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Evaluating the effect of amalgam fillings on caries detection in cone-beam computed tomography images

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ABSTRACT

Background: Dental caries stands as one of the most prevalent dental concerns, with early diagnosis being pivotal in clinical dentistry. Cone-beam computed tomography (CBCT) emerges as a widely utilized modality for dental caries identification, owing to its significant advantages. However, there remains a considerable knowledge gap regarding the efficacy of CBCT scans in detecting dental caries. In line with the as low as reasonably achievable principle, this study endeavors to evaluate the impact of amalgam fillings on the precision of occlusal caries detection in CBCT.

Materials and Methods: This *in vitro* study employed a set of 102 extracted human teeth samples. Among these, six molar teeth were used to create mesial-occlusal-distal amalgam restorations. The remaining teeth were placed in the dental sockets of a dry human skull to restore proximal contacts. CBCT images were obtained and examined by two observers, while histopathological examination was conducted using a stereomicroscope. Comparative analysis of CBCT images and histopathological data was performed using the McNemar test in SPSS software ($\alpha = 0.05$).

Results: The McNemar test results indicated that the nonrestoration group showed greater sensitivity and lower specificity in CBCT imaging than the amalgam-restored tooth group.

Conclusion: The findings suggested that the CBCT technique did not demonstrate effectiveness in diagnosing dental caries around amalgam restorations.

Key Words: Cone-beam computed tomography, dental amalgam, dental caries, radiography

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INTRODUCTION

Dental caries ranks among the most prevalent concerns in dentistry, posing challenges for early detection in clinical practice. Given the variability in caries depth, various dental restoration techniques are employed, underscoring the importance of precise measurement for determining optimal treatment plans and restoration modalities.[1] Intraoral radiographs stand out as a popular choice among the array of caries detection methods and are extensively utilized.[2]

Initially employed for caries detection, bitewing radiographs have evolved to become the prevailing radiographic method.[2,3] Nonetheless, employing intraoral radiographs can present challenges in specific scenarios, such as when patient cooperation

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or tolerance is limited. In such instances, extraoral radiographs are gaining prominence, particularly among children, disabled patients, or individuals with severe gag reflexes.[4] Furthermore, the quality of intraoral films hinges on the expertise of the radiologist. Consequently, the need for low-quality radiographic retakes not only compromises diagnostic accuracy but also escalates the patient's radiation exposure.[5]

Cone-beam computed tomography (CBCT) stands as a widely adopted digital radiography technique, celebrated for its multifaceted advantages. Notably, it offers a comprehensive three-dimensional (3D) depiction of craniofacial structures across axial, coronal, and sagittal planes, thereby enhancing treatment planning.[6,7] Moreover, in various dental specialties such as restorative dentistry and endodontics, CBCT radiography contributes to minimizing treatment complexities alongside other advancements in the field.[8-12]

Two primary types of artifacts are encountered in CBCT radiography, namely scatter and beam hardening, particularly in the presence of metal such as dental amalgam – a common metallic restorative material – which can disrupt the caries detection process.[13,14] Scatter arises when X-ray photons deviate from their intended path following interaction with matter. Conversely, beam hardening occurs when lower-energy photons are preferentially absorbed compared to higher-energy photons as the X-ray beam traverses through an object, resulting in two distinct artifact manifestations: streaking (dark bands) and cupping artifacts (distortion of the metal structure).[15]

Şeker *et al.*'s study[16] and Kayipmaz *et al.*'s findings highlighted the superiority of CBCT imaging over phosphor storage plate (PSP)-based digital and conventional radiographs in detecting occlusal dental caries in the absence of amalgam restoration around the carious lesion.[17] Furthermore, Zhang *et al.*'s investigation revealed no significant disparities in diagnostic accuracy between 3D CBCT systems (e.g., Kodak 9000 and Promax) and traditional intraoral PSPs when detecting noncavitated dental carious lesions.[18] Both Esmaeili *et al.*[19] and Isman *et al.*[20] demonstrated that the beam-hardening effect induced by metal objects, such as orthodontic brackets, can produce artifacts that impede the diagnostic efficacy of CBCT imaging systems. These artifacts, similarly induced by amalgam restorations within the oral cavity, pose challenges for diagnosing dental caries.[13]

This study investigated occlusal surface caries among individuals who had undergone CBCT imaging for various therapeutic objectives. The investigation stemmed from the expanding utilization of CBCT in dentistry, the conflicting outcomes of previous research regarding its efficacy in caries diagnosis, and the impact of metallic artifacts on the diagnostic process.

MATERIALS AND METHODS

Sample collection and preparation

This *in vitro* study employed a random selection process to procure a sample of human permanent posterior teeth through the formula $n = \dfrac{z_1^2 - \frac{a}{2} p(1-p)}{d^2}$ where $p = 0.5$ and $z = 1.96$ ($n = 102$, comprising 52 molars and 46 premolars, with a confidence interval of 95% and a margin of error of 0.10), with and without caries. These teeth were extracted due to orthodontic treatment or periodontitis. Subsequently, all calculus and debris were meticulously removed, and the teeth were disinfected using 2% NaClO for 20 min, followed by storage in 0.9% NaCl solution. All procedures performed in the present study were approved by the Ethical Committee of Isfahan University of Medical Sciences (#IR.MUI.REC.1395.3.186).

A total of six molar teeth were selected to undergo preparation of mesial-occlusal-distal (MOD) cavities, subsequently restored with amalgam. The gingival floor of the cavity was positioned 2 mm coronal to the tooth's cementoenamel junction (CEJ), followed by crown sectioning to separate the crown and root, 2 mm apical to the CEJ. The remaining teeth were divided into 24 groups, each comprising four teeth, encompassing both maxillary and mandibular posterior teeth. The tooth crowns were embedded in red wax (Polywax, Tehran, Iran), with the proximal surfaces in contact, mirroring the arrangement of human dentition within a quadrant.

To ensure proper occlusion between the jaws, six intact dry skulls were provided to secure teeth within their respective dental sockets for each study group. The mandible was affixed to the cranium and immobilized to maintain its position securely.

Cone-beam computed tomography examination

Each group underwent CBCT examination utilizing a Soredex CBCT unit (Helsinki, Finland) with 350 μm voxel size and field of view (FOV) 7.5 cm × 14.5 cm and the parameters set at 89 kVp, 6 mA, and 12.6 s. Subsequently, one molar tooth in each skull was replaced with an amalgam-restored molar. All groups underwent CBCT examination under identical exposure conditions. Volumetric CBCT data were reconstructed using OnDemand3D Dental 1.0.9.1343 (USA) software. Two proficient dental radiologists, each possessing a minimum of 6 years of radiology experience, independently evaluated all acquired images.

In a dimly lit room, the researchers assessed the images randomly on a similar computer equipped with a 22-inch 32-bit monitor (LG, Seoul, Korea) boasting a resolution of 1440 × 6900 pixels. The monitor was positioned at a consistent distance from the viewer, approximately 60 cm. Evaluation of the occlusal surface in the mesiodistal tooth plane (panoramic view) was conducted, employing a two-point scale to denote the absence or presence of caries (1 = definitively carious; 2 = definitively not carious). Cases for which diagnosis was uncertain were excluded from the study. To mitigate the impact of memory loss and ensure intraobserver reliability, each examination was performed twice independently, with a 2-week interval between assessments.

Histopathological examination

For the histopathological examination, the tooth samples were sliced into 0.4 mm-thick sections in the mesiodistal plane, aligned parallel to the long axis of the teeth. Each section underwent evaluation by a pathologist using a stereomicroscope (Zoom Trinocular, SMP200) at ×15. Any observed white-spot lesions or areas displaying yellowish-brown discoloration in the enamel or dentin were identified as carious lesions. Among all the sections, the slice showcasing the most profound carious lesion in an individual tooth was selected for scoring: 0 = absence of carious lesions on the occlusal surface and 1 = presence of occlusal caries.

Data analysis

The mean values of the following parameters were reported both before and after amalgam restoration: specificity, sensitivity, false-positive and false-negative ratios (false-positive rate [FPR] and false-negative rate [FNR], respectively), and positive and negative predictive values (NPVs) (positive predictive value [PPV] and NPV, respectively), calculated for each observer. Caries detection accuracy in radiographic sections was assessed by comparing histopathological findings with radiological observations using McNemar test analysis conducted with SPSS V22.0 (IBM/Chicago/USA) ($\alpha = 0.05$).

RESULTS

Table 1 presents the histopathological outcomes of the occlusal surfaces of 96 teeth. Intraobserver kappa coefficients ranged from 0.759 to 0.844 for the first observer and from 0.716 to 0.867 for the second observer. In addition, the interobserver kappa coefficient, calculated based on the mean values for each parameter from each observer, fell within the range of 0.631–0.769. A high intraobserver kappa coefficient signifies robust intraobserver agreement; hence, calculations were conducted using each observer's initial readings.

The Cochran test findings revealed significant disparities between the histopathological assessments of the teeth and the CBCT images obtained before and after amalgam restorations. Subsequently, McNemar's test was conducted, with the results outlined in Table 2. The McNemar test indicated no statistically significant difference between CBCT radiography before amalgam restoration placement and the pathological view of the teeth (Pv = 0.296, κ =0.004, and Pv = 0.294) [Figure 1].

However, a statistically significant difference was observed between CBCT radiography and the pathological view following amalgam restoration placement (Pv = 0.001, κ = 0.207, and Pv = 0.024) [Figure 2].

Table 3 presents the specificity, sensitivity, NPV, PPV, FNR, and FPR values for CBCT readings obtained before and after amalgam restoration. CBCT images

Table 1: Percentage and prevalence of caries on the surface of each tooth

Analyzed factor	Percentage	Prevalence
Noncarious	52	50
Enamel carious lesions	13.5	13
Carious lesions in the outer half of the dentin	27	26
Carious lesions in the inner half of the dentin	7.5	7
Total	100	96

Table 2: Results of the McNemar test on the cone-beam computed tomography images

Analyzed factor	Pathological evaluation			*P*	Kappa coefficient
	Carious lesion	Noncarious lesion	Total		
before amalgam restoration					
Radiographic evaluation					
Carious lesion	23	13	36	0.296	0.294
Noncarious lesion	20	40	60		
Total	43	53	96		
Following amalgam restoration					
Radiographic evaluation					
Carious lesion	15	8	23	0.001	0.024
Noncarious lesion	28	45	73		
Total	43	53	96		

Table 3: Specificity, sensitivity, false-positive rate, false-negative rate, positive predictive value, and negative predictive value values for radiographic evaluation before and following amalgam restorations

CBCT	Specificity	Sensitivity	FPR	FNR	PPV	NPV
Before the placement of the amalgam-restored tooth	75.4	53.4	63.8	66.6	36.1	33.3
After the placement of the amalgam-restored tooth	84.9	34.8	65.2	61.6	34.7	38.3

CBCT: Cone-beam computed tomography; FPR: False-positive rate; FNR: False-negative rate; PPV: Positive predictive value; NPV: Negative predictive value

exhibited higher sensitivity and lower specificity both before and after amalgam restoration.

Based on the receiver operating characteristic curve (ROC curve) analysis, the sensitivity of CBCT radiography in detecting caries is higher before amalgam restoration, but the specificity is higher after restoration [Table 3 and Figure 3].

DISCUSSION

Despite extensive research on CBCT's efficacy in dentistry, several challenges remain to be addressed.[21] Consequently, the current study aimed to assess the influence of amalgam fillings on CBCT-based occlusal caries detection accuracy, particularly considering deviations from strict adherence to the as low as reasonably achievable principle.[22]

This research revealed that severe carious lesions exhibited low specificity values, indicating CBCT's limitations in detecting noncarious occlusal lesions around amalgam restorations. In addition, reduced sensitivity values suggested an inability to detect demineralized enamel areas on the approximal surface in the presence of amalgam restorations. Furthermore, the ROC curve underscored the CBCT imaging's inaccuracy in caries detection when amalgam restorations were present. Similarly, in Kulczyk *et al*.'s study, CBCT sensitivity for caries detection on surfaces adjacent to amalgam fillings ranged from 0.27 to 0.30 for enamel and from 0.47 to 0.56 for dentin. Specificity values for enamel proximal and distal lesions were 0.48 and 0.53, respectively, and for proximal and distal dentin lesions, they ranged from 0.33 to 0.38. Intraobserver reliability was 0.84, and interobserver reliability was 0.49. These findings corroborate the current study's conclusions, suggesting that CBCT radiography may not be highly accurate in diagnosing dental caries.[23] Indeed, various studies have produced conflicting findings regarding the accuracy of CBCT imaging in caries detection. In this study, CBCT images demonstrated low sensitivity and specificity values for detecting occlusal caries. Zhang *et al*. analyzed the detection accuracy of proximal caries using film, PSP, and CBCT. They compared the results with histological examination, considered the gold standard, and utilized film, PSP, ProMax 3D, and Kodak 9000 3D imaging systems. The findings indicated similar detection accuracy of proximal noncavitated carious lesions between CBCT imaging and film- and PSP-based intraoral imaging.[18]

Haiter-Neto *et al*. reported sensitivity values of 13%–18% for NewTom and 21% for Accuitomo CBCT imaging systems across various FOV sizes (6, 9, and 12 inches). This diminished sensitivity could be attributed to subtle dental caries and a high ratio of sound-to-carious surfaces, mirroring findings in the present study. Their research also indicated lower caries detection accuracy with the

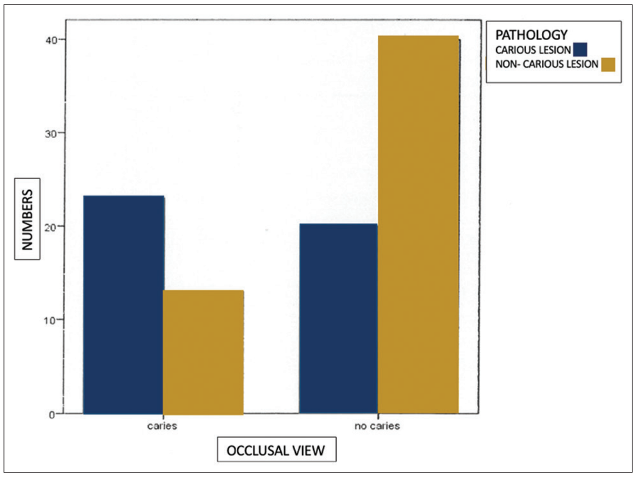

Figure 1: The result of McNemar test in cone-beam computed tomography imaging before amalgam restoration.

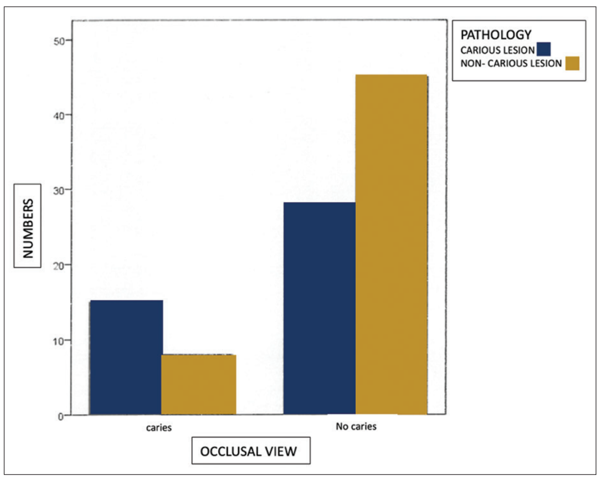

Figure 2: The result of McNemar test in cone-beam computed tomography imaging after amalgam restoration.

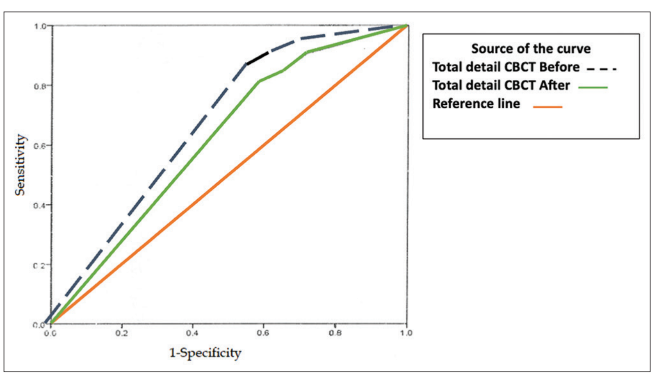

Figure 3: Receiver operating characteristic curve for the diagnosis of occlusal caries before and after amalgam filling.

NewTom third-generation CBCT compared to the 3DX Accuitomo CBCT and intraoral modalities.[6] However, in contrast to our findings, Tarim Ertas *et al.* demonstrated that CBCT imaging surpassed other modalities in the detection of deep occlusal caries.[24]

In their study, Nabha *et al.* concluded that metal objects such as amalgam could generate artifacts in 3D imaging, thereby impeding the diagnosis and prognosis of dental diseases.[25] They also highlighted that MOD amalgam restorations could result in notable artifacts in CBCT images.

One limitation of this study is that it was conducted in *in vitro* conditions and the imaging was done without motion and in the absence of soft tissues around the mouth and teeth. Future research endeavors are advised to explore additional investigations with expanded sample sizes within a clinical environment. While the present study focused on occlusal caries, it is suggested that forthcoming studies explore the evaluation of carious lesions on proximal surfaces. *In vivo* studies with larger sample sizes hold the potential to yield more precise and comprehensive results.

CONCLUSION

This research uncovered the inadequate efficacy of CBCT imaging in detecting occlusal caries surrounding amalgam restorations.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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