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Original Article

Association between occlusal plane cant correction and temporomandibular joint status in children and adolescents with mild skeletal facial asymmetry

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Abstract: Objective: To compare the outcomes of occlusal plane cant correction versus conventional orthodontic treatment on temporomandibular joint (TMJ) status and craniofacial symmetry in children and adolescents with mild skeletal facial asymmetry. Methods: A total of 124 patients were enrolled and allocated into an occlusal plane cant correction group (n=61) and a conventional treatment group (n=63) according to the treatment protocol. Changes in occlusal plane cant, TMJ-related clinical symptoms, imaging parameters, and craniofacial asymmetry indices were evaluated before and after treatment. Results: The correction group achieved a significantly greater reduction in occlusal plane cant. After treatment, the incidences of TMJ clicking, tenderness, and deviation during mouth opening were significantly lower in the correction group. Imaging analyses showed superior condylar adaptive remodeling and improved joint space parameters in the correction group. In addition, craniofacial asymmetry improved more markedly in this group. The extent of occlusal plane correction was significantly associated with improvements in asymmetry indices and TMJ imaging parameters, and served as an independent predictor of TMJ symptom improvement. Conclusion: In children and adolescents with skeletal facial asymmetry, accompanied by occlusal plane cant, active correction of the occlusal plane cant is more effective than conventional orthodontic treatment in improving craniofacial symmetry and enhancing TMJ health.

Keywords: Orthodontic treatment, mild skeletal facial asymmetry, occlusal plane inclination correction, temporomandibular joint, correlation analysis

Introduction

Skeletal facial asymmetry is a common type of malocclusions encountered in clinical practice and is defined as asymmetric growth or spatial positioning of the maxillofacial skeleton in three dimensions [1]. This condition not only results in impaired facial aesthetics and negatively affects patients' psychological well-being [2], but also causes various functional impairments such as occlusal disharmony and reduced masticatory efficiency [3, 4]. Among its associated complications, temporomandibular disorders (TMDs), involving the temporomandibular joint (TMJ), demonstrate a close relationship with skeletal facial asymmetry [5]. Children and adolescents are in a crucial stage of craniofacial growth and development; therefore, early intervention during this stage is essential to guide coordinated jaw development, prevent progressive asymmetry due to functional compensation, and reduce the risk of long-term TMJ pathology [6, 7].

The occlusal plane serves as an operational reference plane connecting the maxillary and mandibular dentitions, and its spatial orientation and inclination directly reflect the relative positional relationship between the upper and lower jaws. Occlusal plane cant is considered a dental reflection of underlying skeletal asymmetry and a major biomechanical factor influ-

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encing mandibular movement patterns, masticatory muscle activity, and condylar positioning within the glenoid fossa in patients with skeletal facial asymmetry [8]. Classical orthodontic theory emphasizes that assessment of the occlusal plane is a core component in the diagnosis of complex malocclusions. Imaging studies have shown that patients with mandibular deviation often show bilateral asymmetry in condylar morphology and position, which indicates a strong interaction between occlusion and TMJ health [9]. Even though occlusal plane cant has been associated with facial asymmetry and TMJ-related symptoms [10], there remains no consensus on whether it should be regarded as a primary treatment target or merely a secondary outcome in orthodontic treatment. More importantly, whether targeted correction of occlusal plane cant can enhance skeletal symmetry and promote adaptive structural remodeling and functional restoration of the TMJ remains to be fully elucidated through well-designed controlled clinical trials.

Conventional orthodontic treatment is effective in aligning dentition and correcting sagittal positions of the molar. Nevertheless, it often provides limited control over vertical and transversal skeletal discrepancies, especially occlusal plane cant. Clinically, a significant proportion of patients undergoing conventional orthodontic treatment still present with residual facial asymmetry or TMJ pain after treatment [11]. This implies that standard therapy may primarily address dental alignment without fully optimizing the overall biomechanical balance of the stomatognathic system, which can partly explain the low therapeutic gains in some patients. Therefore, there is a need to expand treatment strategies to include interventions addressing three-dimensional jaw posture correction.

Based on the above considerations, this study aimed to conduct a controlled comparative analysis of a treatment plan incorporating active occlusal plane cant correction versus traditional orthodontic treatment in children and adolescents with mild skeletal facial asymmetry. Specifically, this study compared the two approaches in terms of reduction in occlusal plane cant, improvement in TMJ clinical symptoms and imaging parameters, and enhancement of craniofacial skeletal symmetry. Our findings are expected to provide high-quality evidence to support clinical diagnosis and treatment decision-making for this demanding type of malocclusion.

Materials and methods

Study design

This retrospective study was reviewed and approved by the Ethics Committee of Kunming Medical University Affiliated Stomatological Hospital (approval number: KYKQ2025MEC0-057). All procedures were conducted following the Declaration of Helsinki [12]. Due to the retrospective nature of this study, the requirement for written informed consent from participants was waived. To safeguard confidentiality and protect personal privacy, all patient-related information was de-identified before any analytical procedures were performed.

Study population

Eligible patients were retrospectively identified through a systematic review of the electronic medical record system and the picture archiving and communication system. Medical records of patients with mild skeletal facial asymmetry who completed comprehensive orthodontic treatment at our institution between January 2023 and January 2025 were screened according to predefined inclusion and exclusion criteria. Follow-up data were collected, with the follow-up period ending in January 2026. Only cases with complete clinical and imaging data at both pre-treatment and follow-up time points were included in the final analysis (**Figure 1**).

Inclusion criteria: (1) age between 8 and 16 years at treatment initiation; (2) diagnosis of mild skeletal facial asymmetry confirmed by cone-beam computed tomography (CBCT), defined as mandibular deviation > 2 mm; (3) presence of a clearly identifiable occlusal plane cant; (4) completion of the full course of orthodontic treatment with complete and well-documented clinical records.

Exclusion criteria: (1) presence of craniofacial syndromes, a history of maxillofacial trauma, previous TMJ surgery, or systemic diseases such as rheumatoid arthritis; (2) prior orthodontic treatment; (3) use of combined orthodontic-

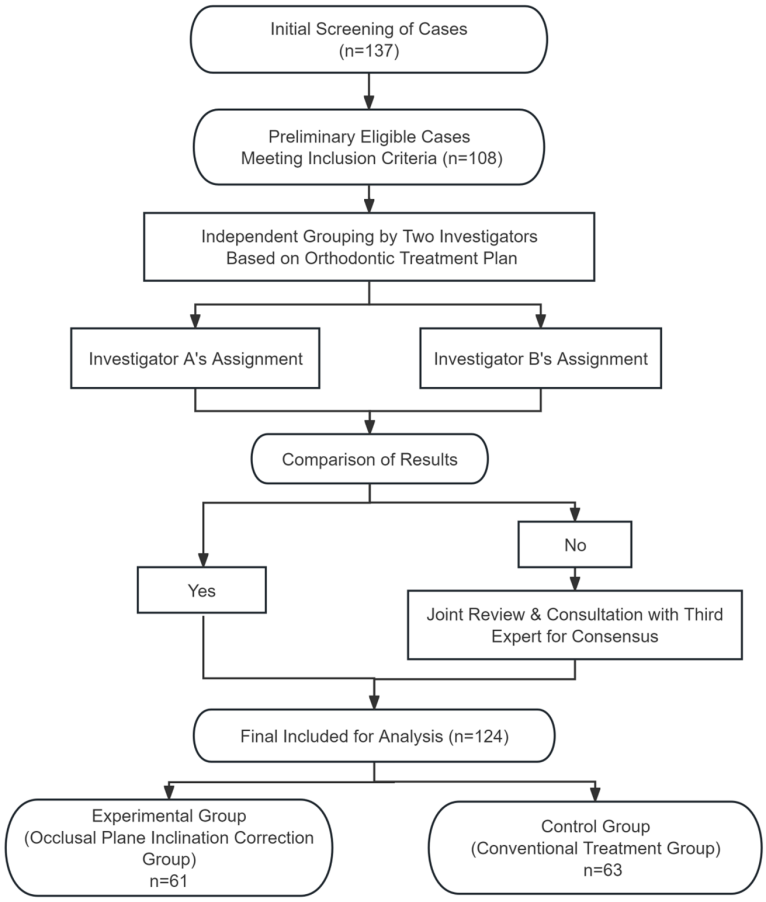

Figure 1. Flowchart for case selection.

orthognathic treatment during the study period; (4) evidence of overt organic TMJ pathology; and (5) incomplete, missing, or poor-quality clinical or key imaging data.

Grouping and interventions

Based on the actual treatment process and orthodontic treatment planning, all eligible cases (n=124) were independently reviewed by two senior orthodontists who were blinded to the study objectives. Comprehensive medical records, including treatment plans, follow-up notes, and pre- and post-treatment dental models and photographs, were reviewed. All patients in both groups were treated with fixed orthodontic appliances by the same experienced orthodontic team. According to the intervention approach, the patients were divided into an experimental group (n=61; occlusal plane cant correction) and a control group (n=63; conventional treatment).

Patients in the occlusal plane cant correction group (experimental group) were treated according to a standardized treatment plan. The primary objective was to reduce the occlusal plane cant angle to ≤2° on post-treatment posteroanterior cephalometric radiographs, thereby achieving improved craniofacial symmetry. A structured treatment algorithm was applied, prioritizing skeletal anchorage for vertical control in cases with moderate-to-severe cant (>3°), with asymmetric extraction employed as an adjunctive strategy based on individual facial features. These correction measures were implemented through a combination of techniques, including asymmetric extraction, unilateral vertical control of posterior teeth using temporary skeletal anchorage devices (TSADs), application of class III intermaxillary elastics and midline-correcting elastics, and selective occlusal adjustment. These interventions were applied in a coordinated approach to systematically correct occlusal plane cant in both the coronal and sagittal planes [13-16]. Among the 61 patients in this group, 34 (55.7%) were treated with temporary skeletal anchorage for unilateral vertical control, 18 (29.5%) underwent asymmetric extractions (mostly single-arch or unilateral premolar extraction), and 9 (14.8%) received treatment mainly involving intermaxillary elastics and selective occlusal adjustment.

Patients in the traditional treatment group (control group) received the standard orthodontic treatment. The main treatment objectives were dental alignment, midline correction, and establishment of appropriate molar relationships. No specific interventions were implemented to actively correct occlusal plane cant; instead, occlusal adjustments relied solely on routine bracket positioning and conventional orthodontic mechanics.

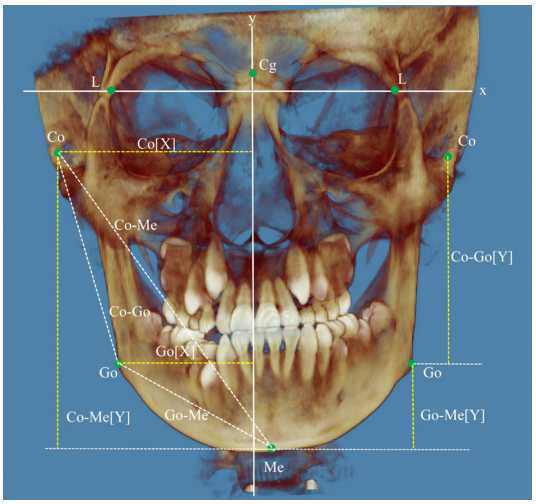

Figure 2. Measurement of facial asymmetry.

Clinical data collection

All assessments were conducted using archived records obtained at two time points: before treatment initiation and after completion of orthodontic treatment. Demographic variables included age and sex. TMJ-related clinical symptoms, including pain, joint clicking, and deviation during mouth opening, were evaluated according to the DC/TMD diagnostic criteria [17].

Posteroanterior cephalometric analysis

For each patient, CBCT scans were obtained before and after the treatment. 3D head orientation and image measurements were performed using Dolphin Imaging software (version 11.95).

Definition of reference planes: (1) Frankfurt horizontal plane (FH plane): defined by the bilateral orbital points and the right porion; (2) Midsagittal plane: defined as the plane perpendicular to the FH plane passing through the nasion and basion; (3) Coronal plane: defined as the plane perpendicular to both the FH plane and the midsagittal plane and passing through the basion.

Measurement of craniofacial symmetry: Five anatomical landmarks were selected: (1) crista galli (Cg); (2) bilateral lateral orbital points (L); (3) condylion (Co); (4) gonion (Go); and (5) menton (Me). The line connecting the bilateral lateral orbital points (L-L) was defined as the x-axis. A perpendicular line passing through Cg to the x-axis was defined as the y-axis, which served as the reference midsagittal plane for assessment of craniofacial symmetry (**Figure 2**).

Horizontal measurements included: (1) distance from condylion to the y-axis (Co(X)); (2) distance from Go to the y-axis (Go(X)); and (3) distance from Me to the y-axis (Me(X)).

Vertical and linear measurements included: (1) mandibular ramus height (Co-Go(Y)); (2) vertical distance from condylion to Me (Co-Me(Y)); (3) vertical distance from Go to Me (Go-Me(Y)); (4) mandibular body length (Go-Me); (5) mandibular ramus length (Co-Go); and (6) total mandibular length (Co-Me).

The asymmetry index (Q) for paired bilateral structures was calculated using the formula: $Q = (G - K)/G \times 100\%$, where G represents the larger value and K the smaller value of the bilateral measurements, and Q indicates the percentage of asymmetry [18].

Measurement of the occlusal plane angle: The occlusal plane angle was defined as the angle formed between the functional occlusal plane and the Frankfurt horizontal (FH) plane [19].

Measurement of temporomandibular joint parameters: The evaluated parameters included condylar volume, condylar surface area, mediolateral condylar diameter, and anteroposterior condylar width, as well as superior joint space, anterior and posterior joint spaces, defined as the minimum distances between the condyle and the corresponding walls of the glenoid fossa (**Figures 3**, **4**). Condylar volume and surface area were calculated following three-dimensional reconstruction of the condyle using Mimics Medical software [20]. Mediolateral and anteroposterior dimensions were measured on the axial slice corresponding to the maximum cross-sectional area of the condyle. Joint space measurements were performed according to the method described by Kamelchuk et al. [21].

Statistical analysis

Statistical analyses were performed using SPSS software (version 27.0; IBM Corp., Armonk, NY, USA). The normality of continuous

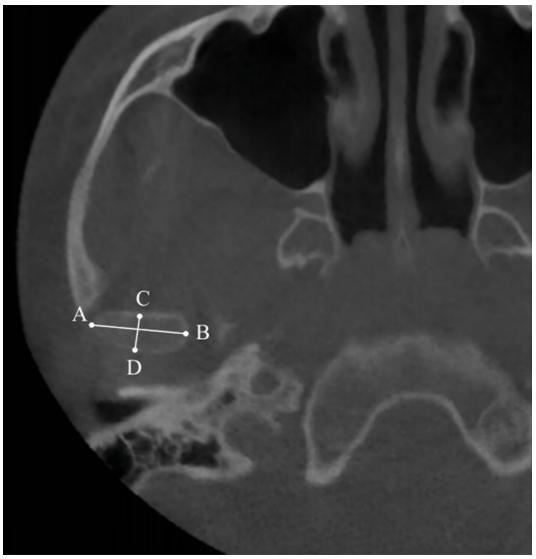

Figure 3. Mediolateral condylar diameter (AB) and anteroposterior condylar width (CD).

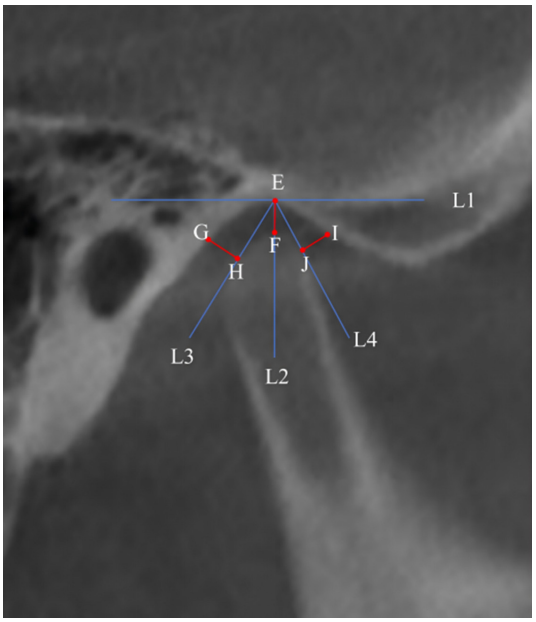

Figure 4. Superior joint space (EF), anterior joint space (GH) and posterior joint space (IJ).

variables was assessed using the Shapiro-Wilk test. Continuous variables were presented as mean ± standard deviation (SD) for normally distributed data or median (interquartile range) for non-normally distributed data, as appropriate. For comparisons of baseline characteristics between the two groups, independent-sample t tests were used for normally distributed continuous variables, whereas the Mann-Whitney U test was applied for non-normally distributed continuous variables. For within-group comparisons of pre- and post-treatment outcomes, paired t tests were used for normally distributed continuous variables, and the Wilcoxon signed-rank test was used for non-normally distributed continuous variables. Categorical variables were expressed as numbers and percentages (n [%]) and compared using the chi-square test or Fisher's exact test, as appropriate.

Pearson correlation analysis was performed to evaluate the associations between the magnitude of occlusal plane cant correction and changes in craniofacial asymmetry indices as well as TMJ imaging parameters. Binary logistic regression analysis was conducted to identify independent predictors of improvement in TMJ clicking, with post-treatment improvement in TMJ clicking as the dependent variable. Variables included in the regression model were selected based on clinical relevance and included sex, age, Me deviation distance, change in occlusal plane cant, and the presence of TMJ tenderness and deviation during mouth opening at baseline. All statistical tests were two-tailed, and a P value < 0.05 was considered statistically significant.

Results

Comparison of baseline characteristics

A total of 124 patients with mild skeletal facial asymmetry were included in the final analysis, comprising 61 patients in the occlusal plane cant correction group and 63 patients in the conventional treatment group. There were no significant differences between the two groups in terms of age, sex, or Me deviation distance at baseline (all P > 0.05), indicating good comparability between the groups (**Table 1**).

Corrective effects on occlusal plane cant

Following treatment, occlusal plane cant was significantly improved in both groups (**Table 2**). Within-group analyses showed that occlusal plane cant was significantly reduced at the end of treatment compared with baseline in both groups (both P < 0.001), with higher magnitude of reduction observed in the experimental group (3.21±1.02 vs. 1.95±1.01) (t=-6.886, P < 0.001), indicating superior efficacy of targeted occlusal plane cant correction.

Table 1. Comparison of baseline characteristics between the two groups

Variables		Control Group (n=63)	Experimental Group (n=61)	t/χ^2	*P*
Age (years)		11.33±2.67	11.95±2.87	-1.242	0.217
Sex (n/%)	Male	25 (39.7%)	22 (36.1%)	0.172	0.678
	Female	38 (60.3%)	39 (63.9%)		
Me deviation distance		3.05±0.59	3.19±0.46	-1.516	0.132

Note: Me, menton.

Table 2. Comparison of occlusal plane cant between the two groups before and after treatment

Time	Control Group (n=63)	Experimental Group (n=61)	t	*P*
Before treatment	3.95±1.00	4.24±1.02	-1.579	0.117
After treatment	2.01±0.64	1.03±0.47	9.601	<0.001
t	12.861	22.450		
P	<0.001	<0.001		

Table 3. Comparison of TMJ-related parameters between the two groups before and after treatment

Variables	Time	Control Group (n=63)	Experimental Group (n=61)	t/χ^2	*P*
TMJ clicking (n/%)	Before treatment	20 (31.7%)	24 (39.3%)	0.782	0.377
	After treatment	12 (19.0%)**	4 (6.7%)**	4.163	0.041
TMJ tenderness (n/%)	Before treatment	24 (38.1%)	25 (41.0%)	0.108	0.742
	After treatment	10 (15.9%)**	3 (4.9%)**	3.963	0.047
TMJ deviation on mouth opening (n/%)	Before treatment	15 (23.8%)	19 (31.1%)	0.839	0.360
	After treatment	9 (14.3%)**	2 (3.3%)**	4.527	0.033

Note: **$P < 0.001$, compare with pre-treatment value. TMJ, temporomandibular joint.

TMJ conditions

At baseline, the prevalence of TMJ clicking, tenderness, or deviation during mouth opening did not differ significantly between the groups (all P > 0.05). After treatment, all three symptoms showed significant improvement within each group (all P < 0.001). Between-group comparisons revealed that, after treatment, the incidences of TMJ clicking, tenderness, and deviation during mouth opening in the experimental group were 6.7%, 4.9%, and 3.3%, respectively, which were lower than those in the conventional treatment group (19.0%, 15.9%, and 14.3%, respectively; all P < 0.001; **Table 3**). These findings suggest that proactive correction of occlusal plane cant is superior to conventional orthodontic treatment in alleviating TMJ clinical symptoms.

TMJ imaging parameters

As shown in **Table 4**, no significant differences were observed between the two groups in any TMJ imaging parameters on the deviated side at baseline (all P > 0.05). Within-group comparisons demonstrated that, in the control group, significant post-treatment changes were observed in condylar volume, condylar surface area, anterior joint space, superior joint space, and posterior joint space on the deviated side (all P < 0.001), whereas no significant changes were found in condylar anteroposterior diameter or mediolateral diameter. In the experimental group, condylar volume, condylar surface area, anteroposterior diameter, anterior joint space, superior joint space, and posterior joint space on the deviated side all showed significant improvements after treatment (all P < 0.001), with no significant change observed in mediolateral condylar diameter.

Between-group comparisons after treatment revealed that the experimental group exhibited significantly greater condylar volume, condylar surface area, anteroposterior diameter, superior joint space, and posterior joint space, as well as a significantly smaller anterior joint space,

Table 4. Comparison of TMJ imaging parameters between the two groups before and after treatment

Groups	Time	Control Group (n=63)	Experimental Group (n=61)	t/χ^2	*P*
Condylar volume (cm^3)	Before treatment	1601.13±331.11	1669.72±339.11	-1.140	0.257
	After treatment	1894.27±256.25**	2019.42±318.98**	-2.404	0.018
Condylar surface area (cm^2)	Before treatment	853.48±118.27	860.93±101.41	-0.376	0.707
	After treatment	933.87±84.67**	967.41±88.69**	-2.154	0.033
Anteroposterior diameter of the condyle (mm)	Before treatment	8.08±0.57	8.12±0.33	-0.445	0.657
	After treatment	8.31±0.76	8.61±0.84**	-2.081	0.039
Mediolateral diameter of the condyle (mm)	Before treatment	18.70±1.45	18.72±1.77	-0.075	0.940
	After treatment	18.81±0.97	18.98±0.89	-1.002	0.318
Anterior joint space (mm)	Before treatment	2.51±0.34	2.50±0.28	0.300	0.765
	After treatment	2.13±0.40**	1.93±0.40**	2.698	0.008
Superior joint space (mm)	Before treatment	2.79±0.45	2.77±0.44	0.169	0.866
	After treatment	3.04±0.30**	3.42±0.34**	-6.927	<0.001
Posterior joint space (mm)	Before treatment	2.31±0.17	2.29±0.17	0.755	0.452
	After treatment	2.87±0.26**	3.07±0.45**	-3.083	0.003

Note: **$P < 0.001$, highlight the potential clinical value of incorporating targeted occlusal plane cant correction into orthodontic treatment planning. TMJ, temporomandibular joint.

compared with the control group (all P < 0.05). No significant between-group difference was observed in mediolateral condylar diameter. These results indicate that targeted correction is more effective in promoting condylar morphological remodeling and optimizing TMJ joint space distribution.

Changes in mandibular and craniofacial symmetry

Prior to treatment, no significant differences were observed between the two groups across all measured asymmetry indices, including Co(X), Go(X), Co-Go(Y), Co-Me(Y), Go-Me(Y), Co-Go(L), Go-Me(L), and Co-Me(L) (all P > 0.05). Within-group comparisons demonstrated that all asymmetry indices were significantly reduced after treatment in both groups (all P < 0.001) (**Table 5**). Between-group comparisons at the end of treatment showed that the experimental group exhibited significantly lower values for all asymmetry indices compared with the control group (all P < 0.001), indicating a more pronounced improvement in craniofacial skeletal symmetry following targeted occlusal plane cant correction.

Correlation between occlusal plane cant correction and craniofacial asymmetry

The correlation between the magnitude of occlusal plane cant correction and changes in craniofacial asymmetry indices are shown in **Table 6**. The extent of occlusal plane cant correction was significantly negatively correlated with all asymmetry indices (all P < 0.05), with the strongest correlations observed for Go(X) and Go-Me(Y). These findings indicate that greater correction of occlusal plane cant is associated with more substantial reductions in craniofacial asymmetry and greater improvements in overall facial symmetry.

Correlation between occlusal plane cant correction and TMJ parameters

The correlations between the magnitude of occlusal plane cant correction and key TMJ imaging parameters are presented in **Table 7**. The extent of occlusal plane cant correction was significantly positively correlated with condylar morphological parameters, including condylar volume, surface area, anteroposterior diameter, and mediolateral diameter, with the strongest correlation observed for condylar volume. In addition, the magnitude of correction was positively correlated with superior joint space (r=0.415, P < 0.001) and posterior joint space (r=0.413, P < 0.001), and negatively correlated with anterior joint space (r=-0.358, P < 0.001). These findings suggest that greater correction of occlusal plane cant is closely associated with adaptive condyle remodeling on the deviated side and more favorable TMJ joint space distribution.

Table 5. Comparison of asymmetry rates between the two groups after treatment

Parameters	Time	Control Group (n=63)	Experimental Group (n=61)	t/χ^2	*P*
Co(X)	Before treatment	7.67±1.71	7.48±1.67	0.616	0.539
	After treatment	5.60±1.11**	4.12±1.04**	8.177	<0.001
Go(X)	Before treatment	11.20±2.13	11.60±1.97	-1.076	0.284
	After treatment	7.14±1.11**	4.37±0.77**	16.186	<0.001
Co-Go(Y)	Before treatment	8.53±1.41	8.45±1.42	0.317	0.752
	After treatment	4.93±0.73**	3.40±0.89**	10.536	<0.001
Co-Me(Y)	Before treatment	4.27±0.63	4.22±0.64	0.341	0.733
	After treatment	2.72±0.71**	2.16±0.71**	4.427	<0.001
Go-Me(Y)	Before treatment	16.57±1.52	16.15±1.53	1.580	0.117
	After treatment	6.17±1.07**	3.33±0.98**	15.343	<0.001
Co-Go	Before treatment	12.42±1.43	12.48±1.59	-0.231	0.818
	After treatment	5.02±0.52**	3.26±0.85**	13.862	<0.001
Go-Me	Before treatment	12.38±1.49	12.56±1.53	-0.670	0.504
	After treatment	5.12±0.51**	3.47±0.94**	12.055	<0.001
Co-Me	Before treatment	7.09±1.20	6.95±1.19	0.648	0.518
	After treatment	4.84±0.71**	3.45±0.87**	9.765	<0.001

Note: $^{**}P < 0.001$, compare with pre-treatment value. Co(X), distance from condylion to the y-axis; Go(X), distance from gonion to the y-axis; Co-Go(Y), mandibular ramus height; Co-Me(Y), vertical distance from condylion to menton; Go-Me(Y), vertical distance from gonion to menton; Co-Go, mandibular ramus length; Go-Me, mandibular body length; Co-Me, total mandibular length.

Table 6. Correlation analysis between the magnitude of occlusal plane cant correction and various asymmetry parameters

Variables	r	*P*
Co(X)	-0.384	<0.001
Go(X)	-0.468	<0.001
Co-Go(Y)	-0.324	<0.001
Co-Me(Y)	-0.201	0.025
Go-Me(Y)	-0.426	<0.001
Co-Go	-0.334	<0.001
Go-Me	-0.368	<0.001
Co-Me	-0.300	<0.001

Note: Co(X), distance from condylion to the y-axis; Go(X), distance from gonion to the y-axis; Co-Go(Y), mandibular ramus height; Co-Me(Y), vertical distance from condylion to menton; Go-Me(Y), vertical distance from gonion to menton; Co-Go, mandibular ramus length; Go-Me, mandibular body length; Co-Me, total mandibular length.

Binary logistic regression analysis of factors associated with TMJ symptom improvement

To identify independent predictors of improvement in TMJ symptoms, binary logistic regression analysis was performed, with post-treatment improvement in TMJ clicking as the dependent variable. Independent variables included sex, age, Me deviation distance, change in occlusal plane cant, and the presence of TMJ tenderness and deviation during mouth opening at baseline (**Table 8**). After adjustment for all covariates, only the change in occlusal plane cant remained an independent predictor of TMJ symptom improvement, indicating that greater correction was associated with a higher likelihood of improvement in TMJ clicking.

Discussion

The current study provides a comparative evaluation of conventional orthodontic therapy versus a treatment strategy incorporating active occlusal plane cant correction in children and adolescents with mild skeletal facial asymmetry. The effects of these approaches on TMJ status and craniofacial symmetry, as well as the relationship among these outcomes, were systematically analyzed. The findings indicate that active correction of occlusal plane cant is more effective than traditional orthodontic treatment in reducing occlusal plane cant, alleviating TMJ-related clinical symptoms, promoting favorable TMJ morphological changes, and improving craniofacial skeletal symmetry. These results corroborate established orthodontic principles and provide valuable guidance for clinical practice.

Table 7. Correlation analysis between the magnitude of occlusal plane cant correction and TMJ imaging parameters

Variables	r	*P*
Condylar volume	0.454	<0.001
Condylar surface area	0.303	<0.001
Anteroposterior diameter of the condyle	0.401	<0.001
Mediolateral diameter of the condyle	0.282	0.002
Anterior joint space	-0.358	<0.001
Superior joint space	0.415	<0.001
Posterior joint space	0.413	<0.001

Note: TMJ, temporomandibular joint.

The results of this study further highlight the central role of the occlusal plane as a critical diagnostic and therapeutic parameter in the management of facial asymmetry. A targeted correction strategy demonstrated superior efficacy in reducing occlusal plane cant, which represents a key morphological feature of facial asymmetry. Traditionally, occlusal plane cant has been considered a dental manifestation of underlying three-dimensional skeletal imbalance. Previous studies have suggested that reestablishment of vertical and transverse facial harmony greatly depends upon effective correction of occlusal plane cant [22]. In addition, three-dimensional morphologic researches using computed tomography have further demonstrated a significant correlation between occlusive plane cant and skeletal asymmetry, supporting its objective value in diagnostic assessment [23]. In the present study, correction of occlusal plane cant was associated with significantly greater improvements in skeletal asymmetry indices, and the magnitude of correction showed a strong correlation with reductions in these indices. From a therapeutic perspective, these findings further reinforce the role of the occlusal plane as a core element in both diagnosis and treatment planning for patients with skeletal facial asymmetry.

Importantly, our results indicate that improvement in occlusal plane cant is accompanied by concurrent enhancement of TMJ health. Active intervention targeting occlusal plane cant represents a key therapeutic step in restoring overall facial coordination and functional balance [24]. The present study provides clinical evidence that active correction of occlusal plane cant during orthodontic treatment can effectively guide adaptive structural changes within the TMJ. The corrective strategy may disrupt abnormal functional patterns induced by occlusal interference and help reestablish balanced vertical and sagittal relationships between the maxilla and mandible. By improving intermaxillary coordination and achieving more stable occlusal contacts, abnormal intra-articular loading may be reduced, thereby facilitating normalization of TMJ structure and function [25]. These findings are consistent with previous studies demonstrating associations between occlusal asymmetry and TMJ functional and structural alterations [26].

Beyond alterations in dental force distribution and mandibular spatial positioning, occlusal plane cant correction may contribute to a more favorable biomechanical environment for adaptive condylar remodeling. In this study, the magnitude of occlusal plane correction was positively correlated with increases in condylar volume and anteroposterior diameter on the deviated side, supporting the concept of functional condylar remodeling. This adaptive response is consistent with prior reports highlighting the sensitivity of condylar cartilage to mechanical loading [27]. In addition, the observed optimization of TMJ joint space morphology aligns with earlier studies indicating that changes in mandibular position can influence TMJ joint spaces [9, 28]. Collectively, these findings suggest that correction of occlusal plane cant not only improves craniofacial morphological asymmetry but also contributes to adaptive structural and functional remodeling of the TMJ.

At the level of TMJ clinical symptoms, the present study demonstrates that active correction of occlusal plane cant is associated with improvements in TMJ clicking, tenderness, and deviation during mouth opening. Previous studies have reported a close connection between the TMD and occlusal factors [29]. Our results further specify this relationship by showing that targeted intervention addressing occlusal plane cant can facilitate clinical symptom improvement in patients with TMJ disorders.

Furthermore, binary logistic regression analysis identified the magnitude of the occlusal

Table 8. Binary logistic regression analysis of factors associated with improvement in TMJ symptoms

Variables	B	Standard error	β	*P*	OR	95% CI	
						Upper limit	Lower limit
Sex (Female vs. Male)	1.252	0.785	2.540	0.111	3.497	0.750	16.300
Age	0.205	0.131	2.479	0.115	1.228	0.951	1.586
Me deviation distance	0.631	0.618	1.042	0.307	1.880	0.559	6.316
Change in occlusal plane cant	-1.589	0.384	17.142	<0.001	0.204	0.096	0.433
TMJ tenderness (Yes vs. No)	-1.329	0.762	3.045	0.081	0.265	0.060	1.178
Deviation on mouth opening (Yes vs. No)	-0.328	0.717	0.209	0.647	0.72	0.177	2.936

Note: CI, confidence interval; TMJ, temporomandibular joint; Me, menton.

plane cant correction as an independent predictor of TMJ clicking improvement, highlighting its clinical relevance. This finding emphasizes not only the relationship between a defined treatment target and functional outcomes, but also the importance of proactively assessing and addressing occlusal plane cant in the planning of treatment for functional asymmetry. Accordingly, a detailed orthodontic evaluation should include assessment of the vertical relationships, especially the transverse slope of the occlusal plane, as neglecting this aspect may predispose patients to post-treatment instability and TMJ complications [30].

Several limitations of this study should be acknowledged. First, as a retrospective analysis, outcome assessment relied primarily on static morphologic measurements derived from CBCT. Although this approach allows precise quantification of osseous changes, it does not permit dynamic evaluation of disc position, intra-articular soft tissue status, or masticatory muscle activity, all of which are essential for a comprehensive assessment of TMJ adaptive remodeling. Second, although patients with a documented history of TMJ arthritis, trauma, or previous TMJ surgery were excluded, and baseline clinical symptoms were comparable between groups, comprehensive evaluation of TMJ internal structure (e.g., disc position, erosions, or osteophytes) using MRI was not performed. Consequently, we cannot completely rule out pre-existing or concurrent intrinsic TMJ pathology as a potential confounding variable. This is especially relevant given the complex, bi-directional relationship between TMJ disorders and jaw deformities, whereby skeletal asymmetry may influence TMJ structure and function, while intrinsic TMJ pathology may also contribute to mandibular asymmetry. Thus, the observed improvements in TMJ status cannot purely be accredited to correction of the occlusal plane cant, and the potential influence of underlying TMJ conditions should be considered. Third, all patients were in a period of active growth and development. The high potential of bone remodeling during this period could potentially influence treatment outcomes, and therefore, these findings may not be directly generalizable to adult populations. Finally, outcome evaluation was limited to completion of active orthodontic therapy. The long-term stability of occlusal plane cant correction and the persistence of improvements in TMJ clinical symptoms and imaging parameters remain unclear due to the lack of extended follow-up data. These shortcomings underscore the need for future prospective, randomized controlled trials incorporating multimodal evaluation methods, including magnetic resonance imaging [31, 32], and extended follow-up, to further validate the sustainability and clinical relevance of occlusal plane cant correction.

Conclusion

This comparative analysis has shown that, in children and adolescents with mild-to-moderate skeletal facial asymmetry and occlusive plane cant, a treatment strategy incorporating active occlusal plane cant corrective is more effective than conventional orthodontic approach in improving craniofacial symmetry and TMJ-related clinical and imaging outcomes.

Our findings support the inclusion of 3D assessment of occlusal plane cant as a routine component of diagnostic evaluation, and highlight the clinical value of incorporating targeted

occlusal plane cant correction into orthodontic treatment planning.

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Disclosure of conflict of interest

None.

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