UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ODONTOLOGIA DE PIRACICABA

JOÃO PEDRO ANTUNES DOS SANTOS CORVINI

Avaliação de alterações na morfologia condilar: influência da aplicação de filtros em imagens de tomografia computadorizada de feixe cônico de diferentes resoluções

Evaluation of condylar condylar morphological alterations: influence of filters in Cone-Beam Computed Tomography acquired with different resolutions

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Trabalho de Conclusão de Curso apresentado à Faculdade de Odontologia de Piracicaba da Universidade Estadual de Campinas como parte dos requisitos exigidos para obtenção do título de Cirurgião Dentista

Orientador: Prof.ª Dr.ª Deborah Queiroz de Freitas França

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RESUMO

O objetivo no presente trabalho foi avaliar a influência do tamanho do voxel e da aplicação de filtros no diagnóstico das alterações de morfologia condilar em tomografia computadorizada de feixe cônico (TCFC). Para isso, exames de TCFC de 18 pares de crânio seco e mandíbula (36 articulações temporo-mandibulares) foram adquiridos no aparelho OP300 Maxio com os tamanhos de voxel de 0,085, 0,125 e 0,280mm. Três examinadores avaliaram os exames em três modos: sem filtro, com filtro “1x” e com filtro “2x”, totalizando 324 exames. Os tipos de alterações a serem avaliados foram: osteófito, aplainamento, erosão, esclerose e pseudocisto. Os valores de diagnóstico foram calculados e analisados pela Análise de Variância (α=5%). Os valores de área sobre a curva ROC, sensibilidade e de especificidade não sofreram influência do voxel e do filtro ($p>0,05$). Para o aplainamento e osteófito, o menor tamanho de voxel obteve maior número de diagnóstico verdadeiro-positivo. Para a erosão, mais verdadeiro-positivos foram obtidas com o maior voxel, mas o número de falso-positivos também aumentou. Em relação aos filtros, de um modo geral, houve uma tendência em diminuir os verdadeiro-positivos para osteófitos e erosão e aumentar os falso-positivos no aplainamento com o filtro "2x". Foi possível concluir que, no geral, o diagnóstico não foi afetado pelo tamamnho do voxel e aplicação dos filtros. No entanto, é necessária atenção com a ocorrência de diagnóstico falso-positivo com um tamanho de voxel maior para a erosão e com o filtro "2x" para o diagnóstico de aplainamento.

Palavras-chave: Articulação temporomandibular, Tomografia Computadorizada de Feixe Cônico, diagnóstico.

ABSTRACT

The aim of this study was to evaluate the influence of voxel size and the application of filters in the diagnosis of condylar morphology changes in cone-beam computed tomography (CBCT). For this purpose, CBCT scans of 18 dry skull and mandible pairs (36 temporomandibular joints) were acquired in the OP300 Maxio scanner with voxel sizes of 0.085, 0.125 and 0.280 mm. Three examiners evaluated the scans in three modes: without filter, with "1x" filter and with "2x" filter, totaling 324 scans. The types of changes to be evaluated were: osteophyte, flattening, erosion, sclerosis and pseudocyst. The diagnostic values were calculated and analyzed by Analysis of Variance (α=5%). Area over the ROC curve, sensitivity and specificity values were not influenced by voxel and filter ($p>0.05$). For flattening and osteophyte, smaller voxel size obtained higher number of true-positive diagnosis. For erosion, more true-positives were obtained with the largest voxel, but the number of false-positives also increased. Regarding the filters, in general, there was a tendency to decrease the true-positives for osteophytes and erosion and increase the false-positives for flattening with the "2x" filter. It was possible to conclude that, overall, the diagnosis was not affected by the voxel size and application of the filters. However, attention is needed with the occurrence of false-positive diagnosis with a larger voxel size for erosion and with the "2x" filter for the diagnosis of flattening.

Key-words: Temporomandibular joint, Cone beam computed tomography, diagnostic.

Sumário

Introdução

A Disfunção temporomandibular (DTM) é um grupo heterogêneo de doenças complexas de etiologias variadas e muitas vezes multifatoriais, as quais podem afetar a musculatura mastigatória bem como os componentes articulares da articulação temporo-mandibular (ATM), como o disco articular, os ligamentos e os componentes ósseos da articulação temporomandibular (Barghan et al., 2011), representados pela cabeça da mandíbula, fossa articular do osso temporal e eminência articular.

Sinais e sintomas podem incluir dor, estalo, limitação de abertura, desvio na abertura e fechamento de boca e crepitação (Dos Anjos Pontual et al., 2012; Taalat et al., 2016). A crepitação pode ser indicativa de alterações morfológicas das estruturas ósseas envolvidas. No caso das cabeças da mandíbula, erosão, aplainamento, osteófito e esclerose podem indicar uma alteração adaptativa ou, até mesmo, degenerativas (Ahmad et al., 2009; Bastos et al., 2013). Essas alterações podem levar à instabilidade e dor na articulação temporomandibular (ATM) (Bastos et al., 2013; Dias et al., 2012).

A patofisiologia de tais alterações permanece incerta, sendo que duas principais teorias foram propostas buscando sua explicação, partindo do pressuposto de que tais alterações, as quais possuem caráter degenerativo, resultam de um remodelamento disfuncional da articulação, em função de uma diminuição da capacidade de adaptação das estruturas da articulação e, ainda, de um estresse crônico ou agudo ao qual são submetidas as estruturas da articulação, os quais excedem sua capacidade adaptativa natural. Dessa forma, percebe-se que a base dessas proposições está na capacidade adaptativa do próprio indivíduo, a qual é associada com sua condição geral de saúde, ao passo que idade avançada, doenças sistêmicas e fatores hormonais podem definir a capacidade adaptativa da ATM, contribuindo para um remodelamento disfuncional das estruturas articulares, mesmo quando os estresses biomecânicos considerados naturais estão em atuação (Tanaka et al., 2008).

Dependendo do quadro, o exame clínico pode ser considerado insuficiente para determinar a condição da ATM (Dias et al., 2012). Uma das condições degenerativas mais comuns da ATM é a Osteoartrite, que pode ser definida como uma condição degenerativa da articulação caracterizada pela deterioração do tecido articular e concomitante remodelação da camada de osso subcondral, sendo considerada uma doença relacionada à idade pela OMS (Mani et al., 2016). Os sinais e sintomas dessa condição são mais frequentemente observados nos estágios mais avançados da doença, quando as alterações em osso, cartilagem articular e disco articular já progrediram de modo irreversível (Bianchi et al., 2020), o que faz com que o exame de imagem tenha um papel relevante no diagnóstico precoce dessas alterações, quando é requisitado.

Em termos de imaginologia, os sinais característicos da Osteoartrite também são osteófito, aplainamento, erosão e esclerose, acometendo a cabeça da mandíbula (Dos Anjos Pontual et al., 2012).

Quando nos referimos às alterações degenerativas da cabeça da mandíbula, os exames de imagem mais indicados são aqueles que fazem uso de radiação ionizante, dentre os quais destacamos: a radiografia panorâmica, a radiografia transcraniana, a tomografia computadorizada de feixe em leque, diversas vezes referida na literatura como tomografia computadorizada (TC) apenas e a tomografia computadorizada de feixe cônico (TCFC) (Talmaceanu et al., 2018). Já quando nos referimos às alterações nos componentes de tecido mole da articulação, o exame de imagem mais indicado para o diagnóstico passa a ser a ressonância magnética nuclear (RMN) (Talmaceanu et al., 2018)

Os exames bidimensionais, como a panorâmica, podem comprometer a visibilidade das estruturas de interesse, devido à sobreposição de estruturas (Nascimento et al., 2014). O Critério Diagnóstico para Pesquisa em Disfunções Temporomandibulares (RDC/TMD), que funciona como uma diretriz para o correto diagnóstico das DTMs de acordo com dados presentes na literatura, recomenda o uso da tomografia computadorizada (TC) como modalidade de imagem para avaliação de alterações morfológicas ósseas da ATM, para pesquisas e avaliações clínicas (Ahmad et al., 2009). O alto custo e dose relativamente mais alta da TC tornam a TCFC uma alternativa para a avaliação dos componentes ósseos das ATM (Taalat et al., 2016)

Os scanners ou aparelhos de TCFC para uso na Odontologia em especial, mas também em especialidades médicas correlatas como a cirurgia de cabeça e pescoço e a otorrinolaringologia (Piotrowska-Sewery et al., 2019) foram introduzidos em 1998. Atualmente, a TCFC é utilizada em uma série de especialidades odontológicas, tais como a implantodontia, endodontia, cirurgia maxilofacial e ortodontia (Pauwels R et al., 2015)

As imagens de TCFC são compostas por unidades cúbicas chamadas de voxels, os quais, podem possuir diferentes tamanhos o que possui relação direta com a resolução espacial ou nitidez da imagem (Verner et al., 2015), que representa a capacidade da imagem em distinguir dois objetos (Oliveira-Santos et al., 2019). Além do tamanho do ponto focal e do tamanho do voxel, o pico da voltagem (kVp), a corrente do tubo (mA) e o campo de visão são alguns outros fatores da aquisição doe xame que podem influenciar na qualidade da imagem (Verner et al., 2015) e, possivelmente, o diagnóstico.

O tamanho do voxel pode ser definido a partir das medidas de sua altura, largura e profundidade, sendo que, no caso das imagens de TCFC, é geralmente isotrópico, ou seja, com as três medidas iguais, O tamanho do voxel de uma imagem tridimensional é equivalente aos pixels que formas as imagens bidimensionais, sendo que, também os pixels possuem relação direta com a resolução espacial dessas imagens (Spin-Neto R et al., 2012)

A medida da resolução espacial de uma imagem bidimensional é dada pela unidade pixels por polegadas, ao passo que uma resolução de 300 ppi teria a correspondência matemática de um tamanho de voxel de 0,085mm (Spin-Neto et al., 2012)

As imagens adquiridas com tamanho de voxels menores resultam em resoluções espaciais maiores, mais nítidas, sob um ponto de vista subjetivo (Spin-Neto et al., 2012), porém, o tamanho de voxel menor irá indiretamente aumentar a dose de radiação ao paciente no momento do exame (Spin-Neto et al., 2012), pois os fatores de exposição precisam ser ajustados, o que é potencialmente prejudicial ao organismo do paciente (Brenner et al., 2007).

Do ponto de vista dosimétrico e técnico, a dose de radiação de um aparelho de raios X pode ser definida a partir da variação de três parâmetros de exposição: kVp, mA e tempo de exposição do paciente (dado em segundos) . Um modo de se reduzir a dose de radiação a que o paciente é exposto pode ser obtido a partir da diminuição da mA, mantendo o tempo de exposição fixo. Outros modos podem ser alterando a colimação do feixe de raios X, a filtragem dos raios X, bem como a utilização da tecnologia da radiação pulsátil, a qual atua reduzindo o tempo de exposição (Palomo et al., 2008).

Para que os profissionais possam lidar do melhor modo possível com as condições acerca da dose de radiação envolvida nos exames de imagem que utilizam radiação ionizante, conceituou-se a ideia da dosagem de radiação seguindo o padrão ALARA, que em inglês significa “as low as resonably achievable”, que em tradução livre pode ser definido como “a mais baixa o quanto for possível para um exame racionalmente adquirido”. Porém, de modo a nortear com maior precisão os profissionais, a European Academy of Dental and Maxillofacial Radiology (EADMFR) conceituou uma ideia da dosagem de radiação seguindo o padrão ALADA, que, por sua vez, significa “as low as resonable diagnostically acceptable”, uma evolução da ideia da ALARA, em que a dosagem de radiação de um exame de imagem deve ser a mais baixa possível para uma imagem de qualidade aceitável para determinada tarefa de diagnóstico (Jaju et al., 2015).

Outro fator que está diretamente ligado à qualidade da imagem, juntamente com a resolução espacial, é o ruído da imagem, o qual pode ser definido como a variabilidade aleatória de valores de cinza dos voxels em uma imagem, os quais possuem várias fontes e possuem relação direta com a aplicação das ferramentas de pós-processamento, uma vez que certas ferramentas podem amplificar ou reduzir o ruído das imagens, o que também compromete sua qualidade (Marques et al., 2021).Outro efeito de certos filtros é aumentar ou diminuir o contraste entre os voxels adjacentes (Verner FS et al., 2016). Na literatura consultada, os filtros têm sido estudados para utilização na avaliação de defeitos peri-implantares (Bayrak et al., 2020), perda óssea alveolar (de Sousa et al., 2017), complicações endodônticas (Verner et al., 2016), fraturas radiculares verticais (Ferreira et al., 2015) (De Martin e Silva et al., 2018) e longitudinais (Nascimento et al., 2014), mas pouco tem sido pesquisado sobre a aplicação no diagnóstico de alterações ósseas condilares.

Desse modo, o objetivo no presente estudo foi avaliar a influência da aplicação de filtros e dos tamanhos de voxel utilizados para a aquisição do exame de TCFC no diagnóstico das alterações de morfologia condilar

Artigo

Manuscrito submetido submetido ao periódico Clinical Oral Investigations

Title: Do voxel size and filter application on CBCT images improve the diagnosis of condylar morphological alterations?

Running title: Effect of voxel size and filter application on the condylar morphology

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Abstract

Objectives: To evaluate the influence of voxel size and filter application on the diagnosis of condylar morphological alterations in cone beam computed tomography (CBCT).

Materials and Methods: CBCT scans of 36 temporomandibular joints were acquired using OP300 Maxio with voxel sizes of 0.085, 0.125, and 0.280 mm. Three radiologists evaluated the condyles in the CBCT volumes under three filter modes: no filter, “1x” sharpen filter, and “2x” sharpen filter. Diagnostic values were calculated by comparing the evaluators' responses with the reference standard and compared among experimental groups using analysis of Variance (α=5%).

Results: The area under the ROC curve, sensitivity, and specificity were not affected by voxel size and filter application ($p>0.05$). For osteophyte and flattening, there were more true positive responses in smaller voxel size. For erosion, the increase of true and false positive responses occurred with a larger voxel size. Overall, there was a tendency to decrease true positives for osteophyte and erosion and increase false positives especially in flattening with the "2x" sharpen filter.

Conclusions: The diagnosis of condylar morphological alterations is not influenced by the voxel size and the application of the filters. However, attention is needed with the occurrence of false-positive diagnosis with a larger voxel size for erosion and "2x" sharpen filter for flattening.

Clinical relevance: A lower radiation dose protocol can be used in the diagnosis of condylar morphological alterations.

Keywords: diagnostic imaging; cone-beam computed tomography; radiographic image enhancement.

Introduction

Temporomandibular joint disorders (TMD) is a collective term of disorders that can affect soft-tissues and osseous components of the temporomandibular joint (TMJ) and related muscles [1]. Crepitus can be indicative of morphological alterations in the involved bony structures. In the case of the condyle, these alterations may indicate an adaptive or even degenerative alterations [2][3], which can result in TMJ instability and pain [3][4].

Depending on the case, the clinical examination may be considered insufficient to determine the condition of the TMJ [4]. According to Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), a definitive diagnosis for TMJ intra-articular disorders requires computed tomography (CT) or magnetic resonance imaging [5]. Thus, in disorders involving the osseous structures of the TMJ, the use of CT scans is essential for the diagnosis [6]. The high cost and relatively higher dose of CT make cone beam computed tomography (CBCT) a good alternative for TMJ bony components evaluation [7].

The tube voltage, tube current, field of view, and voxel size are some acquisition factors that may influence image quality [8] and possibly the diagnosis. The voxel size is directly related to the spatial resolution [8], which represents the ability of the image to distinguish two objects [9]. Despite the fact that images acquired with smaller voxel sizes seems to have higher quality in a subjective assessment, in most CBCT units it requires higher X-ray exposure and an increased reconstruction time. Besides that, it can contribute with the formation of noisy images and may not improve the diagnostic capability of the exam [10].

Other possibility offered by CBCT is the use of post-processing tools, such as enhancement filters, to obtain an improved image quality avoiding a new X-ray exposure [3]. Filters are used to increase or decrease the contrast between adjacent voxels, and noise [11]. In previous studies, filters have been used for the evaluation of peri-implant defects [12], alveolar bone loss [13], endodontic complications [11], vertical [14][15] and longitudinal root fractures [16], and condylar morphological alterations [3, 8, 17, 18]. However, none of them evaluated the influence of voxel size and the application of filters; therefore, the effect of their combination remains unclear.

CBCT volumes with higher voxel sizes tend to have smooth edges of the structures, which could impair the detection of condylar morphological alterations. Conversely, sharpening filters increase the contrast between structures and their definition in the image. Thus, our hypothesis is that the combination of a larger voxel with filter application could generate diagnostic values similar to images acquired with smaller voxel sizes. Therefore, the aim of this study was to evaluate the influence of voxel size and filter application on the diagnosis of condylar morphological alterations in CBCT.

Material and methods

The study design was approved by the local Institutional Ethics Committee (protocol *4.509.446*).

Sample selection and preparation

This *in vitro* study was conducted using 18 pairs of dry skulls and mandibles (36 TMJs), each pair belonging to the same individual. The inclusion criteria were skulls and mandibles with integrity of anatomical parts and presence of dentition (total or partial), allowing stable occlusion. Another selection was made based on the analysis of the presence of morphological alterations in the mandibular condyles. Two evaluators with at least ten years of experience in TMJ imaging evaluation, independently assessed the condyles macroscopically and high-resolution CBCT volumes (6.3 mA, 0.085 voxel size, 90kVp) for the presence of five types of morphologic alterations: flattening (loss of rounded contour of at least one of the surfaces), erosion (loss of continuity of the cortical bone), osteophyte (exophytic formation of the condyle surface), pseudocysts (well-circumscribed osteolytic area adjacent to subcortical bone without cortical destruction), and sclerosis (any increase in the cortical thickness in the load-bearing areas) . Example of a condyle with flattening is shown in Figure 1 (superior and latero-superior views). A consensus was reached in cases of disagreement. The distribution of condylar morphology alterations in the sample is described in Table 1.

Figure 1 - Example of a condyle with flattening: a – superior view; b - latero-superior view.

Table 1. Distribution of condylar morphology conditions in the sample, according to the affected side.

Condylar Morphology		Right n (%)	Left n (%)	Total n (%)
Normal		8 (72.7)	3 (27.3)	11 (100)
With alteration		10 (40)	15 (60)	25 (100)
Alteration	Osteophyte*	4 (30.8)	5 (23.8)	9 (26.5)
	Flattening*	8 (61.5)	9 (42.9)	17 (50)
	Erosion*	1 (7.7)	7 (33.3)	8 (23.5)
	Sclerosis	0 (0)	0 (0)	0 (0)
	Pseudocysts	0 (0)	0 (0)	0 (0)
Alterations Total		13 (100)	21 (100)	34 (100)

* Isolated or associated with other alterations

A layer of wax was placed on the mandibular fossa of the temporal bone, articular eminence, and mandibular condyle. Each pair of skulls and mandibles was positioned with the condyle within the mandibular fossa and maintained in position with elastic bands.

Image acquisition

The skulls and mandibles were placed in a container with water to simulate the soft tissues and positioned in the OP300 Maxio CBCT unit (Instrumentarium Tuusula, Finlândia). Each TMJ was scanned individually, and the following acquisition parameters were kept constant: 90 kVp, 6.3 mA, and a 50x50 mm field of view. The images were acquired with three voxel sizes: 0.085, 0.125 and 0.280 mm.

Image evaluation

The DICOM data obtained were analyzed with the software program OnDemand 3D (Cyberned Inc., Seoul, Republic of Korea). Three evaluators, different from those who set the reference standard, with a minimum of 2 years of experience in TMJ images and blinded to the acquisition protocol used, were calibrated as explained below. The evaluation was performed independently for each evaluator in three stages: in the first stage, the images were evaluated without the application of imaging filter. In the second one, the images were evaluated with "1x" sharpen filter and, in the third stage, with "2x" sharpen filter. For each stage, the images were randomized, and a 30-day interval was established. The 324 resulting images (36 TMJs x 3 voxels sizes x 3 filters) were evaluated. Representative images of each experimental condition are shown in Figure 2.

The evaluators were trained to select the axial reconstruction representing the largest medio-lateral size of the condyle and obtain the parasagittal reconstructions perpendicular to the medio-lateral long axis, as represented in Figure 3. In addition, the evaluation of the condyle was dynamic (i.e., scrolling through all the parasagittal slices) to evaluate the whole structure. A 5-point scale was used to assess the presence of alterations in condylar morphology, defined as: 1 - definitely absent; 2 – probably absent; 3 - uncertain; 4 - probably present; 5 - definitely present. If the evaluators ranked 4 or 5, they should indicate which alteration (flattening, erosion, osteophyte, pseudocysts and/or sclerosis) was present. They were also instructed that, for each condyle considered "altered", more than one alteration could be indicated. To indicate and classify the condylar morphologic alterations, the evaluators should notice them in at least two sequential parasagittal reconstructions.

The evaluation was done using LCD monitors in a dimly lit room. The use of brightness, contrast and zoom was allowed. Thirty days after, 30% of the sample was randomly and blindly revaluated to determine intra-evaluators reproducibility.

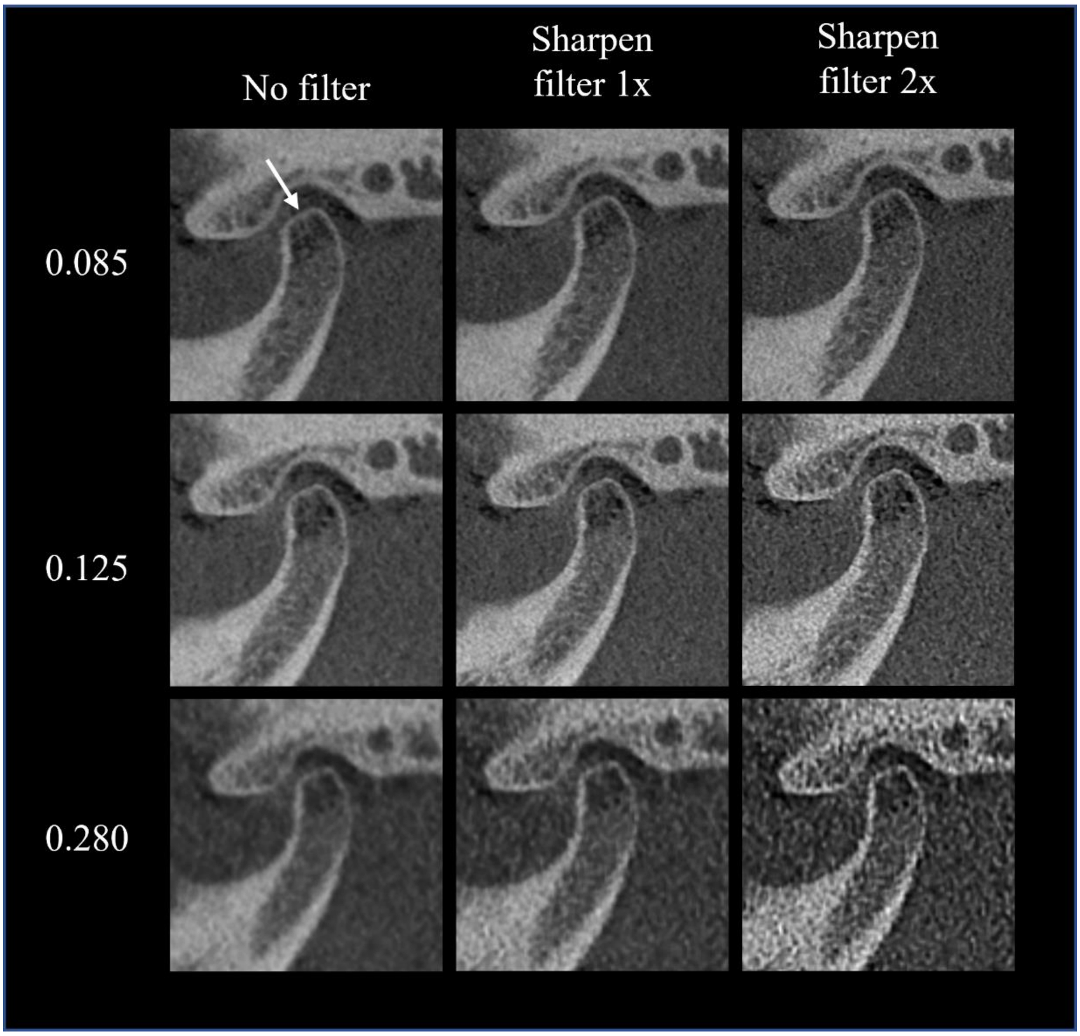

Figure 2 - Examples of each experimental condition, according to the voxel sizes an filter (parasagittal view).

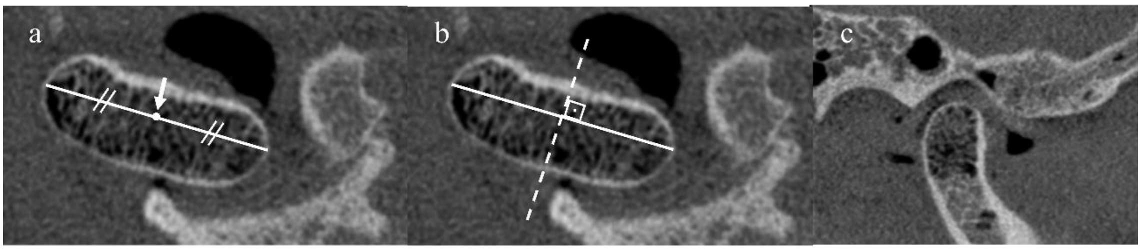

Figure 3 – Evaluation of the condyle: selection of the axial reconstruction representing the largest medio-lateral size of the condyle (a), adjust of the parasagittal plan (b) to obtain the parasagittal reconstructions perpendicular to the medio-lateral long axis (c).

Data analysis

Intra- and inter-evaluators reproducibility were measured using the weighted Kappa index. The values were interpreted by using previously reported criteria: 0.81-1.00 (almost perfect), 0.61-0.80 (substantial), 0.41-0.60 (moderate), 0.21-0.40 (fair), and 0.20-0.00 (poor)[19]. The area under the receiver operating characteristic (ROC) curve, sensitivity and specificity values were calculated. Analysis of Variance (two-way) was used to test the influence of the variables studied (voxel size and filter mode) on the diagnostic values. A descriptive analysis of the types of morphological alterations was performed, which resulted in true-positive, false-positive, and false-negative values according to the protocols.

The statistical analyses were performed in SPSS software version 23.0 (IBM Corp, Armonk, NY, USA). For all analyses, the significance level considered was 5%. The null hypothesis considered that there was no influence of the use of filters and the voxel sizes of the exams on the detection of condylar morphological alterations.

Results

The inter- and intra-evaluators agreement were poor to fair (0.119-0.361), and fair to almost perfect (0.295-1.000), respectively.

The area under the ROC curve, sensitivity and specificity values were not affected by voxel size and filter modes ($p>0.05$) (Table 2).

Figure 4 shows the graphs with percentages of true positives, false positives and false negatives for osteophyte, flattening and erosion according to the tested protocols. Regarding the detection of osteophyte, there were more true positive responses in smallest voxel size

(0.085mm); in the images of largest voxel (0.280mm), the non-filter mode presented higher values of true positive answers. The false negative values increased in the images with the largest voxel with increased filter application. In relation to flattening, the smaller voxel sizes (0.085 and 0.125mm) also increased the number of true positive, but also the false positive, especially when one of the filters was applied. For erosion, the increase in true and false positive responses occurred as voxel size increased. False negative responses for erosion were more frequent when “2x” sharpen filter was applied. Regarding pseudocysts, the false positive values were 0.9% in the protocols without filter and 0.280 mm voxel size and 0.9% in the “1x” filter with 0.125 mm voxel size, while in the other protocols, the value was null. In sclerosis, the false positive values ranged from 0.9% in the “2x” filter with 0.085 mm and 0.125 mm voxel size to 9.3% in the no filter with 0.085 mm voxel size. Overall, there was a tendency to decrease number of true positives for osteophyte and erosion and an increased number of false positives especially for flattening with the “2x” filter.

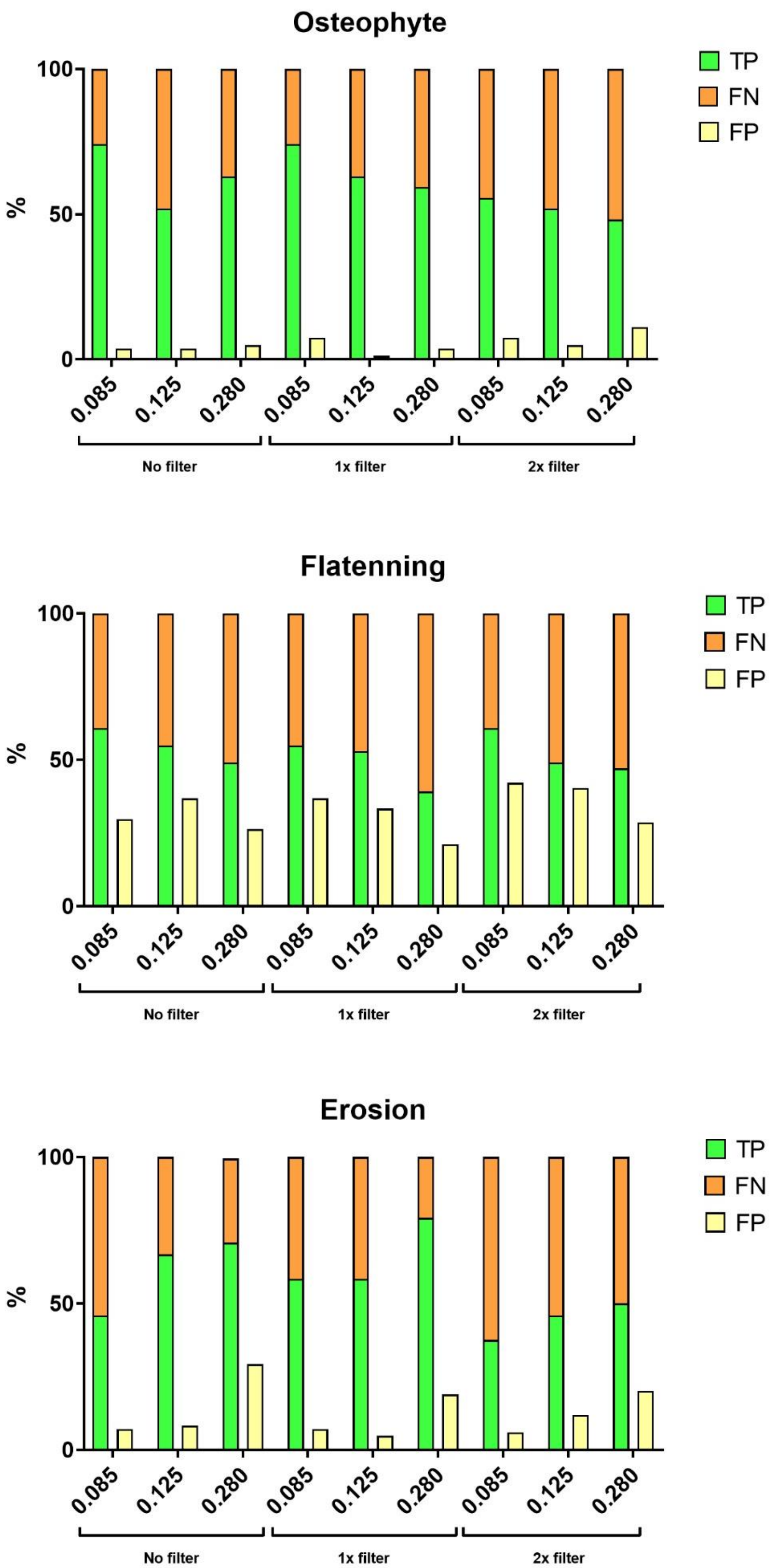

Figure 4 - Graphs with percentages of true positives, false positives and false negatives for osteophyte, flattening and erosion according to the tested protocols

Table 2: Mean (and standard deviation) of the area under the ROC curve, sensibility, and specificity according to the voxel size and the application of filters

	Area under the ROC curve			Sensibility			Specificity		
Sharpen Filter [a]	Voxel size (mm) [b]								
	0.085	0.125	0.280	0.085	0.125	0.280	0.085	0.125	0.280
No	0.81 (0.12)	0.76 (0.05)	0.71 (0.06)	0.83 (0.06)	0.79 (0.20)	0.79 (0.13)	0.64 (0.24)	0.61 (0.14)	0.55 (0.09)
1x	0.73 (0.01)	0.75 (0.07)	0.76 (0.07)	0.80 (0.17)	0.69 (0.39)	0.71 (0.14)	0.55 (0.27)	0.64 (0.24)	0.70 (0.21)
2x	0.68 (0.11)	0.60 (0.26)	0.67 (0.08)	0.76 (0.28)	0.79 (0.20)	0.71 (0.12)	0.55 (0.09)	0.45 (0.09)	0.58 (0.14)

[a] There was no significant influence ($p>0.05$) regarding filter application.

[b] There was no significant influence ($p>0.05$) regarding voxel size.

Discussion

The use of sharpen filters “1x” or “2x” and different voxel sizes did not influence the diagnosis of condylar morphological alterations assessed trough CBCT volumes, which denies the authors’ hypothesis. Therefore, regarding the application of filters, clinicians could evaluate the condylar morphology according to their preference. Furthermore, larger voxel sizes can be used, leading to a lower X-ray exposure to the individuals without compromising the diagnosis. We intended to verify if the filter application could compensate the lower voxel size and, consequently, reduce the radiation dose to the patient. However, attention to false-positive diagnosis is required with a larger voxel size for erosion and “2x” sharpen filter for flattening.

A previous study [8] highlighted that the detection of sclerosis was improved by the application of filters and, besides that, the two sharpening filters evaluated achieved the best score. However, other study [18] have found that the detection and classification of condylar morphological alterations was not influenced by filter application. Such different results may be influenced by different software applications, which may present different options for sharpening filters. Nevertheless, filters comparison among different software may not be straightforward as the manufacturers do not disclose their algorithm functioning [20].

In both studies [8, 18], the voxel size used (0.250 mm) was similar to the largest voxel in the present study (0.280 mm). However, other parameters differed: field of view (16x8 cm [8, 18] *versus* 5x5 cm in the present study) and kilovoltage (120 kVp [8, 18] *versus* 90 in the present study), which makes it difficult to compare with our results. When the FOV is reduced, the spatial resolution can be increased [21]. Despite that, using an acquisition protocol with two smaller FOV instead of one bigger is preferable, since it does not affect the diagnosis [22]. Regarding the kilovoltage, the present study employed a lower value of kilovoltage and still presented an accurate diagnosis of condylar morphological alterations.

To establish protocols for CBCT acquisition and voxel setting is highly important due to the various diagnostic tasks in dentistry [10]. The influence of the voxel size in the detection and classification of condylar morphological alterations becomes even more challenging in view of the several alterations that can occur in condyle. The voxel size is inversely proportional to image sharpness, which mean that smaller voxel sizes lead to increased image sharpness [21]. However, it is important to highlight that the voxel size reduction results in an increased image noise [21] and, since the voxel size may be directly related to the radiation dose, it is important to keep the ALADAIP [23] concept in mind. Regarding the detection of condylar morphological alterations, a study showed that the voxel size did not influence the diagnosis of erosions, flattening or condylar deformations [24]. In relation to the detection of sclerosis, a smaller voxel size with a higher field of view size performed better [25]. We believe that the detection of condylar morphological alterations is alteration-dependent and, therefore, different results are found for each one of them.

In the present study, the diagnosis of condylar morphological alterations was alteration dependent. For osteophyte and flattening, more true positives values were registered in smaller voxel size. Due to the discreet feature of these alterations, we believe that a higher resolution improves the diagnosis. Regarding erosion, a larger voxel size led to an increased number of true positives values but also false positives responses. Considering our sample, we believe that the erosions when present were large and easier to detect, but also the lower resolution of some scans could lead the normal condyle to an erosion-like aspect. The false negatives increased in the images with the largest voxel and filter application, and this can be justified due to synergetic effect of the lower resolution and noise increase by the filter application, jeopardizing proper image evaluation.

The false positive values of flattening tended to be higher in the "2x" sharpen filter. The findings suggest that the application of the filter favored increased contrast between the grayscales of the image [13], which subjectively contributed to hindering the rounded contour of the cortical bone, contributing the misdiagnosis of flattening.

It was possible to notice a low intra and inter-evaluators agreement, which could be explained by means of the inherent difficulties in the TMJ diagnosis. They had no clinical information and its association with the CBCT volume is crucial for the correct diagnosis. In addition, we have to consider the need to classify the alteration besides to determine the presence or absence.

Our study presented some limitations, such as the inherent characteristics of an *ex vivo* study, which does not permit to evaluate clinical data. However, the *ex vivo* nature allowed a highly controlled situation. Also, we tested one CBCT unit and our sample did not have pseudocysts and scleroses. We encourage new studies to assess other CBCT units and, if it is possible, including pseudocysts and scleroses in their samples. Conversely, as positive points, we highlight that the present study used condyles that already had morphological alterations due to a naturally developed condition, differently from the previous studies [24–28] that created these defects artificially with the use of metal drills, which could make the diagnosis be easier. In addition, we included several types of alterations assessed while some previous studies evaluated only one condition [26–28].

Conclusion

Although the accuracy of diagnosis of TMJ morphological alterations is not influenced by the voxel size and the application of the filters, clinicians should beware of false positive diagnoses with 0.280 mm voxel size for erosion and with “2x” filter application for flattening.

COMPLIANCE WITH ETHICAL STANDARS

Conflict of interest: The authors declare that they have no conflict of interest.

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Ethical approval: All procedures performed in this study were conducted in accordance with the ethical standards of the local Research Ethics Committee (protocol number # 4509446), and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: For this type of study, formal consent is not required.

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CONCLUSÃO

A aplicação de filtros é contraindicada para o diagnóstico de alterações condilares na ATM em exames de TCFC adquiridos com maior tamanho de voxel. Além disso, no geral, imagens com maior tamanho de voxel levam a maior erro na identificação da alteração do tipo aplainamento, e com menor tamanho de voxel a maior erro na identificação de erosão

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Anexo 3 – Comprovante de submissão do manuscrito

Ref: Submission ID 295ec3f7-f715-4a32-9da3-764f658c9c91

Dear Dr Santos-Corvini,

Please note that you are listed as a co-author on the manuscript "Do voxel size and filter application on CBCT images improve the diagnosis of condylar morphological alterations?", which was submitted to Clinical Oral Investigations on 09 September 2022 UTC.

If you have any queries related to this manuscript please contact the corresponding author, who is solely responsible for communicating with the journal.

Kind regards,

Editorial Assistant
Clinical Oral Investigations