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# Effect of dental restorations materials on the voxel density value of CBCT

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**Aim:** To assess the effect of various dental restorations positioned outside the field of view (FOV) on voxel Density Value (VDV) in CBCT scans, specifically examining variations of VDV in low- and high-dose imaging protocols.
**Materials and methods:** An ex-vivo study was conducted using dentate human skull and mandible with missing lower right second premolar. A layer of pink baseplate wax was applied to simulate soft tissues. Different restorations (implants, porcelain-fused-to-metal (PFM) bridges, and zirconium bridges) were placed sequentially in three distinct locations outside the FOV. Standardized CBCT scans for lower right premolar region were acquired using both low-dose (90 kV, 3.2 mA) and high-dose (90 kV, 6.3 mA) protocols in absence and presence of different restorations in the three locations outside of FOV, both protocols were applied. Standardized CBCT scans of all specimens were taken using a GENDEX GDXP-700 (KAVO, Biberach, Germany). Two calibrated and blinded oral radiologists measured VDV, comparing high-dose and low-dose images without (gold standard group) and with (test group) restorations outside the FOV.
**Results:** Significant differences in VDV were observed between control and experimental groups, particularly at the apex of the region of interest, with varying effects based on the restoration type and imaging dose. High-dose imaging generally showed more pronounced differences compared to low-dose imaging ($p < .001$). Among all restorations, titanium implants provided the most significant difference, ensuring affected outcomes and overall efficacy in dental practice.
**Conclusion:** Different restorations outside the FOV significantly impact VDV in CBCT imaging with both high and low dose protocols.

**Keywords:** CBCT, Voxel Density Values, Dental Restorations, Artifacts, Low-dose, High-dose

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## Introduction

Cone-beam computed tomography (CBCT) is a valuable imaging modality that provides three-dimensional images of the maxillofacial structures. CBCT has an optimal <1mm resolution and isotropic voxels.[1] However, the main limitation of CBCT is the presence of artifacts. Image artifacts are distortions of recorded data on CBCT images. One of the causes of artifacts is the presence of high-density objects, it occurs due to the interactions between x-ray beam and high-density dental materials with high atomic numbers causing beam hardening.[2]

Previous study reported that the presence of dental implants, metallic fillings, crowns, and root canal fillings in the field of view (FOV) could inversely affect the image quality due to artifacts production and subsequently impair the final diagnosis.[3] Moreover, there is another source of artifacts, which is called exomass-related artifacts. The structures are present outside the FOV, but at the same axial plane between the tube and the image receptor. These artifacts have variable appearances within the CBCT images; discrete stripe-like, ring-like patterns, double contours, and an overall lack of sharpness.[4]

Some studies reported that when the FOV, voxel size and all exposure settings were fixed, altering the arrangement of the objects had a noticeable impact on the voxel density values (VDV).[5] They reported that the voxel values were greatly affected by exomass. This effect varies along the FOV, and it is direction dependent.[3,5] Therefore, this study was designed to assess the effect of different types of dental restorations present outside the field of view on the voxel density value of CBCT and the effect of decreasing radiations doses on VDV values.

## Materials and Methods

An ex-vivo study was carried out in the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Ain Shams University after approval from the faculty research ethics committee (FDASU-Rec EM012233). Sample size calculation was performed using G*Power version 3.1.9.7. Power analysis was designed to have adequate power to apply a statistical test of the null hypothesis that there is no difference would be found between groups. By adopting an alpha level of (0.05) and a beta of (0.2) i.e., power=80% and an effect size of 0.087 calculated based on the results of a previous study[3]; the predicted sample size (n) was 20 scans.

One dry human skull and mandible were borrowed out from the Anatomy Department, Faculty of Medicine, Ain Shams University. The skull and mandible were fully dentate except for the missing lower right second premolar. According to Mostafa., et al A layer of pink baseplate wax of two mm thickness was used as a soft tissue simulation. The wax covered the buccal, palatal, and lingual cortical bones of the maxilla and mandible. Careful consideration was taken to ensure the wax was applied uniformly and bubble-free.[6]

### Study grouping and specimen preparation

Study groups were divided according to the position of restoration in the area outside FOV: Upper left (UL), Upper right (UR), and Lower left (LL). For each location, three different restorations were used. Subgroup A: Implant only made of titanium (Zimvie- Seol- South Korea), Subgroup B: Porcelain Fused to Metal (PFM) bridge (Dentium Co., Seoul, Korea), Subgroup C: Zirconium bridge: made of multi hybrid layers of pre-sintered zirconium oxide blanks for dental CAD/CAM system (Daegu-Korea). The location of these restorations was oriented to keep them outside FOV which is the lower right side missing second premolar area. Each restoration was placed individually in each one of the three locations in the premolar molar area in each quadrant before each image acquisition.

**Image Acquisition**

Standardized CBCT scans of all specimens were taken using a GENDEX GDXP-700 (KAVO, Biberach, Germany). For imaging the lower right premolar area (FOV), we used a 5x5 cm FOV and two imaging protocols. First, low dose protocol (90 kVp - 3.2 mA – 1.2 S – 33 $mGycm^2$) and second high-dose protocol (90 kVp – 6.3 mA – 8.7 S – 482 $mGycm^2$) with voxel size of 0.2 mm. The laser light beam was adjusted to ensure the positioning of the region of interest within the FOV (Figure 1).

**Figure 1: Positioning of skull and mandible assembly during CBCT scanning.**

A total of 20 CBCT experimental scans for the same region of interest were obtained. As the three regions outside the FOV have received the three restorations sequentially and imaged twice using low and high doses. Additional two control scans of the region of interest were taken with absence of any restoration in the three regions outside FOV to be assigned as the control group.

**Image analysis**

DICOM images of all scans were exported to a third-party software On Demand3D (Cyber Med, Seoul, Republic of Korea). The control scan of each protocol was fused with each one of the corresponding experimental scans of the same protocol using the software's fusion module. After selecting the two volumes, manual registration was used to merge the two volumes, followed by cropping the region of interest (ROI) to reduce image noise. Subsequently, an auto-registration tool was applied, and the final processed images were saved (figure 2). Two calibrated oral radiologists measured the VDV on the fused volume. They used a 3D ROI tool and adjusting circle tool just below the apex of missed 2$^{nd}$ premolar and to be within cancellous bone in the three fused images (axial, sagittal, and coronal) (Figure 2).

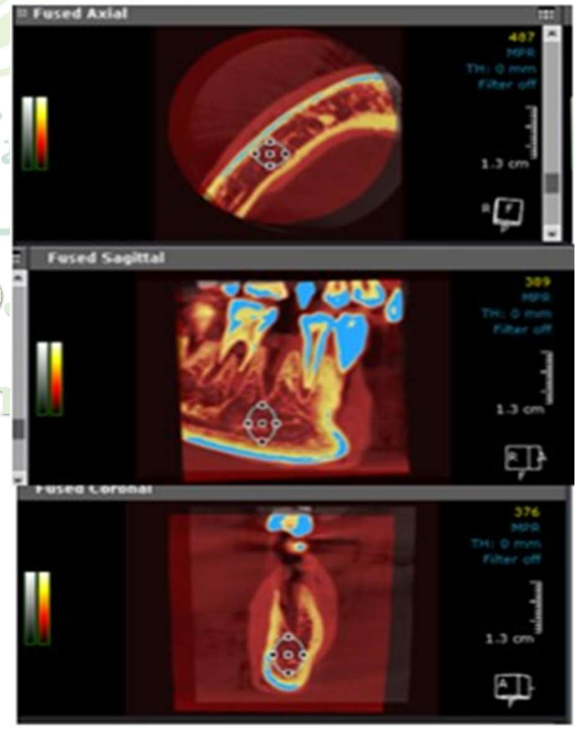
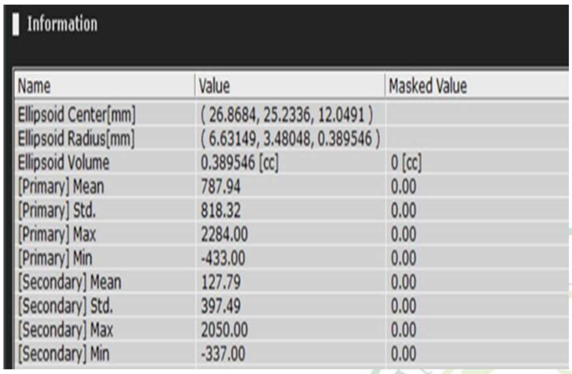



**Figure 2: Fused axial, coronal and sagittal images with ROI at the apex area of missing second premolar within the cancellous bone.**

The mean VDV of control and study groups were recorded for each observer (figure 3). The mean value of two observers' readings was used for statistical analysis.



| Name | Value | Masked Value |
|---|---|---|
| Ellipsoid Center[mm] | ( 26.8684, 25.2336, 12.0491 ) | |
| Ellipsoid Radius[mm] | ( 6.63149, 3.48048, 0.389546 ) | |
| Ellipsoid Volume | 0.389546 [cc] | 0 [cc] |
| [Primary] Mean | 787.94 | 0.00 |
| [Primary] Std. | 818.32 | 0.00 |
| [Primary] Max | 2284.00 | 0.00 |
| [Primary] Min | -433.00 | 0.00 |
| [Secondary] Mean | 127.79 | 0.00 |
| [Secondary] Std. | 397.49 | 0.00 |
| [Secondary] Max | 2050.00 | 0.00 |
| [Secondary] Min | -337.00 | 0.00 |

**Figure 3: CBCT 3D ROI showing the VDV on the primary (control) and secondary volumes.**

## Statistical analysis

The data were analysed using (IBM, Armonk, New York )SPSS version 26. The Shapiro–Wilk test evaluated the data's normal distribution, which was shown to be normal (P > 0.05). the parametric quantitative data was presented as mean ±SD and were compared by analysis of variance (ANOVA).

## Results

There was a significant difference in VDV among low and high dose protocol when the PFM bridge was placed in the upper right side and lower left side. While there was no significant difference in VDV when the PFM bridge was placed on the upper left side.

There was a significant difference in VDV among low and high dose protocol when the titanium implant was placed in the upper right side, upper left side and lower left side.

There was a significant difference in VDV among low dose protocol when the zirconium bridge was placed on the upper left side only. While there was no significant difference in VDV when the zirconium bridge was placed in upper right side and lower left side. Regarding the high dose protocol, when the zirconium bridge was placed on the lower left side and upper right side it showed a significant difference in VDV. There was no significant difference in VDV with high dose protocol when the zirconium bridge was placed on the upper left side. (table 2-3)

**Table 2: Comparing VDV at low dose CBCT imaging between the control group and the experimental groups**

| Restoration and outside region | | Voxel density value | | P. value |
|---|---|---|---|---|
| | | Control | Experimental | |
| PFM bridge A | LL | 386±35.5 | 315.4±20.9 | 0.014* |
| | UL | 46±16.3 | 56.7±23.4 | 0.484 |
| | UR | 782.9±4.2 | 108.2±41.5 | <0.001** |
| Implant B | LL | 810.2±6 | 135.3±171 | <0.001** |
| | UL | 640.3±18.8 | 203.8±11.2 | <0.001** |
| | UR | 634±15.3 | 44.6±23.5 | <0.001** |
| Zirconium bridge C | LL | 314.6±171.1 | 108.9±64.7 | 0.090 |
| | UL | 100.3±11.9 | 24.1±10.2 | <0.001** |
| | UR | 513.6±54.6 | 328.8±144.5 | 0.054 |

*** P<0.05 is significant, ** p <0.001 is highly significant.**

**Table 3: Comparing VDV at high dose between the control group and the studied groups**

| (VDV) 5 (2nd premolar) | | High dose | | P. value |
|---|---|---|---|---|
| | | Control | Group | |
| 3D ROI At the apex | 3A | 660±34.5 | 824.2±9.4 | <.001** |
| | 2A | 548.3±142.4 | 307.5±216.3 | .112 |
| | 1A | 485.4±110.2 | 211.2±137.8 | .021* |
| 3D ROI At the apex | 3B | 103±5 | 158.5±2.5 | <.001** |
| | 2B | 503.3±4.5 | 308.1±11.4 | <.001** |
| | 1B | 554.7±22.2 | 204.2±35.8 | <.001** |
| 3D ROI At the apex | 3C | 260.5±3.1 | 103.8±33.1 | <.001** |
| | 2C | 256.7±67 | 297.6±232.2 | .746 |
| | 1C | 337.9±6.3 | 405.7±15.5 | <.001** |

**Data are presented as mean ±SD. ROI: region of interest, VDV: Voxel Density Values. A: PFM bridge, B: implant, C: zirconium bridge,1: upper right, 2: upper left, 3: lower left.**

## Discussion

The aim of the present study was to assess the effect of different types of dental restorations present outside the field of view on the voxel density value of CBCT. Bone density measurements in multi-detector CT and CBCT can be adversely affected by high-density restorations, such as metals or specific ceramics, because of artifact creation and measurement interference. These materials exhibit much higher x-ray attenuation compared to bone, leading to artifacts that obscure or distort bone structures resulting in an inaccurate measurement of the adjacent bone density.[7]

Our study offers significant advantages over others by incorporating a more realistic and comprehensive methodology. Moshfeghi et al.[8] investigated the effect of different exposure settings (60 and 90 kVp, 2 and 10 mA) on CBCT image quality but did not examine the effects of using both high and low radiation doses across the study. Further, Candemil et al.[3], conducted their research on polypropylene cylindrical phantoms instead of a real skull.

In the present study, the use of a human dry skull and mandible helped to target the artifacts in CBCT slices. The bony structure of the skull gives a background that is as realistic as possible for artefacts. However, it is important to consider that the thickness of the bone around the orbital floor alternates because of the complex anatomy and this may affect the measured gray values, as well. In addition, metal artifacts are enhanced especially in the soft-tissue region because of the lower contrast of the soft-tissue in CBCT images. [9] On the contrary, Candemil et al., conducted their previous study on artifacts of metal objects located in the exomass on a polypropylene cylindrical phantom.[3,10]

Ideally, soft tissue simulating material should simulate as closely as possible its attenuation and scattering characteristics of x-rays, since these factors have been shown to directly influence the gray values of bones and dental tissues.[11] Therefore, we used a layer of pink baseplate wax of two mm thickness covering the buccal, palatal, and lingual cortical bones of the maxilla and mandible as a soft tissue simulation. The pink wax is accepted in the literature and was used by several studies to simulate soft tissue in patients imaging.[12,13]

On the other hand, Demirturk et al.[14] used a dry human mandible to individually insert dental implants of three different materials (titanium–zirconium, titanium, and zirconia).

Several methodologies were found in the assessed diagnostic studies, either regarding the type of artificially induced bone defect or the different CBCT protocols applied. Schwindling et al.[15] analyzed the accuracy of PR, low-dose CBCT, and high-dose CBCT for identification, classification, and measurement of peri-implant bone lesions in Titanium implants. The accuracy of PR and CBCT were similar in the identification of defects, although low-dose CBCT images provided more accurate identification of defect morphology. High-dose CBCT slightly increased the diagnostic performance, albeit at the expense of a 14 times higher dose.[27]

Our scanning protocol was 90 kVp which was the highest kVp found in the Gendex 3D machine. It is a moderate kVp and produces an optimal image quality without increasing patient radiation dose. Also, we used two mAs (3.2 mA and 6.3 mA) on the measured VDV. Similarly, a previous study investigated the effect of the mA alone on cone-beam computerized tomography image quality.[16] Although other studies investigated the combined effects of both mA and kVp on metal artifacts in CBCT using with different currents (8, 12, and 16 mA) and different voltages (70, 78, and 84 kVp).[17,18]

Our study is in accordance with the current results, Moshfeghi et al.[8] investigated the effect of 60 and 90 kVp voltage, and 2 and 10 mA amperage on CBCT image quality and found that the presence of metal objects in the exomass area and lower amperage decreased image quality.

Precise selection of exposure parameters, such as voltage and amperage play an important role in enhancement of image quality and reduction of patient radiation dose. It has been reported that CBCT with high exposure parameters decreases the noise and improves image homogeneity, which results in more accurate image reconstruction of tissues with close density values and enables the observer to differentiate between close GVs. On the other hand, high exposure parameters increase the patient radiation dose.[19]

Oliveira et al.[20] reported that changing the amperage and voltage affected the artifacts caused by the exomass; however, the effect of changing the voltage was greater than the amperage on exomass artifacts. Another advantage of increasing the voltage in CBCT scanners is the reduction in patient radiation dose.[19] Thus, increasing the voltage yields a more homogenous image with less artifacts and lower patient radiation dose.

In addition, Shokri et al.[21] investigated exposure settings of 90 kVp, 10 mA, 6.1 s, two different sizes of FOVs (4 × 6 cm2 and 6 × 8 cm2), and two different resolution modes (high: 133 µ voxel size and low: 200 µ voxel size) and Sancho-Puchades et al.[22] applied 120 kV acceleration voltage, 5 mA beam current, FOV diameter of 16 cm, FOV height of 6 cm, 600 projections, 360° rotation, voxel size of 0.25 mm stated that the amount of artifacts induced by the zirconium implant was significantly higher than the titanium implant group which is in accordance with our findings of titanium implants.

However, unilateral/bilateral presence of metal objects in the exomass area alone had no significant effect on the VDV and image quality, although its interaction with the type of metal object had a significant effect on the VDV and image quality. And these outcomes of the previous research align well with the findings of my study. Also, they concluded that increasing the amperage and voltage decreased metal artifact generation caused by the exomass. Metal artifacts in the exomass can affect the VDV and cause image distortion, Moshfeghi M et al.[8]

According to Cebe F et al, and Abu El-Ela WH et al we decided to use dental restorations such as the placement of titanium implant, and construction of bridges for each region individually to be adapted to the corresponding teeth to simulate the clinical situations as much as possible.[23,24] However, another study by Codari M et al used a cylinder made of different materials rather than actual restorations. [25]

In our study titanium implant in any region outside FOV decreased the VDV when using the low-dose protocol. However, using high-dose imaging presented variable effects of titanium implants. The VDV increased when it was present in the region adjacent to FOV, and the VDV decreased when it was presented in the opposing arch.

Our findings were supported by Candemil et al.[26] who demonstrated that the mean voxel value decreased in the presence of different metal (titanium, cobalt–chromium, and amalgam) objects in the exomass.

According to a previous study by Shokri et al.[21], the number of artifacts induced by the zirconium implant was significantly higher than the titanium implant group. However, Chagas et al.[27] found no significant difference regarding diagnostic accuracy between CBCT images of peri-implant bone defects around titanium implants and zirconium dioxide implants.

In our study when using the low-dose protocol, all types of used restorations significantly decreased the VDV in the region of interest. Among the restorations which we investigated titanium implant was the highest restoration with statistical difference in changing the VDV in any region outside FOV <0.001, followed by PFM bridge in opposing corresponding region and adjacent region <0.001** and finally zirconium bridge only when it presented in the opposite region in the opposing arch <0.001**. Our findings were supported by Candemil et al,[26] who demonstrated that the mean voxel value decreased in the presence of different metal (titanium, cobalt–chromium, and amalgam) objects in the exomass. Similarly, Kocasarac et al.[14] indicated that dental implants present in the exomass created images with higher standard deviation SD and higher artifacts compared with implants within the FOV and showed that the zirconia implant produced the highest SD values (more heterogeneous grey values, corresponding to greater artefact expression) which mean affected VDV.

The higher the atomic number, the more beam hardening will occur.[28] Schulze provided an analytical evaluation on the artefact-level caused by zirconia-implants (Y-TZP) versus pure titanium implants. Y-TZP composition as typical zirconium-oxide material with Yttrium-oxide additive was selected as representative for zirconia-implants, they found that there was up to 225% more attenuation of the x-ray-beam were observed for Y-TZP compared to titanium.[29]

According to the Mendeleev table, titanium atoms have an atomic number of 22 and a density of 4.506 $g.cm^{-3}$, and zirconium atoms have an atomic number of 40 and a density of 6.511 $g.cm^{-3}$. This difference in atomic numbers and densities of the two implant materials may justify the higher number of artifacts in zirconium implants.[21]

Thus, high atomic number and high physical density increase artifact generation when exposed to x-ray radiation[31], and this increase is directly proportionate to the change in VDV. Increased variability in VDV indicates greater effects of artifacts on CBCT images, and subsequent reduction of image quality.[32]

Sancho-Puchades et al.[22] compared the artifacts generated by titanium, titanium-zirconium, and zirconium implants in vitro. They inserted implants in 20 bone models of human mandibles and investigated the number of artifacts in CBCT images. They concluded that the number of artifacts produced by zirconium implants was more considerable than others which are aligned with our findings.[22]

Kocasarac et al.[14] indicated that dental implants present in the exomass created images with higher standard deviation and higher artifacts compared with implants within the FOV, and showed that the zirconia implant produced the highest standard deviation values (more heterogeneous grey values, corresponding to greater artefact expression) which was in agreement with the our findings.

In our study while using high-dose imaging protocol the presence of titanium implant, PFM bridge in region adjacent to FOV, and presence of Zirconium bridge in the opposite arch resulted in significant increase in the VDV. While the VDV decreased when the implant and PFM bridge in the opposing arch and Zirconium bridge in region adjacent to FOV.

Candemil et al,[26] concluded that the presence of metal objects in the exomass areas significantly decreased the mean VDV and increased the noise, which agreed with the present findings.

Regarding the presence of PFM bridge, the VDV showed significant variable measures compared to control group when the PFM bridge presented in two regions: adjacent and opposing corresponding region to FOV. When using low dose imaging, presence of PFM bridge in opposing corresponding region and adjacent region significantly decreased the VDV. While using the high dose imaging, PFM bridge in region adjacent to FOV resulted in significant increase in the VDV. However, PFM bridge in region opposing corresponding region induced decrease of VDV.

One of the limitations of our in-vitro study was the lack of motion artifacts, which can be problematic in the clinical setting and may affect the VDV measurements. The current results can pave the way for further studies on other CBCT scanners and different dental materials with a better simulation of the clinical setting. Also, different voxel sizes and exposure parameters can be evaluated in future studies.

## Conclusions

The presence of different types of dental restorations outside the FOV significantly affects the VDV measured in CBCT scans. Restorations outside the FOV significantly impact VDV in CBCT imaging. Low dose protocol shows significant difference with PFM bridge in upper arch both sides, implant is highly significant in all three groups, zirconium bridge is highly significant in exomass area only. While in high dose protocol show significant differences with PFM in exomass and upper right area, implant in three groups, zirconium in exomass and upper right areas.

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