Functional changes of the lateral pterygoid muscle in patients with temporomandibular disorders: a pilot magnetic resonance images texture study

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Abstract

Background: Texture features were the intrinsic properties of the human tissues and could efficiently detect the subtle functional changes of involved tissue. The pathologic changes of the lateral pterygoid muscle (LPM) were significantly correlated with the temporomandibular disc displacement. However, the occult functional changes of LPM could not be detected by the naked eye on the medical images. The current study was aimed to evaluate the functional changes of the LPM in the patients with temporomandibular disorders (TMDs) using texture analysis.

Methods: Twenty-nine patients with TMD were performed with magnetic resonance (MR) imaging on a 3.0T MR scanner, who were consecutively recruited from the TMD clinic of Hainan Hospital of Chinese People’s Liberation Army General Hospital from February 2019 to September 2019. The patients were classified into three groups according to the disc displacement: disc without displacement (DWoD), disc displacement with reduction (DDWR) and disc displacement without reduction (DDWoR). The gray-level co-occurrence matrix method was applied with the texture analysis of LPM on the axial T2-weighted imaging. The texture features included angular second moment, contrast, correlation, inverse difference moment, and entropy. One-way analysis of variance was used for grouped comparisons and receiver operating characteristics (ROC) curve analysis was applied to evaluate the diagnostic efficacy of the texture parameters.

Results: Texture contrast of LPM presented significantly lower in DWoR (46.30 [35.03, 94.48]) than that in DWoD (123.85 [105.06, 143.23]; test statistic = 23.05; P < 0.001). Texture entropy of LPM showed significant differences among DWoD (7.62 ± 0.33), DDWR (6.76 ± 0.35), and DDWoR (6.46 ± 0.39) (PDDoD-DDWR < 0.001, PDDoD-DDWoR < 0.001, and PDDWR-DDWoR = 0.014). Area under the ROC curve (AUC) demonstrated that texture entropy had an excellent diagnostic accuracy for DWoD-DDWR (AUC = 0.96) and DWoD-DDWoR (AUC = 0.98).

Conclusion: The texture contrast and entropy could identify the altered functional status of LPM in patients with TMD and could be considered as the effective imaging biomarker to evaluate the functional changes of LPM in TMD.

Keywords: Entropy; Magnetic resonance imaging; Pterygoid muscle; Temporomandibular joint disorders

Introduction

Temporomandibular disorders (TMDs) were a common and self-limited clinical syndrome, characterized by the pain in temporomandibular joint (TMJ) or its affiliated tissues.1 TMD was common in adults and one third of adults reported having symptoms,2 which had costed to $4 billion per year for the TMD management in the last decade.

Etiology of TMD still remained unclear, and it might be multi-factorial. The most common cause was the TMJ disc displacement,3 which should not be solely used to diagnose TMD.4 The other cause was the masticatory muscle disorder according to the anatomical origin, such as local myalgia, myofascial pain, myofibrotic contracture, myositis, myosplasm, and neoplasia.1 Masticatory muscles included masseter muscle, temporalis muscle, medial pterygoid muscle (MPM), and lateral pterygoid

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The first three masticatory muscles could elevate the mandible and close the mouth, and the morphometry and edematous change would be associated with pain-related TMD. The LPM could protract the mandible and produce the “side to side” movement of the jaw, and the upper head all inserted in the disc for the three LPM attachment types. Although the upper head of the LPM insertion on the disc could increase the percentage of disc displacement without reduction, the type of LPM insertion does not appear to relate with disc displacement while muscle pathologic changes were significantly correlated with the disc displacement.

The superior head of LPM inserted on the disc over the three types might increase the risk of anterior displacement, and then reduce the function of the superior head of LPM and finally cause the muscle atrophy. The myospasm of the superior head of LPM could also cause the TMJ disc displacement.

The common magnetic resonance (MR) technique to evaluate the structure and function of LPM mainly included as follows: (1) diffusion tensor imaging to evaluate the morphological alterations of the LPM; (2) the intravoxel incoherent motion (IVIM) MR imaging (MRI) to quantitatively evaluate diffusion and perfusion status of LPM; (3) muscle morphology and volume measurement of LPM; (4) angle between LPM and condyle to identify risk factors for sideways disk displacement of TMJ.

The included criteria were listed as follows: (1) Only suffered from disc disorders without the hypomobility or hypermobility disorders; (2) No fractures or congenital/developmental disorders; and (3) No any treatment before the MRI examination. The patients with the following criteria should be excluded out: (1) masticatory muscle disorders or coronoid hyperplasia; (2) imaging artifacts influencing the diagnosis of TMD; and (3) the contraindication for MRI. Fifty-eight TMJs (29 subjects) were classified into three subtypes according to the TMJ disc location: (1) TMJ disc without displacement (DWoD); (2) TMJ disc displacement with reduction (DDWR); and (3) TMJ disc displacement without reduction (DDWoR) [Figure 1A–E].

The TMJ data were obtained from a GE three-tesla MR system (SingHdxt; GE Healthcare, Milwaukee, WI, USA), and a conventional eight-channel quadrature head coil was used. All subjects were instructed to lie in a supine position,
and formed padding was used to limit head movement. The sequence included axial T2-weighted imaging (T2WI) and oblique sagittal proton density weighted imaging (PDWI) with close and open mouth position. The imaging parameters of T2WI were listed as follows: TR (repetition time) = 3600 ms, TE (echo time) = 92.5 ms, FOV (field of view) = 21 cm × 21 cm, Matrix = 320 × 288, NEX (number of acquisition) = 2, slice thickness = 3 mm, slice gap = 4 mm. The imaging parameters of PDWI included as follows: TR (repetition time) = 2423 ms, TE (echo time) = 30 ms, FOV (field of view) = 14 cm × 14 cm, Matrix = 288 × 192, NEX (number of acquisition) = 2, slice thickness = 2 mm, slice gap = 1.

Image review
All the MRIs were reviewed on the picture archiving and communication system (PACS) workstation. The disc displacement was diagnosed based on the oblique PDWI with close and open mouth position. The masticatory muscles were evaluated on the axial T2WI to exclude the patients with the masticatory muscle disorders. The imaging findings were blindly reviewed in consensus by two experienced neuroradiologists without knowing the clinical information.

Texture analysis
The texture features of LPM were measured over the superior belly of the LPM with the maximal area using GLCM method with the GLCM plugin (Version 0.4) on ImageJ (Version 1.50) ([https://imagej.nih.gov/ij](https://imagej.nih.gov/ij)) [Figure 2]. The GLCM plugin was set as follows: the size of the step in ImagJ (Version 1.50) (https://imagej.nih.gov/ij) [Figure 2]. The GLCM plugin was set as follows: the size of the step in pixels = 1, the direction of the step = 0 degrees, and the texture parameters angular second moment (ASM), contrast, correlation, inverse different moment (IDM), and entropy (27,29) were selected. The whole region of interest (ROI) was drawn on the LPM slice with the maximal area using freehand selection method avoiding the adjacent fat and bone components. ROI was placed for three times by the same neuroradiologist on the same slice, and the mean value of texture parameter was regarded as the final value.

Statistical analysis
The normal distribution data were presented as mean ± standard deviation (SD), and non-normal distribution data were presented as median (P25, P75). The texture ASM, contrast, and correlation were performed with Kruskal-Wallis one-way analysis of variance (ANOVA) for its non-normal distribution, and all pairwise method was used to perform multiple comparisons. Texture IDM and entropy were performed with one-way ANOVA for its normal distribution, and LSD method was applied with the post hoc multiple comparisons when equal variance was assumed. Otherwise, Dunnett’s T3 was applied when equal variance was not assumed. Receiver operating characteristics (ROC) curve analysis was applied to evaluate the diagnostic efficacy of the texture parameters with significant group difference. The diagnostic accuracy could be assessed according to the area under the curve (AUC): 0.9 to 1.0 = excellent; 0.8 to 0.9 = good; 0.7 to 0.8 = fair; 0.6 to 0.7 = poor; 0.5 to 0.6 = fail. (31)

Statistically significant difference was set at a P < 0.05. Statistical analysis was performed using the PASW Statistics Software Version 18.0 (SPSS Inc., Chicago, IL, USA).

Results
Comparison of texture features among DWoD, DDWR, and DDWoR groups
Table 1 demonstrated that texture contrast presented significantly lower in DDWoR (46.30 [35.03, 94.48]) than that in DWoD (123.85 [105.06, 143.23]); test statistic = 23.05; P < 0.001), and texture entropy showed significant differences among DWoD (7.62 ± 0.33), DDWR (6.76 ± 0.35), and DDWoR (6.46 ± 0.39) (F value = 60.32, P value = 0.000, P_{DWoD-DDWR} = 0.000, and P_{DDWR-DDWoR} = 0.014) [Figures 3 and 4]. Texture ASM, correlation, and IDM presented no significant difference among DWoD, DDWR, and DDWoR (H value = 4.499 and P = 0.109, H value = 3.368 and P = 0.186, and F value = 1.929 and P = 0.155, respectively).

ROC analysis of the texture contrast and entropy among DWoD, DDWR, and DDWoR groups
Texture contrast presented a good diagnostic accuracy for DWoD-DDWoR (AUC = 0.88, cut-off value = 69.23, sensitivity = 70.00% and specificity = 100.00%), and fair accuracy for DWoD-DDWR (AUC = 0.72) and DDWR-DDWoR (AUC = 0.73) [Table 2 and Figure 5]. Table 2 demonstrated that texture Entropy had an excellent diagnostic accuracy for DWoD-DDWR (AUC = 0.96, cut-off value = 7.34, sensitivity = 100% and specificity = 81.82%) and DWoD-DDWoR (AUC = 0.98, cut-off value = 7.10, sensitivity = 95.00% and
Discussion

The MRI evaluation for the skeletal muscle commonly included the signal changes on T1WI and T2WI, the volume measurement[21] and the muscle morphology[14,20] based on the conventional MRIs. The functional MRI could provide the diffusion and perfusion status of muscle[19] based on IVIM MRI, muscle blood flow and oxygenation based on nuclear MRI (NMRI) and spectroscopy,[32] the muscle energetics based on the 31P NMRI,[33] and the measurement of minimal fat in normal skeletal muscles based on T2 relaxation time mapping (T2 maps) and MR spectroscopy.[34] However, the functional MRI examination commonly had a low cost-benefit efficacy because of its large medical cost and consumed time. Recently, texture analysis, as an non-invasive technique to detect the subtle changes of human tissue, had presented some progress in the muscle evaluation, such as internal obturator muscles after radiotherapy for prostate cancer based on the T1WI and T2WI MRIs,[35] the paraspinal musculature in MRI of the lumbar spine,[36,37] and muscular dystrophy classification.[38] In the current study, texture analysis was mainly used to identify the subtle change of LPM, which could not be observed abnormal signal by the naked eyes.

GLCM was a common second order texture analysis method to detect the relationship of the selected two points in different distance, direction, and magnitude, which could quantitatively characterize the spatial distribution of pixels for selected images and extract the texture features from the gray information.[27] The common texture measurement included first order, second order, third...

Table 1: Comparison of the texture features among DWoD, DDWR, and DDWoR groups for the patients with TMD.

| Parameters  | DWoD (n = 22) | DDWR (n = 16) | DDWoR (n = 20) | F or H value | P  |
|------------|---------------|---------------|----------------|--------------|----|
| ASM (×10⁻³) | 2.0 (2.0, 3.0) | 2.0 (1.5, 2.0) | 3.0 (2.0, 4.0) | 4.499*       | 0.109 |
| Contrast   | 123.85 (105.06, 143.23) | 96.51 (59.71, 113.01) | 46.30 (35.03, 94.48) | 19.514*       | <0.001 |
| Correlation (×10⁻³) | 3.0 (3.0, 4.0) | 3.0 (2.0, 3.5) | 4.0 (2.0, 5.0) | 3.368*       | 0.186 |
| IDM        | 0.24 ± 0.03   | 0.22 ± 0.04   | 0.25 ± 0.05    | 1.929*       | 0.155 |
| Entropy    | 7.62 ± 0.33   | 6.76 ± 0.35   | 6.46 ± 0.39    | 60.352*      | <0.001 |

Data are presented median (P25, P75) for non-normal distribution and means ± standard deviation for normal distribution. *H value for Kruskal-Wallis one-way ANOVA. †F value for one-way ANOVA. There was significant difference for texture contrast between DWoD and DDWoR (adjusted P = 0.001). There was significant difference for texture entropy for DWoD vs. DDWR (P = 0.000), DWoD vs. DDWoR (P = 0.000) and DDWR vs. DDWoR (P = 0.014). ANOVA: Analysis of variance; DWoD: Disc without displacement; DDWR: Disc displacement with reduction; DDWoR: Disc displacement without reduction; TMD: Temporomandibular disorders; ASM: Angular second moment; IDM: Inverse different moment.
and higher order textures, and GLCM was a second order texture defining the relationship between two pixels (usually neighboring) in the original image. Therefore, GLCM method was applied to extract the texture features and the distance in pixels was set as 1 in the current study. Texture contrast was also called as “Sum of Square Variance,” which represented the local variations in the gray-level co-occurrence matrix. In the current study, the texture contrast of LPM presented a downtrend, and the significant difference was identified between DWoD and DDWoR. LPM was inserted on the TMJ disk, and the functional change would increase the risk of anterior displacement. In this study, conventional MRIs confirmed that there was no abnormal signal on LPM. Therefore, the texture analysis could be used to detect the subtle changes, which was not observed by the naked eyes. The current results also suggested that the decreased texture contrast would influence the function of LPM, and then induce the disk displacement. Further ROC analysis demonstrated that texture contrast could provide a good level to detect the functional changes of LPM between DWoD and DDWoR. Therefore, the texture contrast could be considered as an imaging biomarker for the evaluation of LPM in patients with TMD.

Texture entropy showed the amount of information of the image for compression. The loss of the information could be measured by the entropy, which had been used to evaluate the function of the periaqueductal gray matter, the pancreatic neuroendocrine tumor, and the malignant breast tumors. In this study, texture entropy of LPM also presented significantly decreased in DDWR and DDWoR compared with DWoD, which could be speculated that the loss of information of LPM might be the cause of anterior disk displacement. The current results also suggested that the texture entropy of LPM presented lower in DDWoR than that in DDWR, which demonstrated that texture entropy might be associated with displacement extent. IVIM method confirmed that the increased perfusion of superior belly LPM could be observed in the TMJ with anterior disc displacement without reduction, and the increased perfusion might influence the status of LPM, which was sensitively detected by texture entropy. Further ROC analysis demonstrated that texture entropy had an excellent evaluating accuracy for the status of LPM for DDWR and DDWoR distinguished from DWoD. Therefore, texture entropy could be considered as effective and persuasive imaging biomarkers for the status evaluation of LPM for TMJ with disc displacement.

Table 2: ROC analysis of texture contrast and entropy among DWoD, DDWR, and DDWoR.

| Texture parameters | Area  | 95% CI      | Cut-off value | Sensitivity (%) | Specificity (%) |
|--------------------|-------|-------------|---------------|-----------------|-----------------|
| Contrast           |       |             |               |                 |                 |
| DWoD-DDWR          | 0.72  | 0.54–0.92   | 109.90        | 75.00           | 72.73           |
| DWoD-DDWoR         | 0.88  | 0.77–0.99   | 69.23         | 70.00           | 100.00          |
| DDWR-DDWoR         | 0.73  | 0.56–0.90   | 54.55         | 65.00           | 87.50           |
| Entropy            |       |             |               |                 |                 |
| DWoD-DDWR          | 0.96  | 0.91–1.00   | 7.34          | 100.00          | 81.82           |
| DWoD-DDWoR         | 0.98  | 0.96–1.00   | 7.10          | 95.00           | 95.45           |
| DDWR-DDWoR         | 0.72  | 0.55–0.89   | 6.46          | 55.00           | 87.50           |

DWoD: Disc without displacement; DDWR: Disc displacement with reduction; DDWoR: Disc displacement without reduction; CI: Confidence interval.
The current study investigated the altered status of LPM using GLCM method, and the results were interesting and persuasive. However, there were some limitations in this study. First, GLCM measurement should include more parameters setting such as the size of the step in pixels and the direction of the step; Second, only one texture technique was used in this study. The other novel texture method should also be involved in the future study, such as histogram analysis, gray-level run-length matrix and local binary patterns. Lastly, texture analysis was performed on the T2WI images, and the other images (T1WI, DWI, and PDWI) should also be investigated in future.

In conclusion, the current 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. GLCM texture features evaluation could provide the direct imaging evidence to explain the mechanism for the alter status of LPM in TMD.

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Conflicts of interest
None.

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