



The impact of different dental restorations on detection of proximal caries by cone beam computed tomography

Walaa Hussein Abu El-Ela¹ · Mary Medhat Farid¹ · Mona Abou El-Fotouh¹

Received: 28 July 2021 / Accepted: 27 September 2021 / Published online: 3 October 2021
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Abstract

Objectives To evaluate the effects of different types of restorations on observer ability to detect proximal caries in CBCT images.

Materials and methods Forty human premolars and molars with artificial proximal caries were placed proximal and distal to 5 molars having different restorations (amalgam, composite, resin-modified glass ionomer cement (RMGIC) fillings, zirconia, and lithium disilicate crowns) and a non-restored molar. CBCT scans were obtained using i-CAT[®] Next Generation. Images were rated twice by 2 observers. The exact depth of artificial caries was histologically established. Sensitivity, specificity, and area under the receiver operating characteristic curve (Az) values were calculated.

Results Caries detection in teeth surfaces mesial and distal to amalgam showed compromised specificity and accuracy. Moreover, caries detection in teeth surfaces mesial to zirconia crown showed low sensitivity, specificity, and accuracy. Capability of CBCT in detection of proximal caries in teeth adjacent to composite, RMGIC, and lithium disilicate was comparable to those adjacent to non-restored molar.

Conclusions CBCT scans performed for tasks other than caries detection should be assessed for proximal caries in absence of any restorations as well as in presence of composite, RMGIC fillings, and lithium disilicate crowns. However, CBCT should not be used for proximal caries detection in teeth adjacent to amalgam and teeth surfaces mesial to zirconia crowns.

Clinical significance It is important to investigate the influence of artifacts produced by various restorations on CBCT-based caries detection to optimize CBCT benefits, caries diagnosis and avoid unnecessary treatment of sound surfaces.

Keywords Dental caries · Artifacts · Dental restoration · Crowns · Cone beam CT

Introduction

Early detection of dental caries is very important, as caries progression leads to substantial health and economic burdens on patients and society [1]. Although proximal caries in posterior teeth is commonly detected with the aid of intraoral bitewing radiography [2], bitewing detects only about 60% of proximal carious lesions [3].

Cone beam computed tomography (CBCT) is a valuable addition to 2-dimensional radiographic modalities in maxillofacial region examinations, as it provides clear images free of superimpositions, magnification, and distortions. When

there are no adjacent restorations, several studies reported better sensitivity, specificity, and accuracy of CBCT images compared to those of intraoral radiography in the detection of proximal caries [4–6]. While some studies revealed that CBCT diagnostic accuracy was similar to that of conventional and digital intraoral modalities [7–9], other studies stated that CBCT proximal caries detection accuracy was lower than that of intraoral radiographs [10, 11].

A variety of restorative materials are used by dentists and recognized on projection radiographs. They have variable levels of radiopacity depending on their atomic number, thickness, and density [12]. In CBCT, interaction of the polyenergetic X-ray beam with high-density materials commonly produces beam hardening artifacts [13, 14]. Such artifacts are presented as bright streaks and dark bands. The bright streaks may cover the carious lesion leading to false-negative diagnosis, while dark bands may convey false impressions of carious lesions [15, 16]. These artifacts

✉ Walaa Hussein Abu El-Ela
dr.walaahusseini@asfd.asu.edu.eg

¹ Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Ain Shams University, Monazamet El Wehda El Afriqeya St, Cairo, Egypt

inhibit the diagnostic ability of CBCT images by decreasing contrast, concealing structures, and consequently impairing diagnosis [17].

Many studies have investigated the effect of different restorative materials on detection of *recurrent caries* by CBCT with conflicting results. Some studies found that CBCT has a similar diagnostic ability in detection of recurrent caries under amalgam and composite fillings [18, 19]. Other studies declared better accuracy of CBCT images for recurrent caries detection in presence of composite than amalgam restorations [20, 21]. Recurrent caries under zirconia and lithium disilicate crowns was accurately detected using CBCT [22].

Few studies have evaluated the accuracy of CBCT in detection of *proximal caries* in presence of different restorations. Amalgam fillings were assessed in two previous studies regarding their effect on detection of proximal caries by CBCT [15, 16]. Only one study assessed composite, resin-modified glass-ionomer cement (RMGIC), and zirconia inlay restorations [15]. Zirconia and lithium disilicate crowns were not previously evaluated regarding their influence on proximal caries detection by CBCT.

Considering the continuous influx of new dental materials with various X-ray attenuating properties and the increased use of CBCT in dental practice, this study aimed to evaluate the impact of artifacts produced by 5 current and frequently used restorative materials on the accuracy of CBCT-based detection of proximal carious lesions.

Materials and methods

This *ex vivo* study was expedited from review by Ain Shams University Faculty of Dentistry Ethics Committee. Assuming a diagnostic accuracy of 70% with an error margin of 10% and a significance level of 95%, the required sample size was 80 surfaces [16].

Preparation of artificially carious teeth

Forty sound human molars and premolars were included in the study. The teeth were extracted for orthodontic and periodontal reasons matching the selection criteria: no cracks and restorations, no developmental anomalies or hypoplastic structures, and no cavitations caries. Randomly selected 20 proximal surfaces were left sound, while other 60 proximal surfaces were prepared to possess varying degrees of artificial proximal caries. On the proximal surface of the test tooth just below the contact area, a circular piece of rubber was applied; then the tooth was coated with a fast-drying acid-resistant nail polish except for the rubber circle. After the varnish dried, the rubber circle was removed leaving a circular window of 2 mm diameter of exposed enamel. The

teeth were kept individually immersed in 8 ml of 5% formic acid solution for 10 or 20 or 30 h to induce different lesion depths. After completion of demineralization time, the teeth were cleaned with acetone to remove the varnish [23].

Preparation of artifact-producing teeth

To evaluate the effects of various restorations, three molars with mesial-occlusal-distal (MOD) cavity were prepared to receive one of the following filling materials: amalgam (Cavex, Haarlem, Netherlands), composite (Valux Plus, 3 M ESPE, St Paul, MN, USA), and RMGIC (GC Fuji® II LC, GC Corporation, Tokyo, Japan). Another two molars were prepared with chamfer margin for each of 2 different full-coverage computer-aided design and computer-aided manufacture crowns: zirconia (Natura Z Block, DMAX Co., Ltd., Daegu, Korea) and lithium disilicate (IPS e.max® CAD; Ivoclar Vivadent AG, Schaan, Liechtenstein). Moreover, one non-restored molar was used as a control tooth. The non-restored and 5 restored molars served as artifact-producing teeth.

Assembling the teeth in the dry mandible

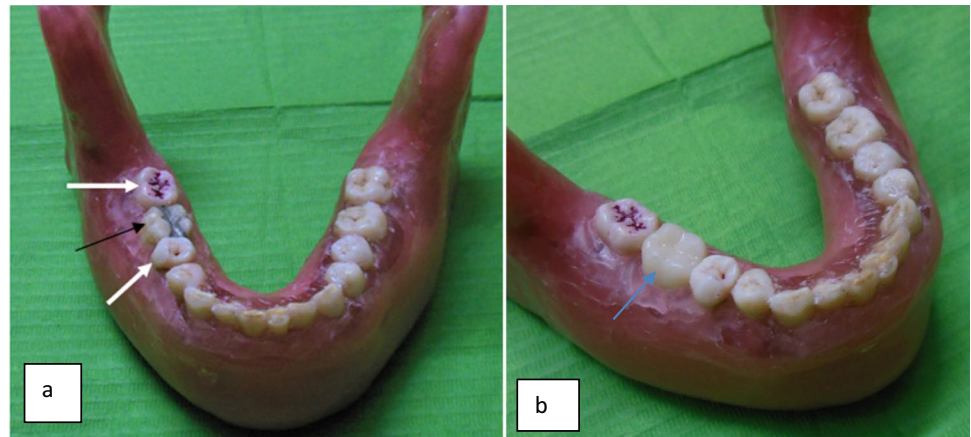
The artificially carious teeth were divided into 20 groups each composed of one premolar and one molar. Group by group, the teeth were assembled in the empty sockets of the right second premolar and second molar in proximal contact with one artifact-producing molar positioned in place of the first molar in a dry human dentate mandible. Then the whole mandible was covered with three layers of softened pink wax buccally and lingually to simulate soft tissues during exposure (Fig. 1).

CBCT scanning

Standardized CBCT scans for the mandible were obtained using i-CAT® Next Generation CBCT scanner (Imaging Sciences International, Hatfield, PA) at 120 kV, 5 mA, field of view (FOV) 16 × 5 cm, voxel size 0.2 mm, and an exposure time of 26.9 s. The mandible was stabilized using a strengthened paper box mounted on the supporting plate of the machine. The midline of the mandible was adjusted with the anterior vertical laser light, while the posterior vertical laser light was placed just anterior to the ramus of mandible. The horizontal laser light was adjusted to be parallel to the occlusal plane of the teeth.

The first scanned group of artificial carious teeth was then removed from the mandible, and the subsequent groups were placed in their positions and scanned without changing the artifact-producing molar. A total of 120 CBCT scans were obtained as each one of the six artifact-producing molars was imaged with the 20 groups of artificially carious teeth.

Fig. 1 The same set of artificially carious teeth (white arrows) placed in proximal contact with molar restored with MOD amalgam filling (black arrow) (a) and molar restored with lithium disilicate crown (blue arrow) (b)



Radiographic image analysis

All CBCT images were reconstructed at 0.2 mm thickness to optimize proximal caries detection. Two calibrated and blinded dental radiologists with 10-year experience assessed the images using the inherent i-CAT Vision™ software viewer and the same computer monitor (15.6-inch HD LED) with a resolution of 1920×1080 under subdued lights conditions. The observers investigated the proximal surfaces of artificially carious teeth extending from the occlusal surface to the cemento-enamel junction by scrolling through different orthogonal and non-orthogonal sections and rated the proximal surfaces using a four-grade scale:

- 0: Sound
- 1: Radiolucency in the outer half of the enamel
- 2: Radiolucency extending more than half of the enamel up to the dentino-enamel junction (DEJ)
- 3: Radiolucency extending through enamel and outer half of dentin [24]

Observers were allowed to perform any needed image adjustments to improve radiographic image analysis. Each observer assessed 20 scans in each viewing session with 2-week intervals with a total of 12 separate viewing sessions 2 sessions for each artifact-producing molar. A total of 120 CBCT scans counting up to 480 proximal surfaces were rated by each observer twice. According to the proximity of the surface being investigated to the artifact-producing molar, artificially carious surfaces were divided into two groups: 240 surfaces mesial to the artifact-producing molars and 240 surfaces distal to the artifact-producing molars. Figure 2 demonstrates an example of CBCT images of the same set of artificially carious teeth in the vicinity of the studied restorations and the non-restored molar.

Microscopic examination

After completion of the radiographic assessment, each tooth was sectioned in a mesiodistal direction. Two blinded oral pathologists examined both sides of each section under a stereomicroscope (Olympus DP 10, SZ-PT, Japan) with 10× magnification with consensus (Fig. 3). They scored caries according to the deepest spot in both sections using a four-grade scale [25]:

- 0: No caries apparent
- 1: Carious lesions in the outer half of enamel only
- 2: Carious lesions in more than half of enamel up to the DEJ
- 3: Carious lesions penetrating the DEJ and in the outer half of dentin

Data analysis

Statistical Package for the Social Sciences (SPSS®) (IBM Corporation, NY, USA) version 17 for Windows was used for data analysis. Intra- and inter-observer agreements were assessed using weighted kappa values and interpreted as follows: < 0.10 no agreement, 0.10–0.40 poor, 0.41–0.60 moderate, 0.61–0.80 strong, and 0.81–1.00 excellent agreement. For CBCT caries detection in teeth adjacent to different restorations, sensitivity, specificity, and area under the receiver operating characteristic (ROC) curve (Az) values were calculated and compared using z test. The significance level was set at $P < 0.05$.

Results

Table 1 shows the analytical data of the artificially carious teeth based on histological examination. Strong to excellent intra-observer and moderate to excellent inter-observer

Fig. 2 Corrected sagittal views of the same set of artificially carious teeth in the vicinity of different restorations and non-restored molar

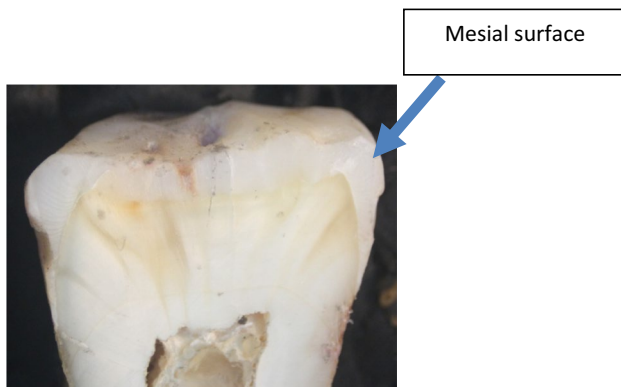
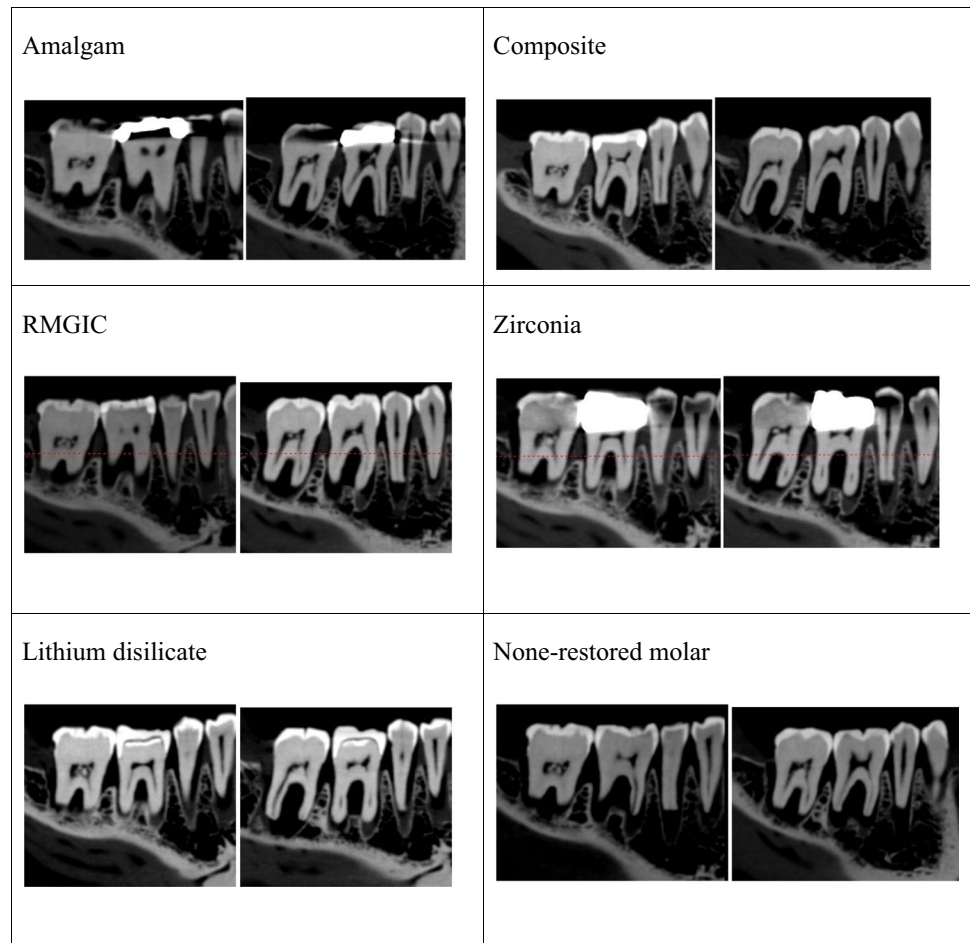


Fig. 3 Stereomicroscope image of lower right second molar with score 1 in mesial surface and score 2 in the distal surface

agreements were found for CBCT proximal caries detection in presence of different restorations and non-restored molar (Table 2). The least inter-observer agreement was found for caries detection in teeth surfaces mesial to zirconia followed by teeth surfaces distal to amalgam.

Caries detection sensitivity in mesial and distal surfaces of teeth adjacent to studied restorations was generally high

Table 1 True cavitations status of the tooth surfaces according to histological examination

	Mesial	Distal	Total no. of tooth surfaces	%
Sound	10	10	20	25
Outer enamel caries	3	4	7	8.75
Caries reaching DEJ	11	12	23	28.75
Outer dentine caries	16	14	30	37.5
Total	40	40	80	100

(0.87–0.99). The specificity of sound surface detection ranged from 0.45 to 1.00 for mesial surfaces and from 0.83 to 0.95 for distal surfaces (Table 3). Accuracy of CBCT-based caries detection in mesial and distal teeth surfaces ranged from 0.70 to 0.99 (Table 4).

Compared to control tooth, teeth surfaces mesial to amalgam filling showed highly significant less specificity and accuracy. Teeth surfaces distal to amalgam showed significantly less sensitivity and accuracy of CBCT-based caries detection. In addition, teeth surfaces mesial to

Table 2 Kappa values for intra- and inter-observer agreement

	Intra-observer reliability				Inter-observer reliability			
	Mesial surfaces		Distal surfaces		Mesial surfaces		Distal surfaces	
	Observer 1	Observer 2	Observer 1	Observer 2	Reading 1	Reading 2	Reading 1	Reading 2
Amalgam	0.63	0.85	0.75	0.65	0.66	0.69	0.52	0.67
Composite	0.96	0.92	0.71	0.92	0.85	0.89	0.66	0.67
RM GIC	0.87	0.96	0.79	0.87	0.81	0.79	0.70	0.74
Lithium disilicate	0.88	0.96	0.81	0.79	0.84	0.76	0.67	0.58
Zirconia	0.91	0.64	0.94	0.83	0.41	0.75	0.63	0.72
Non-restored	0.89	0.92	0.83	0.71	0.85	0.89	0.62	0.74

Table 3 Diagnostic performance of CBCT-based detection of proximal caries

	Mesial surfaces				Distal surfaces			
	Sensitivity	Specificity	PPV	NPV	Sensitivity	Specificity	PPV	NPV
Amalgam	0.97	0.45	0.84	0.82	0.89	0.83	0.94	0.72
Composite	0.96	1.00	1.00	0.89	0.95	0.93	0.97	0.86
RMGIC	0.96	1.00	1.00	0.89	0.95	0.95	0.98	0.86
Lithium disilicate	0.97	0.93	0.98	0.90	0.99	0.93	0.98	0.97
Zirconia	0.87	0.90	0.96	0.69	0.96	0.93	0.98	0.88
Non-restored	0.97	1.00	1.00	0.91	0.97	0.93	0.98	0.90

PPV positive predictive value, NPV negative predictive values

Table 4 Area under the curve for CBCT-based detection of proximal caries in the vicinity of different restorations and non-restored molar

	Mesial				Distal			
	Az	SE	P-value	95% CI	Az	SE	P-value	95% CI
Amalgam	0.70	0.05	0.00	0.59–0.81	0.89	0.03	0.00	0.83–0.95
Composite	0.98	0.01	0.00	0.96–1.00	0.97	0.01	0.00	0.94–0.99
RMGIC	0.98	0.01	0.00	0.96–1.00	0.97	0.01	0.00	0.95–1.00
Lithium disilicate	0.98	0.01	0.00	0.96–1.00	0.99	0.01	0.00	0.98–1.00
Zirconia	0.89	0.03	0.00	0.83–0.95	0.97	0.01	0.00	0.95–1.00
Non-restored	0.98	0.01	0.00	0.96–1.00	0.98	0.01	0.00	0.96–1.00

zirconia crown showed significantly less sensitivity, specificity, and accuracy (Table 5).

Discussion

The present study investigated the potential effects of different dental fillings and permanent full crowns on the accuracy of CBCT-based proximal caries detection. Moreover, the diagnostic ability of CBCT in detection of proximal caries in absence of any restorations was assessed.

CBCT is not the investigation of choice for caries detection due to the higher radiation dose involved compared to intraoral radiography [26]. However, when CBCT is done for any other reason and if it is found to be accurate in proximal caries detection in the presence of different restorations, then

it is the responsibility of the radiologist/clinician to check for presence of caries without prescribing further radiographs according to the ALARA principle.

Our study sample consisted of extracted sound human premolars and molars. Artificial proximal caries with different depths were induced using 5% formic acid as it is well accepted that chemically induced caries with acids could precisely simulate the clinical situation [19, 27]. Similar to Gaalaas et al. [6], a dry human mandible was used, and the teeth were adapted with their roots into the empty sockets in proximal contact to simulate the real dental arch as much as possible.

It is well-known that image degradation is proportional to the number of restorations in the jaws [28]. For this reason, we attempted to assess the artifacts produced by one restoration in the dental arch and avoid the effect of multiple

Table 5 Sensitivity, specificity, and accuracy of CBCT-based detection of proximal caries among surfaces mesial and distal to different restorations compared to non-restored molar using Z-test

	Sensitivity		Specificity		Az	
	Mesial	Distal	Mesial	Distal	Mesial	Distal
Amalgam ~ non-restored						
z-statistic	0	2.26	5.51	1.35	4.22	2.61
P-value	1	0.024*	0.000**	0.176	0.000**	0.009**
Composite ~ non-restored						
z-statistic	0.34	0.65	0	0	0	0.26
P-value	0.734	0.518	1	1	1	0.791
RMGIC ~ non-restored						
z-statistic	0.34	0.65	0	0.46	0	0.26
P-value	0.734	0.518	1	0.644	1	0.791
Lithium disilicate ~ non-restored						
z-statistic	0	1.36	1.77	0	0	0.92
P-value	1	0.175	0.077	1	1	0.357
Zirconia ~ non-restored						
z-statistic	2.80	0.34	2.05	0	2.61	0.26
P-value	0.005**	0.734	0.040*	1	0.009**	0.791

* $P < 0.05$ significant** $P < 0.01$ highly significant

restorations. Although radiation dose was not an issue in this *ex vivo* study, medium FOV 16×5 cm and 0.2 mm voxel size were used for CBCT scanning of a single arch as this is the most frequently used setting used for most dental diagnostic tasks.

Intra-observer agreement was better than inter-observer agreement for caries detection in the vicinity of amalgam and zirconia restorations. This might indicate that each observer was more or less consistent in differentiating caries from streaks and dark bands. Similarly, Kulczyk et al. [16] declared excellent intra-observer and moderate inter-observer agreements in CBCT detection of proximal caries in presence of amalgam filling.

Strong to excellent intra- and inter-observer agreement for proximal caries detection was found in teeth surfaces in the vicinity of composite, RMGIC fillings, lithium disilicate crown, and non-restored molar. Likewise, Cebe et al. [15] reported excellent inter-observer reliability for CBCT caries detection in teeth surfaces mesial and distal to composite and RMGIC fillings. Moreover, Aglarci et al. [22] revealed strong inter-observer consistency for recurrent caries detection under lithium disilicate crowns. Besides, Belem et al. [29] showed strong intra- and inter-observer reliability in detection of enamel proximal caries using CBCT in absence of any restoration.

Presence of amalgam filling in the FOV resulted in intense beam hardening artifacts that have a broad effect involving both mesial and distal surfaces of the two adjacent teeth. The ability to detect sound teeth surfaces mesial and carious lesions distal to amalgam restoration by CBCT is considerably compromised. A possible explanation is that

the dark bands that appeared close to amalgam restoration mimicked carious lesions, which made it challenging to recognize sound teeth surfaces close to amalgam, while bright streak artifacts were more pronounced further away from the amalgam restoration and masked carious lesions in distal teeth surfaces.

Likewise, Cebe et al. [15] reported that caries detection in surfaces mesial to amalgam showed low specificity, while distal surfaces showed low sensitivity using Planmeca CBCT unit (ProMax 3D Mid, Helsinki, Finland). However, compared to our results, they obtained a much lower sensitivity of caries detection in distal surfaces and total inability (0% specificity) to detect sound surfaces mesial to amalgam. This could be explained by the low 90 kV CBCT used in that study which amplified the beam hardening artifacts.

Conversely, Kulczyk et al. [16] evaluated the influence of amalgam fillings on the detection of proximal caries by NewTom 3G CBCT (Quantitative Radiology, Verona, Italy). They observed very low sensitivity and specificity of caries detection in teeth surfaces mesial and distal to amalgam filling and ascribed these results to image intensifier tube and charge-coupled device (ITT/CCD) detector and larger FOV 15×13 cm which increased the beam hardening artifacts of amalgam.

Presence of zirconia crown in the FOV produced intense beam hardening artifacts that were confined and only affected mesial surfaces of adjacent teeth. These artifacts greatly reduced the sensitivity and accuracy of caries detection in mesial tooth surfaces, while caries detection in teeth surfaces distal to zirconia crown was comparable to non-restored molar and other tested restorations.

On the contrary, Cebe et al. [15] declared low sensitivity of caries detection in teeth surfaces distal to zirconia inlay and very low specificity in mesial teeth surfaces. Even though they studied zirconia inlay in MOD cavity compared to full coverage zirconia crown in the present research, they reported more widespread artifacts. Lower scanning kV could be responsible for the amplified zirconia artifact in that study.

Otherwise, the present study showed favorable sensitivity, specificity, and accuracy of CBCT in the detection of proximal caries in teeth adjacent to composite, RMGIC, and lithium disilicate. These restorations presented acceptable radiopacity within the useful range and did not affect the diagnostic ability of CBCT for proximal caries detection.

Similarly, Aglarci et al. [22] assessed the diagnostic ability of NewTom 5G CBCT in detection of natural recurrent caries left under zirconia, lithium disilicate, and metal-supported ceramic full crowns. They declared that CBCT could be used as a post-treatment diagnostic technique for detecting caries under fixed crowns.

In contrast, Cebe et al. [15], when investigating the effect of composite and RMGIC on proximal caries detection, revealed low sensitivity of caries detection in distal teeth surfaces and very low specificity of caries detection in mesial teeth surfaces. These differences could be attributed to multiple factors: low scanning kV, high filler content of the hybrid composite (68% by volume) [30] compared to the single filler type 100% zirconia/silica (66% by volume) used in the current study, besides, they assessed natural proximal carious lesions with visually intact proximal surfaces where detection of caries is even more challenging.

The present study revealed optimal sensitivity (0.97), specificity (1.00 to 0.93), and accuracy (0.98) of CBCT for proximal caries detection in absence of any restorations. Similarly, Belem et al. [29] showed high sensitivity (0.88), specificity (0.87), and accuracy (0.88) in detection of proximal enamel caries using i-CAT® CBCT unit working with high kV 120. Flat-panel CBCT-based images show limited beam hardening artifacts from the high-density nearby enamel [31, 32].

Alternatively, Wenzel et al. [4] registered high specificity (0.99) and accuracy (0.85) but low sensitivity (0.58) for detection of proximal surfaces cavitations using 3D Accu-tomo CBCT (FPD 80, Morita Corp. Ltd., Tokyo, Japan). Furthermore, Krzyzostaniak et al. [10] reported a low Az value (0.63) of NewTom 3G CBCT in detection of non-cavitated proximal lesions. These differences are probably related to the IIT/CCD detector of the used CBCT machines.

Moreover, Sansare et al. [5] found relatively sub-optimal sensitivity (0.75–0.79), specificity (0.77), and accuracy (0.76–0.78) in detection of proximal caries clinically using Kodak 9000 3D CBCT system (Carestream Health Inc., Rochester, NY, USA). Like i-CAT® Next Generation CBCT

used in the current work, Kodak 9000 3D CBCT system implements a flat-panel detector. The lower sensitivity and specificity reported by Sansare et al. [5] compared to our results might be due to low scanning 80 kV and their in vivo experimental design. CBCT patients' scans have considerably more image noise than ex vivo images because soft tissues increase scattered radiation.

The limitation of the present experiment was eliminating clinical conditions that might impede diagnosis. A clinical study design would yield more realistic results, but the challenge in clinical studies is to obtain a meaningful validation gold standard for the radiographic findings. In addition, using teeth with natural caries might mimic the clinical situation more closely than obvious cavities produced chemically. The present study assessed the diagnostic ability of CBCT for proximal caries detection only in teeth adjacent to the restorations. Further studies should be performed to assess the rest of teeth in the dental arch.

Conclusion

Beam hardening artifacts produced by amalgam fillings compromise caries detection ability in the mesial and distal surfaces of adjacent teeth by CBCT. Zirconia crowns only decrease caries detection ability in the mesial surfaces of the adjacent teeth by CBCT. Otherwise, CBCT is a highly valid examination technique for proximal caries detection in absence of any restoration as well as in teeth close to composite, RMGIC fillings, and lithium disilicate crown.

Funding The work was supported by the Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Ain Shams University.

Declarations

Ethics approval This article does not contain any studies with human participants or animals performed by any of the authors. This ex vivo study was expedited from review by Ain Shams University Faculty of Dentistry Ethics Committee.

Conflict of interest The authors declare no competing interest.

Informed consent For this type of study, formal consent is not required.

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