Influence of Cone Beam Computed Tomography Settings on Implant Artifact Production: Zirconia and Titanium

Taruska Ventorini Vasconcelos, DDS, PhD1/Eduarda Helena Leandro Nascimento, DDS, MS2/ Boulos B. Bechara, DDS, MS3/Deborah Queiroz Freitas, DDS, PhD2/ Marcel Noujeim, DDS, MS3

Purpose: This in vitro study assessed the artifact production related to titanium and zirconia implants in cone beam computed tomography (CBCT) and compared the effect of different protocol settings on image quality for both materials. Materials and Methods: A titanium implant and a zirconia implant were placed in a dry mandible. CBCT scans were obtained separately for each implant using the ProMax 3D (Planmeca) unit; 20 protocols were tested with varying kilovoltage (70 to 90 kVp) and resolution (high and low), and with and without a metal artifact reduction tool. Standard deviation and contrast-noise ratio were calculated in regions of interest adjacent and distant to the implant. Results: The zirconia produced more artifacts and its images were more affected by the different protocols than titanium. High kVps and an activated metal artifact reduction tool decreased the standard deviation values related to both implants. Activation of the metal artifact reduction tool also increased contrast-noise ratio values for both implants, whereas increasing kVp improved them only on titanium images. The standard deviation and contrast-noise ratio were not affected by resolution. Conclusion: The zirconia implant generated more image artifacts than the titanium implant. Increasing kVp and the metal artifact reduction tool are efficient in decreasing the CBCT artifacts for both implants, whereas resolution does not affect their production. Int J Oral Maxillofac Implants 2019;34:1114–1120. doi: 10.11607/jomi.7129

Keywords: artifacts, cone beam computed tomography, dental implant

Cone beam computed tomography (CBCT) has been recommended for imaging in preoperative implant assessment, since it provides a high-quality three-dimensional image, with no magnification, and is extremely useful for assessing bone and performing accurate measurements.1,2 Conversely, due to CBCT artifact production, postoperative implant evaluation is compromised.3,4 Image artifacts are inconsistencies in the image data that do not correspond to the physical characteristics of an evaluated object. Their production is related to the CBCT scanner technical aspects, but the object composition has an important effect as well, since some objects can act as a filter that alters the x-ray spectrum, depending on their atomic number and density.5 Therefore, if a traditional titanium implant is present in the jawbone, the presence of artifacts that compromise CBCT image quality may be unavoidable.3 Zirconia implants have emerged as an alternative to titanium based on patients’ esthetic demands, as the color of a titanium implant might be reflected through the gingival tissues, resulting in a darkening aspect at the cervical area.6 However, despite its biocompatibility, mechanical, and osseointegration properties,6–8 one of the components of zirconia implants is a high-density material with a relatively high atomic number (zirconium, Z = 40), which is also prone to produce artifacts in CBCT images.9–12 From a technical point of view, these artifacts are produced by the data acquisition process, and it is not possible to avoid them if no additional artifact suppressing means are applied.3 Consequently,
companies have been putting effort into developing techniques for artifact reduction. Previous in vitro studies have evaluated the effect of different approaches and showed that the artifact reduction tool, through the postprocessing reconstruction algorithm, as well as the exposure settings variation were able to reduce the deleterious effect of the artifacts, produced by different metallic or high-density materials, by standardizing gray values and increasing contrast-noise ratio.13,14

Despite the advantages of CBCT, intraoral periapical radiography is still the standard method for postoperative implant evaluation. Nevertheless, due to the two-dimensional aspect, it is not completely appropriate to assess the bone around dental implants, since there is a lack of visualization of the buccal and lingual cortical plates, and only interproximal bone assessment is possible.2,15

Thus, the effort to minimize the negative effect of artifacts produced by other materials in CBCT images should also be evaluated in the presence of dental implants, in order to improve the postoperative evaluation. However, as artifact production is directly influenced by the object, the effect of the postprocessing or exposure parameters in improving image quality may vary according to the type of dental implant.

Therefore, this in vitro study evaluated the artifacts produced by titanium and zirconia implants in CBCT images, obtained from a wide range of acquisition protocols; additionally, it compared the effect of different settings on image improvement for the different materials.

**MATERIALS AND METHODS**

Two types of dental implants were used for the analysis of artifact production: a zirconium oxide implant (Z-Look3, Z-systems) and a titanium implant (Titamax, Neodent), both with the same size and diameter (4 × 11 mm).

**Phantom and Implant Placement**

On the right posterior region of one dry partially edentulous human mandible, a point was marked to indicate the position of the implants; an epoxy resin-based tissue substitute block was fixed on the buccal cortical to serve as a reference for the implant position and the axial image selection later. The mandible was covered with a layer of wax to simulate soft tissue attenuation, where two areas were cut into a rectangular shape at the buccal cover on both sides in order to standardize the mandible position for the image acquisition.

An operator with experience in implant dentistry placed the implants. Before placing each implant to acquire the CBCT scans, the operator progressively prepared the area where the implants would be inserted using a cylindrical drill (KG, Sorensen). During progressive enlargements, both implants were manually inserted into the area until they could be placed and removed from the bone without resistance. This prevented possible damage to the mandible that could be caused by replacing the implants during the study. The implants were used in a sequence; first, the zirconia implant was placed and the first part of the data was acquired. After this, the zirconia implant was removed and the titanium implant was placed in the same position, and the second part was conducted following the same procedures. The mandible received one kind of implant at each time, and the materials were not matched.

Subsequently to the implant insertion, the mandible was placed in a container and fixed to the bottom with impression material, adapted to the symphysis and the posterior body, as well as to the rectangular areas in the wax layer, so the mandible position was standardized.

**CBCT Scanning**

Prior to CBCT acquisitions, the phantom was fixed to the machine platform. Forty scans were acquired in two sessions with the ProMax 3D unit (Planmeca Oy). For the first session, the zirconia implant was placed and 20 scans were performed under different exposure protocols, in a series divided into two groups: 10 scans were taken with the artifact reduction tool in medium level and the other 10 scans without it. Five k-voltage (kVp) settings (70, 76, 80, 86, and 90 kVp) and two resolution modes (high-resolution, voxel 0.16 mm; and low-resolution, voxel 0.32 mm) were used. Field of view size (8 × 8 cm) and milliamperage (8 mA) settings were constant for all scans.

Thereafter, 20 scans were taken with the titanium implant inserted, under the same protocols and groups.

**Image Analysis**

Under dim light conditions, all datasets were individually assessed by an oral radiologist previously calibrated (T.V.V.). For each CBCT scan, an axial reconstruction was selected at the upper level of the epoxy block. All reconstructions were selected at the same axial level; to be consistent, the distance from the apex of the implant to the axial reference line was measured at the coronal reconstruction, and this measurement was used as a reference to select the axial image in all CBCT scans. Then, images were saved and evaluated using the ImageJ software (NIH Image).

On each axial image, the histogram of two areas was calculated using a macro, so the regions of interest
(ROI) were standardized for all the images: (1) over the bone, close to the implant (implant area); and (2) over the water, distant from the implant (control area) (Fig 1). The mean gray level and the standard deviation of the ROIs were determined, and the contrast-to-noise ratio was calculated:

\[
\text{CNR} = \frac{|\text{Mean}_{\text{Implant}} - \text{Mean}_{\text{Control}}|}{\sqrt{(\text{SD}^2_{\text{Implant}} + \text{SD}^2_{\text{Control}})}}
\]

**Table 1** SD Titanium and Zirconia Results According to Protocols for Control and Implant Area

<table>
<thead>
<tr>
<th>Protocol</th>
<th>kVp</th>
<th>MAR</th>
<th>Resolution</th>
<th>Titanium</th>
<th></th>
<th>Zirconia</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SD control</td>
<td>SD implant</td>
<td>SD control</td>
<td>SD implant</td>
</tr>
<tr>
<td>1</td>
<td>70</td>
<td>Off</td>
<td>Low</td>
<td>9.66</td>
<td>14.88</td>
<td>10.71</td>
<td>25.91</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>On</td>
<td>Low</td>
<td>10.71</td>
<td>10.12</td>
<td>9.52</td>
<td>18.30</td>
</tr>
<tr>
<td>3</td>
<td>70</td>
<td>Off</td>
<td>High</td>
<td>5.98</td>
<td>14.11</td>
<td>6.21</td>
<td>25.82</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>On</td>
<td>High</td>
<td>6.30</td>
<td>11.35</td>
<td>6.03</td>
<td>16.67</td>
</tr>
<tr>
<td>5</td>
<td>76</td>
<td>Off</td>
<td>Low</td>
<td>9.76</td>
<td>14.14</td>
<td>7.62</td>
<td>24.36</td>
</tr>
<tr>
<td>6</td>
<td>76</td>
<td>On</td>
<td>Low</td>
<td>7.13</td>
<td>11.96</td>
<td>7.91</td>
<td>16.90</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
<td>Off</td>
<td>High</td>
<td>4.50</td>
<td>12.45</td>
<td>4.48</td>
<td>25.27</td>
</tr>
<tr>
<td>8</td>
<td>76</td>
<td>On</td>
<td>High</td>
<td>5.22</td>
<td>9.81</td>
<td>5.42</td>
<td>14.78</td>
</tr>
<tr>
<td>9</td>
<td>80</td>
<td>Off</td>
<td>Low</td>
<td>6.91</td>
<td>11.91</td>
<td>7.78</td>
<td>24.18</td>
</tr>
<tr>
<td>10</td>
<td>80</td>
<td>On</td>
<td>Low</td>
<td>8.55</td>
<td>11.99</td>
<td>6.21</td>
<td>15.79</td>
</tr>
<tr>
<td>11</td>
<td>80</td>
<td>Off</td>
<td>High</td>
<td>4.54</td>
<td>11.91</td>
<td>4.82</td>
<td>24.47</td>
</tr>
<tr>
<td>12</td>
<td>80</td>
<td>On</td>
<td>High</td>
<td>4.51</td>
<td>9.56</td>
<td>4.14</td>
<td>14.43</td>
</tr>
<tr>
<td>13</td>
<td>86</td>
<td>Off</td>
<td>Low</td>
<td>6.16</td>
<td>11.33</td>
<td>6.08</td>
<td>23.95</td>
</tr>
<tr>
<td>14</td>
<td>86</td>
<td>On</td>
<td>Low</td>
<td>4.54</td>
<td>9.36</td>
<td>5.53</td>
<td>14.33</td>
</tr>
<tr>
<td>15</td>
<td>86</td>
<td>Off</td>
<td>High</td>
<td>4.19</td>
<td>10.61</td>
<td>4.25</td>
<td>22.81</td>
</tr>
<tr>
<td>16</td>
<td>86</td>
<td>On</td>
<td>High</td>
<td>4.81</td>
<td>9.61</td>
<td>4.18</td>
<td>14.35</td>
</tr>
<tr>
<td>17</td>
<td>90</td>
<td>Off</td>
<td>Low</td>
<td>5.41</td>
<td>11.91</td>
<td>5.68</td>
<td>22.10</td>
</tr>
<tr>
<td>18</td>
<td>90</td>
<td>On</td>
<td>Low</td>
<td>5.64</td>
<td>9.99</td>
<td>5.40</td>
<td>10.93</td>
</tr>
<tr>
<td>19</td>
<td>90</td>
<td>Off</td>
<td>High</td>
<td>3.67</td>
<td>10.32</td>
<td>3.80</td>
<td>22.78</td>
</tr>
<tr>
<td>20</td>
<td>90</td>
<td>On</td>
<td>High</td>
<td>3.79</td>
<td>9.45</td>
<td>3.87</td>
<td>13.18</td>
</tr>
</tbody>
</table>

© 2019 BY QUINTESSENCE PUBLISHING CO, INC. PRINTING OF THIS DOCUMENT IS RESTRICTED TO PERSONAL USE ONLY. NO PART MAY BE REPRODUCED OR TRANSMITTED IN ANY FORM WITHOUT WRITTEN PERMISSION FROM THE PUBLISHER.

**RESULTS**

**Statistical Analyses**

The standard deviation and contrast-noise ratio of the titanium and zirconia implant images were analyzed. An analysis of variance (ANOVA) and post hoc Tukey test, with a significant P value < .05, were conducted using the main effects of the type of implant, metal artifact reduction tool, resolution, kVp, and their two-way interactions. Moreover, the interaction of contrast-noise ratio and standard deviation for each combination of settings was evaluated.

**Standard Deviation**

The data for standard deviation at the control and implant area are shown in Table 1. ANOVA indicated that zirconia implants produced more artifacts than titanium implants, according to the standard deviation values (P < .0001). The results also showed that the main effects of the metal artifact reduction tool and kVp were significant (P < .0001 and P = .041, respectively), indicating that the standard deviation was...
Vasconcelos et al

lower when the metal artifact reduction tool was active than when the metal artifact reduction tool was off for both implants, and 90 and 86 kVp provided lower values than 70 kVp. However, the resolution did not affect the standard deviation ($P = .453$). The line plots in Fig 2 illustrate how the standard deviation in the implant area decreased as the kVp increased, as well as when the metal artifact reduction tool was activated. This occurred for both implants; however, the metal artifact reduction effect was stronger for zirconia than titanium implant images.

**Contrast-to-Noise Ratio**

Similarly to standard deviation, contrast-noise ratio was affected by the type of implant ($P < .0001$), with the values for zirconia images being lower than for titanium images. There was also evidence that the metal artifact reduction tool had an effect on the mean value of contrast-noise ratio for both implants ($P < .0001$), whereas kVp had an effect only on titanium images ($P = .008$). In that case, in general, 90 and 86 kVp provided higher values than 70 kVp. However, the contrast-noise ratio was not affected by resolution ($P = .158$). The line plots of contrast-noise ratio (Fig 3) show that the metal artifact reduction tool generally increased the contrast-noise ratio.

**Contrast-to-Noise Ratio and Standard Deviation**

Figures 4a and 4b show scatterplots of contrast-noise ratio and standard deviation for titanium implants and zirconia implants, respectively. The letters indicate the machine settings that provide the best combinations of high contrast-noise ratio and low standard deviation, starting with letter A. For both implants, the protocols 90 kVp, low resolution, and metal artifact reduction tool on as well as 86 kVp, high resolution, and metal artifact reduction tool on appeared to be among the best ones. Table 2 identifies the four best machine settings for each implant.

Figures 5 and 6 show examples of axial images of the best protocols for titanium and zirconia, respectively, as well as their correspondent images without the metal artifact reduction tool.
DISCUSSION

Image artifacts related to high-density materials can severely degrade the quality of CBCT scans and, consequently, impair the desired diagnosis. Among these materials, dental implants stand out because they are increasingly used in dentistry and are nonremovable items present within or adjacent to the ROI to be evaluated. For this reason, efforts to optimize exposure factors are essential for image quality improvement; however, few studies have compared artifact production related to different types of dental implants or the effect of several acquisition protocols on image quality. In the present study, it was found that the

![Graphs showing scatterplots of contrast-noise ratio (CNR) and standard deviation for titanium and zirconia implants.]

![Examples of axial images showing the best protocols for titanium and zirconia implants.]

### Table 2: Best (Higher CNR and Lower SD) Protocol Settings Combination for Titanium and Zirconia Implants

<table>
<thead>
<tr>
<th>Best combinations</th>
<th>kVP</th>
<th>Resolution</th>
<th>MAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Titanium</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>86</td>
<td>High</td>
<td>On</td>
</tr>
<tr>
<td>B</td>
<td>90</td>
<td>Low</td>
<td>On</td>
</tr>
<tr>
<td>C</td>
<td>90</td>
<td>High</td>
<td>On</td>
</tr>
<tr>
<td>D</td>
<td>80</td>
<td>High</td>
<td>On</td>
</tr>
<tr>
<td><strong>Zirconia</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>90</td>
<td>Low</td>
<td>On</td>
</tr>
<tr>
<td>B</td>
<td>86</td>
<td>Low</td>
<td>On</td>
</tr>
<tr>
<td>C</td>
<td>90</td>
<td>High</td>
<td>On</td>
</tr>
<tr>
<td>D</td>
<td>86</td>
<td>High</td>
<td>On</td>
</tr>
</tbody>
</table>

CNR = contrast-noise ratio; MAR = metal artifact reduction.
amount of artifacts is associated with the type of dental implant, and acquisition protocols influence the quality of the image related to titanium or zirconia differently.

In this study, the artifacts were objectively evaluated by calculating standard deviation in an area adjacent to the implant and contrast-noise ratio. These parameters were chosen because they provide, respectively, an overall estimation of the extent of darkening and brightening related to artifacts and of image contrast resolution, which were also used by previous studies on this subject matter. Additionally, a single human mandible was used to standardize the radiation scattering caused by bone structures and to reliably evaluate the artifacts caused in the hard tissue adjacent to the implant. Both titanium and zirconia implants also had standardized dimensions (4 x 11 mm) to avoid biases related to different amounts of high-density materials in artifact production. Conversely, some in vitro studies used homogenous phantoms, different mandibles, or varying dimensions of the studied materials for artifact evaluation.

The zirconia implant was related to higher production of artifacts than titanium implants, as previously reported. Considering the standard deviation of the gray values, it can be stated that the lower standard deviation values in the ROI adjacent to the implant are related to low artifact expression. Similar to previous studies, increased kVp and use of the metal artifact reduction tool positively affected the image quality, reducing standard deviation values. However, the effect of such parameters was substantially more marked for zirconia implants. These results can be attributed to some important factors.

First, the main action of high kVp in artifact production is to decrease the beam-hardening phenomenon, which is caused by the absorption of low-energy x-ray photons by high-density objects. Thus, this phenomenon increases the mean energy of the beam and disturbs the reconstruction process of the images. High kVp increases the mean energy of photons, which would be absorbed less by high-density objects, and consequently, fewer artifacts would be produced. Additionally, high kVp reduces the contrast, which may contribute to higher homogeneity of the images. However, it should be kept in mind that levels of kVp used in CBCT units produce images with adequate contrast to diagnostic tasks in dentistry.

Also, metal artifact reduction tools have been developed through postprocessing algorithms and used in order to limit the effect of artifacts on the image quality. Although the manufacturers do not reveal exactly how the metal artifact reduction tool works, it appears to reduce the variability of gray values by applying a threshold corresponding to the mean gray values of the image, and correcting any area that is much more or less dense than the threshold. This process can occur through iterative or projection modification methods. While in the iterative methods, the reconstruction process uses only noncorrupted projections, since it discards those affected by metal artifacts, in the projection modification method, the corrupted raw data are segmented and replaced by estimated values. However, despite the efforts, there is still no consensus on its actual effectiveness in different diagnostic tasks.

Concerning the different degrees of effect of these parameters on the titanium and zirconia images, this can be explained by different density, physical properties, and atomic numbers of titanium (Z: 22) and zirconium (Z: 40) that compound the implants, which directly influence their interaction with the x-ray beam. The results of the present study reaffirm that the metal artifact reduction tool works better when more artifacts are present, as was found in previous studies.

Although it is expected that a larger number of basis images decreases the artifact production, the resolution modes (low or high) had no influence on the standard deviation or contrast-noise ratio values in any protocols evaluated in the present study. This result is consistent with that reported by Pauwels et al (2013), who evaluated the standard deviation values of voxels adjacent to titanium and lead rods and observed no difference between high and low resolution protocols for some devices. In the CBCT unit studied (ProMax 3D), voxel size varies according to the resolution mode; this by itself does not seem to have an influence on the results, since voxel size does not directly affect the measurement of standard deviation in large heterogenous regions. Since there were no differences between the resolution modes, and the high mode increases the radiation dose to the patient and the image reconstruction time, the use of the low mode is beneficial.

Whereas images that showed the lowest standard deviation combined with the highest contrast-noise ratio had good quality, some of the best protocol setting combinations were the same for titanium and zirconia implants. Additionally, the top three combinations are clearly distinct from each other for the zirconia implant in terms of contrast-noise ratio and standard deviation values, while there is little separation among the top five combinations for the titanium implant. This highlights how protocols act differently for each implant as well as how the choice of acquisition protocol can influence the image quality, especially for zirconia implants. Therefore, professionals must bear in mind that selection of the acquisition protocol should take into account the type of material present in the scanning region, the image quality required for diagnosis, and the radiation dose to the patient.

Despite the wide variety of acquisition protocols evaluated here involving two materials commonly
used in implantology, further studies should be performed on artifact production by other high-density materials, such as orthodontic brackets and prosthetic crowns, and in other CBCT devices in order to seek protocols that provide effective reductions in the expression of image artifacts. On this point, although there are many CBCT machines on the market and each have their own characteristics, studies have shown a trend of high kVp and metal artifact reduction tools decreasing artifacts. Moreover, a recent study found that most CBCT machines may be able to quantitatively assess alveolar bone quality, with a level of accuracy that approaches microcomputed tomography, which is an important aspect in implantology.

In addition, studies on the effect of acquisition protocols on different diagnostic tasks are needed to assist the professional decision-making on which protocol to choose for specific clinical indications, as determined by the ALARA (as low as reasonably achievable) principle.

CONCLUSIONS

This study demonstrated that zirconia and titanium implants produced different amounts of artifacts, with zirconia implants generating more artifacts. Increasing kVp and the metal artifact reduction tool are efficient in decreasing the artifacts for both implants, whereas spatial resolution does not affect their production. Therefore, also considering the radiation dose for patients, the use of 90 kVp, low resolution, and activated metal artifact reduction tool are recommended for both types of implants.

ACKNOWLEDGMENTS

The authors reported no conflicts of interest related to this study.

REFERENCES