Case Report

TMJ contrast enhancement in CBCT images using a new algorithm

Acta Radiologica Open
11(1) 1–6
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DOI: 10.1177/20584601221074565
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Abstract
Magnetic resonance imaging (MRI) is considered the gold standard to reliably diagnose inflammation in the temporomandibular joint (TMJ) of patients with juvenile idiopathic arthritis (JIA). However, even MRI imaging is dependent on the familiarity of the radiologist with the normal appearance of the TMJ; therefore, new approaches are needed. Our purpose here is to improve imaging quality of cone beam computed tomography (CBCT) as a tool to help in the diagnosis of JIA in the TMJ. We have designed and applied a filter (the Stacking Enhancement Filter) over a stock of CBCT images from the TMJs of two patients with JIA. We then made a visual comparison of the results with archival images from MRI of the same patients, to show that the filter substantially improves the visual quality of the image. The work on the image contrast and the increase of the difference of appearance between tissues of different densities (all the anatomical structures that are present within the joint) leads to an improvement of the resulting images of the TMJ without the use of a chemical contrast agent. We conclude that CBCT could be used as a filter tool for the analysis of the TMJs affected by arthritis. Our image processing technique yields images that possible improve the range of use of CBCT.

Keywords
temporomandibular joint, juvenile idiopathic arthritis, cone beam computed tomography, diagnostic imaging

Introduction

Dental X-rays (cone beam computed tomography (CBCT)) help the dentist to evaluate many oral diseases and conditions and also play an important role in the accurate diagnosis and treatment planning. When using X-rays, a compromise must be found: on the one hand, their potential danger; on the other, the dose is linked to image quality and this may not be lowered so far that it jeopardizes the diagnostic outcome of a radiographic procedure. Hardware and software techniques are enriching the field with new possibilities and, among them, they could be useful to reduce the radiation dose and to improve the quality of the image, what is called *image optimization*.

This is particularly important in pediatric population, specifically at a pre-orthodontic phase, when special care must be taken. De Grauwe et al.[1] in a recent review have evaluated the use and efficacy of CBCT in this population. They summarized its use for dental diseases under certain protocols[2,3] and concluded that the use of CBCT is justified for the analysis of the temporomandibular joint (TMJ). From this basis, we have tried to expand the potential of this technique; namely, our aim is to obtain as much information as possible from CBCT images of the TMJ and, for that, we propose an algorithm (which we call *Stacking Enhancement Filter* (SEF)) that provides contrast enhancement of the images obtained. With our computer enhancement features applied to the CBCT data, it is possible to magnify areas of interest and to readjust the gray scale and image contrast to

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enhance areas such as the ones mainly composed of soft tissue. We have applied this idea with a retrospective analysis of CBCT images of the TMJs of two patients with juvenile idiopathic arthritis (JIA) affecting that joint.

Case history

We have recruited participants, affected by JIA, from the Rheumatology Service of the University Hospital of Santiago de Compostela (Spain). This small group of patients is being treated systemically at the Rheumatological Service and they were diagnosed inflammation in the TMJ. In order to establish a care protocol, we obtained the approval of the ethical board of the institutional ethics committee of the clinical research of the Autonomous Community of Galicia before conducting this investigation (Ethics Approval Number 2012/438), to ensure our compliance with the recommendations of the Declaration of Helsinki and Tokyo for humans. Accordingly, our protocol complied with these guidelines. Moreover, we obtained written consent of the participating patients to use the data of CBCT images for this study and to evaluate their craniofacial growth. Some of these JIA patients were sent to perform an MRI scan to evaluate the activity of the disease in the TMJ according to the protocol established by the Rheumatological Service. From this group of JIA patients who have done both CBCT and MRI images, we randomly selected two for TMJ evaluation, in order to compare the two imaging modalities in the dental field.

All scans were performed on the same MRI scanner, using the same surface coils and scanning protocols, and made by the same radiologist. MRI was performed using a 1.5 T MRI system (Magnetom Symphony, Maestro Class; Siemens, Erlangen, Germany) and a double-loop array of coils in a closed mouth (neutral) position for the TMJ.

The MRI scanner used in this study serves as a descriptive anatomical guide: it allows to describe and to delimitate the different anatomical parts of both TMJs (mandibular condyle and surrounding soft tissues). Images of bilateral sagittal, coronal, and axial planes of the TMJs were acquired. In this study, we focused only on observing the axial plane because it is the plane that we compare with the images from the CBCT. The following sequences were used in this study: pre-contrast T1-weighted axial fast spin echo (slice thickness of 3.0 mm; gap of 3.0 mm; repetition time (TR) of 3000 ms; echo time (TE) of 101 ms) and contrast enhanced axial fat-saturated T1-weighted fast spin echo (slice thickness of 3.0 mm; slice gap of 3.0 mm; TR of 559 ms; TE of 13 ms). The post-contrast axial images were acquired within 5 min after intravenous (IV) administration of gadolinium-based contrast (Gadovist, Schering Pharma, Berlin, Germany).

The variables evaluated by the radiologist on the MRI images were the enhancement of the synovial membrane and the condylar morphology. The enhancement of the synovial membrane, which indicates synovitis (synovial inflammation), was defined as an increase in the signal intensity of the synovium. In order to observe this tissue enhancement after the injection of the intravenous contrast, we have compared the axial fat-saturated T1-weighted post-contrast (static) MRI images with the corresponding pre-contrast axial images. For comparison with the CBCT images obtained after the application of the SEF filter, we have only used the contrast enhanced axial fat-saturated T1-weighted fast spin echo, as a guide for the observation of similarities of the anatomical structures between the two imaging techniques.

CBCT scans were acquired with the i-CAT CBCT scan (Imaging Sciences International, Hatfield, PA). The CBCT protocol used a field of view of 12 cm × 16 cm and the parameters indicated in Table 1. Each case was composed of 328 images. The volume element, or voxel, has isotropic resolution; thus, each slice was composed of 536 × 536 points, with a pixel size of 0.3 mm. Axial, coronal, and sagittal views were available simultaneously by software manipulation.

The SEF is a new algorithm specially designed for enhancing the visualization of relevant 3D anatomical structures from a set of 2D slices, coming from a volumetric image. The algorithm can be described as a four-step process (Figure 1): First, the subset of slices is selected from the whole volume of a CBCT DICOM series. Then, a smoothing algorithm is applied to the selected slices, followed by a process of enhancement. Finally, the slices are stacked applying a different grade of transparency for each pixel, which is relative to its own gray level value.

This process is equivalent to obtaining an X-rays slice with a similar thickness of the portion of the body (here the TMJ) that represents the set of images originally selected. The main difference is that, now, the visualization of several anatomical structures related to specific tissues has been enhanced.

After the SEF algorithm run, the filter assigns shades of gray to CBCT numbers that fall within the range selected by applying pre-recorded levels of transparency for each pixel. In this way, all values higher than the specified range (in the current example, 350) will appear white, and any value lower than 10 will appear black. If we increase the window width, a wider range of values will be included in the grayscale range; therefore, more values will be assigned to each shade of gray, and we reach the objective of this work: to distinguish the different structures within the joint space of the TMJ. The algorithm takes less than 5 min on a PC running Windows with 8 GB RAM. No additional resources are needed. After applying the algorithm, a fine tuning procedure can be performed manually to improve the visualization of the structures of interest. This procedure is similar to the window/level step performed with CT images. This manual adjustment takes no more than 2 min for a human operator with a certain degree of training. Figure 2 shows the differences between a normal image view from an

Table 1. CBCT imaging protocol used to obtain the images of this study.

CBCT Model	Peak voltage (kVp)	Tube current (mA)	Exposure time (ms)	Slice thickness (mm)
i-CAT	120	5	4	0.3

CBCT, cone beam computed tomography.

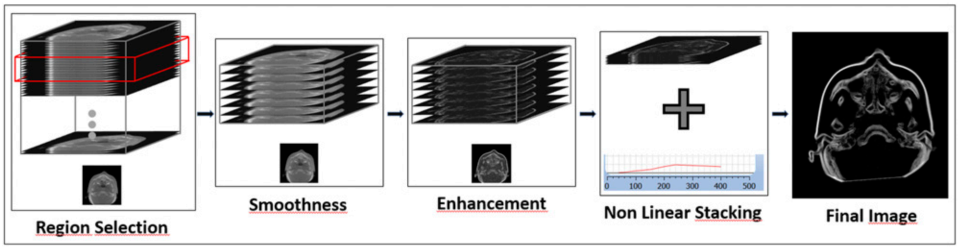

Figure 1. The algorithm (*Stacking Enhancement Filter*, SEF) can be described as a four-step process. Here, we show a schematic view of the flow of the algorithm. First, the subset of slices is selected from the whole volume of a CBCT DICOM series. Then, a smoothing algorithm is applied to the selected slices followed by a process of enhancement. Finally, the slices are stacked applying a different grade of transparency for each pixel, which is relative to its own gray level value. The 3D object enhances the visualization of the different anatomical structures of the skull. The projection of this volume, on a 2D plane, constitutes the final image.

axial CBCT and the image view after applying our specific filter correction (SEF) algorithm.

According to the anatomical approach, we speak of topographic anatomy, where spatial separations are appealed. In the absence of anatomical description for the different structures which belong to the TMJ in a CBCT, our objective in this work is to make a topographic anatomical analysis enhancing the contrast of the articular zone, in order to visually describe in a grayscale the structures found there.

The results were as follows.

Patient I. A 14-year-old girl with oligoarticular JIA without systemic treatment. She does not present clinical or serological parameters of disease activity, but she complains with TMJ palpation. She has a facial profile of Class III (the lower teeth and jaw project further forward than the upper teeth and jaw), with hypomaxilla and presents a decrease in the mandibular range of motion, as well as the maximum opening capacity. She complains of pain in both TMJs. The rheumatologist refers her to MRI to evaluate the degree of activity in the TMJ. According to the report from the MRI specialist, both TMJs are similar, affected with anterior disc displacement in closed month.

In Figure 3(a)) we see that the axial view of the MRI image does not show thickening in the temporomandibular synovia of both TMJs. Also, the MRI report from the specialist describes a normal condylar position, no presence of osteophytes and no signs of arthropathy. After applying our SEF, and after the generation of a 3D object, we can observe a shape in the lateral-distal part of the left condyle (marked with an arrow in Figure 3(b)). This shape is also present in different views or planes of the 3D object when it is rotated for observation (Figure 3(c)).

Patient II

A 13-year-old girl with oligoarticular JIA of ANA+ type (antinuclear antibody-positive JIA). This patient is in active phase, with Methotrexate 2.5 mg. She complains of noises and pain in left TMJ and presents a mandibular asymmetry. The rheumatologist refers her to MRI. The radiologist's report informs that both TMJs are similar, showing diffuse synovial enhancement after contrast in both TMJs. Note in Figure 4(a) the presence of synovial enhancement in the corresponding axial fat-saturated postgadolinium T1-weighted image of both TMJs. A slight irregularity in the condylar shape can also be observed. When we apply our SEF to the CBCT, we find the same feature (Figure 4(b)).

Discussion

TMJ inflammation can be assessed only by gadolinium-enhanced magnetic resonance imaging (MRI) to view the active component of synovial fluid and tissue enhancement, but in the absence of signs of active TMJ arthritis on MRI, patients may still have TMJ involvement.[4] The difficulty remains in knowing how to efficiently diagnose and monitor TMJ arthritis, and MRI evaluation needs to be performed by a radiologist aware of the normal appearance of the joint during the course of the child's development.[5] Kellenberger et al.[6] have developed a pictorial atlas describing the TMJ's normal and abnormal appearance, but no studies have been

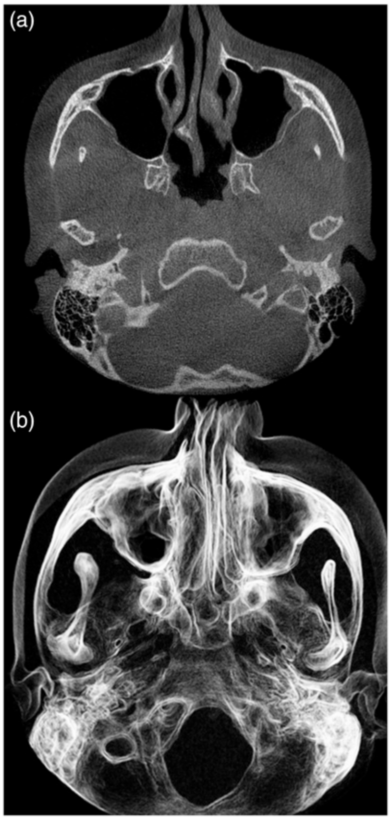

Figure 2. (a) Raw data of a single CBCT slice (0.3 mm). (b) The above image after being processed, integrating 20 slices; this image offers more contrast and can be analyzed from a 3D point of view.

performed to determine the perfect follow-up period for the MRI. Larheim et al.[7] have shown that the interpretation of pathologies from imaging findings is often complicated by the presence of similar findings in asymptomatic volunteers, as well as by the use of inadequate imaging techniques and poor image quality. But, in this framework, Von Kalle et al.[8] found that contrast enhancement is a normal finding in the soft tissue and the condyle of the TMJ in children and adolescents. The patient's age and need for sedation, costs and clinical consequences have to be taken also into account. Summarizing the central themes and topics, the dilemma is when to use an imaging technique with side effects for an infant patient.

With this work, we try to contribute to this point. We agree with the latest research that suggests that it becomes necessary more research on more available diagnostic tests and the development of new measuring techniques to be able to continuously evaluate this joint.[5]

We start from the point that CBCT is the standard modality to assess bone tissue and MRI is the one to assess soft tissues and the gold standard to reliably diagnose TMJ inflammation in JIA patients. In relation to this point (MRI and JIA disease), we take advantage of the fact that contrast enhancement is a normal finding in the soft tissue and the condyle of the TMJ in children and adolescents.[8] With our computer enhancement features applied to the CBCT data, it is possible to magnify areas of interest and to readjust the gray scale and image contrast to enhance areas such as the ones mainly composed of soft tissue.

Usually, the rheumatologist is reluctant to put a patient into treatment when the clinical symptoms and blood parameters do not indicate the presence of inflammation. In this case, MRI is the modality of choice to confidently establish the diagnosis of arthritis into the TMJ, but patients with TMJ symptoms despite equivocal MRI results may benefit from having the choice of an alternative and rapid screening test.

The filter was developed after detecting the doubts of some rheumatologists with the MRI results. In fact, as pointed by Twilt and Stoustrup,[5] the management of TMJ arthritis is difficult due to the uniqueness of the joint, confusion over terminology, need for multidisciplinary care in diagnosis, interception, and the fact that the majority of patients are clinically asymptomatic. They add that between 17 and 87% of JIA patients have TMJ arthritis, depending on the method used to determine TMJ arthritis and highlight that even MRI imaging is dependent on the familiarity of the radiologist with the normal appearance of the TMJ, and the ability to follow changes over time by using TMJ arthritis scoring methods. Now we are adding a new resource to observe the intraarticular space, that is, a volume (an improvement that, as far as we know, had not been done so far). This is possible because, with the filter, we have a better tissue differentiation. This is important if we take into account that inflammation means more intraarticular fluid, and therefore more intraarticular volume. At this point, it is important to note that the processed image of a healthy joint would surely also display a certain intraarticular volume (due to the synovial liquid) and, therefore, the mere existence of such volume is not itself a parameter that qualitatively define which joint is healthy and which is ill. But the key is the quantitative approach, the quantitative increase of volume. In fact, we do believe that the present work is opening a new task: to establish protocols or parameters that define boundaries in the quantification volumes, in order to delimit a threshold beyond which an atlas could be created. This atlas would indicate probabilities of active inflammation in the TMJ.

Can this technique be applied to all degree of TMJ disorders? If we take into account that this concept includes all disorders (and not only those that indicate the presence of inflammation), then further work is necessary to probe its efficacy. But, whenever arthritis or inflammation is present in the joint with TMJ abnormalities, this technique becomes useful, following the procedure described here. We have started with patients with JIA and activity parameters of arthritis in their clinical records. Also, the physician suspected of possible signs of inflammation in their TMJs. In

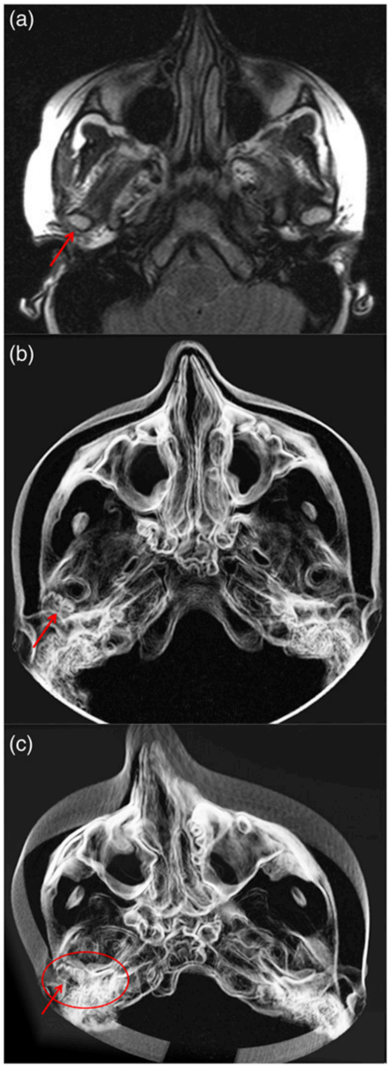

Figure 3. 14-year-old girl with oligoarticular juvenile idiopathic arthritis without systemic treatment. (a) MRI (upper image) and CBCT views. After applying our SEF, and after the generation of a 3D object, we can observe a shape in the lateral-distal part of the left condyle (arrowhead). (b) This shape is also present in different views or planes of the 3D object when it is rotated for observation.

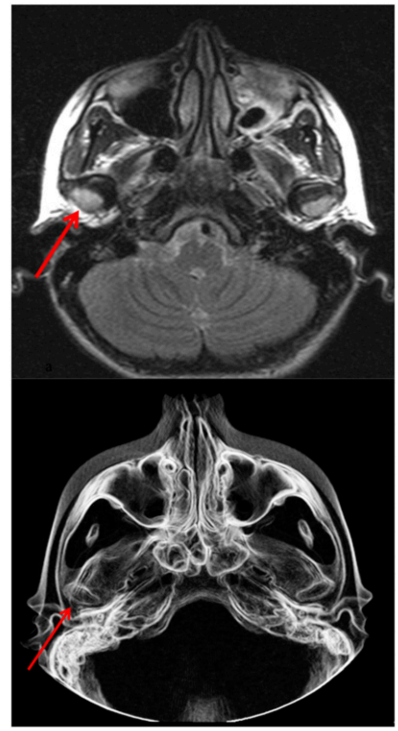

Figure 4. A 13-year-old girl with oligoarticular juvenile idiopathic arthritis. According to the report from the MRI specialist, both TMJs are similar. (a) Note the presence of synovial enhancement in the corresponding axial fat-saturated postgadolinium T1-weighted image of the TMJ (arrow). It is also seen a slight irregularity in the condylar shape. (b) CBCT view after the application of our filter. The arrow describes the same anatomical position in both images.

those cases, we have evidenced that this technique is suitable for both patients in the initial and advanced stages of arthritis. The reason for this statement is based on the presence of an inflammatory state in the joint. As said above, an inflammatory process manifests with fluid and consequently an increase in the volume of that area.

In conclusion, our proposal is that, after the application of the SEF to the CBCT data set, we are able to have an image with more information. We are concerned about the side effects of both techniques (radiation from a CBCT and chemical contrast agent from MRI), and we believe that understanding the underlying principles of imaging techniques will allow users of this technology to tailor the imaging protocol to the individual needs of the patient to achieve the more appropriate images with the fewest possible side effects. There is a lack of statements or guidelines from authoritative bodies regarding the use of low-dose protocols in dental medicine. In the pathology of the TMJ, CBCT could, at least, be used as a previous filter to select patients to perform an MRI. However, just like what is being done with MRI, further studies must be done about the parameters that affect image quality, in order to establish a gradient of observation to display the various anatomical parts of the TMJ from CBCT data.

Acknowledgments

The authors are grateful to I. Lete, Radiologist from the Complejo Hospitalario Universitario de Conxo, Santiago de Compostela, for his help with the MRI part of this work.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

Contributorship

MFO was involved with patients, rheumatologic and orthodontic issues, performed the image analysis and co-wrote the article. PGT worked on the image algorithms. AM was involved with the patients and the rheumatologic issues. JM coordinated the study and co-wrote the article. All authors participated in the discussions and revised and approved the final manuscript.

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