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Efeito da miliamperagem da tomografia computadorizada de feixe cônico em artefatos a diferentes distâncias de implantes de zircônia e titânio e no diagnóstico de defeitos ósseos periimplantares

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Área de Concentração: Reabilitação Oral

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Resumo

Mancini, A.X.M. Efeito da miliamperagem da tomografia computadorizada de feixe cônico em artefatos a diferentes distancias de implantes de zircônia e titânio e no diagnóstico de defeitos ósseos perimplantares [Dissertação]. Ribeirão Preto: Universidade de São Paulo, Faculdade de Odontologia de Ribeirão Preto; 2020

Os Objetivos deste estudo foram *(1)* avaliar o efeito da miliamperagem (mA) da tomografia computadorizada de feixe cônico (TCFC) na magnitude dos artefatos em regiões localizadas a diferentes distâncias dos implantes de titânio ou zircônia, com e sem a ativação da ferramenta de redução de artefatos metálicos (MAR) e *(2)* avaliar o efeito da mA da TCFC na acurácia de diagnóstico de defeitos ósseos periimplantares (deiscências e fenestrações). O estudo foi dividido em duas etapas. Na etapa 1, mandíbulas humanas foram escaneadas antes e após a instalação de implantes dentários de titânio e de zircônia, com quatro miliamperagens diferentes (4 mA, 6,3 mA, 8 mA e 10 mA), com e sem a ativação da MAR. O efeito da mA no desvio padrão (DP) dos valores de cinza e na razão contraste / ruído (RCR) foi avaliado em regiões de interesse localizadas a 1,5 cm, 2,5 cm e 3,5 cm dos implantes. Na etapa 2, foram utilizados 12 segmentos de costela bovina com 5 implantes em cada, obtendo-se 30 implantes com defeitos (deiscências e fenestrações) e 30 implantes sem defeitos, estes foram escaneados com três miliamperagens diferentes: 4mA, 8mA e 10mA. Três especialistas em Radiologia Odontológica e Imaginologia analisaram as imagens e classificaram a presença de defeitos ósseos periimplantares em uma escala de 5 pontos. A área sob a curva ROC (Az), sensibilidade e especificidade foram calculadas. Na presença de implantes de titânio, foi encontrada uma diminuição significativa no DP dos valores de cinza, aumentando-se a mA de 4mA para 6,3mA ou 8mA. Para implantes de zircônia, exames com 8 mA apresentaram melhores resultados para todas as distâncias. A MAR melhorou a RCR nos exames com implantes de zircônia em todas as distâncias testadas, enquanto que nenhuma diferença foi observada com o uso da MAR para implantes de titânio. Não foi observada diferença para os valores de Az para a detecção de defeitos ósseos periimplantares nas imagens obtidas com 4, 8 ou 10mA ($p > 0,05$). Além disso, a mA não afetou a sensibilidade e a especificidade na detecção dos defeitos ósseos periimplantares ($p > 0,05$). Conclui-se que um aumento da mA pode melhorar a qualidade geral da imagem na presença de implantes, em todas as distâncias analisadas. Quando um implante de zircônia está presente, esse aumento no mA deve ser maior em comparação com os exames com implantes de titânio. A ativação da MAR melhorou a qualidade da imagem apenas nos exames com implantes de zircônia. O emprego de, mAs mais altas não significou melhora na detecção de defeitos ósseos periimplantares, portanto, não é recomendado para esta tarefa de diagnóstico.

Palavras-chave: Tomografia Computadorizada de Feixe Cônico, Artefatos, Implante Dentário

Abstract

Mancini, A.X.M. Effect of cone beam computed tomography tube current in artifacts at different distances from zirconia and titanium implants and in the diagnosis of perimplant bone defects [Dissertação]. Ribeirão Preto: Universidade de São Paulo, Faculdade de Odontologia de Ribeirão Preto; 2020

The Aims of this study were: (a) To evaluate the effect of cone beam computed tomography (CBCT) tube current (mA) on the magnitude of artifacts at different distances from titanium or zirconia implants, with and without the activation of the reduction of metal artifacts (MAR) tool, and (b) to evaluate the effect of mA on the accuracy of CBCT in the diagnosis of peri-implant bone defects (dehiscences and fenestrations). For the first part of the study, human jaws were scanned before and after the installation of titanium and zirconia dental implants, with four different tube currents (4 mA, 6.3 mA, 8 mA and 10 mA), with and without MAR activation. The effect of mA on the standard deviation (SD) of the gray values and on the contrast-to-noise ratio (CNR) was evaluated in regions of interest located at 1.5 cm, 2.5 cm and 3.5 cm from the implants. For the second part, 12 bovine rib segments were used with 5 implants each, obtaining 30 implants with bone defects (dehiscences and fenestrations) and 30 implants without defects, which were scanned with three different tube currents: 4mA, 8mA and 10mA. Three oral radiologists analyzed the images and scored the detection of peri-implant bone defects on a 5-point scale. The area under the ROC curve (Az), sensitivity, and specificity were calculated. When titanium implants are present, a significant decrease in the SD of gray values was found when the mA was increase from 4 to 6.3 or 8mA. For zirconia implants, 8 mA showed better results for all distances. MAR improved the CNR in the presence of zirconia implants at all distances, while no difference was observed with the use of MAR for titanium implants. No significant differences were observed for the values of Az for the detection of peri-implant bone defects in the images obtained with 4, 8 or 10mA ($p > 0.05$). In addition, mA did not affect the sensitivity or specificity for the detection of peri-implant bone defects ($p > 0.05$). In Conclusion, an increase in mA can improve the overall image quality in the presence of implants, at all tested distances. When a zirconia implant is present, this increase in mA should be greater compared to exams with titanium implants. The activation of MAR improved the image quality only between exams with zirconia implants. However, this improvement in the image with the use of higher mAs did not mean an improvement in the detection of peri-implant bone defects, therefore, it is not recommended for this diagnostic task.

Key Words: Cone-Beam Computed Tomography, Artifacts, Dental Implant

SUMÁRIO

Contextualização do Tema

A prevalência e incidência de perdas dentárias causadas por cáries e doença periodontal tem reduzido nas últimas décadas, contudo, estas continuam sendo um problema global de saúde pública (Kassebaum et al., 2014). A reabilitação oral com o uso de implantes dentários osseointegrados é considerada uma opção previsível de tratamento para a perda de dentes (Esposito et al., 2005; Levin et al, 2006), com altas taxas de sucesso, especialmente na mandíbula (Goodacre et al., 2003; Chee & Jivraj 2007). Contudo, falhas e complicações podem ocorrer comprometendo os resultados estéticos e funcionais e, em alguns casos, culminando na perda do implante (Levin et al., 2008; Misch & Wang, 2008). Falhas e complicações podem estar relacionadas ao planejamento cirúrgico e/ou protético, ao nível de experiência do cirurgião-dentista, a características do implante e a fatores relacionados ao paciente (idade, estado geral de saúde, hábitos, variações anatômicas) (Porter & von Fraunhofer, 2005; Misch & Wang, 2008).

Os implantes localizados nas regiões posteriores da mandíbula apresentam riscos específicos, relativamente frequentes, relacionados a perfurações de estruturas adjacentes como a cortical do osso por lingual, devido à concavidade referente à fóvea submandibular, e o canal mandibular com potenciais lesões no nervo alveolar inferior, ocasionando distúrbios sensoriais importantes (Leong et al., 2011, Juodzbalys et al., 2011; Shavit et al., 2014, Gaeta-Araujo 2020). Também é relatada uma relação entre o mal posicionamento de implantes com perfurações de estruturas anatômicas e deiscência óssea com exposição de roscas do implante (Gaeta-Araujo 2020). Portanto, a correta angulação do implante é um dos fatores determinantes do sucesso, e deve ser determinada previamente a partir do planejamento protético, a fim de garantir resultados estéticos e estabilidade biomecânica (Misch & Wang, 2008).

Exames bidimensionais de imagem, como as radiografias panorâmica e periapical, apresentam limitações técnicas relacionadas à sobreposição de imagens, que dificultam a avaliação pré-operatória da qualidade óssea e de características anatômicas relevantes da mandíbula. Exames seccionais são recomendados para a avaliação pré-operatória para a instalação de implantes dentários, e a tomografia computadorizada de feixe cônico (TCFC) é o método de imagem de escolha para essa finalidade porque permite determinar com precisão a espessura da tabua óssea, sua altura, conformação anatômica e a relação com estruturas adjacentes (Tyndall et al., 2012).

Apesar das vantagens do uso da TCFC no planejamento pré-operatório dos implantes, este tipo de exame apresenta algumas limitações, como dose de radiação relativamente alta em comparação a exames bidimensionais, e a presença de artefatos de imagem. Artefatos são discrepâncias entre a imagem visual reconstruída e o conteúdo real do objeto, ou sejam, estruturas visualizadas após a reconstrução do volume obtido no TCFC, mas que de fato não existem no objeto real avaliado (Schulze et al., 2011). Os artefatos tem impacto relevante na qualidade das imagens de TCFC e, em alguns casos, podem até torná-las diagnosticamente inutilizáveis (Nagarajappa et al., 2015). A formação de artefatos está relacionada a diversas variáveis como a composição dos objetos e sua localização no *fiel of view* (FOV), limitações do algoritmo usado pelo sistema da TCFC para reconstruir as imagens e até diferenças entre o coeficiente de atenuação recebido pelo sensor e as caraterísticas físicas reais do objeto (Schulze et al., 2011). Apesar de serem mais pronunciados nas proximidades da fonte geradora, os artefatos podem se estender por pelo menos 3,5 cm (Fontenele et al., 2018).

Materiais de alta densidade, como implantes dentários de titânio e zircônia, geram uma quantidade considerável de artefatos (Sancho-Puchades et al., 2015). Devido ao alto número atômico destes materiais, o tipo de artefato mais comum é o endurecimento do feixe ou *beam-hardening*, que ocorre quando a estrutura do objeto age como um filtro bloqueando a passagem de feixes com menos energia, aumentando assim a energia média que atinge o sensor e resultando em erros na reconstrução dos dados, que são visualizados como estruturas lineares, sombras e faixas organizadas (Pauwels et al., 2013). Similarmente, o *photon starvation* causa erros nos dados da projeção devido à quase completa atenuação do feixe de raios X por objetos de metal grandes e / ou densos. Quando esses efeitos são combinados com outros efeitos, como o ruído de dispersão de raios-X, que é uma perturbação indesejada de um sinal, distribuída aleatoriamente e/ou não aleatoriamente que tende a obscurecer o conteúdo da informação e geram uma variação significativa nos valores de cinza próximos a materiais muito densos, produzindo imagens que podem ser diagnosticavelmente inaceitáveis, uma vez que artefatos podem obscurecer estruturas e patologias próximas (Schulze et al., 2010).

Portanto, o uso da TCFC para avaliação pós-operatória dos implantes é limitado. A avaliação pós-operatória com exames de imagem tem como objetivo avaliar a posição final do implante após a cirurgia, e, em avaliações regulares de acompanhamento, visualizar a interface entre o implante e o osso e a altura óssea periimplantar (Tyndall et al., 2012). A radiografia periapical é o exame de escolha para estas avaliações pós-operatórias, nos casos de ausência de sintomas e potenciais complicações (Tyndall et al., 2012). A radiografia panorâmica também pode ser utilizada, quando a reabilitação for mais extensa, com múltiplos implantes. Apesar da presença de artefatos, COLOCAR ACADEMIA recomenda a TCFC pós-operatória em duas situações clínicas: 1) imediatamente após a cirurgia se o paciente apresenta sensibilidade alterada ou mobilidade do implante; 2) quando a perda do implante é prevista, pois as falhas requerem avaliação completa para reconhecer o verdadeiro problema e fornecer o melhor planejamento para eventual correção (Tyndall et al., 2012).

A TCFC usa doses de radiação mais elevadas em comparação com outros exames odontológicos de imagem, como radiografias periapicais e panorâmicas. O princípio ALADA (*as low as diagnostically acceptable*) deve ser aplicado a todos os exames que usam radiação ionizante, a fim de equilibrar a qualidade da imagem e a dose de radiação para resultados diagnósticos aceitáveis (Carter et al., 2008). Mais recentemente, sugeriu-se uma atualização a este princípio (ALADAIP - as low as diagnostically acceptable, being indication-oriented and patient-specific), acrescentando-se o conceito de que os exames de TCFC devem ser otimizados de acordo com características do paciente e com a indicação ou tarefa de dianóstico (Oenning et al., 2018). A otimização das imagens da TCFC pode ser realizada pela seleção de protocolos de aquisição adequados para tarefas de diagnóstico específicas. O FOV (*field of view* - campo de visão), tamanho do *voxel*, tempo de varredura, *half / full scan*, tensão do tubo (kVp) e miliamperagem (mA) são exemplos de configurações de exposição que podem ser ajustadas para aplicação otimizada de TCFCs (Kwong et al., 2008; Sur et al., 2010; Dawood et al., 2012).

Miliamperagens mais altas, em geral, melhoram a qualidade da imagem ao reduzir o ruído, no entanto, existe uma relação proporcional direta entre a mA e a dose de radiação empregada (Pauwels et al., 2015). Por outro lado, a kVp tem um papel mais complexo no equilíbrio da qualidade da dose / imagem, com efeitos na energia do feixe e na quantidade de fótons. Tem sido demonstrado que uma maior kVp pode melhorar a detecção de defeitos ósseos peri-implantares (Pinheiro et al., 2017). Tamanhos maiores de FOV estão associados a doses de radiação mais altas (Pauwels et al., 2012) e podem produzir mais artefatos em comparação com FOVs menores. Exames com menores *voxels* (ou seja, maior resolução) e menor FOV podem fornecer uma detecção mais acurada de defeitos ósseos periimplantares quimicamente simulados (Pinheiro et al., 2015). O uso de *full scan* desempenha melhor detecção de defeitos perimplantares que *half scan* quando utilizados tamanhos de voxels semelhantes (de-Azevedo-Vaz et al., 2013). Existem ferramentas de software, como MAR (*metal artifact reduction*), que consistem em algoritmos utilizados na reconstrução das imagens para reduzir artefatos, contudo, a contribuição desses algoritmos em diferentes tarefas de diagnóstico é controversa na literatura (Parsa et al., 2014; de-Azevedo-Vaz et al., 2016).

A avaliação do efeito das variações na mA para tarefas de diagnóstico específicos é relevante para o uso otimizado da TCFC. Um estudo recente mostrou que o aumento da mA melhora significativamente o desempenho diagnóstico na detecção de fraturas radiculares verticais em dentes com pinos metálicos e guta-percha (Gaêta-Araujo et al., 2017). Por outro lado, a utilização de mA mais baixa, apesar de seu efeito na qualidade da imagem (ou seja, maior ruído), pode reduzir significativamente a dose de radiação empregada e ainda produzir resultados clinicamente aceitáveis em tarefas de diagnóstico específicas (Gaêta-Araujo et al., 2017; Pauwels et al. 2015). Portanto, mais estudos são necessários para aprimorar as recomendações de protocolos específicos para exames de TCFC, tanto para fins de avaliação de implantes quanto para outras indicações quando implantes estão presentes na região.

O objetivo deste estudo foi avaliar o efeito da miliamperagem (mA), em exames de TCFC, na magnitude dos artefatos gerados pelos implantes dentários de titânio e zircônia a diferentes distancias destes, e na acurácia de diagnóstico de defeitos ósseos (deiscências e fenestrações) periimplantares.

O estudo foi divido em duas etapas, gerando dois artigos. O artigo referente à etapa 1 (Artigo 1) foi submetido ao periódico *Clinical Oral Investigations*. O artigo referente à etapa 2 (Artigo 2) está formatado para submissão ao *Imaging Science in Dentistry*.

Artigo 1 (Submetido ao periódico Clinical Oral Investigations)

Artefacts at different distances from titanium and zirconia implants in cone-beam computed tomography: effect of tube current and metal artefact reduction

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Key Words: Cone-Beam Computed Tomography, Artefacts, Titanium Implants, Zirconia Implants, Tube Current

Abstract

Objectives

To evaluate the effect of cone-beam computed tomography (CBCT) tube current (mA) on the magnitude of artefacts at different distances from titanium or zirconia implants, with and without activation of metal artefact reduction (MAR).

Material and Methods

Human mandibles were scanned before and after the installation of dental implants, with four different tube currents (4 mA, 6.3 mA, 8 mA and 10 mA), with and without activation of MAR. The effect of mA on the standard deviation (SD) of gray values and contrast to noise ratio (CNR) were assessed in regions of interest located 1.5 cm, 2.5 cm, and 3.5 cm from implants.

Results

In the presence of titanium implants, a significant decrease in SD was found by increasing tube current from 4mA to 6.3mA or 8mA. For zirconia implants, 8 mA yielded better results for all distances. MAR improved CNR in the presence of zirconia implants at all distances, whereas no differences were observed with the use of MAR for titanium implants.

Conclusion

Increased tube current can improve overall image quality in the presence of implants, at all the distances tested. When a zirconia implant is present, such increase in mA should be higher in comparison to that for examinations with titanium implants. Activation of MAR improved image quality only among examinations with zirconia implants.

Clinical Relevance

Artefact-generating implants are common in the field of view of CBCT examinations. Optimal exposure parameters, such as tube current, ensure high image quality with lowest possible radiation exposure.

Introduction

The presence of high density and high atomic number materials (e.g. metals) in the field of view (FOV) of cone-beam computed tomography (CBCT) examinations may generate a considerable amount of image artefacts [1-3]. Artefacts are discrepancies between the visualized structure and the real content of the object under investigation [1,2], decreasing the diagnostic quality of images [2]. Artefacts are more pronounced in the vicinity of the metal; however, they can extend for at least 3.5 cm around implants [4].

Due to the high atomic number of implant materials, the most common types of artefact are due to beam hardening and photon starvation. Beam hardening occurs because the object acts as a filter that predominately blocks X-ray photons with less energy. The resulting discrepancy in average energy between different areas of the detector manifests as errors in the reconstruction of the data, which are visualized as linear structures, shadows and organized bands [5]. Similarly, photon starvation causes errors in the projection data due to (almost) complete attenuation of the X-ray beam by large and/or dense metal objects.

CBCT uses higher radiation doses compared to other dental imaging exams, such as periapical and panoramic radiographs. The ALADA principle (as low as diagnostically acceptable) should be applied to all examinations that use ionizing radiation, in order to balance the image quality and the radiation dose for acceptable diagnostic results [7]. The optimization of CBCT images can be performed by selecting appropriate acquisition protocols for specific diagnostic tasks. Field of view (FOV), voxel size, scan time, half / full rotation, tube voltage (kV), tube current (mA) and metal artefact reduction (MAR) are examples of scan settings that can be adjusted for optimized application of CBCT [8-10].

Higher mA, in general, improves image quality by reducing noise. However, there is a direct proportional relationship between mA and the radiation dose to the patient [11]. Therefore, the evaluation of the effect of variations in mA for specific diagnostic tasks is relevant to the optimized use of the CBCT. A recent study showed that the increase in mA significantly improves the diagnostic performance in detecting vertical root fractures in teeth with metal posts and gutta-percha [12]. On the other hand, the use of lower mA, despite its effect on image quality (i.e. greater noise), can significantly reduce the radiation dose employed and still produce clinically acceptable results for specific diagnostic tasks [11,12]. Therefore, further studies are needed to improve the recommendations of specific protocols for CBCT exams, both for the purpose of evaluating implants and for other indications when implants are present in the FOV.

The objective of this study was to evaluate the effect of CBCT tube current (mA) on the magnitude of the artefacts caused by titanium and zirconia implants at different distances from the artefact-generating object, with and without activation of metal artefact reduction (MAR) tool.

Methodology

Sample preparation

Cylindrical phantoms, containing human mandibles immersed in ballistic gelatin [13], were created for this study. Ten eviscerated human mandibles were obtained from the Anatomy Laboratory of Ribeirão Preto School of Dentistry. and each one was inserted in the center of a cylindrical plastic box (16-cm diameter) containing 1 cm in height of ballistic gelatin, previously poured into the container. A 1.8x1.0x0.7cm block of dental impression material (Condensation Silicone - Yller Reflex, Pelotas, Brazil) was placed on the buccal cortex of the anterior region of each mandible, at the center of the alveolar ridge. Two cervical vertebrae (C1 and C2) were placed posterior to the mandibles and ballistic gelatin was then poured into the boxes to form 16x8cm cylindrical phantoms (Figure 1).

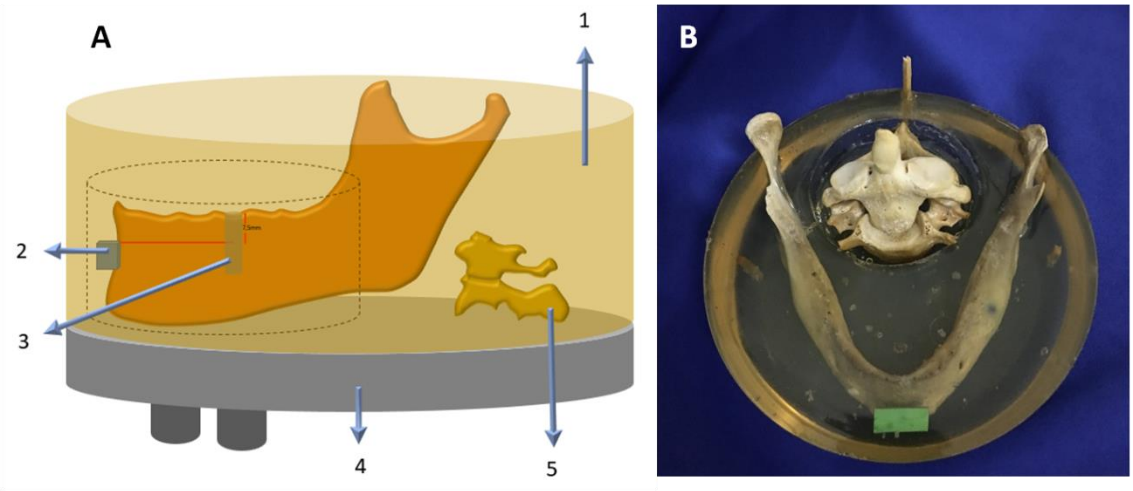

Figure 1. Schematic drawing (A) and photograph (B) showing lateral and upper views, respectively, of the ballistic gelatin phantom containing the mandible and cervical vertebrae, supported by the standardized device for the acquisition of tomographic images. 1 - Ballistic gelatin; 2 - condensation silicone block; 3 - Implant to be installed in the region of tooth 46; 4 - Acrylic device produced to standardize acquisitions; 5 - Cervical vertebrae. The cylinder with dotted lines represent the field of view in the CBCT exams (8x6cm).

CBCT image acquisition

For the acquisition of CBCT images, an acrylic device with 16cm diameter (Figure 1a) was manufactured to attach to the support of the machine and allow the standardized positioning of the phantoms and location of the FOV. The phantoms were then scanned using an OP300 Maxio CBCT unit (Instrumentarium, Tuusula, Finland), operating at 90 kVp, 0.085 mm voxel size, 8x6 cm FOV. The tube current was set at four different levels: 4 mA, 6.3 mA, 8 mA and 10 mA. The metal artefact reduction (MAR) tool was disabled during the acquisition of the exams. After each acquisition without MAR, new reconstructions of the same raw data were obtained with the activation of MAR algorithms

After the acquisition of the initial images (i.e. mandibles without implants), 3.75 x 13mm titanium implants (HE Conico - Intraoss, São Paulo - Brazil) were installed in 5 mandibles, and 3.3 x 12mm zirconia implants (Pure Ceramic - Straumman , Basel - Switzerland) in the other 5 mandibles. All implants were inserted in the edentulous region corresponding to tooth 46. The portion of the ballistic gelatin covering the region was removed, an osteotomy following a sequence of drills recommended by the manufacturers was performed, and the implant was inserted manually using a ratchet. After implant placement, new gelatin was poured to refill the removed portions.

The phantoms with the implants were then scanned using the same scanning parameters described above. Therefore, a total of 160 exams were acquired (10 phantoms x before/after implant placement x 4 different tube currents x with/ without MAR – Figure 2). Axial slices were exported in DICOM format for analysis using ImageJ (National Institutes of Health, Bethesda, MA, USA) based on the study of Fontenele et al. (2018).

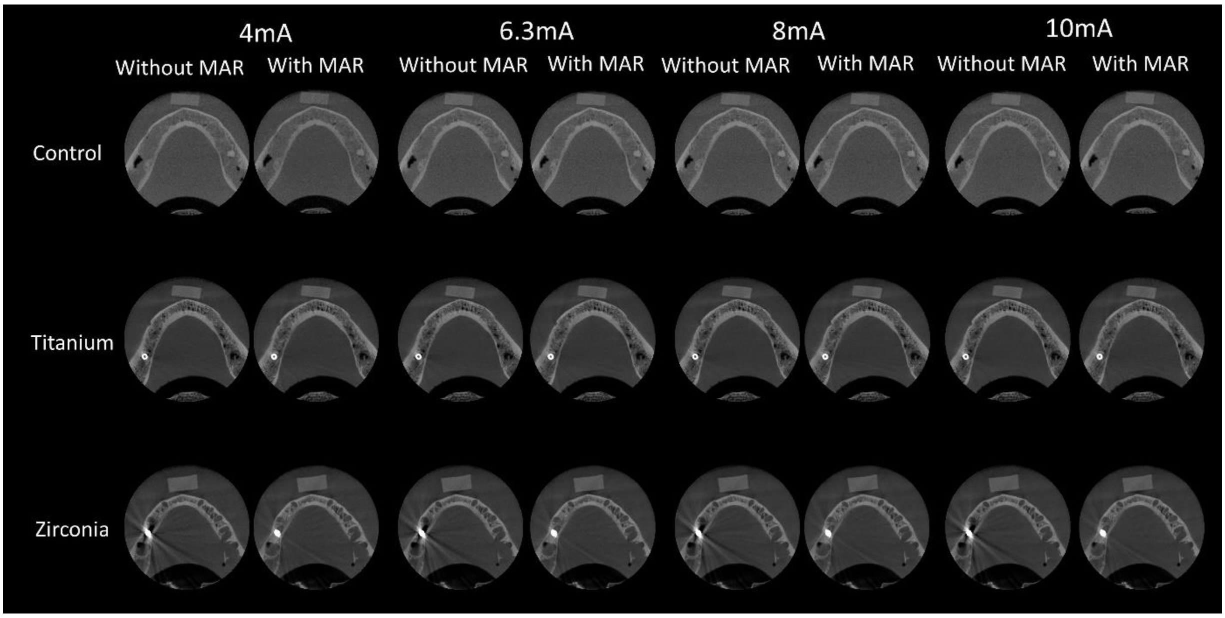

Figure 2. Axial Images represent implants (control in the first row, titanium in the second row, and zirconia in the third row) with different tube currents (4mA, 6.3mA, 8mA, and 10mA) and with/without the application of MAR.

Image assessment

In the axial slice in which the condensation silicone block was first visualized, a line was determined in the center of the implant and following the long axis of the mandibular body on the right side. Additional lines were then determined at different angles from the first line (65°, 90°,115°, and 140°). From the center of the implant, three semicircles with radii of 1.5, 2.5 and 3.5 cm were drawn. Finally, twelve 2.8 x 2.8 mm regions of interest (ROI) were established at the intersection of the circles and lines (Figure 3). Mean (M) and the standard deviation (SD) of the gray values were registered for each ROI. The macro function of ImageJ was used to determine and evaluate the same ROIs of each phantom in different conditions. An additional ROI was determined in the condensation silicone block to serve as a control area for the, calculation of the contrast-to-noise ratio (CNR) according to the formula [14]:

$$CNR = \frac{M\ IMPLANT - M\ CONTROL}{\sqrt{SD^2 IMPLANT + SD^2 CONTROL}}$$

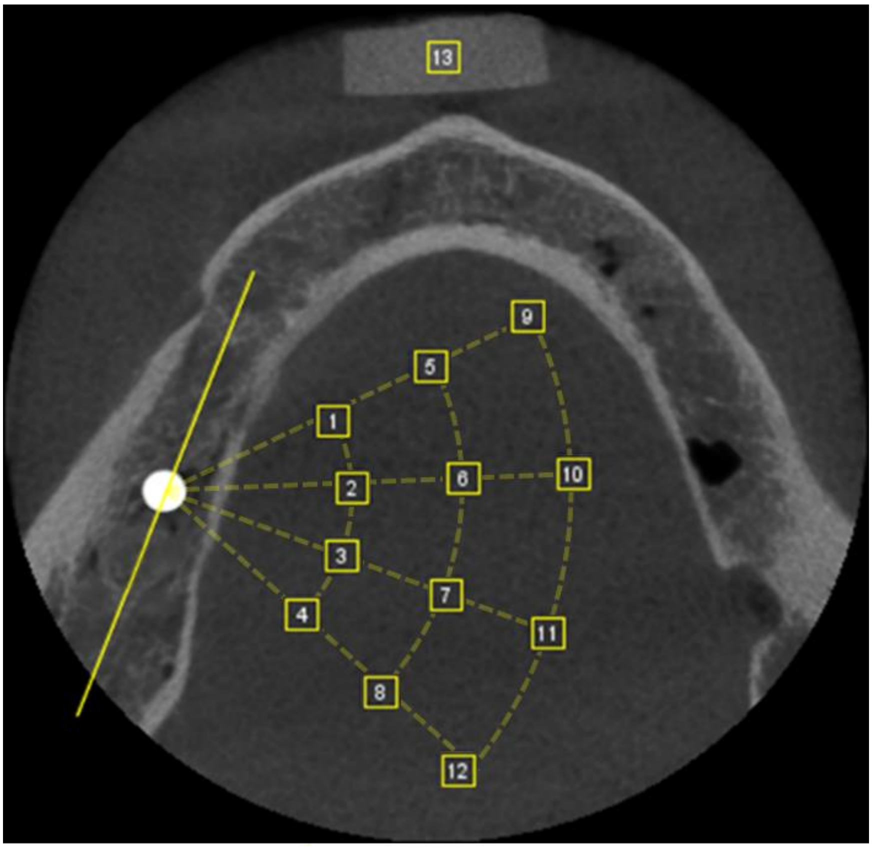

Figure 3. Regions of interest in the ballistic gel (1-12) and silicone block (13). Initially, a reference line was drawn along the long axis of the hemimandible and passing through the center of the implant. Additional lines were then determined at 65°, 90°,115°, and 140° (dotted lines) from the reference line. Three semicircles with radii of 1.5, 2.5 and 3.5 cm (dotted curves) were drawn from the center of the implant. Finally, the center of the twelve ROIs were determined at the intersection of the circles and lines (adapted from Fontenele et al., 2018).

Data analysis

Standard deviation (SD) and the contrast-to-noise ratio (CNR) were compared with repeated measures analysis of variance (ANOVA) and post-hoc Tukey's test in order to test the effects of different tube currents at different distances from titanium and zirconia implants, and the effect of MAR algorithm. Statistical analyses were performed using SPSS software (IBM Corp., Armonk, NY - USA), with significance level set at α=0.05.

Results

Mean SD values of the ROIs at different distances from the implants, with and without MAR and with different tube currents, are shown in Table 1. Overall, an increase in mA resulted in significant decrease of SD ($p \leq 0.05$). In the presence of titanium implants, significant decrease in SD was achieved by increasing tube current from 4mA to 6.3mA or 8mA. For the zirconia implants, 8mA yielded better results for all distances. ROIs at 1.5cm from zirconia implants had significantly higher SD than those in the titanium implant and control groups. There was no statistically significant difference in SD between ROIs with and without MAR for control and implant groups ($p > 0.05$). However, in the zirconia group lower SD was achieved by the activation of MAR at 2.5cm distance for all tube currents and at 3.5cm for 8mA ($p \leq 0.05$).

Table 1. Mean (SD) of the SD of gray values of the ROIs from control (no implant), titanium and zirconia implant groups, according to their distance to the implant, tube current (mA) and MAR condition.

SD of grey values – Mean (standard deviation)

Group	Distance	Without MAR				With MAR			
		4mA	6.3mA	8mA	10mA	4mA	6.3mA	8mA	10mA
Control	**1.5 cm**	41.9^{a} (7.4)	34.5^{b} (5.8)	33.2^{b} (5.7)	29.6^{c} (1.4)	41.9^{a} (7.4)	34.5^{b} (5.8)	33.2^{b} (5.7)	30.2^{c} (6.0)
	2.5 cm	39.7^{a} (3.2)	32.4^{b} (2.8)	29.6^{c} (2.9)	28.4^{c} (2.5)	39.7^{a} (3.2)	32.4^{b} (2.8)	29.6^{c} (2.9)	28.5^{c} (2.3)
	3.5 cm	38.6^{a} (3.7)	32.9^{b} (3.1)	30.4^{c} (2.6)	28.9^{d} (3.3)	38.3^{a} (3.0)	32.6^{b} (2.8)	30.1^{c} (2.2)	28.9^{d} (2.9)
Titanium	**1.5 cm**	41.8^{a} (0.9)	34.0^{b} (1.3)	33.4^{b} (1.8)	32.0^{b} (0.6)	41.5^{a} (4.3)	35.0^{b} (3.8)	34.5^{b} (4.6)	33.3^{b} (3.6)
	2.5 cm	41.0^{a} (5.90)	33.9^{b} (6.7)	33.1^{b} (6.20)	31.4^{b} (4.8)	41.0^{a} (5.0)	33.5^{b} (6.5)	33.7^{b} (5.1)	32.0^{b} (4.3)
	3.5 cm	37.20^{a} (1.5)	33.0^{b} (1.5)	29.9^{c} (1.4)	29.0^{c} (2.2)	37.7^{a} (2.4)	34.0^{b} (2.5)	30.8^{c} (3.1)	30.1^{c} (2.5)
Zirconia	**1.5 cm**	63.1^{a*} (18.3)	57.2^{a*} (18.0)	53.5^{b*} (18.1)	53.1^{b*} (20.9)	55.3^{a*} (21.6)	49.7^{a*} (21.6)	47.4^{b*} (21.3)	46.6^{b*} (22.2)
	2.5 cm	42.50^{a} (6.4)	36.03^{b} (3.9)	33.44^{bc} (5.3)	32.77^{c} (5.2)	$38.66^{a\dagger}$ (4.8)	$32.15^{b\dagger}$ (2.9)	$30.89^{b\dagger}$ (4.9)	$29.07^{b\dagger}$ (4.1)
	3.5 cm	40.31^{a} (4.2)	35.86^{a} (3.5)	33.29^{ab} (3.20)	30.50^{b} (1.2)	38.64^{a} (4.3)	33.67^{b} (2.9)	$31.17^{b\dagger}$ (3.8)	28.89^{b} (1.6)

MAR, metal artefact reduction.
Different superscript lowercase letters indicate differences between tube currents (mA) (i.e. comparisons within rows)
* indicates statistically significant difference between implant groups and control
† indicates statistically significant difference between without MAR and with MAR

Mean CNR values of the ROIs are shown in Table 2, with and without MAR, according to tube currents and distances. In the presence of implants, significant increase in mean CNR at all three distances is observed when tube current is increased from 4mA to 6.3mA ($p \leq 0.05$). In all tube currents, lower CNR was observed at 1.5cm from the zirconia implants compared with the titanium implants, and at 4mA the CNR was lower at all distances without MAR ($p \leq 0.05$). There were no significant differences between scans with or without MAR in the control and titanium group, but MAR use increased CNR values in most conditions tested (mA *vs* distances) in the zirconia group ($p \leq 0.05$).

Table 2. Mean (SD) of the CNR values of the ROIs from control (no implant), titanium and zirconia implant groups, according to their distance to the implant, tube current (mA) and MAR condition.

CNR – Mean (standard deviation)

Group	Distance	Without MAR				With MAR			
		4mA	6.3mA	8mA	10mA	4mA	6.3mA	8mA	10mA
Control	**1.5 cm**	8.0^{a} (0.9)	9.1^{b} (1.3)	9.5^{c} (1.4)	9.9^{c} (1.7)	8.0^{a} (0.9)	9.1^{b} (1.3)	9.5^{c} (1.4)	9.7^{c} (1.5)
	2.5 cm	8.3^{a} (1.5)	9.5^{b} (2.0)	10.1^{c} (2.3)	10.3^{c} (2.4)	8.3^{a} (1.5)	9.5^{b} (2.0)	10.1^{c} (2.3)	10.2^{c} (2.3)
	3.5 cm	8.3^{a} (1.5)	9.4^{b} (1.9)	9.94^{c} (2.2)	10.15^{c} (2.5)	8.3^{a} (1.5)	9.4^{b} (1.9)	9.9^{c} (2.2)	10.0^{c} (2.4)
Titanium	**1.5 cm**	7.1^{a*} (0.7)	8.2^{b} (0.8)	8.4^{b} (1.1)	8.5^{b} (0.8)	7.3^{a} (1.0)	8.1^{b} (1.1)	8.3^{b} (1.3)	8.4^{b} (1.1)
	2.5 cm	7.1^{a} (0.8)	8.1^{b} (0.8)	8.36^{b} (1.3)	8.5^{b} (0.9)	7.1^{a} (1.0)	8.0^{b} (1.1)	8.2^{b} (1.4)	8.3^{b} (1.1)
	3.5 cm	7.3^{a} (1.1)	8.2^{b} (1.1)	8.59^{b} (1.6)	8.7^{b} (1.3)	7.3^{a} (1.3)	8.0^{b} (1.3)	8.4^{b} (1.7)	8.5^{b} (1.4)
Zirconia	**1.5 cm**	6.8^{a*} (1.3)	7.7^{b*} (1.5)	8.1^{b*} (1.8)	7.8^{b*} (1.8)	$7.7^{a\dagger}$ (1.2)	$8.7^{b\dagger}$ (1.4)	$9^{c\dagger}$ (1.3)	$8.8^{c\dagger}$ (1.4)
	2.5 cm	8.5^{a*} (2.0)	9.7^{b} (2.1)	10.3^{b} (2.5)	9.8^{b} (2.4)	$9.0^{a\dagger}$ (1.9)	$10.3^{b\dagger}$ (2.0)	$10.8^{c\dagger}$ (2.6)	$10.4^{c\dagger}$ (2.4)
	3.5 cm	8.4^{a*} (1.7)	9.5^{b} (2.0)	9.9^{b} (2.3)	9.6^{b} (2.0)	$8.8^{a\dagger}$ (1.8)	9.9^{b} (2.0)	$10.4^{c\dagger}$ (2.3)	$10.1^{c\dagger}$ (2.0)

MAR, metal artefact reduction.

Different superscript lowercase letters indicate differences between tube currents (mA) (i.e. comparisons within rows)

* indicates statistically significant difference between implant groups and control

† indicates statistically significant difference between without MAR and with MAR

Discussion

The assessment of the impact of different CBCT parameters on the formation of image artefacts is essential to promote optimized CBCT acquisition protocols, combining the lowest radiation possible with the best image quality achievable for different diagnostic tasks [8,9,11,18-22]. Similar to the results observed in the present study for titanium and zirconia implants, a previous study found that higher mA reduced the magnitude of artefacts related to metallic intracanal posts at different distances from the artefact-generating material [17]. There is a direct relationship between tube current, radiation dose, and image quality [5,11]. Therefore, practical decisions for optimal tube current applied to CBCT acquisition should take into consideration the image requirements of specific diagnostic tasks [11,12,17].

Overall, when tube current increased from 4mA to 6.3mA or 8mA, significantly less artefacts (i.e. higher CNR and lower SD values) were found for both titanium and zirconia groups, at all three distances from implants. The analysis of the SD of gray values and the CNR has been widely used in previous studies to demonstrate the magnitude and extension of artefacts at different distances [5,14-16]. High SD and low CNR values are associated with degradation of the image, which is usually higher in the vicinity of the implants [3-5,15].

In this study, significant differences in SD and CNR were observed between zirconia and control groups in ROIs located at 1.5cm distance from implants, even when the tube current was increased. At 2.5cm from the zirconia implant, an increase in mA improved CNR, and the difference to the controls became non-significant at that distance. Similarly, at 1.5cm from titanium implants, CNR increased to values comparable to control when tube current was increased from 4mA to 6.3mA. When MAR was activated, CNR significantly increased for the ROIs in the zirconia group. However, SD at 1.5cm from zirconia implants remained significantly different from the control with MAR. These results show that image degradation within 1.5cm from zirconium remained high, even with the improved CNR observed at all distances caused by increased mA and MAR activation. Zirconia implants are known to generate more artefacts than titanium implants [3,18].

The activation of MAR increased CNR at all three distances only for the zirconia group, regardless of the tube current used. Also, a significant decrease in SD related to MAR activation was observed only for all ROIs located at 2.5cm from zirconia implants, and those at 3.5cm from zirconia implants with 8mA. However, no effect of MAR was observed for titanium implants. As MAR has been shown to be effective only when artifacts are pronounced [19,20], in the control group (i.e., without implants) and in the titanium group the effect of the tool is expected to be limited or even non-existent [19]. Importantly, MAR is a tool that acts in the image post-processing step and therefore does not affect the radiation dose, only the reconstruction time [21]. Literature reports that in the presence of implants, the MAR tool does not affect the vicinity of implants [22] and has not improved different diagnostic tasks close to implants [23]. However, there is no consensus on the influence of MAR. Further studies should be carried out to assess the true impact of MAR under different circumstances and in different CBCT units, considering that the algorithm function related to the activation of MAR is not disclosed by manufacturers and may vary among the machines that offer that tool.

In the present study, human mandibles and adjacent vertebrae were included in ballistic gelatin, which has been considered the best material to simulate the attenuation and dispersion caused by soft tissues [13]. The 8x6cm FOV used in this study encompassed only part of the phantom. C1 and C2 vertebrae were added for a more realistic composition of the exomass [24] involved in CBCT examinations of the mandible. An acrylic device was used to guide the position of the standardized phantoms, and scripts and macros from ImageJ software were used for each of the 10 mandibles, to ensure precise assignment of all ROIs in the images with different tube currents, as well as before and after implant placement. ROIs were placed in areas containing ballistic gelatin, which would correspond to the location of soft tissues in a clinical scenario. The aim of the study was not to assess the influence of artefacts on soft tissue; however, the selection of a homogeneous material was important to compare the influence of the different tube current settings on image quality parameters measured at different distances from the implants.

There are limitations in all studies that use SD and CNR to quantify the formation of artefacts. One limitation is related to the concomitant influence of noise inherent to CBCT images, which affects mainly SD (and therefore CNR) values. In other words, it is impossible to determine how much the effects on SD and CNR in this study are due to reduced quantum noise rather than artefact reduction. Another limitation is related to the fact that the streaks generated by high atomic number materials have a variable spacing pattern. Therefore, ROIs may be completely or partially included in these streaks in some of the mandibles. This justifies the importance of analyzing multiple ROIs in different mandibles with varying anatomical configurations, and it explains the relatively high variance of the CNR and SD values, particularly among the ROIs near zirconia implants.

The results of this study showed that noise and artefacts related to the presence of implants may be reduced by an increase in tube current. For the conditions studied, 6.3mA yielded the best results for most of the conditions with titanium implants, with or without MAR. For zirconia implants, the best results were found when 8mA was used with MAR. The influence of tube current on SD and CNR is clear; however, recommendation of specific mA values cannot be determined for all diagnostic tasks, number and distribution of implants, or for multiple CBCT machines [11] due to several combinations of acquisition parameters employed in each CBCT model. Previous studies have shown, for example, that artefacts produced by implants are influenced by their anatomical location in the dental arch [25] and are more pronounced when implants have peripheral locations in the FOV [26]. Less artefacts are expected to be produced in exams with small FOV [27] and higher kVp [19], whereas voxel size does not seem to affect their production [18]. Whether or not an increase in radiation dose due to a higher tube current is warranted remains an open question, and will need to be addressed for specific diagnostic tasks.

In conclusion, increased tube current can improve overall image quality in the presence of implants, at all the distances tested. The increase in tube current should be higher when a zirconia implant is present, compared to that for examinations with titanium implants. Activation of MAR improved image quality only among examinations with zirconia implants. More evidence regarding potential improvement in image quality and diagnostic performance in diagnostic image quality is needed, especially considering the linear relation between tube current and radiation dose.

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Artigo 2 (Formatado para submissão ao periódico Imaging Science in Dentistry)

Effect of tube current on the diagnosis of peri-implant bone defects

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Abstract

Purpose

To evaluate the effect of tube current (mA) on the accuracy of cone beam computed tomography (CBCT) in the diagnosis of peri-implant bone defects (dehiscences and fenestrations).

Material and Methods

Twelve bovine rib segments were used with 5 implants each, thus obtaining 30 implants with defects (dehiscences and fenestrations) and 30 implants without defects. The segments were included in ballistic gelatin and scanned with three different milliamperages: 4mA, 8mA and 10mA. Three oral radiologists analyzed the images and scored the detection of peri-implant bone defects in a 5-point scale. The area under the receiver operating characteristic curve (Az), sensitivity, specificity, and interobserver agreement were calculated. Diagnostic values were compared by analysis of variance ($\alpha=0.05$).

Results

No difference was observed for Az values for the detection of peri-implant bone defects for images acquired with 4, 8, or 10mA ($p>0.05$). Also, tube current did not affect peri-implant bone defect sensitivity and specificity ($p>0.05$). Values for the intraobserver and interobserver agreements ranged from fair (0.31 and 0.32) to substantial (0.66). Intraobserver agreements ranged from substantial (0.63 and 0.79) to almost perfect (0.87).

Conclusion

The use of increased CBCT tube current does not improve the detection of peri-implant bony defects, therefore, it is not recommended for this diagnostic task.

Introduction

Oral rehabilitation using osseointegrated dental implants is considered a predictable treatment option for tooth loss[1,2] with high success rates, especially in the mandible[3,4]. However, complications may occur and compromise aesthetic and functional results and, in some cases, culminate in the loss of the implant[5,6.] Perforation of the lingual cortical bone in the submandibular fossa region and injuries to the lower alveolar nerve, that is the most affected structure among perforations in mandible, may cause significant sensory disturbances [7,8], and peri-implantitis may result in bone loss and dehiscence. The correct angulation of the implant is one of the determinants of success, and must be determined in advance from prosthetic planning, in order to guarantee aesthetic results and biomechanical stability[6].

Image examinations are required for planning in order to guarantee proper implant insertion. Two-dimensional imaging exams, such as panoramic and periapical radiographs, have inherent limitations related to image overlapping, which hinder the preoperative assessment of bone quality and relevant anatomical characteristics of the mandible. Sectional exams are recommended for preoperative evaluation for the installation of dental implants, and cone beam computed tomography (CBCT) is the imaging method of choice for this purpose because it allows accurate determination of bone thickness, height, anatomical conformation, and relationship with adjacent structures[9].

Despite the advantages of using CBCT in the preoperative planning of implants, its use after implant insertion is restricted, mainly due to the occurrence of image artefacts. Beam hardening is the most common artefact related to the presence of dense and high atomic number objects, such as implants, which produces hypodense images that may impair diagnosis of adjacent structures[10,11] and can also extend for at least 3.5 cm[12]. Therefore, postoperative CBCT exams are indicated only in cases of altered sensitivity or mobility of the implant immediately after surgery or when implant loss is predicted, as failures require a thorough assessment to recognize the real problem and provide the best planning for eventual correction[9].

Optimized acquisition protocols for specific diagnostic tasks are important to obtain diagnostically acceptable images while keeping the radiation dose received by the patient as low as possible. Previous studies have shown that combinations of different parameters in CBCT acquisition protocols like kilo-voltage, size of voxels and field of views and mA may have an impact in diagnostic performance regarding the detection of peri-implant bone defects[13,14,15,16,17]. The use of higher mA improves image quality, mainly due to noise reduction, however, there is a direct relationship between mA and radiation dose[18]. Therefore, the aim of this study was to evaluate the effect of tube current on the accuracy of CBCT in the diagnosis of peri-implant bone defects (dehiscences and fenestrations).

Material and Methods

Sample preparation

Fresh eviscerated bovine ribs were sectioned, obtaining twelve 8-cm long segments, with thickness between 10 and 15mm, and height between 25 and 30cm. Five 3.75 x 13mm titanium implants (HE Conico - Intraoss, São Paulo - Brazil) were installed in each segment, with a 1-cm distance between implants.

Peri-implant bone defects were produced in half (n=30) of the implant sites. Fifteen implant sites had simulated dehiscences and fifteen had fenestrations. For the simulation of dehiscence, a spherical bur (#3017 HL; KG Sorensen, São Paulo, SP, Brazil) was used to create a 2.5mm-diameter semi-elliptical defect in the cortical bone. The defect was created after osteotomy and prior to implant insertion. For the simulation of fenestrations, the implant drills used in the osteotomy were inserted further to create a cortical perforation at the lower portion of the rib segment.

Image acquisition

The bovine rib segments were placed in the center of 10cm x 6cm x 3cm plastic containers, which were then filled with ballistic gelatin to simulate the attenuation and dispersion caused by soft tissues[19] (Figure 1). CBCT images were acquired in an OP300 Maxio unit (Intrumentarium, Tuusula, Finland), with 8x6cm FOV, 90 kVp, 0.085mm voxel, with MAR tool activated and different tube currents: 4mA, 8mA, 10mA. A total of 36 scans were obtained (12 segments; 3 tube currents – Figure 2). The ballistic gelatin blocks containing the rib segments were scanned without the plastic containers, and their positions in the CBCT unit were standardized according to the orientation lights.

Figure1 - Image showing the bovine rib with the implants installed included in ballistic gelatin in order to simulate the soft tissues

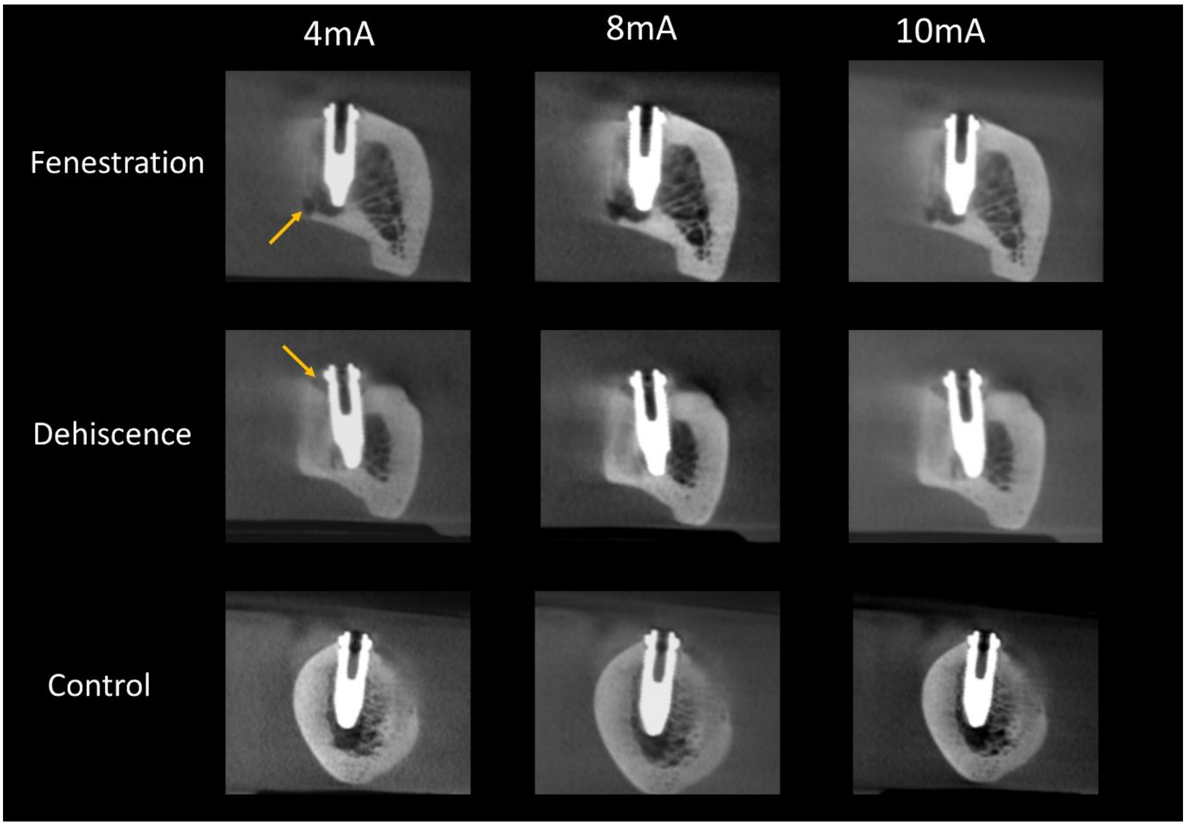

Figure 2 - Sagittal sections of CBCT images showing implants associated with fenestration, dehiscence and absence of bone defect (control group) with different tube current settings (4mA, 8mA, and 10 mA).

Image evaluation

The CBCT images were randomly evaluated using OnDemand3D software (Cybermed Inc, Seoul, Republic of Korea) in a dimly-lit ambient by 3 oral radiologists blinded to the exposure parameters used (4mA, 8mA and 10mA). The observers were recommended to reorient the axial, coronal and sagittal planes to align with the long axis of the implants. In addition, the observers were oriented to analyze all multiplanar reconstructions, as well as freely adjust brightness, contrast and zoom. The images were scored according to a 5-point scale: (1) defect definitely absent; (2) defect probably absent; (3) uncertain diagnosis; (4) defect probably present; (5) defect definitely present. Thirty days after the end of the evaluations, 20% of the sample was re-evaluated to verify the intraobserver and inter-observer agreement.

Statistical analysis

The IBM SPSSv.22 (SPSS Inc, Chicago, IL, USA) was used for statistical analysis. Weighted-Kappa test was used to calculate intra- and interobserver agreement. Areas under ROC curve (z) were calculated for each observer according to each tube current used. Sensitivity and specificity values were obtained after dichotomization of the scores (scores 1 to 3 were considered as absence of defects, while scores 4 and 5 were considered as presence of defects). Analysis of variance was used to compare the Az, sensitivity, and specificity values obtained for the different tube currents. The level of significance adopted was 5% ($p \leq 0.05$).

Results

Interobserver agreements ranged from fair (0.31 and 0.32) to substantial (0.66). Intraobserver agreements ranged from substantial (0.63 and 0.79) to almost perfect (0.87).

Table 1 shows the diagnostic values of the different tube current parameters tested, obtained for each observer and the means and standard deviations. There were no statistically significant differences in Az values between the tube currents tested (p>0.05). Specificity and sensitivity were also not significantly impacted by the changes in the tube current (p>0.05).

Table1. Area under the receiver operating characteristic curve (Az), sensitivity, and specificity for each observer and their mean (SD) of the detection of peri-implant bone defects according to the different tube current protocols tested.

		4mA	**8mA**	**10mA**
Az	Observer 1	0.69	0.55	0.68
	Observer 2	0.59	0.61	0.62
	Observer 3	0.69	0.55	0.61
	Mean (SD)	0.66 (0.06)	0.57 (0.04)	0.64 (0.04)
Sensitivity	Observer 1	0.70	0.47	0.61
	Observer 2	0.47	0.37	0.39
	Observer 3	0.60	0.37	0.50
	Mean (SD)	0.59 (0.12)	0.40 (0.06)	0.50 (0.11)
Specificity	Observer 1	0.63	0.53	0.63
	Observer 2	0.83	0.73	0.70
	Observer 3	0.80	0.70	0.78
	Mean (SD)	0.76 (0.11)	0.66 (0.11)	0.70 (0.07)

Discussion

Postoperative imaging of implants aims to assess the final position of the implant after surgery, the interface between the implant and the bone, and the peri-implant bone height, despite the inherent limitations related to two-dimensional image overlap, periapical radiographs, or panoramic radiographs in case of more extensive rehabilitation with multiple implants, are the exams of choice for postoperative evaluations in cases of absence of symptoms and potential complications[9]. CBCT is not recommended as a standard choice for post-implantation evaluation due to the presence of metal artifacts, which may hinder adequate assessment of osseointegration and peri-implant defects. However, CBCT exams may be indicated in cases of potential post-operative complications where 3D imaging is required for proper diagnosis. Therefore, optimization of image acquisition protocols is important to obtain diagnostically acceptable images with the lowest radiation dose possible. The present study aimed to assess whether an increase in tube current would significantly impact the formation of artifacts and, consequently, the diagnosis of peri-implant bony defects.

Results demonstrated that higher mA was not associated with better performance for this diagnostic task. Increased tube current leads to noise reduction and, consequently, better image quality[18]. However, the findings of the present study reveal that such increase in image quality was not sufficient to influence the detection of peri-implant bone defects. Moreover, since tube current has a direct relationship with radiation dose[18], this finding is clinically relevant because it indicates that lower mA, and consequently lower dose, may be used when a CBCT is obtained for the assessment of suspected peri-implant defects.

Several studies have dealt with optimization of different acquisition protocols for the detection of peri-implant defects. It has been shown that the effect of the selected FOV does not seem to influence the performance of this diagnostic task[17]. Combinations of different parameters in CBCT acquisition protocols have also been tested. The effect of different scanning modes (i.e. number of frames) combined with different voxel sizes[14], and with different FOV[20], have been investigated, showing that protocols with higher number of acquisition frames are more accurate to detect peri-implant defects. Because of the combination of different settings in those studies, it is difficult to identify which setting would isolatedly produce significant positive impact on the diagnostic task. A previous study using bovine ribs showed that the use of metal artifact reduction (MAR) algorithm did not improve the detection of peri-implant fenestrations and dehiscences on CBCT scans[13]. Another similar study, assessed the accuracy of CBCT images obtained with and without MAR in detecting simulated buccal peri-implant and buccal periodontal defects concluded that there is no difference among CBCT images obtained with and without MAR modes[21].

Image artifacts, especially those related to beam hardening phenomenon when dense and/or high atomic number objects are present[11], impair the diagnostic performance of CBCT images. Dental implants, restorations, intracanal posts, and orthodontic appliances are the main sources of beam hardening in CBCT images, acting as filters for the lower energy X-ray photons and increasing mean beam energy, thus erroneously generating areas with higher gray values. This reading inconsistency results in the presence of hypodense bands adjacent to the implants that can be misinterpreted as peri-implant bone defects and generate false-positive diagnoses[22,23].

In the present study, several aspects found in an *in vivo* situation were carefully simulated. Although both external and internal aspects of bovine ribs resemble human mandibular bones, the variety of certain anatomical features found among humans (i.e. shapes, cortical thickness, and trabecular microarchitecture) could not be reproduced. Moreover, although the use of five implants per segment, can lead to a sum of artifacts due to the presence of additional artifact-generating sources, the presence of multiple implants represent is not an uncommon clinical situation[8].

Conclusion

The use of increased CBCT tube current does not improve the detection of peri-implant bony defects, therefore, it is not recommend for this diagnostic task.

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Considerações Finais

A TCFC permitiu o avanço considerável do uso de exames tridimensionais na Odontologia nas últimas décadas. Esta tecnologia surgiu como uma alternativa à tomografia computadorizada helicoidal, com as vantagens de ser um aparelho relativamente menor, de custo reduzido e que emprega doses de radiação relativamente mais baixas. As aplicações da TCFC na Odontologia já são inúmeras e sua utilização já é uma realidade para profissionais e pacientes.

Contudo, os exames de TCFC ainda apresentam limitações relacionadas à qualidade da imagem, principalmente devido aos artefatos relacionados aos materiais de alta densidade e/ou alto número atômico. A presença destas fontes geradoras de artefatos é comum, pois diversos materiais utilizados em tratamentos odontológicos apresentam estas características: materiais obturadores, retentores intrarradiculares, restaurações em amálgama, implantes de titânio ou zircônia, bráquetes ortodônticos, entre outros. Estes artefatos aparecem como faixas e bandas escuras ou claras, e quando se somam ao ruído inerente a imagem, dificultam significativamente o diagnóstico de condições como, por exemplo, fraturas radiculares e perfurações de estruturas anatômicas por implantes, sejam estas próximas a estes materiais, ou até mesmo a distância. Até o momento, nenhum avanço tecnológico foi capaz de eliminar este problema. Contudo, formas de melhorar a qualidade da imagem tem sido o objetivo de inúmeros estudos, seja por meio de utilização de filtros digitais para manipulação da imagem em softwares de visualização, algoritmos de reconstrução (como na ferramenta MAR), ou, principalmente, por meio de seleção adequada de diferentes parâmetros de aquisição mantendo-se a dose de radiação em nível aceitável.

Diferente de outros fatores, como quilovoltagem e tamanho de voxel e FOV, ainda são escassos estudos sobre o efeito da miliamperagem na produção de artefatos oriundos de implantes de titânio e zircônia. Estudos voltados à otimização da miliamperagem são importantes, pois este parâmetro tem uma relação direta com a dose de radiação. No presente trabalho encontramos que um aumento da miliamperagem na presença de implantes de titânio melhora a imagem e que esse aumento precisa ser maior na presença de implantes zircônia. A ferramenta de redução de artefatos metálicos (MAR) melhorou as imagens somente nos casos da presença de implante de zircônia, o que pode estar relacionado também com a maior geração de artefatos deste material. A ferramenta ainda é objeto de muita discussão na literatura e necessita de mais estudos para comprovar sua real eficácia. Em relação à tarefa de diagnostico abordada na segunda etapa do trabalho, o uso de miliamperagens mais altas não desempenhou papel significativo na melhora da acurácia. Considerando que quando aumentamos a miliamperagem, aumentamos a radiação à qual o paciente é exposto e uma acurácia semelhante é obtida para avaliação de defeitos periimplantares, seu aumento não se justifica para esta tarefa de diagnóstico.

Portanto, este estudo contribui com o emprego otimizado da tomografia computadorizada de feixe cônico, relacionado à seleção da miliamperagem adequada, em duas situações clínicas: 1) quando um exame é realizado por diversas indicações clínicas e o paciente possui materiais geradores de artefatos próximos ou em até 3,5cm da região de interesse, recomenda-se um aumento da miliamperagem já que há uma melhora da qualidade geral da imagem em relação a presença de artefatos; quando implantes de zircônia estão presentes este aumento precisa ser maior do que quando estão presentes implantes de titânio; e a utilização de MAR somente se justificou nas situações com a presença de zircônia, onde foi notada melhora na qualidade da imagem; 2) quando um exame é realizado para avaliação pós-operatória de implantes para a detecção de defeitos ósseos, miliamperagens mais altas não são necessárias para essa tarefa de diagnostico.

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Anexos

Metodologia Detalhada

Etapa 1: Efeito da miliamperagem na tomografia computadorizada de feixe cônico em artefatos a diferentes distâncias dos implantes de titânio e zircônia

Preparação da Amostra

Fantomas cilíndricos, contendo mandíbulas humanas imersas em gelatina balística considerado o melhor material para simular a atenuação do feixe de raio-x causado pelos tecidos moles (Lopes, 2018), foram criados para este estudo. Dez mandíbulas humanas evisceradas foram obtidas no Laboratório de Anatomia da Faculdade de Odontologia de Ribeirão Preto, após hidrata-las por 24 horas, cada uma foi inserida no centro de uma caixa plástica cilíndrica (16 cm de diâmetro) contendo 1 cm de altura de gelatina balística, previamente derramada no recipiente. Um bloco de material de impressão dentária de 1,8x1,0x0,7cm (Silicone de Condensação - Yller Reflex, Pelotas, Brasil) foi colocado no cortical bucal da região anterior de cada mandíbula, no centro da crista alveolar, este bloco de silicone tem a função de orientar a altura do corte axial a ser avaliado em cada mandíbula e também será a área de controle para o cálculo da razão contraste-ruído em virtude de sua densidade homogenea. Duas vértebras cervicais (C1 e C2) foram colocadas posteriormente às mandíbulas permitindo uma simulação mais próxima da realidade clínica, do efeito das estruturas que estão presentes fora da área do exame (FOV – field of view).e a gelatina balística foi então despejada nas caixas para formar fantasmas cilíndricos de 16x8cm (Figura 1).

Aquisição das Imagens.

Para a aquisição de imagens de TCFC, um dispositivo de acrílico com 16 cm de diâmetro (Figura 1a) foi fabricado para prender ao suporte da máquina e permitir o posicionamento padronizado dos fantomas e a localização do FOV. Os fantomas foram então escaneados usando uma unidade OP300 Maxio CBCT (Instrumentarium, Tuusula, Finlândia), operando a 90 kV, tamanho de voxel de 0,085 mm, FOV de 8x6 cm. A miliamperagem foi ajustada em quatro níveis diferentes (4 mA, 6,3 mA, 8 mA e 10 mA), com e sem a ativação da ferramenta de redução de artefato de metal (MAR).

Após a aquisição das imagens iniciais (ou seja, mandíbulas sem implantes), foram instalados implantes de titânio de 3,75 x 13 mm (HE Conico - Intraoss, São Paulo - Brasil) em 5 mandíbulas e implantes de zircônia de 3,3 x 12 mm (Pure Ceramic - Straumman, Basel - Suíça) nas outras 5 mandíbulas. Todos os implantes foram inseridos na região desdentada correspondente ao dente 46. A porção da gelatina balística que cobre a região foi removida, foi realizada a osteotomia utilizando a sequência de brocas recomendadas pelos fabricantes e o implante foi inserido manualmente usando uma catraca. Após a colocação dos implantes, foi derramdo uma nova gelatina para preencher as porções removidas.

Os fantomas com os implantes foram então escaneados usando os mesmos parâmetros descritos acima. Portanto, foram adquiridos 160 exames (10 fantomas x antes / após a colocação do implante x 4 correntes de tubo diferentes x com / sem MAR - Figura 2). Os cortes axiais foram exportados no formato DICOM para análise utilizando ImageJ (Institutos Nacionais de Saúde, Bethesda, MA, EUA), com base no estudo de Fontenele et al. (2018).

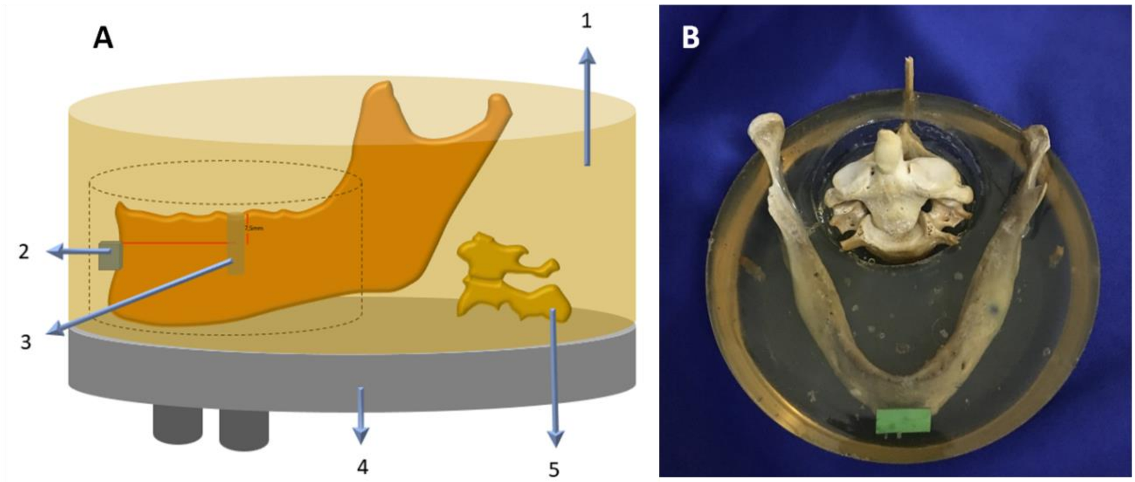

Figura 1. Desenho esquemático (A) e fotografia (B) mostrando vistas lateral e superior, respectivamente, do fantoma de gelatina balística contendo a mandíbula e a vertebra cervical, suportado pelo dispositivo padronizado para aquisição de imagens tomográficas. 1 - Gelatina balística; 2 - bloco de silicone de condensação; 3 - Implante a ser instalado na região do dente 46; 4 - Dispositivo acrílico produzido para padronizar aquisições; 5 - Vértebras cervicais. O cilindro com linhas pontilhadas representa o campo de visão (FOV) nos exames CBCT (8x6cm).

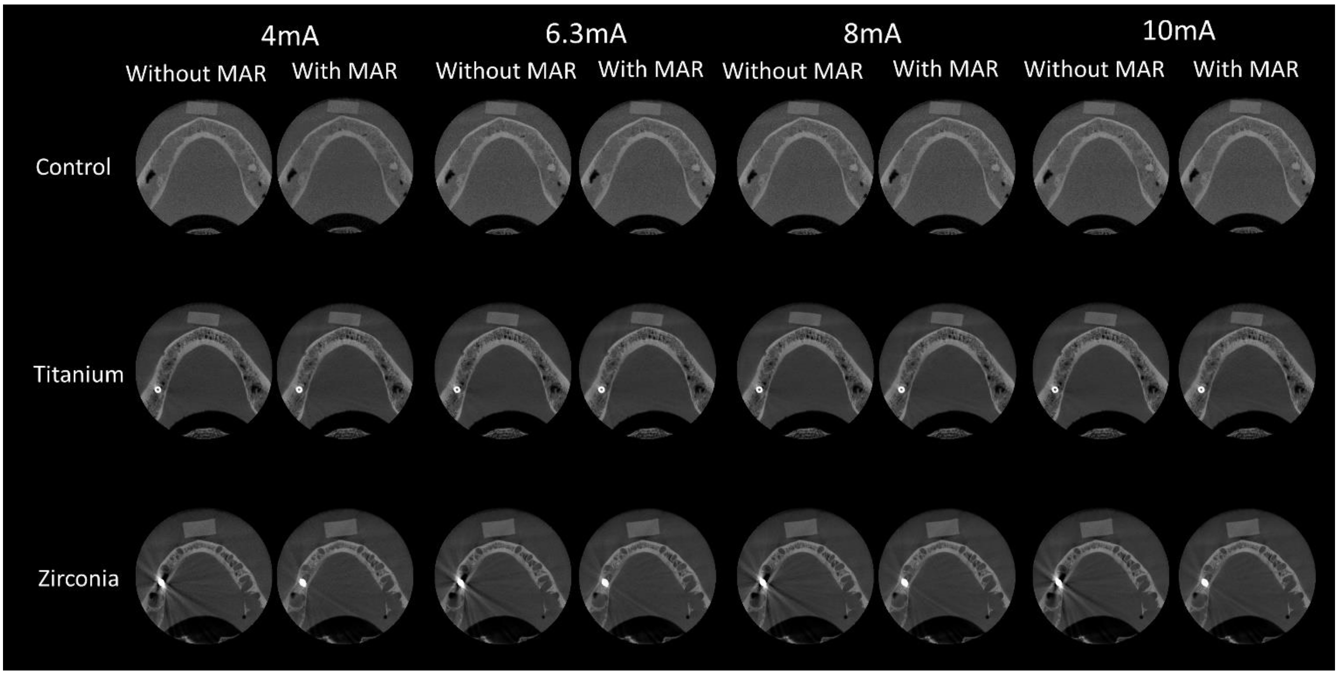

Figura 2. Imagens axiais representam condições (controle na primeira linha, titânio na segunda linha e zircônia na terceira linha) com diferentes miliamperagens (4mA, 6,3mA, 8mA e 10mA) e com / sem a aplicação de MAR.

Avaliação das Imagens

No corte axial em que o bloco de silicone de condensação foi visualizado pela primeira vez, foi determinada uma linha no centro do implante e seguindo o longo eixo do corpo da mandibular no lado direito. Linhas adicionais foram então determinadas em ângulos diferentes da primeira linha (65 °, 90 °, 115 ° e 140 °). Do centro do implante, foram desenhados três semicírculos com raios de 1,5, 2,5 e 3,5 cm. Finalmente, doze regiões de interesse de 2,8 x 2,8 mm (ROI) foram estabelecidas na interseção dos círculos e linhas (Figura 3). A média (M) e o desvio padrão (DP) dos valores de cinza foram registrados para cada ROI. A função macro do ImageJ foi usada para determinar e avaliar os mesmos ROIs de cada fantoma nas em diferentes condições. Um ROI adicional foi determinado no bloco de silicone de condensação para servir como área de controle para o cálculo da razão contraste-ruído (RCR) de acordo com a fórmula:

$$RCR = \frac{M\ IMPLANTE - M\ CONTROLE}{\sqrt{DP^{2} IMPLANTE + DP^{2} CONTROLE}}$$

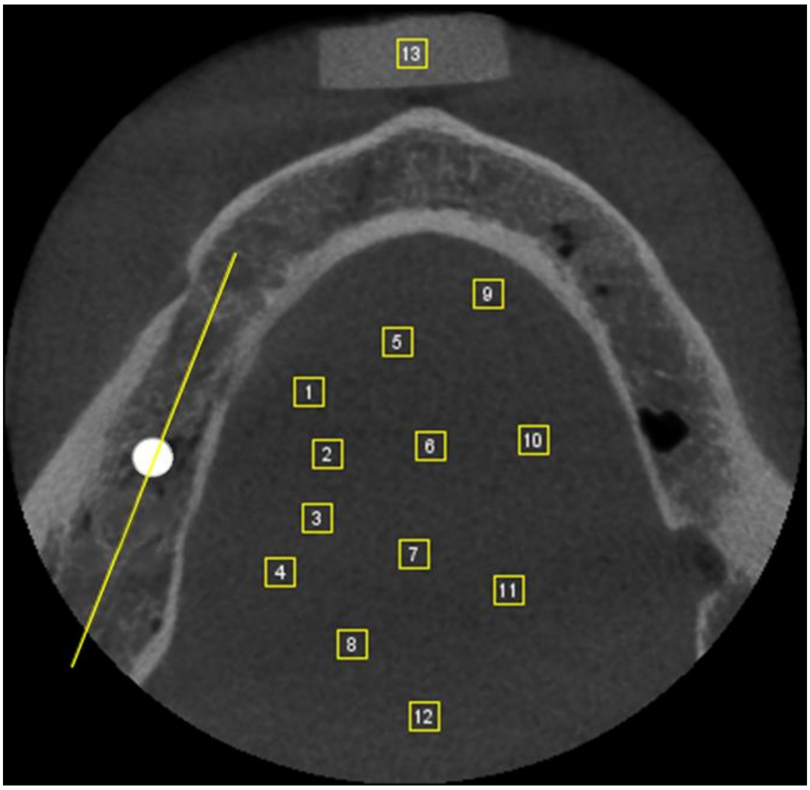

Figura 3. Regiões de interesse na gelatina balística (1-12) e no bloco de silicone (13). As regiões foram determinadas automaticamente com base em uma linha de referência (14) através do centro do implante ao longo do longo eixo da hemimandíbula (adaptado de Fontenele et al., 2018).

Analise Estatística

O desvio padrão (DP) e a relação contraste / ruído (RCR) foram comparados com a análise de variância de medidas repetidas (ANOVA) e o teste post-hoc de Tukey, a fim de testar os efeitos de diferentes miliamperagens a diferentes distâncias dos implantes de titânio e zircônia e o efeito do algoritmo MAR. As análises estatísticas foram realizadas no software SPSS (IBM Corp., Armonk, NY - EUA), com nível de significância estabelecido em $\alpha = 0{,}05$.

Etapa 2: Efeito da miliamperagem no diagnóstico de defeitos ósseos perimplantares

Preparação da Amostra

Costelas bovinas frescas evisceradas foram seccionadas, obtendo doze segmentos de 8 cm de comprimento, com espessura entre 10 e 15mm e altura entre 25 e 30cm. Foram instalados cinco implantes de titânio de 3,75 x 13 mm (HE Conico - Intraoss, São Paulo - Brasil) em cada segmento, com uma distância de 1 cm entre os implantes.

Defeitos ósseos peri-implantares foram produzidos em metade (n = 30) dos locais dos implantes, em quinze locais foram simuladas deiscências e em outros quinze foram simuladas fenestrações. Para a simulação da deiscência, uma broca esférica (# 3017 HL; KG Sorensen, São Paulo, SP, Brasil) foi utilizada para criar um defeito semi-elíptico de 2,5 mm de diâmetro no osso cortical no que seria a cervical do segmente. O defeito foi criado após a osteotomia e antes da inserção do implante. Para a simulação de fenestrações, as brocas de implantes utilizadas na osteotomia foram inseridas além do tamaho do implante utilizado para criar uma perfuração cortical na porção inferior do segmento da costela. A ordem dos locais com defeitos e sem e seu número em cada segmento de costela foi feito de forma randômica para assim não obtermos um padrão de localização.

Aquisição das Imagens

Os segmentos de costela bovina foram colocados no centro de recipientes de plástico de 10cm x 6cm x 3cm, que foram preenchidos com gelatina balística para simular a atenuação e dispersão causada pelos tecidos moles (Fig. 4). As imagens CBCT foram adquiridas em uma unidade OP300 Maxio (Intrumentarium, Tuusula, Finlândia), com FOV de 8x6 cm, 90 kV, voxel de 0,085 mm e diferentes miliamperagens: 4mA, 8mA, 10mA. Foram obtidos 36 exames (12 segmentos; 3 miliamperagens – Figura 5). Os blocos de gelatina balística contendo os segmentos das costelas foram digitalizados sem os recipientes de plástico, e suas posições na unidade CBCT foram padronizadas de acordo com as luzes de orientação e com dispositivo de acrílico produzido para padronizar as aquisições.

Figura 4 - Imagem mostrando a costela bovina com os implantes instalados incluídos na gelatina balística para simular os tecidos moles

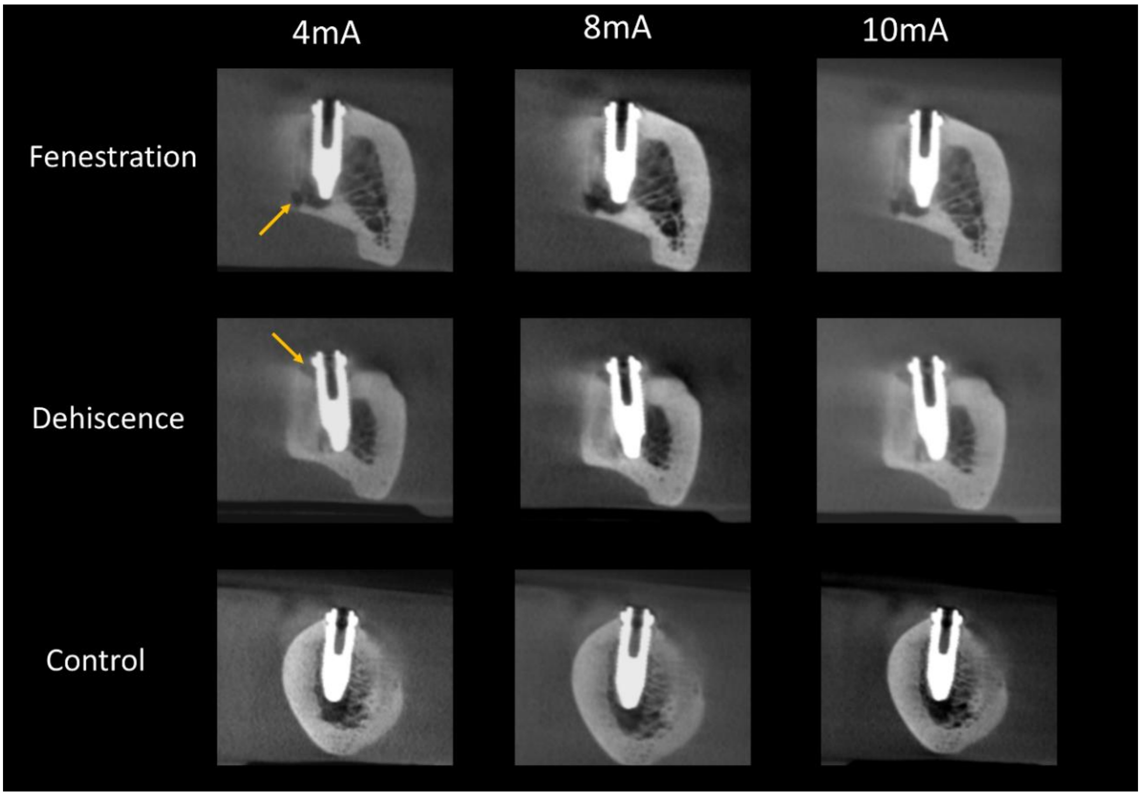

Figura 5 - Cortes sagitais das imagens de TCFC mostrando implantes associados à fenestração, deiscência e ausência de defeito ósseo (grupo controle) com diferentes configurações de corrente do tubo (4mA, 8mA e 10 mA).

Avaliação das Imagens

As imagens da TCFC foram avaliadas usando o software OnDemand3D (Cybermed Inc, Seul, República da Coréia) em um ambiente pouco iluminado por três radiologistas orais cegos aos parâmetros de exposição utilizados (4mA, 8mA e 10mA). Recomendamos aos observadores que reorientassem os planos axial, coronal e sagital para alinhar com o eixo longo dos implantes. Além disso, os observadores foram orientados a analisar todas as reconstruções multiplanares, bem como ajustar livremente o brilho, o contraste e o zoom. As imagens foram pontuadas de acordo com uma escala de 5 pontos: (1) defeito definitivamente ausente; (2) defeito provavelmente ausente; (3) diagnóstico incerto; (4) defeito provavelmente presente; (5) defeito definitivamente presente. Trinta dias após o final das avaliações, 20% da amostra foi reavaliada para verificar a concordância intraobservador e interobservador.

Análise Estatística

O IBM SPSSv.22 (SPSS Inc, Chicago, IL, EUA) foi utilizado para análise estatística. O teste Kappa ponderado foi utilizado para calcular a concordância intra e interobservadores. As áreas sob a curva ROC (Az) foram calculadas para cada observador de acordo com cada corrente de tubo utilizada. Os valores de sensibilidade e especificidade foram obtidos após a dicotomização dos escores (os escores 1 a 3 foram considerados como ausência de defeitos, enquanto os escores 4 e 5 foram considerados como presença de defeitos). A análise de variância foi usada para comparar os valores de Az, sensibilidade e especificidade obtidos para as diferentes correntes de tubo. O nível de significância adotado foi de 5% ($p \leq 0{,}05$).