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EVALUATION OF EFFECT OF ANATOMIC LOCATION ON ARTEFACT FORMATION DUE TO DENTAL IMPLANT IN CBCT- A RETROSPECTIVE STUDY

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ABSTRACT

Purpose: Artefact quantification can aid in identifying the impact of implant artefact on anatomic site and diagnostic accuracy. Therefore, this study was undertaken to evaluate the effect of anatomical location on artefacts formation caused by titanium dental implants using CBCT.

Materials and method: Total 104 CBCT scans with titanium dental implants placed in anterior and posterior region of jaw were obtained and were equally divided into 4 groups according to the location of implant. The image was then analyzed by Image J Software and histogram was obtained. The minimum and maximum grey values along with their actual standard deviation were determined using the histogram to determine artefact quantification.

Results: Both maxilla and mandible showed a significant higher percentage of artefacts at all the levels except level 1. No significant difference was observed in the percentage of metal artefacts produced by implants between maxilla and mandible irrespective of anterior and posterior region. No statistically significant difference was observed in the percentage of metal artefacts produced by implants between isolated and adjacent implants.

Conclusion: The anatomic location influences the amount of metal artefacts generated, as more predilection for the posterior region of maxilla and mandible was found while intergroup comparison showed significant higher percentage of quantification at the cervical level of implant.

Keywords: CBCT, metal artefacts,dental implants.

INTRODUCTION

Cone Beam Computed Tomography (CBCT) has become an indispensable tool for the pre- and post-operative evaluation of dental implants and the surrounding anatomical structures.[1,2] In the post-operative phase, CBCT plays a crucial role in identifying signs of peri-implantitis, and evaluating parameters such as marginal bone levels and bone-to-implant contact. However, one of the most significant challenges associated with post-operative CBCT imaging is the formation of metal artefacts caused by the presence of dental implants.[3] These artefacts appear as radiographic distortions or false structures that do not correspond to actual anatomical features.[4] The presence of metal artefacts can severely compromise image quality by obscuring vital anatomical details, thus hindering accurate diagnosis. Moreover, these distortions increase the time required for image interpretation and may affect clinical decision-making, particularly in cases where precise evaluation of peri-implant tissues is essential.[5,6]

Dental implants are commonly fabricated from high-density metals such as titanium, zirconium, and titanium-zirconium alloys. The high atomic number and density of these materials contribute to the formation of artefacts in CBCT images due to differential attenuation and absorption of X-rays, leading to a phenomenon known as beam hardening.[7,8] These artefacts typically appear as hyperdense linear streaks radiating from the implant surface, often accompanied by hypodense scattered areas in the surrounding region.[7,9,10]

The most probable cause of artefact formation in CBCT images is the preferential absorption of low-energy photons by the metallic implant, rather than high-energy photons, which alters the X-ray attenuation profile and affects the image reconstruction process.[7□9□11]
During post-surgical follow-up, these metal artefacts significantly reduce tomographic image quality due to extreme variations in gray values around the implant site. This hampers the accurate assessment of osseointegration and the detection of conditions such as peri-implantitis, thereby affecting the reliability of post-surgical evaluation.[12-14]
To enhance image quality and diagnostic accuracy, it is essential to understand the underlying causes of artefact formation and explore methods to minimize or prevent them. An essential component of this is the quantification of metal artefacts, which remains a relatively underexplored area. Notably, there is a lack of comprehensive studies evaluating artefact quantification produced by titanium dental implants using CBCT.[12] Furthermore, there is a significant paucity of data from Indian studies focusing on the influence of anatomical location on metal artefact formation.[12□15]
Therefore, the present study was undertaken to evaluate the effect of anatomical location on the formation of metal artefacts caused by titanium dental implants using CBCT.

MATERIALS AND METHODS

This retrospective observational study was conducted following approval from the Institutional Ethical Committee. The primary objective was to quantify metal artefacts produced by dental implants concerning their anatomical location and at various equidistant axial sections of the implant.
CBCT scans were obtained from a private imaging centre, where a total of 104 CBCT scans of patients with dental implants placed in the anterior and posterior regions of the maxilla and mandible were included. All scans were acquired using the Orthophos SL CBCT machine, equipped with 3D Diagnostic Software version 4.2. The scanning parameters were as follows: tube voltage of 85 kVp, tube current ranging from 4 to 7 mA, an exposure time of 14 seconds, and varying fields of view (5 × 5 cm, 8 × 8 cm, and 11 × 11 cm) with a 12-bit grayscale resolution.

Inclusion Criteria

- CBCT scans showing titanium dental implants with prosthesis placed in the anterior or posterior region of the maxilla or mandible, irrespective of the patient's age or gender.

Exclusion Criteria

1. CBCT scans of implants placed in the zygomatic bone.
2. CBCT scans with restorations, crowns, or metallic posts in proximity to the implant site.

A total of 104 CBCT scans meeting the inclusion criteria were obtained, with titanium dental implants placed in either the anterior or posterior regions of the maxilla and mandible. In addition, implants were further classified as isolated implants or adjacent implants, based on their spatial relationship. Implants placed within 5 mm of each other were considered adjacent implants.
These scans were equally divided into four groups based on the anatomical location of the implant:

- Group I — 26 implants placed in the anterior maxilla
- Group II — 26 implants placed in the posterior maxilla
- Group III — 26 implants placed in the anterior mandible
- Group IV — 26 implants placed in the posterior mandible

All CBCT images were imported into DICOM-compatible software, and each scan was systematically evaluated at five predefined axial levels along the length of the implant. These included the cervical level, the level between the cervical and middle third, the middle level, the level between the middle and apical third, and the apical level. This approach allowed for a comprehensive assessment of metal artefact formation at different implant sections, providing insight into the variation of artefacts along the vertical extent of the implant across different anatomical locations.

Quantification of Metal Artefacts in CBCT

Image J software (version 1.52a, National Institutes of Health, USA) was used for the quantitative assessment of artefacts on the selected axial sections of each implant. Within the software, a region of interest (ROI) with a diameter of 10 mm was selected, positioning the implant at the center of the ROI. The image was then analyzed using the histogram function of the software to obtain the minimum and maximum grey values, along with the actual standard deviation (SD) of the grey values within the selected area.

The CBCT machine used in this study operated on a 12-bit scale, providing 4096 grey values. Based on this, the maximum theoretical standard deviation was calculated, which corresponds to half of the total grey value range, i.e., 2048 grey values.

The percentage of metal artefact formation was calculated using the formula described by Pauwels et al. (2013):

Artefact Quantification (%) = Actual SD/Theoretical Maximum SD×100

Where:

- Actual Standard Deviation = Derived from the minimum and maximum grey values obtained using the ImageJ software.
- Theoretical Maximum Standard Deviation = Half of the grey value range of the CBCT machine (i.e., 2048 grey values).

Thus, the actual SD was expressed as a percentage of the maximum theoretical SD. A higher percentage indicates a greater degree of artefact formation, reflecting the severity of image distortion caused by the metallic implant.

Statistical methods

The data on metal artefacts was obtained according to anterior, posterior, maxilla and mandible sites for isolated and adjacent implants and summarized in terms of mean, standard deviation and median. The comparison of median artefacts between different paired categories was performed using Mann-Whitney U test, while across slice comparison was performed using Kruskal-Wallis test. All the analyses were carried out in SPSS ver 26.0 (IBM Corp, USA) software and the statistical significance was tested at 5% level.

RESULTS

All the CBCT scans were evaluated at 5 different axial levels (Fig. 1). No significant difference was observed in the percentage of metal artefacts produced by implants between the anterior maxilla and anterior mandible (Table 1). No significant difference was observed in the percentage of metal artefacts produced by implants between the posterior maxilla and posterior mandible (Table 2). Both maxilla and mandible showed a significant higher percentage of artefacts at all the levels except level 1. (Table 3) No significant difference was observed in the percentage of metal artefacts produced by implants between maxilla and mandible irrespective of anterior and posterior region (Table 4). No significant difference was observed in the percentage of metal artefacts produced by implants between maxilla and mandible with isolated implants (Table 5). No significant difference was observed in the percentage of metal artefacts produced by implants between maxilla and mandible with adjacent implants (Table 6). No statistically significant difference was observed in the percentage of metal artefacts produced by implants between isolated and adjacent implants (Table 7). A statistically significant difference was observed in the percentage of metal artefacts produced by implants across 5 different levels of dental implants (Table 8).

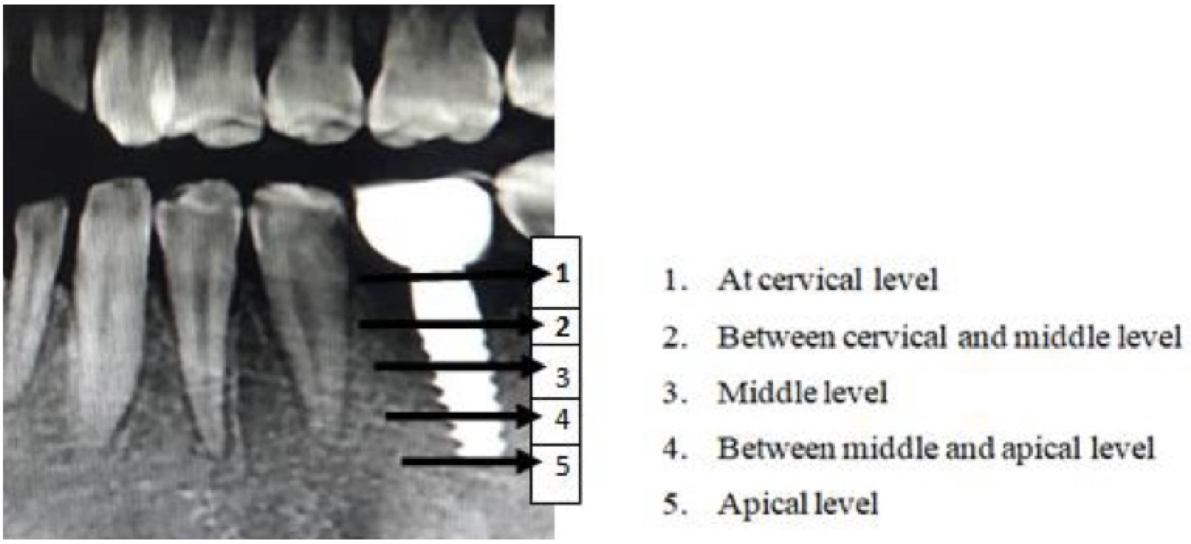

Figure 1: CBCT image showing equidistant five axial levels from cervical to apical.

Figure 2: Showing Area of interest with a diameter of 10 mm with implant as centre.

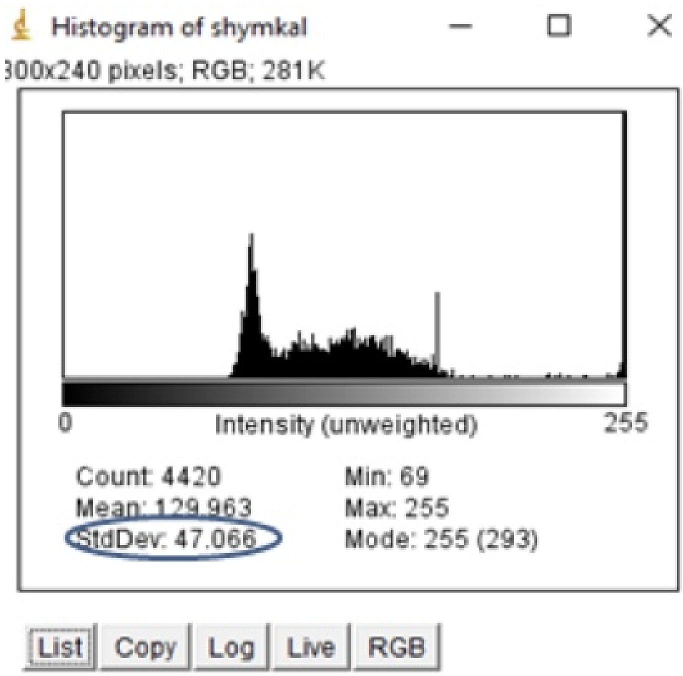

Figure 3: Histogram analysis

Table 1: Comparison of metal artefacts in percentage between anterior maxilla and anterior mandible.

5 different levels of Dental implant			Cervical level	Cervical and middle level	Middle Level	Middle and apical level	Apical level
Site	Maxillary	N	26	26	26	26	26
		Mean	2.78	2.53	2.34	2.13	1.80
		SD	0.15	0.10	0.09	0.11	0.10
		Median	2.75	2.50	2.30	2.10	1.80
	Mandibular	N	26	26	26	26	26
		Mean	2.85	2.60	2.39	2.16	1.79
		SD	0.22	0.17	0.17	0.15	0.17
		Median	2.90	2.60	2.40	2.20	1.80
P-value*			0.240	0.106	0.302	0.348	0.813

SD: Standard deviation; *Obtained using Mann-Whitney U test

Table 2: Comparison of metal artefacts in percentage between posterior maxilla and posterior mandible

5 different levels of dental implant			Cervical level	Cervical and middle level	Middle level	Middle and apical	Apical level
Site	Maxillary	N	26	26	26	26	26
		Mean	2.87	2.65	2.44	2.22	1.90
		SD	0.12	0.09	0.12	0.12	0.11
		Median	2.90	2.70	2.45	2.20	1.90
	Mandibular	N	26	26	26	26	26
		Mean	2.89	2.60	2.40	2.19	1.85
		SD	0.17	0.12	0.13	0.11	0.16
		Median	2.90	2.60	2.40	2.20	1.85
P-value*			0.560	0.112	0.074	0.068	0.148

SD: Standard deviation; *Obtained using Mann-Whitney U test

Table 3: Comparison of metal artefacts in percentage between anterior region of maxilla and mandible and posterior region of maxilla and mandible.

5 different levels of dental implant			Cervical level	Cervical and middle level	Middle Level	Middle and apical	Apical level
Site	Anterior region of both jaws	N	52	52	52	52	52
		Mean	2.82	2.56	2.37	2.14	1.80
		SD	0.19	0.14	0.14	0.13	0.14
		Median	2.80	2.50	2.30	2.10	1.80
	Posterior region of both jaws	N	52	52	52	52	52
		Mean	2.88	2.62	2.42	2.21	1.88
		SD	0.15	0.11	0.13	0.12	0.14
		Median	2.90	2.60	2.40	2.20	1.90
P-value*			0.099	**0.026**	**0.031**	**0.015**	**0.012**

SD: Standard deviation; *Obtained using Mann-Whitney U test; Bold p-values indicate statistical significance.

Table 4: Comparison of metal artefacts in percentage between maxilla and mandible irrespective of anterior and posterior region.

5 different levels of dental implant			Cervical level	Cervical and middle level	Middle level	Middle and apical level	Apical level
Site	Maxillary	N	52	52	52	52	52
		Mean	2.83	2.59	2.39	2.17	1.85
		SD	0.14	0.12	0.12	0.12	0.11
		Median	2.90	2.60	2.40	2.20	1.90
	Mandible	N	52	52	52	52	52
		Mean	2.87	2.60	2.39	2.18	1.82
		SD	0.20	0.15	0.15	0.13	0.17
		Median	2.90	2.60	2.40	2.20	1.80
P-value*			0.149	0.634	0.987	0.907	0.394

SD: Standard deviation; *Obtained using Mann-Whitney U test

Table 5: Comparison of metal artefacts in percentage between maxilla and mandible with isolated implants.

5 different levels of dental implant			Cervical Level	Cervical and middle level	Middle level	Middle and apical level	Apical level
Region	Maxillary	N	30	30	30	30	30
		Mean	2.85	2.61	2.40	2.19	1.84
		SD	0.14	0.12	0.13	0.13	0.12
		Median	2.90	2.60	2.40	2.20	1.90
	Mandible	N	24	24	24	24	24
		Mean	2.90	2.59	2.40	2.19	1.81
		SD	0.21	0.16	0.18	0.15	0.15
		Median	2.90	2.60	2.40	2.20	1.85
P-value*			0.243	0.675	0.957	0.943	0.581

SD: Standard deviation; *Obtained using Mann-Whitney U test

Table 6: Comparison of metal artefacts in percentage between maxilla and mandible with adjacent implants.

5 different levels of dental implant			Cervical level	Cervical and middle level	Middle level	Middle and apical level	Apical level
Site	Maxillary	N	22	22	22	22	22
		Mean	2.79	2.56	2.37	2.16	1.86
		SD	0.14	0.11	0.10	0.11	0.10
		Median	2.80	2.50	2.30	2.20	1.90
	Mandibular	N	28	28	28	28	28
		Mean	2.85	2.61	2.39	2.17	1.83
		SD	0.18	0.14	0.13	0.12	0.18
		Median	2.90	2.60	2.40	2.20	1.80
P-value*			0.167	0.162	0.550	0.848	0.500

SD: Standard deviation; *Obtained using Mann-Whitney U test

Table 7: Comparison of metal artefacts in percentage caused by isolated and adjacent implants irrespective of maxilla and mandible

5 different levels of dental implant			Cervical level	Cervical and middle level	Middle Level	Middle and apical level	Apical Level
Implants	Isolated	N	54	54	54	54	54
		Mean	2.87	2.60	2.40	2.19	1.83
		SD	0.18	0.14	0.15	0.14	0.14
		Median	2.90	2.60	2.40	2.20	1.90
	Adjacent	N	50	50	50	50	50
		Mean	2.82	2.59	2.38	2.16	1.85
		SD	0.16	0.13	0.12	0.12	0.15
		Median	2.80	2.60	2.40	2.20	1.85
P-value*			0.107	0.641	0.309	0.313	0.645

SD: Standard deviation; *Obtained using Mann-Whitney U test

Table 8: Comparison of metal artefacts in percentage produced across 5 different levels of dental implants.

		5 different levels of dental implant				
		Cervical level	Cervical and middle level	Middle level	Middle and apical level	Apical level
Artifacts	N	104	104	104	104	104
	Mean	2.85	2.59	2.39	2.18	1.84
	SD	0.17	0.13	0.14	0.13	0.14
	Median	2.90[a]	2.60[b]	2.40[c]	2.20[d]	1.90[e]
P-value*		**< 0.0001**				

*Obtained using Kruskal-Wallis test; SD: Standard deviation; Bold p-value indicate statistical significance; Different alphabets in the superscript indicate significant difference in the pairwise comparison.

DISCUSSION

Artefact formation in CBCT scans is influenced by several factors, including the implant material, field of view (FOV), CBCT machine specifications, tube voltage (kVp), anatomical site, and voxel size.[3] These artefacts significantly reduce image quality and can adversely affect the interpretation and diagnostic accuracy of CBCT scans.[5–6]

In CBCT imaging, three-dimensional images are composed of voxels, with each voxel assigned a gray value that reflects the degree of X-ray attenuation as the beam passes through the scanned object. The gray values in CBCT images are directly influenced by the atomic number and density of the materials within the scan.[12–15]

Dental implants are commonly fabricated from metals such as titanium, zirconium, and titanium-zirconium alloys, all of which have a higher atomic number and density compared to surrounding bone and soft tissues.[17] This difference leads to the formation of beam hardening artefacts, primarily due to variations in the attenuation and absorption of the X-ray beam.[7–8] As the X-rays pass through these high-density materials, low-energy photons are preferentially absorbed, rather than high-energy photons, resulting in artefacts.[8–9] These artefacts manifest as hyperdense streaks radiating from the implant surface, often accompanied by hypodense scattered areas, which can obscure adjacent anatomical details.[7–9–10]

Previous studies have shown that zirconium implants tend to produce more pronounced metal artefacts compared to titanium implants, primarily due to the higher atomic number and density of zirconium.[18-23] Considering these findings, the present study specifically focused on titanium implants, as they are the most commonly used implant material in clinical practice in this region. Limiting the study to titanium implants also minimized potential variability and bias in artefact quantification.

The widespread preference for titanium implants by implantologists can be attributed to their proven clinical efficiency, cost-effectiveness, high treatment success rates, and relatively lower propensity for artefact formation, compared to other implant materials. In the present study, metal artefact formation around dental implants was evaluated with respect to anatomical location and implant positioning. When comparing implants placed in the anterior and posterior regions, irrespective of the jaw, it was observed that implants placed in the posterior regions of both the maxilla and mandible produced a significantly higher percentage of artefacts at all evaluated levels, except at Level 1 (cervical level) (Table 3).

However, no statistically significant difference was found in the percentage of artefacts between implants placed in the maxilla and mandible, regardless of the specific anatomical site (Table 4). This finding is in partial contrast to the study by Oliveira et al.,[15] who reported that gray values obtained from CBCT scans for similar objects varied depending on anatomical location, likely due to differences in surrounding structures.

Interestingly, Machado et al.[12] observed a greater number of artefacts in implants placed in the anterior regions of the jaws, but predominantly at the middle and apical levels. The difference in findings compared to the present study could be attributed to the presence of multiple adjacent implants in their sample, which may have exacerbated artefact formation.

Valizadeh et al.[14] also emphasized the influence of object position within the FOV on gray value variations due to interactions between X-rays and adjacent anatomical structures. Furthermore, the concept of exomass—the craniofacial structures both inside and outside the FOV—has been shown to contribute to artefact variability depending on anatomical site.[1□18]

Adjacent anatomical structures, such as the skull base and spinal column, can affect gray value measurements in both the maxilla and mandible.

In the present study, artefact quantification was carried out at five different axial levels of the implant, and significant differences in gray values were observed among these levels (Table 9). This is contrary to Machado et al.,[2] who reported no significant difference when artefacts were assessed at three levels (cervical, middle, and apical). One potential explanation is the presence of prosthetic crowns in their study, often made of materials like cobalt-chromium, which possess a higher atomic number than titanium and are known to produce pronounced artefacts, particularly at the cervical level.[2□11]

It is well-established that implants, being high-density materials, attenuate X-ray beams to a greater extent than surrounding bone or soft tissues.[17□24] Consequently, it is often predicted that a greater percentage of artefacts would be observed between adjacent implants compared to isolated implants. However, in the present study, no significant difference in artefact percentage was noted between adjacent and isolated implants (Table 7), consistent with the findings of **Machado et al.**[2] A plausible explanation for this could be the use of a small region of interest (ROI) measuring 10 × 10 mm, which may have limited the detection of artefact variations. It is anticipated that employing a wider ROI might reveal a greater degree of artefact formation between adjacent implants.

In a related context, Rabelo et al.[25] investigated artefact formation by different root canal filling materials in CBCT images, considering variables such as tube voltage (kVp) and tube current (mA). Their study concluded that exposure parameters had no significant impact on artefact formation.

Future in vitro studies are recommended to assess the influence of other imaging parameters—such as voxel size, slice thickness, and FOV—on artefact formation by dental implants or similar materials. Such research could help optimize CBCT scanning protocols to minimize artefact production and enhance diagnostic accuracy, ultimately contributing to improved patient care in implant dentistry.

From these findings, it can be concluded that metal artefacts are inevitable in CBCT imaging of dental implants. Moreover, the anatomical location plays a crucial role in determining the extent of artefact formation, with a higher predilection observed in the posterior regions of both the maxilla and mandible.

CONCLUSION

The present study concludes that artefact formation in CBCT imaging is significantly influenced by the anatomical location of dental implants, with a higher predilection for the posterior regions of both the maxilla and mandible. Additionally, quantification of metal artefacts at equidistant axial sections from the cervical to apical regions of the implant revealed significant differences, with the highest percentage of artefact formation observed at the cervical level. These findings highlight the importance of anatomical site consideration and axial implant level in the assessment and interpretation of CBCT scans for implant cases.

Limitations and Future Prospects

1. This study did not account for other technical factors known to influence artefact formation, such as field of view (FOV), voxel size, and slice thickness. Future in vitro studies are warranted to comprehensively evaluate the impact of these parameters on artefact generation by dental implants and other high-density materials. Such studies may contribute to optimizing CBCT protocols to minimize artefact formation and improve diagnostic accuracy.

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