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Vertical Growth Pattern and Posterior Eruption Space of the Developing Mandibular Second Molar: A Retrospective Cross-Sectional Study

Running Title: Posterior Eruption Space in Different Growth Patterns

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Abstract

Background: The role of the vertical growth pattern in the etiology of mandibular second molar eruption disturbance is controversial; this relationship has mostly been examined through whether or not the tooth erupts, and the eruption space left anterior to the ramus for the second molar has not been directly measured and compared across different growth patterns. The aim of this study was to evaluate whether the available posterior eruption space and molar angulation for the developing mandibular second molar differ among individuals with vertical, normal, and horizontal growth patterns.

Methods: A total of 132 individuals (aged 9–18 years), in whom at least two-thirds of the second molar root development was complete, were included in this retrospective cross-sectional

study. Individuals were divided into vertical (n=44), normal (n=44), and horizontal (n=44) growth pattern groups according to SN/GoGn° and FMA° values. On lateral cephalometric radiographs, the gonial angle, Y-axis, posterior/anterior facial height ratio, ramus height, mandibular corpus length, and effective mandibular length were measured; on panoramic radiographs, the first molar–ramus distance, ramus distance/second molar mesiodistal width ratio, molar inclination angle, second molar mesiodistal width, and eruption depth were measured. One-way ANOVA and eta-squared (η^2) effect size were used for between-group comparisons, and Pearson correlation analysis was used to assess associations.

Results: The groups differed markedly in gonial angle ($p < 0.001$; $\eta^2 = 0.497$), Y-axis ($p < 0.001$; $\eta^2 = 0.444$), and posterior/anterior facial height ratio ($p < 0.001$; $\eta^2 = 0.671$). In contrast, none of the panoramic measurements differed significantly among the groups: molar inclination angle ($p = 0.584$), first molar–ramus distance ($p = 0.260$), second molar mesiodistal width ($p = 0.274$), ramus distance/mesiodistal width ratio ($p = 0.390$), and eruption depth ($p = 0.976$); all effect sizes were negligible ($\eta^2 = 0.000$ – 0.021). Before adjustment for multiple testing, the first molar–ramus distance and second molar width correlated positively with mandibular corpus length, effective mandibular length, and ramus height in all three groups ($r = 0.33$ – 0.64); after Benjamini–Hochberg correction, the associations of second molar width with mandibular corpus length and effective mandibular length remained significant in all three groups, whereas those of the first molar–ramus distance were retained in the normal and horizontal groups but not in the vertical group.

Conclusion: The available posterior eruption space and molar angulation for the developing mandibular second molar did not differ among cephalometrically distinct vertical growth pattern

groups. In this cross-sectional sample, the available posterior eruption space was associated with mandibular size, whereas no association with the vertical facial pattern was identified.

Keywords: mandibular second molar; tooth eruption; vertical growth pattern; cephalometric analysis; mandibular growth

Introduction

Tooth eruption is a complex biological process in which the tooth moves from its developmental position toward the occlusal plane through a coordinated series of cellular and mechanical events directed largely by the dental follicle, which forms the eruption pathway and guides bone remodeling.[1–4] The process is influenced by general (endocrine, genetic, systemic) as well as local factors, and disruption of any of these may lead to delayed eruption or impaction.[5–7]

The mandibular second molar occupies a critical position for the functional integrity of the posterior dental arch segment: it stabilizes the posterior vertical dimension and the curve of Spee and is a fundamental component of an ideal occlusion,[8–11] whereas its impaction or partial impaction may cause root resorption of the adjacent first molar, irregularity of the occlusal plane, and extrusion of opposing teeth.[12, 13] Eruption disturbance of this tooth is rare compared with other permanent teeth (reported impaction prevalence, 0.06–1.7%) but remains a clinically important diagnostic problem, and unilateral involvement is more common than bilateral.[14–19]

Its etiology is multifactorial. Local factors, chiefly space deficiency in the posterior region of the mandible and insufficient arch length, dental factors such as the position and angulation of the tooth germ, and skeletal factors such as the mandibular growth pattern and ramus morphology have all been implicated.[10, 15, 18–22] The skeletal component is biologically plausible, because the eruption path of the second molar is created by resorptive remodeling at

the anterior border of the mandibular ramus: the tooth begins development in a mesially inclined position close to the ramus and uprights as this mechanical obstacle is removed.[23] The direction of mandibular growth and the resulting ramus position would therefore be expected to determine the posterior space left in front of the tooth.[21, 23]

Most of the evidence for this expectation, however, derives from the third molar. Björk related the likelihood of third molar eruption to the distance between the second molar and the ramus and to the direction of condylar growth, and subsequent studies linked impaction to skeletal facial type, reporting that a vertical growth pattern aggravates posterior space deficiency. [24–27] At the second molar level the picture is inconsistent: a lower gonial angle, a more frequent skeletal Class II relationship and a pronounced vertical condylar growth pattern have been reported in individuals with eruption disturbance,[21, 22, 28, 29] whereas McKeon et al. found the difference in gonial angle to be non-significant.[30] Because the second molar erupts considerably earlier, the ramus has undergone less remodeling at the time of its eruption, and craniofacial morphology also influences the timing of dental development;[31, 32] findings for the third molar therefore cannot be generalized directly to the second molar.[22]

Critically, these studies inferred the role of the growth pattern from whether the tooth erupted or from how it was positioned, rather than from direct measurement of the space itself, so whether the posterior eruption space available to the developing second molar actually differs between vertical facial types remains untested. The aim of this study was to evaluate, on lateral cephalometric and panoramic radiographs, whether the available posterior eruption space (first molar–ramus distance) and molar angulation for the developing mandibular second molar differ among vertical, normal, and horizontal growth pattern groups. Based on the view that a vertical

growth pattern leads to space deficiency in the posterior region, it was hypothesized that these measurements would differ among individuals with different craniofacial growth patterns.

Materials and Methods

Study Design and Sample

This retrospective cross-sectional study was approved by the Istanbul Kent University Health Sciences Research Ethics Committee (approval no. 2025-06, dated 06.08.2025) and was conducted in accordance with the principles of the Declaration of Helsinki. Lateral cephalometric and panoramic radiographs of patients who presented to the Orthodontics Clinic, Faculty of Dentistry, Istanbul Kent University between 2021 and 2025 were retrospectively screened.

The screening and selection process is summarized in Figure 1 (STROBE flow diagram). A total of 210 patient records with paired panoramic and lateral cephalometric radiographs obtained between 2021 and 2025 were screened. Fifty-four records were excluded on predefined criteria (radiographs of insufficient diagnostic quality, $n=8$; mandibular second molar root formation $<2/3$, $n=19$; systemic disease, syndrome, or cleft lip/palate, $n=3$; history of mandibular second molar trauma, $n=2$; first molar or second premolar extraction, $n=6$; previous orthodontic treatment, $n=14$; previous orthognathic surgery, $n=2$), leaving 156 eligible patients. A further 12 patients with discordant SN/GoGn° and FMA° classifications were excluded, yielding 144 patients with concordant classification (48 per growth-pattern category). To obtain comparable, demographically balanced groups, 44 age- and sex-matched patients were randomly selected from each category, resulting in a final study population of 132 patients (one mandibular second molar per patient; 132 teeth). The unit of analysis was the patient (one second molar per patient), and the sample-size/power evaluation was performed accordingly. A sensitivity power analysis

performed with G*Power 3.1.9.4 (Heinrich-Heine-Universität, Düsseldorf, Germany) showed that, for a one-way analysis of variance with three groups at 80% power ($1-\beta=0.80$) and a 5% significance level ($\alpha=0.05$), this sample was sufficient to detect an effect size of Cohen's $f \geq 0.27$ (corresponding to $\eta^2 \approx 0.07$). Because the effect sizes observed for the panoramic measurements were well below this threshold ($\eta^2=0.000-0.021$), the non-significant findings are supported by negligible observed effect sizes rather than by p values alone.

Inclusion criteria were: (1) individuals with simultaneously obtained, diagnostic-quality panoramic and lateral cephalometric radiographs; (2) systemically healthy individuals; (3) individuals in whom at least two-thirds of the mandibular second molar root had developed. This developmental threshold was chosen because it corresponds to the physiological eruption stage at which the second molar would normally be expected to emerge into the oral cavity; thus, only teeth still possessing active eruptive potential were assessed, while teeth too immature to have entered the eruption phase were excluded.[5, 33] Exclusion criteria were: a history of craniofacial syndrome or cleft lip and palate; a history of trauma affecting the second molar; a history of extraction of a first molar or second premolar; a history of orthognathic surgery; previous orthodontic treatment; and distortion or technical error severe enough to preclude radiographic evaluation. Eligibility was confirmed by measurements made on the radiographs in addition to clinical records.

The ages of the evaluated individuals ranged from 9 to 18 years (mean 11.45 years; median 11 years), and the sample comprised 63 males (47.7%) and 69 females (52.3%).

Group Formation

Individuals were divided into three vertical growth pattern groups according to the SN/GoGn° (mandibular plane angle) and FMA° (Frankfort mandibular plane angle) values measured on lateral cephalometric radiographs:

- **Vertical growth pattern (Group V, high angle):** SN/GoGn° > 38° and FMA° > 30°
- **Normal growth pattern (Group N):** SN/GoGn° 26–38° and FMA° 20–30°
- **Horizontal growth pattern (Group H, low angle):** SN/GoGn° < 26° and FMA° < 20°.

[34, 35]

Two reference planes (SN/GoGn°, based on the anterior cranial base, and FMA°, based on the Frankfort horizontal plane) were used together rather than relying on a single measurement, because the two angles are derived from different craniofacial references and their combined use reduces the risk of misclassification that can occur when only one plane is considered. An individual was assigned to a growth-pattern group only when the SN/GoGn° and FMA° values were concordant (i.e., both angles fell within the same category); the 12 patients with discordant SN/GoGn° and FMA° classifications were excluded, leaving 144 patients with concordant classification (48 per growth-pattern category). Each group consisted of 44 individuals (Group V: 20 males, 24 females; Group N: 23 males, 21 females; Group H: 20 males, 24 females), matched for age and sex distribution across the groups.

Radiographic Protocol

All radiographs were obtained with the same device (Castellini X-Radius Compact, Imola, Italy) by the same technician. Lateral cephalometric radiographs were taken with the patients in maximum intercuspation, with the lips in the rest position, and in the natural head position. For panoramic radiographs, the patient's head was positioned so that the Frankfort horizontal plane

was parallel to the floor; a bite stick and a chin–head support were used to prevent movement. For both imaging modalities, the focus–object distance was 150 cm, the focus–film distance 15 cm, the current 10 mA, the voltage 82 kVp, and the exposure time 6.7 seconds. In the panoramic measurements, linear measurements were corrected by taking into account the device-specific magnification factor.

All measurements were performed using Nemoceph 10.4.2 cephalometric software for Windows (Nemotec Dental Systems, Madrid, Spain). All radiographic measurements were performed by two independent, calibrated investigators. To assess inter-observer reliability, the radiographs of 30 randomly selected patients were measured independently by both investigators. To assess intra-observer reliability, the same 30 radiographs were re-measured by one investigator two weeks after the initial assessment. Agreement was quantified using the intraclass correlation coefficient (ICC), calculated with a two-way random-effects model for absolute agreement, single measures (ICC [2,1]). Coefficients were calculated separately for each cephalometric and panoramic variable analysed rather than for the measurement set as a whole. Agreement was excellent throughout: the variable-specific intra-observer coefficients ranged from 0.91 to 0.97 and the variable-specific inter-observer coefficients from 0.92 to 0.96. The single overall value cited for inter-observer agreement, 0.94, is the arithmetic mean of the variable-specific coefficients listed in Additional file 1 and therefore summarizes agreement across these measurements rather than the reliability of any individual variable. The variable-specific coefficients and their 95% confidence intervals are given in Additional file 1 (Table S1).

Cephalometric Variables

The Sella, Nasion, Gnathion, Articulare, Gonion, Menton, Condylion, Orbitale, and Porion points were used in the cephalometric analysis.[36] For classification of the vertical growth

pattern, the SN/GoGn° (the angle between the mandibular plane and the SN plane) and FMA° (the angle between the Frankfort horizontal plane and the mandibular plane) were calculated.[36]

To assess the skeletal validity of the group separation, the following variables were measured: gonial angle (Ar-Go-Me), Y-axis angle, anterior facial height (Nasion–Menton), posterior facial height (Sella–Gonion), posterior/anterior facial height ratio (Jarabak ratio; S-Go/N-Me $\times$ 100), lower anterior facial height (ANS–Menton)[36], ramus height (Gonion–Condylion), and—as indicators of mandibular size—mandibular corpus length (Gonion–Menton)[37] and effective mandibular length (Condylion–Gnathion)[38]. It has been reported that insufficient mandibular corpus length may increase the risk of molar impaction by causing space deficiency in the posterior region[37]; the effective mandibular length measurement is used to assess the growth potential of the mandible and to distinguish whether anomalies arise from the position or the size of the jaw.[38]

Panoramic Variables

Posterior eruption space and molar angulation measurements were performed on panoramic radiographs; the reference points and measurements are illustrated on a representative panoramic radiograph in Figure 3. Because each individual had bilateral mandibular second molars, only one mandibular second molar per patient was included in the analysis to ensure the independence of observations; the individual therefore served as the unit of analysis. When both mandibular second molars fulfilled the inclusion criteria, the right mandibular second molar was selected. If the right mandibular second molar did not meet the inclusion criteria, the left mandibular second molar was included. The side analysed was recorded for every patient, and the distribution of the analysed sides did not differ significantly among the growth-pattern groups (Group V: right side 68.2%; Group N: 61.4%; Group H: 61.4%; $p = 0.745$). The reference points included the deepest

concavity point at the anterior border of the mandibular ramus, the furcation points of the first and second molars, the distal contour points, and the midpoints of the occlusal surfaces. The long axes of the first and second molars were defined as the line connecting the midpoint of the occlusal surface and the furcation point of the relevant tooth; the occlusal plane (OP) was defined as the line passing through the buccal cusp tips of the mandibular first premolar and first molar.[39]

The measurements derived from these references were:

(1) Molar inclination angle (MIA): the angle between the long axes of the mandibular first and second molars, measured as the inclination angle in accordance with the definition proposed by Evans.[10]

(2) First molar–ramus distance (MM1–ramus distance; RD): the horizontal distance from the perpendicular dropped from the distal contour of the first molar to the occlusal plane to the anterior border of the ramus; this measurement directly reflects the anatomical space available for eruption of the second molar.

(3) Second molar mesiodistal width (MM2 mesiodistal; MM2 WIDTH): defined as the distance between the mesial and distal contours of the second molar.

(4) Ramus distance/second molar mesiodistal width ratio: a ratio obtained by dividing the first molar–ramus distance by the second molar mesiodistal width, reflecting individual differences in tooth size.

(5) Eruption depth (ED): defined as the vertical distance from the marginal tubercle of the second molar to the occlusal plane.

In addition to these metric measurements, three categorical variables were recorded from the same panoramic radiograph. Two of them describe different attributes of the position of the tooth

and are therefore reported separately: the eruption type is a categorical grading of vertical depth against the crown of the adjacent first molar, complementing the metric eruption depth defined in (5), which is measured relative to the occlusal plane, whereas the ramus relationship expresses the horizontal relationship of the distal surface of the second molar to the anterior border of the ramus.

(6) Eruption type (depth of the second molar, Types I–III): because the original Pell and Gregory classification was developed anatomically for the mandibular third molar,[40] the depth of the second molar was assessed with the modified classification used by Kuang et al., in which depth is graded against the crown of the adjacent first molar:[41] Type I, the most occlusal point of the second molar crown is level with the occlusal half of the first molar crown; Type II, the most occlusal point lies within the gingival half of the first molar crown; Type III, the most occlusal point lies apical to the cemento-enamel junction of the first molar.

(7) Ramus relationship (Levels A–C): the relationship between the distal surface of the second molar and the anterior border of the ramus was evaluated by adapting the underlying principle of the Pell and Gregory classification to the second molar region:[40] Level A, the distal surface of the second molar lies anterior to the anterior border of the ramus, so that the space between the first molar and the ramus is sufficient for normal eruption; Level B, the distal surface is level with the anterior border of the ramus, so that this space is only partly sufficient; Level C, the distal surface lies posterior to the anterior border of the ramus, so that no space for eruption remains between the first molar and the ramus. Because only this horizontal principle was adapted, the levels A–C used here denote the ramus relationship and not the depth positions A–C of the original Pell and Gregory classification; depth is captured separately by the eruption type defined above.

(8) Eruption status at the time of imaging: recorded as erupted when any part of the crown of the second molar had emerged into the oral cavity, and as not yet erupted otherwise.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics 27 (IBM Corp., Armonk, NY, USA). The conformity of continuous variables to a normal distribution was assessed with the Kolmogorov–Smirnov test. Because the normality assumption was not met for the age variable, the Kruskal–Wallis test was used for its between-group comparison. For the between-group comparison of all other continuous variables (cephalometric and panoramic), one-way ANOVA was applied; for variables with a significant difference, the Tukey HSD post hoc test was used to identify the source of the difference. To evaluate the importance of between-group differences beyond reliance on the p value alone, the eta-squared (η^2) effect size was calculated for each comparison; this approach was preferred in order to distinguish, especially for the non-significant panoramic comparisons, whether the observed “absence of difference” reflected a true similarity or a finding due to insufficient power. Categorical variables such as sex distribution were compared with the chi-square test. Associations between panoramic and cephalometric measurements were assessed with Pearson correlation analysis; correlation coefficients were interpreted as weak for $r=0.00–0.29$, moderate for $r=0.30–0.49$, moderate-to-strong for $r=0.50–0.74$, and strong for $r\geq 0.75$. Categorical outcomes recorded from the panoramic radiographs — eruption status, eruption type (Types I–III) and the ramus relationship (Levels A–C) — were compared among the groups with the chi-square test. Because the sample spanned the 9–18-year age range, eruption status was additionally examined in a binary logistic regression including growth-pattern group, age, and sex, with the group effect assessed by a likelihood-ratio test. It should be noted that, at the age at which these records were obtained, a mandibular second molar that had

not yet emerged into the oral cavity is developmentally expected; accordingly, “not yet erupted” in this study denotes a tooth that had not emerged at the time of imaging and does not imply pathological impaction, which can only be established once the expected eruption time has passed. The level of statistical significance was set at $p < 0.05$. In addition to p values and η^2 effect sizes, 95% confidence intervals for the group means are reported (Tables 2 and 3) to indicate the precision of the estimates. Because Table 4 involves a large number of correlation tests, the associated p values were adjusted for multiple comparisons using the Benjamini–Hochberg false-discovery-rate procedure, and both unadjusted and adjusted values are presented. Potential confounding across the broad age range (9–18 years) was addressed in two ways. First, it was controlled at the design stage: the three growth-pattern groups were matched for age and sex, with no significant between-group difference in either variable (Table 1). Second, to verify that the univariate findings were not attributable to residual confounding, each panoramic outcome was additionally analysed in a multivariable general linear model (analysis of covariance) that included growth-pattern group as the fixed factor and age and sex as covariates. Adjusted (estimated marginal) means with 95% confidence intervals, the p value for the group effect, and the partial eta-squared (η^2) effect size are reported in Table 5; adjusted means were estimated at the mean age of the sample (11.45 years) and averaged over the observed sex distribution.

Results

A total of 132 individuals—aged 9 to 18 years (mean 11.45; median 11), 63 males (47.7%) and 69 females (52.3%)—were included in the study. Individuals were divided into three groups of 44: vertical growth pattern (Group V, $n=44$), normal growth pattern (Group N, $n=44$), and horizontal growth pattern (Group H, $n=44$). No statistically significant difference was found

among the groups in age (Kruskal–Wallis, $p=0.435$) or sex distribution (chi-square, $p=0.761$; Table 1), indicating that the groups were demographically comparable.

Table 1. Comparison of the groups by age and sex distribution.

	Group V	Group N	Group H	p
Age, Mean $\pm$ SD (median) (min–max)	11.28 $\pm$ 1.89 (11) (9–18)	11.31 $\pm$ 1.65 (11) (9–18)	11.76 $\pm$ 1.92 (11.3) (9.3–17)	0.435 ^a
Sex, n (%)				
Male	20 (45.5%)	23 (52.3%)	20 (45.5%)	0.761 ^b
Female	24 (54.5%)	21 (47.7%)	24 (54.5%)	

^a Kruskal–Wallis test; ^b chi-square test.

Cephalometric Validation of Group Separation

To test whether the vertical growth pattern groups were truly skeletally distinct, cephalometric variables not directly used in group formation were compared (Table 2). Statistically significant differences with large effect sizes were found among the groups in gonial angle ($p<0.001$; $\eta^2=0.497$), Y-axis angle ($p<0.001$; $\eta^2=0.444$), and posterior/anterior facial height ratio ($p<0.001$; $\eta^2=0.671$). Post hoc analyses revealed that Group V had a significantly higher gonial angle and Y-axis values and a significantly lower posterior/anterior facial height ratio than Groups N and H, whereas Group H showed the opposite, most pronounced horizontal tendency in these variables. Significant but small-to-moderate effect-size differences were also found in ramus height ($p=0.012$; $\eta^2=0.066$) and posterior facial height ($p=0.014$; $\eta^2=0.064$); for these variables, Group H showed significantly higher values than Group V. In contrast, no significant differences were found among the groups in mandibular corpus length ($p=0.270$; $\eta^2=0.020$), effective mandibular length ($p=0.813$; $\eta^2=0.003$), anterior facial height ($p=0.303$; $\eta^2=0.018$), or lower facial height ($p=0.060$; $\eta^2=0.043$). These results show that the three groups differ in gonial angle, Y-axis, and facial height ratio, but remain similar in the absolute dimensional measures of the mandible (corpus length, effective length). The contrast between the large effect sizes for

these facial-form variables and the negligible effect sizes for all panoramic eruption-space measures is summarized in Figure 2.

Table 2. Comparison of the groups by cephalometric measurements.

Variable	Group V Mean $\pm$ SD (95% CI)	Group N Mean $\pm$ SD (95% CI)	Group H Mean $\pm$ SD (95% CI)	p	η^2
Gonial angle (°)	132.23 $\pm$ 6.58 (130.23–134.23)	126.05 $\pm$ 4.35 (124.73–127.37)	118.95 $\pm$ 5.39 (117.31–120.59)	<0.001*	0.497
Ramus height (mm)	37.82 $\pm$ 7.32 (35.59–40.05)	40.61 $\pm$ 7.47 (38.34–42.88)	42.80 $\pm$ 8.40 (40.24–45.36)	0.012*	0.066
Mandibular corpus length (mm)	61.61 $\pm$ 9.96 (58.58–64.64)	64.20 $\pm$ 10.86 (60.90–67.50)	65.25 $\pm$ 11.53 (61.74–68.76)	0.270	0.020
Effective mandibular length (mm)	99.95 $\pm$ 15.87 (95.12–104.78)	102.23 $\pm$ 17.09 (97.03–107.43)	101.48 $\pm$ 17.65 (96.11–106.85)	0.813	0.003
Anterior facial height (mm)	109.14 $\pm$ 17.86 (103.71–114.57)	108.07 $\pm$ 17.81 (102.65–113.49)	103.57 $\pm$ 17.93 (98.12–109.02)	0.303	0.018
Posterior facial height (mm)	64.39 $\pm$ 10.60 (61.17–67.61)	69.45 $\pm$ 11.42 (65.98–72.92)	71.64 $\pm$ 13.02 (67.68–75.60)	0.014*	0.064
Posterior/anterior facial height ratio (%)	59.14 $\pm$ 3.49 (58.08–60.20)	64.18 $\pm$ 2.03 (63.56–64.80)	69.14 $\pm$ 2.98 (68.23–70.05)	<0.001*	0.671
Y-axis (°)	71.73 $\pm$ 3.51 (70.66–72.80)	68.36 $\pm$ 2.32 (67.65–69.07)	65.57 $\pm$ 2.59 (64.78–66.36)	<0.001*	0.444
Lower facial height (mm)	62.41 $\pm$ 10.38 (59.25–65.57)	60.86 $\pm$ 10.23 (57.75–63.97)	57.27 $\pm$ 10.28 (54.14–60.40)	0.060	0.043

Values are mean $\pm$ SD (95% confidence interval). One-way ANOVA; * $p < 0.05$. η^2 , eta-squared effect size. Different superscript letters in a row (where present) indicate post-hoc (Tukey HSD) between-group differences.

Between-Group Comparison of Posterior Eruption Space and Molar Angulation

The between-group comparison of the panoramic measurements reflecting the available posterior eruption space and angulation for the developing mandibular second molar is presented in Table 3. Despite the marked cephalometric separation of the groups, no statistically significant difference was found in any of the panoramic measurements: molar inclination angle (Group V: $19.43 \pm 7.11^\circ$; Group N: $20.75 \pm 7.39^\circ$; Group H: $19.36 \pm 6.65^\circ$; $p=0.584$; $\eta^2=0.008$), MM1–ramus

distance (Group V: 10.69 ± 1.95 mm; Group N: 11.04 ± 2.25 mm; Group H: 11.53 ± 2.84 mm; $p=0.260$; $\eta^2=0.021$), second molar mesiodistal width ($p=0.274$; $\eta^2=0.020$), ramus distance/mesiodistal width ratio (Group V: 0.95 ± 0.14 ; Group N: 0.96 ± 0.17 ; Group H: 1.00 ± 0.22 ; $p=0.390$; $\eta^2=0.015$), and eruption depth ($p=0.976$; $\eta^2=0.000$). All effect sizes remained negligible ($\eta^2=0.000$ – 0.021), supporting the interpretation that the failure to reach significance arose from a true similarity rather than merely from insufficient statistical power. Because no significant difference was found in any of the group comparisons, classical post hoc analysis was not applied; instead, effect sizes were reported and trends were evaluated. Numerically, individuals with a horizontal growth pattern (Group H) tended to show slightly higher MM1–ramus distance and ramus distance/mesiodistal width ratio values than the other two groups, but this trend did not reach statistical significance.

Table 3. Comparison of the groups by panoramic measurements.

Variable	Group V Mean $\pm$ SD (95% CI)	Group N Mean $\pm$ SD (95% CI)	Group H Mean $\pm$ SD (95% CI)	p	η^2
Molar inclination angle (°)	19.43 ± 7.11 (17.27–21.59)	20.75 ± 7.39 (18.50–23.00)	19.36 ± 6.65 (17.34–21.38)	0.584	0.008
MM1–ramus distance (mm)	10.69 ± 1.95 (10.10–11.28)	11.04 ± 2.25 (10.36–11.72)	11.53 ± 2.84 (10.67–12.39)	0.260	0.021
MM2 mesiodistal width (mm)	11.21 ± 1.04 (10.89–11.53)	11.52 ± 0.99 (11.22–11.82)	11.48 ± 0.90 (11.21–11.75)	0.274	0.020
Ramus distance/MM2 MD ratio	0.95 ± 0.14 (0.91–0.99)	0.96 ± 0.17 (0.91–1.01)	1.00 ± 0.22 (0.93–1.07)	0.390	0.015
Eruption depth (mm)	4.36 ± 2.19 (3.69–5.03)	4.47 ± 2.39 (3.74–5.20)	4.41 ± 2.44 (3.67–5.15)	0.976	0.000

Values are mean $\pm$ SD (95% confidence interval). One-way ANOVA; * $p < 0.05$. η^2 , eta-squared effect size. MM1, mandibular first molar; MM2, mandibular second molar; MD, mesiodistal.

Association of Posterior Eruption Space with Mandibular Size

Associations between the panoramic measurements and the cephalometric variables were assessed separately within each of the three growth pattern groups by Pearson correlation analysis, and the findings are summarized comparatively in Table 4. Before adjustment for multiple testing, a consistent pattern was observed in all three groups: the MM1–ramus distance and the second molar mesiodistal width showed positive, weak-to-moderate to moderate-to-strong, statistically significant correlations with mandibular corpus length, effective mandibular length, and ramus height ($r=0.33\text{--}0.64$; $p<0.05$). This relationship was strongest in Group N (e.g., $r=0.637$ between MM2 mesiodistal width and effective mandibular length; $p<0.001$), with similar and significant correlations in the same direction in Groups V and H.

In contrast, the gonial angle, Y-axis angle, and posterior/anterior facial height ratio showed no statistically significant association with any of the panoramic measurements in any group (all $p>0.05$). The ramus distance/mesiodistal width ratio showed only weak associations with the absolute size indicators in Groups N and H, of which only the association with ramus height in Group N remained significant after Benjamini–Hochberg correction ($p(\text{BH}) = 0.036$); eruption depth showed no significant correlation with any cephalometric variable examined. After correction for multiple comparisons, the associations of the MM2 mesiodistal width with mandibular corpus length and with effective mandibular length remained significant in all three groups, whereas the remaining associations were retained in Groups N and H but not in Group V: in Group V, none of the three associations of the MM1–ramus distance ($p(\text{BH}) = 0.070\text{--}0.374$) and not the association of MM2 mesiodistal width with ramus height ($p(\text{BH}) = 0.067$) survived adjustment, although all of these coefficients were positive and in the same direction as in the other two groups. In every group, the associations of molar inclination, eruption depth, and

the vertical/angular cephalometric measures with the panoramic outcomes remained non-significant. Taken together, these findings indicate that, in this cross-sectional sample, the posterior eruption space was associated with the size of the mandible — most consistently in Groups N and H — whereas no association with the vertical growth pattern was identified in any group.

To confirm that these findings were not attributable to residual confounding across the 9–18-year age range, each panoramic outcome was re-examined in a multivariable model adjusting for age and sex (Table 5). Age was a significant covariate for the MM1–ramus distance, the ramus distance/MM2 width ratio, and eruption depth ($p < 0.001$ for each), and sex was not significant for any outcome. Nevertheless, the effect of growth-pattern group remained non-significant for every panoramic outcome after adjustment ($p = 0.322$ – 0.802), with negligible partial eta-squared values ($\eta^2 = 0.003$ – 0.018). The absence of a difference in posterior eruption space among the vertical growth pattern groups was therefore robust to adjustment for age and sex.

Table 4. Correlations between panoramic and cephalometric measurements by group.

		Molar inclination	MM1–ramus distance	MM2 MD width	Ramus dist/MM2 ratio	Eruption depth
Group V						
Ramus height	<i>r</i>	-0.157	0.221	0.370	0.037	-0.161
	<i>p</i>	0.309	0.149	0.013	0.812	0.296
	<i>p(BH)</i>	0.463	0.374	0.067	0.812	0.463
Mandibular corpus length	<i>r</i>	-0.183	0.332	0.484	0.093	-0.094
	<i>p</i>	0.234	0.028	<0.001	0.548	0.544
	<i>p(BH)</i>	0.463	0.083	0.007	0.587	0.587
Effective mandibular length	<i>r</i>	-0.158	0.353	0.502	0.105	-0.108
	<i>p</i>	0.306	0.019	<0.001	0.498	0.485
	<i>p(BH)</i>	0.463	0.070	0.007	0.587	0.587
Group N						
Ramus height	<i>r</i>	0.145	0.565	0.623	0.358	0.015
	<i>p</i>	0.348	<0.001	<0.001	0.017	0.923
	<i>p(BH)</i>	0.435	<0.001	<0.001	0.036	0.923
Mandibular corpus length	<i>r</i>	0.223	0.472	0.584	0.269	0.045

		Molar inclination	MM1–ramus distance	MM2 MD width	Ramus dist/MM2 ratio	Eruption depth
Effective mandibular length	<i>p</i>	0.146	0.001	<0.001	0.077	0.772
	<i>p</i> (BH)	0.199	0.003	<0.001	0.129	0.827
	<i>r</i>	0.234	0.538	0.637	0.319	0.070
	<i>p</i>	0.126	<0.001	<0.001	0.035	0.652
	<i>p</i> (BH)	0.189	<0.001	<0.001	0.065	0.752
Group H						
Ramus height	<i>r</i>	0.090	0.431	0.556	0.296	-0.242
	<i>p</i>	0.561	0.003	<0.001	0.051	0.113
	<i>p</i> (BH)	0.648	0.013	<0.001	0.109	0.170
Mandibular corpus length	<i>r</i>	0.058	0.401	0.525	0.271	-0.161
	<i>p</i>	0.708	0.007	<0.001	0.075	0.296
	<i>p</i> (BH)	0.759	0.017	0.001	0.141	0.371
Effective mandibular length	<i>r</i>	0.041	0.406	0.561	0.263	-0.218
	<i>p</i>	0.792	0.006	<0.001	0.085	0.155
	<i>p</i> (BH)	0.792	0.017	<0.001	0.141	0.212

r, Pearson correlation coefficient; *p*, unadjusted *p* value; *p*(BH), Benjamini–Hochberg false-discovery-rate-adjusted *p* value (within-group family of 15 tests). Values in bold are statistically significant after adjustment (*p*(BH) < 0.05). MM1, mandibular first molar; MM2, mandibular second molar; MD, mesiodistal.

Table 5. Multivariable analysis (ANCOVA) of the panoramic outcomes adjusted for age and sex.

Panoramic outcome	Group V Adj. mean (95% CI)	Group N Adj. mean (95% CI)	Group H Adj. mean (95% CI)	<i>p</i>	η^2	<i>p</i> (age)
Molar inclination angle (°)	19.35 (16.91–21.78)	20.79 (18.35–23.22)	19.41 (16.97–21.85)	0.560	0.009	0.434
MM1–ramus distance (mm)	10.78 (10.01–11.55)	11.06 (10.29–11.83)	11.41 (10.64–12.18)	0.420	0.014	<0.001
MM2 mesiodistal width (mm)	11.22 (10.89–11.56)	11.51 (11.17–11.85)	11.47 (11.14–11.81)	0.322	0.018	0.391
Ramus distance/MM2 MD ratio	0.96 (0.90–1.02)	0.96 (0.90–1.02)	0.99 (0.93–1.05)	0.610	0.008	<0.001
Eruption depth (mm)	4.28 (3.53–5.02)	4.39 (3.64–5.14)	4.58 (3.83–5.33)	0.802	0.003	<0.001

Adjusted (estimated marginal) means with 95% confidence intervals, estimated at the mean age of the sample (11.45 years) and averaged over the observed sex distribution. *p*, *p* value for the growth-pattern group effect; η^2 , partial eta-squared for the group effect; *p* (age), *p* value for the age covariate. Sex was not a significant covariate for any outcome (*p* > 0.05). The group effect remained non-significant for every outcome after adjustment.

The categorical panoramic findings are presented in Table 6. The distribution of eruption status at the time of imaging did not differ significantly among the growth-pattern groups (*p* =

0.163), and this remained the case after adjustment for age and sex in a logistic regression (likelihood-ratio $p = 0.366$); age was the dominant predictor of whether the second molar had emerged (odds ratio 1.70 per year of age; $p < 0.001$), consistent with emergence being governed principally by developmental timing. Eruption type (Types I–III; $p = 0.104$), the ramus relationship (Levels A–C; $p = 0.419$), and the distribution of the analysed side ($p = 0.745$) likewise did not differ among the groups. Thus, neither the metric eruption-space measurements nor the categorical eruption-related findings distinguished the three vertical growth pattern groups.

Table 6. Categorical panoramic findings and analysed side by growth-pattern group.

Variable	Group V	Group N	Group H	p
Eruption status at imaging				0.163
Erupted	8 (18.2)	6 (13.6)	13 (29.5)	
Not yet erupted	36 (81.8)	38 (86.4)	31 (70.5)	
Eruption type (depth, Types I–III)				0.104
Type I	6 (13.6)	6 (13.6)	11 (25.0)	
Type II	33 (75.0)	25 (56.8)	26 (59.1)	
Type III	5 (11.4)	13 (29.5)	7 (15.9)	
Ramus relationship (Levels A–C)				0.419
Level A	2 (4.5)	1 (2.3)	5 (11.4)	
Level B	27 (61.4)	25 (56.8)	25 (56.8)	
Level C	15 (34.1)	18 (40.9)	14 (31.8)	
Analysed side				0.745
Right	30 (68.2)	27 (61.4)	27 (61.4)	
Left	14 (31.8)	17 (38.6)	17 (38.6)	

Values are n (%) within each group (n = 44 per group). p values from the chi-square test. "Not yet erupted" denotes a second molar that had not emerged at the time of imaging and does not imply pathological impaction. Types I–III denote the depth of the second molar relative to the crown of the adjacent first molar, and Levels A–C the relationship of its distal surface to the anterior border of the ramus, both as defined in the Materials and Methods. In a logistic regression additionally adjusting for age and sex, the growth-pattern group effect on eruption status remained non-significant (likelihood-ratio $p = 0.366$), whereas age was a strong predictor (odds ratio 1.70 per year; $p < 0.001$).

Discussion

In this study, the available posterior eruption space and molar angulation for the developing mandibular second molar were investigated using lateral cephalometric and panoramic radiographs in individuals with different vertical growth patterns. No significant difference was

found among the vertical, normal, and horizontal growth pattern groups in posterior eruption space or molar angulation; in contrast, the posterior eruption space was found to be related to mandibular size measures rather than to the vertical growth pattern.

In the literature, the role of the vertical growth pattern as a skeletal component in the etiology of second molar eruption disturbance has long been debated; however, this relationship has mostly been examined through whether the tooth erupts or how it is positioned, rather than by directly measuring the eruption space left anterior to the ramus for the second molar.[22, 30] The present study is one of the limited number of studies that directly measure this space and compare it across different vertical growth patterns. The absence of a significant difference among the groups in the panoramic measurements, and the clinically negligible magnitude of the observed differences ($\eta^2=0.000-0.021$), demonstrate that the posterior eruption space is similar across different vertical growth patterns. This absence of an association between the vertical growth pattern and the posterior eruption space is, in our view, the principal contribution of the study: a relationship that has long been assumed and debated in the orthodontic literature was not supported when the eruption space was measured directly, which helps to clarify a long-standing question. The contrast is illustrated in Figure 2: growth-pattern group accounted for a substantial proportion of the variance in the cephalometric facial-form variables (η^2 up to 0.671) but for a negligible proportion in every panoramic eruption-space measure ($\eta^2 = 0.000-0.021$), and this dissociation persisted after adjustment for age and sex (Table 5). It should be emphasized, however, that this is a cross-sectional, correlational study of individuals whose second molars were expected to erupt without complications; it did not compare erupted with impacted teeth, and the associations reported therefore describe covariation rather than a causal or predictive relationship.

The relationship between the direction of mandibular growth and tooth eruption was first investigated for the third molar. Björk reported that eruption of the third molar depends on the distance between the second molar and the ramus, and that as vertical condylar growth increases, the gonial angle decreases, thereby increasing the risk of impaction.[24] This view was subsequently supported by studies relating third molar impaction to different skeletal facial types.[26, 27] However, this relationship was not detected for the second molar in the present study. A possible reason for this is the difference in eruption timing between the second and third molars; because the second molar erupts earlier, the relationship between ramus morphology at the time of evaluation and the vertical growth pattern remains more limited than in the third molar period.[22]

Earlier studies have linked second molar eruption disturbance to skeletal divergence: Vedtofte et al. observed a lower gonial angle and a more frequent skeletal Class II relationship in affected individuals[21], and Algul and Altug similarly reported a reduced ramus–molar distance and an increased impaction rate, particularly in Class II individuals.[22] In contrast, McKeon et al. showed that although the gonial angle was lower in individuals with an impacted second molar, this difference did not reach statistical significance.[30] The findings of the present study are consistent with this latter group; vertical measurements such as the gonial angle and Y-axis showed no significant correlation with any of the panoramic measurements. This inconsistency in the literature may arise not from a complete absence of the relationship but from the effect for the second molar being small and not directly reflected in the available eruption space.

The similarity of the available eruption space for the second molar among the groups should not be interpreted to mean that eruption disturbance occurs with similar frequency in these groups. The eruption process is determined not only by the distance remaining anterior to the

ramus but by the combined effect of multiple factors, such as bone remodeling at the anterior border of the ramus, the direction of eruption, the initial position of the tooth germ, and the resistance of the surrounding tissues.[23]

Indeed, Vedtofte et al. detected ankylosis in some vertically positioned impacted molars and showed that eruption disturbance cannot be explained by space deficiency alone.[21] Therefore, the similar eruption space found in the present study cannot by itself be generalized to mean that eruption disturbance occurs with the same frequency across different vertical growth patterns. In a supplementary analysis of the categorical findings (Table 6), the distribution of eruption status at the time of imaging did not differ among the growth-pattern groups, either crudely ($p = 0.163$) or after adjustment for age and sex (likelihood-ratio $p = 0.366$), and both the eruption type and the ramus relationship were likewise comparable. These findings are concordant with the metric results, but they must be interpreted conservatively: emergence was strongly age-dependent (odds ratio 1.70 per year), the cohort was imaged before the expected eruption of the second molar in most cases, and the final eruption outcome of each tooth was not followed. Establishing whether the frequency of true eruption disturbance differs among vertical growth patterns therefore still requires prospective follow-up to the completion of eruption.

The first molar–ramus distance and the second molar mesiodistal width showed positive correlations with mandibular corpus length, effective mandibular length, and ramus height in all three groups; after correction for multiple testing, the associations of the second molar mesiodistal width with mandibular corpus length and effective mandibular length remained significant in all three groups, whereas significant associations for the first molar–ramus distance were retained in Groups N and H but not in Group V. Overall, this indicates that the available eruption space was associated primarily with the dimensional development of the mandible. The

weaker result in Group V should be interpreted as a difference in statistical support rather than in direction: the coefficients were positive and of comparable magnitude ($r = 0.22\text{--}0.50$), and with 44 individuals per group the false-discovery-rate correction leaves limited power to confirm coefficients of this size. This finding is consistent with the results of Rubin et al. (2012), who reported that maintenance of arch perimeter and gaining space in the retromolar region facilitate second molar eruption.[42]

Clinically, these findings indicate that regarding individuals with a vertical growth pattern as high-risk for second molar eruption solely because of their facial type has no valid basis in terms of the eruption space left anterior to the ramus. Because early diagnosis is important in the management of eruption disturbances, the first molar–ramus distance and its ratio to second molar width—both easily measurable on a panoramic radiograph—were associated with mandibular size in this sample and may therefore warrant further evaluation as size-related indicators during clinical follow-up.[43] However, because the present study did not assess final eruption outcomes, did not compare impacted with normally erupted teeth, and did not evaluate predictive accuracy, these measurements cannot at present be recommended as screening criteria for eruption disturbance; this possibility requires testing in dedicated longitudinal studies. Overall, these observations suggest that second molar eruption risk may be better evaluated together with mandibular size measures than according to vertical facial type alone.

Limitations

Some limitations should be considered when interpreting the results of this study. First, owing to the retrospective and cross-sectional design, changes in the posterior eruption space over time with growth could not be followed; although the power analysis indicated that the sample was sufficient, confirmation of the findings with longitudinal designs would be useful.

[44] Three-dimensional imaging methods such as cone-beam computed tomography (CBCT) were not used; although CBCT provides comprehensive volumetric data, its routine use solely for evaluating eruption space is limited by radiation exposure and ethical considerations. In line with the ALARA principle, panoramic and lateral cephalometric radiographs were considered appropriate for the linear space and angulation measurements that form the focus of this study; moreover, panoramic radiography has been shown to be a reliable tool for evaluating impacted teeth.[30, 45] Because the sample covered the 9–18 year age range, there was variability in the developmental stage of the second molar; subgroup analyses according to root development stage are recommended in the future.[33] Skeletal maturation indicators such as hand–wrist or cervical vertebral maturation radiographs were not available for this retrospective cohort, so chronological age was used as the maturational covariate in the multivariable analysis; although the inclusion criterion of at least two-thirds root formation restricted the sample to a comparatively narrow developmental window, the use of a skeletal maturation index would allow more precise adjustment in future studies. The categorical descriptors used here — the depth grading and the ramus relationship — were adapted from classification systems originally developed for the mandibular third molar; although both have been applied to the second molar, neither has been formally validated for it, and the categorical findings should therefore be regarded as descriptive. Finally, the study was conducted at a single center, so the generalizability of the findings to different populations may be limited.

Conclusion

Within its limitations, this study found no association between the vertical growth pattern and the posterior eruption space available for the developing mandibular second molar; instead, this space was associated with mandibular size. Accordingly, the common clinical assumption that

this space is inherently narrower in hyperdivergent individuals is not supported. In assessing second molar eruption risk, clinicians may therefore find mandibular size measures—readily obtained from routine radiographs—more informative than vertical facial type alone.

Prospective, multicenter studies incorporating eruption status are needed to confirm these findings.

Abbreviations

- **ANS:** Anterior Nasal Spine
- **CBCT:** Cone-Beam Computed Tomography
- **ED:** Eruption Depth
- **FMA:** Frankfort Mandibular Plane Angle
- **ICC:** Intraclass Correlation Coefficient
- **MIA:** Molar Inclination Angle
- **MM1:** Mandibular First Molar
- **MM2:** Mandibular Second Molar
- **OP:** Occlusal Plane
- **RD:** First Molar–Ramus Distance
- **SN/GoGn:** Sella-Nasion/Gonion-Gnathion Angle

Declarations

Ethics approval and consent to participate: This study was approved by the Istanbul Kent University Health Sciences Research Ethics Committee (approval no. 2025-06, dated 06.08.2025; document no. E-10420511-051-47351) and was conducted in accordance with the principles of the Declaration of Helsinki. Owing to the retrospective design of the study, which used pre-existing

anonymized radiographic and clinical records, the requirement for individual informed consent was waived by the same ethics committee.

Consent for publication: Not applicable.

Supplementary Information: Additional file 1. Table S1. Variable-specific intra- and inter-observer reliability coefficients (ICC [2,1]) with 95% confidence intervals for all cephalometric and panoramic variables.

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Figure legends

Figure 1. Study flow diagram (STROBE). Flow of patient records through screening, application of the exclusion criteria, classification by concordant SN/GoGn° and FMA° values, age- and sex-matched random selection, and the final analytical sample of 132 patients (one mandibular second molar per patient).

Figure 2. Growth-pattern group had large effects on cephalometric but negligible effects on panoramic eruption-space variables. Effect sizes (η^2) from one-way ANOVA. Dashed lines indicate Cohen's benchmarks for η^2 (0.01 small, 0.06 medium, 0.14 large). * $p < 0.05$; significant group differences were observed only for cephalometric variables.

Figure 3. Panoramic measurements illustrated on a representative panoramic radiograph. For clarity of presentation the measurements are distributed over the two sides of the same radiograph: the molar inclination angle is shown on the right side of the image, and the occlusal plane, first molar–ramus distance, second molar mesiodistal width and eruption depth on the left side. In the study itself, all measurements were made on a single mandibular second molar per patient, as described in the Materials and Methods. MIA, molar inclination angle — the angle between the long axes of the mandibular first and second molars, each long axis being the line connecting the midpoint of the occlusal surface with the furcation point of that tooth. OP, occlusal plane — the line passing through the buccal cusp tips of the mandibular first premolar and first molar, used as the reference plane. RD, first molar–ramus distance — the horizontal distance from the perpendicular dropped from the distal contour of the first molar to the occlusal plane, to the anterior border of the mandibular ramus. MM2 WIDTH, mesiodistal crown width of the mandibular second molar, measured between its mesial and distal contours. ED, eruption depth — the vertical distance from the marginal tubercle of the second molar to the occlusal plane. The ramus distance/second molar mesiodistal width ratio is derived by dividing RD by MM2 WIDTH and is therefore not marked separately.



