

Effect of different cone beam computed tomography settings on artifact production in titanium and zirconia dental implants: An in vitro study

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Abstract

Background. The use of dental implants in the treatment of edentulous patients is increasing. Zirconia implants are an alternative to titanium implants, offering advantages in terms of aesthetics and biological compatibility. However, the number of artifacts observed on radiographic images with zirconia implants compared to titanium implants is yet to be determined.

Objectives. The purpose of this study was to evaluate the impact of different cone-beam computed tomography (CBCT) parameters on the production of artifacts in zirconia and titanium implants.

Material and methods. A dry human mandible was coated with wax to simulate human soft tissues and examined. Subsequently, titanium and zirconia implants were placed at the same points in the posterior region of the mandible. The production of artifacts on CBCT scans was evaluated using 2 parameters. The first parameter, the standard deviation within the region of interest (SD_{ROI}), is based on a comparison of the gray levels at implant and control areas. The second parameter was the contrast-to-noise ratio (CNR), which was evaluated for different protocols created by various combinations of the field of view (FOV) area, milliamperage [mA] intensity and metal artifact reduction (MAR) programs.

Results. The study found that zirconia implants produced more artifacts than titanium implants. However, the production of artifacts in zirconia implants could be significantly reduced by increasing the mA values, performing CBCT scans with smaller FOV areas, and enabling MAR programs.

Conclusions. The production of artifacts is a disadvantage of zirconia implants, but this drawback can be mitigated by selecting appropriate protocols for the CBCT device.

Keywords: titanium, zirconia, dental implant, tomography, artifact

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Introduction

Radiographic imaging is the diagnostic tool used in oral implantology from pre-treatment planning to post-treatment control.¹ This tool is used to evaluate the alveolar bone in the peri-implant region and to control the passive fit of the cemented restorations that are frequently used in implant prostheses.^{1,2} Although panoramic radiographs are the most commonly used imaging method in dental implantology, the use of cone-beam computed tomography (CBCT) is increasing daily as it provides more detailed analysis than orthopantomography (OPG).³ Recently, there has been concern that CBCT images are prone to metal artifacts that obscure the visualization of the peri-implant region and alveolar bone.⁴

In radiology, an artifact is defined as the presence of visual, reconstructed radiographic data that is not part of the radiographically examined object.⁵ Artifact production is related to the technical aspects of CBCT. Some objects can act as filters that change the X-ray spectrum depending on their atomic number and density. Therefore, the object being scanned has importance in artifact production.⁶

The photons emitted by the X-ray source are absorbed as they pass through objects, with low-energy photons being more absorbed than others. This results in an increase in the average energy of the remaining high-energy photons, a phenomenon known as the “beam hardening effect”. This effect occurs more frequently in metal objects due to their denser nature and is one of the most common causes of the formation of metal artifacts. Beam hardening results in the formation of 2 types of artifacts: cupping artifacts, which are distortions of metallic structures due to different types of absorption; and linear artifacts, which are lines and dark bands that may appear between 2 dense objects.⁷

In recent years, metal artifact reduction (MAR) programs have been developed for CBCT devices to minimize the effects of artifacts on image quality. These programs define a threshold image representing the average gray values to reduce the variability of gray values and reduce artifacts by moving high or low gray values closer to the threshold value.^{8–10}

At present, CBCT devices use various algorithms to reduce the formation of metal artifacts. The most commonly used methods are projection completion techniques and iterative approaches. Projection completion methods identify inconsistencies in the projection data due to incomplete representation of metal objects and accurately reconstruct these deficiencies using various techniques. These approaches typically encompass metal segmentation, projection addition and final image painting reconstruction. On the other hand, iterative reconstruction techniques are typically based on the optimization of selected functions, which leads to a reduction in the formation of artifacts.¹¹

Zirconia has recently emerged as an alternative to titanium in dental implants. Its aesthetic advantages include a tooth-like color, high osseointegration potential and a lower microbial dental plaque deposition rate than titanium.^{12,13} These properties contribute to the health of the peri-implant tissues, which have a higher inflammatory potential than currently available periodontal tissues.^{14,15}

Currently, zirconia material is also used in prosthetic restorations. The advanced mechanical properties of zirconia crowns have yielded promising results in the field of prosthetic restorations, especially in patients diagnosed with TMJ disease or bruxism.^{16,17}

Despite the abovementioned advantages of zirconia implants, the zirconium element in zirconia implants is a dense material with a relatively high atomic number ($Z = 40$), which may result in these implants producing more artifacts on CBCT scans.¹⁸

This in vitro study aimed to assess the impact of different CBCT settings on the production of artifacts in zirconia and titanium implants.

Material and methods

The study protocol was approved by the Non-Interventional Clinical Research Ethics Committee of Nuh Naci Yazgan University, Kayseri, Turkey (31.05.2020; decision No. 2021/221). Two different implants were used to analyze the production of artifacts: zirconia implants (NobelPearl® Tapered; Nobel Biocare, Istanbul, Turkey); and titanium implants (NobelActive®; Nobel Biocare). The dimensions of both implants were identical (5.5 mm × 12.5 mm).

Study modeling and implant placement

A dry human mandible coated with wax was used in the study to simulate soft tissue attenuation. A gutta-percha cone was placed on the lingual aspect of the alveolar crest as a reference point to ensure standardization in the selection of a section in implant images prior to all CBCT scans. Initially, CBCT scans were conducted on the mandible before implant placement. Then, zirconia and titanium implants were placed in the dry mandible, which was fixed to the container with impression material to ensure CBCT standardization. Finally, CBCT scans were performed (Fig. 1).

CBCT scans

All CBCT scans were taken using a 90 kilovoltage peak (kVp) and a 0.2-μm voxel size on KaVo ORTHOPANTOMOGRAPH™ OP 3D Pro (KaVo, Tuusula, Finland). First, a zirconia implant was placed in the left posterior region of the dry mandible, and CBCT images were obtained with different field of view (FOV) areas (the milliamperere [mA] intensity was fixed

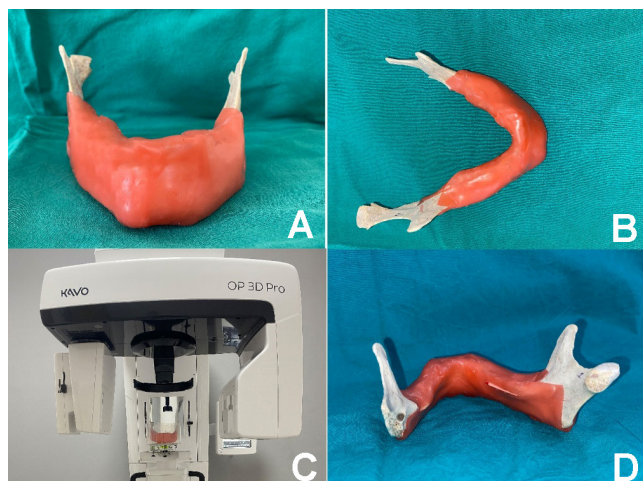


Fig. 1. Study material

A,B. Dry human mandible coated with wax; C. Cone-beam computed tomography (CBCT) procedure; D. Placement of the gutta-percha cone

at 3.2 mA), mA intensity values (FOV field was fixed at 8×8) and MAR programs in the on or off state (Table 1). Then, a titanium implant was placed in the same region, and the aforementioned protocol was repeated.

CBCT data evaluation

All CBCT images were evaluated by a radiologist with 4 years of experience. The first axial section at the level where the gutta-percha began to appear in the axial plane towards the mandibular basis was taken as a reference.

In the coronal plane, the measurement of the vertical linear distance was taken as a reference+, specifically the axial section of the first coronal section where the gutta-percha began to appear. All measurements were made on the same axial section, which was equidistant from the axial reference section.

Gutta-percha is a radiopaque material that can be easily identified on CBCT scans. Therefore, we used a gutta-percha cone as a determinant to provide standardization in both coronal and axial sections in our study.¹⁹

The contrast-to-noise ratio (CNR) was calculated according to Kursun-Cakmak et al. using the following formula (Equation 1)²⁰:

$$CNR = \frac{|M_{\text{implant}} - M_{\text{control}}|}{\sqrt{SD_{\text{implant}}^2 + SD_{\text{control}}^2}} \quad (1)$$

where:

CNR – contrast-to-noise ratio;

M – mean;

SD – standard deviation.

Regions of interest (ROIs) were identified in both the control and implant areas in the first axial section in which the gutta-percha was observed on CBCT scans. A spherical ROI with uniform dimensions was selected (10-mm diameter). This ROI encompassed the entire implant and the surrounding bone tissue area.²¹

The minimum and maximum gray values were determined using the ImageJ histogram tool (<https://imagej.net/ij/download.html>). These values were then used to calculate the mean (M) and standard deviation (SD). Histograms were determined using these ROIs. To obtain the minimum and maximum grayscale values used in the determined histograms, the SD and M values of both the implant ROI and the control ROI were calculated (Fig. 2,3).²¹

Statistical analysis

The statistical analysis was conducted using the IBM SPSS Statistics for Windows software, v. 22.0 (IBM Corp., Armonk, USA). The normal distribution of the groups was determined by the Shapiro–Wilk test and Q–Q plots. As the groups exhibited a normal distribution, an independent t -test was used to evaluate the paired groups, and one-way analysis of variance (ANOVA) was employed to evaluate groups of more

Table 1. Cone-beam computed tomography (CBCT) parameters according to different FOV areas, mA intensity values and MAR programs

Protocol No.	FOV	3.2 mA	3.2 mA	3.2 mA	3.2 mA	MAR program
1	13 cm × 15 cm	7	7	7	7	ON
	8 cm × 15 cm	7	7	7	7	
	8 cm × 8 cm	7	7	7	7	
	6 cm × 8 cm	7	7	7	7	
	5 cm × 5 cm	7	7	7	7	
2	13 cm × 15 cm	7	7	7	7	OFF
	8 cm × 15 cm	7	7	7	7	
	8 cm × 8 cm	7	7	7	7	
	6 cm × 8 cm	7	7	7	7	
	5 cm × 5 cm	7	7	7	7	
Protocol No.	FOV	3.2 mA	5 mA	6.3 mA	8 mA	MAR program
3	8 cm × 15 cm	8	8	8	8	ON
	8 cm × 15 cm	8	8	8	8	
	8 cm × 15 cm	8	8	8	8	
	8 cm × 15 cm	8	8	8	8	
	8 cm × 15 cm	8	8	8	8	
4	8 cm × 15 cm	8	8	8	8	OF
	8 cm × 15 cm	8	8	8	8	
	8 cm × 15 cm	8	8	8	8	
	8 cm × 15 cm	8	8	8	8	
	8 cm × 15 cm	8	8	8	8	

FOV – field of view; MAR – metal artifact reduction. Data presented as number (n).

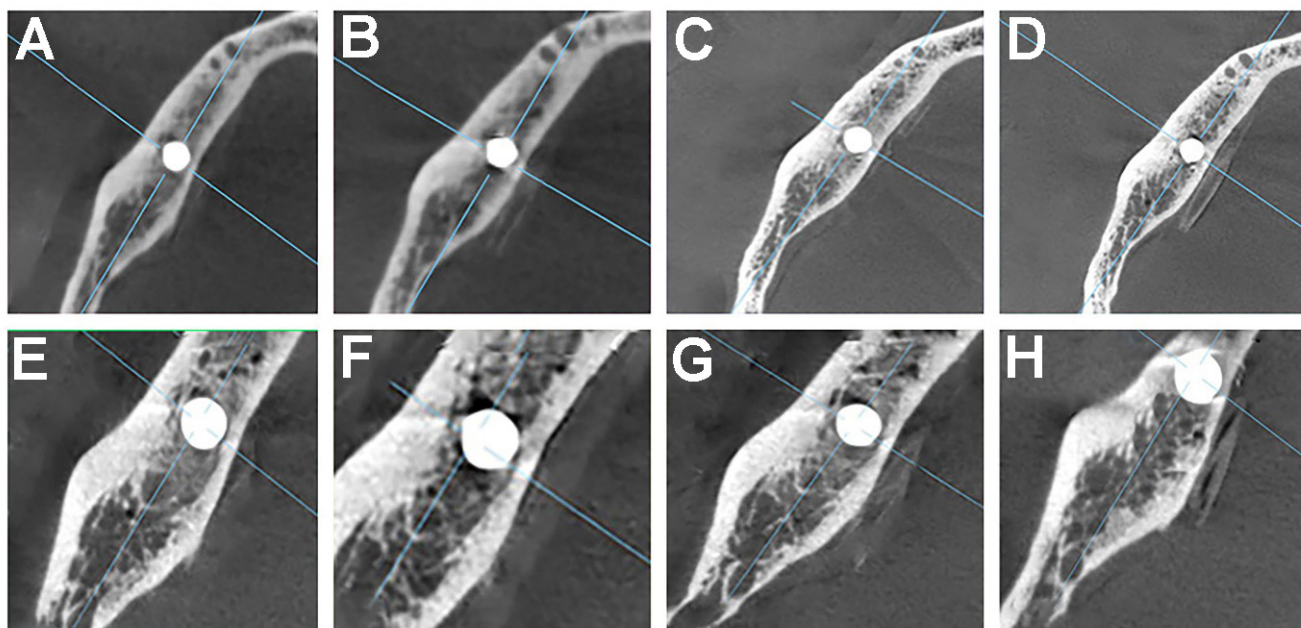


Fig. 2. CBCT sections with different parameters in the axial plane

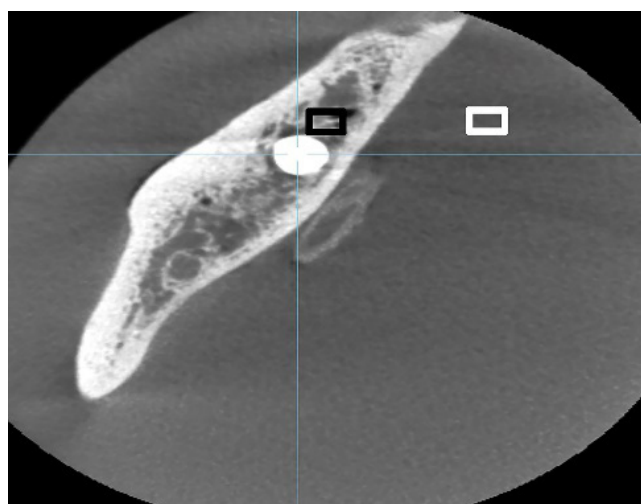


Fig. 3. Axial image representing the regions of interest (ROIs)

than two. The homogeneity of variance in more than 2 groups was determined by the Levene's test. If the variance was homogeneous, Tukey's honestly significant difference (HSD) test was used, and the Games–Howell test was employed as a post hoc test. A p -value <0.05 was considered statistically significant.

The number of artifacts present in the zirconia and titanium implants was quantified using the CNR and the standard deviation within the region of interest (SD_{ROI}) values of the gray areas around the implant. The differences between the 2 implant types with regard to these 2 parameters were evaluated by means of an independent t -test.

One-way ANOVA and post hoc tests were applied to examine the relationship between the CNR and SD_{ROI} values and between the FOV areas and mA values, which represent different parameters of CBCT.

In the independent t -tests, the sample size for each group was 35, with a power of 0.95 and an effect size of 0.8. In one-way ANOVA tests, the total sample size for the FOV areas was 35 (5 FOV area groups, $n = 7$ per group), and the total sample size for the mA intensity values was 32 (4 groups, $n = 8$ per group), with a power of 0.95 and an effect size of 0.8.

Results

The zirconia implant generated significantly more artifacts in both parameters than the titanium implant when the MAR program was deactivated (Table 2) ($p < 0.01$). Conversely, no significant difference was observed in either parameter between the zirconia implant and the titanium implant when the MAR program was activated (Table 3) ($p = 0.07$).

For the titanium implants, the post hoc Tukey's test results demonstrated a statistically significant difference between the SD_{ROI} values in the 6 cm $\times$ 8 cm and 5 cm $\times$ 5 cm FOV area groups (Table 4) ($p < 0.05$).

Table 2. Statistical comparison of the CNR and SD_{IMP} values for both implant types (MAR program deactivated)

Variable	Implant type	n	$M \pm SD$	p -value
CNR	titanium implant	35	1.21 ± 0.32	0.000*
	zirconia implant	35	0.62 ± 0.39	
SD_{IMP}	titanium implant	35	354.70 ± 69.26	0.000*
	zirconia implant	35	696.42 ± 48.98	

M – mean; SD – standard deviation; CNR – contrast-to-noise ratio; SD_{IMP} – implant standard deviation. There were statistically significant differences between the CNR and SD_{IMP} parameter groups ($p < 0.05$, independent t -test).

Table 3. Statistical comparison of the CNR and SD_{IMP} values for both implant types (MAR program activated)

Variable	Implant type	n	$M \pm SD$	p-value
CNR	titanium implant	35	1.89 $\pm$ 0.27	0.891
	zirconia implant	35	1.91 $\pm$ 0.53	
SD_{IMP}	titanium implant	35	283.88 $\pm$ 67.77	0.445
	zirconia implant	35	304.79 $\pm$ 79.66	

SD_{ROI} – standard deviation within the region of interest. There were no statistically significant differences between the CNR and SD_{ROI} parameter groups ($p = 0.07$, independent t-test).

Table 4. Statistical comparison of the SD_{ROI} values around the titanium implants according to the FOV area and mA groups

Group	n	$M \pm SD$	F	p-value
FOV	13 cm $\times$ 15 cm	7	393.80 $\pm$ 44.34	3.618
	8 cm $\times$ 15 cm	7	375.200 $\pm$ 19.501	
	8 cm $\times$ 8 cm	7	341.40 $\pm$ 86.00	
	6 cm $\times$ 8 cm	7	402.43 $\pm$ 44.47 ^a	
	5 cm $\times$ 5 cm	7	260.70 $\pm$ 44.74 ^b	
Intensity	8 mA	8	354.85 $\pm$ 66.23	0.399
	5 mA	8	383.20 $\pm$ 42.99	
	3.2 mA	8	368.54 $\pm$ 44.71	
	6.3 mA	8	323.02 $\pm$ 111.90	

Different superscript letters show statistical differences between the groups ($p = 0.03$, Tukey's multiple comparison test).

In addition, the results of the post hoc Tukey's test showed a statistically significant difference between CNR values in the 13 cm $\times$ 15 cm and 5 cm $\times$ 5 cm FOV field groups ($p < 0.05$). However, the differences between the mA groups and CNR values were not statistically significant (Table 5) ($p > 0.05$).

Table 5. Statistical comparison of the CNR values for the titanium implants according to the FOV area and mA groups

Group	n	$M \pm SD$	F	p-value
FOV	13 cm $\times$ 15 cm	7	1.63 $\pm$ 0.075 ^a	3.788
	8 cm $\times$ 15 cm	7	1.56 $\pm$ 0.31	
	8 cm $\times$ 8 cm	7	1.29 $\pm$ 0.14	
	6 cm $\times$ 8 cm	7	1.08 $\pm$ 0.40	
	5 cm $\times$ 5 cm	7	1.02 $\pm$ 0.10 ^b	
Intensity	8 mA	8	1.25 $\pm$ 0.24	0.517
	5 mA	8	1.40 $\pm$ 0.27	
	3.2 mA	8	1.45 $\pm$ 0.34	
	6.3 mA	8	1.18 $\pm$ 0.44	

Different superscript letters show statistical differences between the groups ($p = 0.02$, Tukey's multiple comparison test).

For the zirconia implant, the post hoc Tukey's test revealed a statistically significant difference between the SD_{ROI} values in the 8 cm $\times$ 8 cm and 5 cm $\times$ 5 cm FOV area groups ($p < 0.05$). However, the differences between the mA groups and SD_{ROI} values were not statistically significant (Table 6) ($p > 0.05$).

Table 6. Statistical comparison of the SD_{ROI} values around the zirconia implants according to the FOV area and mA groups

Group	n	$M \pm SD$	F	p-value
FOV	13 cm $\times$ 15 cm	7	726.73 $\pm$ 37.18	3.994
	8 cm $\times$ 15 cm	7	692.20 $\pm$ 43.82	
	8 cm $\times$ 8 cm	7	771.06 $\pm$ 82.29 ^a	
	6 cm $\times$ 8 cm	7	663.67 $\pm$ 36.37	
	5 cm $\times$ 5 cm	7	627.80 $\pm$ 15.13 ^b	
Intensity	8 mA	8	727.42 $\pm$ 66.09	0.634
	5 mA	8	697.75 $\pm$ 40.35	
	3.2 mA	8	678.30 $\pm$ 33.32	
	6.3 mA	8	734.40 $\pm$ 103.80	

Different superscript letters show statistical differences between the groups ($p = 0.03$, Tukey's multiple comparison test).

Additionally, the results of the post hoc Tukey's test demonstrated a statistically significant difference between the CNR values in the 13 cm $\times$ 15 cm and 5 cm $\times$ 5 cm FOV area groups as well as between the 8 cm $\times$ 15 cm and 5 cm $\times$ 5 cm FOV area groups. However, the differences between the mA groups and CNR values were not statistically significant (Table 7) ($p > 0.05$).

Table 7. Statistical comparison of the CNR values for the zirconia implants according to the FOV area and mA groups

Group	n	$M \pm SD$	F	p-value
FOV	13 cm $\times$ 15 cm	7	1.01 $\pm$ 0.08 ^a	6.671
	8 cm $\times$ 15 cm	7	0.91 $\pm$ 0.23 ^a	
	8 cm $\times$ 8 cm	7	0.49 $\pm$ 0.40	
	6 cm $\times$ 8 cm	7	0.62 $\pm$ 0.23	
	5 cm $\times$ 5 cm	7	0.08 $\pm$ 0.14 ^b	
Intensity	8 mA	8	0.70 $\pm$ 0.38	1.495
	5 mA	8	0.54 $\pm$ 0.24	
	3.2 mA	8	0.50 $\pm$ 0.36	
	6.3 mA	8	0.61 $\pm$ 0.43	

Different superscript letters show statistical differences between the groups ($p = 0.02$, Tukey's multiple comparison test).

Discussion

The formation of artifacts was evaluated in this study using 2 parameters. The first parameter, the SD_{ROI} , is based on a comparison of the gray levels at the implant and control areas. The second parameter is the CNR. These parameters were determined for an overall estimate of the degree of dark and light areas associated with artifact formation and have been used in previous studies to evaluate artifact formation.^{22–25}

Pauwels et al. and Parsa et al. demonstrated the formation of artifacts based on the difference between ROI values of the gray areas in the peri-implant region.^{26,27} The authors stated that if, during the CBCT procedure, the SD scores of the color values of the gray areas in the relevant

ROI were lower, lower artifact production may occur. The current study observed a reduction in the number of artifacts in regions with lower SDs in the gray values. These results are consistent with those previously reported by Pauwels et al. and Parsa et al.^{26,27}

Titanium and zirconia are 2 substances with different densities, physical properties and atomic numbers ($Z = 22$ for titanium and $Z = 40$ for zirconium). Zirconia exhibits a higher atomic number and density than titanium, which results in a greater propensity for artifact formation compared to titanium.²⁴

Demirturk Kocasarac et al. and Sancho-Puchades et al. observed that zirconia implants produced more artifacts than titanium or titanium alloy implants.^{28,29} In our study, when the MAR program was not activated, a greater number of artifact products associated with zirconia implants was found, in alignment with the current literature.

The existing literature indicates that the presence of metal artifacts can be minimized by reducing the FOV area and section thickness.^{30,31}

The results of our study align with those reported in the literature. As the FOV area increased, the number of artifacts increased, and this rise showed statistically significant differences between some FOV area groups. Conversely, an increase in the mA intensity increased the number of X-ray photons, which reduced the CNR by reducing quantum mottling in the radiograph.³² Although the increase in the mA intensity decreased the CNR, this difference was not statistically significant.

In our study, it was observed that the MAR program reduced both the CNR and the SD_{ROI} .

Since the evaluation of artifact formation of titanium and zirconia implants of different sizes may have introduced limitations to the study, we used implants of the same size (5.5 mm × 12.5 mm).

A variety of experimental models can be employed to evaluate the production of artifacts around an implant. For example, in the study by Smeets et al., implants were embedded in gelatin and the production of artifacts was investigated.³³ A study by de-Azevedo-Vaz et al. examined the dehiscence around implants where bovine ribs were used for the experimental model, with the implants placed within the bovine ribs.³⁴ Schulze et al., Benic et al., and Harris et al. evaluated the gray areas around the implant using dental stone and silicone material.^{5,35,36} Freire-Maia et al. and Pena de Andrade et al. used a dry human mandible in their study.^{37,38}

Similarly, we used a single dry human mandible to standardize the production of artifacts for both implant types. The dry mandible was coated with wax to simulate soft tissue.

Limitations

This study had 2 major limitations. First, it should be noted that this was a cadaveric study. The second major limi-

tation of the described process is that it is only applicable to the mandible. Given the morphological differences, such as bone density and the trabecular structure of the maxilla and mandible, it is uncertain to what extent the results obtained in the mandible represent the maxilla. Additionally, according to the review by Pauwels et al., the CNR may have certain limitations in determining image quality.³⁹

Conclusions

Within the limits of the current study, artifact formation in zirconia implants can be reduced by modifying various CBCT parameters, using smaller FOV areas and larger mA values, or by using a MAR program; nevertheless, this problem cannot be solved definitively. However, with the future development of MAR programs for CBCT devices, this issue could be eliminated. The current study provides a potential solution to the artifact problems commonly observed in zirconia implants.

Ethics approval and consent to participate

The study protocol was approved by the Non-Interventional Clinical Research Ethics Committee of Nuh Naci Yazgan University, Kayseri, Turkey (31.05.2020; decision No. 2021/221).

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

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