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RELAÇÃO ENTRE IMPLANTES DENTÁRIOS E O CANAL MANDIBULAR: INFLUÊNCIA DA REDUÇÃO DE ARTEFATOS METÁLICOS NO DIAGNÓSTICO COM TOMOGRAFIA COMPUTADORIZADA DE FEIXE CÔNICO

DENTAL IMPLANTS AND THE MANDIBULAR CANAL: INFLUENCE OF METAL ARTIFACT REDUCTION IN THE DIAGNOSTIC WITH CONE-BEAM COMPUTED TOMOGRAPHY

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Doctoral Thesis presented to the School of Dentistry of Ribeirão Preto, University of São Paulo to obtain the Doctoral of Science degree - Postgraduate Program: Dentistry

Concentration area: Oral Rehabilitation

Advisor: Profa. Dra. Camila Tirapelli

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DEDICO ESTE TRABALHO

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RESUMO

Motta, RJG. **Relação entre implantes dentários e o canal mandibular: Influência da Redução de Artefatos Metálicos no diagnóstico com Tomografia Computadorizada de Feixe Cônico**. 2023. 43p. Tese (Doutorado). Faculdade de Odontologia de Ribeirão Preto, Universidade de São Paulo. Ribeirão Preto, 2023.

O objetivo deste estudo foi avaliar a influência do Metal Artefact Reduction (MAR) no diagnóstico de implantes dentais relacionados com o canal mandibular (CM) utilizando Tomografia Computadorizada de Feixe Cônico (TCFC). Implantes dentais guiados foram instalados em cada hemiarco de dez mandíbulas humanas secas, na região do primeiro molar inferior: 0.5mm superior à cortical do CM (upCM/n=8) e 0.5mm no interior do CM (inCM/n=10). As mandíbulas foram incluídas em gelatina balística e escaneadas com dois equipamentos de TCFC com configurações definidas: 90Kvp, MAR ON e MAR OFF, e diferentes correntes de tubo (4mA, 8mA e 10mA). Dois Cirurgiões Dentistas Especialistas em Radiologia (CDER) e dois Cirurgiões Dentistas Clínico Gerais (CDCG) examinaram as imagens e pontuaram (escala de 1-5) a relação entre implante dental e CM. Dados foram analisados para sensibilidade, especificidade e acurácia. Teste Fisher foi utilizado considerando MAR, examinadores, mA e equipamentos de TCFC como fatores de variação. Examinadores CDCG e CDER foram observados através de Kappa considerando a concordância inter e extra examinadores com o real contato entre implante e CM (intervalo de confiança de 95%). Especificidade foi no geral maior que sensibilidade para ambos CDCG e CDER. Ativação do MAR não afetou a sensibilidade e reduziu-a dependendo do equipamento TCFC e examinador; concordância intra examinador foi maior para CDER comparada ao CDCG. Concordância inter examindador foi no geral pobre. Devido a eficácia limitada do MAR, este não deve ser utilizado para escaneamentos TCFC para avaliação de contato entre implantes e o canal mandibular.

Palavras-chave: diagnóstico por imagem, tomografia computadorizada de feixe cônico, canal mandibular, implantes dentais

ABSTRACT

Motta, RJG. **Dental implants and the mandibular canal: influence of metal artifact reduction in the diagnostic with cone-beam computed tomography**. 2023. 43p. Thesis (Doctorate). Dentistry Faculty of Ribeirão Preto, University of São Paulo. Ribeirão Preto, 2023.

The aim of this study was to evaluate the influence of Metal Artefact Reduction (MAR) in the diagnosis of dental implants regarding the mandibular canal (MC) using Cone Beam Computed Tomography (CBCT). Guided dental implants were installed in each hemiarch of ten dried human mandibles in the region of lower first molar: 0.5mm superior to the MC cortical (upMC/n=8) and 0,5mm inside the MC (inMC/n=10). Mandibles were included in ballistic gelatin and scanned with two CBCT devices under defined setups: fixed 90 kVp, MAR ON and OFF, and different tube currents (4mA, 8mA and 10mA). Two Dentomaxillofacial Radiologists (DMFR) and two Doctor of Dental Surgery (DDS) examined the images and scored (1-5 scale) the relation between the dental implant and MC. Data were analyzed for sensitivity, specificity and accuracy. Fisher test was used to consider MAR, examiners, mA and CBCT devices as factors of variation. DDS and DMFR examiners were observed through Kappa considering the interexaminer and intraexaminer agreement with the real contact between the implant and MC (confidence level of 95%). Specificity was overall higher than sensitivity for both DDS and DMFR. MAR activation did not affect the sensitivity and decreased it depending on CBCT device and examiner; intraexaminer agreement was higher for DMFR compared to the DDS. Interexaminer agreement was overall poor. Due to the limited efficacy of MAR, it should not be used when conducting CBCT scans for the evaluation of contact between the implant and the mandibular canal.

Keywords: diagnostic imaging, cone-beam computed tomography, mandibular canal, dental implants

SUMMARY

1. Introduction

1. INTRODUCTION

The cone-beam computed tomography (CBCT) is a well-established radiographic exam for treatment planning with dental implants and could be useful in the postoperative period, (Harris et al., 2012; Tyndall et al., 2012; Jacobs R et al., 2018), however, the high density of dental implants generates image artefacts (Schulze et al., 2010; Schulze et al., 2011; Pauwels et al., 2013; Codari et al., 2017; Shokri et al., 2022), which affect the image quality and can interfere in the diagnostic task. In this context, efforts have been made to add tools (e.g. metal artefact reduction-MAR) into CBCT devices to allow better image quality.

Postoperative pain after dental implant placement is a type of condition that requires attention and clinical decision-making in the following 36 hours after the procedure when nerve disturbance is into consideration due to the contact or closeness between the dental implant and the mandibular canal (MC) which contain the inferior alveolar nerve (IAN). Its diagnosis is based mainly on the visualization of this condition (Khawaja & Renton, 2009; Renhilde et al., 2014). To avoid it, a distance between the dental implant and MC is suggested as 1.5 mm to prevent implant damage to the underlying IAN when biomechanical loading is taken into consideration (Sammartino et al., 2008). Nevertheless, dental implant postoperative pain can be also caused by indirect trauma of IAN when the dental implant is not necessarily into the MC (Jacobs et al., 2014).

Considering CBCT to evaluate the relation between dental implants and MC a point that comes out is that artefacts caused by dental implants can interfere with or impair diagnosis. Artefacts are discrepancies between the reconstructed visual image and the real content of the object in the presence of high-density materials, such as titanium and zirconia. A common type of artefact is beam-hardening, which occurs when the object acts as a filter blocking the passage of beams with less energy, thus increasing the average energy that hits the sensor, resulting in errors in the reconstruction of the data. Bringing to clinical practice, the image of vicinity to density materials turns unreliable, showing bright streaks, darkening areas, or the complete loss of gray values (Schulze et al., 2010; Schulze et al., 2011 Pauwels et al., 2013). Another type of artefact that can interfere in the diagnostic task of identifying the contact between the implant and MC is blooming, which overestimates the object of high-density extending voxels around it, unreliably increasing their dimensions in the reconstructed images. Clinically, the blooming artefact can impair the assessment of adjacent structures around density materials. Due to the artificial increase in implant diameter caused by the blooming, part of the surrounding bone or bony defect will be overlapped by the implant and thus not be visible (Vanderstuyft et al., 2019; Wanderley et al., 2021; Tarce et al., 2022). Vanderstuyft, et al., 2019 confirmed, in a cadaver study, that the thickness of the buccal peri-implant bone was underestimated by 0.3 mm due to blooming effect. In addition, Tarce, et al., 2022 emphasized the necessity of future studies investigating the CBCT parameters on implant blooming efforting the development of clinical exam protocols.

Previous studies have been investigating the CBCT-related parameters in the artefact generation, such as mA, field of view (FOV), kilovoltage peak (kVp), and CBCT device (Schulze et al., 2010; Schulze et al., 2011; Pauwels et al., 2013; Codari et al., 2017; Freitas et al., 2018; Wanderley et al., 2021; Sawicki et al., 2022; Safi et al., 2022). The artefact generation is being studied and related to CBCT unit (Freitas et al., 2018; Vasconcelos et al., 2019; Vasconcelos et al., 2020), material (Queiroz et al., 2018; Vasconcelos et al., 2019; Vasconcelos et al., 2020; Mancini et al., 2021), positioning (Vasconcelos et al., 2019), and scanning protocol (Freitas et al., 2018; Vasconcelos et al., 2019; Mancini et al., 2021; Khosravifard et al., 2021). In search to limit their effects, algorithms for Metal Artefact Reduction (MAR) were developed and are available on CBCT devices as MAR tool however, its efficacy is controversial in the literature (Do et al., 2011; Parsa et al., 2014; de-Azevedo-Vaz et al., 2016; Queiroz et al., 2017; de Faria Vasconcelos et al., 2020; Fontenele et al., 2021; Nascimento et al., 2022). A previous study reported no significant difference in the activation of the MAR in the vicinity of dental implants in human dry mandibles using a quantitatively gray value measure (Parsa et al., 2014); contrarily, other investigations found a decrease in the artefacts depending on CBCT device and material (Vasconcelos et al., 2020; Mancini et al., 2021). It is worth mentioning that studies in literature have mainly focused on evaluating image quality through quantitative methods. Studies on the influence of MAR in diagnostic tasks, for example, the relation between dental implants and MC remain scarce.

Considering artefacts generated by the implant on the CBCT image, the necessity of accurate diagnosis about the relation between dental implants and CM, the MAR tool available and, the gap of investigation in practice-like scenarios; the purpose of this study was to evaluate the influence of MAR in the diagnosis of dental implants and the mandibular canal relation using different CBCT devices, tube current (mA), and examiners background. The null hypothesis of this study was that the use of MAR might not influence the diagnostic accuracy of relations between dental implants and the mandibular canal.

2. Proposition

2. PROPOSITION

This study evaluated the influence of Metal Artifact Reduction tool in the diagnostics of dental implants and the mandibular canal relation using CBCT.

The specific questions this study aimed to answer were:

- Is there difference on accuracy of diagnosis depending on MAR?
- Is there difference on accuracy of diagnosis depending on tube current?
- Is there difference on accuracy of diagnosis depending on CBCT equipment?
- Is there difference on accuracy of diagnosis depending on examiner background?
- Is there a specific setup (MAR, mA, CBCT, operator) where sensitivity is significantly greater? The same for specificity.

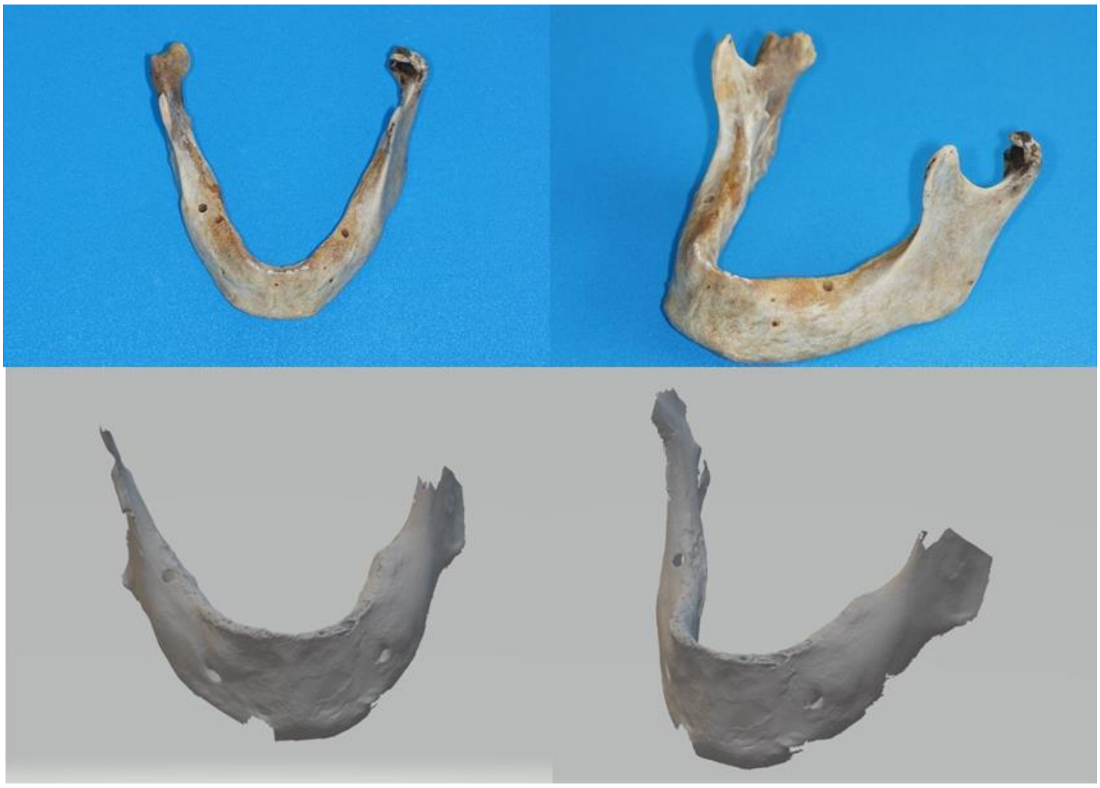
3. Materials and Methods

3. MATERIALS AND METHODS

3.1 Sample preparation

This study was approved by the local ethics committee CAAE: 55985621.8.0000.5419 and conducted in accordance with the Declaration of Helsinki. Ten dried human mandibles were scanned using an intraoral scanner (TRIOS 3, 3Shape, Copenhagen, Denmark) and a CBCT device (Eagle 3D, Dabi Atlante, Ribeirão Preto, Brazil) resulting in STL (Standard Triangle Language) and DICOM (Digital Imaging and Communications in Medicine) files, respectively. The STL and the DICOM files were superimposed by an experienced professional using software for digital tridimensional (3D) planning (3Shape Implant Studio, Copenhagen, Denmark). Through CAD (computer assisted design) the titanium dental implants (3.5 x 10mm, Unitite Prime, S.I.N. Implant System, São Paulo, Brazil) were digitally positioned on the region of the mandibular first molar, at each hemiarch, and according to defined positions in relation to MC: up to 0.5mm superior to the MC (upMC group), and 0.5mm inside the MC, with perforation of MC cortex (inMC group) (Figure 1a-d). Then, the surgical guide, corresponding to these dental implants defined positions, was digitally designed and, thereafter, 3D-printed (printing manufacturer) (Figure 2a). The dental implants were guided installed using the implant-guided surgery system (S.I.N. Implant System) and the sequence of drills according to the manufacturer, reaching a torque of 32N/cm by a ratchet (Figure 2b). Two implants were not able to be held on the sites due to lack of toque, totalizing 18 implants corresponding to the groups upMC (N=8) and inMC (N=10). Similar to Mancini et. al 2021, each mandible with implants installed was inserted in a cylindrical container (18cm diameter) containing a 6cm depth of ballistic gelatin (Lopes et al., 2019; Mancini et al., 2021).

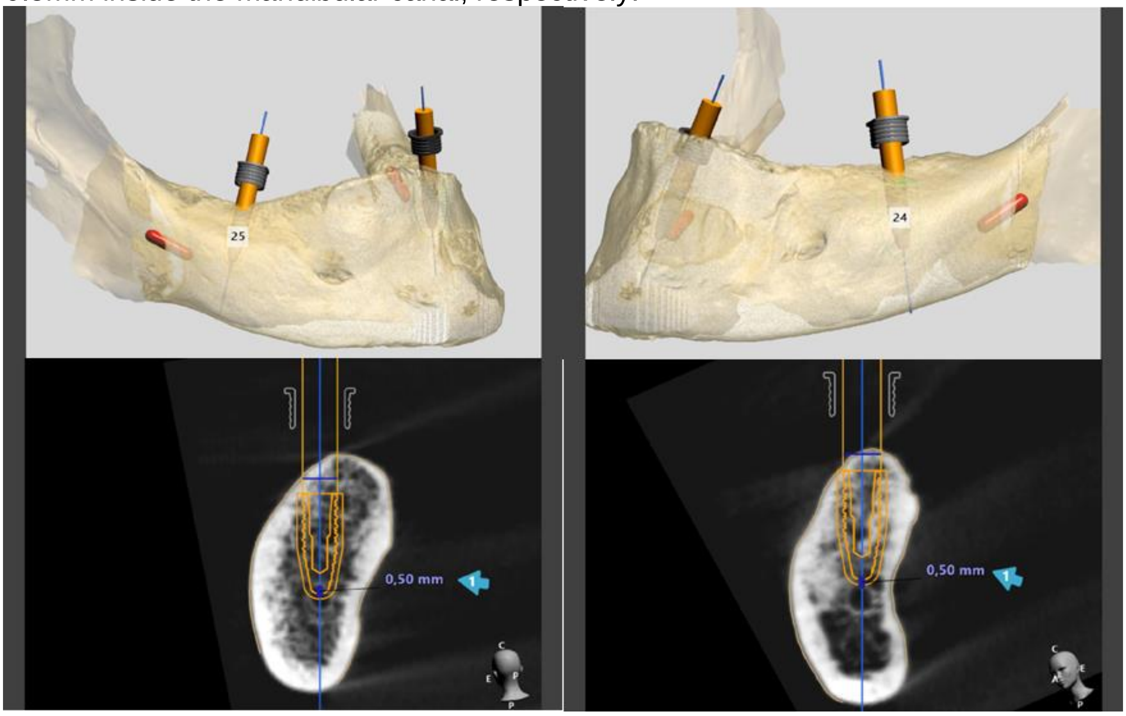
Figure 1. Dried mandibles before 3Shape scan above and STL file used to plan the Surgical Guides below.



An experienced professional planned on the software 3Shape Implant Studio (3Shape, Copenhagen, Denmark), the positions of the implants according to the determined positions on the First Inferior Molar (1IM) regarding mandibular canal (MC) contact and 3D Printer created a Surgical Guide for each one of the sites proposed in two different groups (Figure 2):

- upMC: 1IM: up to 0.5mm superior to the MC
- inMC: 1IM: 0,5 mm inside the MC (perforation of the MC cortex)

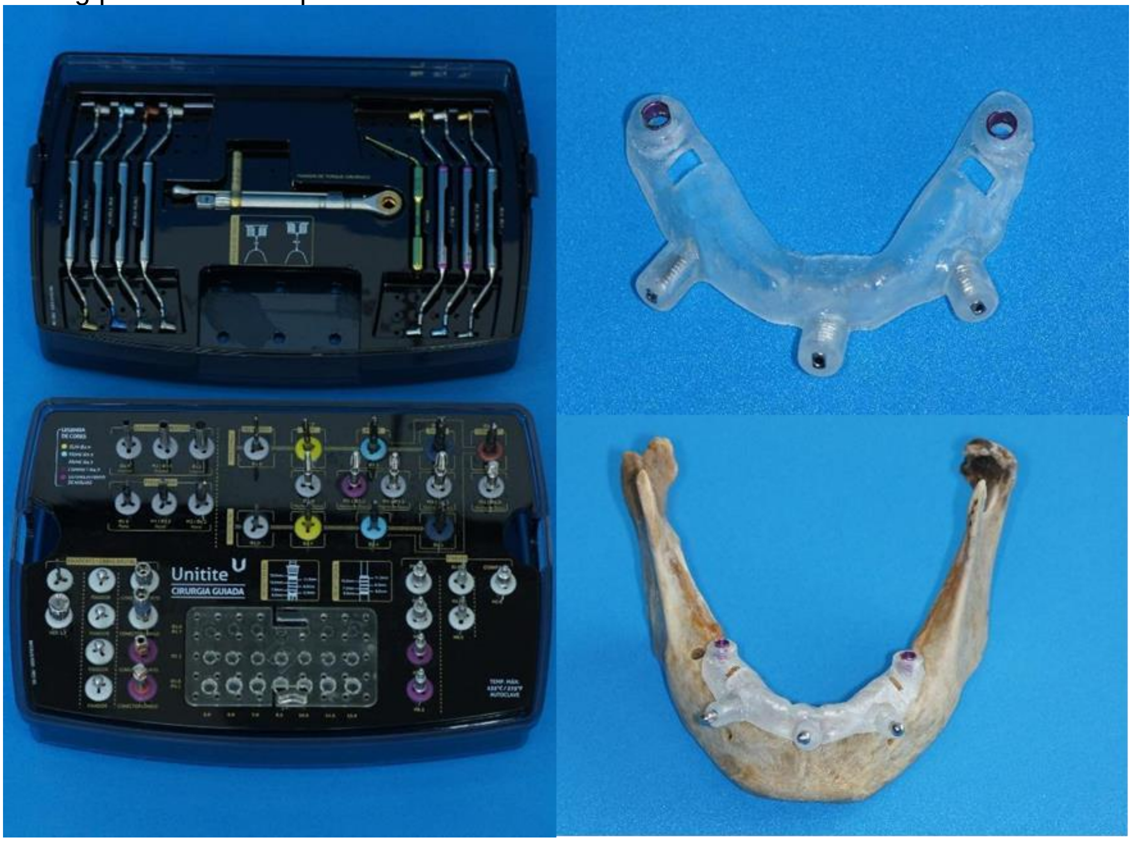
Figure 2. Dental implant positioned digitally on the superimposition of STL and DICOM files. a and b: Dental implant digitally planned to position on the right and left hemiarch, respectively. c and d: dental implants positioned up to 0.5mm mandibular canal and 0.5mm inside the mandibular canal, respectively.



Titanium dental implants followed a pattern of 3.5 x 10mm titanium implants (Unitite Prime – SIN Implant System, São Paulo - Brazil) installed in 20 mandibular hemiarch according to the groups above described.

An osteotomy following a sequence of drills using an Implant Guided Surgery Kit (SIN Guided Surgery – SIN Implant System, São Paulo - Brazil) recommended by the manufacturer were performed, and the implants inserted manually using a ratchet until it reaches a torque of 32N/cm (Figure 3).

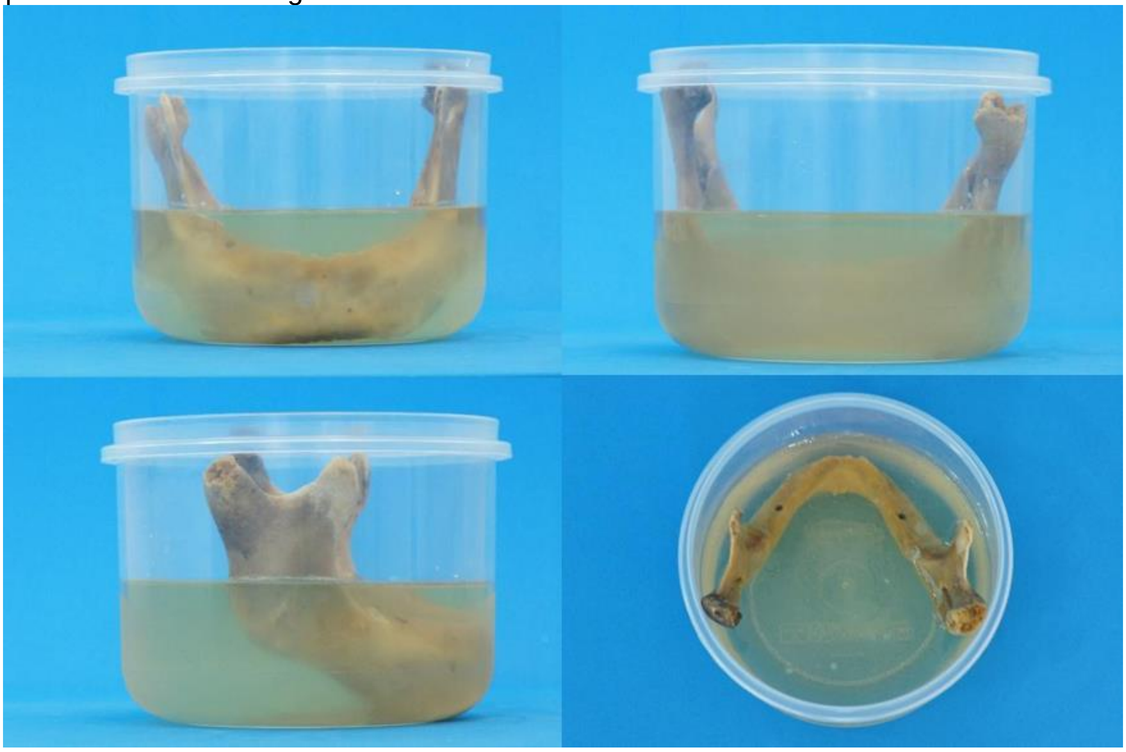
Figure 3. Implant Guided Surgery Kit (SIN Guided Surgery – SIN Implant System, São Paulo - Brazil); Surgical Guide; and Surgical Guide fixed in the mandible ready for drilling protocol and implant installation.



Throughout the installation process 2 implants were not able to be held on the sites due to lack of torque or fail in the correct positioning and the subjected areas were excluded from the study. Although 18 implants were successfully installed with the predefined protocol. After a CBCT following periapical radiographs were performed for each of the implanted region to confirm the predefined conditions, allocating the dental implants inserted as upMC (8) and inMC (10).

Following the study of Mancini et. al 2021, 10 cylindrical phantoms, containing the dried human mandibles were immersed in ballistic gelatin. The eviscerated mandibles were obtained from the Anatomy Laboratory of Ribeirão Preto School of Dentistry. Each mandible was inserted in the center of a cylindrical plastic box (18-cm diameter) containing a 6 cm depth of ballistic gelatin, previously poured into the container. (Figure 4).

Figure 4. Phantom made from the mandible positioned in the center of a cylindrical plastic box in ballistic gelatin.



3.2 CBCT image acquisition

For the acquisition of CBCT images, an acrylic device with 18cm diameter was manufactured to attach to the support of the machines and allow the standardized positioning of the phantoms and location of the FOV. The phantoms were then scanned using 2 different CBCT units, OP300 Maxio® (Instrumentarium, Tuusula, Finland) and Eagle 3D (DABI, Ribeirão Preto, Brazil);

The CBCT equipment were operated at maximum KvP, with and without activation of metal artefact reduction tool (MAR) and with different tube current as follow:

- OP300 Maxio (Instrumentarium, Tuusula, Finland): 90 kV; 6x4 cm FOV size; 130 µm voxel size; 6.1s exposure time; 4 and 10 mA with MAR activation (MAR ON) and without MAR activation (MAR OFF).

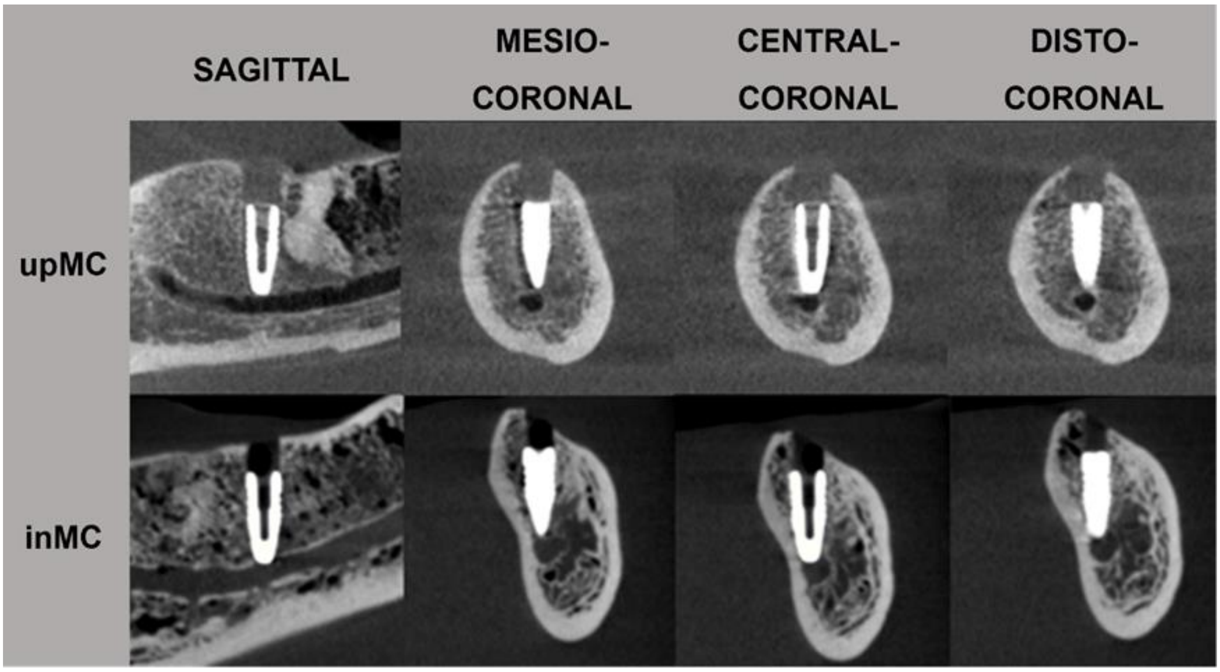
- Eagle 3D (Dabi Atlante, Ribeirão Preto, Brasil): 85 kV; 5x5 cm FOV size; 130 µm voxel size; 20.5 s exposure time; 4 and 8 mA with MAR activation (MAR ON) and without MAR activation (MAR OFF).
- A total of 144 CBCT exams were acquired (i.e. 8 CBCT scan protocols x 18 implants).

3.3 Image selection and capture

In order to select images for examiner's analysis, CBCT scans were observed by an experienced professional using OnDemand 3D software, where he was allowed to use all tools from the software to reassure the diagnostics previously determined. The open-source software 3D Slicer (slicer.org) was then used to transform and register the exams to create a pattern through the subjects regarding reorientation and window/level.

From each CBCT exam four images were captured using the software's own tool in .bmp extension at 24-bit RGB. Three at the coronal plane (perpendicular to the long axis of the implant at mesial, central and distal according to the apex) – starting from the central using the posterior-anterior reorientation tool 1mm anterior was determined to be the mesial, and 1mm posterior the distal images - and one image from the sagittal plane considering the implant apex or its closest contact with MC after defined coronal reorientation, totaling 576 images that were analyzed (Figure 5).

Figure 5. Screen captures taken on ImageJ after reorientation on 3D Slicer at Coronal Plane and a representative of the area at (a) Sagittal Plane, in sequence: (b) mesial, (c) central, (d) distal slices at coronal and sagittal plane capture.



3.4 Image Analysis

Four professionals with two different backgrounds, two Dental Maxillo-facial Radiologist (DMFR) and two Doctor of Dental Science (DDS) with previous formation on imaging diagnostic, examined the captured images in a quiet and **dimmed** light room using a Coronis Fusion 6MP Screen (Barco NV, Kortrijk, Belgium) and the software ImageJ (National Institutes of Health, Bethesda, Maryland, USA) which allowed them to control W/L, zoom, contrast and brightness, the images were analyzed in stacks grouping all 4 images of each exam simultaneously (sagittal and coronal). The assessments were made with a score scale from 1 to 5:

1. Definitely no contact of the implant with MC interior
2. Probably no contact of the implant with MC interior
3. Inconclusive
4. Probably in contact of the implant with MC interior
5. Definitely in contact of the implant with MC interior

The professionals were divided according to their professional background and the analyses were made through forced agreement among the two DMFR and the same for the two DDS.

3.5 Data Analysis

Considering the Likert scale used to analises images, 3 (inconclusive) was considered as upMC.

Data was analyzed in terms of sensitivity, specificity and accuracy considering MAR, examiners, tube current and CBCT equipment; Fisher exact test was applied to observe the interaction between these factors under variance. Kappa was applied for calculating interexaminer agreement and intraexaminer agreement with the known true positives and true negatives. For kappa, the considered rates were considered: poor agreement = less than 0.20; fair agreement = 0.20 to 0.40; moderate agreement = 0.40 to 0.60; good agreement = 0.60 to 0.80; very good agreement = 0.80 to 1.00.

Statistical analyses were obtained through SPSS Statistics 20 (IBM), Minitab 16 (Minitab Statistical Software) e Excel Office 2010 (Microsoft), with confidence intervals of 95% ($p<0,05$).

4. Results

4. RESULTS

Table 1 shows sensitivity, specificity and accuracy considering the factors of variation in the study and **Table 2** shows the p values considering the comparisons done.

Table 1. Sensitivity, specificity, and accuracy considering different examiners, CBCT devices, and MAR activation.

		Sensitivity		Specificity		Accuracy	
		DMFR	**DDS**	**DMFR**	**DDS**	**DMFR**	**DDS**
Eagle 3D	**4mA MAR OFF**	90,0%	70,0%	87,5%	100%	88,9%	83,3%
	8mA MAR OFF	90,0%	50,0%	87,5%	100%	88,9%	72,2%
	4mA MAR ON	40,0%	70,0%	100%	100%	66,7%	83,3%
	8mA MAR ON	50,0%	70,0%	100%	75,0%	72,2%	72,2%
OP 300	**4mA MAR OFF**	90,0%	40,0%	87,5%	100%	88,9%	66,7%
	10mA MAR OFF	80,0%	40,0%	87,5%	100%	83,3%	66,7%
	4mA MAR ON	90,0%	30,0%	100%	100%	94,4%	61,1%
	10mA MAR ON	90,0%	30,0%	87,5%	100%	88,9%	61,1%

DMFR: Dentomaxillofacial Radiologists; DDS: Doctor of Dental Surgery; MAR: Metal Artefact Reduction.

Table 2. P values for comparisons between different examiners, CBCT devices, and MAR activation.

		DMFR			DDS		
		Sensitivity	**Specificity**	**Accuracy**	**Sensitivity**	**Specificity**	**Accuracy**
MAR off x MAR on	**Eagle 3D 4mA**	*0,019**	*0,302*	*0,109*	*1,000*	*1,000*	*1,000*
	Eagle 3D 8mA	*0,051**	*0,302*	*0,206*	*0,361*	*0,131*	*1,000*
	OP 300 4mA	*1,000*	*0,302*	*0,546*	*0,639*	*1,000*	*0,729*
	OP 300 10mA	*0,531*	*1,000*	*0,630*	*0,639*	*1,000*	*0,729*

DMFR: Dentomaxillofacial Radiologists; DDS: Doctor of Dental Surgery; MAR: Metal Artefact Reduction.

Regarding sensitivity (true positives of dental implants in MC interior, correctly identified), statistical difference is found when comparing MAR ON vs MAR OFF on Eagle 3D device at 4mA and 8 mA for the DMFR as the examiner. With MAR ON, sensitivity decreased significantly (*p<0.05*) for DMFR examiner on Eagle 3D device, compared to MAR OFF. Comparing MAR ON vs MAR OFF considering the DDS examiner on Eagle 3D it was shown similar sensitivity at 4mA and an increase when MAR was activated at 8Ma (50 to 70%). Regarding specificity (true negative of dental implants with no contact with MC interior, correctly identified), it varied from 87,5% to 100% without statistical difference in any comparison, being the lowest value of 75% with MAR ON on Eagle 3D at 8mA. Concerning accuracy, values were overall high with MAR OFF and decreased when MAR was activated on Eagle 3D (for DMFR) at 4mA and 8mA. On the other hand, considering DMFR, the same did not occur on OP300 where the accuracy achieved the highest at 4mA with MAR ON (94, 4%). When the DDS examiner is compared to DMFR, the latter achieved greater accuracy in identifying the relation between the dental implant and MC, for most experimental setups (Table 1).

Table 3 shows the inter and intra-examiner reliability regarding the diagnosis of detection of mandibular canal cortex perforation by implants and the digital 3D planned.

Table 3. Inter and intra-examiner reliability regarding the diagnosis of detection of mandibular canal cortex perforation by implants and the digitally 3D planned.

		DMFR*	DDS*	DMFR x DDS**
Eagle 3D	**4mA MAR OFF**	0,775	0,675	0,458
	8mA MAR OFF	0,775	0,471	0,471
	4mA MAR ON	0,372	0,675	0,620
	8mA MAR ON	0,471	0,444	0,111
OP 300	**4mA MAR OFF**	0,775	0,372	0,372
	10mA MAR OFF	0,667	0,372	0,222
	4mA MAR ON	0,889	0,276	0,111
	10mA MAR ON	0,775	0,276	0,276

DMFR: Dentomaxillofacial Radiologists; DDS: Doctor of Dental Surgery; MAR: Metal Artefact Reduction.

The influence of MAR considering the intra-examiner reliability varied along the different experimental setups. Overall, DMFR showed a good agreement with the true positives and true negatives on OP300 (0,6 to 0,8) for all MAR scenarios and mA protocols; the same happened for Eagle 3D with MAR OFF. Interestingly, DMFR showed a fair agreement (0,3 to 0,4) with true positives and true negatives at Eagle 3D images with MAR ON in both mA. DDS overall showed a poor agreement with the true positives and negatives (0,3 to 0,1) on OP300, either MAR OFF or ON; it slightly increased to a fair agreement on Eagle 3D. It is interesting to note that intraexaminer agreement with the true positives and negatives were different at all experimental setups, being always greater for DMFR. Consequently, the interexaminer agreement was overall poor.

5. Discussion

5. DISCUSSION

This study showed that sensitivity in the diagnosis of the contact of dental implants with the mandibular canal can vary depending on the use of the MAR, mA, CBCT device, and examiner background. Therefore, the null hypothesis was rejected. It has clinical relevance because postoperatively, the suspicion of close contact or perforation of the CM cortical by dental implants requires precise and fast intervention to minimize the occurrence of permanent injury of IAN (Khawaja & Renton, 2009); nevertheless, such diagnosis can be difficult by artefacts on CBCT.

Discussing the study design and methodology, the diagnostic task of identifying the relation between the MC and a dental implant placed at the position of the first lower molar was chosen because of its clinical relevance as literature relates posterior sites of the mandible presenting usually low vertical height, especially at the first and second molars region where the MC has the farthest distance from the inferior mandibular cortical and hence closest to the alveolar border (Safari et al., 2022). The use of dry human mandibles in ballistic gelatin allows the creation of a more clinical-like scenario in a controlled environment (Mancini et al., 2021; Lopes et al., 2019). Regarding it, the correct positioning of the dental implant at 0.5mm superior to the MC cortical or at 0.5mm inside the MC was the major task in this study to evaluate the relation with the MC, as measures within the in the recommended distance of 1.5mm from the nerve are more likely to be properly diagnosed by CBCT, nevertheless, the most inaccurate diagnosis are in positions inferior to these distances. It probably happens because of two types of artefacts, beam-hardening and, especially, blooming (Schulze et al., 2010). In the care of placing the dental implant in the correct position according to the study design, we opted for a bone-supported surgical guide which can lead to an apical accuracy documented in the literature of clinical studies varying from 0.4 to 1.2 at the apex (Mistry et al., 2021, Chen, Nikoyan, 2021). Using guided surgery along with CBCT during the in vitro intraoperative and postoperative allowed the experienced operator to achieve accurate positioning. Still discussing the methods, the use of static images for the diagnostic task is justified by an accurate registration of the region of interest, along the experimental groups. Additionally, it allowed examiners to consider images in the same position to decide their diagnosis, leaving aside structures that would confuse them and interfere with the focus of the actual task. Furthermore, such a static images method was used similarly by other authors (Vasconcelos et al., 2019, Shokri et al., 2019; Mancini et al., 2021). In relation to factors that would vary the presence of artefacts and interfere with the diagnostic task, a literature review found variances in scanning protocol (kVp and FOV) may affect the occurrence of artefacts around dental implants (Codari et al., 2017; Queiroz et al., 2017; Freitas et al., 2018; Vasconcelos et al., 2019; Shokri et al., 2019; Vasconcelos et al., 2020; Khosravifard et al., 2021; Sawicki et al., 2022), however, regarding the variation on mA it does not have a consensus around the influence on artefacts (Pauwels et al., 2013; Shokri et al., 2019; Mancini et al., 2021; Sawicki et al., 2022). Therefore, it is feasible to reduce the incidence of artefacts and improve the image quality by appropriate modification of the exposure parameters; in this sense, this study tested the MAR tool with these parameters allowing the investigation of these different setting protocols under the same conditions. However, the reduction of artefacts is often associated with a significant increase in radiation exposure; hence, an effort should be made to minimize the radiation dose in line with the ALARA (as low as reasonably achievable) principle (Sawicki et al., 2022). Still, among aspects that can influence artefacts, de-Azevedo-Vaz, et al., 2016 evaluated the effect of MAR algorithm and the voxel size on diagnostic accuracy and found no significant difference between 0.2 and 0.3 mm voxel sizes for the detection of fenestration and dehiscence. Since a larger voxel size decreases the patient radiation dose, the use of a larger voxel size considering the diagnostic task of bone measure, for the assessment of peri-implant cortical bone is recommended (de-Azevedo-Vaz et al. 2016). Concerning the examiners, literature reports that professional backgrounds can influence the results in a diagnostic task involving CBCT most because of the "learning bias" (Schriber et. al 2020). In this sense, the examiners in this study were divided according to their professional backgrounds in DMFR and DDS.

Discussing the results, specificity was overall higher than sensitivity in all scenarios suggesting that it is easier to diagnose a true negative (no contact when there is no contact) than a true positive (contact when contact exists) for both DDS and DMFR. Concerning MAR, sensitivity was more affected than specificity, and it is concerning that MAR activation decreased sensitivity in various experimental scenarios, nevertheless, statistical difference was found when comparing MAR ON vs MAR OFF on Eagle equipment in both mA tested (4mA and 8 mA) for the DMFR as the examiner. The information regarding sensitivity and specificity has clinical relevance, as identifying the true positive is crucial concerning clinical decision-making in the postoperative period. Also interestingly, the most expressive value for accuracy was reached for the DMFR on OP300 with the lowest tube current (4mA) with MAR tool activated, yet this result was not statistically significant. Justifying the results of this study the benefits of the MAR tool is not a consensus in studies considering other diagnostic tasks. Compared with studies that tested the MAR tool under a diagnostic task involving dental implant, Salemi et al., 2021 in a diagnostic of fenestration and dehiscence by two radiologists found that sensitivity, specificity and accuracy were higher with MAR OFF for both CBCT devices used (different of those of this present study). de-Azevedo-Vaz et al., 2016 found no improvement in the same diagnostic task using MAR tool and Fontenele et. al 2022, found no influence of MAR and kVp on the diagnosis of buccal and lingual peri-implant dehiscence in the presence of titanium and zirconia implants. Contrarily, a positive result for MAR activation is observed in previous studies that analyzed MAR effect in quantitative analysis. Khosravifard et al., 2021 found that MAR tool and reduced FOV size significantly decreased the number of streak artefacts. In a study of Freitas et al, 2018, MAR decreased the pronounced CBCT artefact generated by titanium and zirconia implants, also, the increase of kVp influenced artefact reduction. Vasconcelos et al., 2019, compared artefacts from different materials and CBCT devices; founding differences for both factors. Mancini et al., 2021, tested MAR under different mA and materials; they found that higher mA improves overall image quality and a higher mA would be necessary for zirconia in comparison to titanium. Vasconcelos et al., 2020, found a MAR tool performance depending on the materials and the CBCT unit; the MAR activation resulted in a reduction of the experimental cylinder volume for two of three CBCT tested. It is interesting to note that in studies analyzing image quality through quantitative analysis, the MAR activation appears to reduce artefact efficiently, nevertheless, in studies involving diagnostic tasks the MAR activation does not represent a significant increase in diagnostic accuracy.

Considering the DDS and DMFR backgrounds, DDS showed more incorrect diagnoses than DMFR in most experimental scenarios. In the literature, differences can be found between examiners regarding sensitivity and specificity in the CBCT exam. Schriber et al., 2020, found that DMFR examiners reported a more accurate performance than OMFS (oral and dentomaxillofacial surgeon) in the diagnostic accuracy of peri-implant bone defects using CBCT. In turn, Zhang et al., 2021 found that agreement between experienced dentists (5 years of experience in implant imaging) was better than inexperienced examiners in the diagnostic task of detection of a peri-implant defect by CBCT and periapical radiographic. This result is in accordance with the present study, in which, DMFR had a superior agreement with the correct diagnosis. Considering intra-examiners agreement, Salemi et al., 2021, showed, by two experienced radiologists, a poor to a moderate agreement with MAR ON and good to excellent with MAR OFF, in accordance with the results found in this study. Fontenele et al., 2021, by three oral radiologists, found an intra- and inter-examiner agreement ranged from slight (weighted kappa=0.10 and 0.13, respectively) to substantial (weighted kappa=0.64 and 0.69, respectively) in the diagnostic task of detection of buccal and lingual peri-implant dehiscence in titanium and zirconia implants.

Among the limitations of this study, it can be mentioned the in vitro condition, nevertheless, such a study design (different mA and CBCT devices) would be impossible with regular patients due to ethical reasons. In this sense, the use of dried human mandibles could be a good simulation to the practice-like clinical scenario, in addition to the use of ballistic gelatin which was found by Lopes et al., 2019 as the best soft tissue simulant considering their comparisons. Further studies involving different diagnostics tasks need to be done varying CBCT equipment, MAR configurations and materials presented in the FOV.

6. Conclusion

6. CONCLUSION

The diagnostic accuracy of the relation between dental implants and the mandibular canal was not improved considering MAR activation. Hence, due to the limited efficacy of MAR, it should not be used when conducting CBCT scans for the evaluation of contact between the implant and the mandibular canal.

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