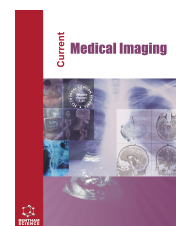




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RESEARCH ARTICLE

Effects of Dental Metal Implant Number and Configuration on PET/CT Quantification and Image Quality: A Phantom-Based Study

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Abstract:

Introduction/Objectives:

Dental metal implants can generate artifacts in PET/CT imaging, particularly in the head and neck region, affecting quantitative accuracy. This study evaluated variations in standardized uptake value (SUV), contrast (C), and contrast-to-noise ratio (CNR) across predefined dental implant configurations differing in both implant number and spatial arrangement and assessed their effects on simulated tongue, nasopharyngeal, and laryngeal lesions.

Methods:

A custom-designed head and neck phantom containing extracted human teeth and up to eight titanium dental implants was used. Simulated tongue, nasopharyngeal, and laryngeal tumors were filled with F-18 FDG. PET/CT scans were acquired using seven implant configurations (0–8 implants) and reconstructed as attenuation-corrected (AC), AC with metal artifact reduction (AC+MAR), and non-attenuation-corrected (NoAC) images. SUV, contrast, and CNR were calculated using standardized ROIs.

Results:

Compared with the implant-free configuration, tongue tumor SUV decreased by 11% and 9.1% on AC and AC+MAR images, respectively, at eight implants. Nasopharyngeal and laryngeal SUV showed only minimal descriptive change with increasing implant number and configurations on AC+MAR images. Contrast and CNR followed similar trends on AC and AC+MAR images, whereas NoAC images consistently showed substantially lower contrast and CNR regardless of implant number.

Discussion:

Although MAR reduced implant-induced artifacts and partially attenuated SUV underestimation, it did not eliminate the configuration-dependent trend observed across the predefined implant arrangements. Lesions farther from the implants appeared less affected after MAR; however, this should be regarded as a hypothesis-generating observation from a single phantom experiment, requiring validation in patient studies and phantom models with varying implant-to-lesion distances.

Conclusion:

Dental implants may affect PET/CT quantification, particularly for lesions adjacent to multiple implants; SUV measurements in these regions should be interpreted with caution.

Keywords: PET/CT image quality, Dental implant, Metal artifact, Attenuation correction, Metal artifact reduction (MAR).

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1. INTRODUCTION

Hybrid positron emission tomography/computed tomography (PET/CT) is a fundamental imaging modality in oncology, providing both metabolic and anatomical informa-

tion for tumor detection, staging, and assessment of treatment response. In particular, fluorine-18 (F-18) fluorodeoxyglucose (FDG) PET/CT plays a crucial role in the evaluation of head and neck malignancies, including tumors of the oral cavity, tongue, and lips. Accurate lesion delineation and reliable quantitative measurements in these regions are essential for clinical decision-making [1, 2]. However, PET/CT imaging is

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susceptible to various artifacts, especially in the head and neck region where metallic materials such as dental restorations and implants represent significant sources of degradation. These high-density structures cause pronounced streak artifacts and inaccurate Hounsfield unit (HU) values on CT images due to physical effects such as beam hardening, photon starvation, and scatter [3, 4]. Martin *et al.* demonstrated that metallic dental implants can disrupt CT-based attenuation correction, leading to significant deviations in standardized uptake value (SUV) measurements on PET images [5]. Similarly, Abdoli *et al.* reported that these deviations vary depending on whether the artifact appears as hypodense (dark streak) or hyperdense (bright streak) [6].

Since CT data are used for attenuation correction in PET imaging, metal-induced CT artifacts propagate into PET images, resulting in errors in quantitative assessment. Prior studies have shown that dental implants can significantly bias SUV measurements due to impaired attenuation correction, with the magnitude and direction of this bias depending on artifact characteristics [6]. These effects are particularly problematic in small and anatomically complex regions [5]. In addition to SUV deviations, metal-induced artifacts degrade overall image quality by increasing image noise and reducing lesion contrast, thereby impairing visualization of anatomical structures and lesion conspicuity. Consequently, the contrast-to-noise ratio (CNR), a key determinant of lesion detectability, may also be adversely affected. Artifact-related heterogeneous background activity and localized noise increases make it more difficult to distinguish true lesion signals [7]. These challenges are further amplified in anatomically complex areas such as the tongue and lips, where small lesions are common. The clinical impact of metal artifacts is particularly pronounced in oral tumors due to their proximity to dental structures. This may adversely affect both lesion detectability and quantitative accuracy. In some cases, metal artifacts may obscure lesions on CT, whereas CT-based attenuation correction errors may produce false-positive uptake or obscure true lesions on PET/CT [4, 8]. Therefore, a comprehensive understanding of the impact of metal artifacts on PET/CT imaging is essential for accurate interpretation in this region.

Various MAR techniques have been developed to mitigate these effects. While these approaches have been shown to improve image homogeneity, reduce noise, and enhance quantitative accuracy, their clinical benefit in terms of lesion detectability and SUV reliability remains a subject of debate [9].

Although the impact of dental metal implants on PET/CT imaging has been generally demonstrated in the literature, studies systematically evaluating the incremental effect of increasing implant number on quantitative parameters and image quality are limited. In particular, there is a lack of controlled phantom-based studies investigating changes in SUV, contrast, and CNR across predefined implant

configurations differing in implant number and spatial arrangement. The aim of this study was to evaluate variations in PET/CT quantification and image quality across predefined dental implant configurations differing in both implant number and spatial arrangement. Additionally, artifact-related changes were descriptively assessed in regions representing tumors of the tongue, nasopharynx, and larynx located at different positions relative to the implants.

2. MATERIALS AND METHODS

2.1. Phantom Design

The head-and-neck phantom consisted of a cylindrical plexiglass water tank with a height of 18.6 cm, a diameter of 21.6 cm, and a total volume of 6.82 L. The top cover was secured to the body using plastic screws to ensure stability during imaging and to prevent fluid leakage.

To stabilize the dental model and simulated tumors within the tank, a plexiglass support apparatus ($17 \times 8 \times 0.8$ cm) with upper and lower stands was used. The dental model was positioned 5 cm above the base of the phantom. To mimic real anatomy, extracted human teeth were placed into removable sockets on maxillary and mandibular alveolar process models.

To simulate pathological uptake regions, three cylindrical plastic inserts were used: a tongue tumor insert (1.0 cm diameter, 2 cm height, 1.96 mL volume) placed between the maxilla and mandible; a laryngeal tumor insert (15 mL) positioned in the posterior-inferior part of the tank; and a nasopharyngeal tumor insert (33 mL) positioned 13 cm above the base. The distances from the nearest implant were 7.5 cm for the nasopharynx and 5.5 cm for the larynx. The phantom was designed not for exact anatomical replication but to enable controlled and reproducible quantitative measurements. All inserts were fixed securely to prevent displacement during imaging.

To generate metal artifacts, titanium dental implants were placed in predefined and reproducible positions within the dental model. A total of eight implants were used, with four placed symmetrically in the maxilla and four in the mandible.

2.2. F-18 FDG Activity, PET/CT System Specifications, and Imaging Protocols

The phantom background was filled with F-18 FDG at a concentration of 0.60 kBq/mL, while the simulated tumor regions (tongue, nasopharynx, and larynx) were filled at 3.7 kBq/mL. The total tumor volume of 49.96 mL was filled with FDG at a clinically relevant activity concentration of 3.7 kBq/mL, which decreased to approximately 2.53 kBq/mL after a 1-hour uptake period. The background volume (6410 mL) was filled with a total activity of 3.9 MBq at the time of imaging to ensure homogeneous distribution. The phantom was then positioned in the scanner (Fig. 1). All imaging was performed using a GE Omni Legend PET/CT system.



Fig. (1). Positioning of the phantom in the PET/CT scanner during image acquisition.

CT acquisition parameters: tube voltage 120 kVp, tube current 65 mA, rotation time 0.7 s, slice thickness 3.75 mm, pitch 1.375:1, and table speed 27.5 mm/rotation.

PET acquisition parameters: acquisition time 2 minutes per bed position, axial field of view (FOV) 157 mm, transaxial FOV 512 mm, matrix size 384×384 , spatial resolution 5.0 mm (FWHM at center), and sensitivity 8.5 cps/kBq. All scans were processed according to routine clinical protocols. PET images were reconstructed using the VUE Point HD algorithm with 22 subsets and 3 iterations.

The study was performed using commercially available titanium dental implants. All implants used in this study had a diameter of 4.0 mm and a length of 10.0 mm and, according to the manufacturer's technical specifications, were manufactured from Commercially Pure Titanium Grade 4 (CP Ti Grade 4), with a density of 4.5 g/cm^3 . The implants were inserted into the extracted human teeth and used to create the different implant configurations evaluated in this study.

PET/CT acquisitions were performed using seven implant configurations. These were, respectively, 8 implants, 6 implants, 4 implants, 2 implants, 1 implant in the mandible, 1 implant in the maxilla, and 0 implants (no implants). In successive acquisitions, the number of implants was systematically reduced while maintaining symmetry as much as possible. For the two single-implant configurations, implants 4 and 8 were retained separately in the mandible and maxilla, respectively, to represent different spatial relationships with the

simulated tongue tumor. Thus, the configurations were predefined according to both implant number and spatial arrangement. Because reducing the number of implants necessarily altered their spatial distribution, implant number and implant location were not experimentally independent factors in this design. Therefore, comparisons among configurations represent the combined effect of implant number and spatial arrangement and should not be interpreted as isolating the effect of implant number alone. The full configuration comprised eight implants, with four implants symmetrically positioned in the maxilla and four in the mandible. To facilitate rapid and reproducible changes between configurations, PET/CT acquisitions were performed with the phantom positioned so that the removable upper section faced upward. All configurations were implemented according to the predefined and reproducible arrangement scheme shown in Fig. (2). For metal artifact reduction, the Smart Metal Artifact Reduction (Smart MAR) algorithm available on the system was used. Smart MAR is a vendor-specific proprietary algorithm developed by GE HealthCare. It reduces streak artifacts caused by high-attenuation metallic structures by performing corrections at the projection (sinogram) level. Initially, metallic regions are automatically segmented, and the affected projection data are interpolated. Iterative reconstruction is then performed using the corrected projection data, and the resulting image is combined with the original data to preserve anatomical accuracy. PET images were reconstructed with standard attenuation correction (AC) and attenuation correction with metal artifact reduction (AC+MAR).



Fig. (2). Titanium dental implants numbered 1–8 in the maxilla and mandible (left) and the corresponding implant configurations used in the study (right).

2.3. Image Quantification

Image quantification was performed on attenuation-corrected (AC) and attenuation-corrected with metal artifact reduction (AC+MAR) PET images. In addition, contrast (C) and contrast-to-noise ratio (CNR) were calculated from non-attenuation-corrected PET images (NoAC).

Three distinct ROI categories were used according to their specific analytical purposes: tumor ROIs, background ROIs, and artifact-related ROIs.

Tumor ROIs: Tumor ROIs were defined separately on sagittal slices for the simulated tongue, nasopharyngeal, and laryngeal lesions, with the same fixed ROI size applied consistently to the corresponding measurements across implant configurations and reconstruction methods. For each simulated tumor, SUVmax was automatically calculated using the system software and was used as the primary quantitative endpoint for regional comparisons.

Background ROIs: A total of 10 background ROIs were positioned inside and outside the dental model. The first ROI was manually drawn with a fixed diameter, and the remaining nine ROIs were generated by copying this template to predefined locations, thereby ensuring identical ROI size and shape. Of these 10 background ROIs, three were positioned intraorally, between the maxilla and mandible and distant from the dental structures, while seven were positioned extraorally, outside the dental model. For the calculation of contrast and CNR, ROI background was defined as the mean counts obtained across all 10 background ROIs. Background noise ($\sigma_{\text{background}}$) was defined as the standard deviation of the

measurements obtained across these 10 background ROIs.

Artifact-related ROIs: For a separate analysis of local metal artifact effects, ROIs were placed in regions corresponding to dark streak artifacts, bright streak artifacts, and artifact-free reference regions. The three intraoral ROIs located away from dental structures were additionally used as artifact-free reference ROIs for this analysis. These reference ROIs were used to compare SUV measurements in artifact-affected and artifact-free regions and were not used separately to calculate background noise for CNR.

Lesion contrast (C) and contrast-to-noise ratio (CNR) were calculated as follows [10]:

$$C = \frac{ROI_{\text{lesion}} - ROI_{\text{background}}}{ROI_{\text{background}}} \quad (1)$$

ROI_{lesion} : mean ROI counts within the simulated tumor

$ROI_{\text{background}}$: mean ROI counts obtained from 3 intraoral and 7 extraoral background regions

Contrast (C) and contrast-to-noise ratio (CNR) were calculated using the following formulas:

$$CNR = \frac{ROI_{\text{lesion}} - ROI_{\text{background}}}{\sigma_{\text{background}}} \quad (2)$$

$\sigma_{\text{background}}$ is the standard deviation of the measurements obtained from the 10 background ROIs.

2.4. Statistical Analysis

Statistical analyses were performed using SPSS (Statistical

Package for the Social Sciences, IBM Corp., Armonk, NY, USA). SUV measurements obtained from attenuation-corrected (AC) and attenuation-corrected with metal artifact reduction (AC+MAR) images at identical anatomical locations were compared as matched measurements derived from the same phantom acquisition. As an exploratory comparison of the two reconstruction methods, both a paired-samples t-test and the non-parametric Wilcoxon signed-rank test were calculated.

Since each configuration was represented by a single phantom acquisition, independent replicate observations were not available for each implant number–reconstruction method–tumor region combination. Therefore, inferential statistical analyses evaluating the effects of implant number, tumor region, or their interaction with the reconstruction method were not performed, as the study design did not provide the independent replicate observations required for reliable estimation of within-group variability. Accordingly, comparisons based on implant number and simulated tumor region were presented descriptively using graphical trends and relative percentage changes rather than inferential statistical testing.

Accordingly, the statistical comparison was restricted to matched AC and AC+MAR measurements obtained from identical predefined ROIs. These analyses were performed for

exploratory purposes only and should not be interpreted as confirmatory statistical inference because the ROIs originated from the same phantom acquisition and therefore do not represent independent experimental units. A p-value < 0.05 is reported only as an exploratory descriptive indicator and should not be interpreted as evidence of statistical significance beyond the context of this controlled phantom study.

3. RESULTS

In sagittal sections obtained from CT, AC, and AC+MAR images with eight implants, dark streak and bright streak artifacts were clearly visible in CT and AC images, whereas a noticeable reduction of these artifacts was observed in AC+MAR images (Fig. 3).

3.1. SUV Analysis

In the absence of dental implants, SUV values obtained from AC and AC+MAR images were comparable across all simulated tumor regions. In implant-free PET/CT images of the tongue tumor, SUVmax values were 6.81 and 6.82 for AC and AC+MAR images, respectively. Across the predefined implant configurations, a gradual, descriptive decrease in tongue SUVmax values was observed in both AC and AC+MAR images Fig. (4A).

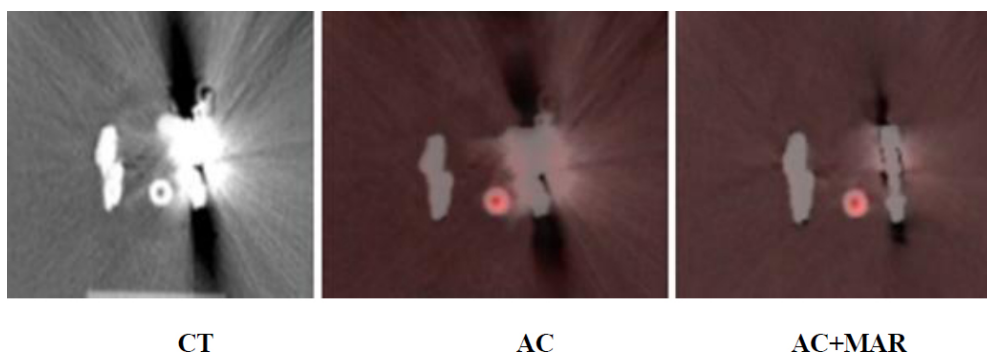
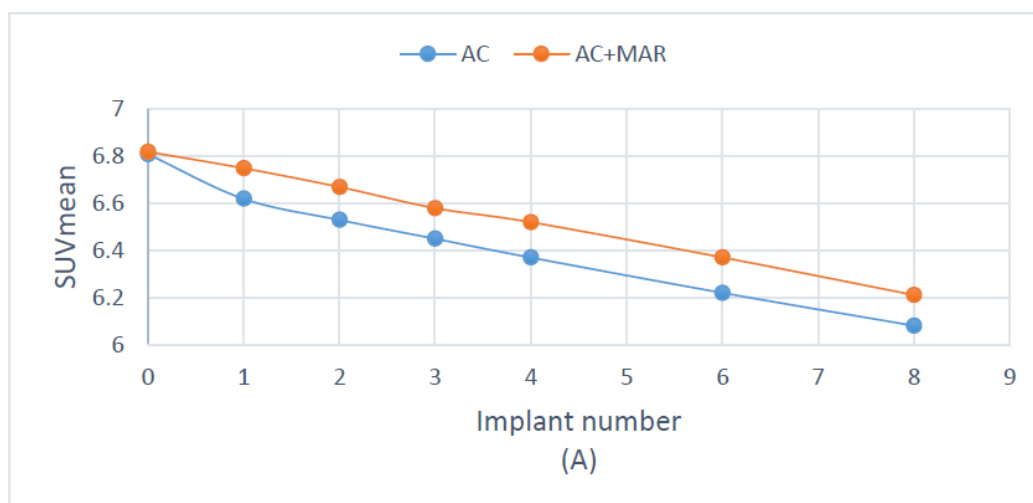


Fig. (3). Sagittal images of the phantom. CT with metal artifacts (with implants), attenuation-corrected PET (AC), and attenuation-corrected PET with metal artifact reduction applied (AC+MAR).



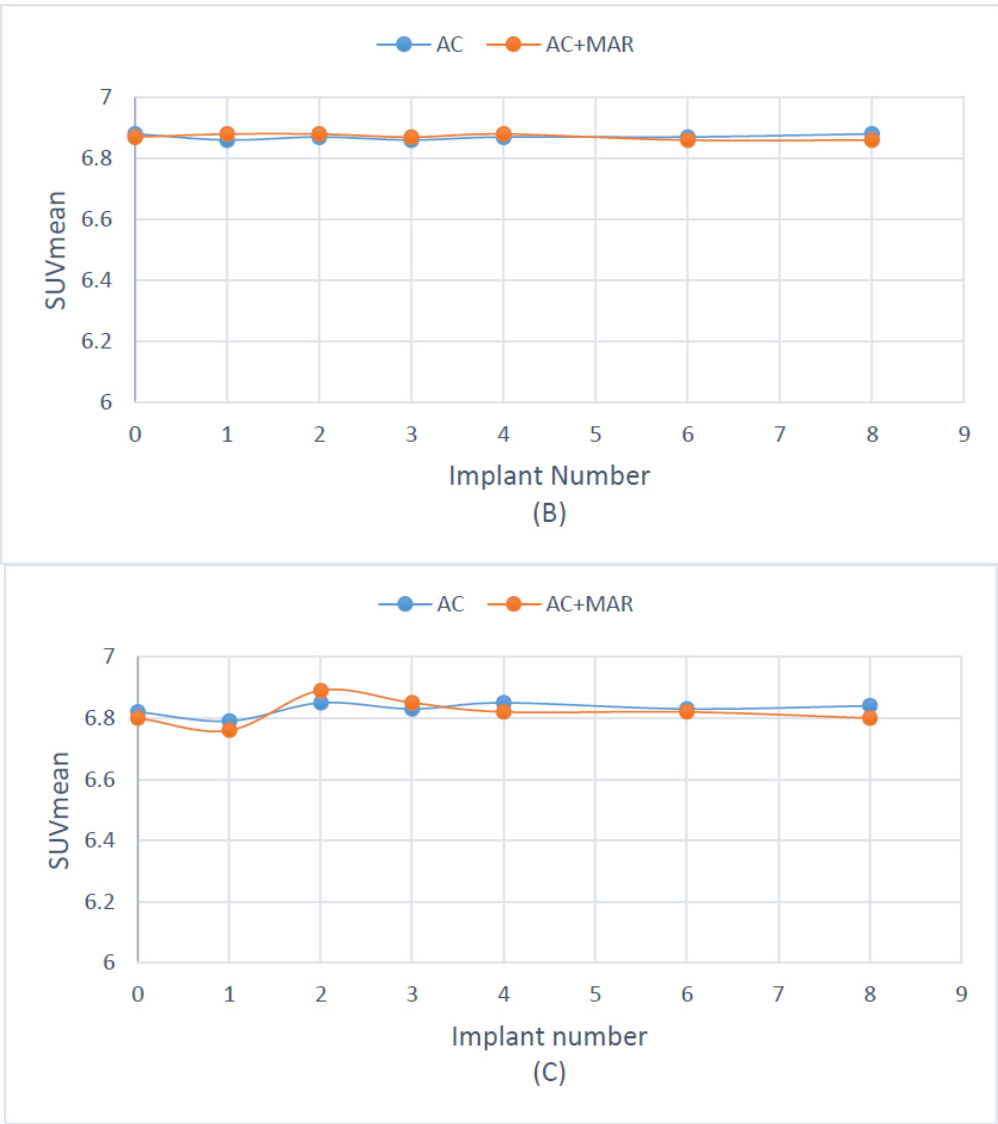


Fig. (4). Variation of SUV values across the predefined implant configurations. Tongue (A), Nasopharynx (B), Larynx (C).

In the tongue tumor, SUV values in AC images decreased from 6.81 (no implants) to 6.08 (eight implants), corresponding to an 11% reduction. Similarly, in AC+MAR PET/CT images, SUV values decreased from 6.82 to 6.21 (9.1% reduction). The absolute SUVmax values for the simulated tongue lesion across all seven predefined implant configurations are presented in Table 1. Across these configurations, SUVmax values ranged from 6.81 to 6.08 on AC images and from 6.82 to 6.21 on AC+MAR images. These values demonstrate the descriptive pattern observed across the predefined configurations; however, because the configurations differed in both implant

number and spatial arrangement, the observed variations cannot be attributed solely to implant number. In the nasopharyngeal tumor, SUVmax values were 6.88 and 6.88 (AC) and 6.87 and 6.86 (AC+MAR) for the implant-free and eight-implant conditions, respectively, corresponding to a 0.0% and -0.15% change. In the laryngeal tumor, the corresponding SUVmax values were 6.82 and 6.84 (AC) and 6.80 and 6.80 (AC+MAR), corresponding to a +0.29% and 0.0% change Fig. (4B and C). These changes were substantially smaller than those observed in the tongue tumor (11.0% and 9.1% for AC and AC+MAR, respectively).

Table 1. SUVmax values of the simulated tongue lesion on AC and AC+MAR images across the seven dental implant configurations.

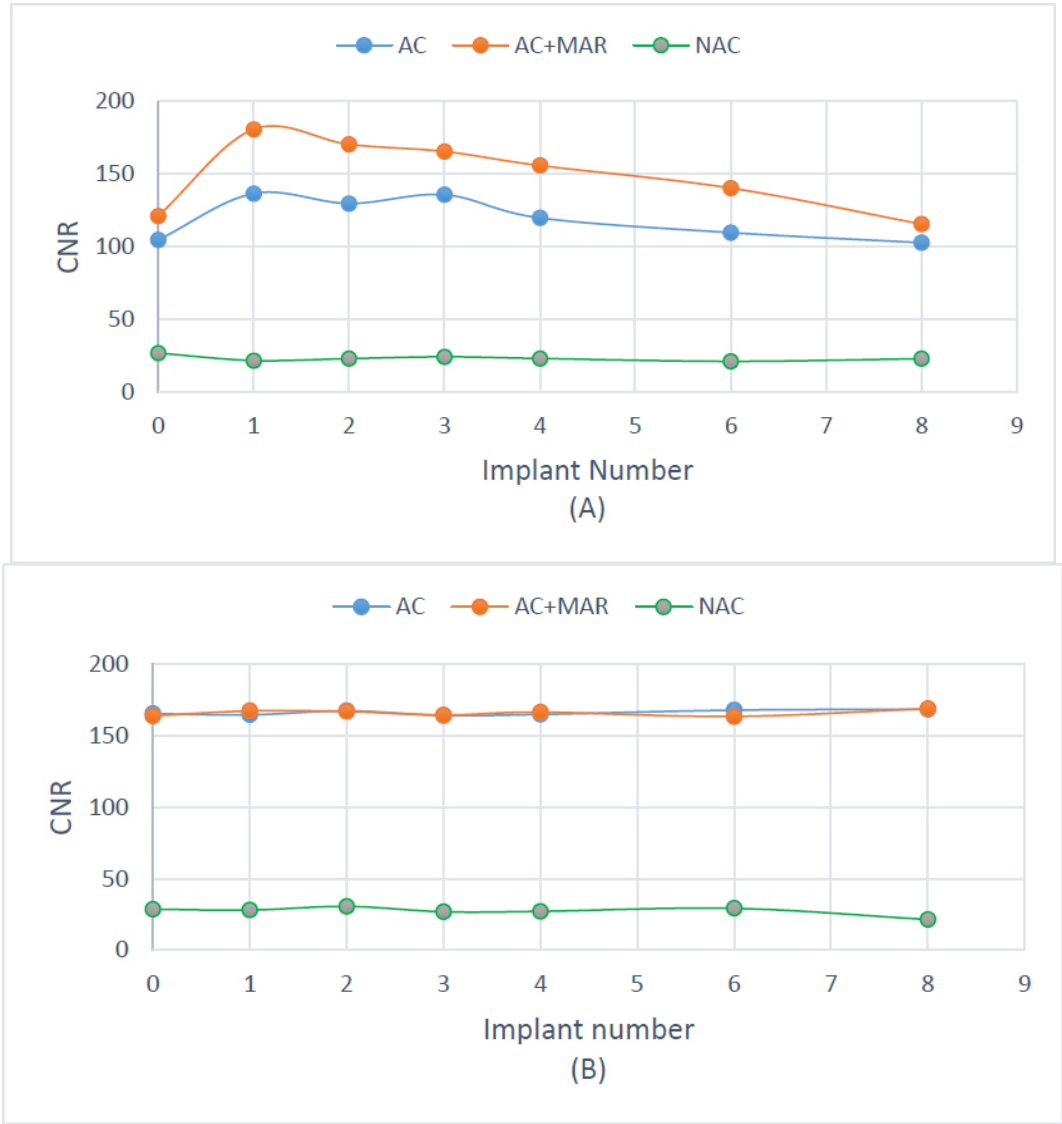
Configurations	AC SUVmax	SUVmax AC+MAR
1	6.81	6.82
2	6.62	6.75

Configurations	AC SUVmax	SUVmax AC+MAR
3	6.53	6.67
4	6.45	6.58
5	6.37	6.52
6	6.22	6.37
7	6.08	6.21

3.2. CNR Analysis

In the simulated tongue tumor, CNR values were consistently higher in AC+MAR images than in AC images across all implant configurations Fig. (5A). Descriptive variations in CNR were observed across the predefined implant configurations, which differed in both implant number and spatial arrangement. Although CNR gradually decreased with increasing implant number, the reduction was less pronounced in AC+MAR images, representing descriptively higher image-

quality metrics after metal artifact reduction. In the nasopharyngeal and laryngeal tumors, CNR values obtained from AC and AC+MAR images followed similar trends across implant configurations and exhibited only minimal descriptive variation with implant number. CNR values in AC+MAR images were approximately 12% lower than those in implant-free images, a magnitude substantially smaller than that observed in the tongue tumor Fig. (5B and C). CNR values in NoAC images were consistently and considerably lower than those in AC and AC+MAR images across all regions.



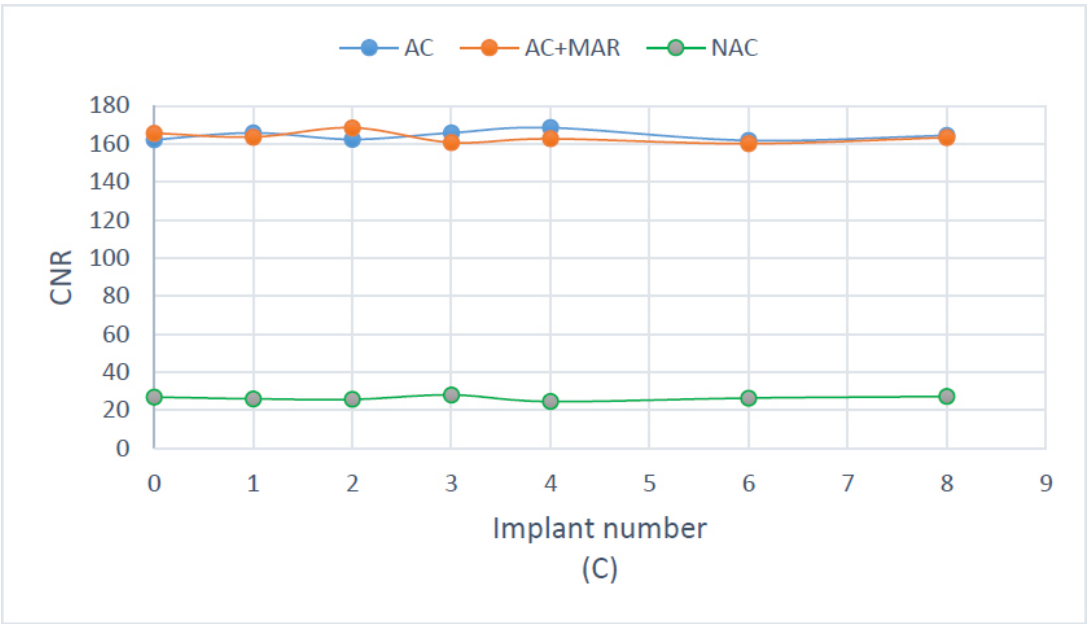
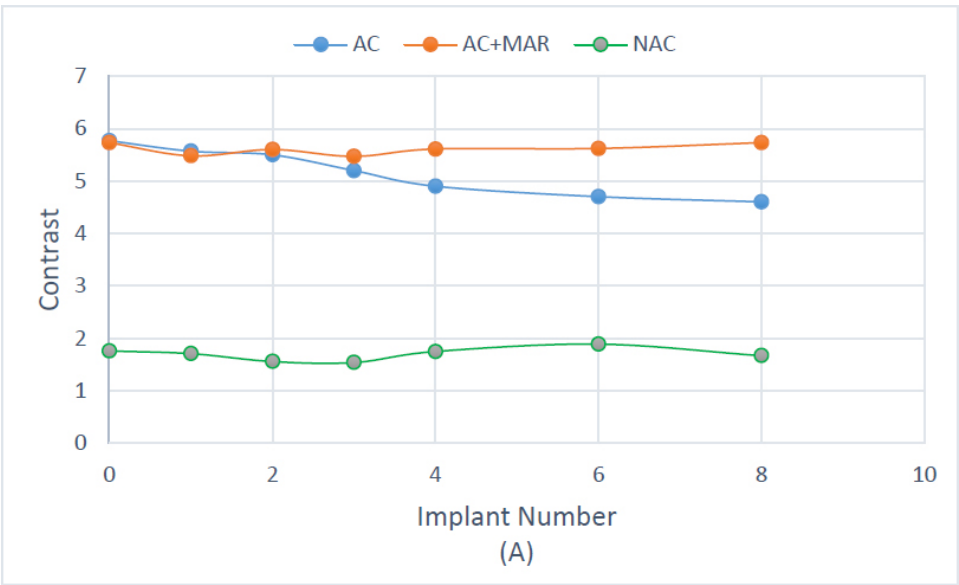


Fig. (5). Variation of CNR values across the predefined implant configurations. Tongue (A), Nasopharynx (B), Larynx (C).

3.3. Contrast Analysis

Lesion contrast values in the tongue tumor were higher in AC+MAR images than in AC images in configurations with higher implant numbers. In contrast, NoAC images demonstrated substantially lower contrast values, consistent with the expected contribution of attenuation correction to lesion detectability. Although contrast values were descriptively higher in AC+MAR images than in AC images, a slight decreasing trend with increasing implant number was observed, particularly in the tongue region.

In the other simulated tumors, contrast values measured from AC and AC+MAR images were comparable and showed only minimal descriptive variation across implant configurations Fig. (6). These descriptive findings indicate variation in quantitative PET measurements across different reconstruction methods and implant configurations, with more pronounced changes observed in configurations containing greater numbers of implants in the current phantom experiment. Contrast values in NoAC images were consistently and considerably lower than those in AC and AC+MAR images.



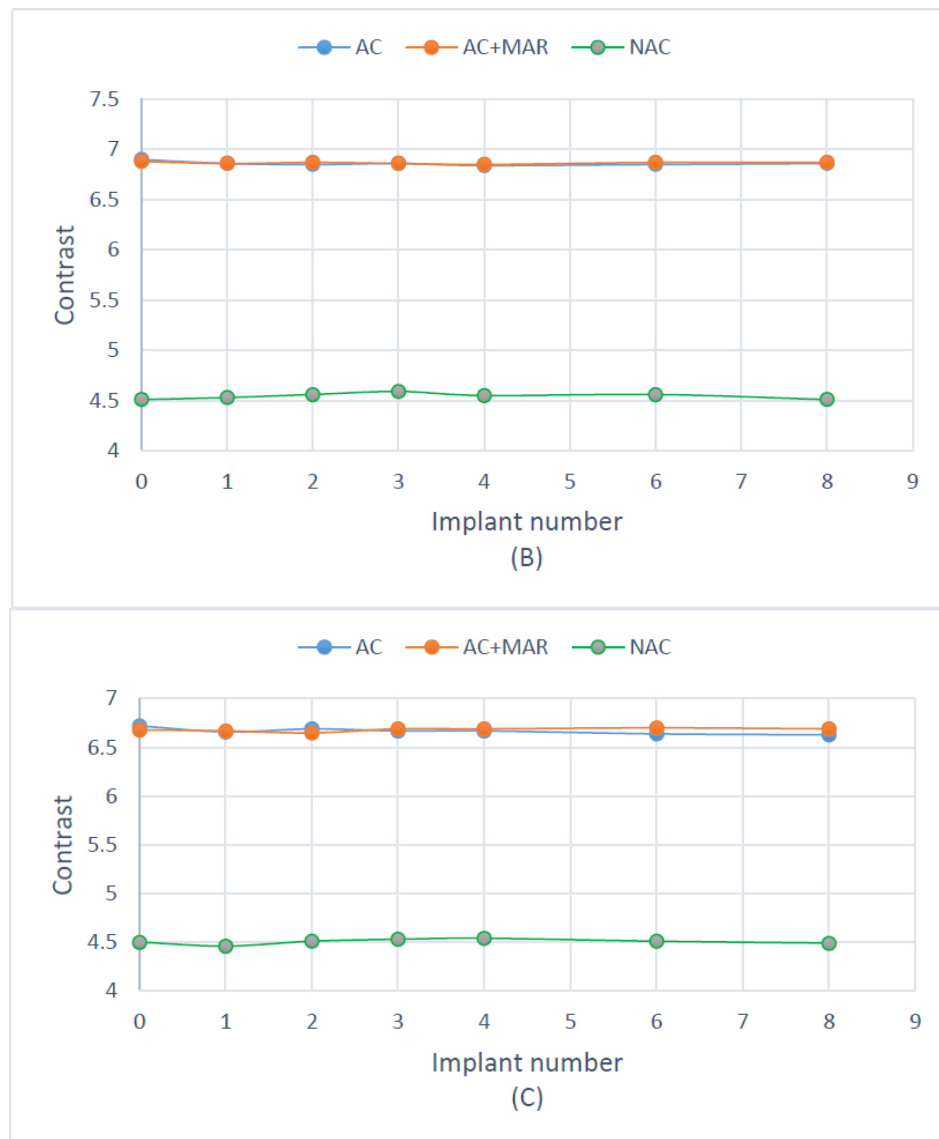


Fig. (6). Variation of contrast values across the predefined implant configurations. Tongue (A), Nasopharynx (B), Larynx (C).

3.4. Effect of Dark Streak and Bright Streak CT Artifacts on SUV Values

The heterogeneous distribution of hyperdense and hypodense streak artifacts caused by metal implants in CT images resulted in local overcorrection and undercorrection during attenuation correction, leading to fluctuations in SUV, contrast (C), and CNR values. To assess the impact of dark streak and bright streak artifacts on SUV measurements, ROIs were placed in dark streak, bright streak, and artifact-free reference regions Fig. (7).

Since the ROI defined for the simulated tongue tumor encompassed the entire lesion boundary, it reflected the combined effects of both dark streak and bright streak artifacts. In PET/CT images with the maximum number of implants (eight implants), SUV values measured in dark streak regions affected by artifacts were found to be 52.74% and 25% lower than normal values in AC and AC+MAR images, respectively, compared to reference ROIs drawn from artifact-free regions

outside the tumor. In contrast, SUV values measured in bright streak regions were higher than normal. SUVmax and SUVmean values measured in dark streak, bright streak, and artifact-free reference regions, together with their relative changes, are presented in Table 2.

3.5. Statistical Evaluation

SUV measurements obtained from attenuation-corrected (AC) and attenuation-corrected with metal artifact reduction (AC+MAR) images were compared. For this purpose, matched SUV measurements were obtained from 10 predefined ROIs, including three intraoral and seven extraoral regions representing dark streak, bright streak, and artifact-free areas. An exploratory paired-samples t-test and Wilcoxon signed-rank test were calculated to summarize the direction and approximate magnitude of the differences between AC and AC+MAR reconstructions ($t(9) = -5.40$, $p < 0.001$; Wilcoxon $p = 0.0039$).

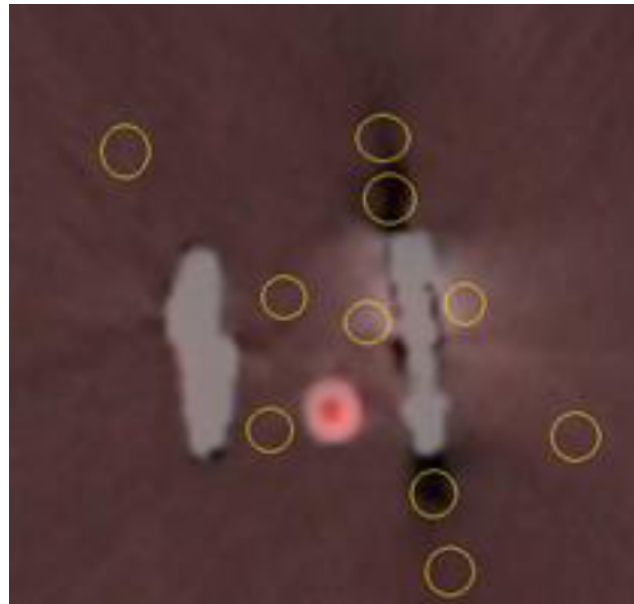


Fig. (7). ROIs drawn from dark streak, bright streak, and normal regions on the AC+MAR image.

Table 2. SUV measurements in artifact-related and artifact-free reference regions.

ROI type	AC SUV _{max}	Change (%)	AC SUV _{mean}	Change (%)	AC+MAR SUV _{max}	Change (%)	AC+MAR SUV _{mean}	Change (%)
Artifact-free	0.91 ± 0.12	—	0.81 ± 0.15	—	0.92 ± 0.18	—	0.82 ± 0.11	—
Dark streak	0.43 ± 0.21	−52.7	0.34 ± 0.21	−58.0	0.69 ± 0.18	−25.0	0.67 ± 0.18	−18.3
Bright streak	1.14 ± 0.31	+25.3	0.99 ± 0.29	+22.2	1.02 ± 0.32	+10.9	0.87 ± 0.18	+6.1

Because these 10 ROIs were derived from a single phantom and a single acquisition rather than from independent experimental units, the statistical analysis should be regarded as exploratory rather than confirmatory. The reported p-values are therefore intended only to characterize the consistency and approximate magnitude of the observed differences between matched ROIs under the two reconstruction methods. They should not be interpreted as evidence of independent statistical replication or generalized to the effects of implant number, simulated tumor region, or their interactions.

4. DISCUSSION

In this study, the effects of dental metal implants on PET/CT image quality and quantitative accuracy were systematically evaluated in a controlled phantom setting. The findings showed descriptive reductions in SUV measurements and image-quality parameters, including CNR and contrast, particularly in the simulated lesion located near the dental implants. Unlike previous studies, the present work evaluated descriptive variations in PET/CT quantitative and image-quality parameters across predefined implant configurations differing in both implant number and spatial arrangement, including simulated tumor regions located at different distances from the implants. Given the widespread use of PET/CT in oncology, the influence of metal artifact-induced quantitative deviations on clinical interpretation is of considerable importance. Previous studies have shown that metal artifacts

can disrupt CT-based attenuation correction, leading to errors in SUV values and potentially affecting diagnostic evaluation. Shimamoto *et al.* evaluated the effects of a dental metal bridge on PET quantification using a phantom model and demonstrated that the magnitude and direction of SUV changes depended on the location of the simulated tumor relative to bright and dark streak artifacts [11]. In contrast, the present study evaluated seven predefined dental implant configurations differing in both implant number and spatial arrangement and descriptively assessed their effects on SUV, contrast, and CNR across simulated lesions at different locations. Similarly, prior studies have reported that metal artifact reduction (MAR) algorithms can alter SUV measurements and thereby influence clinical interpretation [12, 13].

The impact of metal implants on PET/CT imaging is largely attributed to the propagation of CT-based artifacts into the attenuation correction process [14]. These effects can result in significant quantitative inaccuracies in PET images [13]. Metallic materials produce characteristic dark streak and bright streak artifacts in CT due to physical phenomena such as beam hardening, photon starvation, and scatter. These artifacts introduce errors in attenuation maps, leading to inaccurate estimation of activity concentration [4, 15]. Previous studies have reported that metal artifacts may cause both overestimation and underestimation of SUV values [16]. In the present study, the overall decrease in SUV suggests a dominant influence of hypodense artifacts. However, it should be noted

that SUV measurements are subject to various physical and methodological limitations and must be interpreted with caution [17].

In the present phantom data, AC+MAR reconstruction was associated with reduced artifact extent and higher image-quality metrics compared with AC, in line with previous reports [18]. However, lower SUV values persisted across configurations containing greater numbers of implants even after MAR application, suggesting that MAR may not eliminate artifact-related effects [19]. Importantly, because implant number and spatial arrangement varied simultaneously across the predefined configurations, this pattern should be interpreted as configuration-dependent rather than as an isolated effect of implant number.

To evaluate the impact of CT-based attenuation correction and MAR on PET quantification, ROIs were defined in dark streak, bright streak, and artifact-free reference regions. SUV deviations were calculated relative to the artifact-free reference ROIs. In regions affected by dark streak artifacts, SUV_{max} values were 52.74% and 25% lower than the corresponding reference values on AC and AC+MAR images, respectively. In contrast, SUV_{max} values in bright streak regions were 25.3% and 10.9% higher than the corresponding reference values on AC and AC+MAR images, respectively. These findings are consistent in direction with those reported by Shimamoto *et al.*, who observed SUV_{mean} underestimation of approximately 25.0–32.4% in dark streak regions and overestimation of 2.5–5.0% in bright artifact regions using PET/CT scanners with CT-based attenuation correction [11]. Numerically, the local SUV deviations observed in the present phantom were greater, particularly in the dark streak region; however, direct comparison should be made cautiously because different SUV metrics and experimental conditions were used. Differences in the type and spatial configuration of the metallic material, scanner and reconstruction characteristics, artifact geometry, ROI definition, and the SUV metric used (SUV_{max} versus SUV_{mean}) may have contributed to the differences between the studies. These findings may be particularly relevant for understanding PET quantification in phantom models simulating tumors located adjacent to dental implants, such as tongue and lip tumors. In contrast, the simulated nasopharyngeal and laryngeal tumors, which were positioned farther from the implants, showed only small descriptive SUV variations across implant configurations (maximum relative change $\leq 0.29\%$ in the present phantom experiment).

CNR and contrast analyses provided further descriptive evidence of differences in image-quality metrics across reconstruction methods. AC+MAR reconstruction consistently yielded higher CNR and contrast values than AC across the implant configurations. This pattern may be explained by the reduction of metal-related artifacts and improved image homogeneity associated with MAR algorithms. These findings are consistent with previously reported quantitative observations in the literature [4, 9, 15]. Furthermore, greater artifact severity and lower image-quality and quantitative metrics were descriptively observed in configurations containing greater numbers of implants. However, because implant number and spatial arrangement were not

independently varied, these findings should be interpreted as configuration-dependent observations. The analysis of NoAC images represents an additional contribution of this study. However, the markedly low CNR and contrast values observed in NoAC images suggest that their apparent stability likely reflects the absence of attenuation correction rather than improved quantification, limiting their clinical applicability.

Even when PET acquisition and reconstruction parameters are carefully optimized, quantitative accuracy remains limited by the partial volume effect (PVE), particularly in small lesions whose dimensions approach the system spatial resolution. Under these conditions, spill-out of counts beyond the lesion boundaries into adjacent voxels leads to systematic underestimation of SUV values, especially in small, thin, and irregularly shaped lesions such as early tongue tumors [20]. In the present study, this inherent limitation may have been further aggravated by dental implant–induced dark streak artifacts. Unlike PVE, which primarily reflects the limited spatial resolution of PET, dark streak artifacts originate from CT attenuation correction errors and produce localized under-correction of PET activity. Consequently, when a small tongue lesion is located adjacent to multiple dental implants, both mechanisms may act in the same direction, potentially contributing to greater SUV underestimation than would be expected from PVE alone. This interpretation is consistent with the progressively lower tongue tumor SUV values observed across the predefined implant configurations, together with the 52.74% decrease in SUV within dark streak regions on AC images (25% after AC+MAR). Therefore, the combination of PVE and implant-related attenuation correction errors may substantially reduce quantitative accuracy and lesion conspicuity in small oral cavity tumors, even after MAR is applied.

Additionally, dental implant–related artifacts in the head and neck region have been reported to complicate clinical interpretation and may lead to false-positive or false-negative findings, particularly in oral tumors [21]. The heterogeneous distribution of dark streak and bright streak artifacts observed in CT images likely results in localized over- and under-correction during attenuation correction, leading to fluctuations in SUV, contrast, and CNR values. These effects may be particularly relevant in small-volume lesions and may further complicate clinical interpretation. Because the present study was based on a single phantom experiment without independent replicate acquisitions, regional differences observed among the tongue, nasopharyngeal, and laryngeal lesions should be interpreted as descriptive rather than statistically established. In the present phantom model, SUV measurements at the simulated laryngeal tumor location (5.5 cm from the nearest implant) exhibited only minimal variation across the predefined implant configurations after AC+MAR reconstruction compared with the larger changes observed in the simulated tongue tumor located closer to the implants. Likewise, the simulated nasopharyngeal tumor (7.5 cm from the nearest implant) showed virtually no change across implant configurations (0.0% in AC and -0.15% in AC+MAR images). As the most pronounced configuration-dependent changes in SUV_{max} were observed in the simulated tongue lesion, the absolute SUV_{max} values for all seven implant configurations

are presented in Table 1. In contrast, the simulated nasopharyngeal and laryngeal lesions, which were located farther from the dental implants, showed only minimal descriptive variations in SUVmax across configurations and were therefore not included in Table 1. This difference should be interpreted as a descriptive observation of the present phantom model rather than evidence of an independent distance-dependent effect.

These observations do not establish quantitative stability or clinically meaningful implant-to-lesion distance thresholds and require validation in studies including independent replicates or patient data. Although the controlled phantom design enabled systematic evaluation of implant-related artifacts while minimizing biological and technical confounding factors, it does not reproduce important aspects of clinical PET/CT imaging, including patient motion, physiological tracer biodistribution, tissue heterogeneity, and anatomical variability. Therefore, the present findings should be regarded as experimental observations rather than clinically validated evidence. In particular, the minimal SUV variation observed for the simulated laryngeal lesion located 5.5 cm from the nearest implant should not be interpreted as a clinically applicable distance threshold. Instead, this observation should be considered hypothesis-generating and warrants validation in clinical studies or phantom experiments incorporating multiple implant-to-lesion distances.

5. STUDY LIMITATIONS

Several limitations should be acknowledged. This study was performed using a single phantom model with one PET/CT system, one implant material, one implant geometry, and simulated lesions positioned at fixed anatomical locations. Therefore, the observed quantitative effects may not fully represent the wide range of clinical conditions encountered in patients. Because ROI-level measurements within a single phantom acquisition are not statistically independent, the paired comparisons reported in this study are susceptible to pseudoreplication. Therefore, the associated p-values should be interpreted as exploratory rather than confirmatory. Future studies should incorporate repeated independent acquisitions or multiple phantoms to enable statistically valid inferential analyses, as well as prospective patient cohorts and different implant configurations to validate the clinical relevance of these findings. Another limitation is the absence of independent replicate acquisitions for each implant configuration. Consequently, factorial statistical analyses evaluating the main effects of implant number, reconstruction method, lesion region, and their interactions could not be performed reliably. Future phantom studies incorporating repeated acquisitions and independent phantom repositioning will enable mixed-effects or factorial statistical analyses.

CONCLUSION

In this phantom model, dental metal implants caused observable changes in PET/CT quantification and image quality measurements. Variations across the predefined implant configurations showed a descriptive trend toward decreases in SUV, contrast, and CNR; these findings represent descriptive observations rather than statistically inferred relationships.

Although MAR reconstruction partially reduced implant-related artifacts, it did not completely eliminate their effects. Lesions located farther from the implants appeared to be less affected by implant-related artifacts; however, this observation requires validation in clinical studies before any distance-based recommendations can be made. Therefore, quantitative PET findings, particularly for lesions located close to multiple implants, should be interpreted with caution.

AUTHORS' CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: E.T.A., M.D., R.L.U.B.: Study conception and design; S.C., N.Y., E.T.A.: Data collection; E.T.A., M.D., R.L.U.B.: Analysis and interpretation of results; E.T.A., M.D., R.L.U.B.: Draft manuscript. All authors reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

PET/CT	= Positron emission tomography/computed tomography
SUV	= Standardized uptake value
C	= Contrast
CNR	= Contrast-to-noise ratio
F-18 FDG	= Fluorine-18 fluorodeoxyglucose
AC	= Attenuation-corrected
MAR	= Metal artifact reduction
AC+MAR	= Attenuation-corrected with metal artifact reduction
NoAC	= Non-attenuation-corrected
ROI	= Region of interest
HU	= Hounsfield unit
CT	= Computed tomography
FOV	= Field of view
FWHM	= Full width at half maximum
CP Ti Grade 4	= Commercially pure titanium Grade 4
SPSS	= Statistical Package for the Social Sciences
SUVmax	= Maximum standardized uptake value
SUVmean	= Mean standardized uptake value
PVE	= Partial volume effect

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was conducted using a phantom model containing extracted human teeth obtained during routine dental treatment. No human participants were involved, no patient data were collected, and all teeth were fully anonymized before use. Therefore, the study did not constitute human subject research and ethics committee approval was not required according to institutional regulations.

HUMAN AND ANIMAL RIGHTS

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

All the data and supporting information are provided within the article.

FUNDING

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CONFLICTS OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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