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Quantitative MRI texture analysis of the lateral pterygoid muscle in unilateral temporomandibular joint disorders

Tao Huang[1†], Shu-Fan Zhao[1], Zhi-Qiang Song[2*] and Zhong-Cheng Gong[2*]

Abstract

Background This study utilized MRI-based texture analysis to quantify structural alterations in the lateral pterygoid muscle (LPM) among MR images with unilateral anterior disc displacement (uADD) of the temporomandibular joint. Retrospective analysis of anonymized MR images from 232 uADD patients and 123 healthy individuals (January 2022– December 2024), approved by the Ethics Committee of Wenzhou Medical University Affiliated School of Stomatology (Ethics Number: WYKQ 2024008) with waived informed consent due to the use of de-identified retrospective data, was conducted to identify diagnostic markers and possible related pathological changes of disc displacement. According to the inclusion and exclusion criteria four groups of MR images were included in this study: the healthy temporomandibular joints (H-TMJ) of individuals with uADD, joints with anterior disc displacement with reduction (ADDwR), joints with anterior disc displacement without reduction (ADDwoR), and MR images from normal volunteers as the healthy group (HG). Four texture parameters were used for analysis: the angular second moment (ASM), Contrast, inverse difference moment (IDM) and Entropy.

Results Statistically significant differences ($P < 0.05$) were found between groups for the ASM, Contrast, IDM, and Entropy variables, indicating their potential as diagnostic markers. Additionally, Entropy values differed significantly between the ADDwoR and ADDwR groups ($P < 0.05$), highlighting its diagnostic potential in distinguishing these two conditions. The severity of ADD disease showed varying degrees of correlation with specific texture parameters, with significant associations observed for ASM, Contrast, IDM, and Entropy ($P < 0.05$).

Conclusions The texture parameters of the LPM exhibit significant changes in MR images with anterior disc displacement(ADD). Notably, the Entropy value of the LPM demonstrates high diagnostic utility in distinguishing ADDwoR from ADDwR, particularly in cases of complex disc displacement involving deformation or remodeling. Furthermore, the severity of ADD disease shows varying degrees of correlation with specific texture parameters. However, further research is required to validate the relationship between numerical texture changes in the LPM and their corresponding pathological alterations.

†Tao Huang: First author.

*Correspondence:
Zhi-Qiang Song
597918345@qq.com
Zhong-Cheng Gong
gump0904@aliyun.com

Full list of author information is available at the end of the article

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Keywords Anterior disc displacement, Lateral pterygoid muscle, Texture analysis, Temporomandibular disorders

Background

Temporomandibular disorders (TMD) are a group of musculoskeletal diseases that involve the temporomandibular joints (TMJs), the masticatory muscles and all associated tissues [1]. Anterior disc displacement (ADD) is the most common structural disorder among the TMD and can be divided into ADD with (ADDwR) or without reduction (ADDwoR) [2]. The relationship between the lateral pterygoid muscle (LPM) and the TMJ is tight; dysfunction of the LPM, such as excessive or low activity, is believed to underlie displacement of the TMJ disc [3, 4]. MRI is currently the gold standard modality for diagnosing TMD, as it can clearly show the morphology and position of the joint disc as well as the state of the surrounding soft tissues [5]. D'Ippolito et al. [6] and Stimmer et al. [7] confirmed that morphological alterations in the LPM could be recognized in only a small number of TMD patients; specifically, lesions in a small amount of muscular parenchyma and tendon could be detected in fewer than 5% of TMD patients presenting with clinical symptoms. A few studies have measured muscle thickness in TMD patients with MRI; however, this method is not objective and cannot be quantified, and assessing subtle changes in the muscles can be difficult. Texture analysis utilizes mathematical methods to assess grayscale intensity and pixel spatial distribution within images [8], enabling the detection of subtle structural variations that are often undetectable by human vision [9, 10]. Human tissues have inherent texture features, and texture analysis can effectively detect subtle changes in the tissues through an analysis of these features [11, 12]. In maxillofacial research, texture analysis has been used to quantify cysts, tumors, and inflammation [7, 13], besides, texture analysis was mainly used to identify the subtle change of LPM [14].

The gray level co-occurrence matrix (GLCM) has proven to be a popular group of textural features that can be extracted from images. Haralick [15] defined 14 texture features measured from the probability matrix and extracted texture characteristics from remote sensing images. The four most commonly used texture features are angular second moment (ASM), Contrast, Entropy, and inverse difference moment (IDM) [12, 13]. One study demonstrated that altered texture Contrast and Entropy presented in the LPM for TMJ with anterior disc displacement, and texture Contrast and Entropy could be considered as the effective imaging biomarkers to evaluate the status of LPM in TMD [14]. Current research on the texture analysis of the LPM primarily focuses on its alterations in patients with TMD [6], and rheumatoid arthritis [16]. While TMD encompasses multiple disease categories, it remains unclear which specific subtype these changes are associated with. Furthermore, existing studies are limited by relatively small sample sizes. This study, with a large sample size, investigates changes in LPM texture parameters in temporomandibular joint disc displacement, providing diagnostic insights into challenging cases of disc deformation and remodeling on MRI. It also lays a theoretical and data-driven foundation for advancing automated diagnostic methods.

Methods

We conducted a cross-sectional retrospective study adhering to the ethical principles outlined in the World Medical Association Declaration of Helsinki (1964) and its subsequent revisions. The study protocol was approved by the Ethics Committee of Wenzhou Medical University Affiliated School of Stomatology (Ethics Number: WYKQ 2024008). This study used pre-existing anonymized data, and therefore, no additional informed consent was required. The MR images in this study were obtained from patients diagnosed with TMD at the Affiliated Stomatological Hospital of Wenzhou Medical University between January 2022 and December 2024 (with written informed consent provided by all participants) and were analyzed using MR images to diagnose ADDwoR and ADDwR according to the criteria referred by Schiffman E et al. [17].

Inclusion and Exclusion Criteria

Inclusion criteria

1. Patients diagnosed with unilateral anterior disc displacement (uADD) of the temporomandibular joint (TMJ);
2. No prior treatment before the diagnostic MRI examination;
3. No history of congenital developmental abnormalities, recent maxillofacial trauma, or autoimmune diseases.

Exclusion criteria

1. Other disc displacements not meeting the MRI-based diagnostic criteria[17] for ADDwoR or ADDwR were excluded from the analysis.
2. Poor-quality MR images that precluded accurate evaluation or parameter measurement
3. Availability of only unilateral joint scans.

To minimize potential biases, we employed standardized diagnostic protocols for uADD and ensured all MR images adhered to the same technical specifications.

Grouping and Analysis

All MR images meeting the inclusion criteria [17] were classified into the uADD group. This group was further divided into three subgroups: Joints with anterior disc displacement with reduction (ADDwR); Joints with anterior disc displacement without reduction (ADDwoR); healthy joints of uADD (H-TMJ).

For comparison, we recruited normal volunteers to form a healthy group (HG), ensuring age and sex were matched to minimize confounding variables.The healthy group data utilized in this study were retrospectively collected from individuals who underwent routine dental or orthodontic imaging examinations at our institution during the same study period (January 2022–December 2024), These individuals had no clinical symptoms or MRI findings indicative of TMD and were selected as the HG based on strict inclusion criteria: Absence of TMJ pain, clicking, or restricted mouth opening; Normal disc-condyle relationship confirmed via MRI; No history of TMJ trauma or surgical intervention.

After applying pre-defined inclusion/exclusion criteria, 232 uADD MR images (77.9% of screened MR images) and 123 healthy MR images (80.4% of initially collected controls) were included. All retained samples exhibited complete datasets for primary and secondary outcomes, with no requirement for data imputation or exclusion.

MRI protocol and parameter selection

MRI was performed using a 1.5T scanner with standardized acquisition parameters to ensure consistency across all subjects. T2-weighted images in the horizontal plane were selected for analysis, as this plane provides optimal visualization of the LPM and its anatomical relationship with TMJ structures. To minimize variability in imaging conditions, all participants underwent MRI in a standardized supine position, with the head stabilized using foam padding to reduce motion artifacts. The degree of mouth opening was carefully controlled by instructing participants to maintain a relaxed, closed-mouth posture, avoiding voluntary clenching or excessive jaw relaxation. These measures ensured consistent muscle positioning and facilitated reproducible texture analysis across subjects. The parameters analyzed (ASM, IDM, Entropy, and Contrast) were chosen based on their established utility. Previous studies have demonstrated their effectiveness in assessing tissue texture and detecting subtle structural and functional changes [12, 13].

ROI placement, reproducibility and GLCM computation

The region of interest (ROI) was delineated on slices capturing the maximum cross-sectional area of the lateral pterygoid muscle (LPM), utilizing predefined anatomical landmarks to ensure consistent placement while excluding surrounding fascia, adjacent musculature, and bony structures. To enhance reproducibility and minimize observer variability, a single experienced TMD Specialist performed ROI segmentation three times under standardized windowing conditions (Fig. 1), with the mean values subsequently used for statistical analysis.

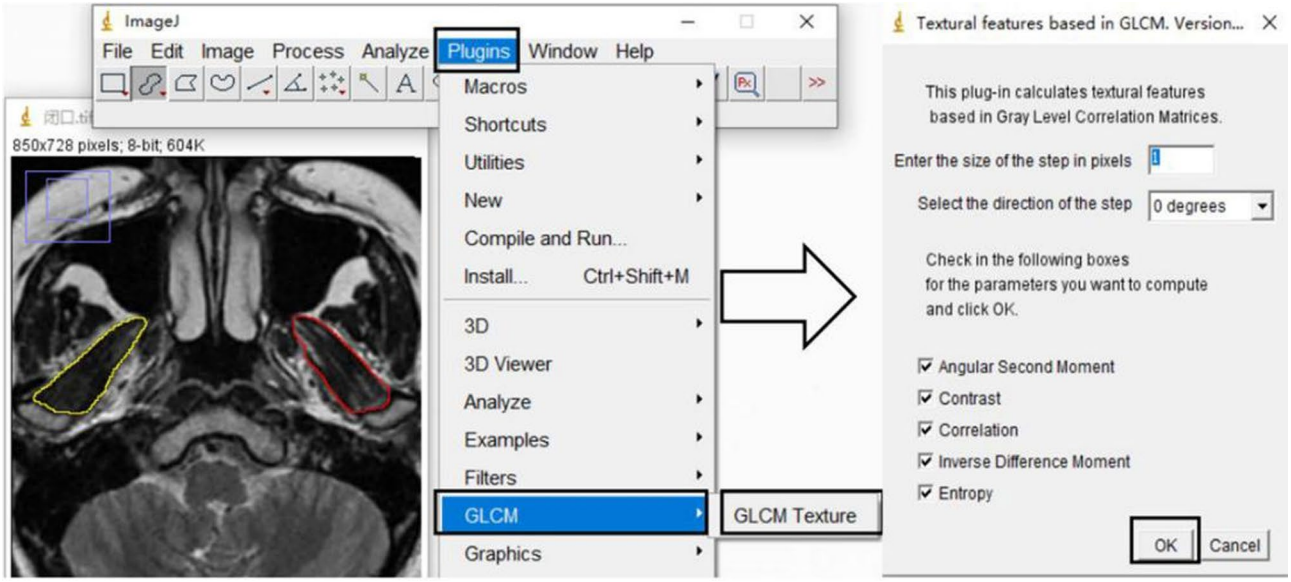

Fig. 1 ROI diagram and GLCM calculation method. Yellow color represents the ROI of the lateral pterygoid muscle on the side with anterior articular disc displacement, and red color represents the ROI of the healthy lateral pterygoid muscle

Table 1 Demographic characteristics of the included MR images

Characteristic	uADD	HG
Total	232	123
Sex		
Male	54	37
Female	178	86
Age (years)	26 ± 9.64	26 ± 10.72
MRI characteristic	Number of TMD	
Total	232	
Disease		
ADDwR	82	
ADDwoR	150	

uADD: unilateral anterior disc displacement; HG: healthy group; ADDwR: anterior disc displacement with reduction; ADDwoR: anterior disc displacement without reduction

All texture feature extractions were conducted using the GLCM plugin in ImageJ (National Institutes of Health, Bethesda, MD, USA), which applies automated boundary refinement based on grayscale thresholding to ensure precise and consistent segmentation.

Statistical methods

Statistical analysis was performed using SPSS 26.0, following these procedures:

1. Assessment of Data Distribution: The Shapiro-Wilk test was used to evaluate normality, while Levene's test was applied to assess homogeneity of variance.
2. Group Comparisons: (1) For normally distributed data with homogeneous variance, values were expressed as mean ± standard deviation and analyzed using one-way analysis of variance, followed by the least significant difference test for post-hoc pairwise comparisons. (2) For non-normally distributed data or data with unequal variance, values were presented as the median and interquartile range and analyzed using the Kruskal-Wallis test.
3. Correlation Analysis: The association between texture parameters and disease severity was assessed using Spearman's rank correlation analysis.

Results

The joints of 123 volunteers without disc displacement, including 86 females and 37 males, with an average age of 26 ± 10.72, were defined as the HG; additionally, a total of 232 MR images had uADD, including 178 females and 54 males, with an average age of 26 ± 9.64 years. These included 82 MR images with joints with ADDwR and 150 MR images with joints with ADDwoR, as shown in Table 1.

Comparisons between the healthy and uADD groups

The results demonstrated no significant differences in texture parameters between the H-TMJ and HG groups. Similarly, ASM, and IDM values showed no significant differences between the H-TMJ and ADDwR groups, whereas Contrast values were significantly different. In contrast, comparisons between the ADDwoR and ADDwR groups revealed significant differences in Entropy values, while other parameters did not differ significantly (Table 2).

Table 2 Statistical comparison of texture parameters among uADD subgroups

Parameter	(I) Group	(J) Group	Mean Difference (I-J)	SE	*P*
ASM	H-TMJ	ADDwoR	-9.90E-05	2.74E-05	< 0.001*
	ADDwR	ADDwoR	-7.04E-05	3.59E-05	0.051
	HG	H-TMJ	-1.65E-05	2.92E-05	0.571
		ADDwoR	-1.16E-04	3.18E-05	< 0.001*
		ADDwR	-4.51E-05	3.73E-05	0.227
Contrast	H-TMJ	ADDwoR	10.97*	2.56	< 0.001*
	AD-DwoR	ADDwR	-5.07	3.36	0.132
	HG	H-TMJ	-3.32	2.73	0.224
		ADDwoR	7.65*	2.98	0.01*
		ADDwR	2.58	3.49	0.461
IDM	H-TMJ	ADDwoR	-0.0086*	0.0029	0.003*
	AD-DwoR	ADDwR	0.0042	0.0039	0.272
	HG	H-TMJ	-0.0020	0.0031	0.521
		ADDwoR	-0.011*	0.003	0.002*
		ADDwR	-0.0065	0.0039	0.101
Entropy	H-TMJ	ADDwoR	0.094*	0.024	< 0.001*
	AD-DwoR	ADDwR	− 0.064*	0.032	0.046*
	HG	H-TMJ	-0.0016	0.026	0.95
		ADDwoR	0.092*	0.028	0.001*
		ADDwR	0.028	0.033	0.392

HG = healthy group; ADDwR = anterior disc displacement with reduction; ADDwoR = anterior disc displacement without reduction; H-TMJ = healthy joint of unilateral anterior disc displacement; ASM = angular second moment; IDM = inverse difference moment

Comparison of H-TMJ, ADDWR, and addwor within the uADD group

Statistically significant differences ($P < 0.05$) were observed in ASM, Contrast, IDM, and Entropy values among the joints in the H-TMJ, ADDWR, and ADDwoR groups, as shown in (Table 3).

Correlation analysis for the ADDwR, addwor and HG

Spearman correlation analysis was performed on data from the ADDWR, ADDwoR, and HG to evaluate the relationship with between the severity of diseases and four texture parameters. The results are presented in (Table 4).

The results showed that ASM, Contrast, IDM, and Entropy were significantly correlated with disease

Table 3 Comparison of texture parameters according to the degree of temporomandibular joint disc displacement

Parameters	median M (P25, P75)			H values	*P*
	H-TMJ (*n* = 232)	ADDwoR (*n* = 150)	ADDwR (*n* = 82)		
ASM	0.000617 (0.0004745, 0.0008405)	0.00070535 (0.000523, 0.000954275)	0.0006376 (0.00052565, 0.000828775)	6.522	0.038
Contrast	122.670 (107.5, 138.2)	108.158 (91.1, 131.4)	117.803 (97.3, 130.0)	15.449	< 0.001
IDM	0.180 (0.2, 0.2)	0.194 (0.2, 0.2)	0.186 (0.2, 0.2)	7.715	0.021
Entropy	8.145 (8.0, 8.3)	8.040 (7.9, 8.2)	8.098 (8.0, 8.3)	11.662	0.003

ADDwR = anterior disc displacement with reduction; ADDwoR = anterior disc displacement without reduction; H-TMJ = healthy joint of unilateral anterior disc displacement; ASM = angular second moment; IDM = inverse difference moment

Table 4 The relationship with between the severity of diseases and four texture parameters(*n* = 355)

Parameters	Pearson's *r*	*P* values
ASM	0.174	0.001
Contrast	-0.134	0.012
IDM	0.166	0.002
Entropy	-0.164	0.002

ADD = anterior disc displacement; ASM = Angular second moment; IDM = inverse difference moment

severity ($P < 0.05$). Specifically, ASM ($r = 0.174$, $P = 0.001$) and IDM ($r = 0.166$, $P = 0.002$) exhibited significant positive correlations, suggesting that their increased values may be associated with greater disease severity. In contrast, Contrast (r=-0.134, $P = 0.012$) and Entropy (r=-0.164, $P = 0.002$) demonstrated significant negative correlations, indicating that higher values may reflect milder disease conditions.

Discussion

GLCM features, including ASM, Contrast, IDM, and Entropy [11], provide a robust framework for analyzing texture characteristics of the LPM in TMD. For instance, ASM can be used to assess the homogeneity of the LPM texture, indicating structural uniformity that may change in pathological conditions [18]. Entropy quantifies the complexity of muscle texture [18], while Contrast reflects the intensity variations and the depth of grooves [19]. Adequate muscle contraction of the LPM promotes effective blood circulation [20], which enhances LPM perfusion [14], clarifies muscle texture, and subsequently increases both Entropy and Contrast values. IDM is a key metric for assessing local uniformity [15]. Muscle edema and inflammatory cell infiltration can cause the local image texture to become uniform and indistinct [21], may resulting in changes in IDM values.

The bilateral nature of TMJ function necessitates a combined evaluation of both joints, as dysfunction in one joint frequently affects the other. For example, studies have shown that unilateral TMJ dysfunction can lead to compensatory changes in the contralateral joint, affecting overall mandibular kinematics and muscle coordination, which may explain the high incidence of bilateral alterations observed in clinical cases [22]. Luo et al. [21] reported that in the TMD group, the LPM exhibited significantly higher ASM and Entropy parameters but lower IDM and Contrast parameters in the sagittal plane compared to the healthy control group. These findings suggest that TMD is associated with alterations in the LPM and related biomechanical changes. This study found no significant differences in the texture parameters of the LPM between HG and H-TMJ groups. However, significant differences were observed between HG and uADD groups, with ASM, and IDM values being higher in ADDwoR, while Contrast and Entropy values were lower. These findings indicating that advanced disc displacement leads to textural alterations in the LPM maybe due to pathological changes such as edema and fatty infiltration [23]. The observed differences in Entropy between ADDwoR and ADDwR groups further support its role as a diagnostic marker. Lower Entropy values in ADDwoR may reflect reduced muscle complexity due to disuse and fatty infiltration [23]. Conversely, the absence of significant differences in texture parameters between ADDwR and HG groups aligns with the notion that ADDwR, asymptomatic state with LPM adaptive structural changes [2].

Inflammatory infiltration in muscle tissue increases the T1 value, while fat infiltration decreases it, with both conditions leading to elevated T2 values [24]. In this study, ROIs were delineated to exclude the fascia; however, since fat infiltration typically occurs along the fascia [25], this may partly explain discrepancies in texture parameter changes compared to previous research. Furthermore, Wang et al. [23] speculated that the increase in fatty infiltration of the LPM might be more pronounced in the fascia area between the superior head and inferior head, delineating the ROI on the largest cross-sectional area of the LPM likely excluded regions with significant fatty infiltration, potentially underestimating its impact and influencing the comparative findings.

Correlation analysis demonstrated that the severity of articular disc displacement was negatively associated with Contrast and Entropy values, indicating reduced textural complexity. Conversely, positive correlations with IDM and ASM values suggest increased homogeneity. As disc displacement progresses, the grooves within the LPM become shallower, leading to increased homogeneity and reduced textural complexity. These changes

are reflected by lower Contrast and Entropy values, indicative of reduced variability in gray-level intensity. Conversely, the increased IDM and ASM values suggest a more uniform texture and stronger spatial relationships between gray levels, likely due to muscle remodeling and adaptive changes, previous studies have reported similar trends, with Luo et al. [21]. highlighting the role of these features in characterizing LPM changes in TMD, these findings suggest that pathological changes, including inflammatory cell infiltration and muscle edema, alter the texture of the LPM. As the severity of ADD disease progresses, the grooves within the muscle become shallower, leading to increased homogeneity and reduced textural complexity [26]. Normal LPM exhibited higher Contrast and Entropy, likely due to preserved muscle function and blood supply, which supports metabolism and structural integrity [21].

Despite the robust findings, this study has limitations. Only four of the 14 Haralick features were analyzed, potentially omitting relevant textural information. Other texture analysis methods, such as histogram analysis and gray-level run-length matrices, may complement GLCM features in future studies. Additionally, the inability to differentiate between the superior and inferior heads of the LPM limits the specificity of our findings, as suggested by Lopes et al. [27]. Finally, the use of a 1.5 T MRI scanner may have constrained resolution, and higher-field strength imaging could provide more detailed insights [28]. Future research should incorporate advanced imaging techniques, such as diffusion tensor imaging (DTI) and magnetic resonance spectroscopy (MRS), to evaluate muscle microstructure and biochemical composition in greater detail. Additionally, integrating clinical findings like patient-reported pain scores, jaw function assessments, and T2 relaxation times of retrodiscal tissue could provide a comprehensive understanding of TMD. These techniques can enhance the detection of subtle pathological changes, improve the specificity of diagnostic markers, and establish stronger correlations between imaging findings and clinical symptoms. This approach will enhance our understanding of LPM pathology in TMD and refine diagnostic and therapeutic strategies. The texture parameters of the LPM show significant potential for automated diagnosis. Leveraging machine learning algorithms, these parameters can inform predictive models to identify pathological conditions and structural abnormalities. This approach promises to improve diagnostic accuracy while minimizing reliance on manual interpretation.

Recent advances in artificial intelligence (AI) and machine learning (ML) have significantly improved medical image analysis. Kaan O. et al. proposed an ML model using KNN and RF algorithms to classify condylar changes and TMJ disc displacements based on MRI images. Their findings highlight the potential of ML in enhancing the automated detection and classification of TMJ abnormalities [29]. Similarly, our study employs texture analysis to quantitatively assess structural changes in the LPM, revealing significant correlations with TMJ disc displacement. Future research could explore the integration of ML with texture analysis to further improve diagnostic accuracy and facilitate automated assessment of TMD.

Conclusions

Our research revealed MR images with ADD experience changes in the texture parameters of the LPM; among these, there are differences in the ASM, Contrast, IDM, and Entropy values of the LPM between healthy individuals and individuals with ADDwoR. The degree of anterior displacement of the articular disc was negatively correlated with the Contrast and Entropy values and positively correlated with the IDM values. Our findings highlight Entropy as a reliable diagnostic marker for differentiating ADDwoR from ADDwR, with significant implications for understanding LPM pathology and advancing automated diagnostic methods for temporomandibular joint disorders.

Abbreviations

ASM	Angular second moment
IDM	Inverse difference moment
LPM	Lateral pterygoid muscle
uADD	Unilateral anterior disc displacement
ADD	Anterior disc displacement
MRI	Magnetic resonance imaging
H-TMJ	Healthy joints of uADD
ADDwR	Anterior disc displacement with reduction
ADDwoR	Anterior disc displacement without reduction
TMD	Temporomandibular disorder
TMJ	Temporomandibular joint
GLCM	The gray level co-occurrence matrix

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Author contributions

Zhong-cheng Gong and Zhi-Qiang Song contributed equally to this work, they conceptualized and designed the study, and critically revised the manuscript for important intellectual content. Tao Huang conceptualized the study, designed the data collection, optimized the statistical methods and drafted the manuscript. And collected and integrated the clinical materials, carried out the statistical analyses and reviewed the manuscript. Shu-Fan Zhao supported MRI information extraction and interpreted the images, coordinated and supervised imaging data acquisition. All authors approved the final manuscript as submit-ted and agree to be accountable for all aspects of the work. The requirements for authorship as stated earlier in this document have been met, and that each author believes that the manuscript represents honest work.

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Data availability

These data are not publicly available, after the research is publicly published, contact the research leader via email for reasonable access.

Declarations

Ethics approval and consent to participate

We conducted a cross-sectional retrospective study adhering to the ethical principles outlined in the World Medical Association Declaration of Helsinki (1964) and its subsequent revisions. The study protocol was approved by the Ethics Committee of Wenzhou Medical University Affiliated School of Stomatology (Ethics Number: WYKQ 2024008). This study used pre-existing anonymized data, and therefore, no additional informed consent was required.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Oral and Maxillofacial Surgery, Affiliated Stomatology Hospital, Wenzhou Medical. University, Wenzhou 325000, China
[2]Oncological Department of Oral and Maxillofacial Surgery, The Affiliated Stomatology Hospital of the First Affiliated Hospital of Xinjiang Medical University, No. 137, Li Yu Shan South Road, Urumqi, Xinjiang 830054, China

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