SHORT COMMUNICATION

Effect of anatomical region on the formation of metal artefacts produced by dental implants in cone beam computed tomographic images

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Objectives: To quantitatively compare metal artefacts produced by implants in different maxillomandibular regions on cone beam CT (CBCT) images.

Methods: A total of 200 implants selected from CBCT examinations were divided into four groups: Group 1 ($n = 50$)—implants located in the anterior maxilla; Group 2 ($n = 50$)—implants located in the posterior maxilla; Group 3 ($n = 50$)—implants located in the anterior mandible and Group 4 ($n = 50$)—implants located in the posterior mandible. The implants were further classified as isolated or adjacent to other implants. Three axial reconstructions were selected for each sampled implant (apical, middle and cervical). On each slice, the artefacts produced by the implants were counted. The Mann–Whitney test was used to compare the variables between groups. The Kruskal–Wallis and Student–Newman–Keuls tests were used to compare the axial reconstructions.

Results: The mandible showed a greater number of artefacts than the maxilla (apical image: $p = 0.0024$; middle image: $p < 0.0001$). The anterior region produced more artefacts than the posterior region (apical image: $p = 0.0105$; middle image: $p < 0.0316$). There was no significant difference in the number of artefacts between isolated and adjacent implants, and the cervical image was most affected by artefacts.

Conclusions: Dental implants always produce metal artefacts in CBCT images, and these artefacts are affected by the anatomical location in the dental arch.

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Introduction

Oral rehabilitation with dental implants has become a frequent dental practice owing to its high degree of predictability and clinical success.¹ Radiographic bone tissue examination is an important tool in diagnosis and monitoring in implantology.^{2,3} Periapical radiography, routinely used in dentistry, is used to detect peri-implant

bone loss and to evaluate osseointegration.⁴ However, since periapical radiography is a two-dimensional examination, its diagnostic value has limitations due to overlaps and geometric distortions.^{3,4}

Cone beam CT (CBCT) has become the most widely used examination in implantology, as it minimizes the limitations of two-dimensional images.^{4,7} Owing to its capacity to provide three-dimensional information,

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CBCT provides high image quality, diagnostic accuracy and linear measurement precision, thus increasing dental implant installation safety and treatment success rates.^{2,3,5-9} However, in the post-surgical follow-up phase, metal artefacts form inside the field of view (FOV), affecting tomographic image quality,^{1-6,9-11} affecting, *e.g.* the visibility of fenestrations and peri-implant dehiscence.^{1,12}

Metal objects such as titanium implants lead to the formation of artefacts by hardening the X-ray beam (*i.e.* beam hardening),^{1,2,12} which is observed in the tomographic image as hyperdense linear streaks irradiating from a high-density object with hypodense areas interspersed between them.^{1,2,6,13} The artefacts caused by beam hardening occur as a result of differences in the attenuation and absorption of X-ray beams when in contact with high-density material.^{2,12,14} When crossing the dental implant, the low-energy X-ray photons are absorbed by the metal, and only the high-energy photons are used to form the image, increasing the average energy of the X-ray beam and changing the tomographic reconstruction process.^{2,6,10} These artefacts tend to cause excessive variation in grey values near the metal structure,³ affecting image quality and making it difficult to evaluate osseointegration and inflammatory processes near the implants.^{4,7,9,15}

Some studies suggest that the formation of metal artefacts can be affected by anatomical region, the position of the object within the FOV and the adjacent anatomical structures outside of the FOV,^{7,8} but there is no consensus regarding which regions (maxilla or mandible, anterior or posterior) are more involved in the formation of artefacts or what the effects of the object's location within the FOV are. Thus, the aim of this study was to use CBCT images to quantify the formation of metal artefacts produced by titanium dental implants installed in different maxillomandibular regions.

Methods and materials

This retrospective, cross-sectional, observational study was approved by the Research Ethics Committee of the Federal University of Juiz de Fora (UFJF, Juiz de Fora, Minas Gerais, Brazil), under protocol no. 1,403,545.

CBCT images showing dental implants in the jaw were selected from the archive of the Dental Radiology Clinic at the UFJF Dental School (Minas Gerais, Brazil). All images were acquired in the same scanner (I-Cat Next Generation, Imaging Sciences International, Hatfield, PA), with an acquisition protocol of 120 kV, 8 mA, 26.9 s rotation, 0.25 mm voxel and an FOV between 6 × 16 and 8 × 16 cm.

We included CBCT examinations of patients of both genders and of any age who had titanium dental implants with presence of prosthetic crowns, located in any region of the maxilla and/or mandible. Implants installed in the zygomatic bone, without the presence

of prosthesis and adjacent to teeth with fillings/crowns/metal posts, were excluded.

Study groups

A total of 200 implants were divided into four groups: Group 1—implants located in the anterior maxilla; Group 2—implants located in the posterior maxilla; Group 3—implants located in the anterior mandible and Group 4—implants located in the posterior mandible.

The sample selection was defined randomly and by convenience, until each group had 50 implants. The formula applied to calculate the sample size was $n = Z^2 p q / e^2$ (equation 1, by Cochran¹⁶), where Z^2 is the abscissa of the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals the desired confidence level, *e.g.* 95%), e is the desired level of precision, p is the estimated proportion of an attribute that is present in the population, and q is $1 - p$. The value for Z is found in statistical tables that contain the area under the normal curve. Considering $\alpha = 5\%$, $Z = 1.96$, $p = 0.80$ (sensitivity), and $q = 0.20$, the minimum sample size was 42 implants.

The implants were further classified as isolated or adjacent to other implants. Adjacent implants were deemed to be those with a maximum distance between them of 5 mm.

Image selection

After examination selection, the images, in uncompressed Digital Imaging and Communications in Medicine format, were imported into RadiantDICOM software (Medixant, Poznan, Poland) for selection of three axial reconstructions for each implant in the sample; one in the apical third, one in the middle third and one in the cervical third. The apical image was defined as the most apical that allowed the entire diameter to be viewed. The cervical image was defined as the most cervical that allowed the entire diameter to be viewed before prosthetic connection. The middle image was that midway between the apical and cervical images previously selected for each individual implant (Figure 1).

Quantification of metal artifacts

The axial reconstructions selected for each implant were individually evaluated using ImageJ software (US National Institutes of Health, Bethesda, MD) to count the artefacts. A circular region of interest (ROI) was selected with standardized dimensions (10 mm diameter). This ROI covered the entire area of the implant and the adjacent bone tissue. The ROI's centre coincided with the implant's centre.

The artefacts present in each selected ROI were counted based on the method described by Pauwels *et al.*⁶ The minimum and maximum grey values were determined using the ImageJ histogram tool. These values were used to calculate the actual standard deviation

Figure 1 (a) CBCT panoramic reconstruction showing the apical (b), middle (c) and cervical (d) images of an implant installed in the mandible.

(SD). The actual SD calculation was performed in Excel, v. 2010 (Windows 10, Microsoft, USA).

The images generated by the CT scanner used in this study have a 16-bit scale (65,536 grey values). From this value, the maximum theoretical SD that corresponds to half the grey values of a 16-bit image was calculated (*i.e.* 32,768 values). According to Pauwels *et al*⁶ artefact quantification is defined as follows: actual SD/theoretical maximum SD $\times$ 100. Therefore, the actual SD was converted into a percentage of the maximum theoretical SD, where higher percentages indicate more pronounced artefacts.

CT scans, axial reconstructions and ROI definitions were selected by a single examiner who was a radiologist with expertise in interpreting CBCT images. To determine method reproducibility, 20% of the examinations were re-evaluated 2 weeks after the first evaluation, and intrarater agreement was considered strong (*r* Pearson: 0.93).

Statistical analysis

The obtained data were statistically analysed using the Statistical Package for Social Sciences program (SPSS, v. 15.0; IBM Corp, Armonk, NY). The significance level adopted was 5% ($p \leq 0.05$). The Mann–Whitney test was applied to compare variables between groups (maxilla $\times$ mandible; anterior $\times$ posterior; isolated $\times$ adjacent). To evaluate the relationship between the three variables

described above (jaws—maxilla/mandible, region— anterior/posterior and implant—isolated/adjacent), a factorial ANOVA was applied. The Kruskal–Wallis and Student–Newman–Keuls tests were used to compare the apical, middle and cervical images.

Results

A total of 200 titanium dental implants were evaluated and divided into groups according to their anatomical location and proximity to other implants (Table 1). The implants evaluated were external hexagon with lengths of 4 to 13 mm and diameters of 3.5 to 4 mm.

When comparing the number of metal artefacts in the mandible and maxilla, the mandible showed significantly higher numbers of artefacts in the apical and middle images (Table 2).

When comparing the number of artefacts in implants installed in the anterior and posterior regions, the anterior region implants showed significantly higher numbers of artefacts in the apical and middle images (Table 3).

The formation of metal artefacts was also compared according to whether the implants were installed in isolation or adjacent to other implants. There was no significant difference in the number of artefacts between isolated and adjacent implants (Table 4).

Table 1 Distribution of dental implants in different study groups

Region	Isolated implants n (%)	Adjacent implants n (%)	Total n (%)
Anterior Maxilla (G1)	7 (3.5)	43 (21.5)	50 (25.0)
Posterior Maxilla (G2)	13 (6.5)	37 (18.5)	50 (25.0)
Anterior Mandible (G3)	5 (2.5)	45 (22.5)	50 (25.0)
Posterior mandible (G4)	3 (1.5)	47 (23.5)	50 (25.0)
Total	28 (14.0)	172 (86.0)	200 (100.0)

Table 2 Comparison of the number of metal artefacts produced by implants installed in the maxilla and mandible

<i>Axial slice</i>	<i>Region</i>	<i>Median</i>	<i>p-value</i>
Apical	Maxilla	16.74	0.0024 ^a
	Mandible	17.69	
Middle	Maxilla	16.98	<0.0001 ^a
	Mandible	18.48	
Cervical	Maxilla	19.75	0.9601
	Mandible	19.54	

^aStatistically significant differences according to the Mann–Whitney test.

Comparing the images (apical, middle and cervical), a significantly higher number of artefacts was always observed in the cervical images (Table 5).

Considering the interaction between the variables tested, it can be observed that, regardless of the assessed images (apical, middle and cervical), there was no statistically significant interaction between variables (factorial ANOVA/ $p \geq 0.05$).

Figure 2 shows various axial reconstructions of the implants and their respective artefacts.

Discussion

CBCT is widely used in the pre-operative stage of dental implant treatment to evaluate bone quantity and quality.^{1,6} However, it is known that in the post-operative phase, in the presence of previously installed implants, tomographic images show metal artefacts, which reduces the indication for CBCT at this stage.

CBCT image information is composed of voxels. These voxels are each identified by a grey value, reflecting the degree of X-ray attenuation when passing through the object under study. The grey values in CBCT are strongly affected by the object's characteristics, such as density and atomic number (Z).^{2,8} As metals have higher physical densities and atomic numbers than the constituent elements of soft tissue and bone,⁵ they promote greater hardening of the X-ray beam. In this interaction, lower energy photons are absorbed by the object in preference to higher energy photons, resulting

Table 3 Comparison of the number of metal artefacts produced by implants installed in the anterior and posterior regions

<i>Axial slice</i>	<i>Region</i>	<i>Median</i>	<i>p-value</i>
Apical	Anterior	17.48	0.0105 ^a
	Posterior	16.93	
Middle	Anterior	17.93	0.0316 ^a
	Posterior	17.24	
Cervical	Anterior	19.57	0.6285
	Posterior	19.53	

^aStatistically significant differences according to the Mann–Whitney test.

Table 4 Comparison of the number of metal artefacts produced by isolated and adjacent implants

<i>Axial Slice</i>	<i>Implant</i>	<i>Median</i>	<i>p-value</i>
Apical	Isolated	17.19	0.8880
	Adjacent	17.22	
Middle	Isolated	16.75	0.3981
	Adjacent	17.50	
Cervical	Isolated	20.69	0.7553
	Adjacent	19.52	

in increased average power of the beam and the production of artefacts, which appear as hyperdense streaks radiating from a high-density object and interspersed by hypodense areas.^{1,2,6,13,17}

Titanium (Z = 22), the constituent material of the implants evaluated in this study, is considered a metal and, as expected, produced artefacts in the tomographic images of all of the maxillomandibular anatomical regions. However, a difference in the number of formed artefacts was observed according to implant location. The number of artefacts was higher in the mandible and in anterior regions (incisors and canines), showing that the grey values of a given object differ depending on its location and adjacent anatomical structures. Variations in density and thickness of maxillary and mandibular bone tissue may explain the difference in the number of artefacts, which is consistent with Oliveira *et al*⁸ findings, who evaluated the effect of anatomical location on the grey values in CBCT images and demonstrated that

Table 5 Comparison of the number of metal artefacts produced between the apical, middle and cervical slices of dental implants

<i>Comparison</i>	<i>Region</i>	<i>Difference between posts</i>	<i>p-value</i>
Apical × middle	Maxilla	1.80	0.8800
	Mandible	11.55	0.3465
	Anterior	6.64	0.5881
	Posterior	6.16	0.6156
	Isolated	1.46	0.8223
	Adjacent	15.75	0.3273
Apical × cervical	Maxilla	57.72	<0.0001 ^a
	Mandible	66.15	<0.0001 ^a
	Anterior	62.17	<0.0001 ^a
	Posterior	69.36	<0.0001 ^a
	Isolated	15.07	0.0208 ^a
	Adjacent	117.70	<0.0001 ^a
Middle × cervical	Maxilla	59.53	<0.0001 ^a
	Mandible	54.60	<0.0001 ^a
	Anterior	55.53	<0.0001 ^a
	Posterior	63.20	<0.0001 ^a
	Isolated	16.53	0.0112
	Adjacent	101.95	<0.0001 ^a

^aStatistically significant differences according to the Kruskal–Wallis and Student–Newman–Keuls tests.

Figure 2 Examples of metal artefacts in CBCT images of dental implants in axial reconstructions.

the same object may have different values depending on anatomical location. Queiroz *et al*¹⁸ evaluating the effect of a metal artefact reduction tool when an artefact generator object was placed in different positions within the FOV, also observed that noise levels were different according to changes in position.

According to Valizadeh *et al*⁷ the object's location within the FOV affects the grey values of a tomographic image. In certain positions, X-rays traverse the long axis of the maxilla or mandible, interacting with dental implants, teeth and adjacent bone on a single plane,¹¹ leading to more artefact formation. Another possible explanation for this variation in artefacts relative to anatomical location is the effect of the exomass, *i.e.* the entire craniofacial area located within and outside the FOV. A significant amount of the patient's tissue attenuates X-rays but is not included in the final image.^{3,4,6,8} The presence of adjacent anatomical structures, such as the skull and spinal column, affects grey value measurements in the maxilla and mandible.^{4,9}

In the present study, a greater number of artefacts was observed in the dental implant's cervical third, likely due to the presence of the prosthesis over the implant. Titanium, the implant's constituent metal, has a smaller atomic number^{4,9} than prosthetic crown alloy materials, such as cobalt-chromium.¹⁰ As stated previously, the higher the atomic number, the greater the number of artefacts. Therefore, the presence of the prosthesis

would have further increased the number of artefacts in the implant's cervical region.

As metals attenuate X-ray beams more than soft tissue and bone,⁵ a larger grey value range, *i.e.* more artefact formation, was expected between adjacent implants. However, when comparing the number of artefacts around isolated implants with those around implants adjacent to others, no significant difference was observed. This result may be explained by the small ROI defined for measuring the artefacts, which was standardized at 10×10 mm and therefore suffered little or no effect from neighbouring implants.

In the present study, it was possible to quantify the effect of artefacts on the tomographic images' grey values, providing an estimate of the extent of these unwanted images caused by dental implants. Although Rabelo *et al*¹⁹ observed that variations of mA and kV do not affect the quantification of artefacts in CBCT images with different intracanal filling materials, it is important to note that other factors may affect artefact formation, such as voxel size, slice thickness and FOV size.⁷ Therefore, it is necessary to develop future *in vitro* studies that take these variables into account when counting the artefacts generated by implants. Moreover, it is essential to develop research that associates the number of artefacts with diagnostic accuracy to ascertain the real level of interference of these unwanted images on clinical dental practice.

Considering the above results, it can be concluded that metal artefacts are always present in CBCT images and that the anatomical region in which the implant is installed affects the number of metal artefacts produced, with more artefacts in the mandible and in anterior regions (incisors and canines).

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Publishing Ethics

This study was approved by the Research Ethics Committee of the Federal University of Juiz de Fora (UFJF, Juiz de Fora, Minas Gerais, Brazil), under protocol no. 1,403,545.