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Cephalometric analysis of the relationship between temporomandibular joint disc displacement and occlusal plane

Yi Liu¹, Yunhao Zheng¹, Yifei Long¹, Chengxinyue Ye¹, Qinlanhui Zhang¹, Xueman Zhou¹, Xin Xiong^{1*} and Jun Wang^{1*}

Abstract

Background The temporomandibular joint (TMJ) is biomechanically complex, with disc displacement (DD) causing dysfunction and pain, while the occlusal plane (OP) influences TMJ mechanics. This study investigates the correlation between disc displacement and OP to inform DD.

Methods This study included adult patients with temporomandibular disorder complaints. Participants were divided into three groups based on magnetic resonance imaging (MRI): normal position (N), disc displacement with reduction (DDwR), and disc displacement without reduction (DDwoR). The sagittal and vertical relationships, mandible morphology, dental relationships, and occlusal related index were evaluated using cephalometric measurements. A regression equation was then established after adjusting confounding factors.

Results ANOVA test showed that statistical differences ($p < 0.05$) could be seen in SNB, ANB, FMA angle, SN-MP, S-Go, Ar-Go and U1-SN among the three groups. As for the occlusal plane related index, FH-OP, FH-POP, MP-OP, FH-U6, FH-L6 had statistical differences with the position of articular disc. The exploration on the occlusal plane related index in sagittal skeletal pattern categorial showed that skeletal pattern did not affect the relationship between the articular disc and the occlusion plane. Additionally, binary logistic regression analysis indicated that the likelihood of DDwoR increases with a one-degree increment in FH-POP and decreases with a one-degree decrement in both FH-U6 and FH-L6.

Conclusions Compared with the other two groups, the DDwoR group possessed different craniofacial features. Additionally, the posterior occlusal plane, not anterior or the complete occlusal plane, and axis inclination of first molar is related to DD. In short, there exists an association between articular disc and OP. However, the causal relationship cannot be confirmed, further investigation is still needed between these factors.

Keywords Occlusal plane, Temporomandibular disorder, Cephalometric analysis, Disc displacement

*Correspondence:

Xin Xiong
dxiongxin@scu.edu.cn
Jun Wang
wangjunv@scu.edu.cn

¹The State Key Laboratory of Oral Diseases & National Center for Stomatology & National Clinical Research Center for Oral Diseases, West China Hospital of Stomatology, Sichuan University, Chengdu, Sichuan 610041, China



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Background

Temporomandibular joint (TMJ) is one of the most biomechanically complex and functionally critical joints in the human body, comprising the articular fovea, mandibular condyle, articular disc, joint capsule, and joint ligament. Among them, the articular disc plays a pivotal role in facilitating smooth joint movement, distributing mechanical stress, and maintaining joint stability [1]. TMJ disc displacement (DD) is a common disease characterized by an abnormal relationship between the articular disc and the condyle, leading to dysfunction and discomfort of the TMJ. In severe cases, DD may even cause pain, limited mandibular movement, and joint injury or necrosis [2, 3]. The disorder can manifest in various forms, including disc displacement with reduction (DDwR), disc displacement without reduction (DDwoR), and medial or lateral disc displacement, each associated with distinct clinical presentations and pain profiles [4].

The occlusal plane (OP) is an imaginary plane defined as the average plane established by the incisal and occlusal surfaces of the teeth, whose position is essential for craniofacial morphology and function [5]. Recent biomechanical studies have demonstrated that the orientation of the OP significantly influences the distribution and magnitude of occlusal forces transmitted to the TMJ. Specifically, clockwise or counterclockwise rotation of OP can change the direction of occlusal force transmitted to the TMJ structure, and the compressive stress on the condyle increases with clockwise rotation of OP, indicating the role of OP on TMJ [6]. Given that the etiology of DD is multifactorial, including trauma, anatomical variations, excessive chewing load, and occlusal factors, the position of OP may play a critical role in the pathogenesis and progression of DD. Conversely, DD can cause changes in the condylar cartilage, leading to occlusal instability and further altering the biomechanical environment of the TMJ [7]. In adolescents, DD may also disrupt the establishment of a stable OP, suggesting a bidirectional relationship between these two factors.

During orthodontic treatment, the symptoms of TMD may exist or worsen in patients with underlying disease. This requires orthodontists to fully consider and inform them before treatment. Therefore, it is vital to identify underlying patients with DD. Since occlusal plane is one of influencing factors of articular disk, and currently there is no research confirming the relationship between DD and occlusal plane, the aim of this study is to explore the correlation between the position of the articular disc and the occlusal plane, and provide reference for clinical dentists and assisting in the prevention and treatment of DD.

Methods

Study populations

The cross-sectional study was approved by the Ethics Committee of West China Hospital of Stomatology, Sichuan University (No. WCH-SIRB-CT-2020-418), and all patients signed an informed consent form in paper. The research collected patients who sought treatment in the Orthodontics Department of West China Hospital of Stomatology, Sichuan University from January 2021 to December 2021. The inclusion criteria were as follows: (1) Clear cephalograms and magnetic resonance imaging (MRI); (2) Age over 18 years old; (3) No history of orthodontic or orthognathic treatment. The exclusion criteria were as follows: (1) Systemic diseases; (2) History of trauma, orthodontic treatment, and orthognathic treatment; (3) The cephalograms and MRI are unclear, making it difficult to accurately measure and judge; (4) Inconsistent types of bilateral articular disc position.

MRI assessment

The analysis was performed using a 1.5 T MRI scanner with a TMJ surface coil and fast spin echo T1 weighted imaging (FSE-T1WI). The PDWI parameter settings were: 2300 ms for repetition time, 45 ms for echo time, 2.5 mm for layer thickness, 2 for excitation frequency, and 288×256 pixels for image matrix. The MRI evaluation was performed by two experienced operators and any disagreement was settled by discussion and consensus. The patients were divided into three groups based on MRI as previous research [8, 9].

Cephalometric evaluation

The cephalograms were all taken at the Radiology Department of West China Hospital of Stomatology, Sichuan University. During the processing of cephalograms shooting, the patients were asked to occlude in intercuspal position without swallowing and chewing, and the head was fixed in natural head position, ensuring that the Frankfort horizontal plane (FH plane) is parallel to the ground. The cephalograms were analyzed by an experienced orthodontist using Uceph software (version 961, Chengdu, China). The cephalometric landmarks are demonstrated in Fig. 1. A total of 17 measurement was evaluated (including 10 angle measurements and 7 distance measurements), and their definitions are shown in Table 1.

Statistical analysis

Data analysis was conducted using IBM SPSS Statistics version 21.0. The threshold for statistical significance was set at a p-value of less than 0.05. Continuous variables exhibiting a normal distribution were described using the mean $\pm$ standard deviation, whereas non-parametric data were represented by the median and interquartile range.

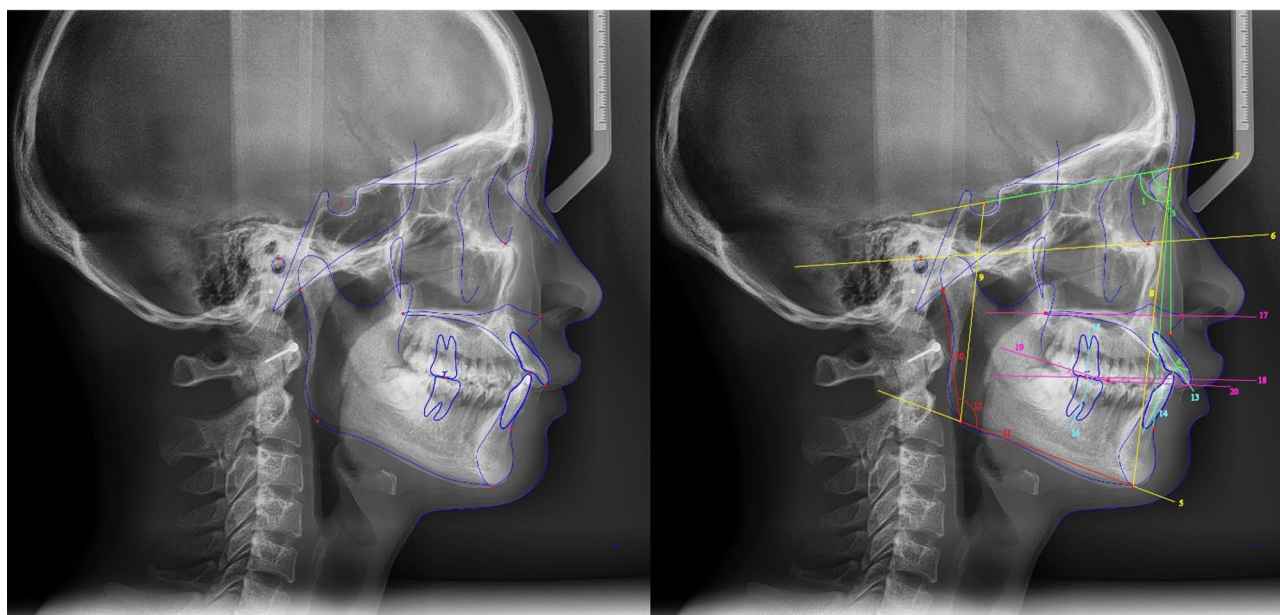


Fig. 1 Planes and angles used in the study. Sagittal relationship (green): (1) SNA; (2) SNB; (3) ANB; (4) Wits. Vertical relationship (yellow): (5) mandibular plane; (6) Frankfort plane; (7) SN plane; (8) anterior facial height, N–Me; (9) posterior facial height, S–Go. Mandible morphology (red): (10) ramus height; (11) mandibular body length; (12) gonial angle. Dental relationship (blue): (13) L1 axis; (14) U1 axis; (15) U6 axis; (16) L6 axis. Occlusal position (purple): (17) palatal plane; (18) occlusal plane; (19) posterior occlusal plane; (20) anterior occlusal plane

Categorical data were summarized in terms of frequency counts and percentages.

To assess the differences in categorical variables across groups, the Chi-square test of independence was employed. For the comparison of cephalometric measurement indicators among the three patient groups, one-way analysis of variance (ANOVA) was utilized for normally distributed data, and the Kruskal-Wallis H test was applied for data that did not meet the assumptions of normality. Post-hoc multiple comparisons were conducted using the Student-Newman-Keuls (SNK) method to determine pairwise differences among the groups.

Given the binary nature of the dependent variable, binary logistic regression analysis was selected to evaluate the relationship between the dependent variable and the independent variables of interest. The dependent variable was coded dichotomously, with 0 representing the N group and DDwR group, and 1 representing the DDwoR group. The primary objective was to assess the association between DD and OP, while statistically controlling for potential confounding variables, namely age and sex.

Quality control

The consistency determination method of TMJDD and cephalometric measurement is consistent with previous research methods, with an intra group correlation coefficient (ICC) and kappa coefficient > 0.7, proving the reliability of the results.

Results

Sample population and characteristic

The study sample comprised a total of 173 subjects, with a mean age of 21.88 ± 10.20 years (Table 2). The age distribution was predominantly within the 20–40 years range, accounting for 80.92% of the sample. The gender distribution was 142 females and 31 males. The distribution of disc displacement conditions was as follows: 69 subjects had normal bilateral disc displacement (N group), 66 subjects had disc displacement with reduction (DDwR group), and 38 subjects had disc displacement without reduction (DDwoR group). Statistical analysis revealed no significant differences in age among the three groups ($p = 0.228$), whereas gender distribution was significantly different ($p = 0.002$). In terms of sagittal skeletal relationships, the prevalence of skeletal class I was highest in both the N group (53.62%) and the DDwR group (48.48%), whereas skeletal class II was most prevalent in the DDwoR group (71.05%), with significant differences observed between groups ($p = 0.002$).

Cephalometric analysis

Following the completion of the normality test, we proceeded to perform an ANOVA test to evaluate the significance of differences in various cephalometric measurements as presented in Table 3. In the context of the sagittal relationship, our analysis revealed statistically significant differences for two key measurements: SNB ($p = 0.03$) and ANB ($p = 0.02$). These findings suggest that there is a notable variation in the sagittal position of the

Table 1 Cephalometric measurements

Measurements	Definitions
Sagittal relationship	
SNA/°	Angle formed by nasion (N)–point A line and sella (S)–nasion (N) plane
SNB/°	Angle formed by nasion (N)–point B line and sella (S)–nasion (N) plane
ANB/°	Angle formed by nasion–A line and nasion–B line
Wits/mm	Distance between vertical lines from A point and B point to OP plane
Vertical relationship	
FMA/°	MP–FH, angle formed by MP plane and FH plane
SN-MP/°	Angle formed by SN plane and MP plane
N-Me/mm	Anterior facial height, distance between nasion (N) and menton (Me)
S-Go/mm	Posterior facial height, distance between sella (S) and Gonion (Go)
Mandibular morphology	
Ar-Go/mm	Ramus height, distance between articulare (Ar) and gonion (Go)
Go-Me/mm	Mandibular body length, distance between gonion (Go) and menton (Me)
Ar-Go-Me/°	Gonial angle, angle formed by Ar–Go line and MP plane
Dental relationship	
U1-L1/°	Interincisal angle, angle formed by the long axes of the upper and lower incisor
U1-SN/°	angle formed by the long axes of the upper and SN plane
FMIA (L1-FH)/°	Frankfort mandibular incisor angle, angle formed by the long axes of the lower incisors and FH plane
IMPA (L1-MP)/°	Incisor mandibular plane angle, angle formed by the long axes of the lower incisors and MP plane
Occlusal related index	
PP-OP/°	Angle formed by PP plane and OP plane
FH-OP/°	Occlusal plane angle, angle formed by FH plane and OP plane
FH-POP/°	Posterior occlusal plane angle, angle formed by FH plane and buccal cusp of maxillary second premolar–buccal cusp of maxillary second molar line
FH-AOP/°	Anterior occlusal plane angle, angle formed by FH plane and incisal ridge of maxillary central incisor–buccal cusp of maxillary second premolar line
MP-OP/°	Angle formed by MP plane and OP plane
FH-U6/°	Angle formed by FH plane and the long axes of the upper first molar
FH-L6/°	Angle formed by FH plane and the long axes of the lower first molar

MP plane Mandibular plane. The line tangent to the lower edge of the mandibular angle through menton, **FH plane** Frankfort horizontal plane. The line connecting orbitale and porion, **SN plane** The line connecting nasion and sella, **PP plane** Palatal plane. The line connecting anterior nasal spine and posterior nasal spine, **OP plane** Occlusal plane. The line between the occlusal midpoint of the first permanent molars and the midpoint of the incisal edges

Table 2 Demographic information

	Normal	DDwR	DDwoR	p-value
Age				
Average	33.17	30.63	31.71	0.228
standard deviation	10.36	10.22	9.83	
Sex categorial				
Male	21 (30.43%)	8 (12.12%)	2 (5.26%)	0.002**
Female	48 (69.57%)	58 (87.88%)	36 (94.74%)	
Sagittal skeletal pattern categorial				
Class I	37 (53.62%)	32 (48.48%)	10 (26.32%)	0.002**
Class II	28 (40.58%)	25 (37.88%)	27 (71.05%)	
Class III	4 (5.80%)	9 (13.64%)	1 (2.63%)	

Categorial data presented as frequency (constituent ratio), * p -value < 0.05, ** p -value < 0.01

Sagittal skeletal pattern categorial is classified by ANB, $1^\circ \leq \text{ANB} \leq 5^\circ$ is classified as skeletal class I, $\text{ANB} > 5^\circ$ is classified as skeletal class II, and $\text{ANB} < 1^\circ$ is classified as skeletal class III

maxilla and mandible between the groups being compared. However, no statistical difference was observed for the Sella-Nasion-A point angle (SNA), indicating that the anteroposterior position of the maxilla relative to the cranial base did not significantly differ among the groups. In terms of the vertical relationship, our study identified statistical differences for FMA angle ($p = 0.001$), SN-MP ($p < 0.001$), and S-Go ($p < 0.001$). These results indicate that there are significant variations in the vertical positioning of the mandible and the overall vertical facial height among the groups under study. Furthermore, we observed statistical differences in the height of the mandibular ramus, as measured from the point Ar to the point Go (Ar-Go), with a p -value less than 0.001, and in the inclination of the upper incisor to the Sella-Nasion line (U1-SN) with a p -value of less than 0.05. These results collectively highlight significant morphological variations in both sagittal and vertical dimensions.

Occlusal plane analysis

As shown in Table 4, there are differences among groups in the angle between the occlusal plane and other planes, FH-OP ($p = 0.037$), FH-POP ($p = 0.004$), MP-OP ($p = 0.017$), FH-U6 ($p = 0.001$), FH-L6 ($p = 0.011$), showing that the occlusal plane is related to different positions of the articular discs. The occlusal plane can be divided into anterior and posterior occlusal plane, and the posterior occlusal plane angle has differences among groups, while the anterior occlusal plane angle has not. Among them, the FH-OP and MP-OP angle of patients with DDwR were higher than those of patients with normal articular discs, and there was no statistical difference between the data of patients with DDwR and the other two groups ($p < 0.05$). Moreover, the FH-POP, FH-U6, and FH-L6 in the DDwoR group showed statistical differences ($p < 0.05$) compared to the other two groups.

Table 3 Comparison of cephalometric measurements in normal, DDwR and DDwoR groups

	Normal (1)	DDwR (2)	DDwoR (3)	p-value	Post-Hoc
Sagittal relationship					
SNA°	83.40 ± 3.69	82.96 ± 2.94	82.32 ± 3.50	0.286	NS
SNB°	78.71 ± 4.15	79.02 ± 3.60	76.36 ± 3.95	0.003**	3 < 2 = 1
ANB°	4.69 ± 2.60	3.94 ± 3.11	5.97 ± 2.50	0.002**	3 > 2 = 1
Wits/mm	1.05 ± 0.43	-0.18 ± 0.49	1.55 ± 0.61	0.050	NS
Vertical relationship					
FMA°	22.61 ± 5.71	23.94 ± 5.57	26.99 ± 5.73	0.001**	3 > 2 = 1
SN-MP°	31.83 ± 5.93	33.19 ± 6.22	37.70 ± 6.21	< 0.001**	3 > 2 = 1
N-Me/mm	115.17 ± 6.07	114.60 ± 7.37	114.88 ± 5.37	0.877	NS
S-Go/mm	79.19 ± 6.40	76.65 ± 5.46	73.23 ± 6.12	< 0.001**	3 < 2 < 1
Mandible morphology					
Ar-Go/mm	48.12 ± 4.81	46.04 ± 4.40	43.87 ± 4.93	< 0.001**	3 < 2 < 1
Go-Me/mm	69.09 ± 4.46	69.94 ± 4.60	68.09 ± 4.61	0.137	NS
Ar-Go-Me°	116.79 ± 6.37	117.93 ± 6.10	118.34 ± 7.59	0.428	NS
Dental relationship					
U1-L1°	125.95 ± 13.81	127.07 ± 14.75	126.51 ± 10.93	0.892	NS
U1-SN°	103.37 ± 8.63	103.67 ± 8.84	99.61 ± 6.28	0.038*	3 < 2 = 1
FMIA (L1-FH)/°	58.56 ± 8.77	59.99 ± 10.73	56.81 ± 9.43	0.271	NS
IMPA (L1-MP)/°	98.84 ± 8.08	96.07 ± 9.28	96.20 ± 8.20	0.126	NS

Data presented as mean ± SD; NS no significance, * p -value < 0.05, ** p -value < 0.01

Table 4 Comparison of cephalometric measurements related to occlusal plane in normal, DDwR and DDwoR groups

	Normal (1)	DDwR (2)	DDwoR (3)	p-value	Post-Hoc
PP-OP/°	7.97 ± 3.25	8.08 ± 3.22	9.14 ± 4.21	0.213	NS
FH-OP/°	7.73 ± 3.78	8.21 ± 3.48	9.68 ± 4.13	0.037*	3 > 1
FH-POP/°	11.44 ± 4.38	10.97 ± 4.05	13.79 ± 4.20	0.004**	3 > 2 = 1
FH-AOP/°	7.94 ± 4.66	7.88 ± 4.36	9.38 ± 4.14	0.201	NS
MP-OP/°	14.88 ± 3.79	15.73 ± 4.52	17.31 ± 4.17	0.017*	3 > 1
FH-U6/°	84.80 ± 3.94	85.30 ± 4.84	81.99 ± 4.49	0.001**	3 < 2 = 1
FH-L6/°	73.45 ± 5.63	73.55 ± 6.00	70.34 ± 4.94	0.011*	3 < 2 = 1

Data presented as mean ± SD; NS no significance, * p -value < 0.05, ** p -value < 0.01

We further explored the occlusal plane related index in sagittal skeletal pattern categorial (Table 5). As there was only 1 patient with class III skeletal pattern in DDwoR group, we only analyzed skeletal class I and class II. As shown in Table 5, we found that among 79 class I patients, PP-OP ($p < 0.01$), MP-OP ($p < 0.01$), FH-OP ($p < 0.01$), FH-POP ($p < 0.01$), FH-AOP ($p < 0.05$) all have statistical differences when articular disc in various status. Meanwhile, among 80 class II patients, there were statistical differences in FH-OP ($p < 0.05$), FH-POP ($p < 0.01$), and FH-L6 ($p < 0.05$). These results collectively emphasize the complex interplay between occlusal plane dynamics, skeletal morphology.

Correlation analysis

Given the minimal inter-group differences in occlusal plane-related indicators between the N group and the DDwoR group, these two groups were consolidated for subsequent analysis to investigate the impact of DDwoR

on the occlusal plane more comprehensively. The results of separated 3 group were shown in Table S1. The statistical non-significance of differences in FH-OP and MP-OP between the DDwR group and the DDwoR group justified their exclusion from further analysis. After accounting for the confounding effects of age and gender, binary logistic regression models were developed to assess the relationship between FH-POP, FH-U6, and FH-L6 and the occurrence of DDwoR. As detailed in Table 6, the variables FH-POP, FH-U6, and FH-L6 were identified as significant predictors of the likelihood of DDwoR. For every one-unit increase in FH-POP, the odds of disc displacement increased by 14.5% ($\text{Exp}(B) = 1.145$, 95%CI: 1.043, 1.258). Similarly, for every one-unit increase in FH-U6 and FH-L6, the odds of disc displacement decreased by 14.6% ($\text{Exp}(B) = 0.854$, 95%CI: 0.776, 0.939) and 11.7% ($\text{Exp}(B) = 0.883$, 95%CI: 0.812, 0.961). These results underscore the importance of considering occlusal plane orientation when assessing the risk of disc displacement.

Discussion

The relationship between occlusal plane and TMJ

This study analyzed the cephalograms of 173 patients to explore the relationship between the position of the TMJ disc and various other indicators. The demographic characteristics of the included population were found to be representative, with an average age, proportion of females, and distribution of DD patients consistent with proportions reported in previous literature [10, 11]. The craniofacial features of DDwoR patients are different from those of the other two groups.

Table 5 Stratified analysis based on sagittal skeletal pattern data presented as mean $\pm$ SD; NS no significance, * p -value < 0.05 , ** p -value < 0.01

	Normal (1)	DDwR (2)	DDwoR (3)	p -value	Post-Hoc
skeletal Class I					
PP- OP/°	6.05 $\pm$ 2.82	8.21 $\pm$ 3.24	9.32 $\pm$ 3.75	0.002**	3 = 2 > 1
MP- OP/°	12.32 $\pm$ 3.53	16.3 $\pm$ 3.17	19.06 $\pm$ 2.6	< 0.001**	3 > 2 > 1
FH- OP/°	5.09 $\pm$ 2.62	8.73 $\pm$ 3.29	10.91 $\pm$ 3.51	< 0.001**	3 > 2 > 1
FH- POP/°	9.42 $\pm$ 3.87	11.55 $\pm$ 3.18	14.85 $\pm$ 3.33	< 0.001**	3 > 2 > 1
FH- AOP/°	6.59 $\pm$ 3.86	8.31 $\pm$ 3.96	9.6 $\pm$ 3.66	0.046*	3 > 1
FH- U6/°	85.41 $\pm$ 4.36	83.9 $\pm$ 4.7	84.29 $\pm$ 4.96	0.387	NS
FH- L6/°	74.58 $\pm$ 6.27	73.52 $\pm$ 4.76	73.19 $\pm$ 5.67	0.658	NS
skeletal Class II					
PP- OP/°	8.85 $\pm$ 2.21	9.73 $\pm$ 3.22	9.81 $\pm$ 4.03	0.478	NS
MP- OP/°	15.43 $\pm$ 3.71	17.07 $\pm$ 4.7	17.54 $\pm$ 4.29	0.159	NS
FH- OP/°	8.48 $\pm$ 2.72	9.66 $\pm$ 3.58	10.79 $\pm$ 3.94	0.0497*	3 > 1
FH- POP/°	10.76 $\pm$ 3.39	13.1 $\pm$ 3.85	14.93 $\pm$ 4.05	< 0.001**	3 = 2 > 1
FH- AOP/°	8.37 $\pm$ 5.4	8.89 $\pm$ 4.28	10.27 $\pm$ 4.22	0.306	NS
FH- U6/°	85.48 $\pm$ 5.14	83.53 $\pm$ 4.18	82.77 $\pm$ 4.24	0.082	NS
FH- L6/°	73.8 $\pm$ 4.73	70.74 $\pm$ 5.97	70.01 $\pm$ 5.08	0.022*	3 = 2 < 1

data presented as mean $\pm$ SD; NS no significance, * p -value < 0.05 , ** p -value < 0.01

Our results showed that the occlusal plane is related to different positions of the articular discs. We found that the POP angle, rather than the AOP angle, in the DDwoR group is greater than that in the N and DDwR groups, and the DDwoR group had an average decrease in the angle of FH-U6 and FH-L6 compared to the N and DDwR groups. Consistently, previous research has shown that if the premolars are in Class II relationship, a downward and backward rotation on the occlusal plane will cause their occlusion to become a Class I relationship, indicating that the occlusal relationship of the teeth is closely related to the occlusal plane [12]. From the

above results, the impact of DDwR on the occlusal plane of patients is not significant, while the occlusal plane of patients with DDwoR may rotate clockwise relative to normal individuals and reversible disc displacement patients. However, as this study is a cross-sectional study, the causality between the occlusal plane and the articular discs still needs further investigation.

The exclusion of significant cephalometric measurements from the logistic regression analysis might have influenced the results. However, given the inherent inter-correlation among cephalometric measurements, it is not necessarily appropriate to exclude these variables from the analysis, as their mutual influence may be integral to the observed outcomes. To explore the findings, we further conducted binary logistic regression analyses adjusted for ANB, age, and sex, as well as FH-MP, age, and sex, respectively (Table S2). The results showed that FH-U6 had statistically difference. These results suggest that the initial observed differences are likely influenced by the complex interplay among cephalometric variables, but are not valid enough to show whether and which cephalometric measurements should be excluded. Therefore, future studies should focus on developing advanced statistical models that account for these interactions, rather than attempting to eliminate confounding variables.

Although researches denied that dental occlusion plays a vital role in the pathophysiology of TMDs, there still exist some evidence that the position of OP might be associated with the occurrence and development of DD. Increased joint load might be one of the causes of TMD [13]. The changes in the angle and position of the occlusal plane can affect the direction of the occlusal force transmitted to the skull, and affect the stress on TMJ [14, 15]. Research has shown that in patients with TMD, the angle between the posterior oblique plane of the maxillary nodule and the posterior occlusal plane is smaller than that in normal individuals, leading to increased joint stress [16]. Meanwhile, pressure on the posterior oblique plane of the joint fossa has been tested, which revealed that the intra-articular pressure at the maximum opening position was lower than the pressure when biting tightly, and generated by women was significantly higher than that of men [17]. Occlusal bite plate was found to be able to reduce the pressure, indicating the position of the occlusal plane can affect the joint's pressure, and may be one of

Table 6 Regression equation after adjusting confounding factors (N + DDwR as reference)

dependent variable	Non-adjusted			Adjusted		
	Exp(B) (95%CI)	Wald χ^2	p -value	Exp(B) (95%CI)	Wald χ^2	p -value
FH-POP	1.157 (1.056,1.268)	9.793	0.002*	1.145 (1.043,1.258)	8.069	0.005**
FH-U6	0.844 (0.767,0.928)	12.364	< 0.001**	0.854 (0.776,0.939)	10.611	0.001**
FH-L6	0.897 (0.833,0.965)	8.574	0.003**	0.883 (0.812,0.961)	8.407	0.004*

Non-adjusted model adjusts for: None; Adjusted model adjusts for: Age, Sex. Data presented as Exp(B) (95%CI), Wald χ^2 , p -value. * p -value < 0.05 , ** p -value < 0.01

the reasons for the high proportion of patients with TMJ disc displacement in women [17]. In addition, through computer model analysis, clockwise rotation (CW) of OP resulted in an increase in compressive stress on the condylar cartilage, while counterclockwise rotation (CCW) slightly reduced compressive stress on the condylar cartilage. The compressive stress is maintained on the medial surface of the condylar cartilage. Moreover, both CW and CCW increase the pressure on the articular disc, with the former exerting greater stress than the latter [6], indicating the existence of a position where the joint bear the least stress. Orthognathic surgery has also found that the condyle process undergoes remodeling after surgery, which may be caused by changes in occlusion [18]. However, many studies have problems with small sample sizes or unreasonable experimental designs, and further in-depth research is required to better answer the question.

The shape of the TMJ, especially the condyle, may in turn affect the position of occlusal plane [19]. Link and Nixon [18] found that most patients with openbite and Class II malocclusion suffered from DD, and they believed that DD may lead to dental and maxillofacial deformities. Research has shown that in DDwR, the condyle is usually S-shaped, while in DDwoR, it is mostly flat and may be related to TMD [20]. There are also studies found that oblique condyles are more common in joints with DDwoR [21]. Although there are differences in the conclusions, they can all indicate that DDwR rarely brings about condylar resorption, while DDwoR often accompanies condylar resorption, leading to unstable occlusion. Moreover, children wear occlusal bite plates, which means changes in the occlusal plane, can be witnessed a simultaneous change on the growth of the condyle or the joint fossa and the mandible [22]. In addition, the extent of mandibular deviation is positively correlated with the inclination of the occlusal plane [23]. These all revealed that the shape and position of condyle may switch occlusal plane, but more evidence is needed.

The position of the articular disc is also closely related to the development of mandible, and may potentially affect the establishment of occlusal plane. Research has shown that after unilateral DD occurs, the growth rate of the bilateral mandibles is inconsistent, increasing the probability of mandibular deviation [24]. And the longer patients suffer DDwoR, the more severe the cartilage changes [25], and the extent of DD is also related to the severity of cartilage damage [7]. Research has shown that when the condylar cartilage is affected, the growth of the ipsilateral mandible is significantly reduced ($p = 0.025$) compared to normal condition, especially in terms of horizontal growth amplitude [7]. These all demonstrated that DD may affect the development of mandible via cartilage damage. Furthermore, the age at which articular cartilage is damaged is also a contributing factor to

TMD. Mature animals showed TMJ cartilage defects 2 weeks after surgery, while animals during growth period did not show significant damage [26]. This inconsistent outcome may result from better compensation of other tissues, such as the masticatory muscle, during growth period. And there is confirmed correlation between masseter resting tension and TMD [27]. These provide evidence for the connection between DD and occlusal plane, but we need to conduct further research to validate this conclusion.

Clinical relevance

Our findings underscore the association between OP and disc displacement, offering orthodontists valuable insights for pre-treatment precautions and future therapeutic strategies. The study suggests that patients with an inclined OP should undergo thorough TMJ evaluation to assess potential risks. Additionally, individuals with a steeper OP may face an elevated risk of developing TMD or encountering treatment-related complications, highlighting the need for early intervention.

For future orthodontic interventions, clinicians should consider modifying OP, as this approach may enhance occlusal balance and alleviate DD symptoms. In cases of severe skeletal discrepancies, orthognathic surgical correction of OP may be essential to achieve both functional and aesthetic optimization.

Shortcomings

The shortcomings of this article include: (1) DDwoR group only has a small sample size of males, the sample size needs to be expanded; (2) The cephalometric analysis itself has limitations. Although we collected patients with consistent articular disc displacements on both sides to reduce data errors caused by bilateral asymmetry, the data may still be interfered due to overlapping anatomical structures and irregular amplification. When measuring angles and distances, standard data errors may also occur due to individual variations. Three-dimensional detection methods such as CBCT and MRI can be used for further exploration, to analyze the relationship between DD and occlusal plane more accurately and comprehensively; (3) This study is a cross-sectional study, and the causal relationship between articular disc and occlusal plane still needs further investigation; (4) This study was conducted on patients seeking orthodontic treatment, and were unable to include individuals with both normal occlusion and healthy TMJ.

Conclusions

Compared with the other two groups, the DDwoR group possessed different craniofacial features. Additionally, the posterior occlusal plane not anterior or the complete OP, is related to DD. The long axis inclination of first

molar, which may affect the angle of OP, is also associated with DD. With each unit increase in FH-POP, the risk of DDwoR increases by 14.5%, while that in FH-U6 and FH-L6 decrease by 14.6% and 11.7%. In short, there exist association between articular disc position and OP, but the causal relationship cannot be confirmed, and the association might be indirect, further investigation is still needed.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

Y. L.: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Roles/Writing – original draft; Y. Z.: Conceptualization; Data curation; Formal analysis; Methodology; Y. L.: Formal analysis; Validation; Investigation; C. Y.: Formal analysis; Validation; Software; Q. Z.: Validation; Software; X. Z.: Data curation; X. X. and J. W.: Conceptualization; Methodology; Project administration; Resources; Funding acquisition; Supervision; Visualization; Writing – review & editing.

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Data availability

The data presented in this study are available on request from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of West China Hospital of Stomatology, Sichuan University (No. WCHSIRB-CT-2020-418). Informed consent was obtained from all subjects.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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