A comparative evaluation of the metallic artifact generated by a ceramic dental implant and a titanium dental implant imaged on cone-beam computed tomographic scans
An ex vivo study

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Why Is This Important?

Dentists are increasingly using cone-beam computed tomography (CBCT) for 3-dimensional evaluation of the maxillofacial skeleton, and CBCT imaging has become the preferred modality to image potential implant sites. The physics behind the CBCT scan acquisition inherently causes artifacts in the presence of metallic structures. Dental implants are traditionally made of titanium alloys that cause metallic artifacts of varying degrees, which consequently obscure proximal anatomy. Metallic artifacts often obstruct the evaluation of peri-implant structures and can limit the diagnosis of conditions like peri-implantitis or associated conditions. It was expected that the introduction of ceramic dental implants would aid in resolving the presence of these artifacts in CBCT scans. There are not many well-designed studies that have investigated differences in metallic artifacts generated by ceramic and titanium dental implants. This study qualitatively and quantitatively evaluated the metallic artifact generated by both types of implants with CBCT imaging and conclusively showed that ceramic dental implants produce more metallic artifacts than titanium dental implants. This outcome is of significance because an increase in artifacts obscures circumferential implant anatomy and limits the evaluation of peri-implant structures and associated pathology.

Abstract

\textbf{Background.} Dental implants are becoming the treatment of choice for restoring edentulous sites. Dental implants are typically made of a titanium alloy, and this produces a metallic artifact that obscures adjacent anatomy when imaged using x-radiation, specifically on cone-beam computed tomographic (CBCT) scans. This artifact makes it challenging to evaluate peri-implant bone levels and any associated pathology. It was hypothesized that the introduction of ceramic implants would help in overcoming this challenge due to the nature and composition of the ceramic. The objective of this study was to compare the metallic artifact produced by ceramic and titanium dental implants when imaged with CBCT.

\textbf{Methods.} Dental implants were placed in the edentulous sites of 2 dry human skulls, and CBCT scans with a standard 360° acquisition and a low-dose 180° acquisition were obtained. The metallic artifact generated by the implants was measured quantitatively using pixel intensity values and qualitatively using a modified Likert scale.

\textbf{Results.} Average pixel intensity values, by gnathic region, ranged from 123.5 through 507 for titanium implants and 500 through 1,088.5 for ceramic implants. Qualitative analysis showed that ceramic implants produced more metallic artifact than titanium implants. Intraoperator and interoperator reliabilities assessed using Cronbach \(\alpha\) showed consistency for both qualitative and quantitative analyses.

\textbf{Conclusion.} Ceramic dental implants produced significantly more metallic artifact when imaged on CBCT scans than titanium implants.

\textbf{Key Words.} Cone-beam computed tomography (CBCT); dental implants; titanium dental implants; ceramic dental implants; beam hardening; metallic artifact; CBCT artifact.
Introduction

Dental implants are increasingly becoming the treatment of choice for restoring edentulous sites. A study done by Elani et al. reported that the prevalence of dental implants increased from 0.7% in 1999-2000 to 5.7% in 2015-2016 according to data from the National Health and Nutrition Examination Survey. It was predicted that the prevalence of dental implants may reach 17% by 2026 if the increase of dental implants continues at the current pace.

One of the key tools in implant treatment planning and placement is imaging the implant site in 3-dimensions using cone-beam computed tomography (CBCT). Cross-sectional images generated from CBCT, along with implant planning software programs, aid in evaluating the implant site for bone levels and proximity to significant structures such as the floor of the sinus and the inferior alveolar nerve. With this, the clinician is able to plan the procedure to ensure that the implant is placed at the appropriate location and does not impinge on any critical anatomic structures in the proximity.

Traditional dental implants are typically made of titanium or titanium alloys owing to their mechanical properties, high corrosion resistance, and biocompatibility. However, there are several disadvantages to using metallic implants. Esthetically, titanium implants are often reported to show discoloration in the gingiva, which can be especially prominent if the patient has a thin gingival phenotype or a high smile line. Furthermore, patients with titanium allergies may be unable to have titanium-based dental implants.

In the past 10 years, ceramic implants have been increasingly considered viable alternatives to titanium implants, especially in the anterior esthetic zone. Ceramic implants have been found to have similar rates of survival, success, and bone loss as traditional titanium implants. Radiographically, a disadvantage of titanium implants is the metallic artifact produced when imaged with CBCT.

This metallic artifact results from a combination of several phenomena but primarily from photon starvation. When imaged with ionizing radiation, metallic objects absorb photons and prevent them from reaching the detector; this often results in artifacts and can lead to nonregistration of data adjacent to the metallic structure. The challenge in the lack of data adjacent to the implant fixture is that the clinician will not be able to assess peri-implant bone levels, the health of the surrounding bone, or the implant’s success or failure using CBCT. Additionally, if CBCT needs to be performed for other diagnostic indications, the artifact could lead to poor-quality or nondiagnostic scans. Several postprocessing programs have been developed to reduce the metallic artifact and are under investigation, such as the metallic artifact reduction (MAR) program, but they are all unable to make the scan completely devoid of the noise induced by the metallic object.

There is lack of conclusive evidence in the literature regarding the metallic artifact produced by ceramic implants, and only a small number of studies have compared the metallic artifact generated by ceramic and titanium dental implants. Because pure ceramic does not produce a metallic artifact, it has been speculated that ceramic implants may improve the results of imaging with ionizing radiation, especially on imaging with CBCT.

The objective of this study was to perform quantitative and qualitative assessments of the metallic artifacts produced by both ceramic and titanium dental implants when imaged with CBCT. In addition, this study evaluated the metallic artifact produced by the implants on a standard 360° CBCT acquisition, and compared it with the artifact produced on a low-dose 180° CBCT scan.

Methods

Implant placement

Two dry, partially edentulous human skulls used in the study were acquired from the Education Support Services (Anatomy Laboratory) of the School of Dental Medicine at University of Connecticut. Any metallic objects remaining in the skulls, such as screws and pins, were removed before implant placement. Putty matrix material (Reprosil; Dentsply Sirona) was used to simulate the soft tissue of the gingiva. Putty was placed on the buccal and palatal aspects of both the mandible and maxilla. Dental implants (PURE Ceramic Implant [Monotype] 4.1 mm regular diameter, zirconia surface, large grit, acid-etched implant surface 10 mm, abutment height 5.5 mm, zirconium dioxide [ZrO2] and ø—4.1 mm, 8.0 mm, titanium; Straumann) were used for the study. Implants were placed in edentulous sites using rope wax (Utility Wax Strips, Large White; Kulzer). CBCT scans were acquired with different combinations of titanium and ceramic implants to simulate clinical scenarios (Table 1). Scans were obtained with implants in different

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<tr>
<th>Scan No.</th>
<th>Protocol</th>
<th>Implant Site</th>
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<tr>
<td>Scan 1</td>
<td>360°</td>
<td>2 Titanium; 9 ceramic</td>
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<tr>
<td>Scan 2</td>
<td>180°</td>
<td>2 Titanium; 9 ceramic</td>
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<td>Scan 3</td>
<td>360°</td>
<td>26 Titanium; 9 ceramic</td>
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<td>Scan 4</td>
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<td>Scan 6</td>
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gnathic sites (anterior maxilla and mandible, posterior maxilla and mandible) as well as in different combinations with the ceramic and titanium implants in the skull alone or at the same time. A total of 18 CBCT scans were acquired using the 360° protocol and the low-dose 180° protocol. A skull with no implants placed served as control.

Image acquisition

CBCT images were acquired using a 3D CBCT scanner (3D Accuitomo; J Morita). The Field of view was 80 × 80 mm with a voxel size of 0.125 mm. The exposure parameters for the standard 360° protocol were 90 kV, 10 mA, with an exposure time of 17.5 seconds. The exposure parameters for the low-dose 180° protocol were 80 kV, 10 mA, with an exposure time of 9.0 seconds.

Image analysis

Before the commencement of the study, a calibration session was conducted by a board-certified oral maxillofacial radiologist (A.T.). The research methodology and the scoring parameters were established. A dental student (E.W.) and an oral maxillofacial radiology resident in training (A.V.) independently evaluated the qualitative and quantitative metallic artifacts of the implants.

Quantitative assessment

The intensity of the metallic artifact was measured using pixel intensity values (PIVs) generated by the CBCT reconstruction program Invivo-6 (Anatomage). The Invivo software program can generate point coordinates of PIVs of an area of interest. The operator placed the cursor at the region of interest, and the software generated a PIV at that particular location. The location points for measuring the PIVs were standardized to facilitate repetitive measurements. The axial slice to be used for measurements was marked with an arrow once the evaluators agreed on which axial image corresponded to the midimplant region on the sagittal plane (Figure 1). Measurements were taken approximately 1 mm buccal to the implant on the predetermined axial image (Figure 1). Raw data were averaged by gnathic region, and the average PIVs were recorded in the anterior maxilla, posterior maxilla, anterior mandible, and posterior mandible for both the 360° and low-dose 180° protocols (Table 2). PIV measurements were repeated for a single implant on one-half of the scans by each observer to perform intraobserver reliability.

Qualitative assessment

Scans were evaluated qualitatively to assess the diagnostic quality using a modified Likert scale. All CBCT images were viewed on a radiology workstation computer, HP Pavilion ZE 2000 (Hewlett-Packard) with a dual monitor display (1,600 × 900-pixel resolution). The viewing conditions (room lighting, display monitor settings) were standardized. Examiners were allowed to manipulate density, contrast, and magnification to simulate actual radiologic practices. The scoring criteria were as follows:

1. Metallic artifact is significant, affects overall scan quality, is obliterating the adjacent anatomy, and can affect diagnosis.
2. Metallic artifact is present and affects overall scan quality, but it does not affect the evaluation of the adjacent anatomy and diagnosis.
3. Metallic artifact is minimal and does not affect the scan quality or diagnosis.
4. No metallic artifact.

Statistical analysis

Statistical analyses were performed using Microsoft Excel and IBM SPSS Statistics 27. Comparative analyses of PIVs were performed using independent \( t \) tests. A \( P \) value of less than .05 was considered statistically significant. The inter- and intraoperator reliabilities of quantitative analyses was assessed using Cronbach \( \alpha \).

Results

In both the standard 360° protocol and the low-dose 180° protocol, the ceramic implant had statistically significant higher PIVs compared with titanium implant (standard 360° protocol: \( P = .016 \); low-dose 180° protocol: \( P = .010 \)) (Table 2, Figures 2, 3).

PIVs produced by the titanium implant in the standard 360° protocol did not have a statistically significant difference compared with the low-dose 180° protocol (\( P = .333 \)) (Table 2). This was also true of the ceramic implant; there was no statistically significant difference between the PIVs produced in the standard 360° and low-dose 180° protocol (\( P = .557 \)) (Table 2).

When comparing PIVs by gnathic region, there was no statistically significant difference between the average PIVs in any of the regions.

The intraobserver reliability was excellent for both observers (Cronbach \( \alpha \) scores, 0.99 for observer 1; 0.96 for observer 2). The interoperator reliability was excellent for the quantitative analysis of PIVs (Cronbach \( \alpha \) score, 0.958 for the 360° protocol; 0.987 for the low-dose 180° protocol).

The qualitative scores obtained by using the modified Likert scale showed a score of 2 for the titanium implant and a score of 1 for the ceramic implant in all image acquisitions by both observers.

Discussion

The metallic artifact generated by implants in CBCT scans poses a significant challenge during radiographic interpretation of the peri-implant bone status.\(^4,8\) The metallic artifact generated by CBCT appears as bright streaks (areas of increased radiodensity) radiating from the metal, interspersed with darker regions (areas of reduced radiodensity) (Figures 4, 5). The reduction in radiodensity obscures peri-implant bone levels. Furthermore, nonregistration of data adjacent to the implant may simulate peri-implant bone loss that leads to erroneous diagnoses. If CBCT can depict early bone loss around the implant, it can be saved before failing. Although intraoral radiographs perform better than CBCT
scans in assessing mesiodistal bone levels around implants because of the minimal metallic artifact, they are limited in their ability to depict circumferential bone levels.

The results of our study showed that ceramic implants produced significantly more metallic artifacts than titanium implants on CBCT scans. This result was somewhat unexpected, since imaging of pure ceramic using CBCT does not cause metallic artifact, as pure ceramic does not contain any inherent metallic fillers. However, ceramic implants used in dentistry are alloys that have metallic structures incorporated throughout; even though several commercially available ceramic dental implants advertise their products as pure ceramic, it may merely be a commercial trademark, as the addition of metallic alloys is necessary to act as a filler to give the required strength to the implant.

Our results may be due to the increased electron densities of the metallic components of the ceramic implants compared with the titanium implants. ZrO₂ is the primary metal oxide used for structural stability in ceramic implants. The atomic number (Z) of zirconium (Z = 72) is higher than that of titanium (Z = 22), and as the Z value increases, electron density also increases. The increased electron density causes absorption of more x-ray photons, and thus fewer photons are able to reach the detector. Therefore, there are likely fewer x-rays hitting the detector when a ceramic implant is imaged than a titanium implant; this may perhaps explain the increase in metallic artifacts adjacent to the ceramic implants. Our findings are consistent with a study by Sancho-Puchades et al.,⁹ which showed that ZrO₂ implants resulted in a 3-fold increase in metallic artifacts compared with titanium, and they attributed this to the difference in Z values.

Our findings are also consistent with a study done by Demirturk Kocasarac et al.,¹⁰ who found that implants that contained titanium, whether pure titanium or a titanium-zirconia combination, had less prominent radiographic artifacts than zirconia implants. They measured these artifacts by choosing the CBCT axial slice that best represented the artifact, whereas in our study, we chose a standardized axial slice that corresponded to the midimplant region on the sagittal plane. Quantitatively, they subtracted the gray level of the darkest pixel from the area of the lightest pixel that would best represent the effect of the artifact, whereas our study measured artifact in 1 standardized area approximately 1 mm buccal to the implant.

A study by Vasconcelos et al.¹¹ also evaluated titanium and ceramic implant artifacts and reported similar results. They found that zirconia implants produced the most significant artifacts when compared with both titanium and titanium-zirconia implants. Our study expands on their findings. In their study, only single implants were evaluated in the mandible; but in our study, titanium and zirconia implants placed alone as well in combinations, in both the mandible and maxilla, were evaluated.

In our study, no statistically significant difference in PIVs between the standard 360° protocol and the low-dose 180° protocol was found for either the titanium or the ceramic implants. Pauwels et al.,¹² reported similar results for high-dose versus low-dose protocols. The authors also compared metallic artifacts generated by CBCT scanners and varied exposure parameters for different protocols. They reported that even an 88% increase in mA did not have any effect on the artifact and concluded that the effect of exposure parameters and high-dose versus low-dose
protocols on artifact reduction is limited.\textsuperscript{13} However, this is challenged in the study by Demirturk Kocasarac et al.,\textsuperscript{10} which showed low-resolution CBCT yielded fewer metal artifacts compared with high-resolution CBCT scans; the advantage of low-resolution scans is a significant decrease in radiation dose.

This ex vivo study showed that metallic artifacts were observed around both ceramic and titanium dental implants, irrespective of their position in the maxilla or mandible. This finding is consistent with studies by Benic et al.\textsuperscript{13} and Sancho-Puchades et al.\textsuperscript{9} The intensity of artifacts in this study varied in different gnathic regions, and the artifacts generated by ceramic implants were more pronounced in the anterior maxilla and mandible for both protocols; however, this finding was not statistically significant (Table 2). However, ceramic implants are usually placed in the anterior esthetic zone, and the increase in artifact in the anterior region should be taken into consideration while planning the treatment and during assessment of peri-implant bone levels.

We qualitatively assessed the effect of the metallic artifact on the overall diagnostic quality of the scan. The qualitative assessment revealed better results for titanium implants than ceramic implants. The metallic artifact generated by the implants in our study was in the buccolingual direction (Figures 4, 5). The artifact was a resultant of the interplay between different effects such as photon starvation, quantum noise, and cup-cap artifact. The direction or orientation of the artifact is critically important.\textsuperscript{6,7} In this study, the primary beam and the redundant data generated during image acquisition were in buccolingual direction; this may be different in other scanners and is a valuable parameter to consider while evaluating artifacts. The orientation of the artifact will determine the anatomic structures that will be obscured. Awareness of the pattern of the artifact is essential to avoid misdiagnosis, as the peri-implant area is critical in assessing bone levels and osseointegration.

In our study, we standardized the size of the titanium and ceramic implants (4.1 mm) for different combinations of acquisitions. We also used a single CBCT scanner and standardized exposure parameters for all the acquisitions. Sancho-Puchades et al.\textsuperscript{9} used different sizes of titanium implants (4.1 mm, 3.3 mm). Pauwels et al.\textsuperscript{12} used titanium and lead rods to simulate implant and high-density restorative materials. Pauwels et al.\textsuperscript{12} also compared different CBCT scanners.

In our ex vivo study, we placed the implants in dry skulls in multiple gnathic combinations to simulate real-life clinical scenarios. Previous studies have used study casts made of type IV dental stone, polymethyl methacrylate phantom, and other materials.\textsuperscript{9,12} However, in our study, we attempted to provide the closest real-life scenario to generate the artifact and provide a conclusive narrative for this concept.

One of the limitations of our study was incorporating fewer edentulous sites and a smaller sample size; however, the multiple combinations simulated were deemed adequate to establish proof of concept. Another limitation was the absence of facial soft-tissue simulation; it is difficult to simulate the soft tissue of the head and neck. However, we believe that even though this soft tissue can theoretically have an effect on the x-radiation beam, it would be minimal. Lastly, a limitation was using PIVs to quantify the artifact. PIVs can be affected by the beam hardening artifact and surrounding materials; therefore, some authors have recommended not using PIVs for imaging.
measuring bone density. However, Azeredo et al. found that there were significant differences in PIVs among 4 different scanners, but they did not vary with different software programs. In our study, we only used 1 CBCT unit. However, we did not measure PIVs in different software programs. PIVs can be standardized by obtaining measurements of known anatomic structures within the scan. Future studies overcoming these limitations could yield better results and provide more insight.

Some amount of metallic artifact is inevitable with available CBCT technology and reconstruction methods. Apart from varying exposure parameters, such as arc trajectory (low-dose 180°, standard 360°), several investigators have also tested various MAR program algorithms. Bechara et al. reported an increase in contrast to noise ratio using the MAR program in the presence of metal. Kamburoglu et al. did not find a significant difference in the assessment of peri-implant bone levels with and without MAR program modes.

Conclusions

This study found that ceramic implants produced significantly more metallic artifacts than titanium implants when imaged on CBCT scans. For both ceramic and titanium implants, there was no significant difference in artifact intensity when using a low-dose CBCT acquisition compared with a standard CBCT acquisition.

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