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Comparison between multislice and cone-beam computed tomography for the identification of simulated bone lesions using 3D reconstruction

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Abstract

Objective: The aim of this study was to compare, by means of three-dimensional reconstructed images, the validity of multislice computed tomography (MSCT) and cone-beam computed tomography (CBCT) in the diagnosis of simulated mandibular lesions.

Methods: Fifteen dry mandibles were perforated using a round bur (diameter of the tip: 1mm) and a high-speed handpiece. The lesions, which differed in dimension, shape and locularity, were produced either in the buccal or lingual cortical bone of the mandibular body. In some cases, the bur just touched the cortical bone, whereas in others, it perforated the medullary bone. Specimens were submitted to CBCT and MSCT. The images were analyzed independently by two experienced examiners using commercially available software (Vítrea®, version 3.4.5; Vital Images Inc., Plymouth, MN, USA) at different sessions according to two protocols: 3D reconstruction of MSCT scans (3D-MSCT) and 3D reconstruction of CBCT scans (3D-CBCT).

Results: There were no significant differences between the two protocols regarding the identification of medullary bone involvement or the number of lesions detected.

Conclusion: The validity of 3D-CBCT for the identification of the number of lesions and of medullary bone destruction was similar to that of 3D-MSCT.

Keywords: Tomography, X-ray computed; imaging, three-dimensional; mandibular diseases

Comparação entre tomografia computadorizada multislice e por feixe cônico na identificação de lesões ósseas simuladas utilizando a reconstrução 3D

Resumo

Objetivo: Comparar por meio da reconstrução tridimensional a validade da tomografia computadorizada multislice e por feixe cônico no diagnostic de lesões simuladas em mandíbulas.

Métodos: Quinze mandíbulas maceradas foram perfuradas utilizando broca esférica (diâmetro da ponta ativa: 1mm) e caneta de alta rotação. As lesões, que apresentavam diferentes dimensões, formatos e locularidade, foram produzidas no corpo das mandíbulas tanto na cortical lingual como na cortical vestibular. Em alguns casos a broca apenas tocou a cortical óssea, enquanto que em outros, houve perfuração acometendo o osso medular. Os espécimes foram então submetidos à TCMS e TCFC. As imagens foram analisadas de forma independente por dois examinadores experientes utilizando o programa de reconstrução de imagens tridimensionais (Vítrea®, versão 3.4.5; Vital Images Inc., Plymouth, MN, USA) em momentos distintos de acordo com dois protocolos: reconstrução 3D com imagens adquiridas em TCMS (3D-TCMS) e reconstrução 3D com imagens adquiridas em TCFC (3D-TCFC).

Resultados: Não houve diferença estatisticamente significante entre os dois protocolos em relação à identificação do envolvimento medular ou do número de lesões ósseas detectadas.

Conclusão: A validade da 3D-TCFC para identificação do número de lesões ósseas e do acometimento do osso medular foi similar a 3D-TCMS.

Palavras-chave: Tomografia computadorizada; reconstrução tridimensional; lesão mandibular

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Introduction

The analysis of diseases in the maxillofacial region has greatly evolved since the introduction of computed tomography (CT), improving the accuracy of the diagnosis and facilitating the planning of surgical procedures to treat oral and maxillofacial lesions [1]. CT images provide valuable information regarding the origin, size and location of lesions and are particularly useful for examining bone lesions. Several authors have stated that CT is useful in the diagnosis of and treatment planning for cystic lesions of the jaws [2,3].

The introduction of multislice computed tomography (MSCT) represented a fundamental evolutionary step in the development and ongoing refinement of CT imaging techniques. A single MSCT scan can yield multiple, thin, overlapping slices that can be rapidly reconstructed, resulting in higher quality reconstructed images and precluding the need for further patient radiation exposure. This technology allows volume data acquisition and three-dimensional (3D) reconstruction of craniofacial structures, which have become essential to the assessment of maxillofacial morphology [1,4].

Cone-beam computed tomography (CBCT) using recently-designed equipment for dental and maxillofacial imaging stands out as a relevant tool in oral and maxillofacial radiology because it provides images of high quality and allows a diagnosis to be established with greater specificity and sensitivity. In addition, CBCT allows images to be acquired using a low dose of radiation, is more readily available and costs less than the other CT methods, which makes the routine use of CBCT feasible in the scope of oral and maxillofacial procedures [5-7].

A number of studies have demonstrated the oral and maxillofacial applications of 3D CT reconstruction, reporting improved image quality using this method and comparing the results obtained using tridimensional reconstruction with those obtained using multiplanar reconstruction (MPR). Although studies regarding the comparison between MSCT and CBCT for different purposes were published, the validity of these using only 3D reconstruction images for identification of bone lesions was scarce, which indicates that more studies are required in order to confirm the hypothesis that CBCT can successfully substitute for MSCT in the evaluation of mandibular bone lesions without compromising the diagnosis.

The purpose of this study was to compare, by means of 3D reconstructed images, the validity of MSCT and CBCT in the diagnosis of mandibular lesions.

Methods

The present study was submitted to and approved by the Committee of Ethics and Research of our Institution, under protocol # 151/2003.

A total of 15 dry mandibles were examined. Lesions involving the cortical bone or the cortical and medullary bone were produced using a round bur (diameter of the tip: 1 mm) and a high-speed handpiece. The lesions, which differed in dimension and shape, were produced either in the buccal cortical bone or in the lingual cortical bone of the mandibular body. In some cases, the bur just touched the cortical bone, whereas in others, it perforated the medullary bone. The handpiece was moved back and forth in order to enlarge the simulated lesions, which ranged in diameter from 1 mm to 3 mm and in depth from 0.5 mm to 3.0 mm. A total of 52 perforations were made. In 7 mandibles, unilocular lesions were produced on the lingual surface of the body of the mandible. In all of these mandibles, the cortical bone was perforated, and the medullary bone was exposed. In 8 mandibles, multilocular lesions (having 3 to 9 loculi each) were produced on the lingual surface of the body of the mandible. In 2 of these mandibles, the buccal cortical bone of the mandibular body was perforated. The cortical bone was perforated and the medullary bone was exposed in all but 1 of the 15 mandibles.

The mandibles were submitted to CT using a CBCT scanner (i-CAT® Cone Beam 3-D Dental Imaging System; Imaging Sciences International, Hatfield, PA, USA) and the following parameters: voxel size of 0.25 mm; raw data acquisition of 40 seconds; exposure settings of 90 kVp and 7 mA; and a display field of view of 15 cm. Subsequently, the mandibles were submitted to MSCT using a CT scanner (Aquilion 64; Toshiba Medical Systems, Tustin, CA, USA) and the following parameters: slice thickness of 0.5 mm; reconstruction interval of 0.3 mm; exposure time of 0.4 seconds (120 kVp, 300 mA and 512 × 512 pixel matrix); bone tissue filter; and a field of view of 18 cm.

For both image acquisition methods, the specimens were placed in a plastic bucket, completely covered with water (in order to simulate soft tissue). The mandibles were maintained in the same position as that used in in vivo studies (using cotton sheets for support).

The original CT data were sent to a workstation in DICOM (Digital Imaging Communication in Medicine) format, recorded onto a DVD-R and transferred to an independent workstation located at our 3D imaging laboratory. All images were displayed and analyzed using commercially available software (Vitrea®, version 3.4.5; Vital Images Inc., Plymouth, MN, USA), and interpreted independently by two experienced examiners (oral and maxillofacial radiologists). The images were analyzed in a random order, in different sessions (with an interval of at least two weeks between sessions), and the examiners were blinded to the technique used for 3D reconstruction.

The examiners were asked to identify the presence or absence of mandibular lesions, the presence of medullary destruction and the loci number of each present lesion in both protocols: 3D-MSCT and 3D-CBCT. The examiners could use software tools as translation, rotation and transparency according to their personal preferences to get a better visualization of the interesting area. During the analysis of the images, only the 3D images were displayed on the computer monitor, the other images (axial slices and

MPR) were hidden (using the software tools) in order not to influence the interpretation. The sample was analyzed twice for each examiner, with minimum interval of 2 weeks between each analysis (Fig. 1 A and B).

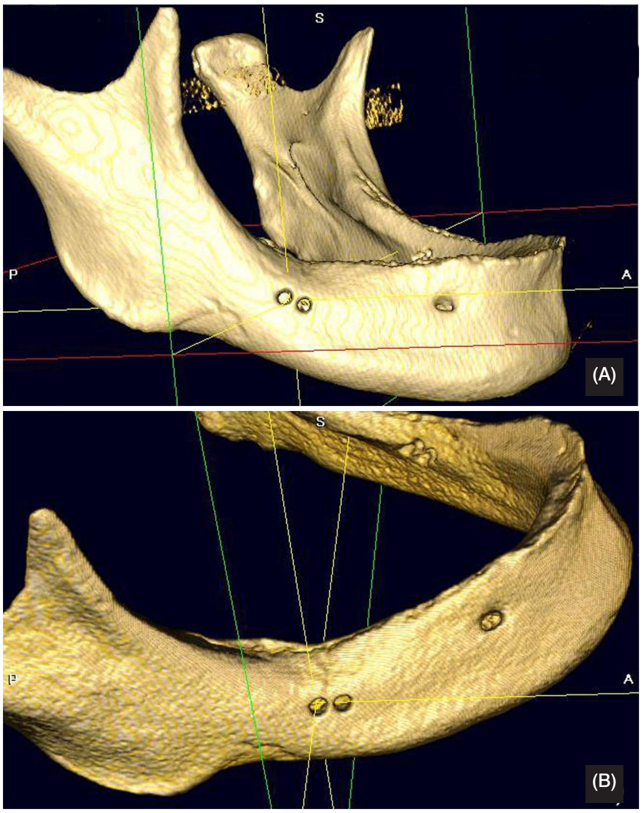

Fig. 1. Images of simulated multilocular lesions in the right body of the mandible involving buccal cortical and medullar bone using 3D-MSCT **(A)** and 3D-CBCT **(B)**.

The perforations in the dry mandibles were considered the gold standard. The examiners had no contact with the specimens.

With regard to the statistical analysis, intra- and inter-examiner analysis was calculated using the kappa statistic and the validity test (sensitivity and specificity) was carried out. In order to summarize results (positive predictive value (PPV), negative predictive value (NPV) and accuracy) and clear reader understanding, the Youden index was used, which attempts to represent test accuracy by a single numerical value (sensitivity + specificity − 1). The program Statistical Package for the Social Sciences, version 12.0 for Windows (SPSS Inc., Chicago, IL, USA) was used. A 95% (p<0.5) confidence interval was used in the evaluation of all items.

Results

The results demonstrated that both 3D-MSCT and 3D-CBCT were highly effective in aiding examiners in identifying the number of lesions and medullary destruction in each specimen.

Table 1 showed the number of simulated bone lesions (unilocular or multilocular) detected by each examiner, attesting the validity of the two protocols, and demonstrated the inter-rater reliability for the variable “type of lesion” (unilocular or multilocular), according to the protocols and the gold standard. The data collected showed that both examiners were able to identify simulated mandibular lesions using 3D-MSCT and 3D-CBCT (over 95% of the lesions were identified). Table 1 showed higher false positive results for bone lesions identification for unilocular lesions for examiner 1 and 2 using both 3D reconstruction image modalities and multilocular lesion using 3D-MSCT.

The kappa statistic was used to assess agreement between examiners. In the sample as a whole, a kappa value of 0.869 was found between 3D-MSCT and 3D-CBCT in the overall evaluation. In addition, the Kappa statistic was used for an individual evaluation of the two protocols, comparing the results obtained by examiner 1, examiner 2, and the gold standard. The Kappa values founded for identification of medullary destruction was worse than that founded for number of lesion identification. Although the two protocols tested were considered statistically significant for the intra- and inter-examiner analyses regarding the number of lesions identified and the identification of medullary bone involvement, which proved the validity of the two methods (Table 2).

Table 1. Relationship between the number of simulated bone lesions (unilocular or multilocular) identified by each examiner according to the protocol and the gold standard.

	Examiner 1 3D-MSCT	Examiner 1 3D-CBCT	Examiner 2 3D-MSCT	Examiner 2 3D-CBCT	Gold Standard
Unilocular	34	37	34	37	29
Multilocular	24	23	24	23	23

Table 2. Kappa and p values for the comparison between examiner 1, examiner 2 and the gold standard for the identification of medullary destruction and the number of lesions.

Protocol	Number of lesions			Medullary destruction		
	Ex 1 vs. Ex 2	Ex 1 vs. GS	Ex 2 vs. GS	Ex 1 vs. Ex 2	Ex 1 vs. GS	Ex 2 vs. GS
	Kappa	Kappa	Kappa	Kappa	Kappa	Kappa
3D-MSCT	0.888	0.903	0.886	0.645	0.551	0.741
3D-CBCT	0.903	0.855	0.887	0.536	0.478	0.696

Ex 1 = Examiner 1; Ex 2 = Examiner 2; GS = Gold Standard; P<0.005.

With regard to the sensitivity and specificity of 3D-MSCT and 3D-CBCT for detecting the number of mandibular lesions, there were no significant intra- or inter-rater differences being 91.2% and 87.6% of sensitivity and 92.3% and 88.9% of specificity respectively (median values), (Table 3).

Table 3. Percentage values of sensitivity and specificity of the protocols regarding the number of simulated mandibular lesions identified by each examiner.

Examiner 1	3D-MSCT	3D-CBCT
Sensitivity	86.3%	82.6%
Specificity	89.6%	86.6%
Examiner 2	3D-MSCT	3D-CBCT
Sensitivity	96.2%	92.68%
Specificity	95%	91.22%

Although there was greater variability in the results obtained using 3D-MSCT, there were no significant intra- or inter-rater differences between the sensitivity (74%) and specificity (93%) of 3D-MSCT and the sensitivity (81.5%) and specificity (95.5%) of 3D-CBCT for detecting medullary bone (Table 4).

Table 4. Percentage values of sensitivity and specificity of the protocols regarding the detection of medullary destruction by each examiner

Examiner 1	3D-MSCT	3D-CBCT
Sensitivity	65%	80%
Specificity	90%	95%
Examiner 2	3D-MSCT	3D-CBCT
Sensitivity	83%	83%
Specificity	96%	96%

Discussion

The present study evaluated the validity of 3D-CBCT and 3D-MSCT for the identification of mandibular lesions. Both methods of image acquisition have advantages and disadvantages regarding radiation dose, acquisition time, cost, scattered radiation and artifacts [1,3,8,9]. The drawbacks should be taken into consideration, since they can influence the quality of the images and the accuracy of the interpretation.

The quality of CT images is affected by several scanning settings. The combination of slice thickness, slice interval, and tube current can influence image quality, especially during reconstruction. Kim et al. [7] reported that thin slices appeared to help establish more accurate 3D CT cranial measurements when a human skull phantom was used. In our study, MSCT with axial slices of 0.5 mm in width and an interval of reconstruction of 0.3 mm were used to optimize the results.

The applicability of MSCT has been widely discussed and includes cranial measurements, the analysis of craniofacial deformities, the diagnosis of and the surgical planning for maxillofacial fractures and lesions, and the surgical planning for implants [1-3,5,7,10,11]. Perrella et al. [10] have shown that MSCT has high sensitivity and specificity for the diagnosis of mandibular lesions even in the presence of dental metallic artifacts. Cara et al. [2] compared different single- and multislice methods (including axial slices and axial slices with MPR) for analyzing simulated lesions in the head of the mandible. The results showed that MSCT images were highly accurate for the detection of bone lesions. The results of a study conducted by Utumi et al. [11] which demonstrated the validity of MSCT using MPR and parasagittal images in order to detect lesions in the mandibular condyle, corroborated the aforementioned study.

Currently, CBCT is a valuable imaging method in oral and maxillofacial radiology. According to Mozzo et al. [12], CBCT is central to diagnostic imaging in dentistry due to the following: no superimposition of structures; no image distortion; low radiation doses; and lower costs for patients.

There are various studies in the literature describing the accuracy of CBCT for the evaluation and detection of bone destruction due to endodontic, periodontal and orthodontic causes [13-15]. However, further studies are necessary in order to determine the sensitivity and specificity of CBCT for detecting bone lesions such as tumors and odontogenic cysts.

CBCT provides images that consist of tiny voxels and are expected to have high spatial resolution. The importance of voxel size stems from a practical observation that very small isotropic voxels result in an extremely large surface mesh model, which is difficult to process in order to create an accurate 3D surface model.

The comparison between MSCT and CBCT in terms of image quality has been suggested by previous studies. Loubele et al. [6], in a study investigating an anthropomorphic phantom, dry mandibles and actual patients, reported better visualization of the lamina dura and periodontal space using CBCT, as well as better visualization of the gingiva and cortical bone using MSCT. Hashimoto et al. [16] reported that CBCT performed better than MSCT when investigating an anthropomorphic phantom and dried maxillary bone. Caraffiello et al. [17] reported that CBCT and MSCT images were equally reliable for the identification of lesions in the teeth, lamina dura, periodontal space and spongy bone. The findings of the present study are in agreement with those of other studies in the literature, since the analysis of 3D-CBCT and 3D-MSCT revealed that the two protocols were similar in terms of their accuracy for the identification of bone lesions.

Studies involving the maxillary complex have compared 3D-MSCT and 3D-CBCT in terms of image quality, efficiency on diagnosis and versatility [16,17]. In order to select the most appropriate imaging method, professionals should take into consideration the patient and the diagnostic task. The quality of an imaging method is largely dependent on the type of scanner, scanning parameters and reconstruction settings, which directly influence the quality of the acquired images, which in turn has an impact on the radiographic visibility of anatomical structures and on the image noise level [6,16,17].

In the present study, 3D-MSCT and 3D-CBCT proved highly accurate for the detection of bone lesions and medullary bone destruction, no significant differences being observed between the two protocols. The data collected in the present study suggest that CBCT is highly sensitive and specific, which is in accordance with the data obtained by Schulze et al. [3]. Our results showed that over 95% of the simulated lesions were identified for both analyzed protocols (Tables 1 and 4).

According to the results presented the examiners found in some analyses more lesions than actually existed (false positive – lower specificity) what could be explained based on image quality that was intimately related with 3D surface. Errors produced at this stage can be related to different parameters, such as slice thickness, movement of the operating table, gantry inclination, voltage, presence of intraoral metal artifacts, and image reconstruction slice thickness on the algorithm with thinner slice thicknesses producing more accurate 3D reconstruction, but also mean longer exposure to radiation, which explains the dilemma involved in determining optimal slice thickness.

Any disturbance on this process could produce an unsatisfactory 3D reconstruction image that can mislead the identification of bone lesion and, specially, the unilocular lesion. The presence of more than one lesion in the same anatomical area could influence examiner and the diagnosis with comparison between the anatomical areas in study.

Furthermore, Cavalcanti et al. [18] demonstrated high false positive and false negative rates when determining mandibular bone invasion using 3-mm-thick axial slices. In the present work, using a 0.5 mm slice thickness with a thinner interval of reconstruction (0.3 mm) for MSCT and 0.25 mm voxel size for CBCT, 91.2% and 87.6% of sensitivity and 92.3% and 88.9% of specificity (median values) were found regarding the number of simulated lesions respectively. Regarding the detection of medullary destruction we founded 74% and 81.5% of sensitivity and 93% and 95.5% of specificity (median values) respectively.

Oliveira et al. [19] using 3D reformations with shaded surface display (SSD) and maximum intensity projection (MIP) for diagnosis of bone changes in mandibular condyles showed that both reconstruction techniques tested present a high frequency of false negative results and, should only be used as adjuvant techniques. According to these authors the false-negative results founded could be explained by the partial volume effects, distortion of contours of structures that are oblique to the slice, or a slice thickness (wide voxels) that is not adequate to the size of the bone change.

The validity of the protocols was confirmed when the results obtained by examiners 1 and 2 with regard to the number of bone lesions were compared with the gold standard (kappa>0.707). With regard to medullary bone destruction, 3D-CBTC and 3D-MSCT also yielded similar results (Tables 2 and 4).

According to Watanabe et al. [20], due to the specific characteristics of the image acquisition process, as well as to the use of an algorithm specific to CBCT, the images produced by CBCT present more noise, which results in degradation of the 3D images produced subsequently. This degradation is due to the parameters of acquisition (kV and mA), and it is essential to determine the correct window width and level in order to improve the interpretation of the images. This might explain the conflicting results for sensitivity and specificity of 3D-CBTC for identifying medullary bone destruction observed in the present study.

Our results showed no significant differences between 3D-MSCT and 3D-CBCT for the detection of simulated mandibular lesions. Despite the good values of specificity and sensitivity, 3D reconstructions should be used in association with axial, coronal and sagittal images (MPR) and cross sectional slices in order to improve the accuracy of the diagnosis of mandibular lesions [21].

In the present study, the use of slices of reduced thickness in MSCT and of voxels of reduced size in CBCT translated to greater sensitivity and specificity, which is in accordance with other studies [13]. Hashimoto et al. [16] have shown the advantages of CBCT, which include reduced exposure to ionizing radiation and exceptional image quality. Image acquisition protocols that are based on thinner slices and smaller voxels produce images of higher quality and are more reliable for the detection of maxillofacial lesions. 3D-CBCT and 3D-MSCT showed similar sensitivity and specificity, with no significant differences between the two protocols.

In spite of the results found in this study, 3D-CBCT and 3D-MSCT were similarly accurate (high sensitivity and specificity) for the identification of the number of bone lesions and medullary bone destruction. Both 3D reconstruction techniques were equivalent in terms of clinical diagnosis.

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