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Relationship between temporomandibular joint space and articular disc displacement

Linyi Zhou[1†], Kejin Tao[2†], Jinjin Ma[3], Xianglong Pan[1], Kedie Zhang[1] and Jianying Feng[1*]

Abstract

Objective Analyse the correlation between the changes in joint space of TMJ and the displacement and degree of articular disc for clinical diagnosis.

Methods Two hundred sixteen TMJs of 108 temporomandibular disorders (TMD) patients with clinical symptoms and MRI examination were included in the study. 30 of these patients had undergone CBCT before MRI. According to the degree of articular disc displacement, the 216 joints are divided into five groups. Group A: no disc displacement (40 cases); group B: mild anterior disc displacement (44 cases); group C: moderate anterior disc displacement (36 cases); group D: severe anterior disc displacement (52 cases); group E: posterior displacement (44 cases). The 132 sides of these anteriorly displaced discs (ADD) were further divided into two groups, anterior disc displacement with reduction (ADDwR) and anterior disc displacement without reduction (ADDwoR). We analysed the concordance of the joint space measured by MRI and CBCT, and explored the relationship between joint space, ln(P/A) values and joint disc displacement.

Results There was no statistically significant difference between the joint spaces measured by CBCT and MRI ($P > 0.05$). The anterior joint space in group B (2.7 ± 0.72 mm) and C (2.82 ± 0.88 mm) was larger than group A (1.82 ± 0.50 mm) ($P < 0.05$), and ln(P/A) value in group B (-0.52 ± 0.34) and C (-0.62 ± 0.43) was smaller than group A (0.04 ± 0.15) ($P < 0.05$). The posterior joint space (3.33 ± 1.28 mm) and ln(P/A) value (0.74 ± 0.33) in group E was larger than group A ($P < 0.05$). There was no significant difference in the anterior, superior and posterior joint space and ln(P/A) value between group D and A ($P > 0.05$). The ADDwR group had a larger anterior joint space (2.72 ± 0.83 mm) than group A ($P < 0.05$), while having a smaller posterior joint space (1.61 ± 0.49 mm) and ln(P/A) value (-0.52 ± 0.39 mm) ($P < 0.05$). Compared with group A, there was no significant difference in the anterior joint space and ln(P/A) value in the ADDwoR group($P > 0.05$).

Conclusion There is no significant change in anterior, supra, and posterior joint space in severe anterior disc displacement. The anterior joint space increases in mild to moderate anterior disc displacement, but does not change in severe anterior disc displacement—the posterior joint space increases when the joint disc is displaced posteriorly. The position of the joint disc cannot be accurately inferred by observing the joint space through CBCT, and a combination of MRI and clinical examination is required to make a definitive judgement.

Keywords MRI, Joint space, ADD, TMD

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Introduction

The temporomandibular joint (TMJ) consists of the articular surface of temporal bone, condyle, articular disc, joint capsule and articular ligament [1]. The articular disc plays an important role in absorbing shock and relieving pressure during the realization of various physiological functions such as chewing and speaking [2]. The condyles are powerfully adaptive, constantly remodelling their shape and position to accommodate tooth wear and occlusal changes. Even so, temporomandibular disorders (TMD) are still one of the most common and frequent disorders of the maxillofacial region [3], the prevalence of TMD reported in the different literatures varies widely, ranging from 7 to 84% [4, 5], occurring in young adults and more often in women [6]. Joint disc displacement is the most common type of TMD and belongs to the category of joint structure disorders, of which ADD is the most common [7]. ADD is divided into ADDwR and ADDwoR according to whether the disc can return to normal position when opening.

Clinical diagnosis of TMD includes clinical examination and imaging examination [8, 9]. Imaging examinations mainly include X-ray plain film, arthrography, CBCT, MRI [10]. MRI can clearly show condylar process, articular disc, and periarticular tissues, and is noninvasive. It is considered the gold standard for assessing TMD [11]. MRI allows for dynamic imaging to observe changes in the joints during movement, which can help assess joint function. However, general dental hospitals are not equipped with MRI equipment, and MRI examination requires patient cooperation, so CBCT is still the preferred auxiliary examination method for TMD in most cases [10]. Some clinicians observe the change of the joint space with the help of CBCT and then speculate about the joint disc [12]. However, the relationship between joint gap changes and joint disc displacement has been controversial [13].

The objective of this study was to analyse the correlation between the changes in joint space of TMJ and the displacement and degree of articular disc, and to provide a reference for clinical diagnosis of the displacement and degree of articular disc.

Materials and Methods

Collection of research subjects

108 patients (216 lateral joints) who attended Zhejiang Aibo Medical Imaging Diagnostic Centre from January to December 2023 were selected for the study. These patients underwent bilateral TMJ MRI for the presence of TMD-related clinical symptoms. The age ranged from 11 to 34 years, with a mean of (21.20 ±5.92) years, of which 26 were male (52 joints) and 82 were female (164 joints). Tracing these 108 patients, 30 of them (60 joints) underwent bilateral TMJ CBCT at the Stomatological Hospital of Zhejiang Chinese Medicine University before MRI, and the interval between the two examinations was not more than 3 months. There were 12 males and 28 females, aged 13–28 years, with a mean of (23.60 ±6.26) years.

Inclusion and exclusion criteria

The DC/TMD (Diagnostic Criteria for Temporomandibular Disorders) standardized protocol and diagnostic taxonomy are indeed highly desirable and widely recognized as essential tools in TMD clinical studies [14]. Inclusion criteria: (1) Patients had TMD symptoms (pain, abnormal jaw movement, joint popping and murmur, and one of the other symptoms [15]) on at least one side of the TMJ; (2) The time interval between the TMJ CBCT and MRI examination was not more than 3 months; (3) No history of maxillofacial trauma, orthodontic treatment, or TMJ treatment; (4) No history of rheumatism, rheumatoid and other systemic diseases. Exclusion criteria: (1)The presence of clinically detectable facial asymmetries; (2) Poor quality of MRI images for poor recognition; (3) Contraindications to MRI examination.

CBCT image acquisition

All 30 patients underwent scanning of bilateral TMJs on the same LARGEV Smart 3D Oral CBCT machine.

Parameter settings: exposure conditions were 100 kV, 4 mA, field of view was 15 cm ×9 cm and 12.5 s exposure time. Scanning position and method: the patient took a standing position, fixed the head, so that the patient's Frankfurt Horizontal (FH) plane was parallel to the horizontal plane, and the median sagittal plane was perpendicular to the horizontal plane. During scanning, the patient was instructed to maintain the posterior teeth in maximum intercuspal position (ICP) [16].

Image reconstruction and processing: TMJ images were reconstructed and processed using the software that came with the CBCT to obtain TMJ reconstructed images in axial, sagittal and coronal sections. Then the reconstructed images were corrected. On the axial image, the interface that could show the largest cross-section of the condyle was selected, and the plumb line of the long axis of the condyle was made to get the corrected oblique sagittal position. The parallel line of the long axis of the condyle was made to get the corrected oblique coronal position.

MRI image acquisition

All 108 patients underwent scanning of bilateral TMJs on the same Siemens 3.0 T superconducting MRI machine.

Parameter settings: PDWI sequence: Time reverse (TR) =2000 ms, Time echo (TE) =28 ms, Field of view (FOV)

= 140 mm × 140 mm, matrix size = 192 × 192, number of layers = 18, layer thickness = 3 mm, layer spacing = 0.1 mm. T2 WI sequence: TR = 3470 ms, TE = 75 ms, FOV = 160 mm × 160 mm, matrix size = 320 × 320, number of layers = 18, layer thickness = 3 mm, layer spacing = 0.1 mm.

Scanning position and method: the patient was placed in a flat position, the head was fixed, the Frankfurt horizontal plane was made perpendicular to the horizontal plane, and the centre of the coil was placed 2 mm in front of the patient's tragus. In the closed position, the patient was instructed to occlude to the ICP; in the open position, the patient was instructed to hold the cotter, slowly open, keep the head immobile, and open the cotter to a comfortable position until it could not be opened (about 3.5 cm or more), and the patient should not be instructed to force the cotter to open forcefully by forcing the patient to endure the pain.

After scanning was completed, MRI images were recorded in DICOM format. Images of MRI opened and closed mouth oblique sagittal T2 weighted imaging (T2 WI), and proton density weighted imaging (PDWI) sequences of 216 lateral joints of 108 patients were collected respectively.

Experimental grouping

Grouping according to the displacement and degree of the articular disc

The normal disc position is the boundary between the low signal of the disc and the high signal of the retrodiscal tissue, located between the 11:30 and 12:30 clock positions [17]. In clinical practice, the position of the articular disc is generally expressed by the disc delimitation angle. Referring to the diagnostic criteria of Drace [18], in the MRI closed oblique sagittal position, there is a distinct demarcation line between the posterior band of the articular disc and Bilaminar Zone called disc-condyle line, and the angle formed by it and the 12-point plumb line of the condylar eminence is the disc-condyle angle. This means disc-condyle angle between 15° anteroposteriorly is a normal disc relationship (Fig. 1 A). More than 15° anteriorly is an anterior displacement of the disc (Fig. 1 B-D), and more than 15° posteriorly is a posterior displacement of the disc [17, 19, 20] (Fig. 1 E). The 216 lateral joints were classified into 3 major groups according to the size of the disc delimitation angle, no articular disc displacement, ADD, and posterior disc displacement [21]. And further classified ADD into 3 groups according to the degree of anterior disc displacement, mild, moderate, and severe ADD [21, 22] (Groups B, C, and D) (Table 1).

Grouping according to the type of articular disc displacement

There were 132 cases of ADD (Group B + Group C + Group D) in the 216 lateral joints. Anterior disc displacement was divided into ADDwR and ADDwoR according to whether the joint disc returned to its normal position in opening (Table 2).

Table 1 Grouping of joint disc displacement and degree

Group	Degree of disc displacement	Disc–condyle angle(°)	Number of joint sides
A	normal disc position	– 15—15	40
B	mild ADD	16—50	44
C	moderate ADD	51—80	36
D	severe ADD	≥ 81	52
E	posterior displacement	≤ – 16	44
total			216

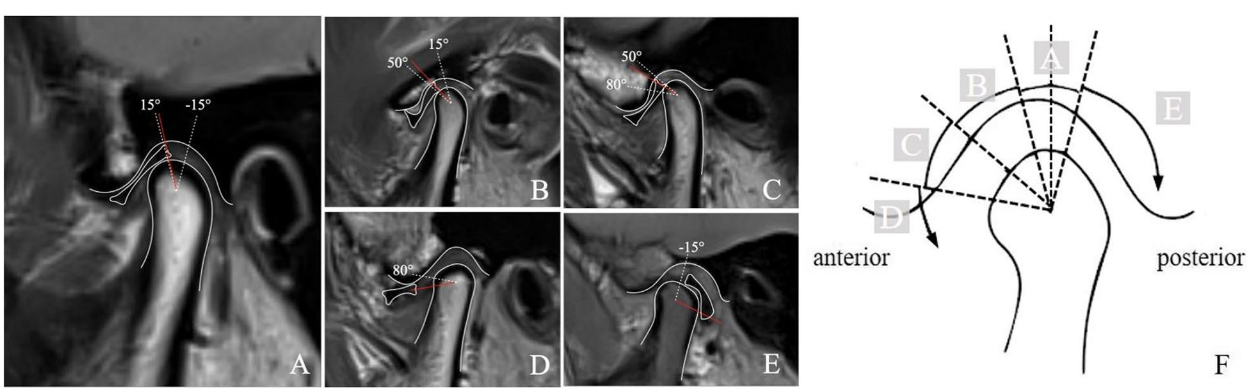

Fig. 1 Schematic diagram of the grouping of disc displacement and degree. **A** Normal disc position (disc-condyle angle: – 15–15°). **B** Mild ADD (disc-condyle angle: 16–50°). **C** Moderate ADD (disc-condyle angle: 51–80°). **D** Severe ADD (disc-condyle angle: ≥ 81°). **E** Posteriorly displaced articular disc (disc-condyle angle: ≤ – 16°). **F** Schematic diagram of five groups

Table 2 Grouping of disc displacement types

Types	Number of joint sides
ADDwR	83
ADDwoR	49
total	132

Measurement method for joint space

The Kamelchuk [23] method was used to measure the joint space: two horizontal lines L1 and L2 parallel to the plane of the FH plane, L1 and L2 were tangent to the joint fossa and the superior edge of condyle, and the perpendicular distance between L1 and L2 was the supra-articular gap, which was denoted by S. The tangents L3 and L4 to the anterior and posterior margins of condyle were made through the tangent point of the superior margin of articular fossa. A plumb line of L3 and L4 was made through the tangent point of the anterior and posterior margin of the condyle. A indicating the anterior joint space and P indicating the posterior joint space.

The CBCT corrected oblique sagittal images were centred and imported into AutoCAD, and the anterior, superior and posterior joint spaces were measured (Fig. 2 A). In the MRI closed oblique sagittal PDWI sequence, the image showing the maximum transverse diameter of the condyle was selected (most of them chose the intermediate interface), fixed and imported into AutoCAD. The anterior(A), superior(S), and posterior joint spaces(P) were measured (Fig. 2 B), and the ln(P/A) value means the logarithmic function of P/A, which means the proportional relationship between posterior and anterior joint space [24]. A value of ln(P/A) < -0.25 indicates that the condyle is in a posterior position in the articular fossa; ln(P/A) >0.25 indicates that the condyle is in an anterior position in the articular fossa; and a value of ln(P/A) between -0.25 and $+0.25$ indicates that the condyle is in an essentially neutral position.

Statistical analysis

The fixation and measurement of all CBCT and MRI images in this study were carried out by two imaging-trained dentists, and the measurements were repeated three times and averaged. All CBCT and MRI images were numbered before measurement to ensure that other information about the images was unknown to the surveyors and subjective interfering factors were removed as much as possible. The data were analyzed and plotted by Graphpad Prism 8.0. One-way analysis of variance and Student *t*-test were used to identify significant differences of the groups. Data were expressed as mean ± standard deviation (SD). If $P< 0.05$, it was considered statistically significant.

Results

Comparison of joint space measured by CBCT and MRI

The joint space measured by CBCT and MRI were shown in Table 3. The results showed that the difference between the right and left joint space on both CBCT and MRI was not statistically significant ($P> 0.05$).

Table 3 Comparison of joint space measured by CBCT and MRI

Measurement location	CBCT	MRI	*t* value	*P* value
right				
anterior joint space (mm)	2.24 ± 1.11	2.14 ± 0.71	− 0.678	0.508
supra joint space (mm)	2.62 ± 0.92	2.75 ± 0.87	1.049	0.311
posterior joint space (mm)	1.78 ± 0.77	1.83 ± 0.61	0.340	0.739
left				
anterior joint space (mm)	2.59 ± 1.08	2.52 ± 0.91	− 0.520	0.611
supra joint space (mm)	2.69 ± 0.85	2.76 ± 0.82	0.396	0.698
posterior joint space (mm)	1.86 ± 0.77	2.11 ± 0.80	1.860	0.083

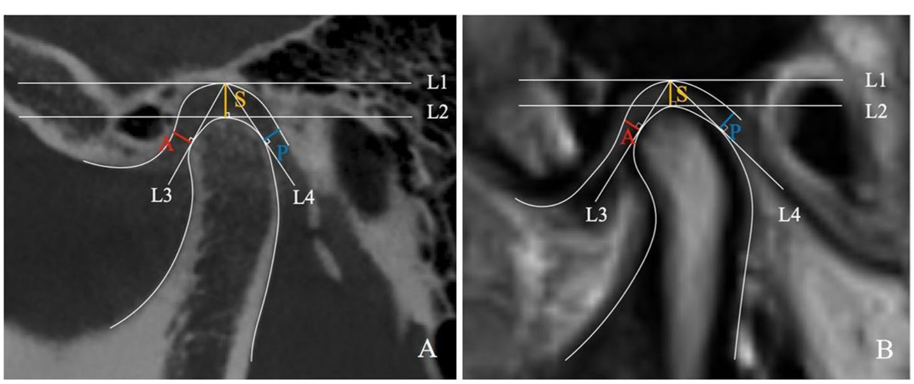

Fig. 2 Kamelchuk's method for measuring CBCT (**A**) and MRI (**B**) articular clearance

Relationship between joint space and articular disc displacement and its extent

Measurements of joint space and ln(P/A) values in the five groups were shown in Table 4 and Fig. 3. The results showed that the anterior joint space of Groups B and C were larger than Group A, and the ln(P/A) values were smaller than Group A ($P < 0.05$). The supra and posterior joint space were not significant compared to those in Group A ($P > 0.05$). The joint space and the ln(P/A) values of Group D were not significant compared with Group A ($P > 0.05$). The posterior joint space and ln(P/A) values of Group E were larger than Group A ($P < 0.05$), and the difference between anterior and superior joint space was not statistically significant ($P > 0.05$).

The relationship between changes in joint space and types of disc displacement

The measurements of joint space and ln(P/A) values in Group A, ADDwR and ADDwoR were shown in Table 5 and Fig. 4. The anterior joint space in ADDwR was larger than Group A, and the posterior joint space and ln(P/A) values were smaller than Group A ($P < 0.05$). The supra joint space was statistically insignificant ($P > 0.05$). In ADDwoR, the joint space and ln(P/A) values were statistically insignificant compared with Group A ($P > 0.05$).

Discussion

Joint space changes are one of the important imaging manifestations of TMD. However, the relationship between joint space changes and joint disc displacement has been controversial. In our study, the mean anterior space, superior space, and posterior space values in normal disc position were 1.82 ±0.5 mm, 2.75

Table 4 Measurements of joint space and ln(P/A) values in each group

Measurement location	Group A	Group B	Group C	Group D	Group E	*F* value	*P* value
anterior joint space (mm)	1.82 ± 0.50	2.78 ± 0.72*	2.82 ± 0.88*	2.05 ± 0.66	1.55 ± 0.50	31.213	< 0.001
supra joint space (mm)	2.75 ± 0.85	2.63 ± 0.81	2.46 ± 0.79	2.55 ± 0.94	3.04 ± 1.19	1.971	0.104
posterior joint space (mm)	1.89 ± 0.56	1.67 ± 0.49	1.52 ± 0.42	1.88 ± 0.57	3.33 ± 1.28#	20.523	< 0.001
ln(P/A)	0.04 ± 0.15	− 0.52 ± 0.34▵	− 0.62 ± 0.43▵	− 0.08 ± 0.18	0.74 ± 0.33▵	100.026	< 0.001

(* indicates comparison with the anterior joint space of group A, $P < 0.05$; # indicates comparison with the posterior joint space of group A, $P < 0.05$; ▵ indicates comparison with the ln(P/A) of group A, $P < 0.05$)

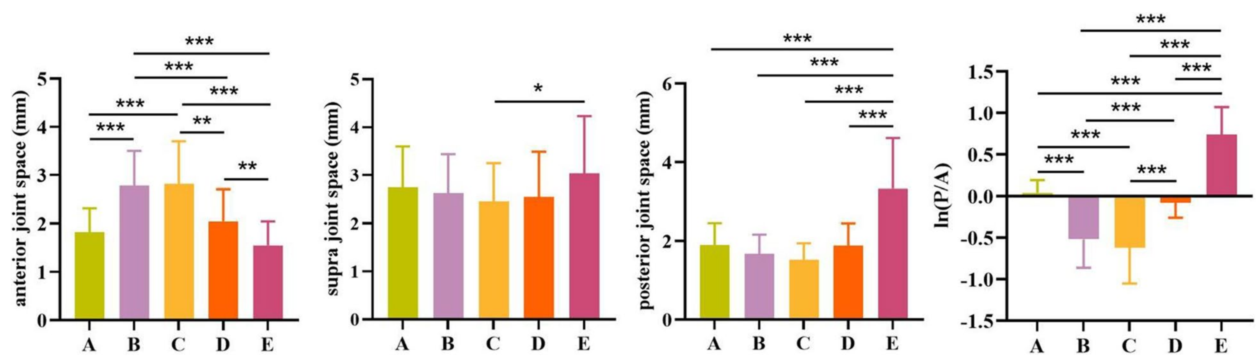

Fig. 3 Comparison of joint space and ln(P/A) values in groups A, B, C, D and E. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Table 5 Measurements of joint space and ln(P/A) in group A, ADDwR and ADDwoR groups

Measurement location	Group A	ADDwR	ADDwoR	*F* value	*P* value
anterior joint space (mm)	1.82 ± 0.50	2.72 ± 0.83*	2.07 ± 0.57	27.254	< 0.001
supra joint space (mm)	2.75 ± 0.85	2.58 ± 0.84	2.51 ± 0.88	0.950	0.389
posterior joint space (mm)	1.89 ± 0.56	1.61 ± 0.49#	1.90 ± 0.54	6.231	0.002
ln(P/A)	0.04 ± 0.15	− 0.52 ± 0.39▵	− 0.09 ± 0.20	58.114	< 0.001

(* indicates comparison with the anterior clearance of group A, $P < 0.05$; # indicates comparison with the posterior joint space of group A, $P < 0.05$; ▵ indicates comparison with the ln(P/A) of group A, $P < 0.05$)

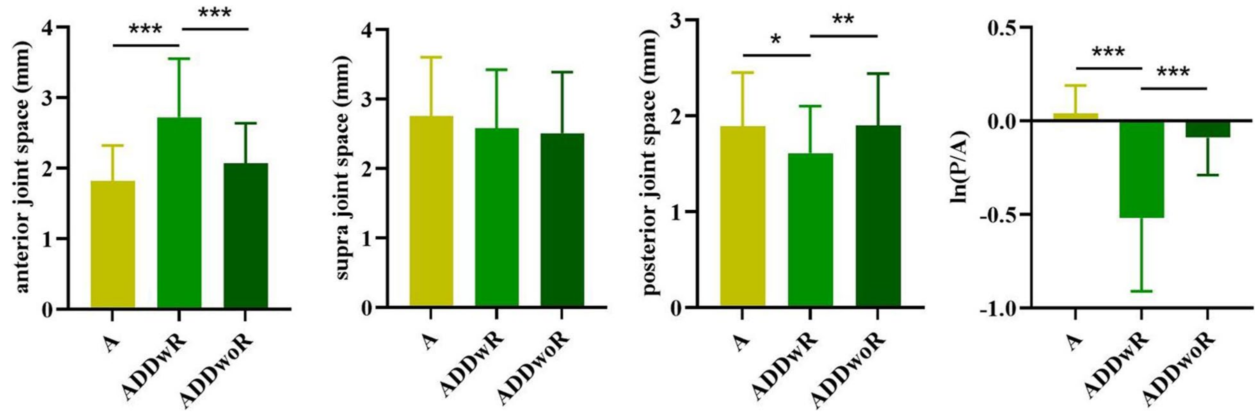

Fig. 4 Comparison of joint space and ln(P/A) values in groups A, ADDwR and ADDwoR. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

± 0.85 mm, and 1.89 ± 0.56 mm, and the ratio was 1.00 to 1.51 to 1.03. Wang [1] measured the joint spaces of 40 healthy adults by CBCT, and the measurements showed that the anterior joint space: 2.08 ± 0.47 ~ 2.12 ± 0.51 mm, the supra joint space: 2.63 ± 0.39 ~ 2.71 ± 0.42 mm, and the posterior joint space: 2.09 ± 0.40 ~ 2.16 ± 0.44 mm. Our results are similar to Wang's. Interestingly, Ikeda [25] proposed the ratio of anterior to superior to posterior joint space was 1.0 to 1.9 to 1.6. Alqhtani [26] believed that there were significant individual differences in joint space, which was influenced by factors such as age and gender. Even so, in most cases the anterior and posterior joint spaces are approximately equal in healthy people, with the condyles located in the so-called central position [27]. Therefore, we believe the observation of the joint space or condylar position is still clinically relevant [28].

The degree of anterior disc displacement can lead to changes in the joint space. In our study, mild and moderate anterior disc displacement resulted in an increase in joint anterior space and ln(P/A) value decreased, whereas there was no change in the anterior space and ln(P/A) value in severe anterior disc displacement. This result suggests that when the joint disc is mildly to moderately anteriorly displaced, the condyle is posteriorly displaced. When the anterior displacement of the joint disc exceeded a certain degree, the joint space and condylar position gradually returned to normal [29]. Zhu [30] found the condyle was displaced superiorly and posteriorly in the ADD by MRI. Xiang [31] obtained the same conclusion through CBCT. Ozawa [32] found the anterior joint space was increased and the posterior joint space was decreased in mild and moderate ADDwR group, whereas there was no change in the posterior joint space in the severe ADDwR group compared to the control group. This is consistent with our conclusions.

Articular disc displacement is the most common type of TMD, which is divided into anteroposterior, lateral, and rotational disc displacement according to the direction of disc displacement [33]. Anterior disc displacement is of great concern, while posterior disc displacement is often overlooked. Interestingly, posterior displacement of the articular disc was found in 44 out of 216 joints included in this study. It was found that in the group with posterior disc displacement, the posterior joint space increased and the ln(P/A) value became larger compared to the control group. This suggests that when the disc is displaced posteriorly, the posterior joint space increases and the condyle is displaced forward. In clinical, patients with posterior displacement of the articular disc do not have obvious clinical symptoms, and therefore there is less literature on it [34–36]. Pullinger [24] suggested that the condyle in a neutral or anteriorly displaced position in the articular fossa facilitated the articular disc to remain in a relatively more stable position and reduced the incidence of TMD-related symptoms.

Based on the type of articular disc displacement, the 132 lateral ADD were divided into ADDwR and ADDwoR. In ADDwR, the anterior joint space increased, the posterior joint space and the ln(P/A) values decreased compared with the control group. No visible changes in joint space and ln(P/A) values were seen in the ADDwoR. This suggests that the anterior joint space increases and the condylar process is displaced posteriorly in ADDwR. The joint space and condylar position gradually returned to normal when the joint disc shifted from ADDwR to ADDwoR. This is consistent with Alqhtani's findings [37]. Some studies found that joint space changes were related to the morphology of the joint disc. In the early stages of TMD, the joint disc was mainly dominated by the widening shape of the posterior band, which led to the enlargement of the anterior joint space [38]. With further progression of the disease, the morphology of the articular disc changed into convex or even folded. This will gradually progress to ADDwoR, resulting in a reduction of anterior joint space, approaching the normal joint space [39]. It has also been found that condylar bony encumbrance and intra-articular effusion were associated with joint space changes. [40, 41].

Many research has explored the value of CBCT and MRI in the diagnosis of TMD. CBCT can display images of bony structures in the joints, but cannot show the morphology and location of the articular discs [42, 43]. As a noninvasive imaging method, MRI can provide high-resolution TMJ bone and soft tissue morphological information [44]. In the open and closed position of the TMJ, it is possible to directly observe whether the articular disc is displaced and its extent. Some scholars have fused CBCT and MRI images [45, 46]. The MRI-CBCT fusion images can clearly show the hard and soft tissues such as articular disc and condyle, as well as their interrelationships. Both CBCT and MRI can observe changes in joint space and can be used to measure the joint space to determine the position of condyle in the joint fossa. In this study, we compared the joint space measured by MRI and CBCT, verified the consistency of the joint space measured by CBCT and MRI. This is consistent with the conclusion of Yu and Schnabl [47, 48].

With the popularity of artificial intelligence(AI) technology, some academics have used deep learning to diagnose TMD. Mackie T [49] developed a method using machine learning to extract articular fossa radiomics and joint space distances to improve joint health and predict patient specific temporomandibular joint OA status. Kim JY [50] developed a deep learning method called Random forest and multilayer perceptron (MLP) to predict TMJ disc perforation based on joint space in MRI. Lee YH [51] developed a deep learning algorithm with a convolutional neural network to detect disc displacement of the TMJ in MRI, and the prediction rate of this model has higher specificity compared to human experts. Our study mainly observed displacement of the articular disc in the sagittal position, and the coronal position needs to be further investigated.

Inevitably, there are certain flaws in this experiment. As our data material was collected from hospitals and imaging centres, this dictated that clinical symptoms became the primary inclusion criteria, without a specific clinical diagnosis. This may have biased the statistical data somewhat when compared to a large sample of normal population.

In conclusion, there is a certain correlation between changes in the anterior and posterior joint space and joint disc displacement. However, even if the ratio of anterior to posterior joint space is normal, there is still a possibility of anterior disc displacement. An increase in posterior joint space may indicate posterior disc displacement. Therefore, the joint disc displacement cannot be speculated clinically by simply observing the joint gap through CBCT, and a combination of MRI and clinical examination is needed to make a definitive diagnosis.

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Authors' contributions
Linyi Zhou, Kejin Tao and Jinjin Ma made substantial contributions to the design, data measurement, and manuscript drafting. Jianying Feng supervised the entire study, while Xianglong Pan, Kedie Zhang significantly contributed to the data analysis. The authors declare no competing interests.

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Data availability
The datasets generated and analyzed during the current study are not publicy available due to privacy restrictions but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
The experimental protocol was established according to the ethical guidelines of the Helsinki Declaration and was approved by the Human Ethics Commit tee of Stomatological Hospital of Zhejiang Chinese Medical University(No. ZCMUHSIRB - 2024101015). Written informed consent was obtained from individual or guardian participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References
1. Wang G, Feng Y, Tang JQ, et al. Measurement and analysis of condylar morphology and thickness of the roof of the glenoid fossa in patients with unilateral second molar scissor bite. Sci Rep. 2024;14(1):24747.
2. Acri TM, Shin K, Seol D, et al. Tissue Engineering for the Temporomandibular Joint. Adv Healthcare Mater. 2019;8(2):e1801236.
3. Lövgren A, Karlsson Wirebring L, Häggman-Henrikson B, et al. Decision- making in dentistry related to temporomandibular disorders: a 5-yr follow-up study. Eur J Oral Sci. 2018;126(6):493–9.
4. Wieckiewicz M, Grychowska N, Wojciechowski K, et al. Prevalence and correlation between TMD based on RDC/TMD diagnoses, oral parafunctions and psychoemotional stress in Polish university students. Biomed Res Int. 2014;2014:472346.

5. Dahlström L, Carlsson GE. Temporomandibular disorders and oral health-related quality of life A systematic review. Acta Odontologica Scandinavica. 2010;68(2):80–5.
6. Qin H, Guo S, Chen X, et al. Clinical profile in relation to age and gender of patients with temporomandibular disorders: a retrospective study. BMC Oral Health. 2024;24(1):955.
7. Lazarin R deO, Previdelli ITS, Silva R dosS, et al. Correlation of gender and age with magnetic resonance imaging findings in patients with arthrogenic temporomandibular disorders: a cross-sectional study. Int J Oral Maxillofacial Surg. 2016;45(10):1222–1228.
8. Park JW, Song HH, Roh HS, et al. Correlation between clinical diagnosis based on RDC/TMD and MRI findings of TMJ internal derangement. Int J Oral Maxillofac Surg. 2012;41(1):103–8.
9. Li DTS, Leung YY. Temporomandibular Disorders: Current Concepts and Controversies in Diagnosis and Management. Diagnostics (Basel, Switzerland). 2021;11(3):459.
10. Talmaceanu D, Lenghel L M, Bolog N, et al. Imaging modalities for temporomandibular joint disorders: an update. Clujul Medical (1957). 2018;91(3):280–287.
11. Chan NHY, Ip CK, Li DTS, et al. Diagnosis and Treatment of Myogenous Temporomandibular Disorders: A Clinical Update. Diagnostics (Basel, Switzerland). 2022;12(12):2914.
12. Tsiklakis K, Syriopoulos K, Stamatakis HC. Radiographic examination of the temporomandibular joint using cone beam computed tomography. Dentomaxillofac Radiol. 2004;33(3):196–201.
13. Mallya SM, Ahmad M, Cohen JR, et al. Recommendations for Imaging of the Temporomandibular Joint. Position Statement from the American Academy of Oral and Maxillofacial Radiology and the American Academy of Orofacial Pain. J Oral Facial Pain Headache. 2023;37(1):7–15.
14. Schiffman E, Ohrbach R, Truelove E, et al. International RDC/TMD Consortium Network, International association for Dental Research; Orofacial Pain Special Interest Group, International Association for the Study of Pain. Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) for Clinical and Research Applications: recommendations of the International RDC/TMD Consortium Network* and Orofacial Pain Special Interest Group†. J Oral Facial Pain Headache. 2014 Winter;28(1):6–27.
15. Chęciński M, Chlubek D, Sikora M. Effects of Hyaluronic Acid (HA) and Platelet-Rich Plasma (PRP) on Mandibular Mobility in Temporomandibular Joint Disorders: A Controlled Clinical Trial. Biomolecules. 2024;14(10):1216.
16. Musa M, Awad R, Izeldin S, et al. Quantitative and qualitative condylar changes following stabilization splint therapy in patients with temporomandibular joint disorders with and without skeletal lateral mandibular asymmetry: a cone beam computed tomographic study. BMC Oral Health. 2024;24(1):363.
17. Ahmad M, Hollender L, Anderson Q, et al. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107(6):844–60.
18. Drace JE, Enzmann DR. Defining the normal temporomandibular joint: closed-, partially open-, and open-mouth MR imaging of asymptomatic subjects. Radiology. 1990;177(1):67–71.
19. Di Paolo C, Qorri E, Falisi G, et al. RA.DI.CA Splint Therapy in the Management of Temporomandibular Joint Displacement without Reduction. J Personalized Med. 2023;13(7):1095.
20. Lei J, Yap AUJ, Li Y, et al. Clinical protocol for managing acute disc displacement without reduction: a magnetic resonance imaging evaluation. Int J Oral Maxillofac Surg. 2020;49(3):361–8.
21. Incesu L, Taşkaya-Yilmaz N, Oğütcen-Toller M, et al. Relationship of condylar position to disc position and morphology. Eur J Radiol. 2004;51(3):269–73.
22. Oğütcen-Toller M, Taşkaya-Yilmaz N, Yilmaz F. The evaluation of temporomandibular joint disc position in TMJ disorders using MRI. Int J Oral Maxillofac Surg. 2002;31(6):603–7.
23. Kamelchuk LS, Grace MG, Major PW. Post-imaging temporomandibular joint space analysis. Cranio: The Journal of Craniomandibular Practice. 1996;14(1):23–29.
24. Pullinger A, Hollender L. Variation in condyle-fossa relationships according to different methods of evaluation in tomograms. Oral Surg Oral Med Oral Pathol. 1986;62(6):719–27.
25. Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009;135(4):495–501. https://doi.org/10.1016/j.ajodo.2007.05.021.
26. Alqhtani NR, Alkhaldi MS, Alanazi AF, et al. Temporomandibular Joint Space Dimensions among Saudi Patients with Temporomandibular Disorders: MRI-Based Retrospective Study. Int J Clin Pract. 2022;2022:5846255.
27. Ma XC. The importance and limitations of medical imaging diagnosis for temporomandibular disorders. Zhonghua Kou Qiang Yi Xue Za Zhi. 2020;55(9):603–7.
28. Ikeda K, Kawamura A. Disc displacement and changes in condylar position. Dentomaxillofac Radiol. 2013;42(3):84227642.
29. Rammelsberg P, Jäger L, Duc JM. Magnetic resonance imaging-based joint space measurements in temporomandibular joints with disk displacements and in controls. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;90(2):240–8.
30. Zhu J, Gong Y, Zheng F, et al. Relationships between functional temporomandibular joint space and disc morphology, position, and condylar osseous condition in patients with temporomandibular disorder. Clin Oral Invest. 2024;28(3):193.
31. Xiang W, Wang M, Li Z, et al. Correlation between temporomandibular joints and craniocervical posture in patients with bilateral anterial disc displacement. BMC Oral Health. 2024;24(1):159.
32. Ozawa S, Boering G, Kawata T, et al. Reconsideration of the TMJ condylar position during internal derangement: comparison between condylar position on tomogram and degree of disk displacement on MRI. Cranio: The J Craniomandibular Pract. 1999;17(2):93–100.
33. Mizuhashi F, Ogura I, Mizuhashi R, et al. Examination of Joint Effusion Magnetic Resonance Imaging of Patients with Temporomandibular Disorders with Disc Displacement. J Imaging. 2024;10(10):241.
34. AlKandari AG, Karkar KT. Uncommon Posterior Disc Displacement of Temporomandibular Joint - A Case Report. Ann Maxillofacial Surg. 2024;14(1):81–4.
35. Afroz S, Naritani M, Hosoki H, et al. Posterior disc displacement of the temporomandibular joint: A rare case report. Cranio: The Journal of Craniomandibular Practice. 2020;38(4):273–278.
36. Westesson PL, Larheim TA, Tanaka H. Posterior disc displacement in the temporomandibular joint. J Maxillofac Surg. 1998;56(11):1266–1273; discussion 1273–1274.
37. Kurita H, Ohtsuka A, Kobayashi H, et al. A study of the relationship between the position of the condylar head and displacement of the temporomandibular joint disk. Dentomaxillofac Radiol. 2001;30(3):162–5.
38. Yang Z, Wang M, Ma Y, et al. Magnetic Resonance Imaging (MRI) Evaluation for Anterior Disc Displacement of the Temporomandibular Joint. Med Sci Mon Int Med J Exp Clin Res. 2017;23:712–8.
39. Zhang J, Yu W, Wang J, et al. A Comparative Study of Temporomandibular Joints in Adults with Definite Sleep Bruxism on Magnetic Resonance Imaging and Cone-Beam Computer Tomography Images. J Clin Med. 2023;12(7):2570.
40. Tsuruta A, Yamada K, Hanada K, et al. Comparison of condylar positions at intercuspal and reference positions in patients with condylar bone change. J Oral Rehabil. 2004;31(7):640–6.
41. Yesiltepe S, Kılcı G, Gök M. Evaluation of the lateral pterygoid muscle area, attachment type, signal intensity and presence of arthrosis, effusion in the TMJ according to the position of the articular disc. J Stomatol Oral Maxillofac Surg. 2022;123(6):e973–80.
42. Hu P, Li J, Ma R, et al. Temporomandibular joint CBCT image segmentation via multi-view ensemble learning network. Med Biol Eng Comput. 2025;63(3):693–706. https://doi.org/10.1007/s11517-024-03225-6.
43. Jeon KJ, Choi YJ, Lee C, et al. Evaluation of masticatory muscles in temporomandibular joint disorder patients using quantitative MRI fat fraction analysis-Could it be a biomarker? PLoS ONE. 2024;19(1):e0296769.
44. Thapar PR, Nadgere JB, Iyer J, et al. Diagnostic accuracy of ultrasonography compared with magnetic resonance imaging in diagnosing disc displacement of the temporomandibular joint: A systematic review and meta-analysis. J Prosthet Dent. 2023;S0022–3913(23):00177–84.
45. He YM, Wang HY, Feng YP, et al. A preliminary study on the registration of MRI and cone beam CT images of temporomandibular joint disc. Zhonghua Kou Qiang Yi Xue Za Zhi. 2020;55(10):772–7.

46. Ma RH, Li G, Sun Y, et al. Application of fused image in detecting abnormalities of temporomandibular joint. Dentomaxillofac Radiol. 2019;48(3):20180129.
47. Yu W, Jeon HH, Kim S, et al. Correlation between TMJ Space Alteration and Disc Displacement: A Retrospective CBCT and MRI Study. Diagnostics (Basel, Switzerland). 2023;14(1):44.
48. Schnabl D, Rottler AK, Schupp W, et al. CBCT and MRT imaging in patients clinically diagnosed with temporomandibular joint arthralgia. Heliyon. 2018;4(6):e00641.
49. Mackie T, Al Turkestani N, Bianchi J, et al. Quantitative bone imaging biomarkers and joint space analysis of the articular Fossa in temporomandibular joint osteoarthritis using artificial intelligence models. Front Dent Med. 2022;3:1007011.
50. Kim JY, Kim D, Jeon KJ, et al. Using deep learning to predict temporomandibular joint disc perforation based on magnetic resonance imaging. Sci Rep. 2021;11(1):6680.
51. Lee YH, Won JH, Kim S, et al. Advantages of deep learning with convolutional neural network in detecting disc displacement of the temporomandibular joint in magnetic resonance imaging. Sci Rep. 2022;12(1):11352.

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