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Utilizing Texture Analysis technique in diagnostic imaging at Dentistry: innovations and applications

Utilizando a técnica de Análise de Textura no diagnóstico por imagem em Odontologia: inovações e aplicações

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ABSTRACT

Background: The Texture Analysis (TA) technique allows the evaluation of intrinsic properties by extracting signal patterns from pixels and voxels in images that are unnoticed by the human eye. In medical imaging, TA has been applied to the characterization of various lesions. In Dentistry, in recent years, we have observed the application of this tool in various specialties. **Objective:** This short communication aims to present the applications of the texture analysis (TA) technique in Dentistry and its possibilities for the coming years. **Material and Methods:** For this brief review, the search was conducted in the Pubmed, LILACS, and Google Scholar databases, using the descriptors "Computer-Assisted Image Processing", "Diagnostic Imaging" and Dentistry". Were included articles that addressed the topic, published in the last 5 years in English, and compatible with the present theme. Considering the 22 articles found, it was observed that, for the most part, AT applications aim to assist in the diagnosis of lesions of the maxillofacial complex. Then temporomandibular disorders and oral manifestations of autoimmune conditions. There are also applications in orthodontics, periodontics, implant dentistry, and cariology. **Conclusion:** The TA technique presents itself as a promising method within dental imaging, since, through its mathematical and quantitative tools, it provides greater accuracy and objectivity. In this way, we can see the emergence of a biomarker that assists professionals in the early diagnosis of injuries. However, the research carried out to date has limitations, and more studies are needed to understand the capabilities of TA.

KEYWORDS

Computer Assisted Diagnosis; Diagnostic Imaging; Dentistry; Radiomics; Radiology.

RESUMO

Contexto: A técnica de Análise de Textura (AT) permite avaliar propriedades intrínsecas extraindo padrões de sinal de pixels e voxels em imagens que são despercebidas pelo olho humano. Na imaginologia médica, a AT tem sido aplicada na caracterização de lesões diversas. Na Odontologia, observamos nos últimos anos aplicação dessa ferramenta em diversas especialidades. **Objetivo:** Esta *short communication* objetiva apresentar as aplicações da técnica de análise de textura (AT) na Odontologia e suas possibilidades para os próximos anos. **Materiais e Métodos:** Foi realizada busca nas bases de dados Pubmed, LILACS e Google Scholar, aplicando os descritores "Computer-Assisted Image Processing", "Diagnostic Imaging" e Dentistry". Foram selecionados artigos compatíveis com a temática, publicados nos últimos 5 anos e publicados em inglês. Considerando os 22 artigos encontrados, observou-se que, majoritariamente, as aplicações de AT objetivam auxiliar no diagnóstico de lesões do complexo maxilofacial. Em seguida, desordens temporomandibulares. Nota-se também aplicações na ortodontia, na periodontia, na implantodontia e na cariologia. **Conclusão:** A técnica de AT apresenta-se como um método promissor dentro na imaginologia odontológica, uma vez que, através de suas ferramentas matemáticas e quantitativas, proporciona maior acurácia e objetividade. Dessa forma, percebe-se o surgimento de um biomarcador que assista ao profissional no diagnóstico precoce de lesões. No entanto, as pesquisas realizadas até o presente momento possuem limitações e mais estudos são necessários para entender as capacidades da AT.

PALAVRAS-CHAVE

Diagnóstico por Computador; Diagnóstico por imagem; Odontologia; Radiômica; Radiologia.

INTRODUCTION

In recent decades, imaging exams have represented significant advancements in complementary medical and dental diagnosis [1,2]. Over the past years, magnetic resonance imaging (MRI) and cone-beam computed tomography (CBCT) have stood out in dentistry due to their effective applications. More recently, predictive Artificial Intelligence tools, such as Machine Learning (ML) and Texture Analysis (TA) techniques, have also gained prominence. This technique promotes enhancing the accuracy and precision of lesion diagnosis in conditions such as brain tumors [3], autoimmune diseases [4], and Diabetes Mellitus [5].

According to Strzelecki et al., texture is perceived by humans as a visualization of complex patterns composed of repeated and spatially organized subpatterns, whose appearance is characteristic. The local subpatterns inside of an image are perceived through parameters like specific brightness, color, roughness, directivity, randomness, and smoothness. The TA technique is a quantitative method that enables the visualization of patterns and variations in the pixels or voxels organization in specific areas of an image. This tool identifies and measures texture levels in images, assisting the operator in perceiving subtle changes that are imperceptible to the naked eye [6].

Texture is defined in the imaging area as a descriptor of the internal structure of human tissues or organs. Consequently, the TA of images is an essential question in the processing and comprehending of diagnostic images [7]. Essentially, TA uses imaging exams as radiographs, computed tomography, and magnetic resonance images as substrates to analyze characteristics quantitatively. This approach, which considers the grey levels in a specified region of interest (ROI) [8,9], allows us to evaluate the existing grey levels in the ROI of an image. It also enables us to understand the relationship between pixels in two-dimensional images and voxels in three-dimensional images, increasing accuracy and aiding in the interpretation of diagnostic images [10].

In this context, Texture Analysis is defined as an image evaluation technique based on quantitative analysis, through the spatial arrangement of pixels or voxels among themselves, in a delimited ROI; and the evaluation of all shades of gray arranged in this same ROI, through histograms. It stands out as a differential because it allows information on regions with different levels of gray that go unnoticed by the operator. Thus, the technique's main indication is the proposal to perform an objective comparative analytical evaluation between images [2,11].

According to the literature, there are different software applications for TA, such as MATLAB [12,13] and Mazda. The last one stood out in medical and dentistry imaging because most studies in those areas have used it as the tool for your aims [14-16]. The Mazda software, then, has six AT methods, emphasizing the grey level co-occurrence matrix (GLCM) and the grey level run length matrix texture (GLRLM) [17]. It's possible to analyze up to 11 parameters in each method, according to Haralick et al. [10] and presented in Figure 1.

Due to the increasing demand for diagnostics with greater precision and accuracy in medicine and dentistry and the growing use of TA, this short communication proposes to conduct a brief review of the current panorama of the applications of the Texture Analysis technique in dentistry, enumerating the limitations of this technique, and future possibilities in oral radiology.

MATERIAL AND METHODS

The search was conducted in the Pubmed, LILACS, and Google Scholar databases, using the descriptors "Computer-Assisted Image

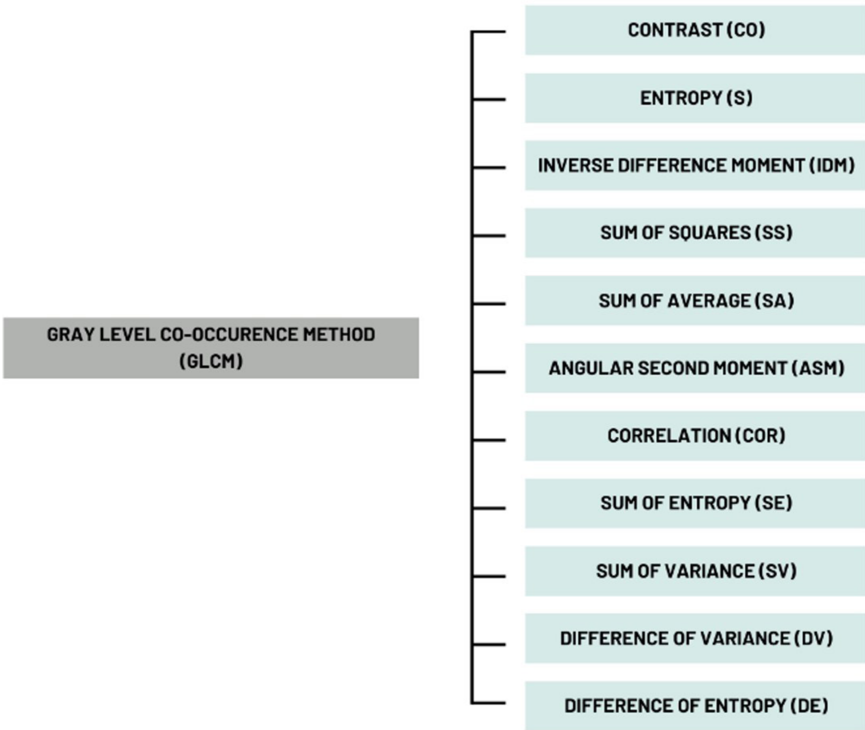

Figure 1 - Example of a texture analysis (TA) method – GLCM - with the eleven parameters that can be evaluated. Source: adapted from Haralick et al. [10].

Processing", "Diagnostic Imaging" and Dentistry". The inclusion criteria were articles that addressed the topic, published in the last 5 years in English, and without restriction as to the country of origin. As exclusion criteria, were selected articles that, through reading the title and abstract, were not related to the proposed topic were excluded. In the end, 22 studies were selected for the preparation of this brief review.

FUNDAMENTAL CONCEPTS

Before conducting a proper review, it is crucial to present essential concepts to understand this topic. Using specialized software, the TA can be understood as the analysis of imaging exams to capture the texture properties of the ROI. Therefore, TA uses a mathematical method for processing and analyzing digital images, which consists of specifying descriptors related to the distribution of grey levels in the image. These descriptors, or properties, are expressed objectively by detecting changes in grey levels of an image [18].

What distinguishes this new model is the quantitative analysis of the grey levels a region should contain once the human eye, no matter how trained and experienced, has limitations, capturing only 60 of the 4000 levels of grey between the pixels of a given area [19].

According to the literature, there are six TA methods, such as GLCM, consisting of a square matrix, in which the number of lines and columns is equal to the grey levels of that image, revealing properties about the spatial distribution of the grey levels on the texture of the image. In a few words, this method simplifies the quantity and the distribution of shades of grey in a determined ROI. The GLRLM method represents pixel series with the same grey level values [6]. In each process, it's possible to analyze up to 11 parameters quantitatively, as Haralick et al. proposed [10]. Figure 2 summarizes how the initial Texture Analysis process takes place.

Pioneering applications

Despite research about the TA starting in the late 1970s [10], the applications only became prominent at the beginning of the 21st century. In Medicine, the studies aimed to distinguish the physiological aspect of tissue from lesions present in different regions of the human body, associating the pathological aspect with considerable contrast, for example.

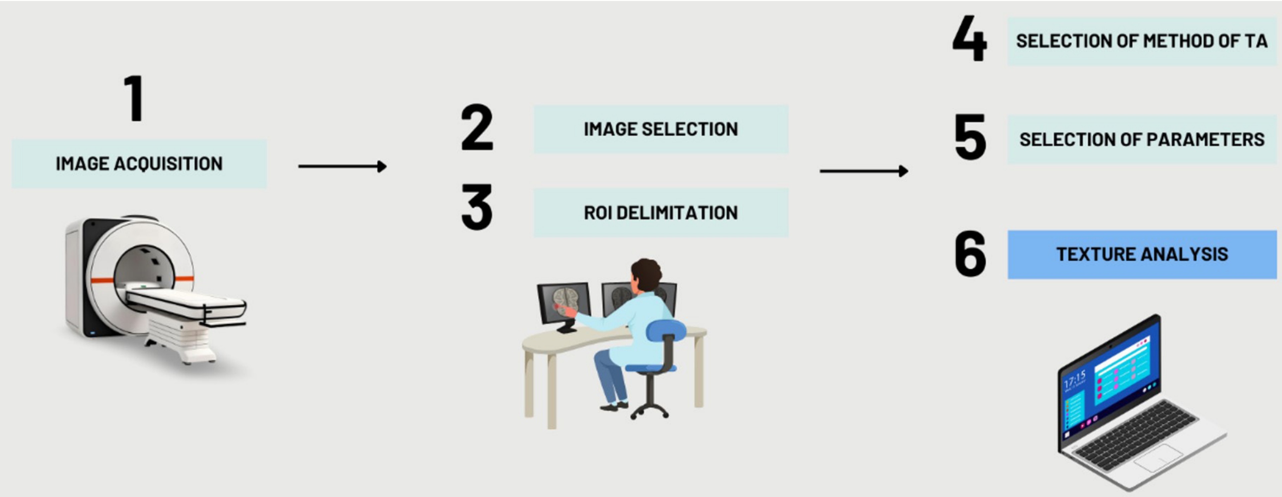

Figure 2 - Flowchart of the texture analysis process, from acquisition, using MRI images as a substrate to applicate Texture Analysis. ROI: Region of interest; TA: Texture Analysis. Illustration prepared by authors.

In medical literature, TA is most present in critical studies, such as the study of Gibala et al., whose purpose was to validate TA as a biomarker for detecting important characteristics in the imaging exam to indicate prostate cancer risk. In this investigation, the findings expressed a high dependency between the characteristics of the image related to cancer markers and, consequently, the risk of cancer [20]. Ye et al. [21], in turn, aimed to explore the total TA value of tumors based on magnetic resonance image (MRI) to differentiate ovarian epithelial tumors borderline to stage I/II malignant ovarian epithelial tumors, whose results suggest that this can be an auxiliary tool on differential diagnostics of this lesions.

It's worth emphasizing the studies that evaluate texture parameters as possible biomarkers for the prediction of cell invasion in these types of cancer: liver [22] and gastric [23], on evaluation of breast imaging on cancer screening [24] and even on complementary analyze of COVID-19 pneumonia [25].

Applications in dentistry

In the last few years, there has been an increasing number of studies involving texture analysis and possible applications. Most studies have applied this tool as an auxiliary diagnostic method on maxillofacial lesions [5,7-9,12-15,26-30]. In this section, we list some applications in Dentistry found in the literature, and Figure 3 presents the distribution of the articles found in our research.

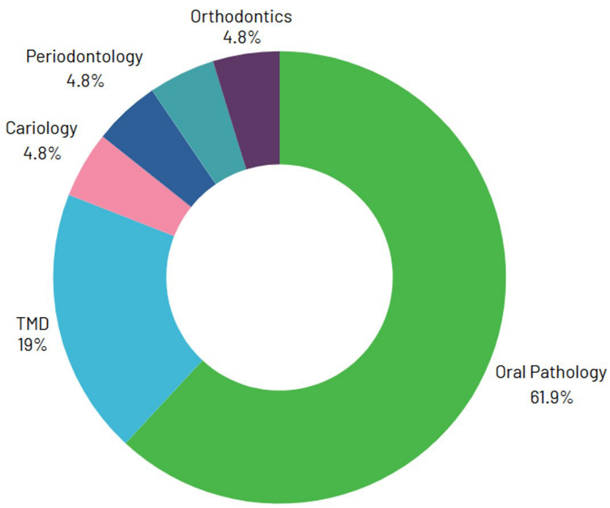

Figure 3 - Illustration of the area distribution of articles involving TA and Dentistry found in the search. TMD: Temporomandibular Disorders. Source: the authors.

- *Bone oral health:* Queiroz et al., assessed variations in trabecular bone using AT and compared TA technical features of different areas in patients with medication-related jaw osteonecrosis (MRONJ). The study used cone beam computed tomography (CBCT) scans and perceived those images of the regions compared presented higher values for the following parameters: contrast (CO), entropy (S), and angular second moment (ASM), regarding healthy areas, suggesting major disorder on those tissues [8].
- *Oral Pathology:* Gomes et al. utilized a substrate magnetic resonance image to consolidate TA as an objective marker to differentiate ameloblastoma from

odontogenic keratocyst. The statistics analysis reveals that two of the eleven parameters presented significant relationships in this differentiation [12]. In comparing odontogenic maxillary sinusitis with non-odontogenic maxillary sinusitis, the research of Costa et al. [15] and Ito et al. [13] obtained statistically significant values in their results about the analyzed parameters. De Rosa et al. [7] published in 2020 the results from the investigation into the use of AT for the characterization of radicular cysts (RC) from periapical granuloma (PG) and the efficacy of this tool in differentiating both lesions, already with histological diagnosis. CBCT images were obtained from 19 patients with periapical lesions (14 RC and 11 PG), confirmed by biopsy.

- *Temporomandibular joint disorders (TMD):* Oliveira et al. [28] aimed to characterize TA parameters of the condylar medullary bone and the superior aspect of the lateral pterygoid muscle (LPM) on Magnetic Resonance Imaging (MRI) for the identification of potential changes in individuals with temporomandibular disorders (TMD). Forthy MRI scans were retrospectively selected, consisting of 20 patients without temporomandibular joint (TMJ) changes (control group) and 20 patients diagnosed with TMD (TMD group). All MRI scans adhered to a consistent protocol. TA was performed using the Mazda, and the ROIs were standardized for all evaluated images. The texture parameters were calculated through the GLCM method. TA results underwent comparison using the Mann-Whitney test. There was a statistically significant difference in the CO and IDM parameters between control and TMD groups, notably evident in images for the region of the condylar medullary bone and the LPM, respectively ($p<0.05$). Figure 4 illustrates one of the steps of texture analysis in a similar study [31], in which MRI images were also used as imaging exams, however, to evaluate possible changes in individuals with migraine headache.
- *Periodontology*: Gonçalves et al. [16] evaluated patients with grade C periodontitis to detect non-visible changes in the image. Statistically significant differences were observed in almost all parameters of the intergroup analysis.
- *Dental Implants*: The study of Costa et al. in 2021 [32] aimed to characterize the alveolar bone of edentulous jaws using CBCT images and TA. Thus, the aim was to correlate the results with the insertion torque, verifying if TA is a predictive tool for implant treatment results. The results showed a direct correlation with the contrast of peri-implant bone and an inverse correlation with the entropy of the bone site of the implant.
- *Orthodontics:* Ito et al. aimed to quantitatively assess the roots of upper central incisors using the AT technique in pre-orthodontic treatment patients, based on Cone Beam Computed Tomography (CBCT) images, as part of a quantitative texture analysis. This retrospective case-control study included 16 patients with external apical root resorption (EARR) and 16 age- and sex-matched patients without EARR (control group), after orthodontic treatment, who underwent pre-orthodontic CBCT to address maxillary deformities. All patients were treated with fixed orthodontic appliances before and after surgical orthodontic treatment. The texture characteristics of the upper central incisors with and without EARR after orthodontic treatment were analyzed using Mazda. Ten texture features were selected, and, thus, four features from the GLRLM method; and six features from GLCM method showed significant differences between both groups ($p < 0.01$) [33].
- *Cariology:* Obuchowicz et al. evaluated the performance of texture feature maps in recognizing discrete demineralization related to caries plaque formation. Digital protocols for intraoral radiographic image analysis, incorporating features beyond texture, such as first-order features (FOF), local binary patterns (LBP), and k-means clustering (CLU), were used. Regarding texture analysis itself, the GLCM and GLRLM methods were employed. All of these methods were applied to transform digital intraoral radiographic images from 10 patients with a confirmed diagnosis of caries, retrospectively reviewed in a dental clinic. The performance of the resulting texture feature maps was compared with that of radiographs evaluated by radiologists

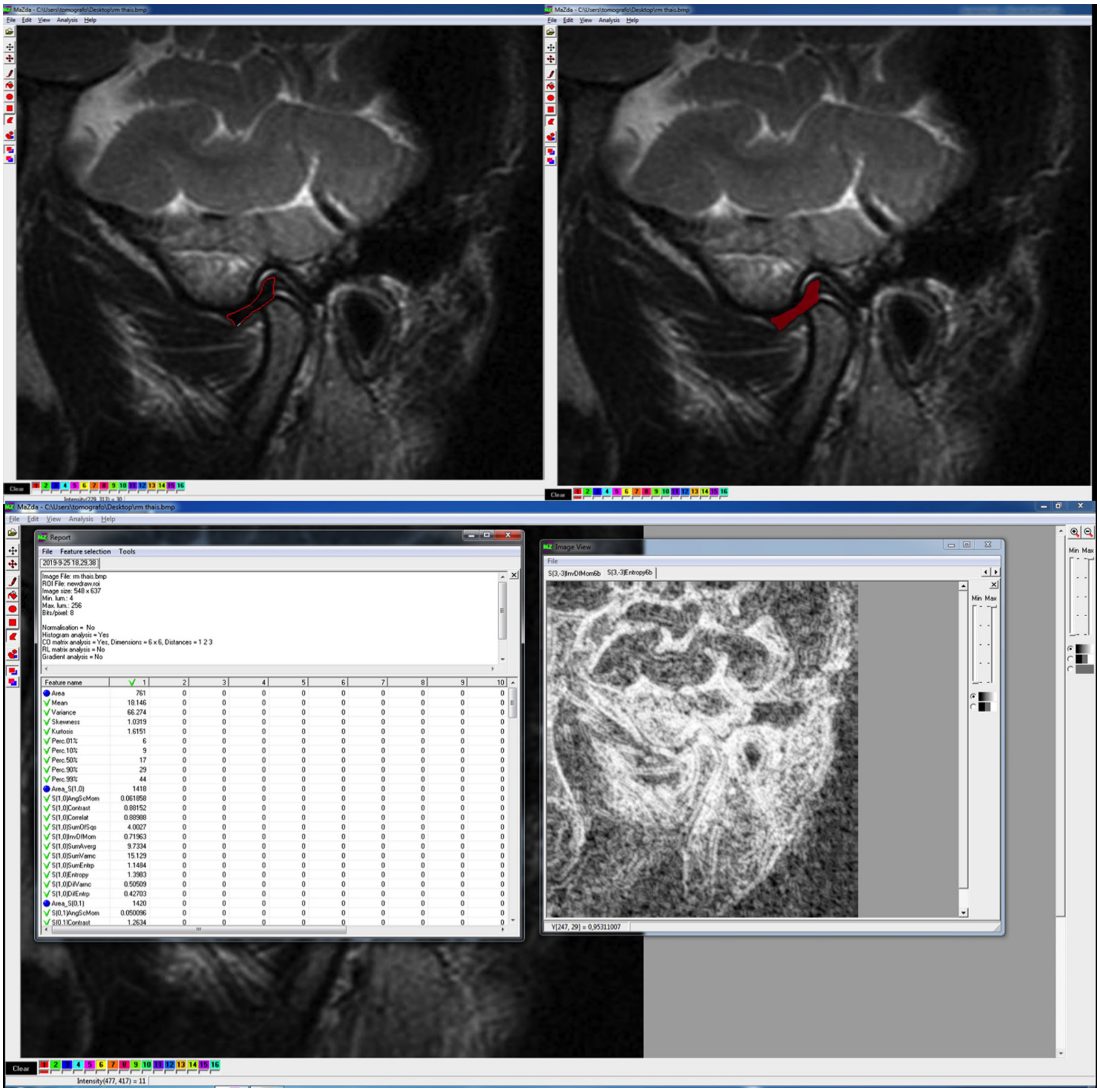

Figure 4 - Example of ROI delimitation of the articular disc in a T2-weighted image of the TMJ and calculation of texture parameters by using the Mazda software. Source: Fardim et al. [31].

and dental specialists. Significantly improved detection of carious spots was achieved through the use of texture feature maps from CLU and FOF. The area affected by caries with sharp margins was well-defined by the CLU approach. A pseudo-three-dimensional effect was observed in the delineation of demineralization zones within the cavity using a specific protocol. In contrast, the LBP and run-length matrix techniques produced less satisfactory results, with blurry edges and less detailed representation of lesions [34].

DISCUSSION

The literature has presented that imaging exams are complementary tools for dental clinic diagnostics, providing more accurate information and helping with treatment success [35-37]. It's important to highlight that, despite the considerable experience of radiologists, there are visual limitations inherent to human beings. Those limitations occurred due to the human capacity for perceiving only a tiny fraction of grey levels and the subjective capacity for analysis, which went unnoticed in some aspects of images that could have atypia [15].

In this context, the advent of an objective and quantitative analysis tool that can analyze the information an ROI can provide through mathematics and objective parameters is an essential appliance in the diagnosis overview. Thus, studies using the TA are emerging in Medicine and Dentistry [2,3,38,39].

We observed the predominant use of the Mazda software in evaluating medical and dental images [8,15,16,28,31,32]. The reason for this predominance is still unclear, suggesting the future realization of comparative studies between Mazda and other programs listed in the literature, such as MATLAB [12,13] and Machine Learning [27]. The articles mainly used the GLCM and GLRLM methods in their research, showing at least one AT considerable parameter in statistics terms for evaluating the object of interest.

The studies of Ricardo et al. [4], Queiroz et al. [8], Gomes et al. [12] and Fardim et al. [31] all presented entropy (S) as a meaningful parameter in the results, suggesting that physiological areas are associated with the lowest disorder. In contrast, areas with lesions are related to higher entropy, as well as other parameters, such as higher contrast.

LIMITATIONS

As well as all image analysis methods, the AT technique has some inherent limitations. Among them, we list the evaluator's skill in determining the ROIs to be analyzed; the variability of image acquisition parameters that can alter the results of the calculation of pixel values by the competition matrix; and also the time spent to calculate texture parameters, which, depending on the size of the region of interest and image resolution, can be quite extensive. In other words, this technique requires specialized training of operators and the acquisition of high-quality images.

We further discuss that reduced sample size in most research, demanding future studies, retrospective or not, that have a more extensive and considerable sample, avoiding biases. Furthermore, there is a need for more studies that aim to compare TA in two-dimensional and three-dimensional images. In addition, future research may have more than one examiner for the initial stages, including the stage of ROI delimitation, provided they are previously calibrated with each other. Barioni et al. discuss the need to standardize analyses for each AT method, and develop guidelines; hence, there is a need for multicenter research groups to develop investigations in this regard [40,41].

Therefore, it's understood that TA is an auxiliary promising tool for dentomaxillofacial diagnosis, which could provide objective information with higher accuracy. However, more studies are needed to verify the feasibility of this technology in clinical routine, such as consolidating your use according to scientific evidence.

CONCLUSION

It was evident that the TA has superior accuracy and can objectively assist in diagnosing critical lesions, which, if detected initially through subtle aspects, can obtain a better prognosis and more appropriate treatment.

Author's Contributions

VGBO, VLR, LFS, SLPCL: Conceptualization. VGBO: Data Curation. VGBO, LFS, ESR, ACDM, MANJ, ALFC, SLPCL: Formal Analysis. VGBO, VLR, LFS, ESR, ACDM, MANJ, ALFC, SLPCL: Funding Acquisition. VGBO, VLR, LFS, SLPCL: Investigation. VGBO, VLR, SLPCL: Methodology. VGBO, SLPCL: Project Administration. VGBO, VLR, LFS, SLPCL: Resources. ALFC, SLPCL: Software ESR, ACDM, MANJ, ALFC, SLPCL: Supervision. SLPCL: Validation. VGBO, VLR, LFS, ESR, ACDM, MANJ, ALFC, SLPCL: Visualization. VGBO, VLR, LFS, ESR, ACDM, MANJ, ALFC, SLPCL: Writing – Original Draft Preparation. VGBO, VLR, LFS, ESR, ACDM, MANJ, ALFC, SLPCL: Writing – Review & Editing.

Conflict of Interest

The authors have no proprietary, financial, or other personal interest of any nature or kind in any product, service, or company presented in this article.

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Regulatory Statement

This article consists of a brief literature review and therefore does not involve the collection of primary data from human or animal subjects. No ethics committee approvals or informed consent forms were required.

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