RESEARCH ARTICLE

Influence of acquisition parameters on the magnitude of cone beam computed tomography artifacts

¹Deborah Queiroz Freitas, ¹Rochardes Cavalcante Fontenele, Eduarda Helena Leandro Nascimento, ²Taruska Ventorini Vasconcelos and ³Marcel Noujeim

¹Department of Oral Diagnosis, Division of Oral Radiology, Piracicaba Dental School, University of Campinas, Limeira, Brazil;

²Division of Oral Radiology, School of Dentistry, Federal University of Bahia, Salvador, Brazil; ³Department of Comprehensive Dentistry, Division of Oral and Maxillofacial Radiology, University of Texas Health Science Center at San Antonio, San Antonio, TX, United States

Aim: To evaluate the influence of kilovoltage (kVp) and metal artifact reduction tool (MAR) on the magnitude of cone beam CT (CBCT) artifacts.

Methods: A titanium and zirconia implants were inserted alternately in a posterior region of a mandible. CBCT exams were acquired with ProMax 3D (Planmeca Oy, Helsinki, Finland) and Picasso Trio machines (Vatech, Hwaseong, South Korea) using 70 kVp, 80 kVp and 90 kVp with and without MAR activation. The other exposure factors remained fixed at 5mA, field of view 80 × 50 mm and voxel 0.20 mm. The scans were performed before and after the insertion of the implants. Regions of interest were determined in different distances from the artifact production area (15, 25 and 35 mm) in an axial image, in which standard deviation (SD) of grayscale values was measured and contrast-to-noise ratio (CNR) was calculated. Analysis of variance was used to compare the data.

Results: Overall, in cases where the artifact was pronounced, MAR was efficient in reducing SD values. MAR also improved the CNR of ProMax images, but did not affect the Picasso images. Additionally, the higher was the kVp, the lower was the SD value and the higher was the CNR in both machines.

Conclusion: In both machines, increasing kVp and MAR are effective in decreasing the CBCT artifacts in all their magnitude when they are pronounced. Therefore, the professionals should choose one of those options or even both considering the purpose of the CBCT imaging and radiation dose for the patient.

Dentomaxillofacial Radiology (2018) 47, 20180151. doi: [10.1259/dmfr.20180151](https://doi.org/10.1259/dmfr.20180151)

Cite this article as: Freitas DQ, Fontenele RC, Nascimento EHL, Vasconcelos TV, Noujeim M. Influence of acquisition parameters on the magnitude of cone beam computed tomography artifacts. *Dentomaxillofac Radiol* 2018; 47: 20180151.

Keywords: cone beam computed tomography; artifact; image quality; diagnosis

Introduction

Cone beam CT (CBCT) has been widely used in dentistry because it provides three-dimensional analysis of maxillofacial structures, which overcomes the limitations of overlapping in two-dimensional techniques.^{1,2} However, artifact production has been pointed as a limitation of this exam.

Artifact is defined as any entity viewed in a reconstructed image but is not present in the region examined. Artifacts are caused by differences between the actual physical conditions and the mathematical formatting used to reconstruct in three dimensions.³ One of the main artifacts is generated by the presence of dense and high atomic number materials in the field of view (FOV) that cause the beam hardening phenomenon. The phenomenon occurs when the lower energy rays of the polyenergetic beam emitted by the X-ray source suffer

Correspondence to: Dr Deborah Queiroz Freitas, E-mail: deborah@fop.unicamp.br

Received 18 April 2018; revised 17 May 2018; accepted 07 June 2018

significant absorption by these materials, resulting in hypodense bands (dark bands).³ The production of CBCT artifact may impair the image quality,^{4,5} increase the interpretation time by covering anatomical structures in the region of interest and reduce the diagnostic accuracy or even prevent it.^{2,6}

Some methods for reducing artifacts in CBCT images during the exam acquisition have been described in the literature.^{2,5–8} It seems that the most effective and easier to use without influence on radiation dose is the metal artifact reduction (MAR) tool that is available in some CBCT machines. Although the manufacturers do not explain how this tool works, it appears to apply a threshold corresponding to the average of the gray values of the image, and any area much more or less dense than the threshold will be corrected; this reduces the variability of gray values, resulting in an image with less artifacts.^{9,10} However, this tool needs an increase in reconstruction time and its effectiveness is still controversial since there is an optimization of image quality,^{2,7,11} with little or no influence on the diagnosis of root fractures, periodontal defects and peri-implant defects.^{2,9,12,13} Adjusting the exposure parameters of the CBCT machine to generate higher energy photons is also a possibility.¹⁴ In this way, the main energy parameter that influences on artifact production seems to be the kilovoltage (kVp).⁵

CBCT artifacts production and its influence on the diagnosis in regions around or near to the artifact producing material is clear.^{5,15,16} Although the artifact might not be restricted to such area, little is known about its magnitude and how it is influenced by changes in acquisition parameters. Therefore, the aim of this study was to evaluate the influence of kVp and MAR on the magnitude of CBCT artifacts.

Methods and materials

Phantom preparation

Two types of dental implants were used: a zirconium oxide implant (Z-Look3, Z-systems, Oensingen, Switzerland) and a titanium implant (Titamax, Neodent, Curitiba, PR, Brazil), both with the same size (4 × 11 mm). Two dry human mandibles were used as phantoms. On the right posterior region of both, an epoxy resin-based (ERB) tissue substitute block (9 × 4 × 4 mm) was fixed with wax to the buccal cortical, to serve as a reference for the implant position and for selecting the axial view that was used for analysis.⁵ An additional ERBS block (18 × 10 × 7 mm) was inserted on the buccal cortical plate of anterior region of the mandible aligned to the middle line and also at the middle level of the implant in height to be included in the axial view used in the later analysis. That block was used as control area since the artifacts seemed to be pronounced in the ERBS block positioned close to the implant, which would make impossible its use as control area.

An operator with experience in implant dentistry placed the implants; first, the zirconium implant was inserted and CBCT acquisitions were performed. After, the zirconium implant was removed and the titanium implant was placed in the same position, and new acquisitions were conducted, following the same procedures. Finally, the titanium implant was removed and a set of CBCT exams were acquired without implants to serve as control images.

During CBCT acquisitions, the mandibles were placed in a container (160 mm diameter) and fixed to the bottom with impression material; the mandible position was standardized by light guides of the machines for all acquisitions. The container was filled with water in order to simulate soft-tissue coverage.^{2,5,6}

CBCT scanning

Two CBCT units with similar acquisition parameters were used for scanning:

- Picasso Trio unit (Vatech, Hwaseong, South Korea): 70, 80 and 90 kVp with and without use of MAR tool. FOV size (8 × 5 cm), milliamperage (5 mA), voxel size (0.2 mm), exposure time (24 s) and frames (720) were constant for all scans.
- ProMax 3D unit (Planmeca Oy, Helsinki, Finland): 70, 80 and 90 kVp with use of three levels MAR tool (low, mid and high) and with no MAR. FOV size (8 × 5 cm), milliamperage (5 mA) and voxel size (0.2 mm) exposure time (12 s) and frames (251) were constant for all scans as well.

In both units, for those exams with use of MAR tool, the function was active before each CBCT acquisition, at the same time of the selection of the other parameters. Prior to CBCT acquisitions, the container with the phantom was fixed to the platform of the machines. The mandible was centered in the FOV. As explained previously, for each machine the scans were performed with zirconium or titanium implant inserted as well as with no implants. Each scan (each parameters setting with each implant or no implant) was repeated 3 times, totaling 54 CBCT acquisitions for Picasso Trio and 108 CBCT acquisitions for ProMax 3D. The difference in number of acquisitions between the machines occurred due to ProMax 3D has three levels of MAR. [Figures 1–4](#) show examples of axial images according to settings studied of Picasso Trio and ProMax 3D machines.

Image analysis

The images were individually assessed by an oral radiologist previously calibrated under dim light conditions. For each CBCT scan, an axial reconstruction was determined at the middle level of the implant height using the ERBS block as reference. The block was indispensable to find the correspondent axial view in scans without implant.

All images were evaluated using the ImageJ software (NIH Image, Bethesda, MD). On each axial image, 11

Figure 1 Examples of cropped axial views of “without implant”, “titanium” and “zirconium” images, according to kVp and MAR for Picasso Trio.

regions of interest (ROIs) were computed using the macro tool of this software; so they were standardized for all the images. Two different macros with the same pattern were recorded: one for each set of images of each machine. For determining the ROIs, a line was drawn on the center of the right posterior body of the mandible passing through the region of the implant. After, a line perpendicular to the first one was drawn. Taking the second line as reference, three lines (one to the posterior and two to the anterior region) were drawn having 25° between each other. Posteriorly, three circles centered in the implant region were determined with radii of 15, 25 and 35 mm. Finally, 11 square ROIs of 2.8 × 2.8 mm were determined in the intersection of lines and circles. An additional ROI with the same dimension was determined in the ERB block to serve as control area (Figure 5A).

Standard deviation (SD) of the gray values of each ROI was obtained as a method to measure image noise/

artifacts.¹⁷ Also, the mean gray level values were determined in order to calculate the contrast-to-noise ratio (CNR):

$$CNR = \frac{|Mean_{Im\ plant} - Mean_{Control}|}{\sqrt{SD_{Im\ plant}^2 + SD_{Control}^2}}$$

The analyses were performed in 8-bits images. The results for 11 ROIs were grouped in 3 regions according to the circles (inner, middle and outer) in order to express the magnitude of the artifacts and the effect of the factors studied (Figure 5B).

Statistical analysis

The analyses were performed using SPSS v. 24.0 (IBM Corp., Armonk, NY) and GraphPad Prism v. 7.0 (GraphPad Software, La Jolla, CA) software, with a significant *p*-value < 0.05.

The SD and CNR were compared by analysis of variance (ANOVA) with *post-hoc* Tukey test, in order to test the main effects of the region, implant, MAR and kVp setting and their interactions. The ANOVA was conducted independently for each machine (Picasso Trio and ProMax 3D); so their results were not matched. The null hypothesis considered that the factors studied did not have an influence on SD or CNR.

Results

Table 1 shows the values of SD found for Picasso Trio images. According to ANOVA, the values were affected by all factors studied (region, implant, MAR and kVp), as well as by all of the interactions (*p* < 0.0001). In general, Region 1 showed higher values (higher noise) than regions 2 and 3 when both implants were present even with MAR activation. In Region 1, where the artifact was detected, zirconium implant presented higher values than those of titanium implant when 80 and 90 kVp were used. In these cases (zirconium, Region 1, and 80 and 90 kVp), MAR was efficient as the values were lower when it was activated. Additionally, the higher was the kVp, the lower was the SD value.

CNR values for Picasso Trio images are presented in Table 2. CNR was affected by region (*p* = 0.012), implant (*p* < 0.0001) and kVp (*p* < 0.0001), but not by MAR (*p* = 0.210) or by their interactions (*p* > 0.05). It was possible to observe Region 1 showed lower values than those of regions 2 and 3. Also, zirconium showed lower values than titanium and control images, and these did not differ from each other. Moreover, the higher was the kVp, the higher was the CNR value.

The SD results for ProMax 3D images are exhibited in Table 3. The effect of all four factors was significant, along with all of the interactions (*p* < 0.0001). The amount of artifacts was strongly dependent on kVp and implant type, the reason why they are described separately. When 70 kVp was used, zirconium images

Figure 2 Examples of cropped axial views of “without implant”, “titanium” and “zirconium” images, 70 kVp, ProMax 3D.

showed higher values than those of titanium and without implant ones for regions 1 and 2. In Region 3, no differences were detected. In 80 kVp, the same pattern was observed for regions 1 and 2, while in Region 3, SD values of zirconium images were higher than those of images without implant. Differently, when 90 kVp was used, in Region 1, zirconium images had the highest SD values, titanium images showed intermediate values, while images without implant had the lowest ones. In Region 2, zirconium images showed higher values than those of others and, in Region 3, no differences were detected. In general, MAR was also efficient when the artifacts were present, except for titanium, 90 kVp, Region 1. Moreover, it is possible to observe the levels of MAR available in ProMax 3D machine did not differ from each other. As for Picasso Trio images, the higher was the kVp, the lower was the SD value.

Concerning to CNR values for ProMax 3D images (Table 4), they were also affected by all four factors and their interactions ($p < 0.0001$). CNR of zirconium

images was lower than the others for all regions when 70 and 80 kVp were used. When 90 kVp was selected, this behavior happened just for Region 1 whereas no differences were detected for regions 2 and 3. In general, MAR improved the CNR when it was low, except for 70 kVp, regions 2 and 3. Differently from the Picasso Trio images, the effect of kVp on CNR varied depending on implant and MAR. For images without implant or with titanium implant, 80 and 90 kVp produced images with higher CNR that did not differ from each other, but both differed from those produced by 70 kVp, except when midlevel MAR was used. In this case, no differences between kVp settings were found. For images with zirconium implant and MAR not activated, low- or midlevel MAR, 90 kVp exhibited images with significant higher CNR than 70 kVp, whereas values from images produced by 80 kVp were intermediate and did not differ from those obtained in images with 70 and 90 kVp. When high-level MAR was used, 80 and 90 kVp produced images with higher CNR that did not differ

Figure 3 Examples of cropped axial views of “without implant”, “titanium” and “zirconium” images, 80 kVp, ProMax 3D.

from each other, but both differed from those produced by 70 kVp.

Discussion

The artifact production is well established in the literature as well the positive effect of MAR and kVp in decreasing it.^{4,5,10,16–18} However, both the production and the positive effect of some parameters seemed to be evaluated just around the artifact-generator object. In this way, we tested the influence of potential effective parameters in regions distant from the metallic object. Nowadays, this analysis is important as many patients that undergo CBCT scans have implants or other metallic materials inside the FOV. So finding some alternatives to decrease the artifact production even distant from the generation object is relevant for clinical practice.

In general, we found the zirconium produced more artifact than titanium implant, which was expected because of their composition and atomic number. Also, it was confirmed by a previous study that evaluated changes in the gray values around different implants.¹⁶ Additionally, we confirmed that the magnitude presents the same pattern, *i.e.* it is higher with zirconium implant.

Another interesting result was artifacts related to titanium implant were practically inexistent from 15 mm distant of the object. Some previous studies found decreasing in artifact intensity with increasing distance from the object when evaluated regions 0.5 mm, 1 mm, and 2 mm from the titanium implant surface.^{16,19} However, we did not expect that it practically disappeared at 15 mm. Concerning the titanium implant, it was also surprising the only protocol that titanium exhibited some artifact (demonstrated by higher SD compared to without implant images) was 90 kVp for both machines.

Figure 4 Examples of cropped axial views of “without implant”, “titanium” and “zirconium” images, 90 kVp, ProMax 3D.

The machines studied were chosen because they both have options of MAR activation and kVp for professionals select when perform exams, which could be effective in decreasing artifact production. According to the results, they seem to be different in artifact production as the magnitude of zirconium artifact was more pronounced in ProMax 3D images. It is true the artifact decreased from region closer to implant to regions farther to implant. However, SD was still higher than images without implant that served as control images.

Despite the different behavior in artifact production, the factors studied (kVp and MAR) performed similarly. In both machines, higher kVps improved the image quality by decreasing SD and increasing CNR. It is well-known that beam-hardening phenomenon is caused by objects that absorb low-energy X-ray photons owing to their high atomic number and increase the mean energy of the beam.^{3,4,20} So, using higher kVp signifies working with high mean energy photons that would be less filtered by the metallic object. This is the

main reason why higher kVp could improve the image quality. However, professionals should keep in mind that the higher the kVp, the higher radiation dose for the patients.²¹ Therefore, the image improvement achieved with higher kVp cannot be the only justification for the increase in radiation dose, and should be limited in cases where such improvement reflects on enhanced image diagnosis.¹⁴

MAR algorithm works during image reconstruction, and has, therefore, no influence on image acquisition or radiation dose.¹⁸ It seems the activation of the MAR applies a threshold in the image, decreasing the extreme gray values corresponding to the artifacts. In the present study, MAR was generally effective in both machines because of decreased SD values. Moreover, its positive effect occurred regardless of its level on ProMax images. According to Queiroz *et al.*¹⁸, a decrease in SD values represents a reduction of gray value variability and greater homogeneity of the image, which suggests a real metal artifact reduction. However, this occurred

Figure 5 Determination of the ROIs to evaluate the magnitude of artifacts. (A) A line was determined in the center of implant image following the long axis of the mandible body; a line perpendicular to the first one was drawn; after, three lines (one to the posterior and two to the anterior region from the last one) were drawn having 25° between each other; then, three circles centered in the implant were determined with radii of 15, 25 and 35 mm. and 11 square ROIs were determined in their intersection. (B) Additional control ROI was placed on the ERBS block; the ROIs were grouped in three regions. ROI, region of interest.

when the artifacts were more pronounced, *i.e.* with zirconium implant. In the few cases where titanium artifact was registered, MAR did not influence the values. This result is similar to that found in a previous study, in which MAR showed a positive influence on CBCT images with dental alloys, but not on artifacts generated by gutta-percha.¹⁸ The authors attributed this results to the fact that gutta-percha does not produce enough image artifact to be significantly reduced by MAR. This theory could also explain our results, as titanium implant produced less artifact than zirconium implant. It is important to note that the study of Queiroz *et al*¹⁸ evaluated objectively image quality around a gutta-percha cylinder phantom and not diagnostic tasks. Regarding the efficiency of the MAR in the diagnosis, its effect is still controversial. While the majority of the studies have found that MAR did not improve the diagnosis, especially when the artifacts were pronounced, such as diagnosis of root fractures in filling roots and peri-implant defects,^{2,9,22,23} a positive effect was observed in the diagnosis of proximal caries lesions.²⁴ The last result added to the improvement in image quality caused by MAR has kept this tool being evaluated.

It is also important to note that MAR does not have any negative effect on images without artifact/implant, which also supports the theory about how MAR works applying a threshold corresponding to the average of the gray values of the image, and corrects only areas much more or less dense than the threshold. As in images without implant there were no areas with mean gray values different from the threshold, no effect happened.

Regarding to the methodology, we chose SD and CNR to measure the artifact production. The main reasons were it is a well establish method¹⁸ and we evaluated two

different machines. As it is known, gray values are not absolute in CBCT as in multidetector-CT²⁵; so the values would vary strongly between the machines. Therefore, we used measures that are more consistent in different machines. Additionally, we believe that some differences in the methodology applied to different machines as using different mandibles did not influence our results and their interpretation as the analysis occurred independently, since their results were not matched in the statistical analysis. For testing the effect of factors studied, the images with implants were compared only to the control images (images without implant) of their corresponding machine. Therefore, CBCT units were not directly compared because we know many characteristics, such as image receptor technology and mathematical algorithms for image reconstruction can also influence the image formation and artifacts expression. However, according to our results, it appears the lower number of basis images, the higher artifact production and it is important to report it.

Finally, it is important to highlight that *in vitro* studies, as the present study, could not present the same X-ray photons interaction of a clinical condition. However, only they allow the researchers to compare different protocols because it would not be possible to repeat images in patients for research purpose.

Conclusion

Both the increase in kVp and the activation of MAR are effective in decreasing the CBCT artifacts in all their magnitude when they are pronounced, independently of the machine. Therefore, the professionals

Table 1 Mean of SD values according to ROIs and protocol settings for Picasso Trio

<i>kVp</i>	<i>ROI</i>	<i>Without implant</i>		<i>Titanium implant</i>		<i>Zirconium implant</i>	
		<i>No MAR</i>	<i>With MAR</i>	<i>No MAR</i>	<i>With MAR</i>	<i>No MAR</i>	<i>With MAR</i>
70 (a)	1	2.64 (0.11) Aa	2.52 (0.18) Aa	2.60 (0.31) Aa	2.72 (0.16) Aa	2.80 (0.15) Aa	2.77 (0.24) Aa
	2	2.12 (0.18) Ab	2.15 (0.18) Ab	2.37 (0.11) Aa	2.34 (0.19) Ab	2.32 (0.06) Ab	2.35 (0.10) Ab
	3	2.48 (0.11) Aa	2.57 (0.03) Aa	2.40 (0.13) Aa	2.34 (0.13) Ab	2.37 (0.10) Ab	2.47 (0.05) Aab
80 (b)	1	2.30 (0.11) BCa	2.17 (0.05) Ca	2.44 (0.26) BCa	2.53 (0.05) ABa	2.83 (0.30) Aa	2.50 (0.22) ABCa
	2	2.12 (0.18) Aa	1.97 (0.13) Aa	2.06 (0.06) Ab	2.15 (0.14) Ab	2.14 (0.05) Ab	2.02 (0.19) Ab
	3	2.31 (0.10) Aa	2.13 (0.08) Aa	2.26 (0.10) Aab	2.33 (0.09) Aab	2.33 (0.04) Ab	2.22 (0.03) Aab
90 (c)	1	2.01 (0.01) Ca	2.09 (0.09) Ca	2.48 (0.13) Ba	2.36 (0.14) Ba	2.75 (0.18) Aa	2.27 (0.16) Ba
	2	1.86 (0.10) Aa	1.90 (0.03) Aa	1.83 (0.03) Ac	1.99 (0.21) Ab	1.99 (0.09) Ab	1.86 (0.03) Ab
	3	2.04 (0.05) Aa	2.06 (0.03) Aa	2.06 (0.04) Ab	2.07 (0.10) Ab	2.20 (0.09) Ab	2.07 (0.10) Aab

kVp, kilovoltage; MAR, metal artifact reduction; ROI, region of interest; SD, standard deviation. Different uppercase letters indicate statistical difference between without implant, titanium and zirconium groups and with MAR and no MAR within each kVp setting; and different lowercase letters indicate statistical difference between ROIs within each group and between kVps, according to ANOVA.

Table 2 Mean of CNR values according to ROIs and protocol settings for Picasso Trio

<i>kVp</i>	<i>ROI</i>	<i>Without implant (A)</i>		<i>Titanium implant (A)</i>		<i>Zirconium implant (B)</i>	
		<i>No MAR</i>	<i>With MAR</i>	<i>No MAR</i>	<i>With MAR</i>	<i>No MAR</i>	<i>With MAR</i>
70 (c)	1 (b)	8.82 (0.77)	8.73 (0.58)	8.22 (0.45)	7.98 (0.41)	7.63 (0.59)	8.14 (0.85)
	2 (a)	9.61 (1.20)	9.36 (0.92)	8.48 (0.38)	8.38 (0.52)	8.00 (0.69)	8.61 (0.86)
	3 (a)	9.27 (0.89)	9.00 (0.71)	8.53 (0.42)	8.45 (0.73)	8.06 (0.70)	8.55 (0.75)
80 (b)	1 (b)	9.95 (1.26)	9.89 (0.70)	9.43 (0.66)	9.43 (0.66)	8.80 (1.04)	8.67 (0.78)
	2 (a)	10.26 (1.39)	10.30 (0.89)	9.90 (0.93)	9.90 (0.93)	9.41 (1.33)	9.28 (0.73)
	3 (a)	10.14 (1.18)	10.18 (0.86)	9.83 (0.83)	9.83 (0.83)	9.40 (1.31)	9.17 (0.85)
90 (a)	1 (b)	9.98 (0.48)	10.68 (0.85)	9.88 (0.80)	10.48 (1.09)	9.37 (0.47)	9.93 (1.24)
	2 (a)	10.59 (0.42)	11.05 (0.94)	10.60 (1.00)	10.87 (1.01)	10.10 (0.90)	10.66 (1.66)
	3 (a)	10.61 (0.52)	10.92 (0.89)	10.47 (0.94)	10.90 (1.20)	10.05 (0.79)	10.57 (1.60)

CNR, contrast-to-noise ratio; kVp, kilovoltage; MAR, metal artifact reduction; ROI, region of interest. Different uppercase letters indicate statistical difference between without implant, titanium and zirconium groups; and different lowercase letters indicate statistical difference between ROIs within each group and between kVps, according to ANOVA.

Table 3 Mean of SD values according to ROIs and protocol settings for ProMax 3D

<i>kVp</i>	<i>ROI</i>	Without implant			Titanium implant			Zirconium implant		
		<i>No MAR</i>	<i>Low-MAR</i>	<i>Mid-MAR</i>	<i>High-MAR</i>	<i>No MAR</i>	<i>Low-MAR</i>	<i>Mid-MAR</i>	<i>High-MAR</i>	<i>High-MAR</i>
70 (a)	1	4.96 (0.47) Ba	5.18 (0.61) Ba	5.41 (0.27) Ba	4.87 (0.29) Ba	5.35 (0.26) Ba	5.74 (0.47) Ba	5.16 (0.61) Ba	5.47 (0.51) Ba	5.13 (0.19) Ba
	2	4.59 (0.65) Ba	4.81 (0.20) Ba	4.47 (0.25) Ba	5.05 (0.47) Ba	5.02 (0.09) Ba	5.19 (0.14) Bab	5.06 (0.23) Aa	4.53 (0.11) Bb	4.64 (0.40) Ba
	3	4.96 (0.29) Aa	5.08 (0.46) Aa	4.96 (0.07) Aa	5.04 (0.60) Aa	4.70 (0.49) Aa	4.69 (0.34) Ab	4.81 (0.05) Aa	5.03 (0.04) Aab	5.13 (0.20) Aa
80 (b)	1	3.71 (0.02) Ca	3.55 (0.19) Ca	3.81 (0.11) Ca	3.68 (0.25) Ca	3.90 (0.17) Ca	3.68 (0.20) Cab	4.00 (0.33) BCa	4.35 (0.35) BCa	4.54 (0.35) Ba
	2	3.56 (0.23) Ba	3.76 (0.18) Ba	3.71 (0.22) Ba	3.69 (0.14) Ba	3.57 (0.20) Ba	3.40 (0.08) Bb	3.70 (0.30) Ba	3.88 (0.47) Bab	3.89 (0.11) Bb
	3	3.41 (0.23) Ba	3.42 (0.29) Ba	3.48 (0.21) Ba	3.63 (0.26) Ba	3.73 (0.07) ABa	4.08 (0.19) ABa	3.97 (0.45) ABa	3.71 (0.65) ABb	4.13 (0.11) ABab
90 (c)	1	2.66 (0.15) Ca	2.68 (0.18) Ca	2.79 (0.17) Ca	2.70 (0.12) Ca	3.22 (0.05) Ba	3.27 (0.09) Ba	3.63 (0.08) Ba	3.21 (0.13) Ba	3.20 (0.18) Ba
	2	2.72 (0.30) Ca	2.74 (0.05) Ca	2.76 (0.24) Ca	2.60 (0.15) Ca	2.70 (0.11) Cb	2.78 (0.08) Cb	2.68 (0.26) Cb	2.81 (0.11) Cb	3.01 (0.19) Ba
	3	2.76 (0.08) Aa	2.88 (0.20) Aa	2.82 (0.05) Aa	2.95 (0.03) Aa	2.85 (0.12) Ab	2.97 (0.02) Ab	3.00 (0.07) Ab	2.91 (0.23) Ab	2.99 (0.26) Aa
										3.26 (0.13) Ac
										2.89 (0.28) Aa

kVp, kilovoltage; MAR, metal artifact reduction; ROI, region of interest; SD, standard deviation.

Different uppercase letters indicate statistical difference between without implant, titanium and zirconium groups and MAR levels and no MAR within each *kVp* setting; and different lowercase letters indicate statistical difference between ROIs within each group and between *kVps*, according to ANOVA.

Table 4 Mean of CNR values according to ROIs and protocol settings for ProMax 3D

<i>kVp</i>	<i>ROI</i>	<i>Without implant</i>						<i>Titanium</i>						<i>Zirconium</i>					
		<i>No MAR</i>	<i>Low-MAR</i>	<i>Mid-MAR</i>	<i>High-MAR</i>	<i>No MAR</i>	<i>Low-MAR</i>	<i>Mid-MAR</i>	<i>High-MAR</i>	<i>No MAR</i>	<i>Low-MAR</i>	<i>Mid-MAR</i>	<i>High-MAR</i>	<i>No MAR</i>	<i>Low-MAR</i>	<i>Mid-MAR</i>	<i>High-MAR</i>	<i>No MAR</i>	<i>Low-MAR</i>
70	1	11.47 (0.61) Aa	12.05 (1.12) Aa	12.11 (0.29) Ab	12.51 (0.11) Aa	11.15 (0.73) Aa	10.14 (0.47) Aa	11.43 (0.84) Aa	10.33 (0.45) Aa	7.91 (0.16) Bb	9.94 (1.13) ABa	9.56 (1.51) ABa	9.87 (0.30) ABa	7.91 (0.16) Cb	9.94 (1.13) Ca	9.56 (1.51) Ca	9.87 (0.30) Ca	7.91 (0.16) Ba	9.94 (1.13) Ba
	2	12.02 (0.41) ABa	13.02 (0.78) ABa	14.27 (1.02) Aa	12.72 (0.83) ABa	12.28 (0.87) ABa	11.31 (0.33) Ba	12.15 (0.58) ABa	11.92 (0.65) ABa	8.82 (1.62) Cb	10.84 (0.47) Ca	10.92 (0.64) Ca	10.21 (1.41) Ca	8.82 (1.62) Cb	10.84 (0.47) Ca	10.92 (0.64) Ca	10.21 (1.41) Ca	8.82 (1.62) Ba	10.84 (0.47) Ba
	3	11.46 (0.57) ABa	12.39 (1.01) ABa	13.06 (0.54) Aab	12.52 (1.22) ABa	12.56 (0.96) ABa	11.82 (0.39) ABa	12.31 (0.55) ABa	11.33 (0.66) ABa	10.68 (0.77) Ba	10.19 (1.81) Ba	10.86 (0.46) Ba	10.04 (0.77) Ba	10.68 (0.77) Ba	10.19 (1.81) Ba	10.86 (0.46) Ba	10.04 (0.77) Ba	10.68 (0.77) Ba	10.19 (1.81) Ba
80	1	14.05 (1.52) Aa	14.63 (1.22) Aa	12.72 (1.43) Aa	11.65 (1.22) Aa	13.28 (0.83) Aa	12.94 (1.40) Aa	12.06 (0.57) Aa	12.91 (0.65) Aa	9.10 (0.60) Ba	11.77 (0.63) ABa	11.42 (2.02) ABa	12.14 (1.35) ABa	9.10 (0.60) Ba	11.77 (0.63) ABa	11.42 (2.02) ABa	12.14 (1.35) ABa	9.10 (0.60) Ba	11.77 (0.63) ABa
	2	14.63 (1.22) Aa	14.54 (0.80) Aa	13.22 (1.53) Aa	12.20 (1.72) ABa	14.65 (0.34) Aa	14.14 (1.17) Aa	13.32 (1.72) Aa	14.51 (0.68) Aa	11.18 (1.38) Ba	12.75 (0.88) ABa	12.14 (0.71) ABa	12.54 (1.01) ABa	11.18 (1.38) Ba	12.75 (0.88) ABa	12.14 (0.71) ABa	12.54 (1.01) ABa	11.18 (1.38) Ba	12.75 (0.88) ABa
	3	14.82 (2.01) Aa	15.28 (1.33) Aa	13.30 (1.14) Aa	12.11 (1.72) ABa	14.16 (0.56) ABa	12.81 (0.74) ABa	12.77 (1.84) ABa	14.88 (1.56) Aa	10.98 (0.87) Ba	11.34 (1.76) Ba	12.50 (0.94) ABa	12.43 (0.30) ABa	10.98 (0.87) Ba	11.34 (1.76) Ba	12.50 (0.94) ABa	12.43 (0.30) ABa	10.98 (0.87) Ba	11.34 (1.76) Ba
90	1	14.80 (2.01) Aa	15.26 (1.64) Aa	13.50 (1.32) Aa	15.05 (0.84) Aa	12.61 (0.42) ABa	13.97 (1.71) Aa	12.15 (0.69) ABa	12.76 (1.15) ABa	10.15 (0.46) Bb	13.20 (1.11) ABa	12.77 (2.22) ABa	13.95 (0.07) Aa	10.15 (0.46) Bb	13.20 (1.11) ABa	12.77 (2.22) ABa	13.95 (0.07) Aa	10.15 (0.46) Bb	13.20 (1.11) ABa
	2	15.05 (1.21) Aa	15.53 (1.26) Aa	13.88 (1.17) Aa	15.75 (0.27) Aa	14.08 (0.47) Aa	15.76 (2.15) Aa	14.38 (0.71) Aa	14.20 (1.67) Aa	13.00 (0.84) Aa	13.98 (0.85) Aa	13.57 (1.63) Aa	13.62 (1.68) Aa	13.00 (0.84) Aa	13.98 (0.85) Aa	13.57 (1.63) Aa	13.62 (1.68) Aa	13.00 (0.84) Aa	13.98 (0.85) Aa
	3	14.89 (1.62) Aa	15.04 (0.79) Aa	13.74 (1.32) Aa	14.82 (0.57) Aa	14.02 (0.46) Aa	15.43 (1.93) Aa	14.00 (0.77) Aa	13.99 (1.77) Aa	13.56 (2.14) Aa	14.31 (2.11) Aa	15.15 (0.28) Aa	13.80 (0.38) Aa	13.56 (2.14) Aa	14.31 (2.11) Aa	15.15 (0.28) Aa	13.80 (0.38) Aa	13.56 (2.14) Aa	14.31 (2.11) Aa

CNR, contrast-to-noise ratio; kVp, kilovoltage; MAR, metal artifact reduction; ROI, region of interest. Different uppercase letters indicate statistical difference between without implant, titanium and zirconium groups and MAR levels and no MAR within each kVp setting; and different lowercase letters indicate statistical difference between ROIs within each group, according to ANOVA.

could choose to use one or the other considering the purpose of the CBCT imaging and radiation dose for the patient. However, they should keep in mind that the positive effect is higher when both are used together.

References

- European Society of Endodontology developed by: Patel S, Durack C, Abella F, Roig M, Shemesh H, Lambrechts P, Lemberg K. European Society of Endodontology position statement: The use of CBCT in Endodontics. *Int Endod J* 2014; **47**: 502–4.
- Bezerra IS, Neves FS, Vasconcelos TV, Ambrosano GM, Freitas DQ. Influence of the artefact reduction algorithm of Picasso Trio CBCT system on the diagnosis of vertical root fractures in teeth with metal posts. *Dentomaxillofac Radiol* 2015; **44**: 20140428. doi: <https://doi.org/10.1259/dmfr.20140428>
- Schulze R, Heil U, Gross D, Bruellmann DD, Dranischnikow E, Schwanecke U, et al. Artefacts in CBCT: a review. *Dentomaxillofac Radiol* 2011; **40**: 265–73. doi: <https://doi.org/10.1259/dmfr/30642039>
- Oliveira ML, Freitas DQ, Ambrosano GM, Haiter-Neto F. Influence of exposure factors on the variability of CBCT voxel values: a phantom study. *Dentomaxillofac Radiol* 2014; **43**: 20140128. doi: <https://doi.org/10.1259/dmfr.20140128>
- Vasconcelos TV, Bechara BB, McMahan CA, Freitas DQ, Noujeim M. Evaluation of artifacts generated by zirconium implants in cone-beam computed tomography images. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2017; **123**: 265–72. doi: <https://doi.org/10.1016/j.oooo.2016.10.021>
- Ferreira LM, Visconti MA, Nascimento HA, Dallemolle RR, Ambrosano GM, Freitas DQ. Influence of CBCT enhancement filters on diagnosis of vertical root fractures: a simulation study in endodontically treated teeth with and without intracanal posts. *Dentomaxillofac Radiol* 2015; **44**: 20140352. doi: <https://doi.org/10.1259/dmfr.20140352>
- Bechara BB, Moore WS, McMahan CA, Noujeim M. Metal artefact reduction with cone beam CT: an in vitro study. *Dentomaxillofac Radiol* 2012; **41**: 248–53. doi: <https://doi.org/10.1259/dmfr/80899839>
- Zhang Y, Yan H, Jia X, Yang J, Jiang SB, Mou X. A hybrid metal artifact reduction algorithm for x-ray CT. *Med Phys* 2013; **40**: 041910. doi: <https://doi.org/10.1118/1.4794474>
- Bechara B, Alex McMahan C, Moore WS, Noujeim M, Teixeira FB, Geha H. Cone beam CT scans with and without artefact reduction in root fracture detection of endodontically treated teeth. *Dentomaxillofac Radiol* 2013; **42**: 20120245. doi: <https://doi.org/10.1259/dmfr.20120245>
- Queiroz PM, Santaella GM, da Paz TD, Freitas DQ. Evaluation of a metal artefact reduction tool on different positions of a metal object in the FOV. *Dentomaxillofac Radiol* 2017; **46**: 20160366. doi: <https://doi.org/10.1259/dmfr.20160366>
- Parsa A, Ibrahim N, Hassan B, Syriopoulos K, van der Stelt P. Assessment of metal artefact reduction around dental titanium implants in cone beam CT. *Dentomaxillofac Radiol* 2014; **43**: 20140019. doi: <https://doi.org/10.1259/dmfr.20140019>
- Kamburoglu K, Kolsuz E, Murat S, Eren H, Yüksel S, Paksoy CS. Assessment of buccal marginal alveolar peri-implant and periodontal defects using a cone beam CT system with and without the application of metal artefact reduction mode. *Dentomaxillofac Radiol* 2013; **42**: 20130176. doi: <https://doi.org/10.1259/dmfr.20130176>
- de-Azevedo-Vaz SL, Peyneau PD, Ramirez-Sotelo LR, Vasconcelos KF, Campos PS, Haiter-Neto F. Efficacy of a cone beam computed tomography metal artifact reduction algorithm for the detection of peri-implant fenestrations and dehiscences. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2016; **121**: 550–6. doi: <https://doi.org/10.1016/j.oooo.2016.01.013>
- Pinto MGO, Rabelo KA, Sousa Melo SL, Campos PSF, Oliveira L, Bento PM, et al. Influence of exposure parameters on the detection of simulated root fractures in the presence of various intracanal materials. *Int Endod J* 2017; **50**: 586–94. doi: <https://doi.org/10.1111/iej.12655>
- de-Azevedo-Vaz SL, Vasconcelos KF, Neves FS, Melo SL, Campos PS, Haiter-Neto F. Detection of periimplant fenestration and dehiscence with the use of two scan modes and the smallest voxel sizes of a cone-beam computed tomography device. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2013; **115**: 121–7. doi: <https://doi.org/10.1016/j.oooo.2012.10.003>
- Sancho-Puchades M, Hämmerle CH, Benic GI. In vitro assessment of artifacts induced by titanium, titanium-zirconium and zirconium dioxide implants in cone-beam computed tomography. *Clin Oral Implants Res* 2015; **26**: 1222–8. doi: <https://doi.org/10.1111/clr.12438>
- Queiroz PM, Groppo FC, Oliveira ML, Haiter-Neto F, Freitas DQ. Evaluation of the efficacy of a metal artifact reduction algorithm in different cone beam computed tomography scanning parameters. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2017; **123**: 729–34. doi: <https://doi.org/10.1016/j.oooo.2017.02.015>
- Queiroz PM, Oliveira ML, Groppo FC, Haiter-Neto F, Freitas DQ. Evaluation of metal artefact reduction in cone-beam computed tomography images of different dental materials. *Clin Oral Investig* 2018; **22**: 419–23. doi: <https://doi.org/10.1007/s00784-017-2128-9>
- Benic GI, Sancho-Puchades M, Jung RE, Deyhle H, Hämmerle CH. In vitro assessment of artifacts induced by titanium dental implants in cone beam computed tomography. *Clin Oral Implants Res* 2013; **24**: 378–83. doi: <https://doi.org/10.1111/clr.12048>
- Pauwels R, Nackaerts O, Bellaiche N, Stamatakis H, Tsiklakis K, Walker A, et al. Variability of dental cone beam CT grey values for density estimations. *Br J Radiol* 2013; **86**: 20120135. doi: <https://doi.org/10.1259/bjr.20120135>
- Ludlow JB, Timothy R, Walker C, Hunter R, Benavides E, Samuelson DB, et al. Effective dose of dental CBCT—a meta analysis of published data and additional data for nine CBCT units. *Dentomaxillofac Radiol* 2015; **44**: 20140197. doi: <https://doi.org/10.1259/dmfr.20140197>
- de Rezende Barbosa GL, Sousa Melo SL, Alencar PN, Nascimento MC, Almeida SM. Performance of an artefact reduction algorithm in the diagnosis of in vitro vertical root fracture in four different root filling conditions on CBCT images. *Int Endod J* 2016; **49**: 500–8. doi: <https://doi.org/10.1111/iej.12477>
- Dalili Kajan Z, Taramsari M, Khosravi Fard N, Khaksari F, Moghasem Hamidi F. The efficacy of metal artifact reduction mode in cone-beam computed tomography images on diagnostic accuracy of root fractures in teeth with intracanal posts. *Iran Endod J* 2018; **13**: 47–53. doi: <https://doi.org/10.22037/iej.v13i1.17352>
- Cebe F, Aktan AM, Ozsevik AS, Ciftci ME, Surmelioglu HD. The effects of different restorative materials on the detection of approximal caries in cone-beam computed tomography scans with and without metal artifact reduction mode. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2017; **123**: 392–400. doi: <https://doi.org/10.1016/j.oooo.2016.11.008>
- Silva IM, Freitas DQ, Ambrosano GM, Bóscolo FN, Almeida SM. Bone density: comparative evaluation of Hounsfield units in multislice and cone-beam computed tomography. *Braz Oral Res* 2012; **26**: 550–6. doi: <https://doi.org/10.1590/S1806-83242012000600011>