeth). Tooth color and enamel status were evenly distributed across all groups, with corresponding *P* values of 0.969 and 0.994, respectively; both odds ratios (OR) and their 95% confidence intervals (95% CI) indicated no significant association between groups. Proportions of teeth free from caries, with no history of pericoronitis, normal periapical membrane space, and absence of periapical radiolucency also showed balanced distribution among subgroups, with *P* values of 0.529, 0.899, 0.918, and 0.847 in turn. Similarly, OR values and 95% CI revealed no meaningful intergroup differences. No statistically significant differences were detected in plaque index (PLI) and tooth wear severity between comparison groups, as reflected by *P* values of 0.988 and 0.961. Corresponding OR values were close to 1, and all 95% CI crossed the null value of 1. Skeletal pattern, including Class I, Class II, and Class III malocclusion, also exhibited balanced distribution across groups (P=0.724, OR=1.082, 95% CI=0.691-1.695), as did mandibular plane angle classified into high-angle and low-angle types (P=0.815, OR=1.057, 95% CI=0.674-1.658). Additionally, age was comparable among the mesial impaction (21.32±1.75 years), horizontal impaction (21.39±1.60 years), vertical impaction (21.13±1.49 years), distal impaction (21.50±1.53 years), and buccal/lingual impaction (20.95±1.65 years) groups, with a non-significant *P* value of 0.766, OR of 0.984, and 95% CI of 0.892-1.086. Collectively, all baseline variables assessed demonstrated no significant intergroup differences, confirming that the five M3M impaction subgroups were well balanced and comparable.

Crowding severity in patients with different impaction orientations

Table 2 displays the detailed distribution of MFDC across patients with varying impaction directions of M3M; as also shown in **Figure 3**, all subjects were classified into three groups according to the degree of crowding: mild crowding (≤4 mm, n=110), moderate crowding (4-8 mm, n=141), and severe crowding (>8 mm,

Table 1. Baseline clinical data of the third molars

Indicator	Mesial impaction group (n=260)	Horizontal impaction group (n=98)	Vertical impaction group (n=79)	Distal impaction group (n=28)	Buccal/Lingual impaction group (n=22)	*P*	OR	95% CI for OR
Tooth color (n%)						0.969	1.022	0.354, 2.944
Normal	247 (95.0)	93 (94.9)	75 (94.9)	26 (92.9)	21 (95.5)			
Slight discoloration	13 (5.0)	5 (5.1)	4 (5.1)	2 (7.1)	1 (4.5)			
Enamel condition (n%)						0.994	0.995	0.258, 3.828
Intact without defects	252 (96.9)	95 (96.9)	77 (97.5)	27 (96.4)	22 (100.0)			
Mild demineralization	8 (3.1)	3 (3.1)	2 (2.5)	1 (3.6)	0 (0.0)			
No caries (n%)	257 (98.8)	96 (98.0)	77 (97.5)	27 (96.4)	21 (95.5)	0.529	1.785	0.294, 10.846
No history of pericoronitis (n%)	245 (94.2)	92 (93.9)	74 (93.7)	26 (92.9)	20 (90.9)	0.899	1.065	0.401, 2.829
The periapical membrane space is normal (n%)	250 (96.2)	94 (95.9)	76 (96.2)	27 (96.4)	21 (95.5)	0.918	1.064	0.326, 3.474
No periapical radiolucency (n%)	248 (95.4)	93 (94.9)	75 (94.9)	26 (92.9)	21 (95.5)	0.847	1.111	0.381, 3.240
PLI (n%)						0.988	0.997	0.673, 1.478
0	156 (60.0)	59 (60.2)	47 (59.5)	17 (60.7)	13 (59.1)			
1	91 (35.0)	34 (34.7)	27 (34.2)	10 (35.7)	8 (36.4)			
2	13 (5.0)	5 (5.1)	5 (6.3)	1 (3.6)	1 (4.5)			
Degree of tooth wear (n%)						0.961	0.989	0.625, 1.564
No wear	182 (70.0)	69 (70.4)	55 (69.6)	20 (71.4)	15 (68.2)			
Mild wear	73 (28.1)	27 (27.6)	23 (29.1)	7 (25.0)	6 (27.3)			
Moderate wear	5 (1.9)	2 (2.0)	1 (1.3)	1 (3.6)	1 (4.5)			
Skeletal pattern (n%)						0.724	1.082	0.691, 1.695
Class I	146 (56.2)	54 (55.1)	44 (55.7)	15 (53.6)	12 (54.6)			
Class II	82 (31.5)	32 (32.7)	25 (31.6)	9 (32.1)	7 (31.8)			
Class III	32 (12.3)	12 (12.2)	10 (12.7)	4 (14.3)	3 (13.6)			
Mandibular plane angle (n%)						0.815	1.057	0.674, 1.658
High-angle type	79 (30.4)	29 (29.6)	23 (29.1)	8 (28.6)	6 (27.3)			
Low-angle type	181 (69.6)	69 (70.4)	56 (70.9)	20 (71.4)	16 (72.7)			
Age (years)	21.32±1.75	21.39±1.60	21.13±1.49	21.50±1.53	20.95±1.65	0.766	0.984	0.892, 1.086

Note: OR: Odds Ratio; 95% CI: 95% Confidence Interval; BMI: Body Mass Index; PLI: Plaque Index.

Table 2. Severity of crowding in different impaction directions [n (%)]

Indicator	Slightly crowded (≤4 mm, n=110)	Moderately crowded (4-8 mm, n=141)	Severely crowded (>8 mm, n=69)	Effect size (Phi)	*P*	X^2
Mesial impaction	49 (44.5)	103 (73.0)	42 (60.9)	0.256	<0.001	21.034
Horizontal impaction	28 (25.5)	7 (5.0)	18 (26.1)	0.277	<0.001	24.548
Vertical impaction	25 (22.7)	27 (19.2)	5 (7.2)	0.151	0.027	7.249
Distal impaction	5 (4.6)	2 (1.4)	2 (2.9)	0.083	0.331	2.213
Buccal/Lingual impaction	3 (2.7)	2 (1.4)	2 (2.9)	0.047	0.704	0.703

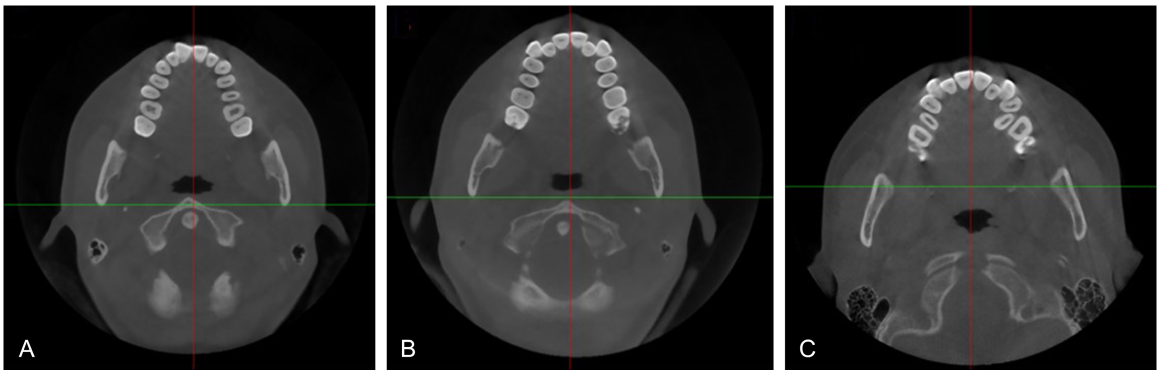

Figure 3. Classification of mandibular crowding severity. A. Mild crowding; B. Moderate crowding; C. Severe crowding.

n=69). Patients with mesial impaction were distributed as 49 cases (44.5%), 103 cases (73.0%), and 42 cases (60.9%) in the mild, moderate, and severe crowding groups, respectively. The Phi coefficient reflecting its correlation with crowding severity was 0.256, with *P*<0.001, indicating a highly significant statistical difference. For those with horizontal impaction, the distribution across crowding categories was 28 cases (25.5%), 7 cases (5.0%), and 18 cases (26.1%), with a Phi value of 0.277 and *P*<0.001. Patients with vertical impaction accounted for 25 cases (22.7%), 27 cases (19.2%), and 5 cases (7.2%), yielding a Phi coefficient of 0.151 and *P*=0.027. By comparison, patients with distal impaction numbered 5 cases (4.6%), 2 cases (1.4%), and 2 cases (2.9%), with a Phi value of 0.083 and *P*=0.331, Similarly, individuals with buccal/lingual impaction were distributed as 3 cases (2.7%), 2 cases (1.4%), and 2 cases (2.9%), with a Phi coefficient of 0.047 and *P*=0.704, suggesting no intergroup variation. Overall, patients with mesial impaction had the highest proportion of severe crowding (60.9%), followed by those with horizontal impaction (26.1%). The prevalences of severe crowding among patients with vertical, distal, and buccal/lingual impaction was all below 10%.

Comparison of observed indicators

As illustrated in **Table 3**, we compared a series of observational indices across five different impaction patterns of the M3M. Our findings revealed that statistically significant differences existed between groups for every single indicator assessed (all *P*<0.05). To be more specific, MFDC was highest in the mesial impaction group, at 7.79±0.66 mm. It ranked second in the horizontal impaction group (7.10±1.04 mm), followed by 6.05±2.08 mm in the vertical impaction group and 5.04±2.76 mm in the distal impaction group. The buccal/lingual impaction group presented the lowest MFDC level, at 3.93±1.22 mm (*P*<0.05). The RSM, however, showed an opposite tendency: the largest value was seen in the buccal/lingual impaction group, while the smallest was recorded in the mesial impaction group (all *P*<0.05). The IAM3M was most oblique in the mesial impaction subgroup, whereas the buccal/lingual impaction subgroup had the most upright orientation (all *P*<0.05). Both CW-M3 and EH-M3 reached their maximum in the mesial impaction group, and declined gradually as the impaction type shifted toward buccal or lingual inclination (*P*<0.05). In contrast, the AD-M2M3 and RC-M3 increased or decreased sequentially from the mesial

Table 3. Comparison of observation indicators (mean ± SD)

Indicator	Mesial impaction group (n=260)	Horizontal impaction group (n=98)	Vertical impaction group (n=79)	Distal impaction group (n=28)	Buccal/Lingual impaction group (n=22)	*P*	Effect size (η^2)	F
MFDC (mm)	7.79±0.66	7.10±1.04	6.05±2.08	5.04±2.76	3.93±1.22	<0.001	0.410	83.682
RSM (mm)	2.06±0.85	2.39±0.33	2.71±0.48	3.40±0.23	4.08±0.57	<0.001	0.364	69.065
IAM3M (°)	32.23±5.26	28.55±3.66	23.90±6.45	19.39±5.12	13.50±2.87	<0.001	0.499	120.060
CW-M3 (mm)	8.81±0.77	8.32±0.60	8.00±0.34	7.49±0.40	6.89±0.46	<0.001	0.384	75.125
EH-M3 (mm)	5.05±0.49	4.73±0.25	4.42±0.19	4.11±0.17	3.76±0.10	<0.001	0.473	108.125
AD-M2M3 (mm)	0.92±0.49	1.14±0.54	1.65±0.48	2.01±0.54	2.49±0.30	<0.001	0.438	93.813
RC-M3 (°)	16.10±2.68	14.94±2.46	12.61±1.37	10.48±1.43	8.47±0.21	<0.001	0.454	100.358

Note: MFDC: Mandibular full dentition crowding; RSM: Retromolar space of the mandible; IAM3M: Impaction angle of the mandibular third molar; CW-M3: Crown width of the mandibular third molar; EH-M3: Eruption height of the mandibular third molar; AD-M2M3: Adjacent distance between the mandibular third and second molars; RC-M3: Root curvature of the mandibular third molar.

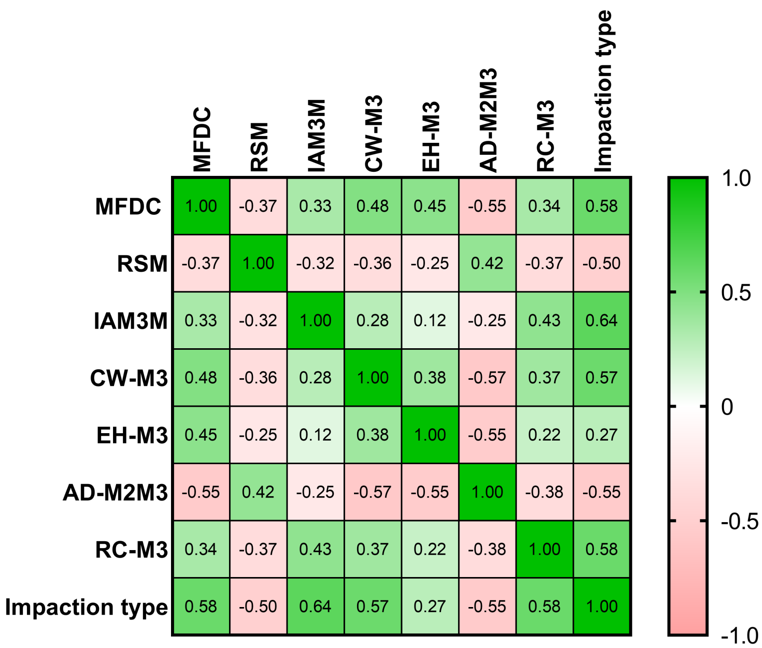

Figure 4. Correlation between impaction types of M3Ms, various observation indicators, and the severity of mandibular dental crowding. The figure illustrates the correlations identified in Spearman's correlation analysis between impaction type of the M3M, RSM, IAM3M, CW-M3, EH-M3, AD-M2M3, RC-M3, and MFDC.

impaction group to the buccal/lingual impaction group (all *P*<0.05). The effect size (η^2) varied from 0.364 to 0.499, which indicates that impaction pattern exerted a substantial effect on each index, with a pronounced overall effect.

Correlations between impaction type of the M3M, observed indicators, and severity of mandibular crowding

Spearman's correlation analysis was employed to investigate potential associations between impaction type of the M3M, RSM, IAM3M, CW-M3, EH-M3, AD-M2M3, RC-M3, and the degree of mandibular crowding represented by MFDC (**Figure 4**). Among these factors, a moderate positive correlation was identified between impaction type of the M3M and MFDC, with a correlation coefficient of r=0.58 (*P*<0.001). This suggests that when impaction of the third molar tends toward a mesial or horizontal orientation relative to buccal/lingual impaction, the severity of anterior dental crowding tends to increase accordingly. Additionally, both CW-M3 and EH-M3 showed moderate positive correlations with MFDC, with r values of 0.48 and 0.45 respectively (both *P*<0.001). In contrast, the AD-M2M3 exhibited a moderate negative correlation with MFDC (r=-0.55, *P*<0.001).

Linear regression analysis for identifying independent risk factors affecting the severity of mandibular crowding

Multiple linear regression with the Enter method was performed with MFDC as the dependent variable. Independent variables incorporated RSM, IAM3M, CW-M3, EH-M3, AD-M2M3, RC-M3, and impaction type, for which dummy variables were established with buccal/lingual impaction serving as the reference category. As demonstrated, the overall regression model was statistically significant (F=51.469, *P*<

Table 4. Independent risk factors for the severity of mandibular crowding screened by linear regression

Indicator	β	B	95% CI for B	*P*	VIF
RSM<2.5 mm	-0.42	-0.38	-0.52, -0.24	<0.001	1.694
IAM3M>30°	0.15	0.12	0.02, 0.22	0.018	2.110
CW-M3	0.08	0.05	-0.08, 0.18	0.456	1.876
EH-M3	0.26	0.23	0.09, 0.37	0.587	1.929
AD-M2M3	-0.21	-0.18	-0.28, -0.08	0.206	2.178
RC-M3	0.11	0.09	-0.04, 0.22	0.549	1.836
Mesial impaction	0.35	0.31	0.16, 0.46	<0.001	1.859
Horizontal impaction	0.41	0.37	0.22, 0.52	<0.001	2.071
Vertical impaction	-0.12	-0.10	-0.25, 0.05	0.395	2.096
Distal impaction	0.09	0.07	-0.08, 0.22	0.498	2.947
Buccal/Lingual impaction	-0.07	-0.06	-0.19, 0.07	0.312	2.360

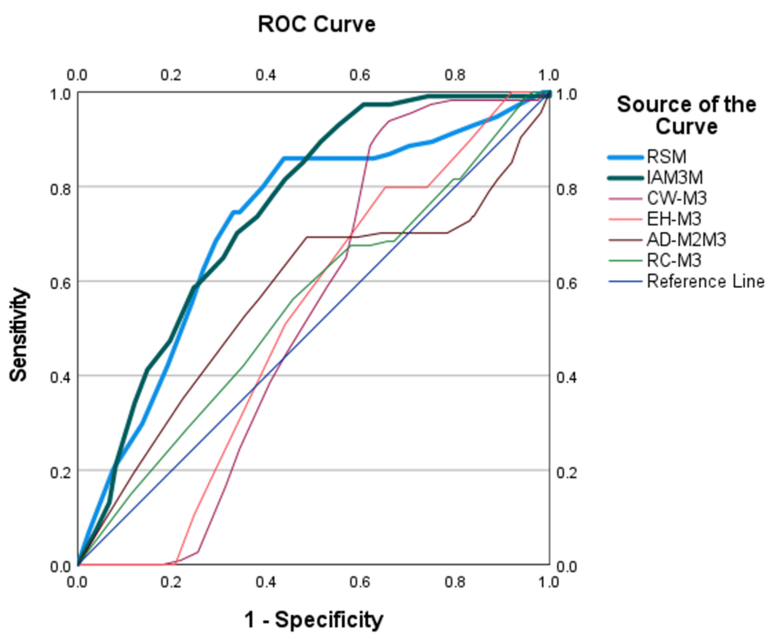

Figure 5. Clinical predictive value of radiographic indicators for severe mandibular crowding. ROC curves of RSM, IAM3M, CW-M3, EH-M3, AD-M2M3, and RC-M3 for predicting severe mandibular crowding, based on 320 study subjects. Note: ROC: Receiver Operating Characteristic.

0.001, R^2=0.429). **Table 4** summarizes the independent risk factors for the severity of mandibular crowding screened via linear regression. The analysis revealed that RSM< 2.5 mm, IAM3M>30°, mesial impaction, and horizontal impaction constituted independent risk factors influencing mandibular crowding severity (all *P*<0.05). Specifically, a smaller RSM (B=-0.38, 95% CI: -0.52, -0.24, β=-0.42, *P*<0.001) corresponded to more severe mandibular crowding. A larger IAM3M, indicating a more inclined impaction angulation (B=0.12, 95% CI: 0.02, 0.22, β=0.15, *P*=0.018), was associated with increased crowding severity. Both mesial impaction (B=0.31, 95% CI: 0.16, 0.46, β=0.35, *P*<0.001) and horizontal impaction (B=0.37, 95% CI: 0.22, 0.52, β=0.41, *P*<0.001) significantly elevated the degree of mandibular crowding. Conversely, CW-M3, EH-M3, AD-M2M3, RC-M3, as well as vertical impaction, distal impaction, and buccal/lingual impaction showed no independent predictive effect on mandibular crowding severity (all *P*>0.05). Variance inflation factor (VIF) values for all independent variables ranged from 1.694 to 2.947, all below the threshold of 3. These results suggest no remarkable multicollinearity among variables, supporting the reliability of the regression model.

Evaluation of the clinical predictive value of radiographic indicators for severe mandibular crowding

Figure 5 and **Table 5** present the efficacy indicators derived from ROC curve analyses for assessing the performance of individual radiographic indicators in predicting severe mandibular crowding. According to the results, the

Table 5. Predictive efficacy indicators of ROC curve for severe mandibular

Indicator	Cut-off	Sensitivity (%)	Specificity (%)	AUC	95% CI for AUC	Goodness-of-fit test (*P*)
RSM	<2.55 mm	79.8	79.1	0.719	0.665, 0.773	0.104
IAM3M	>29.5°	74.9	79.2	0.749	0.703, 0.795	0.251
CW-M3	>8.45 mm	63.2	59.9	0.525	0.475, 0.574	0.199
EH-M3	>6.0 mm	69.6	61.2	0.512	0.459, 0.565	0.321
AD-M2M3	<2.3 mm	62.3	58.4	0.564	0.498, 0.631	0.169
RC-M3	<12.4°	67.6	61.4	0.548	0.487, 0.609	0.241

Note: ROC: Receiver operating characteristic; AUC: Area under the curve.

goodness-of-fit test yielded *P*-values greater than 0.05 for all indices, indicating that the ROC curves for each indicator were well-fitted to the data. Among these variables, the IAM3M achieved the optimal predictive performance. At a cutoff value of 29.5°, IAM3M demonstrated a sensitivity of 74.9%, a specificity of 79.2%, and an AUC of 0.749 (95% CI: 0.703-0.795), suggesting a favorable predictive value for identifying severe mandibular crowding. The RSM ranked second in predictive efficacy. At its optimal threshold of 2.55 mm, RSM showed a sensitivity of 79.8%, a specificity of 79.1%, and an AUC of 0.719 (95% CI: 0.665-0.773), reflecting satisfactory predictive capability. In contrast, the AUC values for RC-M3, CW-M3, EH-M3, and AD-M2M3 were 0.525, 0.512, 0.564, and 0.548, respectively. These values were all close to 0.5, implying that these four indicators possess little to no meaningful predictive value for severe mandibular crowding.

Discussion

In the present study, a total of 487 impacted M3Ms were identified, and the distribution of impaction types showed a marked imbalance. Mesial impaction was the most prevalent pattern, accounting for 53.39% of all cases, followed by horizontal impaction. By contrast, vertical impaction, distal impaction, and buccal/lingual impaction accounted for relatively low proportions. Regarding the severity of mandibular dentition crowding, patients with moderate crowding constituted the largest subgroup, followed by those with mild crowding, while severe crowding was documented in 21.56% of the study population. Notably, significant differences were observed in the distribution of crowding severity across patients with distinct impaction angulations. The highest proportion of severe crowding (60.9%) was found in subjects with mesial impaction, followed by those with horizontal impaction at 26.1%. For patients with vertical, distal, buccal, or lingual impaction, the prevalence of severe crowding remained below 10% in each subgroup. Univariate analysis revealed that MFDC, IAM3M, CW-M3, and EH-M3 all exhibited a gradual decreasing trend across the following sequence: mesial impaction group, horizontal impaction group, distal impaction group, vertical impaction group, and buccal/lingual impaction group. Conversely, RSM, AD-M2M3, and RC-M3 showed an opposing trend, with significant differences detected in pairwise comparisons between all groups. Spearman correlation analysis demonstrated a significant positive correlation between M3M impaction type and MFDC. Similarly, IAM3M, CW-M3, EH-M3, and RC-M3 were positively correlated with the degree of mandibular crowding, whereas RSM and AD-M2M3 showed negative correlations with crowding severity. Multivariate logistic regression analysis further confirmed that mesial impaction, horizontal impaction, IAM3M, and RSM served as independent risk factors affecting the severity of mandibular crowding. In terms of radiographic predictive value, IAM3M achieved the optimal predictive performance for severe mandibular crowding, and RSM also demonstrated favorable predictive capability.

Our study identified mesial impaction as the most common form of M3M impaction, a finding that may be closely linked to the gradual reduction in jaw size and insufficient eruption space for M3M during human evolution [27]. As human diets became increasingly refined, jaw development underwent progressive regression, with reductions in both mandibular length and width. This anatomic change leaves inadequate room for M3M eruption, predisposing the tooth to abnormal angulation. Mesial impaction, in particular, may be attributed to the obstruction exerted by the mandibular second molar; the M3M is restricted by the crown of the second molar during eruption, preventing normal vertical emergence and leading to mesial tilting, a phenomenon partly related to the anatomic characteristics of mandibular development [28]. Mesial and horizontal impactions appear to exert the most pronounced aggravating effects on mandibular crowding, which can be explained by several mechanisms. First, mesially and horizontally impacted M3M exert continuous mesial pressure on the adjacent mandibular second molar, which gradually propagates anteriorly to the entire mandibular anterior dentition, worsening anterior crowding - especially when RSM is deficient [29, 30]. Second, such impactions often present with relatively greater EH-M3 and larger CW-M3, further occupying the limited retromandibular space and compromising overall alignment space for the mandibular dentition, thereby exacerbating crowding. Third, larger IAM3M corresponds to more severely abnormal eruption orientation, creating stronger mechanical pressure on neighboring teeth and disrupting the normal alignment of the mandibular arch, thus increasing crowding severity [31]. The correlations observed between radiographic indicators and mandibular crowding can be interpreted as follows. As the primary space for M3M eruption, insufficient RSM directly impedes M3M eruption and reduces the overall alignment space of the mandibular dentition, explaining its negative correlation with crowding severity [32]. IAM3M reflects the degree of abnormal eruption orientation; a larger angle signifies greater deviation from the normal path and stronger anterior pressure, correlating positively with crowding. Greater CW-M3 occupies more dental arch space and may further intensify dentition crowding. Impacted teeth with higher EH-M3 exert more direct pressure on anterior teeth, which may also contribute to the severity of crowding [33].

A meta-analysis in the existing literature incorporated 13 observational studies [34], four of which reported an association between the presence of M3M and mandibular incisor crowding, consistent with the findings of the current investigation. A retrospective CBCT-based study [35] documented close associations of IAM3M and RSM with mandibular crowding severity, reporting AUC values of 0.745 and 0.717 respectively - results highly consistent with those of our study. However, one cross-sectional investigation [19] stated that the angular pattern of impacted M3M was not a significant factor in the severity of mandibular anterior crowding, which conflicts with our conclusions. This discrepancy may stem largely from substantial differences in sample size: the aforementioned study enrolled only 69 participants, limiting its statistical power and reducing its ability to reflect true population-level associations. In comparison, our study included 320 patients, providing a larger sample that enhances the stability and reliability of statistical outcomes. The insufficient sample size in the previous work likely prevented detection of a potential relationship between IAM3M and mandibular crowding.

The novelty of the present study lies in its systematic analysis of correlations between multiple M3M impaction types and the severity of mandibular crowding, alongside comprehensive assessment of numerous radiographic indicators and their interrelationships. Unlike prior research that focused solely on impaction type or a single radiographic indicator, our analysis offers a more holistic perspective, allowing clearer elucidation of the mechanisms by which impaction patterns influence mandibular crowding. Linear regression analysis was applied to identify independent risk factors for severe mandibular crowding, clarifying the clinical significance of mesial impaction, horizontal impaction, IAM3M, and RSM and providing more targeted evidence for clinical diagnosis and treatment. We further evaluated the predictive value of each radiographic indicator for severe mandibular crowding, and ROC curve analysis confirmed the predictive performance of IAM3M and RSM. This provides an objective basis for the early identification of high-risk individuals with severe crowding and the formulation of personalized therapeutic strategies. Additionally, the relatively large sample size (320 cases) and strict adherence to inclusion and exclusion criteria ensure the robustness and dependability of the study results, rendering our conclusions more clinically meaningful than those derived from small-sample studies.

Limitations of the study and future research directions

As a retrospective investigation, this work inevitably carries several limitations. For one thing, retrospective designs made it impossible to regulate all confounding variables - including genetic backgrounds, harmful oral habits, and previous orthodontic treatment histories, to name just a few. Such factors may have exerted a measurable influence on final outcomes, potentially skewing analyses exploring the link between impaction patterns and mandibular crowding. For another, patient recruitment was limited to a single hospital, resulting in relatively concentrated geographic and age distributions among the study population. This setup raises the risk of selection bias, meaning the generalizability of our findings still requires further verification. In addition, no long-term follow-up was performed in this research. Consequently, we cannot clarify how M3M impaction affects mandibular crowding across different age groups, nor can we evaluate the degree of crowding improvement after surgical removal of impacted teeth. Finally, some degree of subjective measurement error may have existed for certain radiographic indicators, such as the impaction angle and root curvature. Even though all assessments were carried out by experienced dental professionals, inter-observer variability could not be entirely eliminated.

Given the constraints outlined above, future research efforts could be directed toward several key areas. First and foremost, prospective cohort studies should be launched, enrolling participants from diverse regions and age groups. Long-term monitoring would allow observation of changes in M3M impaction types and their corresponding effects on mandibular crowding, while stricter control of confounding factors would help clarify the true nature of their relationship. Second, expanding sample sizes through multi-center recruitment would effectively reduce selection bias and strengthen the external validity of research outcomes. Third, integrating three-dimensional imaging modalities such as CBCT would enhance the precision of radiographic measurements and minimize subjective errors, while also enabling deeper exploration into how three-dimensional positioning of impacted teeth correlates with mandibular dentition crowding. Fourth, interventional studies are warranted to compare the effect of extracting versus retaining impacted third molars on mandibular crowding. Such work would help define clear clinical indications and optimal timing for removal, providing stronger evidence to support personalized treatment planning. Last but not least, combining molecular biological techniques would allow researchers to investigate the role of genetic factors in the development of both impacted molars and mandibular crowding, shedding further light on the molecular mechanisms underlying their association.

Conclusions

The type of M3M impaction is closely associated with the severity of MFDC. Among the evaluated indicators, the IAM3M and RSM demonstrate favorable clinical predictive value for identifying severe mandibular crowding. These indicators can therefore be used clinically to assess the risk of mandibular crowding and assist in formulating individualized diagnosis and treatment strategies.

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We secured a signed informed consent form from every participant.

Disclosure of conflict of interest

None.

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