

Effect of mouth breathing on condylar position in children: A CBCT retrospective study

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Abstract

Objectives

This study aimed to evaluate the effect of mouth breathing (MB) on the condylar position by comparing joint spaces between mouth-breathing and nasal-breathing children aged 7–12 years using cone-beam computed tomography (CBCT).

Methods

244 children aged 7–12 years were categorized as mouth-breathing (n = 124) and nasal-breathing (NB, n = 120) groups. Participants were selected from those who sought orthodontic treatment and had CBCT scans in the Department of Pediatric Dentistry, Zhejiang University Stomatology Hospital from April 2022 to July 2024. Dolphin Imaging software was utilized for three-dimensional reconstruction and measurement of the following joint spaces: anterior, superior, posterior, lateral, and medial. Condylar position was further classified using the condylar ratio. Statistical analysis included t-tests, Mann-Whitney U tests, Wilcoxon signed rank tests and multiple linear regression. $p < 0.05$ was considered statistically significant.

Results

Compared with NB group, MB group showed significantly increased anterior space and decreased superior, posterior, and medial spaces. Condylar ratio analysis revealed a predominance of concentric condyle in MB group, contrasting with anterior condyle predominance in NB group. Additionally, MB group displayed significant bilateral asymmetry in anterior and posterior spaces. Regression analysis confirmed MB independently predicted these positional changes after adjusting for confounders.

Conclusions

MB affects condylar position in children, leading to a more posterior, superior, and medial condylar position compared with nasal-breathing children.

Clinical Relevance

These findings suggest that clinicians should monitor temporomandibular joint status in mouth-breathing children. Early recognition of condylar displacement may guide timely orthodontic intervention to prevent potential joint dysfunction.

Introduction

Mouth breathing (MB) is characterized by a breathing pattern in which airflow enters the airway partially or entirely through the mouth instead of the nose. This phenomenon is a prevalent oral habit among children[1], with an incidence rate ranging from approximately 17% to 50%[2]. MB can be categorized into

obstructive and functional MB². Obstructive MB arises from upper or nasal airway obstructions, whereas functional MB refers to the persistence of MB after obstruction resolution or the habit without any obstructive pathology[3, 4]. Prolonged untreated MB can lead to maxillofacial muscle imbalance due to the posteroinferior rotation of the mandible, resulting in a series of adaptive alterations that affect the growth and development of oral and maxillofacial regions[2, 5, 6].

The mandibular condyle, a key component of the temporomandibular joint (TMJ) and a primary growth center of the mandible, maintains a harmonious relationship with the glenoid fossa under normal conditions[7]. However, the physiological condylar position remains debated. Most studies have focused on the anterior and posterior position of the condyle, while comparatively less attention has been given to the medial and lateral position. Asymptomatic individuals typically exhibit a concentric condyle with the anterior space slightly smaller than the posterior space[8, 9].

In children and adolescents, the condyle undergoes rapid growth due to the active phase of bone metabolism, and MB can affect condylar development during this period[10]. CBCT offers advantages over conventional radiographic techniques in evaluating the TMJ region, and has been widely used for diagnosing TMJ disorders and as a common radiological tool in orthodontic treatment, routinely performed as a standard pre-treatment diagnostic examination for comprehensive treatment planning[11]. Recent CBCT-based studies have indicated that MB may adversely affect the TMJ morphology, including decreased condylar height and a deeper articular fossa[12]. These studies also suggest that MB and sleep disordered breathing could influence the anterior-posterior position of the TMJ, resulting in increased anterior joint space and a posterior condylar position[12, 13]. Posterior displacement of the condyle may increase the risk of anterior disc displacement, thereby inducing temporomandibular joint disorder (TMD)[14]. Multiple animal models have further confirmed that MB can lead to posterior condylar growth, reduced dimensions, and structural damage through mechanisms involving inhibition of chondrogenic differentiation of stem cells, disruption of oxygen-related pathways, and induction of chondrocyte apoptosis[15–18]. Furthermore, multiple signalling pathways—including HIF-1 α /VEGF, RANK-RANKL-OPG, and Sox9/Runx2/Osterix—are involved in MB-related temporomandibular disorder pathology[19]. Together, these mechanistic studies provide important evidence supporting early clinical intervention for MB to prevent abnormal development of the mandible and TMJ.

However, these previous studies did not thoroughly investigate the condylar position and condyle-fossa relationship in mouth-breathing children. Consequently, the present study evaluated whether there are differences in condylar positions and condyle-fossa relationships between mouth-breathing and nasal-breathing children.

Materials and Methods

Sample Size

The sample size for this study was calculated using G*Power software (version 3.1.9.2, Germany), with an effect size of $f = 0.25$ and a significance level of $p = 0.05$. The analysis determined that a sample of 128 children was needed to achieve a statistical power greater than 0.80. To enhance statistical reliability, 244 children were recruited.

Subjects

The study was approved by the ethics board committee, and informed consent was obtained from the parents. All the children were recruited from the Department of Pediatric Dentistry, Zhejiang University Stomatology Hospital between April 2022 and July 2024.

The following inclusion criteria were imposed: (1) aged 7–12 years; (2) clinically diagnosed with MB or those without a history of MB; (3) fully erupted first permanent molars; and (4) availability of complete initial records, including CBCT scans, dental casts, questionnaire survey, intraoral photographs and facial photographs. The exclusion criteria were: (1) previously undergone orthodontic treatment or orthognathic surgery; (2) craniofacial deformities or other developmental disorders; (3) other oral habits; (4) TMJ disorder; and (5) unclear landmarks on CBCT scans.

There is a lack of unified diagnostic criteria for MB. The diagnosis of MB in this study was established based on interrogation, questionnaire survey, clinical examination, breathing tests, radiological examination and otolaryngologist consultation[20–22]. Detailed diagnostic criteria are provided in Supplementary Table S1.

Acquisition and Measurement of condyle-fossa relationship

As part of the standard orthodontic diagnostic protocol at our hospital, all patients scheduled for comprehensive orthodontic treatment undergo pre-treatment CBCT imaging. This examination is routinely performed for three-dimensional cephalometric analysis, assessment of impacted teeth, airway evaluation, and baseline TMJ assessment. Therefore, the CBCT datasets used in this retrospective study were derived from existing patient records obtained during routine clinical care, and no additional radiation exposure was incurred for research purposes.

During the acquisition of CBCT images, participants were instructed to maintain an upright seated position with their heads in a natural posture and their jaws in maximum intercuspation, while refraining from swallowing. The CBCT scans were consistently conducted using an identical protocol on the same cone beam machine (NewTom, Quantitative Radiology, Verona, Italy) with parameters set at 110 kV, 3 mAs, a 15×15 cm field of view, a voxel size of 0.3 mm, and a scan duration of 4.8 seconds. All digital image data were recorded in the Digital Imaging and Communications in Medicine (DICOM) format.

The CBCT data were imported into Dolphin Imaging software (version 11.95) for three-dimensional reconstruction and orientation. In the frontal view, the horizontal reference line was established by

connecting the bilateral orbitales, while the vertical reference line was defined by the nasion and the anterior nasal spine (Fig. 1a). In the right sagittal view, the horizontal reference line was established by connecting the porion and right orbitale (Fig. 1b)[22].

The condylar position-related parameters in the MB and NB groups were measured utilizing the methodologies illustrated in Fig. 2. These parameters include the superior joint space (SS), anterior joint space (AS), posterior joint space (PS), lateral joint space (LS), and medial joint space (MS)[8, 23].

The condylar ratio[24] was used to determine the condylar position. $\text{Condylar ratio} = (\text{PS} - \text{AS}) / (\text{PS} + \text{AS}) \times 100\%$. The condylar ratio of between $\pm 12\%$ was classified as concentric condyle, less than -12% was classified as posterior condyle, and more than $+12\%$ was classified as anterior condyle.

Statistical analysis

All measurements were performed twice by the same investigator, and the average value was used for analysis. To assess measurement consistency, 10 randomly selected patients were re-measured after one month, and intraclass correlation coefficient (ICC) was calculated. Continuous variables were expressed as the mean $\pm$ standard deviation (SD), while the prevalence of categorical variables was expressed as a number and percentage.

For normally distributed data, independent samples t-test was used to compare between MB and NB groups and paired sample t-test was used to compare between AS and PS or LS and MS of the same groups. For non-normally distributed data, the Mann-Whitney U test or Wilcoxon signed rank test was used. Multiple linear regression analysis was performed to analyze the effects of breathing pattern on joint spaces while controlling for gender, age, BMI, Angle classification, skeletal classification, facial profile, and growth pattern. Statistical analyses were conducted using SPSS software (version 27, IBM Corporation, USA). Statistical significance was established at $p < 0.05$.

Results

Demographic and craniofacial characteristics

A total of 244 children (107 boys, 137 girls; mean age 9.2 ± 1.43 years) were enrolled and categorised into two groups: 124 mouth-breathing children (MB group) and 120 nasal-breathing children (NB group, control). The demographic characteristics including age, gender ratio, and BMI showed no statistically significant differences ($p > 0.05$) between the groups (Table 1). However, compared with the NB group, the proportion of children in the MB group with Angle Class II, skeletal Class II, convex profile, and vertical growth pattern was significantly increased (Table 1).

Table 1
Descriptive statistics of demographic and craniofacial characteristics in MB and NB group

Variable		MB group	NB group	p
		n = 124	n = 120	
Age (years)		9.20 ± 1.43	9.20 ± 1.43	0.403
Gender	Male	57 (45.97%)	50 (41.67%)	0.499
	Female	67 (54.03%)	70 (58.33%)	
BMI (kg/m ²)		16.33 ± 2.29	16.33 ± 2.74	0.569
Angle classification	Class I	17 (13.71%)	36 (30.00%)	0.002**
	Class II	98 (79.03%)	70 (58.33%)	
	Class III	9 (7.26%)	14 (11.67%)	
Skeletal classification	Class I	41 (33.06%)	62 (51.67%)	< 0.001***
	Class II	81 (65.32%)	48 (40.00%)	
	Class III	2 (1.61%)	10 (8.33%)	
Facial profile	Straight	18 (14.52%)	50 (41.67%)	< 0.001***
	Convex	105 (84.68%)	63 (52.50%)	
	Concave	1 (0.80%)	7 (5.83%)	
Growth pattern	Vertical	76 (61.29%)	50 (41.67%)	0.003**
	Average	45 (36.29%)	59 (49.17%)	
	Horizontal	3 (2.42%)	11 (9.16%)	
MB: Mouth breathing; NB: Nasal breathing				
** p < 0.01, ***p < 0.001				

Condylar position parameters

Stratified analysis by age groups revealed that the SS in the MB group was reduced compared to the NB group, with the reduction becoming statistically significant in both 9–10 and 11–12 years subgroups (p < 0.01, Table 2).

Significant differences were observed in both AS and PS between MB and NB group. The inter-group comparisons across all age groups confirmed that the MB group had a significantly wider AS and a narrower PS than the NB group (p < 0.01 or < 0.001, Table 2). Intra-group comparison revealed that only

in the 11-12-years MB group was the AS significantly larger than the PS ($p < 0.001$, Table 2), suggesting a potentially more posteriorly positioned condyle in this subgroup. Further comparison of the condylar ratio between the two groups revealed that the NB group had the highest proportion of anterior condyle (72.50%, Table 3), whereas a concentric condyle was most prevalent in the MB group (70.16% on the right, 61.29% on the left, Table 3). MB group had a higher proportion of concentric condyle and posterior condyle as compared to NB group.

Differences in LS and MS were less marked. The only significant inter-group difference was a narrower MS in the 11-12-years MB group compared to NB group ($p < 0.05$, Table 2). The intra-group comparisons showed that in 7–8 years and 11–12 years groups, the LS was significantly less than the MS within the NB group ($p < 0.01$, $p < 0.001$, respectively, Table 2).

Analysis of bilateral joint space differences revealed a significant asymmetry in the anterior and posterior joint spaces of MB group. In contrast, no significant asymmetry was detected in the NB group for any of the joint spaces measured (Table 4).

Table 2
Comparison of joint spaces between MB and NB groups across different age groups

Age group	Joint space (mm)	MB group (Mean $\pm$ SD)	NB group (Mean $\pm$ SD)	p
7–8 years		(n = 43)	(n = 47)	
	SS	2.43 $\pm$ 0.49	2.52 $\pm$ 0.45	0.225
	AS	1.77 $\pm$ 0.40	1.44 $\pm$ 0.23	< 0.001***
	PS	2.01 $\pm$ 0.30	2.27 $\pm$ 0.44	< 0.001***
	AS vs. PS (p)	< 0.001***	< 0.001***	-
	LS	2.12 $\pm$ 0.43	2.03 $\pm$ 0.45	0.187
	MS	2.12 $\pm$ 0.48	2.21 $\pm$ 0.44	0.218
	LS vs. MS (p)	0.944	0.004**	-
9–10 years		(n = 51)	(n = 50)	
	SS	2.34 $\pm$ 0.49	2.57 $\pm$ 0.50	0.002**
	AS	1.73 $\pm$ 0.42	1.62 $\pm$ 0.41	0.006**
	PS	1.95 $\pm$ 0.34	2.18 $\pm$ 0.40	< 0.001***
	AS vs. PS (p)	< 0.001***	< 0.001***	-
	LS	2.09 $\pm$ 0.50	2.16 $\pm$ 0.55	0.381
	MS	2.12 $\pm$ 0.51	2.25 $\pm$ 0.54	0.138
	LS vs. MS (p)	0.741	0.186	-
11–12 years		(n = 30)	(n = 33)	
	SS	2.31 $\pm$ 0.48	2.58 $\pm$ 0.52	0.003**
	AS	1.95 $\pm$ 0.43	1.61 $\pm$ 0.33	< 0.001***
	PS	1.75 $\pm$ 0.28	2.14 $\pm$ 0.36	< 0.001***
	AS vs. PS (p)	< 0.001***	< 0.001***	-
	LS	2.07 $\pm$ 0.49	2.03 $\pm$ 0.41	0.586
	MS	2.18 $\pm$ 0.44	2.36 $\pm$ 0.56	0.047*
	LS vs. MS (p)	0.205	< 0.001***	-

Age group	Joint space (mm)	MB group (Mean $\pm$ SD)	NB group (Mean $\pm$ SD)	p
MB: Mouth breathing; NB: Nasal breathing; SS: Superior joint space; AS: Anterior joint space; PS: Posterior joint space; LS: Lateral joint space; MS: Medial joint space				
* p < 0.05, ** p < 0.01, *** p < 0.001				

Table 3
Condylar position in MB and NB groups based on condylar ratio

condylar position	MB group		NB group	
	right, n = 124	left, n = 124	right, n = 120	left, n = 120
Anterior condyle	27 (21.77%)	37 (29.84%)	87 (72.50%)	87 (72.50%)
Concentric condyle	87 (70.16%)	76 (61.29%)	28 (23.33%)	29 (24.17%)
Posterior condyle	10 (8.06%)	11 (8.87%)	5 (4.17%)	4 (3.33%)
MB: Mouth breathing; NB: Nasal breathing				

Table 4
Bilateral asymmetry of joint spaces

Variable	MB group n = 124	p	NB group n = 120	p
Δ SS	0.02 $\pm$ 0.25	0.481	0.01 $\pm$ 0.30	0.778
Δ AS	-0.05 $\pm$ 0.20	0.031*	0.01 $\pm$ 0.21	0.502
Δ PS	0.06 $\pm$ 0.24	0.004**	0.04 $\pm$ 0.27	0.170
Δ LS	-0.01 $\pm$ 0.25	0.677	0.04 $\pm$ 0.34	0.112
Δ MS	-0.002 $\pm$ 0.28	0.936	-0.03 $\pm$ 0.31	0.237
MB: Mouth breathing; NB: Nasal breathing				
* p < 0.05, ** p < 0.01				

Multiple linear regression analysis

Multiple linear regression analysis, adjusted for demographic and craniofacial confounders, identified the breathing pattern as a significant independent predictor of joint space. MB was a significant positive predictor of the AS ($\beta = 0.255$, $p < 0.001$) and a significant negative predictor of the PS ($\beta = -0.271$, $p < 0.001$), SS ($\beta = -0.171$, $p < 0.001$), and MS ($\beta = -0.137$, $p < 0.01$). No significant association was found with the LS (Table 5).

Table 5
Multiple linear regression analysis of factors affecting the joint spaces

Variable		β P				
		AS	PS	SS	LS	MS
(Constant)		1.197***	2.827***	15.522***	1.993***	2.378***
Breathing pattern (Control group: NB)		0.255***	-0.271***	-0.171***	0.005	-0.137**
Gender (Control group: Male)		-0.096**	-0.011	-0.055	-0.019	-0.215***
Age		0.027*	0.069***	-0.044**	-0.017	-0.006
BMI		0.010	0.003	-0.01	0.013	0.011
Angle classification (Control group: Class I)	Class II	-0.012	-0.040	0.121*	0.014	0.041
	Class III	-0.117	-0.036	-0.046	0.080	-0.078
Skeletal classification (Control group: Class I)	Class II	0.066	0.076**	0.059	0.268***	-0.066
	Class III	0.083	0.123	-0.231	-0.152	0.035
Facial profile (Control group: Straight)	Convex	0.032	-0.064	-0.019	-0.034	0.090
	Concave	-0.102	-0.089	0.091	-0.193	-0.219
Growth pattern (Control group: Average)	Vertical	-0.069	-0.160***	-0.374***	-0.167***	-0.276***
	Horizontal	0.064	-0.061	0.098	0.204*	0.012
R ²		0.168	0.239	0.206	0.125	0.162
Adjusted R ²		0.147	0.219	0.186	0.103	0.141
D-W		2.045	1.887	2.178	2.034	1.970
F		7.992	12.401	10.289	5.635	7.649
Sig/p		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
* p < 0.05, ** p < 0.01, *** p < 0.001						

Discussion

This study aimed to investigate the effect of MB on condylar position in children using CBCT imaging. Our findings demonstrate that mouth-breathing children exhibit significant alterations in condylar position, including posterior, superior, and medial displacement, along with notable asymmetries in joint

spaces, compared to nasal-breathing children. These results underscore the potential influence of MB patterns on TMJ development and highlight the need for early evaluation and orthodontic treatment.

The baseline characteristics revealed MB group showed a higher prevalence of Angle Class II malocclusion, skeletal Class II malocclusion, convex profile, and vertical growth pattern. These findings are consistent with previous studies[25, 26], indicating that MB is associated with specific craniofacial phenotypes, likely due to adaptive mandibular rotation[27] and imbalance of orofacial muscle forces[25, 28].

The anterior and posterior position of the condyle in the glenoid fossa is a focus of research on the condylar position. Ikeda et al. using limited CBCT found that the condyle of asymptomatic patients was positioned anteriorly in the sagittal view, and the ratio of AS to SS to PS was 1.0 to 1.9 to 1.6[8]. Jong-Moon Chae et al. later confirmed that children of different age groups and skeletal patterns exhibited similar sagittal condyle-fossa relationships as the former[29]. The nasal-breathing children in this study also demonstrated similar characteristics of condylar position (Tables 2 and 3). In contrast, mouth-breathing children in this study exhibited a posteriorly displaced condyle, a trend that was particularly pronounced in older age groups (Tables 2 and 3). Lu Jie et al. also identified that mouth-breathing children displayed an expanded AS, but reported no significant change in PS[12]. This discrepancy may be attributed to our larger sample size, which provided greater statistical power to detect subtle differences in PS. This posteriorly displaced condylar position of mouth-breathing children may be attributed to mandibular backward and downward rotation as compensatory mechanisms for airway stenosis[27]. Additionally, an organ culture model demonstrated that mandibular function in an open position (simulating MB) directs mesenchymal cell differentiation toward chondrogenesis in the posterior condyle, resulting in posteriorly directed condylar growth[15]. providing direct experimental support for our clinical finding. Moreover, multiple animal studies have elucidated broader mechanisms by which MB affects condylar development. Wang et al. showed that nasal obstruction suppresses chondrogenic differentiation of condylar mesenchymal stem cells, as evidenced by reduced Sox9, Col2a1, and Acan expression[16]. Hu et al. demonstrated that MB induces tissue hypoxia and activates the Hif-1 α /Vegf axis, indicating oxygen-related pathway disruption[17]. Furthermore, Wang et al. revealed that MB triggers chondrocyte apoptosis via both extrinsic and intrinsic pathways[18]. These mechanistic studies support that prolonged MB adversely affects condylar growth and may contribute to the positional alterations observed in our study. The posterior displacement of the condyle may increase the risk of anterior disc displacement, leading to TMD[14].

Limited studies have discussed the LS and MS in symptomatic or asymptomatic patients in the coronal view. Ikeda et al. demonstrated that the mean ratio of LS to MS was 1.0 to 1.3 in asymptomatic patients, suggesting that the condyle in asymptomatic patients was in a slightly lateral position[23]. It was consistent with the results of nasal-breathing children in this study (Table 2). However, there was no significant difference between the LS and MS of mouth-breathing children. This may reflect lateral condylar resorption or medial condylar remodeling, potentially as part of the broader condylar adaptive

response to altered biomechanical loading. However, further longitudinal and histological studies are needed to elucidate the underlying mechanisms.

The SS of both mouth-breathing and nasal-breathing children was greater than that of other joint spaces in this study (Table 2), which was consistent with previous research[8, 23]. A noteworthy finding was the reduced SS and a superiorly positioned condyle in mouth-breathing children, particularly in the 9–12 age groups (Table 2), suggesting that the risk of superiorly positioned condyle in mouth-breathing children might increase with age and duration of MB. This might be related to the backward and downward rotation of the mandible to compensate for airway stenosis[27]. It was found that patients with anterior disc displacement had a higher condyle position, suggesting that mouth-breathing could affect condyle position which might increase the risk of TMD[14].

Furthermore, mouth-breathing children exhibited significant asymmetry in bilateral anterior and posterior joint spaces, which was not observed in nasal-breathing children (Table 4). In patients with malocclusion, mild asymmetry of the condyle-fossa relationship was commonly observed, and the left condyle more anteriorly positioned than the right[29–31]. The condylar asymmetry might due to normally cranial base asymmetries and side preferences during mastication[31]. We speculated that the reason for the condylar asymmetry in the MB group might be that MB might cause anteriorly and posteriorly asymmetric absorption, which required further validation through animal experiments. Besides, this might also be related to the increased proportion of patients with malocclusion (especially Angle Class II and skeletal Class II) in mouth-breathing children[32] (Table 1).

Multiple linear regression analysis confirmed that MB significantly influenced condylar position parameters, including AS, PS, SS and MS, even after controlling for confounding variables (Table 5). Notably, MB was positively associated with AS and negatively associated with PS, SS, and MS. These results suggest that MB may lead to a posteriorly and superiorly displaced condyle within the glenoid fossa. Thus, this study further analyzed the differences in condylar position parameters between two breathing types across different age groups.

The clinical significance of condylar position and its relationship with TMD remains a matter of controversy[33, 34]. Nonetheless, the condylar position is crucial for functional balance. Changes of the condylar position may cause the articular disc to shift forward or backward, leading to articular disc dysfunction and ultimately causing TMD[35]. Clinical evidence indicates that mouth-breathing in children is associated with a markedly elevated risk of developing TMD[36] and a heightened susceptibility to TMD-related symptomatology[21]. Nevertheless, CBCT analysis of condylar position is important for identifying potential risk factors for TMJ disorders. The results of this study emphasized the adverse effects of mouth-breathing in children on the condylar position, as well as the necessity of early intervention and close screening for mouth-breathing children before early orthodontic treatment.

Several limitations should be acknowledged. The fact that not all children underwent otolaryngologist consultation, despite a structured diagnostic protocol, may have led to underdiagnosis of mild or intermittent mouth breathing, potentially attenuating the observed associations. The cross-sectional

design does not allow causal inference between MB and condylar position changes. The absence of direct TMD assessment means that the relationship between condylar displacement and TMD symptoms remains speculative. Future prospective longitudinal studies should clarify causality and explore whether early intervention can reverse these condylar alterations.

Conclusion

This study demonstrates that MB is associated with a posterior, superior, and medial condylar displacement along with notable asymmetries in the anterior and posterior joint spaces in children, which may be a potential risk factor for TMD. These findings highlight the need for both clinical recognition of MB and radiographic assessment of condylar position in children receiving orthodontic care.

Declarations

Author Contributions

All authors made a substantial contribution to the manuscript, critically revised the text, and agreed with its contents. Conceptualization: Zhifang Wu and Yafen Zhu; Methodology: Zhifang Wu, Yafen Zhu and Jian Wang; Data curation: Jian Wang, Ran Chen, Tao Qiu, Jin Zhao, Xiangtao Liu, Xiao Zhu, Junzhuo Gou and Yafen Zhu; Formal analysis, investigation and visualization: Jian Wang; Writing: Ran Chen and Jian Wang; Review and editing: Zhifang Wu and Yafen Zhu; **Co-first authors: Jian Wang and Ran Chen; Co-corresponding authors: Zhifang Wu and Yafen Zhu.**

Conflict of Interests

The authors declare that there are no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available upon request from the corresponding author.

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Figures

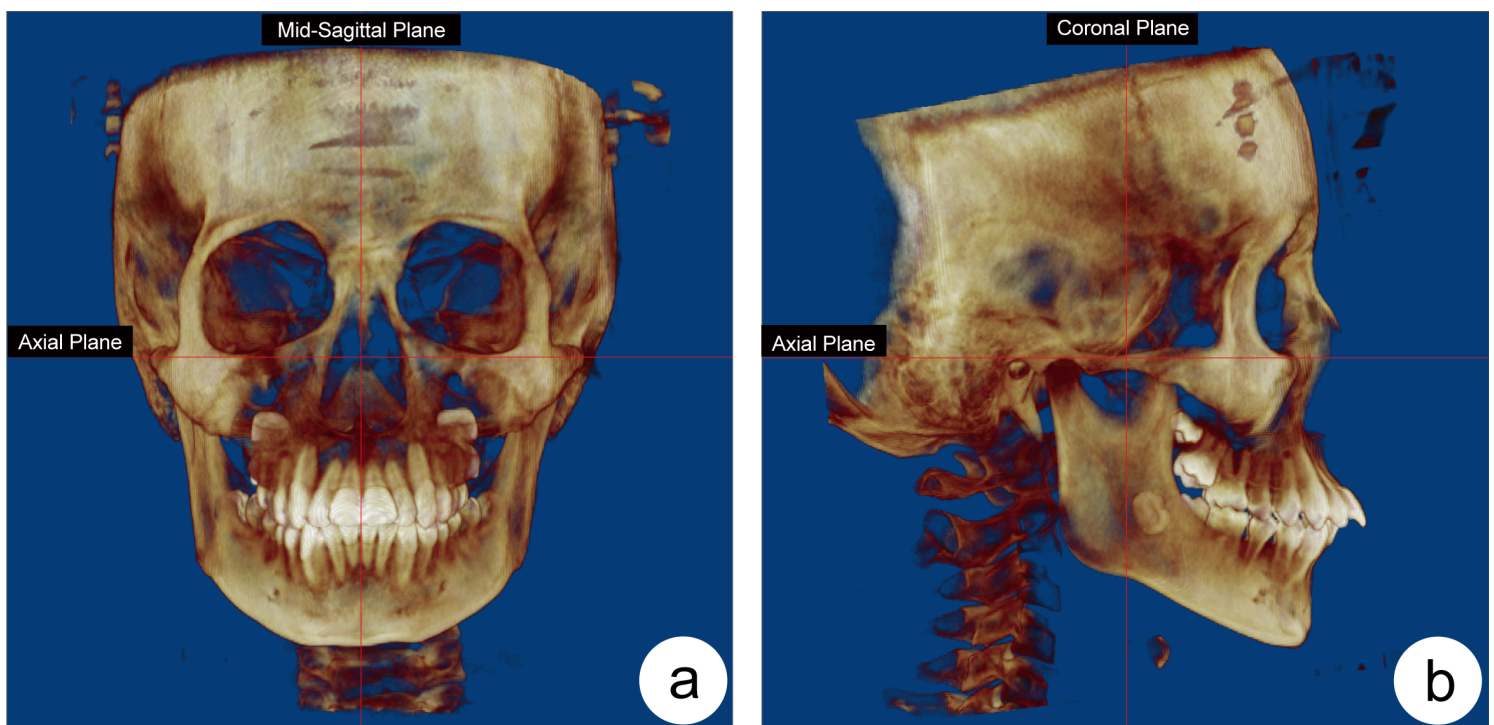


Figure 1

CBCT scan orientation. (a) Frontal view. (b) Right sagittal view.

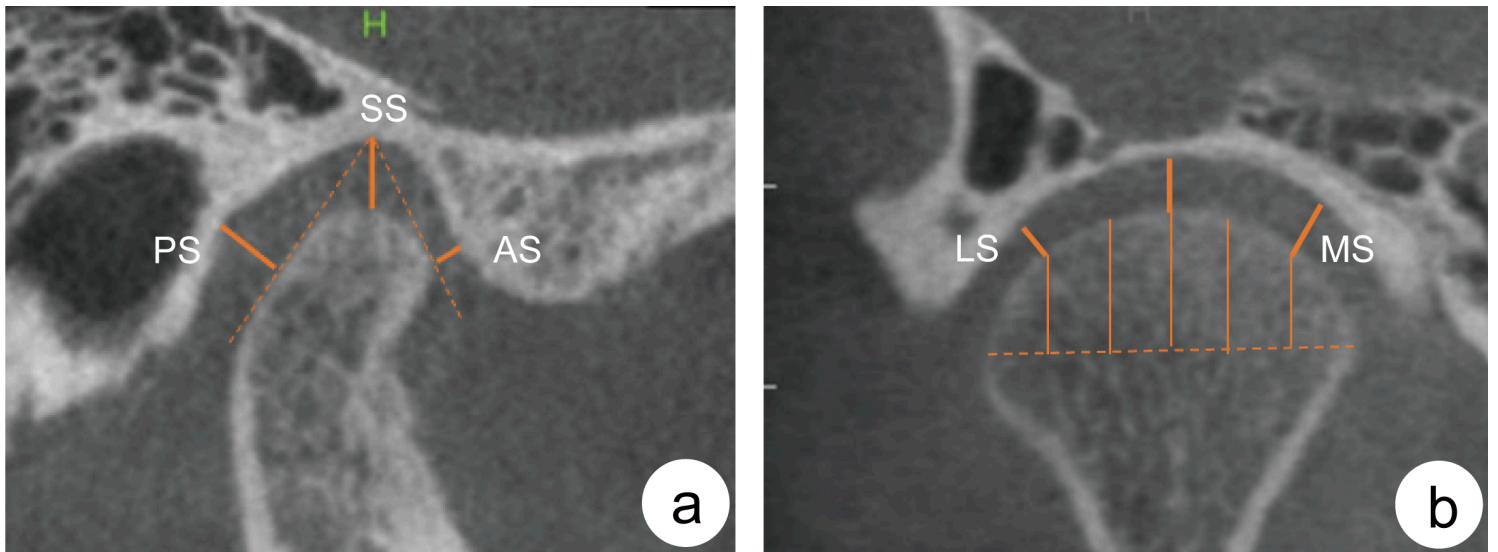


Figure 2

Schematic diagrams of TMJ position measurements. (a) Sagittal view. (b) Coronal view. SS: superior joint space (The distance from the uppermost point of the condyle to the most superior aspect of the glenoid fossa); AS: anterior joint space (The distance from the anterior tangent point of the condyle to the glenoid fossa); PS: posterior joint space (The distance from the posterior tangent point of the condyle to the glenoid fossa); LS: lateral joint space (The distance from the coronal lateral point of the condyle to the glenoid fossa); MS: medial joint space (The distance from the coronal medial point of the condyle to the glenoid fossa).

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