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Potential impact of metal crowns at varying distances from a carious lesion on its detection on cone-beam computed tomography scans with several protocols

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ABSTRACT

Purpose: This study evaluated the impact of artifacts generated by metal crowns on the detection of proximal caries lesions in teeth at various distances using cone-beam computed tomography (CBCT). Additionally, the diagnostic impacts of tube current and metal artifact reduction (MAR) were investigated.
Materials and Methods: Thirty teeth were arranged within 10 phantoms, each containing 1 first premolar, 1 second premolar, and 1 second molar. A sound first molar (for the control group) or a tooth with a metal crown was placed. Of the 60 proximal surfaces evaluated, 15 were sound and 45 exhibited enamel caries. CBCT scans were acquired using an OP300 Maxio unit (Instrumentarium, Tuusula, Finland), while varying the tube current (4, 8, or 12.5 mA) and enabling or disabling MAR. Five observers assessed mesial and distal surfaces using a 5-point scale. Multi-way analysis of variance was employed for data comparison, with $P<0.05$ indicating statistical significance.
Results: The area under the curve (AUC) varied from 0.40 to 0.60 (sensitivity: 0.28-0.45, specificity: 0.44-0.80). The diagnostic accuracy was not significantly affected by the presence of a metal crown, milliamperage, or MAR ($P>0.05$). However, the overall AUC and specificity were significantly lower for surfaces near a crown ($P<0.05$).
Conclusion: CBCT-based caries detection was not influenced by the presence of a metal crown, variations in milliamperage, or MAR activation. However, the diagnostic accuracy was low and was further diminished for surfaces near a crown. Consequently, CBCT is not recommended for the detection of incipient caries lesions. ***(Imaging Sci Dent 2024; 54: 49-56)***

KEY WORDS: Cone-Beam Computed Tomography; Artifacts; Dental Caries; Diagnosis

Introduction

Intraoral radiography is an essential tool in the clinical detection of dental caries lesions. While the bitewing and periapical techniques can sometimes yield images with overlapping structures, they are nonetheless effective in detecting caries lesions and assessing their extent.[1] In contrast, cone-beam computed tomography (CBCT) offers 3-dimensional views of dental structures, yet its usefulness in identifying caries lesions is subject to debate.[2-5] Additionally, CBCT exposes patients to comparatively high doses of radiation, which limits its indication for this diagnostic task. Although CBCT should not be prescribed solely for the evaluation of dental caries, any caries detected incidentally during a CBCT scan performed for other reasons should be reported to alert the relevant clinicians. Early identification of caries lesions is key to preventing the irreversible demineralization of dental tissues and potential damage to the dental pulp.

Restorative materials frequently used in the oral cavity often contain components with a high atomic number, which can generate artifacts that reduce the quality of CBCT

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images.[3-6] The presence of these materials can also hinder the CBCT-based detection of dental caries, a topic that has been explored in the scientific literature.[3-5,7,8] Several studies have investigated the impact of artifacts on the diagnosis of various conditions - such as vertical root fractures, internal and external root resorption, and proximal caries lesion - when these conditions are positioned adjacent to high-density materials, including dental implants, endodontic fillings, and restorative materials.[3-6,9-11]

Recent studies have indicated that metal restorations can impede the CBCT-based detection of caries lesions in adjacent teeth.[4,5] However, insufficient research has involved a substantial volume of high-density materials commonly present in the oral cavity alongside natural caries lesions, which are relatively challenging to detect due to their indistinct borders. Additionally, certain key factors warrant consideration in these studies, such as acquisition and reconstruction parameters. These include the tube current (milliamperage, or mA) and the implementation of metal artifact reduction (MAR), both of which have been shown to impact specific diagnostic tasks.[4,12,13] Relevant factors also include the proximity of the zone of interest to the source of the artifact, which has been demonstrated to relate inversely to the severity of its detrimental effects.[14] In light of these considerations, this study was conducted to assess the impact of artifacts produced by metal crowns on the detection of proximal caries lesions in teeth both near and distant to the artifact-generating object on CBCT images, and to determine the potential effects of the milliamperage and MAR settings on this process. The null hypothesis posited that the presence of a metal crown, the distance between the lesion and the artifact-generating metal, the mA setting, and the activation of MAR would not influence the diagnosis of caries lesions.

Materials and Methods

Phantom preparation

This study received approval from the local institutional research review board (protocol number #37060920.9.0000.5418). The sample consisted of 30 extracted mandibular teeth, divided into 3 groups: 10 first premolars, 10 second premolars, and 10 second molars. Prior to the study, all teeth underwent cleaning and disinfection and were inspected to ensure the exclusion of any with cavitated lesions, restorations, or dental anomalies. Additionally, 2 mandibular first molars were chosen to create an image phantom for the control and study groups. The control tooth retained a healthy, intact crown, whereas the study group tooth featured a metal crown fabricated from a nickel-chromium (NiCr) alloy (Ni = 28, Cr = 24).

The presence or absence of carious lesions was determined using micro-computed tomography (CT), with 2 oral and maxillofacial radiologists reaching a consensus through the use of Data Viewer software (Bruker Corporation, Kontich, Belgium). The teeth underwent imaging with a Skyscan 1174 micro-CT scanner (Bruker Corporation), under a protocol with settings of 50 kV, 800 μAs, a 0.5-mm aluminum filter, a pixel size of 15 μm, 1 frame, a rotation of 0.3°, and a rotation arc of 180° (Fig. 1). The micro-CT assessment indicated that of the 60 proximal surfaces examined, 45 exhibited enamel caries lesions, while 15 were free of lesions.

The 30 teeth were arranged into 10 phantoms, each containing 3 teeth and simulating a clinical scenario in the posterior region. The phantoms were crafted using a 1 : 1 blend of plaster and powdered rice to mimic the appearance of alveolar bone.[15] Each phantom included a first premolar, a second premolar, and a mandibular molar, all of which

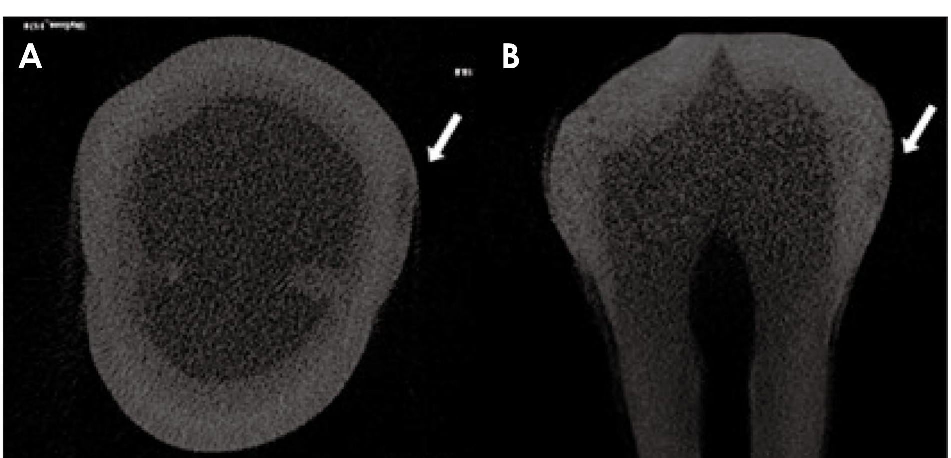

Fig. 1. On micro-computed tomography, axial (A) and sagittal (B) reconstructions of the same tooth display a proximal caries lesion (indicated by the white arrows).

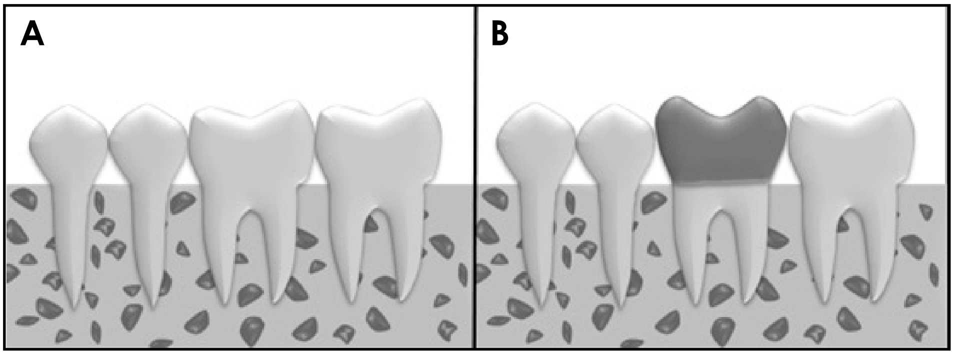

Fig. 2. Schematic illustration of the phantom simulating a clinical condition affecting the posterior region. A. Control group, characterized by a sound first molar. B. Metal crown group, featuring a first molar restored with a metal crown.

were embedded in plaster. A socket was fashioned for the first molar; however, no tooth was permanently affixed. This allowed for the alternate placement of a sound tooth and a tooth with a metal crown to obtain scans for the control group (Fig. 2A) and the study group (Fig. 2B), respectively. The distribution of surfaces with and without caries lesions was randomized but consistent across phantoms, ensuring that the phantoms shared similar proportions of carious and sound surfaces.

Image acquisition

The CBCT scans were acquired using an OP300 Maxio unit (Instrumentarium, Tuusula, Finland) under a protocol of 90 kV, voxel size of 0.125 mm, and field of view of 5 × 5 cm. The milliamperage setting (4, 8, or 12.5 mA) and MAR activation status (either disabled or enabled) were adjusted for each phantom. During acquisition, the phantoms were positioned within a plastic container filled with water to mimic soft tissue attenuation, alongside a partially desiccated mandible to represent the contralateral side of a patient and simulate the exomass (Fig. 3). CBCT scans for all 10 phantoms were captured for the control and metal crown groups (Fig. 4).

Fig. 3. Phantom placed in a plastic container filled with water to simulate soft tissue and with a partial dry mandible to simulate the opposite side.

Image assessment

All scans were randomized and anonymized prior to assessment to ensure blinding of the evaluators to the factors under study. Five oral and maxillofacial radiologists, each with a minimum of 3 years of experience, independently reviewed the CBCT images using OnDemand 3D (CyberMed, Seoul, Korea). During an orientation session, the evaluators were instructed to use all multiplanar reconstructions. They were also permitted to adjust brightness and contrast, as well as to apply filters as needed. The evaluators examined the mesial and distal surfaces of adjacent teeth for the presence or absence of proximal caries lesions, employing a 5-point scale: 1) absent, 2) probably absent, 3) uncertain, 4) probably present, and 5) present. To assess intra-observer agreement, 20% of the scans were selected at random and re-anonymized after a period of 30 days. The evaluators then reassessed these scans under identical conditions to those of the initial evaluation.

Statistical analysis

The data were analyzed using SPSS version 23.0 (IBM Corp, Armonk, NY, USA) and MedCalc version 19.1.3 (MedCalc Software, Mariakerke, Belgium), with the significance level set at 5%. Considering the smallest difference between the groups, the standard deviation, and the number of repetitions for each group, the power of the analysis was determined to be 90%. The weighted kappa test was employed to calculate intraobserver and interobserver agreement, and the results were interpreted using the criteria established by Landis and Koch (1977).[16] The area under the

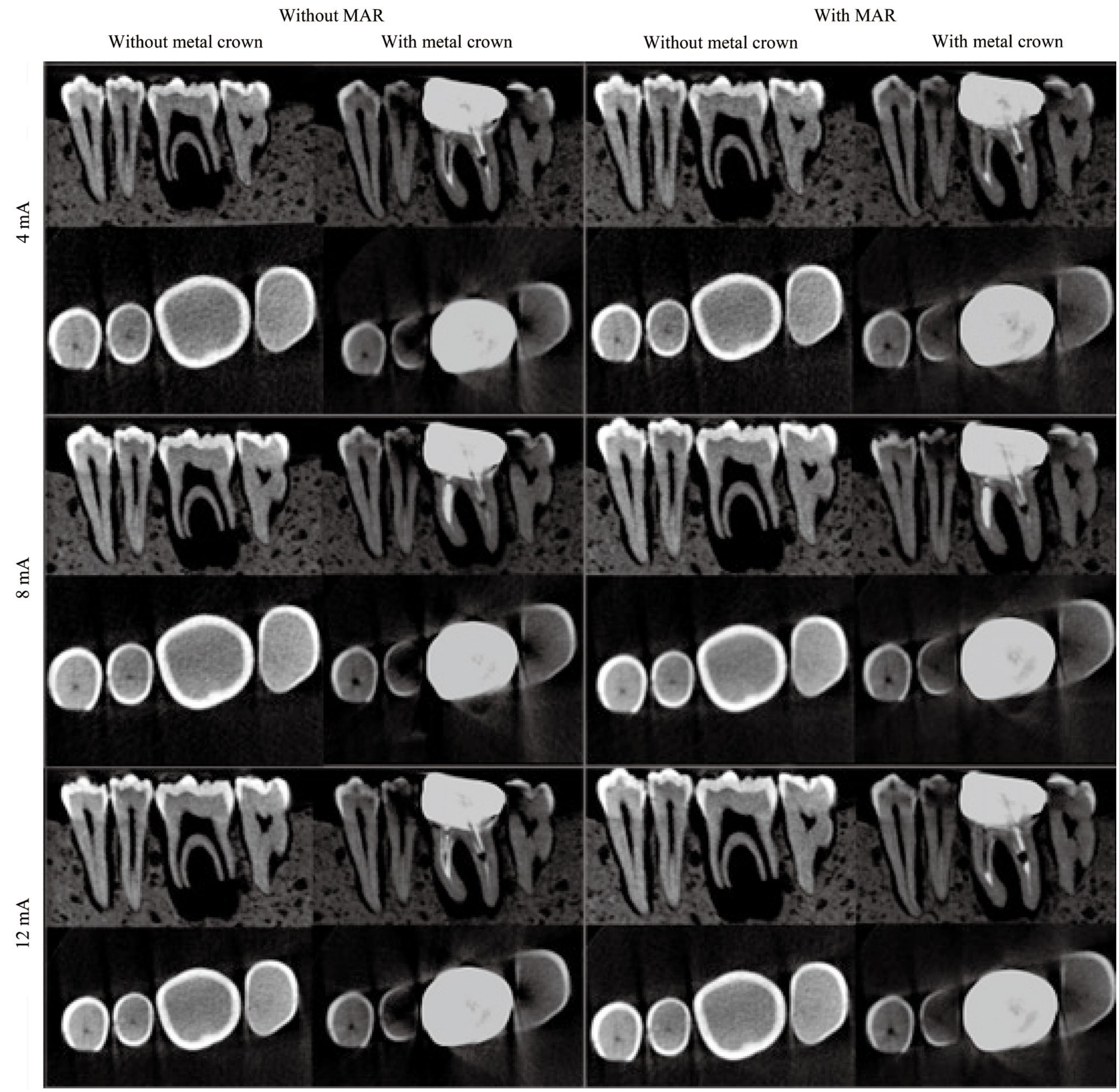

Fig. 4. Sagittal and axial cone-beam computed tomography reconstructions of the control and metal crown groups using the same phantom, under various conditions of current (mA) settings and metal artifact reduction (MAR) activation. The presence of carious lesions was confirmed by micro-computed tomography on the mesial surfaces of the first and second premolars, as well as on the mesial and distal surfaces of the second molar.

receiver operating characteristic curve (AUC), along with sensitivity and specificity for each evaluator, were computed and compared using multi-way analysis of variance. This comparison was performed to assess the impact of the studied factors, including the presence of a metal crown, the distance between the lesion and the sound first molar or the metal crown, the mA level, and the activation of MAR. For the purposes of calculating sensitivity and specificity, scores of 1, 2, and 3 were categorized as indicating the absence of a caries lesion, while scores of 4 and 5 were indicative of the presence of caries. In evaluating the effect of the distance between the lesion and the sound first molar or the metal crown, the distal surface of the second premolar and the mesial surface of the second molar were classified as "close." Conversely, the mesial and distal surfaces of the first premolar, the mesial surface of the second premolar, and the distal surface of the second molar were classified as "distant" in relation to the first molar, where the metal crown was positioned.

Results

The intra-observer agreement ranged from fair (0.367) to substantial (0.661), while the interobserver agreement varied from fair (0.251) to moderate (0.489). Table 1 presents the mean values of AUC, sensitivity, and specificity in the detection of proximal caries using CBCT, categorized by the factors under investigation. The AUC values ranged from 0.40 to 0.60. These figures were consistently lower on surfaces adjacent to the first molar - where a crown was present - compared to more distant surfaces ($P<0.0001$), with the exception of the images taken at 12 mA without MAR in the control group. The presence of a metal crown, the mA level, and the activation of MAR did not significantly influence the AUC ($P>0.05$). The sensitivity ranged from 0.28 to 0.45 and was not significantly affected by the studied factors ($P>0.05$). Specificity values ranged from 0.44 to 0.80, and (in general) were significantly lower on surfaces closer to the first molar compared to distant surfaces. However, for scans performed at 12 mA without MAR in the control group, the specificity was higher for the close surface. Additionally, for scans at 12 mA with MAR in the control group, and without MAR in the metal crown group, the proximity of the surface to the metal object did not significantly impact the results. The AUC, sensitivity, and specificity values suggest that the use of CBCT for detecting non-cavitated caries lesions is of limited applicability.[17]

Discussion

Research regarding the impact of artifacts on diagnostic procedures is widely available in the dental literature.[3-11] These studies have primarily focused on the influence of intracanal materials and the presence of dental implants in the oral cavity.[9-11] Regarding the assessment of artifacts on the identification of carious lesions, previous studies have typically utilized direct restorations[3,4] or orthodontic materials[8] as the artifact sources or have simulated artificial caries lesions.[5] The present study introduced a more complex scenario by simulating robust metal crowns alongside natural proximal caries lesions, which were confirmed using micro-CT. Impacts were also examined of CBCT acquisition parameters, such as the tube current (mA) level, and reconstruction techniques, including MAR activation, on the detection of caries. The effect of the distance between the lesion and the source of the metal artifact was similarly investigated.

Table 1. Area under the receiver operating characteristic curve (AUC), sensitivity, and specificity organized by tube current (mA), use of metal artifact reduction (MAR), and positioning of the evaluated teeth in the cone-beam computed tomography-based detection of proximal caries

mA	MAR	Distance[†]	AUC		Sensitivity		Specificity	
			Control	Metal crown	Control	Metal crown	Control	Metal crown
4	Without MAR	Distant	0.57 (0.07)	0.55 (0.10)	0.35 (0.13)	0.43 (0.15)	0.70 (0.20)	0.70 (0.17)
		Close	0.45 (0.18)*	0.44 (0.21)*	0.37 (0.21)	0.43 (0.23)	0.56 (0.17)*	0.44 (0.22)*
	With MAR	Distant	0.57 (0.03)	0.52 (0.03)	0.40 (0.13)	0.39 (0.11)	0.76 (0.11)	0.62 (0.16)
		Close	0.46 (0.09)*	0.49 (0.12)*	0.33 (0.12)	0.45 (0.23)	0.52 (0.18)*	0.44 (0.36)*
8	Without MAR	Distant	0.60 (0.05)	0.58 (0.06)	0.39 (0.12)	0.41 (0.18)	0.74 (0.09)	0.76 (0.23)
		Close	0.53 (0.10)*	0.48 (0.17)*	0.29 (0.10)	0.29 (0.18)	0.68 (0.18)*	0.64 (0.30)*
	With MAR	Distant	0.57 (0.09)	0.57 (0.04)	0.39 (0.13)	0.42 (0.12)	0.76 (0.15)	0.74 (0.09)
		Close	0.43 (0.12)*	0.40 (0.10)*	0.28 (0.18)	0.32 (0.20)	0.53 (0.30)*	0.56 (0.22)*
12	Without MAR	Distant	0.54 (0.03)	0.59 (0.02)	0.41 (0.13)	0.39 (0.14)	0.68 (0.19)	0.72 (0.11)
		Close	0.59 (0.10)	0.49 (0.09)*	0.36 (0.13)	0.32 (0.18)	0.80 (0.14)*	0.72 (0.11)
	With MAR	Distant	0.53 (0.05)	0.59 (0.07)	0.38 (0.16)	0.45 (0.13)	0.64 (0.13)	0.74 (0.15)
		Close	0.45 (0.04)*	0.41 (0.09)*	0.28 (0.11)	0.37 (0.28)	0.68 (0.11)	0.48 (0.36)*
	P-value	Metal crown	0.447		0.219		0.263	
		Surface	<0.0001		0.051		0.001	
		mA	0.694		0.478		0.085	
		MAR	0.051		0.921		0.132	

*$P<0.05$ compared with distant tooth, †: distance between the lesion and the sound first molar or the metal crown

Contrary to expectations, the presence of a metal crown did not result in poorer caries detection. This surprising outcome may be due to the substantial amount of enamel in the first molar, which can also produce artifacts that complicate the diagnostic process. Furthermore, the small nature of the caries lesions and the type of high-density material used may have impacted caries detection. The present findings stand in contrast to several prior studies that have documented the detrimental effects of artifacts on the identification of caries.[3-5] Factors such as the size of the caries lesion, the dimensions and type of high-density material used, and the quality of the CBCT scans may influence the detection of caries.

In the present study, the mean accuracy value was approximately 0.50 for both groups (that is, with and without a metal crown). This low accuracy value, observed even in the absence of metal artifacts, underscores the inherent difficulty of this diagnostic task when using CBCT images. Previous research assessing the detection of caries lesions with CBCT has also reported low accuracy values even when metal artifacts were not present, which corroborates the findings of the current study.[2,18-20] The present authors propose that the presence of adjacent teeth - specifically, the enamel in contact at the interproximal surfaces - may contribute to the low accuracy values observed, even in the absence of high-density objects.

Crucially, CBCT is not the primary imaging modality for diagnosing dental caries. However, a comprehensive assessment of the oral volume, including both the teeth and the supporting structures, remains essential for preserving the patient's oral health. Should an image suggestive of a carious lesion be detected, the present research indicates that caution is warranted due to the limitations of CBCT in identifying such lesions. This cautionary stance is supported by several previous studies, despite variations in their methodological designs.[3-5,8]

Furthermore, the proximity to the mandibular first molar, where either a dental or metal crown was present, affected the diagnostic outcomes. Despite the generally low diagnostic values for both surfaces, a trend was observed of diminishing AUC and specificity values nearer the first molar (with the mean AUC value declining from 0.56 to 0.47 and the mean specificity value from 0.71 to 0.59). This reduction in diagnostic performance is likely due to the more pronounced nature of artifacts near high-density materials, as demonstrated in previous investigations.[14]

The composition of the present sample, which included more surfaces with carious lesions compared to sound surfaces, likely contributed to the increased sensitivity observed. However, it is important to note that the sensitivity values remained lower than the specificity values, a finding that aligns with results from previous studies.[3,4] This suggests that the sample composition alone does not account for this effect. Although hypodense artifacts could theoretically resemble caries lesions, potentially leading to higher sensitivity and lower specificity, such an effect was not observed. It seems plausible that the artifacts introduced a degree of uncertainty, prompting evaluators to err on the side of caution and favor a negative diagnosis when the presence of a lesion was unclear.

To minimize the impact of metal artifacts in diagnostic tasks, various studies have investigated factors that may affect their manifestation, including changes in current and peak kilovoltage settings as well as the use of MAR. In the present study, variations in both the current (mA) setting and the activation of MAR were tested; however, these adjustments did not enhance the detection of dental caries. This finding aligns with the work of Isman et al.,[8] who observed no significant effect of MAR on caries detection in the presence of orthodontic materials. Conversely, Cebe et al.[4] reported that MAR was effective in certain study groups. The ineffectiveness of MAR in the present study may stem from the fact that a metal crown can produce more artifacts than other restorative materials. This could account for the discrepancies between the present findings and those of previous studies. Another consideration is that MAR technology may perform differently across various CBCT units. The influence of tube current (mA) on diagnosis remains a topic of debate within the dental literature. While some studies have found no significant effect on the identification of secondary caries beneath amalgam fillings in primary teeth,[21] others have noted diagnostic improvements in the detection of root fractures, especially when artifact-producing materials are present.[12,13]

Comparative studies examining caries detection have consistently shown bitewing radiography to be the more accurate and practical method when compared to CBCT. This preference stems from the lower radiation dose and increased accessibility that bitewing radiography provides.[22-24] Additionally, CBCT is particularly susceptible to interference from metal artifacts. Although high-density materials can alter gray values in digital radiography due to automatic exposure compensation, this effect does not significantly compromise the diagnosis of carious lesions.[25] Consequently, bitewing radiography remains the preferred imaging modality for detecting caries lesions, even in the presence of high-density materials.

Notably, the present study was conducted *ex vivo*, limiting its direct applicability to clinical settings. Experiments involving ionizing radiation on humans would pose ethical issues. However, this study was designed to mimic a clinical environment during CBCT acquisition, except for patient movement. In spite of this constraint, rigorous standardization was applied to the sample, phantom, and examination protocols, which were both blinded and independent. The low levels of inter- and intra-examiner agreement observed highlight the inherent difficulty in detecting carious lesions on CBCT images.

In summary, while emphasizing the importance of evaluating the entire CBCT examination, it is essential to recognize the complexities involved in assessing dental crowns. Despite these challenges, clinical examination remains the cornerstone of routine clinical practice, particularly for the detection of caries.

In conclusion, the presence of a metal crown did not adversely affect the detection of incipient caries lesions using CBCT. However, the overall diagnostic utility of CBCT in caries detection was determined to be low, with a further reduction for the surfaces closest to dental or metal crowns. Within this framework, none of the investigated factors enhanced detection capabilities, as neither the application of MAR nor the adjustment of tube current led to improved diagnostic outcomes. Consequently, CBCT is not recommended for the detection of incipient caries lesions.

Conflicts of Interest: None

References

1. Schwendicke F, Tzschoppe M, Paris S. Radiographic caries detection: a systematic review and meta-analysis. J Dent 2015; 43: 924-33.
2. Haiter-Neto F, Wenzel A, Gotfredsen E. Diagnostic accuracy of cone beam computed tomography scans compared with intraoral image modalities for detection of caries lesions. Dentomaxillofac Radiol 2008; 37: 18-22.
3. Kulczyk T, Dyszkiewicz Konwińska M, Owecka M, Krzyżostaniak J, Surdacka A. The influence of amalgam fillings on the detection of approximal caries by cone beam CT: in vitro study. Dentomaxillofac Radiol 2014; 43: 20130342.
4. Cebe F, Aktan AM, Ozsevik AS, Ciftci ME, Surmelioglu HD. The effects of different restorative materials on the detection of approximal caries in cone-beam computed tomography scans with and without metal artifact reduction mode. Oral Surg Oral Med Oral Pathol Oral Radiol 2017; 123: 392-400.
5. Abu El-Ela WH, Farid MM, Abou El-Fotouh M. The impact of different dental restorations on detection of proximal caries by cone beam computed tomography. Clin Oral Investig 2022; 26: 2413-20.
6. Neves FS, Freitas DQ, Campos PS, Ekestubbe A, Lofthag-Hansen S. Evaluation of cone-beam computed tomography in the diagnosis of vertical root fractures: the influence of imaging modes and root canal materials. J Endod 2014; 40: 1530-6.
7. Vedpathak PR, Gondivkar SM, Bhoosreddy AR, Shah KR, Verma GR, Mehrotra GP, et al. Cone beam computed tomography - an effective tool in detecting caries under fixed dental prostheses. J Clin Diagn Res 2016; 10: ZC10-3.
8. Isman O, Aktan AM, Ertas ET. Evaluating the effects of orthodontic materials, field of view, and artifact reduction mode on accuracy of CBCT-based caries detection. Clin Oral Investig 2020; 24: 2487-96.
9. Freitas DQ, Vasconcelos TV, Noujeim M. Diagnosis of vertical root fracture in teeth close and distant to implant: an in vitro study to assess the influence of artifacts produced in cone beam computed tomography. Clin Oral Investig 2019; 23: 1263-70.
10. Helvacioglu-Yigit D, Demirturk Kocasarac H, Bechara B, Noujeim M. Evaluation and reduction of artifacts generated by 4 different root-end filling materials by using multiple cone-beam computed tomography imaging settings. J Endod 2016; 42: 307-14.
11. Gaêta-Araujo H, Nascimento EH, Oliveira-Santos N, Pinheiro MC, Coelho-Silva F, Oliveira-Santos C. Influence of adjacent teeth restored with metal posts in the detection of simulated internal root resorption using CBCT. Int Endod J 2020; 53: 1299-306.
12. Gaêta-Araujo H, Silva de Souza GQ, Freitas DQ, de Oliveira-Santos C. Optimization of tube current in cone-beam computed tomography for the detection of vertical root fractures with different intracanal materials. J Endod 2017; 43: 1668-73.
13. Tangari-Meira R, Vancetto JR, Dovigo LN, Tosoni GM. Influence of tube current settings on diagnostic detection of root fractures using cone-beam computed tomography: an in vitro study. J Endod 2017; 43: 1701-5.
14. Fontenele RC, Nascimento EH, Vasconcelos TV, Noujeim M, Freitas DQ. Magnitude of cone beam CT image artifacts related to zirconium and titanium implants: impact on image quality. Dentomaxillofac Radiol 2018; 47: 20180021.
15. Oliveira ML, Ambrosano GM, Almeida SM, Haiter-Neto F, Tosoni GM. Efficacy of several digital radiographic imaging systems for laboratory determination of endodontic file length. Int Endod J 2011; 44: 469-73.
16. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977; 33: 159-74.
17. Power M, Fell G, Wright M. Principles for high-quality, high-value testing. Evid Based Med 2013; 18: 5-10.
18. Krzyżostaniak J, Surdacka A, Kulczyk T, Dyszkiewicz-Konwińska M, Owecka M. Diagnostic accuracy of cone beam computed tomography compared with intraoral radiography for the detection of noncavitated occlusal carious lesions. Caries Res 2014; 48: 461-6.
19. Cheng JG, Zhang ZL, Wang XY, Zhang ZY, Ma XC, Li G. Detection accuracy of proximal caries by phosphor plate and cone-beam computerized tomography images scanned with different resolutions. Clin Oral Investig 2012; 16: 1015-21.
20. Qu X, Li G, Zhang Z, Ma X. Detection accuracy of in vitro approximal caries by cone beam computed tomography images. Eur J Radiol 2011; 79: 2009-12.
21. Kamburoğlu K, Sönmez G, Berktaş ZS, Kurt H, Özen D. Effects of various cone-beam computed tomography settings on the

detection of recurrent caries under restorations in extracted primary teeth. Imaging Sci Dent 2017; 47: 109-15.
22. Sousa Melo SL, Belem MD, Prieto LT, Tabchoury CP, Haiter-Neto F. Comparison of cone beam computed tomography and digital intraoral radiography performance in the detection of artificially induced recurrent caries-like lesions. Oral Surg Oral Med Oral Pathol Oral Radiol 2017; 124: 306-14.
23. Wenzel A, Hirsch E, Christensen J, Matzen LH, Scaf G, Frydenberg M. Detection of cavitated approximal surfaces using cone beam CT and intraoral receptors. Dentomaxillofac Radiol 2013; 42: 39458105.
24. Gaalaas L, Tyndall D, Mol A, Everett ET, Bangdiwala A. Ex vivo evaluation of new 2D and 3D dental radiographic technology for detecting caries. Dentomaxillofac Radiol 2016; 45: 20150281.
25. Galvão NS, Nascimento EH, Lima CA, Freitas DQ, Haiter-Neto F, Oliveira ML. Can a high-density dental material affect the automatic exposure compensation of digital radiographic images? Dentomaxillofac Radiol 2019; 48: 20180331.