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Dental, Alveolar, and Basal Arch Widths and Maxillary Molar Torque in Skeletal Class III Patients with Different Vertical Facial Patterns: A Cross-Sectional Study

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Abstract

Background: This study compared dental, alveolar, and basal arch widths and maxillary first molar torque among three skeletal Class III groups with different vertical facial patterns and a normal-occlusion control group.

Methods: Seventy-eight patients with skeletal Class III malocclusion were divided

by the mandibular plane angle (MP-FH) into high-angle (n=27), average-angle (n=26), and low-angle (n=25) groups, with 19 individuals with normal occlusion as controls. Dental, alveolar, and basal arch widths and maxillary first molar torque were measured on cephalograms and three-dimensional digital models. Group differences were assessed by one-way analysis of variance (ANOVA) with LSD post hoc tests (Holm correction), with Welch's and non-parametric tests as sensitivity analyses, and analysis of covariance (ANCOVA). ANCOVA adjusted for age and sex, and additionally for ANB in comparisons among the Class III groups; ANB was not included in the four-group comparison because it defined the groups. Correlations were assessed with Pearson correlation (n=78).

Results: Dental and alveolar arch widths were generally greatest in the low-angle group. Maxillary canine and premolar dental arch widths, mandibular intermolar width, and maxillary canine and mandibular premolar alveolar arch widths differed significantly; these differences persisted after adjustment for ANB, age, and sex (all P<0.05). Neither maxillary nor mandibular basal arch width differed significantly across vertical patterns, whereas maxillary basal arch width was narrower than normal occlusion in all three groups (all P<0.001). Maxillary molar torque was greater than normal occlusion in all skeletal Class III groups (P<0.001) but did not differ significantly across vertical patterns. MP-FH correlated negatively with several dental and alveolar arch widths (r=−0.26 to −0.42, all P<0.05); Pearson correlations with basal arch widths were not significant.

Conclusions: In skeletal Class III patients, width differences among vertical patterns occurred mainly at the dental and alveolar levels. Maxillary basal arch width was

narrower than normal occlusion in all three groups, with buccal tipping of the maxillary first molars suggesting dental compensation and limited value of crown-level measurement in assessing transverse relationships. The correlations were exploratory and need further confirmation.

Keywords: skeletal Class III malocclusion; vertical facial pattern; dental arch width; alveolar arch width; basal arch width; molar torque

Background

Class III malocclusion is highly prevalent in Asian populations, with reported prevalence as high as 15.8% in Chinese and Malaysian individuals[1], and is frequently accompanied by vertical and transverse discrepancies. Dental arch width discrepancies directly affect treatment planning and long-term stability, and evidence that vertical facial pattern influences transverse dimensions is accumulating: masseter volume and buccal cancellous bone width are greater in low-angle than in high-angle individuals[2]. Intermolar width tends to be greater in the low-angle than in the high-angle group of skeletal Class III patients[3]; in growing Class III subjects, all transverse widths are already significantly smaller in the high-angle than in the low-angle group at 10 – 14 years of age[4], and this difference persists throughout growth[5]. Such craniofacial abnormalities are present as early as the early mixed dentition[6]; in skeletal Class III malocclusion, the maxillary intermolar and alveolar arch widths are significantly smaller than in normal occlusion[7]; maxillary width is also positively correlated with tongue posture within the skeletal Class I subgroups[8]. However, most previous studies have

addressed only one or two of these levels, and simultaneous measurement and direct comparison of all three arch widths—particularly across vertical facial patterns in skeletal Class III patients—remain limited.

The basal arch is the skeletal boundary that determines dental arch form. Ronay et al. showed that the WALA ridge validly represents the basal arch, with strong correlations between the facial axis (FA) and WALA curves in the canine (r=0.75) and molar (r=0.87) regions[9]. Nevertheless, systematic evidence for width changes across these three levels in different vertical facial patterns remains limited, and the direction and magnitude of basal arch width differences have not been established consistently across studies.

Patients with skeletal Class III malocclusion often compensate for sagittal discrepancies through buccolingual inclination of the posterior teeth, but how this compensation is distributed across vertical facial patterns remains unclear. Hu et al. reported that buccal alveolar bone thickness of the maxillary posterior teeth is significantly thinner in skeletal Class III than in skeletal Class I patients (1.19 – 1.21 mm vs 1.83 mm), increasing the risk of fenestration during decompensation[10]. The present study therefore integrates the three levels into a unified framework to compare their transverse width characteristics and posterior torque compensation patterns in skeletal Class III patients with different vertical facial patterns.

Materials and Methods

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Affiliated Stomatological Hospital of Dalian Medical University (approval no. 2022004). All methods were performed in accordance with the relevant guidelines and regulations, including the Declaration of Helsinki. The skeletal Class III data (lateral cephalograms and three-dimensional digital models) were collected retrospectively, and the normal-occlusion controls were recruited prospectively. Informed consent was obtained from all participants: adult patients provided written informed consent themselves, and for participants under 16 years of age, written informed consent was obtained from their parents, who served as legal guardians. All patient information was anonymized.

Image acquisition

Lateral cephalograms were obtained with a SOREDEX-DPPI unit (Finland) with the patient in the upright position, the Frankfort horizontal plane parallel to the floor, and the teeth in maximum intercuspation.

Participant selection and grouping

Sample selection

Cephalograms and three-dimensional digital models of patients who first attended the Department of Orthodontics between 2019 and 2025 were collected. After excluding records with incomplete data or duplication, 78 patients with skeletal Class III malocclusion were finally enrolled (high-angle, n=27; average-angle, n=26; low-angle,

107 *n*=25). Nineteen individuals with individual normal occlusion (i.e., untreated individuals
108 with only minor occlusal irregularities that do not affect function or esthetics; hereafter
109 referred to as normal-occlusion controls) were recruited from hospital staff, graduate
110 students, and community volunteers during the same period and confirmed by clinical
111 examination by a single orthodontist (≥15 years of clinical orthodontic experience).

112 Inclusion criteria: (1) permanent dentition, age 13–29 years; (2) the skeletal Class III
113 group required both an Angle Class III molar relationship and an ANB (A point–nasion–
114 B point angle) <1.0°, and the normal-occlusion group both an Angle Class I molar
115 relationship and 1.0°≤ANB<4.0° (0°–4° is the range conventionally used to define
116 skeletal Class I in control groups[9], with a normal value of 2°[11]; the upper bound of
117 4.0° excluded any skeletal Class II tendency); (3) the normal-occlusion group
118 additionally required normal overbite and overjet, absence of orthodontic treatment
119 history, and at most minor tooth malpositions that do not affect function or esthetics. The
120 two groups did not overlap in ANB (see the note to Table 3).

121 Exclusion criteria: (1) malformed teeth; (2) history of orthodontic or orthognathic
122 treatment; (3) dental restorations; (4) craniofacial syndromes.

123 Vertical facial pattern classification was based on the criteria of Mastroianni et
124 al.[2]: high-angle group MP-FH>29°; average-angle and normal-occlusion groups 22°
125 ≤MP-FH≤29°; low-angle group MP-FH<22°. Age differed significantly among
126 groups (the normal-occlusion group was slightly older than the skeletal Class III groups,
127 *P*=0.045); this baseline imbalance was corrected by including age as a covariate in the
128 between-group comparisons.

Cephalometric measurements

Cephalometric landmarks were identified with WinCeph 9.0 software; the definitions of the cephalometric angular measurements are shown in Table 1.

Table 1. Definitions of cephalometric angular measurements

Measurement	Abbreviation	Definition
A-point – nasion – B-point angle	ANB	Angle formed by point A (subspinale), nasion, and point B (supramentale), reflecting the sagittal relationship of the maxilla and mandible
Frankfort horizontal (FH) plane	FH	Line connecting the superior-most point of the external auditory meatus (Po) and the lowest point of the infraorbital margin
Mandibular plane angle (MP-FH)	MP-FH	Angle between the mandibular plane (GoGn) and the Frankfort horizontal plane (FH), reflecting the vertical facial pattern

Model measurements

Landmarks and width measurements

Three-dimensional digital models were acquired and measured with the 3Shape Trios 2 scanner and 3Shape OrthoAnalyzer software. Linear measurements obtained from three-dimensional digital models have been shown to be accurate and reproducible[12]. Measurements included dental arch widths (UC-C, UP-P, UM-M, LC-C, LP-P, LM-M), alveolar arch widths (UAC-C, UAP-P, LAC-C, LAP-P), and basal arch widths (UAM-M, LAM-M); the landmarks used for these measurements are illustrated in Figs. 1–3, and abbreviations and full definitions are provided in Table 2. Landmarks and measurement methods followed Ronay et al.[9] and Uysal et al.[13]. All measurements were made on the intraorally scanned digital models of the study participants.

147

148 **Table 2. Dental, alveolar, and basal arch width measurements**

Measurement	Abbreviation	Definition / measurement method
Dental arch width		
Maxillary intercanine dental arch width	UC-C	Distance between the cusp tips of the bilateral maxillary canines
Maxillary interpremolar dental arch width	UP-P	Distance between the buccal cusp tips of the bilateral maxillary first premolars
Maxillary intermolar dental arch width	UM-M	Distance between the mesiolingual cusp tips of the bilateral maxillary first molars
Mandibular intercanine dental arch width	LC-C	Distance between the cusp tips of the bilateral mandibular canines
Mandibular interpremolar dental arch width	LP-P	Distance between the buccal cusp tips of the bilateral mandibular first premolars
Mandibular intermolar dental arch width	LM-M	Distance between the central fossae of the bilateral mandibular first molars
Alveolar arch width		
Maxillary intercanine alveolar arch width	UAC-C	Distance between the two points at the mucogingival junction apical to the bilateral maxillary canine cusp tips
Maxillary interpremolar alveolar arch width	UAP-P	Distance between the two points at the mucogingival junction apical to the contact points between the first and second premolars bilaterally
Mandibular intercanine alveolar arch width	LAC-C	Distance between the projections of the maxillary UAC-C points onto the mandible
Mandibular interpremolar alveolar arch width	LAP-P	Distance between the projections of the maxillary UAP-P points onto the mandible
Basal arch width		
Maxillary intermolar basal arch width	UAM-M	Torque-corrected distance between the FA points of the bilateral maxillary first molars: using the ideal crown inclination of −9° in Andrews' Element III as the reference[14], width decreases by 1 mm per 5° of buccal inclination (relative to −9°) on each side and increases correspondingly with lingual inclination, calculated for both sides and then summed
Mandibular intermolar basal arch width	LAM-M	Distance between the WALA ridge points of the bilateral mandibular first molars (the most prominent point of the soft-tissue ridge immediately coronal to the mucogingival junction, taken directly below the FA point[9])
Torque		
Right maxillary first molar torque	16 torque	Buccolingual inclination of the right maxillary first molar (FDI 16)
Left maxillary first molar torque	26 torque	Buccolingual inclination of the left maxillary first molar (FDI 26)

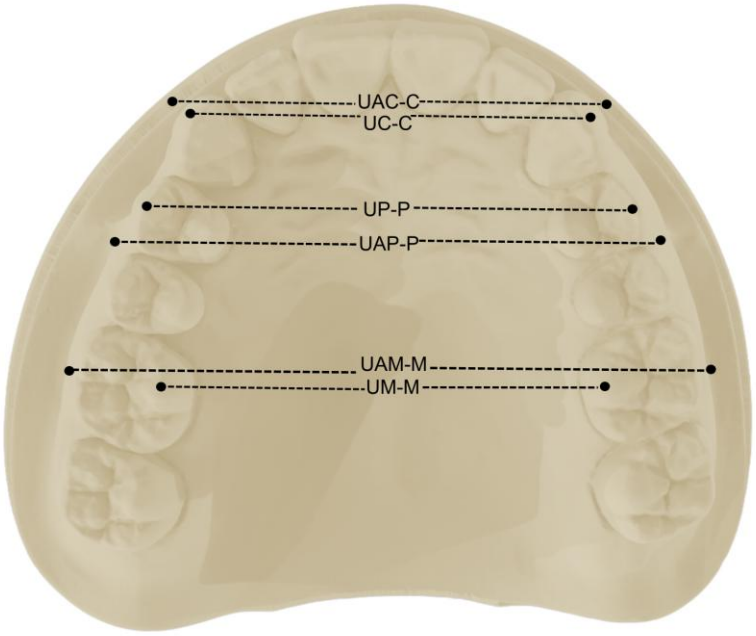
149

150 The maxillary first molar torque (teeth 16 and 26) was measured with 3Shape
151 OrthoAnalyzer software. Torque was defined as the angle between the projection of the
152 facial axis of the clinical crown (FACC) onto the buccolingual plane and a reference line
153 perpendicular to the occlusal plane. This reference line passed through the FA point,
154 which served as the origin. Buccal crown inclination was recorded as positive torque, and

lingual crown inclination as negative torque. Andrews' ideal maxillary first molar crown inclination of −9° [14], a prescription value rather than a measured mean[15] and defined by the FACC[16], was used as the correction reference.

The maxillary intermolar basal arch width (UAM-M) represents an estimated, torque-corrected maxillary intermolar basal arch width, derived indirectly from the measured FA-point distance rather than measured directly on bone. Because dental compensation can mask a skeletal transverse discrepancy, transverse assessment is preferably based on decompensated molar widths[17]; UAM-M was therefore obtained by correcting the measured FA-point distance for torque according to Andrews' Element III rule (each 5° of buccal crown inclination corresponds to a 1 mm change in intermolar width): UAM-M(corrected) = UAM-M(measured) + [(−9°) − T16]×0.2 + [(−9°) − T26]×0.2[14]. Because mandibular first molar torque was not measured, the mandibular basal arch width (LAM-M) used only the WALA ridge measurement without the same correction. Maxillary first molar torque measurement and the torque correction of UAM-M are shown in Fig. 4.

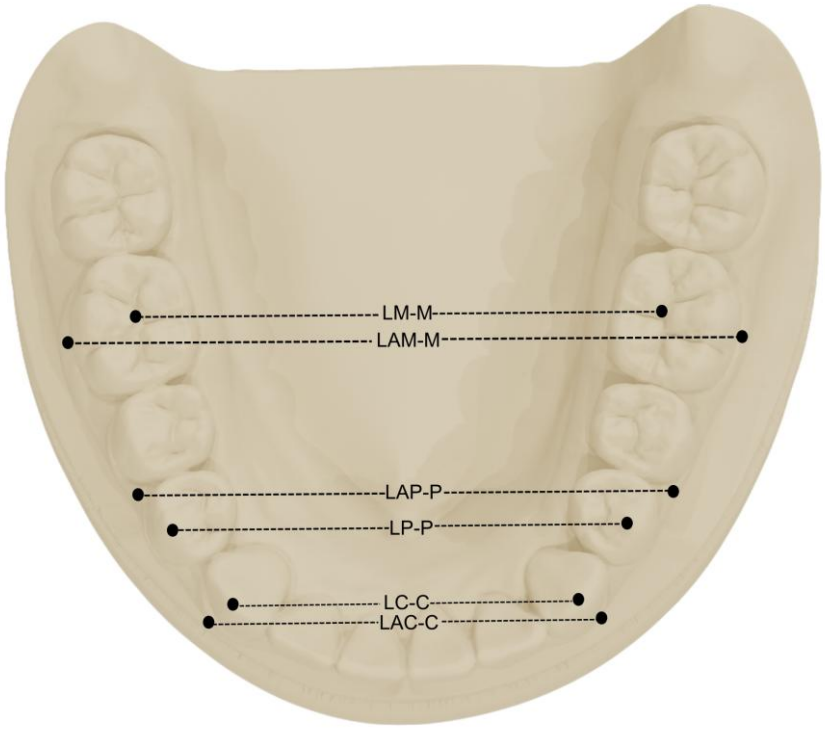
Landmarks: dental arch width used cusp tips, buccal cusps, mesiolingual cusps, and central fossae; alveolar arch width used the mucogingival junction; basal arch width used the maxillary first molar FA point and the mandibular first molar WALA ridge point.



174

175 **Fig. 1** Maxillary occlusal view: landmarks (black dots) and linear measurements
176 used for width assessment at each level.

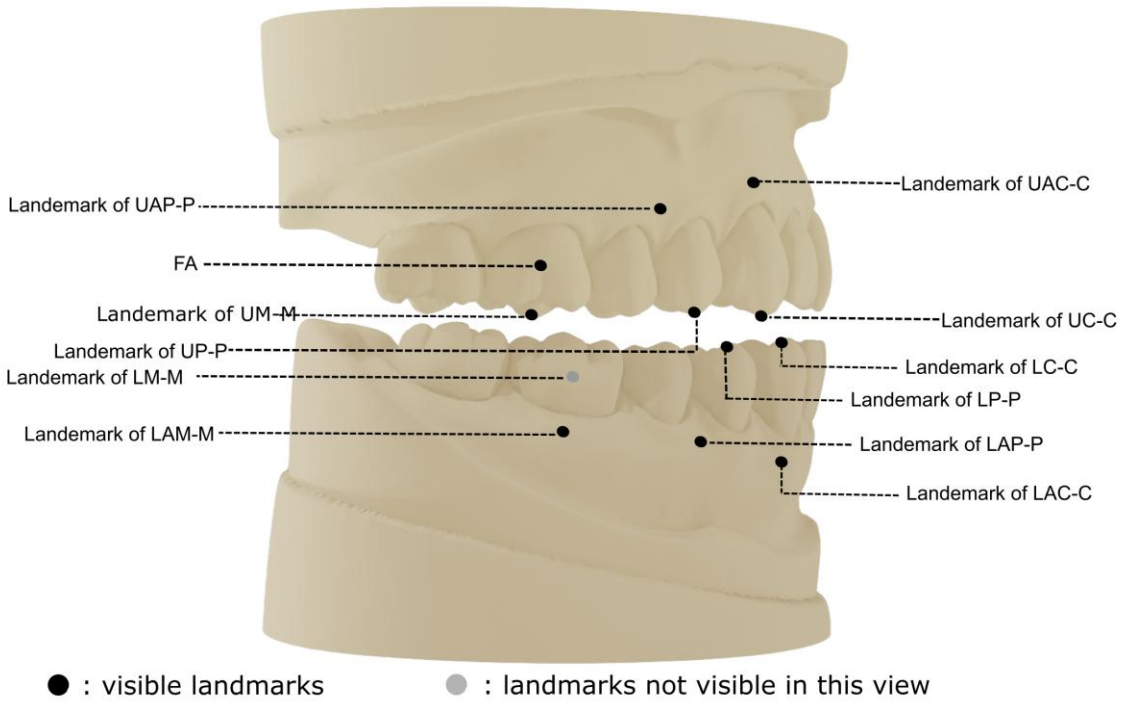
177 The plaster cast shown was used only to illustrate landmark positions and was not
178 measured. Full definitions and abbreviations of all landmarks and measurements are
179 given in Table 2.



180

181 **Fig. 2** Mandibular occlusal view: landmarks (black dots) and linear measurements
182 used for width assessment at each level.

183 The plaster cast shown was used only to illustrate landmark positions and was not
184 measured. Full definitions and abbreviations of all landmarks and measurements are
185 given in Table 2.



186

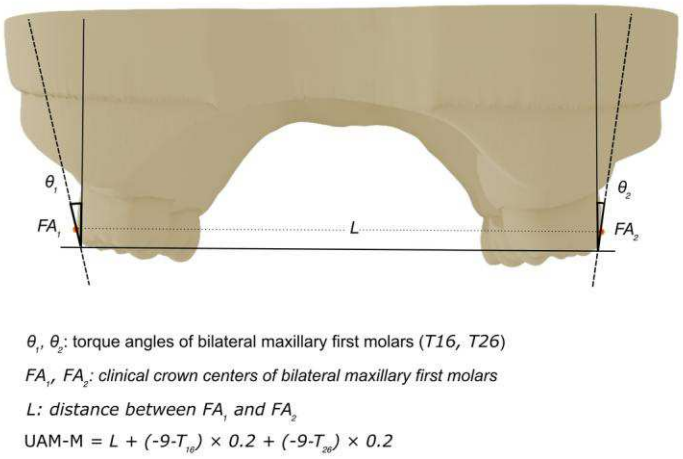
187 **Fig. 3** Buccal view of the right posterior segment: landmarks used for width

188 assessment at each level.

189 The symbol key is given in the figure. The plaster cast shown was used only to

190 illustrate landmark positions and was not measured. Full definitions and abbreviations of

191 all landmarks and measurements are given in Table 2.



192

193 **Fig. 4** Torque correction of the maxillary first molar basal arch width.

194 The symbols and the formula for the torque correction are given in the figure; the
195 definition of torque and the correction of UAM-M are described in Materials and
196 Methods. The plaster cast shown was used only to illustrate the measurement method and
197 was not measured.

198

199 ## Statistical analysis

200 Statistical analysis was performed with SPSS 27.0; two-tailed $P<0.05$ was
201 considered statistically significant, and continuous data are expressed as mean ± standard
202 deviation. Normality was assessed with the Shapiro–Wilk test and homogeneity of
203 variance with the Levene and Brown–Forsythe tests (Additional file 1: Table S1). Because
204 the normality assumption was uncertain, group comparisons were

carried out using three strategies—one-way ANOVA, Welch’s ANOVA and the Kruskal–Wallis test—which gave concordant core conclusions; the primary results are based on one-way ANOVA with LSD post hoc comparisons and Holm correction, the comparisons among the Class III subgroups and those between the subgroups and the control group being treated as separate test families (Additional file 1: Tables S2 and S3). Analyses were performed both at three levels (Class III subgroups) and at four levels (normal-occlusion controls added); baseline imbalance was adjusted by ANCOVA, with ANB, age and sex as covariates at the three-level analysis and age and sex at the four-level analysis, because ANB was the grouping variable. Sex distributions were compared across the four groups using a chi-square test. In the skeletal Class III sample (n=78), correlations between MP-FH and the width variables were assessed with Pearson correlation; because normality was not established for some variables, Spearman’s rank correlation and partial correlations controlling for age were used as sensitivity analyses; these analyses were exploratory and P values were not adjusted for multiplicity. Measurement repeatability was evaluated in a 30-case subsample (low-, average- and high-angle 8 each, normal occlusion 6) using intra- and inter-examiner Dahlberg errors, ICC(1,1) with 95% confidence intervals, and Bland–Altman limits of agreement (Fig. 5; Additional file 1: Table S4). The sensitivity of the basal arch width comparisons to the torque correction is given in Additional file 1: Table S5.

Use of AI-assisted tools. The authors confirm that no generative AI technologies were used in the writing or preparation of this article.

Results

Baseline characteristics of the four groups are presented in Table 3. Measurement reliability was high for all variables (Fig. 5; Additional file 1: Table S4). For the cephalometric measurements, the intra- and inter-examiner Dahlberg errors were 0.25° /0.28° for ANB and 0.29° /0.30° for MP-FH, with ICC(1,1) of 0.981 – 0.998. Among the 14 model-derived variables, the Dahlberg error was 0.17 – 0.29 for intra-examiner and 0.30 – 0.42 for inter-examiner measurements (ICC(1,1) 0.971 – 0.999 and 0.927 – 0.998, respectively). The 95% limits of agreement were narrower for intra- than for inter-examiner measurements for all 16 variables, and the paired t tests detected no clinically meaningful systematic error (2 of the 34 comparisons reached $P<0.05$, close to the 1.7 expected by chance, and all mean differences were smaller than the corresponding random measurement errors; Additional file 1: Table S4).

Table 3 Baseline characteristics of the high-angle, average-angle, low-angle skeletal Class III groups and the normal-occlusion group

Variable	Normal occlusion	High-angle	Average-angle	Low-angle	F/χ^2	P
Sex (male/female)	9/10	14/13	13/13	15/10	**χ^2=0.834**	**0.841**
Age (years)	19.42±1.43	17.41±2.72	17.04±3.32	18.56±3.99	**2.789**	**0.045***
ANB (°)	2.77±0.40	-0.75±1.22	-0.56±1.08	-1.30±1.40	**54.900**	**<0.001***
MP-FH (°)	25.95±1.48	34.72±3.15	26.27±2.17	17.51±2.56	**208.267**	**<0.001***

Note: *$P<0.05$. The ANB values of the skeletal Class III and normal-occlusion groups did not overlap (skeletal Class III ≤0.9°, normal occlusion 1.98° – 3.29°). Sex is expressed as male/female frequency; the sex distribution did not differ significantly across the four groups (χ^2=0.834, P=0.841).

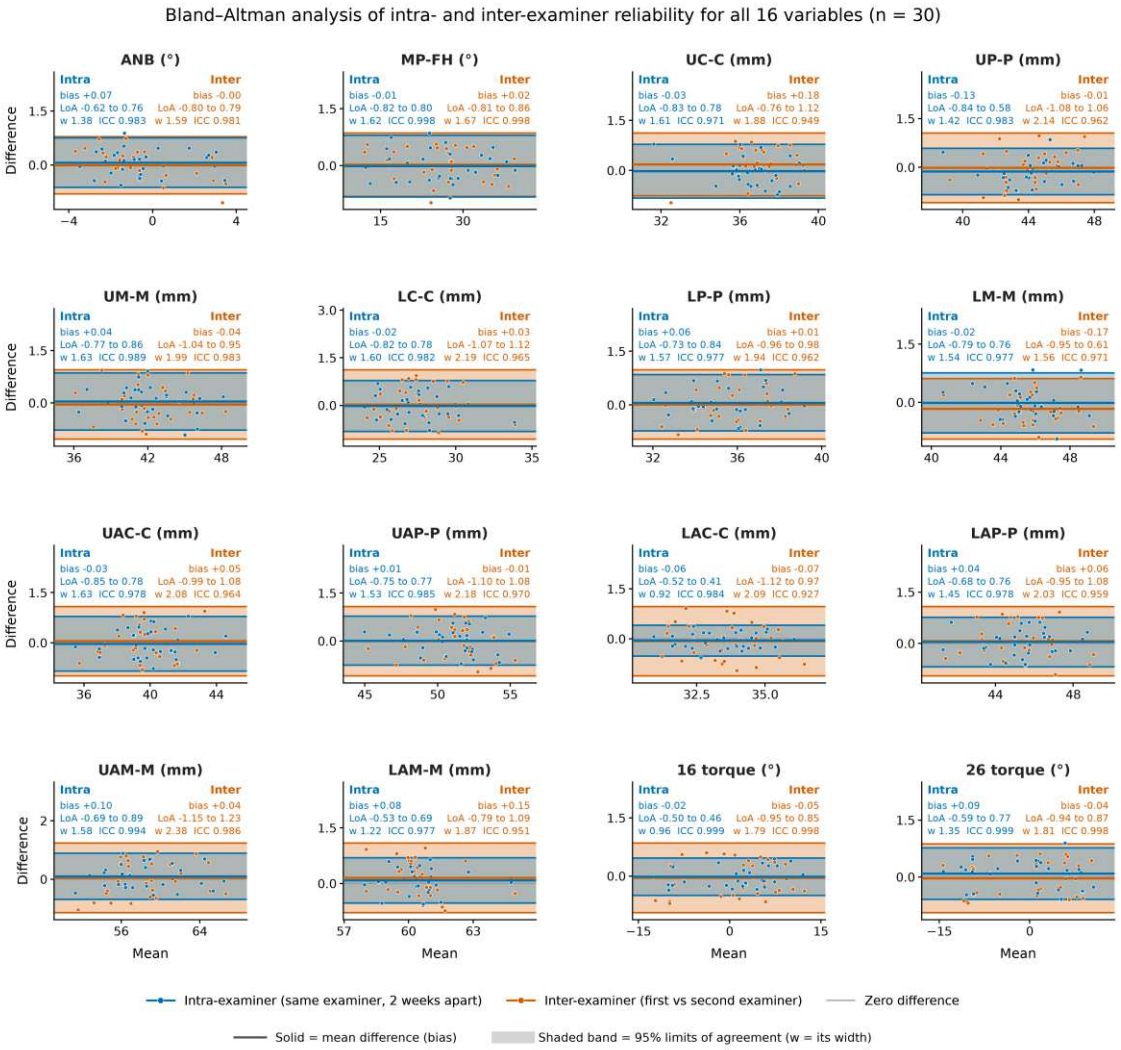


Fig. 5 Bland–Altman analysis of intra- and inter-examiner reliability for all 16 variables.

All values are given in Additional file 1: Table S4.

Dental arch widths in different vertical facial patterns of skeletal Class III

Among the three skeletal Class III groups, UC-C, UP-P, and LM-M dental arch

widths differed significantly, all being greatest in the low-angle group; UM-M, LC-C, and LP-P showed no significant differences (Table 4). Within the three groups, the differences in UC-C and UP-P were between the low-angle group and the other two groups, with no difference between the high- and average-angle groups; the difference in LM-M was between the high- and low-angle groups (letter markers in Table 4).

Compared with normal occlusion, UC-C and UP-P were significantly reduced only in the high-angle group, with no significant differences in the average- and low-angle groups; LM-M was significantly increased only in the low-angle group; UM-M, LC-C, and LP-P did not differ significantly from normal occlusion in any group (Table 4; Fig. 6a).

Table 4 Dental arch widths at different sites in the high-angle, average-angle, low-angle, and normal-occlusion groups (mm)

Group	UC-C	UP-P	UM-M	LC-C	LP-P	LM-M
Normal occlusion	37.10±1.06	45.04±2.00	42.65±2.52	27.82±3.04	35.83±2.26	44.49±1.98
High-angle	35.94±1.65^{b}	43.37±1.40^{b}	42.27±2.55	27.20±1.34	35.28±1.78	44.76±1.44^{b}
Average-angle	36.20±1.80^{b}	43.82±1.77^{b}	42.62±2.84	27.03±1.50	35.38±1.64	45.39±2.23^{ab}
Low-angle	37.49±1.08^{a}	45.44±1.97^{a}	43.00±2.23	28.09±2.32	35.36±2.19	46.40±1.20^{a}
F (three groups)	7.36	10.23	0.53	2.64	0.02	6.26
P (three groups)	0.001*	<0.001*	0.591	0.078	0.979	0.003*
F (four groups)	6.26	7.56	0.36	1.45	0.34	5.57
P (four groups)	<0.001*	<0.001*	0.785	0.233	0.799	0.001*

Note: Values are mean ± SD. a, b: pairwise comparisons within the three Class III groups (different letters, $P<0.05$). $F(3)/P(3)$: one-way ANOVA among the three groups; $F(4)/P(4)$: four-group test including controls; pairwise comparisons of each Class III group with the normal-occlusion group are given in Additional file 1: Table S6. *$P<0.05$.

Alveolar arch widths in different vertical facial patterns of skeletal Class III

Among the three skeletal Class III groups, UAC-C, LAC-C, and LAP-P differed significantly, all being greatest in the low-angle group; UAP-P showed no significant difference (Table 5). Within the three groups, the differences in UAC-C were between the low-angle group and the average- and high-angle groups; the difference in LAC-C was between the low- and high-angle groups; the differences in LAP-P were between the low-angle group and the average- and high-angle groups (letter markers in Table 5). LAC-C showed partially inconsistent results across levels: it did not reach statistical significance at the four-group level, but remained significant at the three-group level and after covariance correction (see “Basal arch widths in different vertical facial patterns of skeletal Class III”).

Compared with normal occlusion, UAC-C was significantly reduced in the high- and average-angle groups, UAP-P was significantly reduced in the high-angle group, and LAP-P was significantly increased in the low-angle group; LAC-C showed no significant difference in any group (Table 5; Fig. 6a). The four-group overall tests of UAP-P and LAC-C reached statistical significance under the Kruskal-Wallis test, inconsistent with the ANOVA results. The difference in UAP-P between the high-angle group and normal occlusion (LSD P=0.048) and the increase in LAP-P in the low-angle group (LSD P=0.040) were borderline, and Welch’s test and the non-parametric test did not yield concordant conclusions (Additional file 1: Table S3), so these results should be interpreted with caution (see “Sensitivity analysis and consistency of conclusions”).

Table 5 Alveolar arch widths in the high-angle, average-angle, low-angle, and normal-occlusion groups (mm)

Group	UAC-C	UAP-P	LAC-C	LAP-P
Normal occlusion	41.10±2.28	52.07±2.45	33.26±1.93	44.71±2.04
High-angle	38.59±1.35[b]	50.37±3.09	32.39±1.57[b]	44.61±1.67[b]
Average-angle	39.34±1.94[b]	50.70±2.22	32.99±1.30[ab]	44.92±1.97[b]
Low-angle	40.49±0.98[a]	51.41±0.84	33.52±1.51[a]	46.03±1.08[a]
F (three groups)	10.78	1.39	3.86	5.37
P (three groups)	<0.001*	0.255	0.025*	0.007*
F (four groups)	10.69	2.40	2.45	3.58
P (four groups)	<0.001*	0.073	0.068	0.017*

Note: Values are mean ± SD. a, b: pairwise comparisons within the three Class III groups (different letters, $P<0.05$). $F(3)/P(3)$: one-way ANOVA among the three groups; $F(4)/P(4)$: four-group test including controls; pairwise comparisons of each Class III group with the normal-occlusion group are given in Additional file 1: Table S6. *$P<0.05$.

Basal arch widths in different vertical facial patterns of skeletal Class III

Among the three skeletal Class III groups, the 16 and 26 torque and UAM-M and LAM-M showed no significant differences (Table 6), indicating that the 16/26 torque and basal arch widths did not differ across vertical facial patterns. The four-group overall test showed significant differences in the 16/26 torque and UAM-M, all originating from differences between the skeletal Class III groups and normal occlusion (Additional file 1: Table S6, all $P<0.05$).

Compared with normal occlusion, the 16 and 26 torque was significantly increased in all three skeletal Class III groups; torque-corrected UAM-M was significantly narrower than normal occlusion in all three groups, consistent with Welch's test and non-parametric tests (Additional file 1: Tables S2 and S3); LAM-M showed no

significant difference in any group (Table 6; Fig. 6b, c).

Table 6 Basal arch widths and torque in the high-angle, average-angle, low-angle, and normal-occlusion groups (mm; °)

Group	16 torque (°)	26 torque (°)	UAM-M	LAM-M
Normal occlusion	-10.31±1.45	-10.15±1.33	64.29±2.19	59.91±0.91
High-angle	3.57±5.04	3.25±6.48	56.72±3.13	60.19±0.91
Average-angle	3.23±6.42	3.04±6.43	56.78±3.00	60.70±2.01
Low-angle	1.95±5.60	1.25±6.10	58.11±1.85	60.31±1.38
F (three groups)	0.58	0.77	2.09	0.82
P (three groups)	0.565	0.467	0.130	0.443
F (four groups)	33.97	25.61	38.28	1.23
P (four groups)	<0.001*	<0.001*	<0.001*	0.304

Note: Values are mean ± SD. a, b: pairwise comparisons within the three Class III groups (different letters, $P<0.05$). $F(3)/P(3)$: one-way ANOVA among the three groups; $F(4)/P(4)$: four-group test including controls; pairwise comparisons of each Class III group with the normal-occlusion group are given in Additional file 1: Table S6. *$P<0.05$.

UAM-M is the result after torque correction of the measured FA-point distance according to Andrews' Element III rule[14]; when the uncorrected values were analyzed, the differences between the three skeletal Class III groups and normal occlusion remained statistically significant under all three methods and were consistent in direction, and the main conclusions were unchanged by the correction (Additional file 1: Table S5). Mandibular first molar torque was not measured, and LAM-M reports only the WALA ridge measurement without the same correction.

ANCOVA with ANB, age and sex as covariates confirmed that, after correction for sagittal skeletal pattern, age and sex, the between-group differences in UC-C, UP-P, UAC-C, LAC-C, LAP-P, and LM-M remained statistically significant (F=3.35–9.19, P=0.0003–0.041), with directions consistent with the uncorrected results; the F and P values for each variable are given in Additional file 1: Table S7.

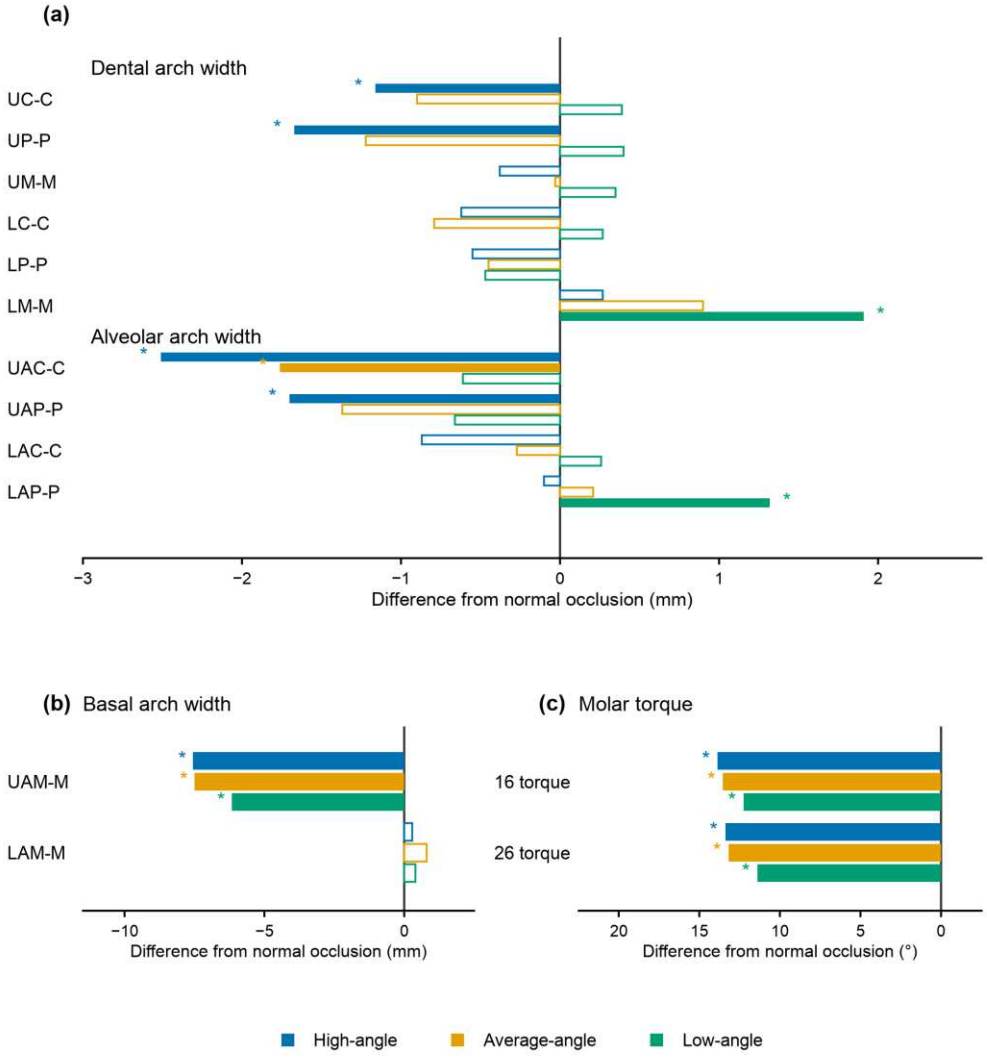


Fig. 6 Arch width and molar torque differences from normal occlusion in skeletal Class III.

Each bar is the difference between the mean of one skeletal Class III group and the mean of the individual normal-occlusion group; * denotes a statistically significant difference from normal occlusion (Holm-adjusted $P<0.05$). (a) Dental and alveolar arch widths; (b) basal arch widths; (c) maxillary molar torque. Exact *P* values are given in Additional file 1: Table S6.

Correlations of mandibular plane angle with dental, alveolar, and basal arch widths in skeletal Class III

In the skeletal Class III sample (n=78), MP-FH was negatively correlated with UP-P, LC-C, LM-M, UAC-C, LAC-C, and LAP-P (r=−0.261 to −0.419, all P<0.05), whereas UC-C and the remaining measures, including the basal arch widths UAM-M and LAM-M, showed no significant correlation (Table 7). UC-C was the only measure whose significance was method-dependent (Pearson r=−0.194, P=0.089; Spearman ρ =−0.256, P=0.024) and was therefore regarded as inconclusive; the remaining conclusions were unchanged under Spearman's rank correlation. In partial correlation analyses controlling for age, all coefficients changed by no more than 0.02; UAM-M moved marginally across the 0.05 threshold (r=−0.219, P=0.054; age-adjusted r=−0.224, P=0.049) and is therefore reported as a weak trend rather than a confirmed association.

Table 7 Correlations of mandibular plane angle with dental, alveolar, and basal arch widths in skeletal Class III (n=78)

Measurement	MP-FH	
	r	*P*
UC-C	-0.194	0.089
UP-P	-0.261	**0.021***
UM-M	-0.067	0.560
LC-C	-0.361	**0.001***
LP-P	-0.002	0.986
LM-M	-0.277	**0.014***
UAC-C	-0.419	**<0.001***
UAP-P	-0.031	0.785
LAC-C	-0.417	**<0.001***
LAP-P	-0.303	**0.007***
UAM-M	-0.219	0.054
LAM-M	-0.070	0.545

Note: *P<0.05. Values are Pearson correlation coefficients (r) and P values; the skeletal Class III sample (n=78) was the primary analysis, and Spearman's rank correlation and partial correlations controlling for age are given in Additional file 1: Table S7.

Sensitivity analysis and consistency of conclusions

All measures were re-examined with Welch’ s test and non-parametric tests (Additional file 1: Tables S2 and S3); the main conclusions were fully consistent across the three methods, with no directional reversals. Inconsistencies were confined to the four-group overall tests of UAP-P and LAC-C and to 5 of the 90 pairwise comparisons, all involving the normal-occlusion group, with *P* values spanning 0.040 – 0.351 (LSD) and 0.007 – 0.273 (Welch and Mann – Whitney), indicating that these borderline comparisons were sensitive to the method used (Additional file 1: Table S3). Conclusions were therefore based on the one-way ANOVA results, and borderline findings were interpreted with caution clinically.

Discussion

This study focused on transverse width differences at the dental, alveolar, and basal arch levels and the posterior torque compensation pattern across different vertical facial patterns in skeletal Class III malocclusion. The main findings are as follows.

1. Dental and alveolar arch widths in relation to vertical facial pattern

The present study showed that the maxillary canine and premolar dental arch widths, the mandibular intermolar width, and the maxillary canine and mandibular

premolar alveolar arch widths were all greatest in the low-angle group. This suggests that the sites sensitive to vertical facial pattern are not limited to the molar region. The vertical-pattern difference in mandibular intermolar width is consistent in direction with the greater low-angle width reported by Chen et al.[4] and Yildirim et al.[3]; on this basis, the present study further distinguished the dental and alveolar arch levels. Hwang et al.[18] also observed a greater maxillary alveolar process width in the low-angle group in skeletal Class I adults, with no difference in intermolar width or molar inclination among the three groups, consistent with the present study in direction; however, that study involved skeletal Class I patients, and population differences should be considered in comparison. The anatomical basis of these differences may lie in the wider buccal cancellous bone at the canine region and stronger masseter function in low-angle individuals[2, 18], with these differences persisting during growth[5].

2. Basal arch width and posterior compensation pattern

The absence of any statistically significant difference in basal arch width across vertical facial patterns is one of the core findings of this study, whereas maxillary basal arch width was narrower than normal occlusion in all three vertical-pattern groups, indicating that maxillary basal transverse deficiency is a common feature of skeletal Class III malocclusion rather than a characteristic of a specific vertical subtype. The correlation between the mandibular plane angle and the maxillary basal arch width was consistently negative but hovered at the significance threshold in every analysis; given the limited sample size, it is best regarded as a weak trend.

Maxillary molar torque likewise differed from normal occlusion but not across vertical patterns. Because the buccolingual inclination and the intermolar width of the maxillary first molars may themselves change during natural growth[19], age was included as a covariate; the adjusted between-group differences remained significant (Additional file 1: Table S7), indicating that the influence of vertical facial pattern on transverse width is independent of sagittal discrepancy. These findings suggest that the vertical differences in skeletal Class III dental arch width were manifested mainly at the dental and alveolar arch levels rather than in measurable changes in basal width, and that posterior buccal-inclination compensation is a common feature of skeletal Class III malocclusion. Relative to the literature, Koo et al.[20] and Liu et al.[21] support the view that crown-level arch measurements may mask skeletal transverse discrepancy and that maxillary basal deficiency already exists in early-mixed-dentition Class III; our results are not entirely consistent with those of Abdulghani et al.[22], possibly because of differences in measurement sites, sagittal classification criteria and sample composition; they agree with the conclusion of Eraydin et al.[23] that molar inclination does not differ across vertical facial patterns; and they are not contradictory to Ahn et al.[24], who used the overall geometric principal component of palatal morphology rather than the inter-FA-point distance as the outcome, representing a different anatomical level. The driving factors of dental compensation may also involve tongue posture[25, 26], compensation in the canine region and its correlation with ANB[27], posterior tooth inclination and sagittal discrepancy[28], and the relationship between transverse dental compensation and skeletal

discrepancy[29]; these variables were not directly measured in this study and await further verification.

3. Clinical implications

Hu et al.[10] reported thinner buccal alveolar bone of the maxillary posterior teeth in Class III than in Class I subjects, and Sendyk et al.[30] reported thinner alveolar bone at cervical levels in Class III, with correlations between buccolingual inclination and bone thickness found mainly in the mandibular teeth. In the present study, maxillary molar torque was significantly greater than normal occlusion in all three skeletal Class III groups, indicating posterior buccal-inclination compensation. Before decompensation treatment in skeletal Class III patients, therefore, and especially in those already showing posterior compensatory buccal inclination, cone-beam computed tomography (CBCT) evaluation of the buccal alveolar bone thickness of the maxillary posterior teeth may be considered to aid individualized risk assessment.

4. Limitations

This study has several limitations. As a cross-sectional observational study, it describes between-group associations only, and the direction of causality remains to be clarified by longitudinal studies; the sample size was relatively limited, so the statistical power of some subgroup comparisons was constrained. The study focused on the torque characteristics of the maxillary first molar, and the overall picture of buccolingual inclination across the entire dentition awaits supplementation by more

comprehensive measurements. The vertical facial pattern composition of the normal-occlusion control group was relatively homogeneous, so the independent effects of skeletal Class III malocclusion and vertical facial pattern, and their potential interaction, still need to be further distinguished in more specifically designed studies. In addition, the correlation analyses between MP-FH and the width variables were performed only in the skeletal Class III sample, so the stability of these correlations awaits confirmation in larger samples.

Conclusions

Transverse widths differ across vertical facial patterns in skeletal Class III malocclusion: the maxillary canine and premolar dental arch widths, the mandibular intermolar width, and the maxillary canine and mandibular premolar alveolar arch widths are all greatest in the low-angle group, whereas the maxillary anterior width is significantly narrower than normal occlusion in the high-angle group.

No statistically significant differences were detected in maxillary or mandibular basal arch width across vertical facial patterns, whereas maxillary basal arch width is narrower than normal occlusion in all three groups; maxillary molar torque is significantly greater than normal occlusion in all groups but does not differ across vertical patterns. Within the skeletal Class III group, the mandibular plane angle was negatively correlated with the maxillary interpremolar, mandibular intercanine and mandibular intermolar dental arch widths and with the maxillary intercanine, mandibular intercanine and mandibular interpremolar alveolar arch widths (r=−0.26

to −0.42, $P<0.05$), but not consistently with the basal arch widths. These findings suggest that transverse width differences across vertical facial patterns were manifested mainly at the dental and alveolar arch levels rather than in measurable changes in basal width; posterior buccal-inclination compensation is a common feature of skeletal Class III malocclusion, and its distribution may lie mainly in the canine and premolar regions, which awaits direct measurement.

List of abbreviations

ANB: A point – nasion – B point angle; ANCOVA: analysis of covariance; ANOVA: analysis of variance; CBCT: cone-beam computed tomography; CI: confidence interval; FA: facial axis; FACC: facial axis of the clinical crown; FH: Frankfort horizontal plane; ICC: intraclass correlation coefficient; LoA: limits of agreement; LSD: least significant difference; MP-FH: mandibular plane to Frankfort horizontal plane angle; SD: standard deviation; WALA ridge: soft-tissue ridge immediately coronal to the mucogingival junction, taken directly below the FA point (see Table 2).

Dental arch widths: UC-C: maxillary intercanine; UP-P: maxillary interpremolar; UM-M: maxillary intermolar; LC-C: mandibular intercanine; LP-P: mandibular interpremolar; LM-M: mandibular intermolar.

Alveolar arch widths: UAC-C: maxillary intercanine; UAP-P: maxillary

interpremolar; LAC-C: mandibular intercanine; LAP-P: mandibular interpremolar.

Basal arch widths: UAM-M: maxillary intermolar; LAM-M: mandibular intermolar (for measurement definitions see Table 2).

T16 (16 torque), T26 (26 torque): buccolingual inclination (torque) of the right and left maxillary first molars, respectively.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of the Affiliated Stomatological Hospital of Dalian Medical University (approval no. 2022004). All methods were performed in accordance with the relevant guidelines and regulations, including the Declaration of Helsinki. The skeletal Class III data (lateral cephalograms and three-dimensional digital models) were collected retrospectively, and the normal-occlusion controls were recruited prospectively. Informed consent was obtained from all participants: adult patients provided written informed consent themselves, and for participants under 16 years of age, written informed consent was obtained from their parents, who served as legal guardians. All patient information was anonymized.

Consent for publication

Not applicable

Availability of data and materials

The datasets supporting the conclusions of this article are included within the article and its additional files.

Competing interests

The authors declare no competing interests.

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Authors' contributions

Yiwen Zhang, Xingyu Guo and Xiyi Shao contributed equally to this work. Yiwen Zhang, Xingyu Guo and Xiyi Shao contributed to Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Visualization, and Writing – original draft. Hani Alnobani contributed to Writing – review & editing, including the translation of the original Chinese draft into English and critical review of the manuscript's clarity, consistency, and reporting. Lin Gui, Qian Yang, Xiaobin Wang and Yun Liu contributed to Investigation, Data curation, and Writing – review & editing. Yun Lu contributed to Resources, Writing – review & editing, Supervision, and Project administration. All authors read and approved the final manuscript.

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Additional files

Additional file 1: Tables S1–S7. Supporting statistical analyses: normality tests (Table S1); sensitivity analyses using Welch's ANOVA and the Kruskal–Wallis test (Tables S2 and S3); intra- and inter-examiner reliability (Table S4); sensitivity of the torque-corrected basal arch width analysis (Table S5); the overall tests and pairwise comparisons for the variables presented in Tables 4–6 (Table S6); and the ANCOVA and partial correlation sensitivity analyses (Table S7). (XLSX 25 KB)

References

[1] Ngan P, Moon W. Evolution of Class III treatment in orthodontics. Am J Orthod Dentofacial Orthop. 2015;148(1):22–36. doi:10.1016/j.ajodo.2015.04.012.

[2] Mastroianni D, Woods MG. 3D-CT assessment of mandibular widths in young subjects with different underlying vertical facial patterns. J World Fed Orthod. 2019;8(2):78–86. doi:10.1016/j.ejwf.2019.02.005.

[3] Yildirim G, Ozturk EA, Acar YB. Influence of vertical facial patterns on dental arch parameters in Class III malocclusions: a cross-sectional study. Turk J Orthod. 2026;39(1):26–34. doi:10.4274/turkjorthod.2026.2025.100.

[4] Chen F, Terada K, Wu L, Saito I. Dental arch widths and mandibular-maxillary base width in Class III malocclusions with low, average and high MP-SN angles. Angle Orthod. 2007;77(1):36–41. doi:10.2319/011006-15r.1.

[5] Wagner DM, Chung CH. Transverse growth of the maxilla and mandible in

539 untreated girls with low, average, and high MP-SN angles: a longitudinal study.
540 Am J Orthod Dentofacial Orthop. 2005;128(6):716–23.
541 doi:10.1016/j.ajodo.2004.09.028.

542 [6] Guyer EC, Ellis EE, McNamara JA, Behrents RG. Components of Class III
543 malocclusion in juveniles and adolescents. Angle Orthod. 1986;56(1):7–30.

544 [7] Kuntz TR, Staley RN, Bigelow HF, Kremenak CR, Kohout FJ, Jakobsen JR. Arch
545 widths in adults with Class I crowded and Class III malocclusions compared with
546 normal occlusions. Angle Orthod. 2008;78(4):597–603. doi:10.2319/0003-
547 3219(2008)078[0597:awiawc]2.0.co;2.

548 [8] Dalaie K, Zeinali H, Behnaz M, Safi Y, Tahmasbi S, Sedighinia M. Correlation of
549 tongue posture with dental arch characteristics in different skeletal patterns using
550 cone-beam computed tomography. J Dent Sch. 2024;42(3):111–9.
551 doi:10.22037/jds.v42i3.45256.

552 [9] Ronay V, Miner RM, Will LA, Arai K. Mandibular arch form: the relationship
553 between dental and basal anatomy. Am J Orthod Dentofacial Orthop.
554 2008;134(3):430–8. doi:10.1016/j.ajodo.2006.10.040.

555 [10] Hu X, Huang X, Gu Y. Assessment of buccal and lingual alveolar bone thickness
556 and buccolingual inclination of maxillary posterior teeth in patients with severe
557 skeletal Class III malocclusion with mandibular asymmetry. Am J Orthod
558 Dentofacial Orthop. 2020;157(4):503–15. doi:10.1016/j.ajodo.2019.04.036.

559 [11] Steiner CC. The use of cephalometrics as an aid to planning and assessing

orthodontic treatment. Am J Orthod. 1960;46(10):721–35. doi:10.1016/0002-9416(60)90145-7.

[12] Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofacial Orthop. 2012;142(2):269–73. doi:10.1016/j.ajodo.2011.12.028.

[13] Uysal T, Usumez S, Memili B, Sari Z. Dental and alveolar arch widths in normal occlusion and Class III malocclusion. Angle Orthod. 2005;75(5):809–13.

[14] Zhang N, Wang T, Yan F, Chen R, Fu X, Ren L. Qualitative and quantitative agreement research on three diagnostic methods for maxillary transverse discrepancy. BMC Oral Health. 2025;25(1):174. doi:10.1186/s12903-025-05495-4.

[15] Lombardo L, Perri A, Arreghini A, Latini M, Siciliani G. Three-dimensional assessment of teeth first-, second- and third-order position in Caucasian and African subjects with ideal occlusion. Prog Orthod. 2015;16:11. doi:10.1186/s40510-015-0086-9.

[16] Andrews LF. The 6-elements orthodontic philosophy: treatment goals, classification, and rules for treating. Am J Orthod Dentofacial Orthop. 2015;148(6):883–7. doi:10.1016/j.ajodo.2015.09.011.

[17] Shen J, Liu Z, Shuai J, Yin Y, Wang Z, Ding W, et al. Transverse dentoalveolar development in Chinese children and adolescents: a cross-sectional study using revised Andrews' Element III analysis. Am J Orthod Dentofacial Orthop.

2025;167(2):144–53. doi:10.1016/j.ajodo.2024.08.015.

[18] Hwang S, Jeong S, Choi YJ, Chung CJ, Lee HS, Kim KH. Three-dimensional evaluation of dentofacial transverse widths of adults with various vertical facial patterns. Am J Orthod Dentofacial Orthop. 2018;153(5):692–700. doi:10.1016/j.ajodo.2017.08.026.

[19] Santana L, Motro M, Bamashmous MS, Kantarci A, Will LA. Buccolingual angulation and intermolar width changes in the maxillary first molars of untreated growing children. Am J Orthod Dentofacial Orthop. 2017;151(5):921–8. doi:10.1016/j.ajodo.2016.10.023.

[20] Koo YJ, Choi SH, Keum BT, Yu HS, Hwang CJ, Melsen B, et al. Maxillomandibular arch width differences at estimated centers of resistance: comparison between normal occlusion and skeletal Class III malocclusion. Korean J Orthod. 2017;47(3):167–75. doi:10.4041/kjod.2017.47.3.167.

[21] Liu F, Huang H, Shi X, Liu Y, Liu D. A study of transverse maxillomandibular discrepancy and dental compensation in early mixed dentition with skeletal Class III malocclusion without posterior crossbite. PLoS One. 2023;18(6):e0287343. doi:10.1371/journal.pone.0287343.

[22] Abdulghani EA, Al-Sosowa AA, Alhashimi N, Cao B, Zheng W, Li Y, et al. Basal and dentoalveolar transverse parameters in different sagittal and vertical malocclusions in adults: a comparative study. Clin Oral Investig. 2024;28(5):276. doi:10.1007/s00784-024-05630-5.

602 [23] Eraydin F, Germeç Çakan D, Tozlu M, Özdemir F. Evaluation of buccolingual
603 molar inclinations among different vertical facial types. Korean J Orthod.
604 2018;48(5):333–8. doi:10.4041/kjod.2018.48.5.333.

605 [24] Ahn MS, Shin SM, Choi YS, Wu TJ, Ko CC, Yamaguchi T, et al. Analysis of the
606 relationship between the morphology of the palate and facial skeletal patterns in
607 Class III malocclusion using structural equation modelling. Orthod Craniofac
608 Res. 2019;22(2):87–92. doi:10.1111/ocr.12283.

609 [25] Balaji M, Ashith MV, Shetty S, Singh A, Kumar HA, Solanki R. Evaluation of
610 the association between tongue posture and the transverse dental compensation
611 in Class III skeletal patients: a retrospective, record-based study. J Clin Exp
612 Dent. 2025;17(8):e958–66. doi:10.4317/jced.62106.

613 [26] Fatima F, Fida M. The assessment of resting tongue posture in different sagittal
614 skeletal patterns. Dental Press J Orthod. 2019;24(3):55–63. doi:10.1590/2177-
615 6709.24.3.055-063.oar.

616 [27] Chen Z, Guo R, Qin Q, Feng J, Zheng Y, Li W. Transverse analysis of maxillary
617 transverse deficiency and sagittal skeletal patterns: a cone-beam computed
618 tomography study. Am J Orthod Dentofacial Orthop. 2025;168(3):317–26.e3.
619 doi:10.1016/j.ajodo.2025.04.001.

620 [28] Hwang S, Song J, Lee J, Choi YJ, Chung CJ, Kim KH. Three-dimensional
621 evaluation of dentofacial transverse widths in adults with different sagittal facial
622 patterns. Am J Orthod Dentofacial Orthop. 2018;154(3):365–74.

623 doi:10.1016/j.ajodo.2017.11.041.

624 [29] Ahn J, Kim SJ, Lee JY, Chung CJ, Kim KH. Transverse dental compensation in
625 relation to sagittal and transverse skeletal discrepancies in skeletal Class III
626 patients. Am J Orthod Dentofacial Orthop. 2017;151(1):148–56.
627 doi:10.1016/j.ajodo.2016.06.031.

628 [30] Sendyk M, de Paiva JB, Abrão J, Rino Neto J. Correlation between buccolingual
629 tooth inclination and alveolar bone thickness in subjects with Class III
630 dentofacial deformities. Am J Orthod Dentofacial Orthop. 2017;152(1):66–79.
631 doi:10.1016/j.ajodo.2016.12.014.

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