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Decoding the dental and skeletal factors behind mandibular second molar impaction: a retrospective cross-sectional study

Hilal Algul[1*] and Ayse Tuba Altug[1]

Abstract

Background Although the etiology behind the failure of second molars to erupt has not been fully elucidated, several contributing factors have been suggested. Even though a considerable number of studies have been published on second molar impaction, only a limited number have examined the influence of mandibular skeletal characteristics via panoramic and cephalometric radiographs. This study aimed to evaluate the relationships between the impaction of mandibular second molars (MM2) and various skeletal and dentoalveolar morphological parameters.

Methods In this retrospective study, panoramic and lateral cephalometric radiographs of individuals aged 11–18 years were examined. Measurements of the study group (SG), consisting of individuals with impacted MM2, and the control group (CG), consisting of individuals with normally erupted MM2, were compared. Subgroups were formed on the basis of skeletal classifications. The primary evaluation parameters included the GoGn/SN angle, gonial angle, molar inclination angle, and ratio of MM1-ramus distance to MM2 mesiodistal crown width. A significance level of $p < 0.05$ was adopted for all the statistical analyses.

Results There was no statistically significant difference in the GoGn/SN angle between the SG and CG. Within the study group, a significant difference in gonial angle was observed only among Class II individuals, where a decreased angle was associated with a more horizontal mandibular growth pattern. The molar inclination angle increased particularly in Class III individuals with impacted teeth, suggesting that increased mesial tipping may play a role in impaction. The most prominent finding was a significantly lower MM1-ramus distance to MM2 crown width ratio in the SG across all skeletal classes.

Conclusions MM2 impaction appears to be a multifactorial predominantly associated with local morphological limitations. Posterior space deficiency and increased mesial inclination were identified as major contributing risk factors. This study highlights the clinical value of early assessment of molar angulation and posterior space availability in preventing MM2 through appropriate orthodontic and surgical planning.

Keywords Gonial angle, Impacted mandibular second molar, Molar inclination angle, Retromolar distance

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Background

The impaction of mandibular second molars (MM2s) is an uncommon dental anomaly, with a prevalence ranging from 0.6% to 3% in the general population [1]. Recent studies have reported that among Caucasian populations, the incidence of MM2 impaction ranges between 0.2% and 1.36% [2–4]. Eruption disturbances involving second molars, such as impaction or partial eruption, may lead to various clinical complications including pain, prolonged orthodontic treatment duration, additional surgical interventions, infections, dentigerous cysts or root resorption of adjacent teeth [5, 6].

Although the etiology of second molar impaction remains unclear, several contributing factors have been proposed. In a cross-sectional study by Evans [7], an increased incidence of MM2 impaction was observed over the past decade among orthodontic patients, with mandibular crowding identified as the most consistent finding. Mandibular second molar impaction is typically categorized into three types of angulations: mesial, vertical, and distal [8]. Among these, mesial angulation is the most frequently observed [8]. Furthermore, an initial angulation exceeding 20° to 24° [7, 9] or greater than 30° [10] has been reported as a significant risk factor for impaction.

Some studies have suggested a link between vertical condylar growth and the impaction of third molars. Increased vertical condylar growth may result in a reduced gonial angle, subsequently leading to decreased space between the mandibular second molar and the anterior border of the ramus [11, 12]. This mechanism may also play a role in second molar impaction.

Despite numerous studies on MM2 impaction, few studies have evaluated mandibular skeletal characteristics via panoramic and cephalometric radiographs. Panoramic radiographs obtained during the pre-treatment period can potentially serve as indicators for predicting eruption disturbances. Radiographic features such as space deficiency, increased crowding, excessive molar angulation, and apical positioning of the tooth may be associated with impaction.

The aims of this study are as follows:

- To evaluate the clinical significance of the angle between the first and second mandibular molars in predicting MM2 impaction;
- To investigate the relationship between decreased space from the distal contour of the first molar to the anterior border of the ramus and the presence of MM2 impaction;
- To examine the associations between MM2 impaction and dentoalveolar, skeletal malocclusion, and growth direction characteristics.

Methods

Study design, ethical approval and statements

This research had a retrospective cross-sectional study design. Ethical approval for this study was obtained from the Non-Interventional Clinical Research Ethics Committee of Ankara University on May 26, 2025 (Approval number: 10/8). All radiographic data were anonymized to protect the confidentiality of personal information. The current study was conducted in accordance with the ethical principles for medical research involving human participants (including research using identifiable human material or data) set out in the World Medical Association's Declaration of Helsinki. Informed consent was obtained from all participants included in the present study, which used retrospective data. Informed consent was also obtained from participants under the age of 16 and their parents/legal guardians.

Procedure

This retrospective study analysed panoramic and lateral cephalometric radiographs collected between 2020 and 2023 from the archives of the Department of Orthodontics, Faculty of Dentistry, Ankara University. A total of 2,771 digital radiographic records from individuals who underwent orthodontic treatment were reviewed.

Radiographic measurements were digitally performed via Dolphin Imaging 11.8 (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) and AutoCAD 2024 (Autodesk Inc., San Francisco, CA, USA).

The physiological eruption time was defined as the period when approximately two-thirds to three-fourths of the final root length of the tooth had developed [13]. Accordingly, mandibular second molars (MM2) that had not erupted despite reaching this developmental milestone - or were deemed unlikely to erupt spontaneously on the basis of radiographic evaluation - were considered impacted.

Inclusion criteria

Participants were included in the study group on the basis of the following criteria:

- Age between 11 and 18 years at the onset of orthodontic treatment (T0),
- The absence of spontaneous eruption of the mandibular second molar (MM2),
- Radiographic evidence indicating that at least two-thirds of the root development of MM2 had been completed,
- Complete orthodontic records, including pre-treatment (T0) panoramic and lateral cephalometric radiographs and clinical photographs, were obtained.

In the control group, where the mandibular second molars had fully erupted, all other parameters were consistent with those of the study group.

The following exclusion criteria were applied to both groups:

- History of prior orthodontic treatment,
- Presence of craniofacial anomalies or syndromic conditions,
- The absence of teeth in the mandibular region other than the third molars,
- The presence of artifacts, distortions, or deficiencies in the radiographic images,
- Medical history indicating any systemic disease.

Individuals presenting with either unilateral or bilateral impaction of the mandibular second molars were included in the study. In individuals with bilateral impaction, each impacted mandibular second molar was evaluated as an independent data, resulting in a total of 54 impacted teeth assessed from 36 individuals. In the control group, all participants exhibited bilateral eruption; therefore, each mandibular second molar was likewise considered separately, yielding 72 erupted teeth from 36 individuals.

On panoramic radiographs, two primary measurements were performed: the inclination angle of the mandibular second molar (MM2) and the horizontal distance between the mandibular first molar (MM1) and the anterior border of the mandibular ramus.

The longitudinal axis of each mandibular molar was defined as the line connecting the midpoint of the occlusal surface and the furcation point. The angle formed between the longitudinal axes of MM1 and MM2 was calculated as the inclination angle (Fig. 1), in accordance with the definition proposed by Evans [7].

The MM1–ramus distance (Fig. 1) was defined as the horizontal distance from the distal height of the contour of the first mandibular molar (MM1) to the anterior border of the mandibular ramus. Initially, a reference line was drawn through the cusp tips of the posterior teeth along the occlusal plane. A perpendicular line was then extended from the distal contour of MM1, followed by a parallel line tangent to it and alignment with the occlusal plane. The horizontal length of this line, extending to the anterior ramus border, was recorded as the MM1–ramus distance.

This measurement was used to assess whether there was sufficient anatomical space in the posterior region to permit the eruption of MM2. To account for individual anatomical variability, the measurement was normalized by dividing it by the mesiodistal crown width of MM2.

On lateral cephalometric radiographs, the skeletal classifications and growth direction patterns of the individuals were assessed via the following parameters:

- The ANB angle was used to determine the sagittal relationship between the maxilla and the mandible;
- The GoGn/SN angle was measured to evaluate the direction of mandibular growth by examining the

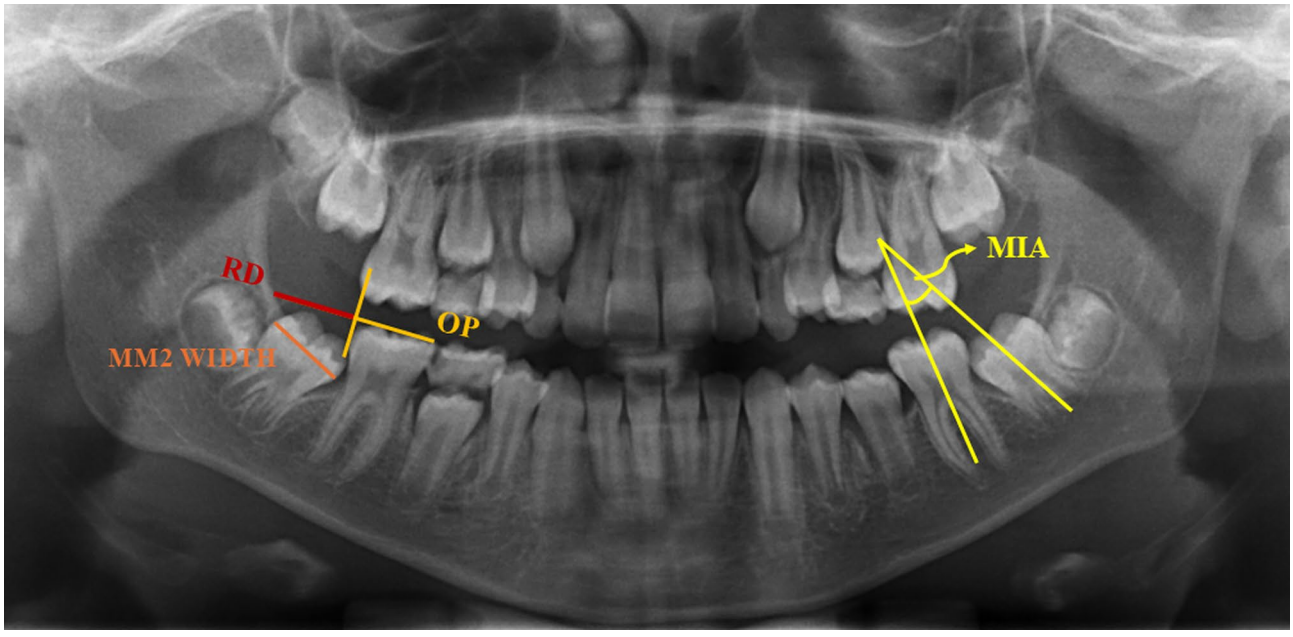


Fig. 1 Panoramic radiograph at a 1:1 magnification ratio. The measurement on the right side shows the ratio of the ramus distance to the MM2 crown width, whereas the left side shows the inclination angle between the mandibular first and second molars. OP: occlusal plane; RD: ramus distance; MM2 width: mesiodistal width of the mandibular second molar; MIA: molar inclination angle

Table 1 Mean age between the study and control groups. The mean ± standard deviation, median, and range (minimum–maximum) are presented for each group. No statistically significant difference was found between the groups ($p > 0.05$)

Group	*n*	Mean	Median	Minimum	Maximum	SD
Study	54	12.53	12.21	11.00	17.17	1.54
Control	72	12.14	12.25	11.08	13.50	0.64
Total	126	12.34	12.25	11.00	17.17	1.19

n: sample size; SD: Standard Deviation

Table 2 Distribution of skeletal classes and genders between the study and control groups

Angle Classification (ANB)	Study *n*	%	Control *n*	%	Total *n*	%
CLASS I	16	29.6	24	33.3	40	31.7
CLASS II	19	35.2	24	33.3	43	34.1
CLASS III	19	35.2	24	33.3	43	34.1
Total	54	100.0	72	100.0	126	100.0
Gender	Study n	%	Control n	%	Total n	%
Male	19	52.8	18	50.0	37	51.4
Female	17	47.2	18	50.0	35	48.6
Total	36	100.0	36	100.0	72	100.0

Note: In the study group, individuals with bilateral impaction were counted twice (54 cases from 36 individuals). In the control group, all individuals had bilateral eruption, resulting in 72 cases from 36 individuals. Thus, skeletal classification is presented by case, while gender distribution is presented by individual. n: sample size

angular relationship between the mandibular plane and the cranial base;

- The gonial angle (Ar-Go-Me) served as an indicator of mandibular morphology and rotational growth pattern.

On the basis of the obtained cephalometric and panoramic measurements, the relationships between MM2 impaction and skeletal classification (Classes I, II, III), growth direction (horizontal, vertical), MM1–ramus distance, and molar inclination angle were statistically analysed.

Statistical analysis

All data obtained in this study were analyzed using IBM SPSS Statistics 22 (SPSS Inc., Chicago, IL, USA). The normality of distribution for continuous variables was assessed via the Shapiro–Wilk test. Since all variables demonstrated a normal distribution ($p > 0.05$), parametric statistical tests were applied. Independent samples t-tests were used for pairwise comparisons between the study and control groups. One-way analysis of variance (ANOVA) was performed for comparisons involving three or more subgroups (e.g., skeletal Classes I, II, and III), and when ANOVA revealed significant differences, Tukey's HSD post-hoc test was applied to identify specific group differences. For data that did not follow a normal distribution, the Friedman test was planned as a nonparametric alternative; however, it was ultimately not required. Categorical variables were reported as frequencies and percentages.

A priori power analysis was performed using G*Power software. Based on the assumptions of 80% power ($1-\beta = 0.80$), a 5% level of significance ($\alpha = 0.05$), and a medium effect size ($f = 0.4$), the minimum required sample size was calculated as 66 individuals (with at least 11 participants in each subgroup). Accordingly, individuals from skeletal Classes I, II, and III were evenly distributed across both the study and control groups. A p-value of less than 0.05 was considered statistically significant for all analyses.

Results

In this study, skeletal and dentoalveolar measurements were compared between individuals with impacted mandibular second molars (MM2) (Study Group, SG) and those with normally erupted MM2 (Control Group, CG). Additionally, the participants were further divided into skeletal subgroups as Classes I, II, and III for subgroup analysis.

1. Demographic distribution
   The mean age of the participants was 12.53 ± 1.54 years in the study group (SG) and 12.14 ± 0.64 years in the control group (CG), with no statistically significant difference observed between the groups (Table 1). The sex distribution was balanced in both cohorts. Similarly, the distribution of individuals across skeletal Classes I, II, and III was homogeneous between the groups (Table 2).

2. GoGn/SN angle

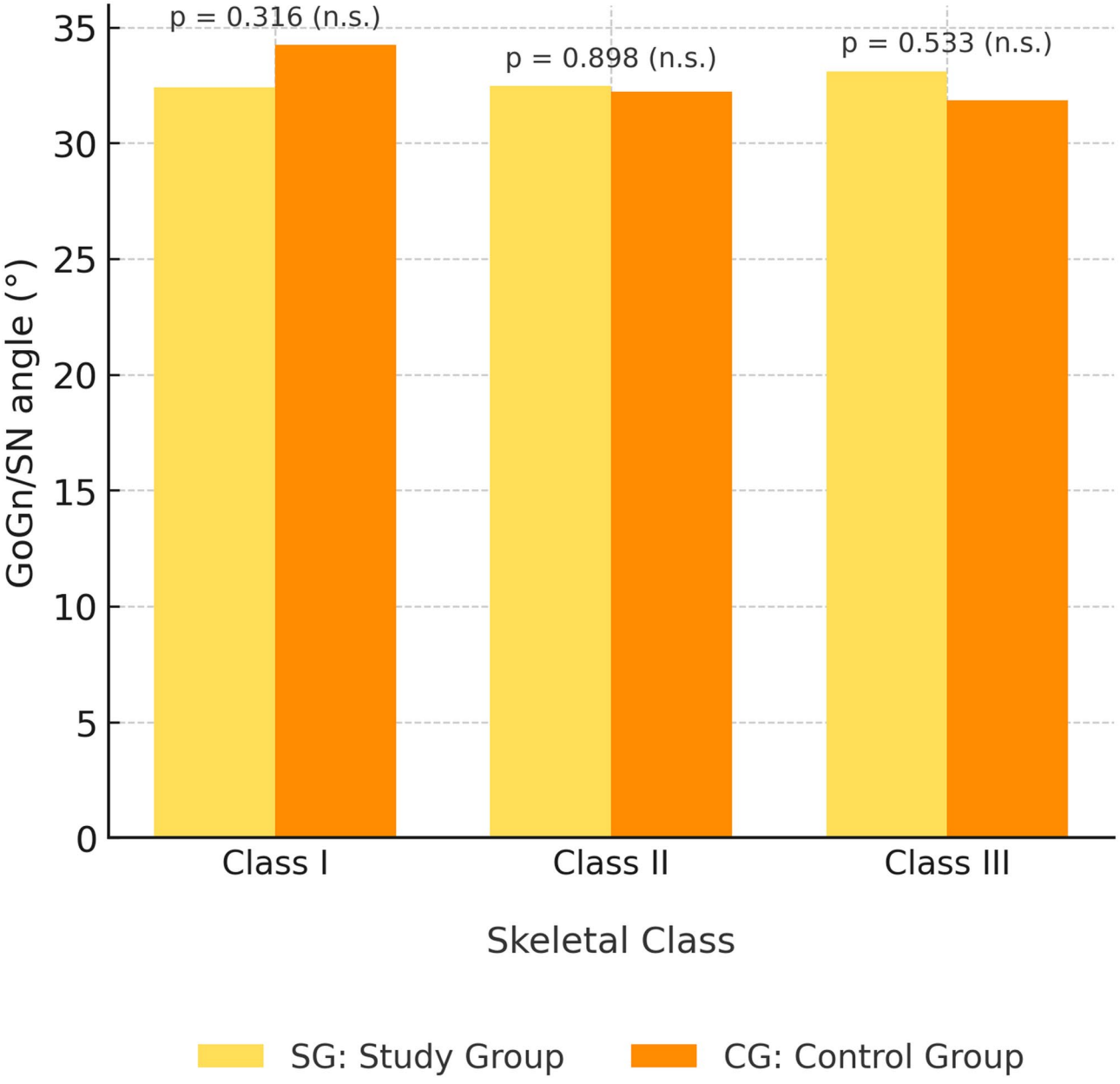


Fig. 2 Mean GoGn/SN angle across skeletal classes. No statistically significant differences were observed between study and control groups in any class (n.s.: not significant)

Table 3 Mean values by groups

Parameter	Class I (SG)	Class I (CG)	Class II (SG)	Class II (CG)	Class III (SG)	Class III (CG)
GoGn/SN Angle (°)	32.4	34.23	32.47	32.22	33.1	31.83
Gonial Angle (°)	127.68	127.9	120.08	124.0	128.13	128.52
Molar Inclination Angle (°)	5.81	4.13	5.16	4.71	12.32	7.96
Ramus Distance/MM2 MD Ratio	0.92	1.46	0.96	1.44	1.04	1.48

SG: Study Group; CG: Control Group; MD: Mesiodistal diameter

The GoGn/SN angles, which reflect the vertical growth pattern were not significantly different between the SG and CG across all the skeletal classes (Fig. 2) (Tables 3 and 4):

- Class I: GoGn/SN = 32.40° (SG), 34.23° (CG), $p = 0.316$.
- Class II: GoGn/SN = 32.47° (SG), 32.22° (CG), $p = 0.898$.

Table 4 Summary of skeletal differences between groups

Parameter	Class I (*p*)	Class II (*p*)	Class III (*p*)	Significance status
GoGn/SN Angle (°)	0.316	0.898	0.533	ns
Gonial Angle (°)	0.928	0.112	0.899	ns
Molar Inclination Angle (°)	0.531	0.897	0.099	ns
Ramus Distance/MM2 MD Ratio	< 0.001	< 0.001	< 0.001	***

MD: Mesiodistal diameter; ns: not statistically significant; ***$p < 0.001$

Table 5 Comparison of measurements between skeletal classes within the study group

Paramater	Class I (SG)	Class II (SG)	Class III (SG)	*p* (ANOVA)
GoGn/SN angle (°)	32.40	32.47	33.10	0.924
Gonial angle (°)	127.68	120.08	128.13	0.015 (*)
Molar inclination angle (°)	5.81	5.16	12.32	0.171
Ramus width/MM2 ratio	0.92	0.96	1.04	0.219

*$p < 0.05$; MD: Mesiodistal diameter

- Class III: GoGn/SN = 33.10° (SG), 31.83° (CG), $p = 0.533$.

These findings suggest that MM2 impaction is not significantly influenced by the vertical skeletal growth pattern.

3. Gonial angle
   The gonial angle, which reflects the direction and rotational pattern of mandibular growth, was significantly difference only within the SG across skeletal classes (ANOVA, $p = 0.015$) (Table 5). According to Tukey's post-hoc test:

- Class II < Class I and Class III.

However, intergroup comparisons between the SG and CG revealed no statistically significant differences in gonial angle values (Fig. 3) (Tables 3 and 4):

- Class I: Gonial angle = 127.68° (SG), 127.90° (CG), $p = 0.928$.
- Class II: Gonial angle = 120.08° (SG), 124.00° (CG), $p = 0.112$.
- Class III: Gonial angle = 128.13° (SG), 128.52° (CG), $p = 0.899$.

This finding suggests that variations in the gonial angle are more closely related to the characteristic features of skeletal classification rather than being directly associated with MM2 impaction.

4. Molar inclination angle
   The molar inclination angle, reflecting the mesiodistal tipping of the MM2, did not significantly differ between the groups overall. However, among Class III individuals, the mean angle was notably greater in those with impacted MM2 (Fig. 4) (Tables 3 and 4):

- Class III: Inclination angle = 12.32° (SG), 7.96° (CG), $p = 0.099$.

Although not statistically significant, the increased mesial inclination observed in Class III individuals may indicate a potential tendency that warrants further investigation.

- Class I: Inclination angle = 5.81° (SG), 4.13° (CG), $p = 0.531$.
- Class II: Inclination angle = 5.16° (SG), 4.71° (CG), $p = 0.897$.

5. Ramus distance/MM2 mesiodistal width ratio
   This ratio serves as a critical measurement to assess whether there is sufficient horizontal space for the eruption of MM2. In all skeletal classes, this ratio was significantly lower in SG individuals than in CG individuals ($p < 0.001$) (Fig. 5) (Tables 3 and 4):

- Class I: Ratio = 0.92 (SG), 1.46 (CG).
- Class II: Ratio = 0.96 (SG), 1.44 (CG).
- Class III: Ratio = 1.04 (SG), 1.48 (CG).

This finding strongly supports the notion that a narrow ramus is a significant anatomical risk factor for MM2 impaction.

Overall evaluation

- The most prominent finding was the relatively insufficient ramus space in individuals with impacted MM2 across all skeletal classes.
- The gonial angle showed statistically significant differences only among skeletal classifications but did not differ significantly between the SG and CG, indicating that there was no direct association with impaction.
- The molar inclination angle may have clinical relevance to MM2 impaction, particularly in Class III individuals.
- The GoGn/SN angle was not significantly associated with impaction.

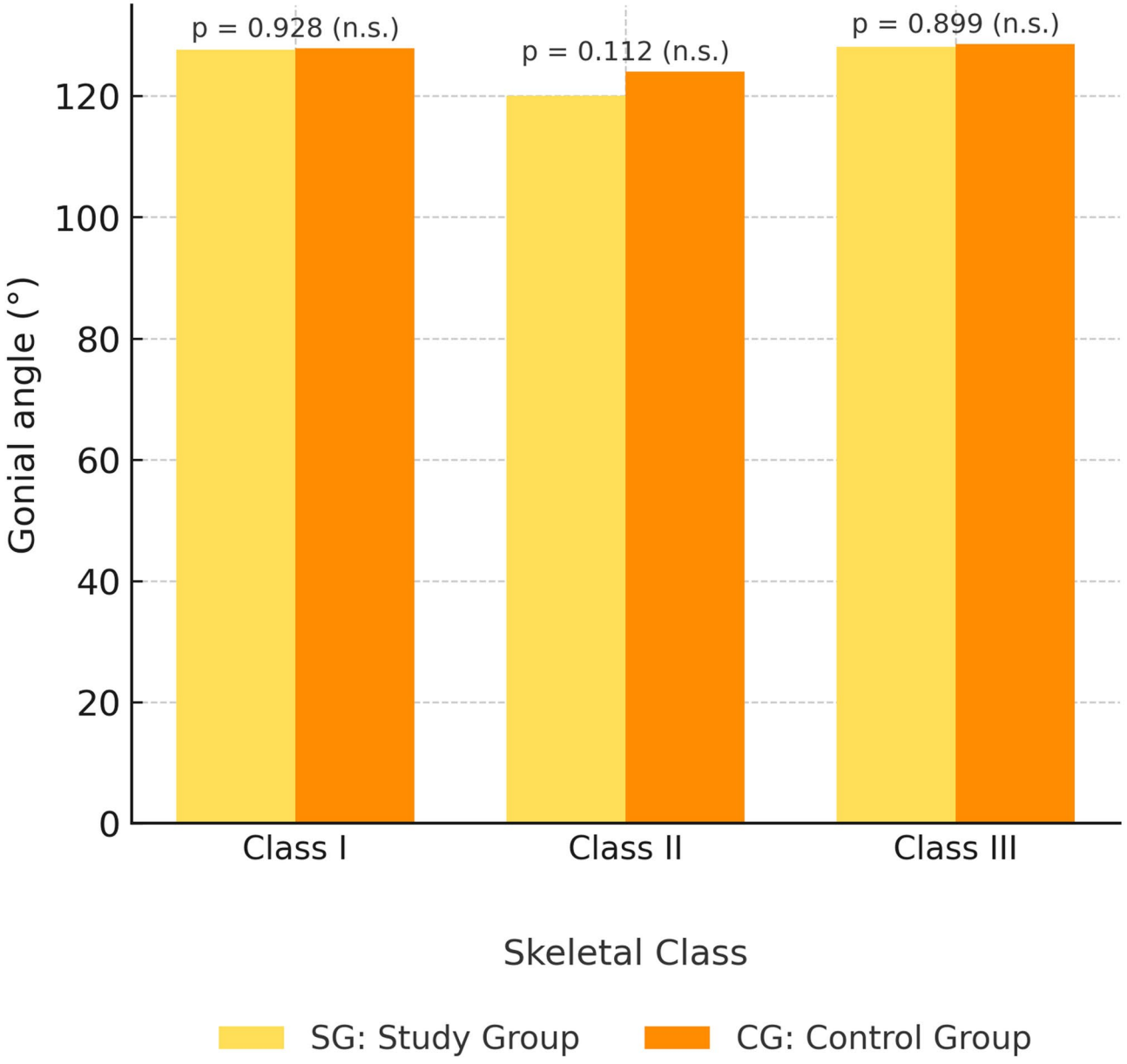


Fig. 3 Mean gonial angle across skeletal classes. No significant intergroup differences in gonial angle values. (n.s.: not significant)

Discussion

Although impaction of mandibular second molars (MM2) is less common than that of third molars, it represents a clinically significant dental anomaly that can pose considerable challenges for early diagnosis and treatment planning. This eruption disturbance is reportedly associated with morphological deficiencies in the posterior segment as well as individual growth patterns. In the present study, the impact of mandibular second molars was comprehensively evaluated in relation to various skeletal and dentoalveolar parameters, including skeletal classification differences, vertical growth patterns, gonial angles, molar inclination, and ramus morphology. The findings revealed that MM2 impaction is not solely related to general skeletal characteristics but is predominantly associated with local anatomical constraints in the posterior mandibular region. This observation is consistent with previous studies that focused primarily on third molar impaction [14–16].

One of the most notable findings in our study was the significantly lower ratio between the ramus space in the retromolar region and the mesiodistal width of the mandibular second molar (MM2) in individuals with impacted MM2. This suggests that impaction primarily results from spatial deficiency in the posterior region. In particular, this ratio was found to be lowest in individuals

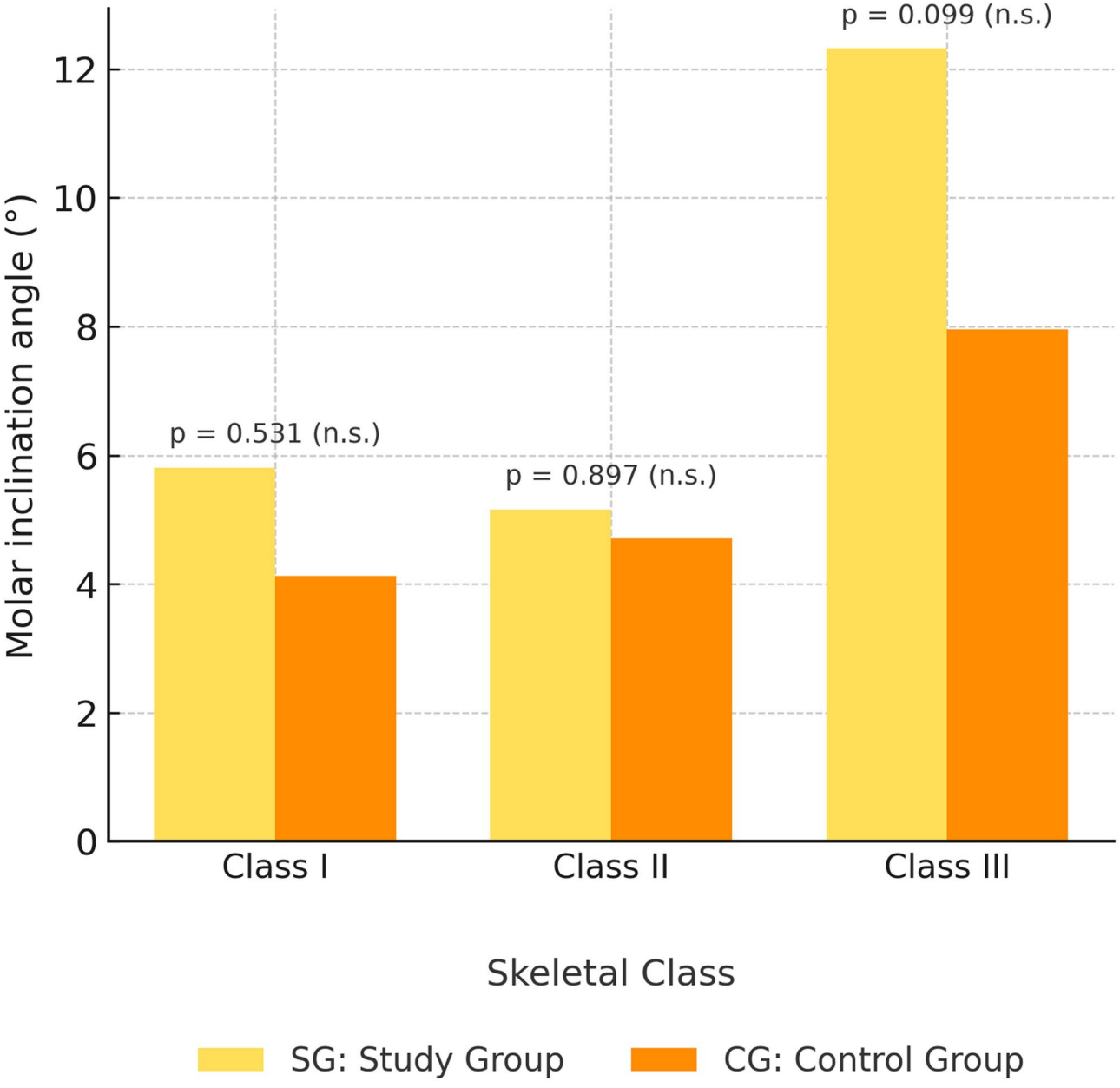


Fig. 4 Mean molar inclination angle across skeletal classes. A greater mesial inclination was observed particularly in Class III individuals with MM2 impaction (n.s.: not significant)

in skeletal Class III, indicating the potential influence of sagittal jaw relationships on the availability of posterior space. These results are consistent with those of previous studies in the literature, which identified inadequate space as the most common risk factor for MM2 impaction and emphasized that this condition may stem from a mismatch between mandibular growth and tooth development. Notably, in impaction cases directly associated with insufficient space, the mesiodistal dimension of the retromolar space is significantly smaller than the width of the MM2 [17, 18].

Similarly, Cassetta et al. [3], reported a significant reduction in the distance between the ramus and the second molar in patients with impacted MM2, along with a more pronounced inclination of the second molar in these individuals. In his classic study on second molar impaction, Evans [7] emphasized that one of the primary causes of impaction is the narrowness of the retromolar area, which prevents the tooth from following its physiological eruption path owing to these anatomical limitations. Similarly, a recent study conducted by McKeon et al. [19], reported that a decrease in the ramus space in the retromolar region was associated with an increased

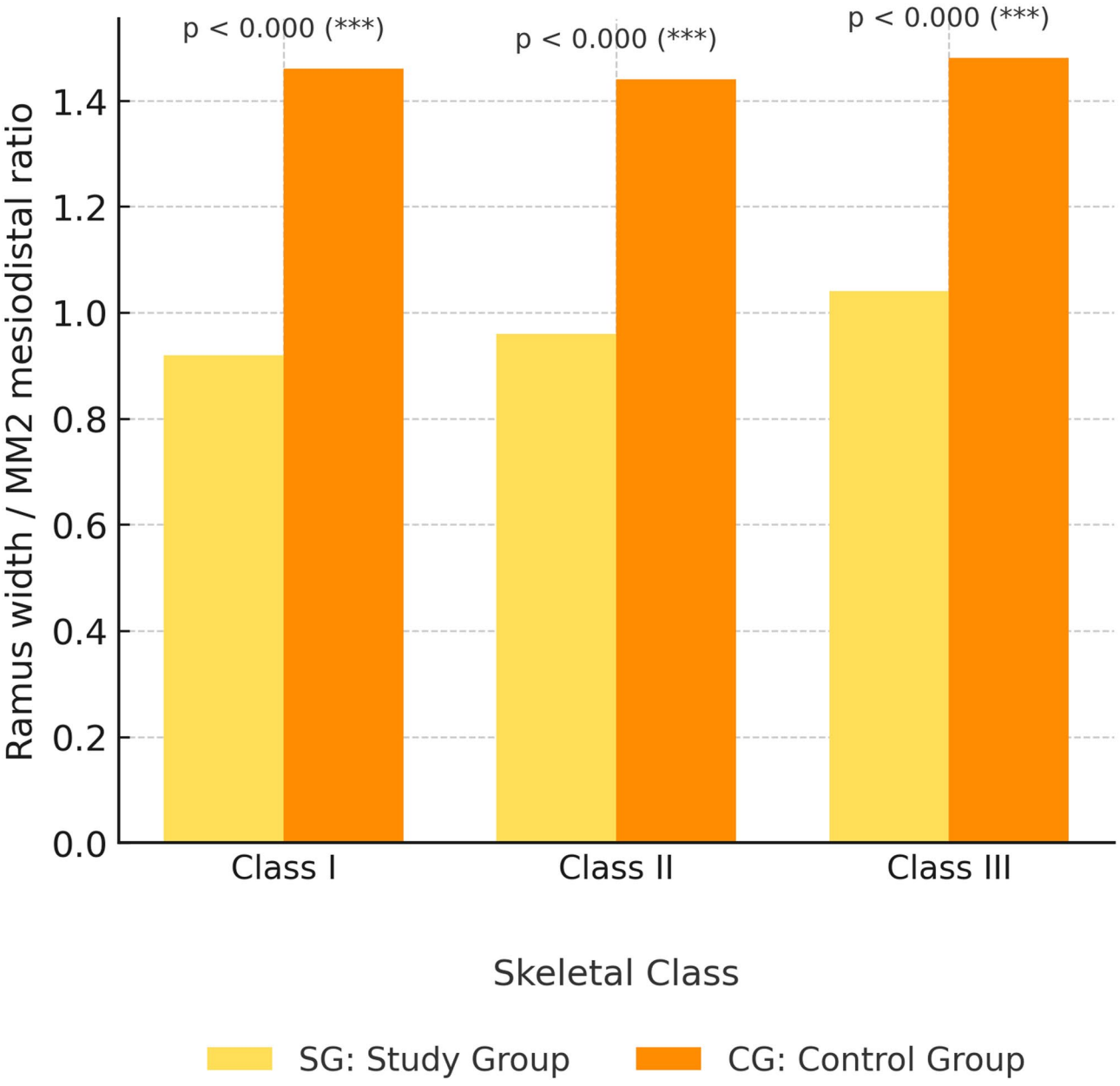


Fig. 5 Mean ramus width/MM2 mesiodistal diameter ratio across skeletal classes. The ratio was significantly lower in the study group for all classes, indicating posterior space deficiency (***$p < 0.001$)

incidence of impaction, and that volumetric parameters such as the TS: SA (Tooth Size: Space Available) ratio supported this trend. Considering these findings, the ramus–molar relationship emerges as a shared and critical morphological determinant of both second and third molar impact.

In our study, the significantly lower ramus space in the retromolar region observed in Class III individuals suggests that this skeletal pattern may contribute to spatial limitations in the posterior segment. Although one might expect increased mandibular length in these individuals, the literature paradoxically reports that the retromolar space is narrower in Class III cases, and that this group has a greater incidence of third molar impaction [20]. This finding contradicts the traditional view proposed by Richardson [21], who suggested that impaction is more common in Class II individuals with short mandibles. However, Behbehani et al. [11] argued that mandibular length alone is not a decisive factor; instead, the width of the retromolar space is shaped by the direction of mandibular growth, ramus morphology, and structural characteristics of the posterior segment [18].

Consequently, the increased rate of impaction observed in Class III individuals may be attributed not

only to sagittal skeletal relationships, but also to localized morphological constraints in the posterior region. The low ramus–molar ratio identified in these individuals supports the presence of such spatial limitations and the associated tendency for impaction. Particularly in Class III cases, dominant anterior mandibular growth may result in a more posterior positioning of the ramus, thereby narrowing the effective space distal to the molars. This morphological relationship is supported by the "forward rotation" growth pattern described by Björk and Skieller [22]. Thus, even in the presence of increased mandibular length, the space available for eruption may remain insufficient, contributing to the development of impaction. While this observation may seem contradictory to classical expectations, it provides a clinically meaningful explanation when considering the dynamics of mandibular growth and morphological configuration.

In our study, the molar inclination angle was found to be significantly increased in individuals with impaction, particularly in those with a skeletal Class III pattern. According to our data, the mean mesial inclination in impacted Class III individuals was 12.32°, whereas it was 7.96° in the control group. Similarly, individuals with Class I and Class II skeletal patterns who exhibited impaction also demonstrated higher inclination angles than their nonimpacted counterparts did. These findings suggest that mesial inclination may play an important role in the pathogenesis of impaction.

In line with these findings, Cassetta et al. [3], reported a notably high mesial inclination angle of 29.12° in patients with impacted MM2, which was significantly greater than the average of 10.14° observed in the control group. Evans [7] also noted a considerable increase in mesial inclination in impacted MM2s, highlighting that such an angle, when combined with limited anatomical space in the ramus region, substantially increases the risk of impaction. This pattern is similarly observed in third molars, where the most frequently encountered mesial angulation according to the Winter classification is recognized as the most predisposed position for impaction [15].

In our study, the concurrent presence of increased mesial inclination and decreased ramus–molar distance ratio in Class III individuals indicates an imbalance in both angular and volumetric aspects of the mandibular posterior segment. This finding supports a mechanism of impaction in which both anatomical spatial limitations and pathological inclination play contributory roles. In this context, mesial inclination should not be regarded merely as a positional variation, but rather as a valuable morphological determinant that directly influences the morphological adequacy of the mandibular posterior segment and may serve as a predictive factor for the development of impaction.

Our study confirmed that the molar inclination angle was significantly increased in individuals with impaction - particularly those with a skeletal Class III pattern. The observed increase in mesial angulation may lead to a deviation from the physiological eruption axis, thereby altering the eruption path and playing a determinative role in the development of impaction. This finding is in direct agreement with the limited body of literature focused on mandibular second molar impaction. Specifically, Evans [7] reported that mesial angulation was significantly elevated in impacted MM2s and that, when combined with the lack of anatomical space in the ramus region, this angular deviation markedly increased the risk of impaction.

The gonial angle is an important craniofacial parameter that influences mandibular growth direction, ramus positioning, and the morphological arrangement of the posterior segment. In our study, no statistically significant difference was found in the gonial angle values between the study and control groups. However, within the study group, a skeletal class-based analysis revealed that Class II individuals presented significantly lower gonial angles. This finding suggests the presence of a more horizontal mandibular growth direction in Class II individuals, in contrast to the wider gonial angles typically associated with dolichofacial growth patterns. In the literature, studies focusing on third molar impaction have reported that the gonial angle may influence eruption potential [16, 23]. For example, Demirel and Akbulut [16] reported an average gonial angle of 121.38° in individuals with impacted third molars, with significantly greater values observed particularly in the Pell-Gregory C2 group. This suggests that individuals with a more vertical growth pattern (i.e., those with larger gonial angles) may experience greater spatial limitations in the posterior segment and, consequently, a greater tendency for impaction [16, 23]. However, in our study, the differences in gonial angle associated with second molar impaction were found to fall within a narrower range than those reported for third molars. Notably, Class II individuals presented lower gonial angles in conjunction with increased rates of impaction. Smaller gonial angles have been associated with a forward rotation growth pattern in the literature, which may lead to a more upright positioning of the mandibular ramus and a resultant narrowing of the functional space allocated for eruption in the retromolar region [12, 22]. Indeed, in our study, the concurrent observation of a reduced gonial angle, decreased ramus–molar distance, and increased mesial inclination angle supported an elevated risk of impaction in these individuals.

Similarly, Cassetta et al. [3] noted that individuals with impaction had lower gonial angles, suggesting that this could be a factor that negatively affects the eruption axis of the molars. McKeon et al. [19], on the other hand,

reported that although the gonial angle was lower in individuals with impaction than in nonimpacted individuals, the difference was not statistically significant.

The concurrent observation of a reduced gonial angle (particularly in Class II individuals) and a decreased ramus–molar distance in second molar impaction cases suggests that posterior spatial limitations due to forward mandibular rotation may be a determining factor. In contrast, in third molars, a greater gonial angle appears to correspond with a deeper impaction pattern. These seemingly contradictory findings may be partially attributed to differences in molar position (second vs. third) and developmental timing. Because second molars erupt earlier in the developmental sequence, they may be more susceptible to relatively minor morphological constraints. In contrast, third molars are more likely to be affected by the later-stage consequences of skeletal morphology, which continues to evolve after the primary growth period. Furthermore, given that the literature on second molar impaction is relatively limited compared with that on third molars, our study provides novel and original data that help fill this gap.

When these two distinct findings are interpreted together, it becomes evident that the gonial angle contributes to the pathogenesis of impaction through different morphodynamic processes related to orientation and depth. A reduced gonial angle, indicative of forward rotation (as seen in Class II), leads to spatial constriction in the posterior segment. Conversely, a larger gonial angle (as observed in Pell-Gregory C2 third molars) reflects a dolichofacial tendency of the mandible and indicates deeper positioning, which increases the depth of impaction. Therefore, the gonial angle provides two distinct and clinically valuable morphological markers for predicting not only growth direction but also the positional and depth-related patterns of both second and third molar impact.

In our study, no statistically significant difference was found between individuals with MM2 impaction and the control group in terms of the GoGn/SN angle. This finding indicates that there is no direct relationship between the vertical growth pattern and second molar impaction. Although the effect of vertically oriented facial morphology on MM2 eruption dynamics remains controversial, the present study supports the notion that this parameter is not a decisive factor in the development of impaction. Indeed, previous studies have also shown that the GoGn/SN angle is not a significant predictor, particularly in third molar impactions, unless evaluated in conjunction with forward rotation or hyperdivergent patterns, which may give it greater clinical relevance [3, 19, 23]. In this context, the GoGn/SN angle alone may be an insufficient indicator for MM2 impaction and should be interpreted alongside other morphological parameters.

The present study has several limitations that should be acknowledged when interpreting the results. First, the retrospective design inherently carries a risk of selection bias, as the data were collected from pre-existing records rather than through prospective, randomized sampling. This may affect the generalizability of the findings across broader populations.

Second, the study relied on two-dimensional panoramic and lateral cephalometric radiographs for the evaluation of anatomical parameters. While these modalities are widely used in clinical orthodontics and provide reliable measurements, they may be limited in their ability to capture three-dimensional spatial relationships fully, particularly in complex anatomical regions such as the retromolar area. Future studies incorporating cone-beam computed tomography (CBCT) could offer more precise volumetric assessments.

Third, the age range of the participants, although relatively narrow and appropriate for evaluating MM2 eruption patterns, may still reflect developmental variability in skeletal and dental maturation. Individual differences in growth timing and molar development stages could influence the observed parameters and outcomes.

Fourth, while the study analysed skeletal Class I, II, and III patterns, other craniofacial variables such as mandibular rotation types, facial asymmetry, or vertical discrepancies were not independently assessed. The inclusion of such variables in future investigations may help further elucidate the multifactorial nature of second molar impaction.

Finally, the relatively limited number of cases in certain subgroups may reduce the statistical power of subgroup comparisons. While power analysis was performed prior to study initiation, future research with larger, multicentred samples could improve the robustness and external validity of the findings. In addition, dental arch crowding, another important factor reflecting space deficiency, was not evaluated in this study. The absence of dental casts or digital models prevented the inclusion of dental crowding as a variable, which constitutes a limitation of the study. Future studies incorporating dental models or digital intraoral scans could overcome this limitation and provide a more comprehensive evaluation of the relationship between arch space conditions and MM2 impaction.

Conclusions

This study evaluated the relationships between mandibular second molar (MM2) impaction and various skeletal and dentoalveolar morphological parameters. These findings demonstrated that increased molar inclination and insufficient effective space in the retromolar region play significant roles in the development of impaction. These parameters were more pronounced in individuals with a skeletal Class III pattern, suggesting that structural

disharmony in the posterior segment may contribute to an elevated risk of MM2 impaction. The gonial angle was significantly different only in Class II individuals, further supporting the multifactorial nature of impaction.

In contrast, no significant differences were observed in general growth pattern indicators such as the GoGn/SN angle, indicating that MM2 impaction is more likely associated with local morphological constraints than with vertical growth tendencies. Although the increased second molar inclination angle observed in Class III individuals ($p = 0.099$) did not reach statistical significance in the present study, this data suggests a potential association that may become evident with larger sample sizes. Future studies with expanded cohorts could further clarify the role of molar inclination in the development of MM2 impaction. Our results highlight the clinical utility of assessing molar angulation and posterior spatial adequacy in the early identification of individuals at risk, providing valuable guidance for both orthodontic and surgical planning to prevent MM2 impaction.

On the basis of these findings, in individuals exhibiting risk factors such as posterior spatial deficiency and increased mesial molar angulation, prophylactic removal of third molar tooth germs during the developmental stage may be considered to facilitate eruption of the second molars. In this context, the present study underscores the importance of early intervention and offers a substantial contribution to clinical decision-making protocols.

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Authors' contributions
A.T.A. contributed to study design, consultation, and manuscript review. H.A. was responsible for data collection, measurements, analysis, and manuscript drafting. A.T.A and H.A authors reviewed and approved the final manuscript.

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Data availability
The radiological records used in this study are accessible through the institutional archive system of Ankara University and are also available to national healthcare institutions. Data are available upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Ankara University Faculty of Dentistry for Non-Clinical Scientific Research (Approval No: 2025/10 – 8). The current study was conducted in accordance with the ethical principles for medical research involving human participants (including research using identifiable human material or data) set out in the World Medical Association's Declaration of Helsinki. Informed consent was obtained from all participants included in the present study, which used retrospective data. Informed consent was also obtained from participants under the age of 16 and their parents/legal guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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