Research Article

Texture Analysis Parameters of Temporomandibular Joint Articular Disc Associated with Clinical and MRI Characteristics of Patients with Temporomandibular Disorders

Suzanni do Amaral Rodrigues Veloso[1], Rosane da Conceição Lago Carvalho[2], Gabriel Cutrim Silva[2], José de Ribamar Castro Veloso[2], Paulo Cézar Simamoto Júnior[3], George Sampaio Bonates dos Santos[1], Rudys Rodolfo De Jesus Tavarez[1], Vandilson Pinheiro Rodrigues[2], and Etevaldo Matos Maia Filho[1]*

[1]*Department of Postgraduate Program in Dentistry, CEUMA University, Brazil*

[2]*Department of Diagnostic Imaging, Federal University of Maranhão São Luíz, Brazil*

[3]*Department of Occlusion, Fixed Prosthesis and Dental Materials, Federal University of Uberlândia, Brazil*

Abstract

Objectives: To correlate the texture analysis (TA) parameters of temporomandibular joint (TMJ) articular disc images with the clinical and imaging characteristics of patients with temporomandibular disorder (TMD).

Methods: A total of 110 Magnetic Resonance Imaging (MRI) of the TMJ were selected from patients with a history of TMD. TA of the articular disc was performed using the Mazda software, and the findings were correlated with the clinical characteristics of the patients and the morphology of the articular disc. The data were subjected to binary logistic regression, and the ROC curve was used to analyze the sensitivity and specificity of each significant variable.

Results: TA parameters were significantly altered in patients with TMD with clinical symptoms of muscle pain and clicking and with imaging changes in signal alteration and effusion. The click is the clinical condition with the most altered TA parameters.

Conclusions: TA can improve the accuracy of TMD diagnosis by distinguishing between the clinical and imaging characteristics, helping in the decision-making process for the treatment of patients with TMD.

INTRODUCTION

The temporomandibular joint (TMJ) is among the most complex joints in the human body. This joint may eventually develop disorders that involve musculoskeletal changes and/or masticatory muscles, known as temporomandibular disorders (TMDs) [1], which, according to the Diagnostic Criteria for TMD (DC/TMD), are divided into Axis I, for physical diagnoses; and Axis II, for assessment of psychosocial status and pain-related disability [2,3]. These are orofacial pain most common chronic diseases, affecting 31% of adults and 11% of children and adolescents in the general population [3,4].

Currently, several TMJ image capture modalities are used, among which conventional computed tomography, cone beam computed tomography and Magnetic Resonance Imaging (MRI) stand out. MRI produces images with excellent resolution, high contrast and good dynamics [5]. It is currently considered the reference method for imaging the soft tissue structures of the TMJ (articular disc, synovial membrane and lateral pterygoid muscle) and has been identified as the best imaging modality for the diagnosis of disc displacements [5-8]. In addition, it can detect the initial signs of TMJ dysfunction, such as thickening of the anterior or posterior band, rupture of the retrodiscal tissue, changes in the shape of the disc and joint effusion [9].

Because images obtained by MRI provide more information than the human eye can capture [10], the quantitative characteristics of the images have been associated with the patient's clinical data and outcomes by analyzing the shape, size, volume and texture of an image to determine whether it represents a normal or pathological structure.

Texture analysis (TA) is a mathematical method for processing and analyzing digital images that consists of extracting descriptors related to the distribution of grey levels that can quantify the texture in the Region of Interest (ROI) of an image and identify the spatial pattern of pixels [11]. Furthermore, it has been used to extract useful parameters generally ignored by the human eye, such as the detection of incipient histopathological changes such as increased vasodilation, presence of edema and increased microcirculation hydrostatic pressure [12].

In 1996, the Mazda software was developed at the Institute of Electronics of the Technical University of Lodz, Poland, for the texture analysis of mammograms [13]. The statistical parameters calculated by the initial version of the software were derived from the co-occurrence matrix, which is a useful tool for performing quantitative analyses of the texture of MR images such as those of the TMJ articular disc. Currently, almost 300 parameters can be calculated using MaZda for each ROI for a given image normalization and quantization option.

Therefore, the objective of this study was to relate the MRI texture analysis parameters of the TMJ articular disc, analysis using Mazda software, with clinical and imaging characteristics obtained by MRI of patients with TMD.

MATERIALS AND METHODS

This study followed the STROBE guidelines, was submitted to and approved by the Ceuma University Research Ethics Committee (Opinion Number: 4776213). An informed consent form was signed by those who agreed to participate. Clinical and demographic data were collected from the digital records of patients with TMD treated at Hospital São Domingos, located in the city of São Luiz, Maranhão, Brazil.

Inclusion criteria

The established inclusion criteria were as follows: patients aged 18 years or older, both sexes, with an MRI examination with good visualization of the structures of interest and a previous history of TMD diagnosed considering clinical characteristics, such as the presence of joint pain, muscle pain (masseter), presence of clicking and

bone changes, and imaging characteristics, such as signal change, effusion, condyle excursion, and disc displacement with and without reduction.

MRI examinations were performed from 2019 to 2023, and the images were acquired using an integrated 1.5 Tesla MRI system (Philips Achieva; Best Noetherlands) with 47 mm micro pumps specifically for use in ATMs. Images were obtained with the patient in the open-mouth and closed-mouth positions so that the entire articular disc was visible in the anteroposterior direction.

A convenience sample of 110 bilateral TMJ images from 55 patients (75% female and 25% male) was selected, with a mean age of 36.36 years.

Texture analysis

For texture analysis, proton density (PD) MR images were selected with a more central sagittal section in which all structures of the articular disc were visible in the anteroposterior direction. Subsequently, the image selected in the DICOM format was converted to the BMP format using the Carestream Vue Pacs software version 11.3.4 (Carestream Health, Inc., Rochester, USA).

Segmentation and texture analyses were performed using the Mazda version 3.30 software (Institute of Electronics, Technical University of Lodz, Poland). The AT was performed at four equidistant points along the disc (Figure 1). To select the points, the brightness, contrast and magnifying glass tools were used to help with the anatomical visualization of the disc.

For TA, a co-occurrence matrix (MCO) biomarker was used, which consisted of a tabulation of the number of different combinations of pixel intensity values (grey

Figure 1 Sagittal sections with the selection of four points subjected to texture analysis.

Table 1: Clinical and imaging variables in TMJ MRI and texture analysis parameters analyzed using the Mazda software.

Clinical features	Image features	Texture analysis parameters
Pain joint	Signal change	· Contrast (represents the amount of local variation in grey levels)
Masseter (muscle pain)	Effusion	· Inverse difference moment (represents the amount of local variation in grey levels)
Click	Condyle excursion	· Angular second moment (measurement of image uniformity)
Bone change	Disc displacement with redution	· Correlation (linear measure dependence of gray level between neighboring pixels)
	Disc displacement without redution	· Sum of squares (measure of dispersion in relation to the mean of the grey level distribution)
		· Entropy (measures the degree of disorder between image pixels)
		· *Sum of average* (measure of dispersion in relation to the mean of the distribution of the sum of grey levels)
		· Sum of variance (dispersion around the mean of the sum distribution of grey level)
		· Sum of entropy (disorganization of the sum distribution of grey level)
		· Difference of variance (dispersion of the gray level difference)
		· Difference of entropy (disorganization of the gray level difference)

levels) in an image and a comparison between the grey levels present in certain areas (ROIs) [14-16].

TAs were performed by two examiners who were blinded to the patient's previous clinical situation. The examiners performed a reading calibration process that consisted of evaluating 30 images and obtaining an intraclass correlation coefficient of 0.927, reflecting an excellent degree of agreement.

The following AT parameters described in a previous study [10], were analysis: contrast, inverse difference moment, secondary angular moment, correlation, sum of squares, entropy, mean of the sum, variance of the sum, entropy of the sum, variance of difference: The clinical and imaging variables of the evaluated TMJs are shown in Table 1.

Statistical analysis

Logistic regression was performed using the Enter method to relate the clinical and imaging characteristics with the parameters of the texture analysis (Table 1). In significant cases, the ROC curve was used to analyze the sensitivity and specificity of the variables, in addition to determining the area under the curve (AUC) of significant parameters. The Youden index was used to determine the best cut-off value of the Mazda software parameters to correctly classify cases with clinical symptoms and imaging characteristics.

The significance level adopted was 5%. SPSS for Windows 26.0 (IBM, Armonk, NY, USA) was used for statistical analysis.

RESULTS

AT parameters were significantly altered in patients with clinical symptoms of muscle pain and clicking and with imaging changes in signal change and effusion (Table 2).

The TA parameters that were significant for clinical and imaging characteristics, as well as the respective sensitivity, specificity, area under the ROC curve (AUC) values and cutoff values are presented in Table 3.

DISCUSSION

MRI is the only imaging method to evaluate TMJs that provides visualization of the fibrocartilaginous articular disc, allowing the analysis of its position, shape, possible signal changes, and function [7,17]. Images were obtained in all planes (sagittal, axial and coronal). In most scanning sequences, T1, T2 weighted, and proton density (PD) images were obtained. DP images are used to visualize the disc–condyle relationship, whereas T2-weighted images are used in the diagnosis of joint inflammation [18].

Bone biomarker co-occurrence matrix (MCO) imaging tabulates the number of different combinations of pixel intensity values (grey levels) in an image. This matrix compares the grey levels present in certain areas that are demarcated using delimitation tools available in image software [14-16]. Using this marker, Bianchi et al. [19], detected condylar bone degeneration. The same matrix type was used in this study.

Sensitivity, specificity, AUC and cutoff values were calculated for each AT parameter that was significant for differentiating clinical and imaging characteristics. Sensitivity demonstrated the ability of the AT parameter to correctly diagnose individuals with certain clinical or imaging characteristics, whereas specificity displayed the ability of the same parameter to detect truly negative individuals, that is, to correctly diagnose individuals who do not have certain clinical or imaging characteristics.

The relationship between sensitivity and specificity was expressed through the ROC curve, but more precisely through the AUC, which represents the accuracy of the test and provides an estimate of the probability of correct classification of a subject by chance. An AUC equal to 0.5 corresponds to a test unable to make the correct diagnosis, whereas an AUC equal to 1 corresponds to a test capable of making the correct diagnosis in all cases, that is, a perfect

Table 2: Result of the analysis of clinical and imaging variables and their respective texture analysis variables with their appropriate p-values.

		AT parameter										
		Contrast	Inverse difference moment	Angular second moment	Correlation	Sum of squares	Entropy	Sum of average	Sum of variance	Sum of entropy	Difference of variance	Difference of entropy
Clinical features	Pain joint	0,388	0,752	0,769	0,180	0,376	0,097	0,242	0,252	0,988	0,679	0,955
	Masseter (muscle pain)	0,082	0,004*	0,104	0,330	0,052	0,239	0,215	0,361	0,149	0,014*	0,499
	Click	0,908	0,749	0,001*	0,005*	<0,001*	0,452	<0,001*	0,003*	0,002*	0,712	0,007*
	Bone change	0,998	0,588	0,575	0,459	0,740	0,957	0,548	0,697	0,774	0,130	0,484
Image features	Signal change	0,505	0,273	0,272	0,668	0,013*	0,961	0,945	0,759	0,752	0,004*	0,736
	Effusion	0,022*	0,923	0,248	0,481	0,869	0,665	0,347	0,728	0,557	0,628	0,425
	Condyle excursion	0,666	0,414	0,760	0,347	0,249	0,735	0,498	0,980	0,923	0,581	0,812
	Disc displacement with redution	0,369	0,371	0,771	0,865	0,729	0,346	0,709	0,725	0,669	0,696	0,654
	Disc displacement without redution	0,439	0,113	0,418	0,507	0,062	0,636	0,850	0,812	0,768	0,137	0,608

* p≤0.05, significant association between clinical and imaging findings with texture analysis parameters.

test [20]. Furthermore, a cutoff value was presented as the best value for a given AT parameter that could better classify the presence of clinical or imaging characteristics.

Table 3 depicts the AT parameters that could distinguish the presence or absence of clinical or imaging characteristics, including sensitivity, specificity, AUC, and cutoff values.

Most AT parameters that were significant had higher specificity values than sensitivity values; that is, they were more efficient in correctly diagnosing patients who did not have certain clinical or imaging characteristics. Furthermore, the majority (75%) of the AUC values were greater than 0.70. This means that these parameters have at least a 70% chance of correctly classifying a clinical or imaging characteristic based on AT parameter values.

The AT parameters inverse difference moment and difference of variance were able to differentiate cases of patients with clinical characteristics of muscle pain, with cutoff values 293.03 and 75.28, respectively. This means that patients who presented values below 293.03 of inverse difference moment are more likely to not have muscle pain. In contrast, results greater than or equal to 293.22 are more likely for the patient to have muscle pain. As for the difference of variance, values lower than 75.28 are more likely for the patient to not have muscle pain, whereas values greater than or equal to 75.28 are more likely to have muscle pain. Similar interpretations were made for the other parameters listed in Table 3.

Clinical characteristics of TMD include clenching,

locking of the jaw and clicking [21].The click was the clinical characteristic variable classified by a greater number of AT parameters. Changes were found in the angular second moment, correlation, sum of squares, sum of averages, sum of variance, sum of entropy, and differences in entropy. However, the best parameters for differentiating patients with clinical clicking symptoms were the sum of squares and the sum of the averages, with AUC values of 0.815 and 0.786, respectively.

The imaging characteristics of signal change measure the homogeneity of the grey-level distribution of the image in MRI examinations [7,17], and the results demonstrated that the AT parameters, sum of squares and difference of variance can be used to classify the signal change.

Joint effusion refers to the accumulation of fluid in a joint. The most common is an increase in the joint fluid itself due to an inflammatory response, which changes the amount of local variation in the grey levels. This term is used to designate a hyperintense signal (brightness) on the T2 sequence observed within a joint on MRI [22]. AT contrast was the only parameter capable of diagnosing stroke in the joints of patients with TMD.

The association of certain AT parameters with clinical and MR data showed that AT can accurately diagnose TMJ. With the evolution of software systems that use artificial intelligence, it will be possible, in the near future, to use the predictive capacity of AT to help professionals make decisions regarding the treatment of TMDs.

Table 3: Significant texture analysis parameters used to differentiate the clinical and imaging characteristics from their respective values of area under the ROC curve (AUC), cut-off value, sensitivity, and specificity.

		AT parameter	p	Sensitivity	Specificity	AUC	Cut-off
Clinical features	Pain joint	Inverse difference moment	0.004	70	84.31	0.775	293.03
		Difference of variance	0.014	70	86.27	0.737	75.28
	Click	Angular second moment	0.001	62.5	93.68	0.759	0.87
		Correlation	0.005	62.5	72.63	0.719	163.77
		Sum of squares	<0.001	87.5	65.26	0.815	0.28
		Sum of average	<0.001	56.25	88.42	0.786	6201
		Sum of variance	0.003	62.5	91.58	0.736	1.51
		Sum of entropy	0.002	91.58	55.56	0.743	1.97
		Difference of entropy	0.007	56.25	77.89	0.712	0.82
Image features	Signal change	Sum of squares	0.013	40	80.85	0.577	0.32
		Difference of variance	0.004	63.08	68.09	0.661	34.47
	Effusion	Contrast	0.022	36.36	90.1	0.685	0.27

CONCLUSIONS, LIMITATIONS & RECOMMENDATIONS

The results suggest that articular disc texture analysis improves the accuracy of TMD diagnosis and distinguishes clinical and imaging characteristics.

40. Among the limitations of this study, we can highlight that texture analysis was performed only on a single section, which may not have involved the most characteristic section of the articular disc change. Furthermore, to perform texture analysis using the Mazda software, images in the DICOM format were converted to BMP, thereby decreasing the resolution. However, there is abundant information that in this format is not perceptible in the visual analysis (which distinguishes approximately 64 grey levels) [23]. Future studies should be conducted to validate our findings and clearly demonstrate which AT parameters are associated with the clinical and imaging characteristics of the TMJ in patients with TMD.

REFERENCES

1. Okeson JP. The classification of orofacial pains. Oral Maxillofac Surg Clin North Am. 2008; 20: 133-144.

2. Schiffman E, Ohrbach R, Truelove E, Look J, Anderson Gary, Goulet JP, et al. 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; 28: 6-27.

3. Rongo R, Ekberg E, Nilsson IM, Al-Kothani A, Alstergren P, Durham J, et al. Diagnostic criteria for temporomandibular disorders (DC/TMD) for children and adolescents: An international Delphi study-Part 1-Development of Axis I. J Oral Rehabil. 2021; 48: 836-845.

4. Valesan LF, Da-Cas CD, Reus JC, Denardin ACS, Garanhani RR, Bonotto D, et al. Prevalence of temporomandibular joint disorders: a systematic review and meta-analysis. Clin Oral Investig. 2021; 25: 441-453.

5. Bag AK, Gaddikeri S, Singhal A, Hardin S, Tran BD, Medina JA, et al. Imaging of the temporomandibular joint: An update. World J Radiol. 2014; 6: 567-582.

6. Liedberg J, Panmekiate S, Petersson A, Rohlin M. Evidence-based evaluation of three imaging methods for the temporomandibular disc. Dentomaxillofac Radiol. 1996; 25: 234-241.

7. Talmaceanu D, Lenghel LM, Bolog N, Hedesiu M, Buduru S, Rotar H, et al. Imaging modalities for temporomandibular joint disorders: an update. Clujul Med. 2018; 91: 280-287.

8. Petscavage-Thomas JM, Walker EA. Unlocking the jaw: advanced imaging of the temporomandibular joint. AJR Am J Roentgenol. 2014; 203: 1047-1058.

9. Tomas X, Pomes J, Berenguer J, Quinto L, Nicolau C, Mercader JM, et al. MR imaging of temporomandibular joint dysfunction: a pictorial review. Radiographics. 2006; 26: 765-781.

10. de Oliveira MS, Betting LE, Mory SB, Cendes F, Castellano G. Texture analysis of magnetic resonance images of patients with juvenile myoclonic epilepsy. Epilepsy Behav. 2013; 27: 22-28.

11. Kuno H, Qureshi MM, Chapman MN. CT Texture Analysis Potentially Predicts Local Failure in Head and Neck Squamous Cell Carcinoma Treated with Chemoradiotherapy. AJNR Am J Neuroradiol. 2017; 38: 2334-2340.

12. Valdes Hernandez MDC, Gonzalez-Castro V, Chappell FM, Sakka E, Makin S, Armitage PA, et al. Application of Texture Analysis to Study Small Vessel Disease and Blood-Brain Barrier Integrity. Front Neurol. 2017; 327.

13. Szczypinski PM, Strzelecki M, Materka A, Klepaczko A. MaZda--a software package for image texture analysis. Comput Methods Programs Biomed. 2009; 94: 66-76.

14. Ditmer A, Zhang B, Shujaat T, Pavlina A, Luibrand N, Vagal A, et al. Diagnostic accuracy of MRI texture analysis for grading gliomas. J Neurooncol. 2018; 140: 583-589.

15. Liu MQ, Zhang XW, Fan WP, He SL, Wang YY, Chen ZY, et al. Functional changes of the lateral pterygoid muscle in patients with temporomandibular disorders: a pilot magnetic resonance images texture study. Chin Med J (Engl). 2020; 133: 530-536.

16. Oliveira MS, Fernandes PT, Avelar WM, Santos SLM, Castellano G, Li LM. Texture analysis of computed tomography images of acute ischemic stroke patients. Braz J Med Biol Res. 2009; 42: 1076-1079.

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17. Aiken A, Bouloux G, Hudgins P. MR imaging of the temporomandibular joint. Magn Reson Imaging Clin N Am. 2012; 20: 397-412.

18. Sano T, Widmalm SE, Yamamoto M, Sakuma K, Araki K, Matsuda Y, et al. Usefulness of proton density and T2-weighted vs. T1-weighted MRI in diagnoses of TMJ disk status. Cranio. 2003; 21: 253-258.

19. Bianchi J, Goncalves JR, Ruellas ACO, Vimort JP, Yatabe M, Paniagua B, et al. Software comparison to analyze bone radiomics from high resolution CBCT scans of mandibular condyles. Dentomaxillofac Radiol. 2019; 48: 20190049.

20. Swets JA. Measuring the accuracy of diagnostic systems. Science. 1988; 240: 1285-1293.

21. Mansur S, Ishak A, Pop I. The magnetohydrodynamic stagnation point flow of a nanofluid over a stretching/shrinking sheet with suction. PLoS One. 2015; 10: e0117733.

22. Adame CG, Monje F, Offnoz M, Martin Granizo R. Effusion in magnetic resonance imaging of the temporomandibular joint: a study of 123 joints. J Oral Maxillofac Surg. 1998; 56: 314-318.

23. Goncalves BC, de Araujo EC, Nussi AD, Bechara N, Sarmento D, Oliveira MS, et al. Texture analysis of cone-beam computed tomography images assists the detection of furcal lesion. J Periodontol. 2020; 91: 1159-1166.