# EFFECT OF METAL ARTIFACTS REDUCTION PROTOCOLS AND ELECTRIC POTENTIAL DIFFERENCE (KVP) ON METAL ARTIFACTS IN CONE BEAM COMPUTED TOMOGRAPHY: A DIAGNOSTIC ACCURACY STUDY

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### ABSTRACT

**Objective:** The aim of this study was to evaluate the validity and reliability of electric potential difference (kVp), with and without the use of metal artifacts reduction tool (MAR), Can the usage of MAR protocols and electric Potential Difference (kVp) reduce the metallic artifacts resulting from metallic structures in CBCT?

**Methodology**: Jaw models with the same radiodensity as the normal average human jaw bones with full veneered crowns attached to them, and were scanned by using Planmeca ProMax® 3D Mid CBCT machine, using different values of kVp, with and without the activation of MAR tool. Romexis® software was used for image analysis. For each crown restoration, the length of the alveolar bone affected by the artifacts under the crown from the crest of the ridge till the inferior border of the mandible was assessed quantitatively.

**Results:** The activation of the MAR tool in the software effectively reducing the effect of the artifacts in the CBCT images when compared to the effect of the different kVp values alone without MAR activation.

**Conclusions:** The activation of MAR tool in the software should be considered to reduce the effect of CBCT artifacts when scanning multiple metallic objects.

**KEYWORDS:** CBCT, Metal Artifacts, MAR, Metal artifacts reduction protocols, kVp.

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## INTRODUCTION

Cone beam computed tomography (CBCT) is considered to be the main diagnostic tool with high potential for diagnosis and treatment planning in the maxillofacial area [27].

Modifications in sensor technology, smaller field of view depending upon the application, and pulsed radiation technique following the ALARA: "as low as reasonably achievable" rule, are considered to be merits of the CBCT [12].

However, ALADA "As Low as Diagnostically Achievable" is now a new concept that requires strict regulation to guidelines on CBCT imaging, two decades after the introduction of CBCT, so it is time to move from ALARA to ALADA [12].

However, CBCT images are more prone to metal artifacts, and in spite of the considerable efforts to reduce such artifacts, the problem have not been yet overcome [6].

By definition, artifact is any distortion or error in the image that is unrelated to the subject being imaged. It is the main cause of deterioration in image quality and in some cases the artifact renders the image completely useless [7].

The main cause behind the appearance of these artifacts is the back projection algorithms that are used to reconstruct three-dimensional images in CBCT units, and when compared to MDCT, CBCT images have more artifacts [8].

Several types of artifacts have been reported with CBCT, the commonly encountered one is the beam hardening artifact [9], which are usually manifested on the final CBCT images as two different artifacts, a cupping artifact and dark bands or streaks [11].

Proposed solutions for the reduction of metal artifacts in CBCT, were recently studied in the previous literature, including software correction tools (MAR), and artifact reduction imaging protocols and techniques, also including operating the CBCT machines at different values of exposure parameters [17].

Milliampere (mA) and kilovoltage (kVp) are the main exposure parameters that help to reduce the production of the CBCT artifacts, although increasing the Kilovoltage (kVp) alone was found to have a greater influence [10].

That's why this study was undertaken to throw the light on the applicability of metal artifact reduction (MAR) protocols or the variation of the electric potential difference (kVp) in an attempt to reduce the metallic artifacts resulting from metallic structures in CBCT.

## MATERIALS AND METHODS

### Materials

The study was conducted using two mandibular models with same radiodenisty as the normal average jaw bones, totally edentulous, with cancellous and cortical bone tissue, without dental nerve. The used models were shipped from (Implant Bone Company, Argentina). The used model's number is M450.

Both models are identical regarding shape, anatomy and density as confirmed by (Implant Bone, Argentina) company.

Full veneered crowns were attached on the ridge of the model by adhesive material at random different positions in the mandibular jaw models during each scan (Figure 1).



Fig. (1): Full veneered crown attached on alveolar crest of the model.

## METHODS

### CBCT Imaging of Jaw Models

#### 1. Standardization of the positioning of the Plastic container during scanning:

A compressed piece of cork was cut to fit the size of the plastic container to support it during scanning for scans. The same piece of cork was used for all scans. Also, the same plastic container was used, and even the same level of water was kept constant throughout the study period (water that filled the plastic container to resemble the soft tissue attenuation effect).

#### 2. Soft Tissue Simulation:

Each jaw model including the dummy implants and the full veneered crown was placed in a plastic container and immersed in water to simulate soft tissue effect and attenuation (Figure 2).
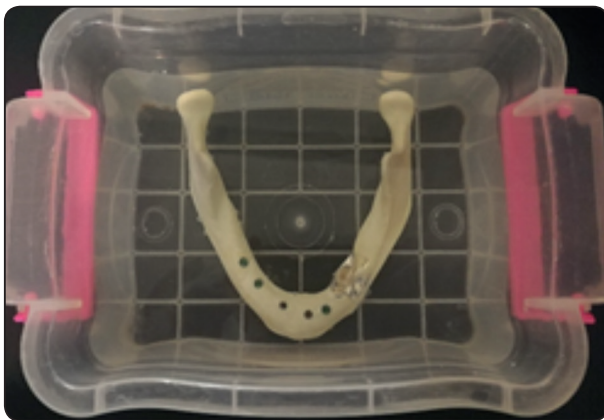


Fig. (2): Jaw model immersed in water tank.

#### 3. Exposure Parameters:

Jaw models were scanned in the Oral and Maxillofacial Radiology Department , Faculty of Dentistry, Cairo University; using CBCT machine Planmeca ProMax® 3D Mid, by adjusting the following exposure parameters:

**I1 (Index test):** CBCT with potential difference **70 kVp** without metal artifacts reduction tool (MAR) activation.

**I2:** CBCT with potential difference **80 kVp** without MAR activation.

**I3:** CBCT with potential difference **90 kVp** without MAR activation.

All these scans were taken using default exposure CBCT parameters; field of view was 20 x 6 cm, milliampere setting was 8 mA with a voxel size of 0.4 mm. All the above exposure parameters were kept constant in all the scans

#### 4. Image Processing:

Primary reconstruction and processing of the scans as well as image analysis were done using Romexis® software (Planmeca- Helsinki-Finland).

For each model, 3 CBCT scans with different kVp set ups (70-80-90 kVp) were acquired as previously mentioned. Then each scan was processed using MAR protocol (Low threshold level) which was saved as a separate new scan. Consequently, each jaw model had six CBCT scans with different kVp set ups with and without MAR (70-80-90 kVp).

### Image Analysis

Image analysis in the current study included quantitative assessments for the length of the alveolar bone affected by the artifacts under the full veneered crown restorations, from the crest of the ridge to the inferior border of the mandible.

On each axial image, the coronal plane was rotated to be perpendicular to the buccal surface of the full veneered crown.

Areas of artifact affection were those affected or masked by the white streaks over the alveolar bone.

The length of the alveolar bone affected under the crowns with artifacts was measured as the perpendicular distance between two tangential lines to the full veneered crown margin and the most apical part of artifact on alveolar bone (Figure 3).
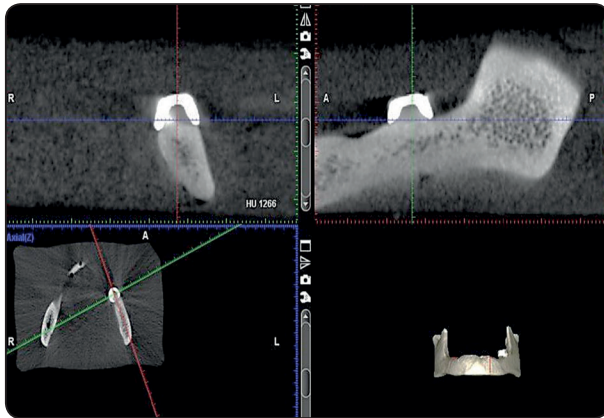
Fig. (3): Orientation of orthogonal planes for measuring crown artifacts

The measurements of the artifacts were performed in bucco-lingual direction on coronal images and in mesio-distal direction on sagittal images, on all CBCT scans with different kVp with and without MAR tool activation (Figure 4).
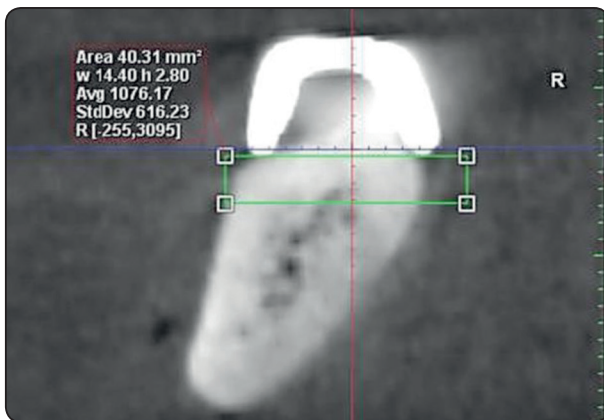


Fig. (4): Measurement of crown artifacts.

## Blinding & Inter and Intra-Observer Agreement

The assessment was done by three oral radiologists with different experience in three separate sessions. The three observers were blind to the results of the each other and inter-observer agreement was evaluated. One of the three oral radiologists assessed the radiographs twice with two weeks interval between two sessions to assess intra-observer agreement.

## Sample size calculation

Sample size calculation was done using R statistical package, version 3.3.1 (21-06-2016).

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Paired T test power calculation was used to detect the proper sample size. Mean differences and standard deviations were estimated according to **Khongkhunthian et al. (2017),** with a power of 80% and a two-sided significance level of 5%.

R statistical package, version 3.3.1 (21-06-2016). Copyright (C) 2016.

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## RESULTS

### Inter & Intra observer Agreement:

*1. Intra-observer Reliability of Measurements of length of the alveolar bone affected under the crown restoration:*

There was a **very strong** reliability and agreement between the two readings of the first observer regarding length of the alveolar bone affected under the crown restoration (Table 1).

TABLE (1): Results of intra-observer reliability assessment between the two readings of the first observer regarding Crown Artifact - Intraclass Correlation Coefficient:

| Intra-observer agreement Crown Artifact | Intraclass Correlation Coefficient | | | Level of agreement |
|---|---|---|---|---|
| | ICC* | 95% CI | p-value** | |
| **Mesiodistal** | 1 | 1-1 | < 0.0001 | Very strong |
| **Buccolingual** | 1 | 1-1 | < 0.0001 | Very strong |

*\*Intraclass Correlation Coefficient ranges from 0.00 to 0.30 indicates lack of agreement and 0.31 to 0.50 as weak, 0.51 to 0.70 as moderate, 0.71 to 0.90 as strong, 0.91– 1 as very strong agreement.*

*\*\*Statistical significance at p-value ≤ 0.05.*

## 2. Inter-observer Reliability of Measurements of the length of the alveolar bone affected under the crown restoration:

There was a **very strong** reliability and agreement between the readings of the three observers regarding length of the alveolar bone affected under the crown restoration (Table 2).

TABLE (2): Results of inter-observer reliability assessment between the two readings of the first observer regarding Crown Artifact - Interclass Correlation Coefficient:

| Inter-observer agreement Crown Artifact | Interclass Correlation Coefficient | | | Level of agreement |
|---|---|---|---|---|
| | ICC* | 95% CI | p-value** | |
| **Mesiodistal** | 0.98 | 0.97 - 0.99 | < 0.0001 | Very strong |
| **Buccolingual** | 0.96 | 0.93 - 0.98 | < 0.0001 | Very strong |

*Interclass Correlation Coefficient ranges from 0.00 to 0.30 indicates lack of agreement and 0.31 to 0.50 as weak, 0.51 to 0.70 as moderate, 0.71 to 0.90 as strong, 0.91– 1 as very strong agreement.*
***Statistical significance at p-value ≤ 0.05.*

## 3. Full Veneered Crowns Artifacts Assessment:

### 1. Different kVp values without MAR:

**70 kVp** without MAR showed the **highest mean length** of 1.72 (±0.37) mm, while **90 kVp** without MAR showed the **lowest mean length** of 1.18 (±0.79) mm. **80 kVp** without MAR showed **mean length** of 1.55 (±0.71) mm. All techniques measurements showed a **statistically significant** effect on the bone (Table 3).

### 2. Different kVp values with MAR:

**90 kVp with MAR** showed the **highest mean length** of 0.31 (±0.67) mm, while both **70 kVp with MAR & 80 kVp with MAR** showed the **lowest mean length** of 0.08 (±0.25) mm. All techniques measurements showed a **statistically insignificant** effect on the bone (Table 3).

TABLE (3): Descriptive analysis of Length of alveolar bone under crown restoration affected by artifacts (mm) at regarding each group and comparisons with Real measurement (zero):

| Length of alveolar bone under crown restoration affected by artifacts (mm) | Mean | ±SD | Median | Min | Max | Comparison with Real measurements Wilcoxon signed rank test for paired data or paired t test | |
|---|---|---|---|---|---|---|---|
| | | | | | | p-value* | Interpretation |
| **90 kVp without MAR** | 1.18 | 0.79 | 1.40 | 0 | 2 | 0.001 | **Statistically Significant difference** |
| **90 kVp with MAR** | 0.31 | 0.67 | 0.00 | 0 | 2 | 0.18** | No Statistically Significant difference |
| **80 kVp without MAR** | 1.55 | 0.71 | 1.75 | 1 | 3 | <0.0001 | **Statistically Significant difference** |
| **80 kVp with MAR** | 0.08 | 0.25 | 0.00 | 0 | 1 | 0.32** | No Statistically Significant difference |
| **70 kVp without MAR** | 1.72 | 0.37 | 1.80 | 1 | 2 | 0.005** | **Statistically Significant difference** |
| **70 kVp with MAR** | 0.08 | 0.25 | 0.00 | 0 | 1 | 0.32** | No Statistically Significant difference |

*Significance level at p-value ≤0.05.*          ***Results of the Wilcoxon signed rank test for Paired Data.*

## DISCUSSION

One of the main advantages of the CBCT modality over that of the medical conventional CT is the reduction in the physical foot print which is considered to be approximately one quarter to one fifth of that of the CT, which consequently affects the overall cost of both machines. This advantage may be of great concern to the radiologists or the dentists, but when considering the patient as an important factor, the reduction in the overall radiation dose and scanning time can be considered to favor CBCT imaging over CT [24].

However, radiologists may face some challenges with the usage of CBCT, mainly its inherent artifacts, which includes any distortion or error in the image that is unrelated to the subject being studied [24, 25].

In a study done by **Lechuga and Weidlich (2016)** [15], they found that the MSCT system appears to have lower artifact, less noise, greater signal-to-noise ratio than CBCT. On the other hand, this may jeopardize the benefit of the lower radiation dose to the patient, especially if the artifacts effects problem can be reduced using different approaches. That's why CBCT was our modality of choice in the current study targeting on the best method to overcome the deterioristic effect of metallic artifacts on the final image.

The main concern in the current study was to evaluate the effect of these resulting artifacts, and assuming the best available technique to reduce their effect on the overall final CBCT images, while exposing the patient to the least acceptable, optimum radiation dose according to the ALARA principle: "As Low As Reasonably Achievable" [12], or more recently, the ALADA principle "As Low As Diagnostically Achievable" [13].

Choosing real sized M450 mandibular models (Implant Bone Company, Argentina) used in this study, was for the satisfying radiopacity and hardness which was proved by the manufacturer

to be equal to type II human bone .Moreover, the internal structure was similar to bone tissue with cancellous and cortical bone types. In addition, these models are made of an unbreakable material which offered easier manipulation during the study steps.

Metal Artifacts may also be caused by other metallic restorations presenting in the area to be scanned, such as dental crown, post and cores, endodontic filling materials and adjacent amalgam restorations. That's why in our study we introduced metallic full veneered crowns that will cause the CBCT artifacts.

During scanning, the models were inserted in a plastic container. And a compressed piece of cork was cut to fit the size of the plastic container to support it during scanning for scans. The same piece of cork was used for all scans .Also, the same plastic container was used, and even the same level of water was kept constant throughout the study. Water was used to simulate soft tissue effect, to simulate the patient's real images, and for the methodology followed to be more realistic, as supported by **(Rabelo et al. 2017)** [23].

Scanning the models was done using 3 different kVp values; 70kVp, 80 kVp & 90 kVp. The same kVp ranges were used as well by **Codari et al. (2017)** [5] who also used the same CBCT machine as in the current work.

Although lower kVp values were used by **Silveira-Neto et al. (2017)** [27], but this was not very supported in the previously reported studies, as this might affect the overall image quality [19, 20]

On the other hand, using 70, 80 & 90 kVp values in our study was due to the following: firstly, the highest kVp found in the ProMax 3D machine was 90 kVp, secondly, increasing the kVp values was found to increase the radiation dose to the patient, without significantly reducing the artifact production, knowing that an overall reduction in

radiation dose is nearly 62% when decreasing the peak kilovoltage from 120 kVp to 100 kVp [20].

Default exposure CBCT parameters were used; including FOV: 20 x 6 cm, mA: 8mA, voxel size: 0.4 mm and were fixed during all the scans to standardize their effect on the final image.

Milliampere and other exposure parameters were made constant during scanning to avoid their effect. Despite the fact that other studies investigated the combined effects of both mA & kVp[3,19,22] , and the effect of the mA alone[28], yet we preferred standardizing all variables except kVp to assure reliable results.

In our study, we believe that studying the effect of kVp alone along with the MAR tool, would be more effective as supported by **(Chindasombatjareon et al. 2011)** [4]**, (Bechara et al. 2012)** [2]**, (Panjnoush et al. 2016)** [19]**, (Codari et al. 2017)** [5]**& (Freitas et al. 2018)** [10]**.**

The accuracy of the linear measurements and the measurement tool (Romexis® software), were one of our main concerns during this study, the used software was found to be accurate in many studies, giving statistically insignificant difference from that of the gold standard [1]**.**

After scanning, the CBCT images were imported and analyzed on Romexis®. MAR tool is an inherited option in the software, it was applied for each scan, so that for each scan we had two versions; with and without the application of the MAR, so as to test the effect of both kVp value variations & MAR tool on the reduction of the artifacts, each kVp value was evaluated with and without the MAR tool activation in each scan.

The application of MAR tool was also recommended by many authors **(Bechara et al. 2012)** [2]**, (Korpics et al. 2016)** [14]**, (Codari et al. 2017)** [5] **& (Freitas et al. 2018)** [10]**,** especially when using physical or simulated phantoms ranging from a simple simulated jaw phantom to a more complex phantom such as the othropomorphic phantom.

Quantitative assessment of the height of bone affected under the crown restorations from the crest of the ridge till the inferior border of the mandible was a novel method not followed by any previously published study up to the authors' knowledge, although similar volumetric analysis was done for the artifacts, with different methodology from that used in this study **(Omar, Abdelsalam, and Hamed 2016)** [18]**, (Sheridan et al. 2018)** [26] **& (Machado, A.H et al. 2018)** [16]**.**

In the current study, there was a very strong intra-observer & inter-observer reliability for measurements of the length of the alveolar bone affected under the crown restoration for both single and double implants. **Codari et al. (2017)** [5] **& Rabelo et al. (2017)** [23] reported in their studies, that better inter-observer and intra-observer agreement were reported when evaluating streaks artifacts as a type of beam hardening, than that for cupping artifacts or any other type of artifacts, varying from moderate to almost perfect. This could be due to the ease of their detection and evaluation.

**70 kVp** without MAR have the **highest mean length** of 1.72 (±0.37) mm, while **90 kVp** without MAR have the **lowest mean length** of 1.18 (±0.79) mm. All techniques measurements showed a statistically significant effect on the bone.

**Meanwhile, 90 kVp with MAR** showed the **highest mean length** of 0.31 (±0.67) mm, while both **70 kVp with MAR** & **80 kVp with MAR** showed the **lowest mean length** of 0.08 (±0.25) mm. All techniques measurements showed a statistically insignificant effect on the bone.

Application of MAR lead to decrease in affected bone under full veneered crowns. Full veneered crowns artifact decreased to be less than 1 mm.

Limited number of studies have been published about the quantitative assessment of the artifacts, and mostly were around dental implants not full metal crowns or other restorative materials, except for **Omar, Abdelsalam, and Hamed (2016)** [18] in their study. They quantitatively assessed metallic

artifacts of different restorative materials in terms of volume not length, using two different segmentation methods by Simplant software & **Sheridan et al. (2018)** [26] who quantitavely assessed the areas of the artifacts surrounding 20 porcelain fused to metal crowns scanned with different FOV sizes.

Another study by **Machado, A.H et al. (2018)** [16]**,** quantitatively assessed the effect of the artifacts surrounding the dental implants by using grey values, where they concluded the effect of the anatomical position of the implants, where maxillary implants had fewer artifacts.

An ex vivo study by **Parsa A, Ibrahim N, Hassan B, Syriopoulos K (2014)** [21] showed that gray values of the voxels directly surrounding the implants, deviate greatly from the original range, whether MAR tool was activated or not, as their results showed no differences in gray value ranges surrounding the metallic structures with and without the activation of MAR tool.

The results of the above mentioned study was in contradictory to the results of our study, this may be due to the following reasons: firstly, the methodology of this study was different from ours, as we did not evaluate the grey values in vicinity of the implants, but we depended on a quantitative method for the evaluation of the effect of the MAR tool on the reduction of the artifacts effects of the surrounding structures to the metallic objects not a qualitative one. Secondly, they used different CBCT machine than what we used in our study, ORTHOPANTOMOGRAPH OP300, without any reporting on the application of the MAR tool in such machine whether effective or not. Consequently, our quantitative analysis and the type of machine used in our study yielded much accurate results.

## CONCLUSIONS

MAR application reduced the effect of the metal induced artifacts related to full veneered crowns more effectively than changing kVp.

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