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RESEARCH ARTICLE

Diagnostic accuracy of different display types in detection of recurrent caries under restorations by using CBCT

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Objectives: To assess the *in vitro* diagnostic ability of CBCT images using seven different display types in the detection of recurrent caries.
Methods: Our study comprised 128 extracted human premolar and molar teeth. 8 groups each containing 16 teeth were obtained as follows: (1) Black Class I (Occlusal) amalgam filling without caries; (2) Black Class I (Occlusal) composite filling without caries; (3) Black Class II (Proximal) amalgam filling without caries; (4) Black Class II (Proximal) composite filling without caries; (5) Black Class I (Occlusal) amalgam filling with caries; (6) Black Class I (Occlusal) composite filling with caries; (7) Black Class II (Proximal) amalgam filling with caries; and (8) Black Class II (Proximal) composite filling with caries. Teeth were imaged using 100×90 mm field of view at three different voxel sizes of a CBCT unit (Planmeca ProMax® 3D ProFace™; Planmeca, Helsinki, Finland). CBCT TIFF images were opened and viewed using custom-designed software for computers on different display types. Intra- and interobserver agreements were calculated. The highest area under the receiver operating characteristic curve (Az) values for each image type, observer, reading and restoration were compared using *z*-tests against Az = 0.5. The significance level was set at $p = 0.05$.
Results: We found poor and moderate agreements. In general, Az values were found when software and medical diagnostic monitor were utilized. For Observer 2, Az values were statistically significantly higher when software was used on medical monitor [$p = 0.036$, $p = 0.015$ and $p = 0.002$, for normal-resolution mode (0.200 mm^3 voxel size), high-resolution mode (0.150 mm^3 voxel size) and low-resolution mode (0.400 mm^3 voxel size), respectively]. No statistically significant differences were found among other display types for all modes ($p > 0.05$). In general, no difference was found among 3 different voxel sizes ($p > 0.05$). In general, higher Az values were obtained for composite restorations than for amalgam restorations for all observers. For Observer 1, Az values for composite restorations were statistically significantly higher than those of amalgam restorations for MacBook and iPhone (Apple Inc., Cupertino, CA) assessments ($p = 0.002$ and $p = 0.048$, respectively).
Conclusions: Higher Az values were observed with medical monitors when used with dedicated software compared to other display types which performed similarly in the diagnosis of recurrent caries under restorations. In addition, observers performed better in detection of recurrent caries when assessing composite restorations than amalgams.
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Introduction

Diagnosis of dental caries may pose problems for the clinician. In order to enable better detection, it is advised that visual examination and probing be combined with other diagnostic aids such as X-ray imaging, laser or light fluorescence-based methods, electrical impedance measurements, ultrasound, MRI etc.[1–3] Development of recurrent caries, which occurs under different types of restorative materials, is considered a major cause of restorative failure and replacement. It is therefore crucial to diagnose early recurrent lesions in order to prevent severe destruction of hard tissue and to enhance the prognosis for a successful treatment outcome.[3]

The use of CBCT in clinical practice offers a number of potential advantages over medical tomography, including lower effective radiation doses, easier image acquisition, less space requirements and greater cost effectiveness. In fact, CBCT has largely replaced medical CT for most dental diagnostic tasks. Previous studies suggested that owing to radiation risk, CBCT must not be routinely used for caries detection; however, available CBCT images taken for different purposes could be used to diagnose carious lesions with the advantage of three-dimensional assessment possibility.[1–3] CBCT systems offer different sensor types, fields of view (FOVs) and exposure settings. However, beam-hardening and metal artefacts that occur in CBCT images are thought to be a limiting factor in detection of recurrent caries under restorations.[3] Such artefacts include streaks around materials as well as dark zones that affect the overall quality of the image. Streak artefacts appear as linear hyper densities that radiate from a metallic object and may extend to the width of the field. Beam-hardening artefacts appear as dark bands adjacent to high-density structures and may mimic disease. Beam hardening may be more pronounced in CBCT than in medical CT, mainly because of the lower kVp and thus lower mean energy of the X-ray beam in CBCT systems.[4–7]

The display type and viewing software are also of paramount importance in the detection of recurrent caries. The display plays a critical role, which is considered to be as important as the ability of the radiation detector or sensor to capture a reliable image. Recent developments in the field of liquid crystal displays (LCDs) have also led to more stable and consistent image quality. This has resulted in a broad choice of monitors with different technical specifications and different screen sizes.[8,9] Besides, tablets and smartphones are among recent innovations in computing technology, which have been incorporated into daily routine life and into professional healthcare. Some important characteristics of these devices, which have led them to become potential tools in diagnostic medicine, include their small size, web access, touch screen display, good processor performance and screen resolution.[10–12]

In view of the importance of radiological diagnosis of recurrent caries under restorations and the potential difference in diagnostic performance of observers for different display types, the aim of the present study was to assess the *in vitro* diagnostic ability of CBCT images using seven different display types in the detection of recurrent caries in extracted human teeth in comparison to the histological gold standard.

Methods and materials

Our study comprised 128 human premolar and molar teeth that were extracted for periodontal or orthodontic reasons. 64 teeth were with dentine caries (16 premolars with occlusal caries, 16 premolars with interproximal caries, 16 molars with occlusal caries and 16 molars with interproximal caries) and 64 control teeth were without caries (32 premolars and 32 molars). Caries status was initially determined by visual and intraoral radiographic examination. Teeth were cleaned of calculus and debris, disinfected in 2% sodium hypochlorite solution for 20 min and stored in distilled water.

Preparation of specimens

8 groups each containing 16 teeth were obtained as follows: (1) 16 teeth with Black Class I (occlusal) amalgam filling without caries; (2) 16 teeth with Black Class I (occlusal) composite filling without caries; (3) 16 teeth with Black Class II (proximal) amalgam filling without caries; (4) 16 teeth with Black Class II (proximal) composite filling without caries; (5) 16 teeth with Black Class I (occlusal) amalgam filling with caries; (6) 16 teeth with Black Class I (occlusal) composite filling with caries; (7) 16 teeth with Black Class II (proximal) amalgam filling with caries; and (8) 16 teeth with Black Class II (proximal) composite filling with caries.

For amalgam restorations, Cavex Avalloy (Cavex Holland BV, Haarlem, Netherlands) was utilized with zinc phosphate liner (Adhesor Cement; SpofaDental, Jicin, Czech Republic). For composite restorations, Filtek™ Ultimate A2 (3M ESPE, Seefeld, Germany) body with Single Bond Universal (3M ESPE) was utilized. In order to simulate recurrent or residual caries under certain amalgam and composite restoration groups, some decayed tissues were left under the prepared Black Class I and Black Class II cavities. A researcher stained each subgroup of teeth with a different colour by using nail polishers. All the stained teeth were blended for random selection for the image acquisition process.

Image acquisition

For imaging procedures, each tooth was placed in the appropriately prepared maxillary and mandibular premolar and molar sockets of a dry skull along with its mandible. The dry skull along with its mandible was covered with 2-cm red wax as a soft-tissue equivalent material. All teeth were randomly placed in the alveolar

sockets in groups of 16 (2 premolars and 2 molars on the left and right hemimandibles and hemimaxillae) in contact. Thereafter, the teeth were imaged using 100 × 90 mm FOV at three different voxel sizes of a CBCT unit (Planmeca ProMax® 3D ProFace™; Planmeca, Helsinki, Finland) as follows: Mode 1: normal-resolution mode at 96 kVp, 10 mA and an exposure time of 12.3 s using 0.200 mm^3 voxel size; Mode 2: high-definition mode at 96 kVp, 10 mA and an exposure time of 15.4 s using 0.150 mm^3 voxel size; and Mode 3: low-resolution mode at 96 kVp, 6 mA and an exposure time of 4.6 s using 0.400 mm^3 voxel size. The researcher who prepared the teeth and knew the study design reconstructed multiplanar reformatted images using the systems' own software program (Planmeca Romexis®; Planmeca). Serial panoramic and cross-sectional views with 1 mm section interval were prepared and then exported and saved in TIFF format.

Image interpretation

A specific calibration session by using 10 images which were not included in the study was conducted prior to the interpretation process. Image sets were viewed separately by two blinded, calibrated and experienced observers in CBCT assessment (one dentomaxillofacial radiologist and one restorative dentistry specialist) in a dimly lit room. No time restriction was placed on the observers. Image sets were viewed at 1-week intervals, and evaluations of each image set were repeated 1 week after the initial viewings. All images were randomized within each imaging protocol. CBCT TIFF images were opened and viewed using standard free-downloadable image-viewing software for computers (Picasa®; Google, Mountain View, CA) on different display types and mail application built in the operating system for smartphones and tablets. Table 1 shows different display types used to detect recurrent caries under restorations using CBCT images in the present study. For the medical diagnostic monitor, images were both evaluated as TIFF images on Picasa software, mail application and also by using dedicated Planmeca software (Planmeca Romexis). Built-in enhancement tools of the software were used if deemed necessary. Figure 1 shows cross-sectional images obtained at normal mode 1 (0.2 mm^3 voxel size) using Romexis software and displayed on medical monitor.

The cross-sectional aspects of each restored tooth were randomly evaluated for the presence/absence of caries under restorations and were scored using a 5-point scale as follows: 1 = caries definitely present; 2 = caries probably present; 3 = uncertain–unable to tell; 4 = caries probably not present; and 5 = caries definitely not present. A total of 128 teeth (32 maxillary premolars and 32 mandibular premolars, and 32 maxillary molars and 32 maxillary molars) were assessed.

Histological validation of the caries' status was performed by serially sectioning each tooth mesiodistally in parallel to the long axis of the crown using an Accutom-50 (Struers, Ballerup, Denmark). Both sides of each section were examined under a stereomicroscope (×10, Stemi 2000; Carl Zeiss, Jena, Germany). Teeth were recorded as either sound or as having a caries lesion, which was defined as a demineralized white or yellowish-brown discoloured area in the enamel or dentine. Histological status was determined

Table 1 Display types used in study

Display group	*Manufacturer*	*Model*	*Greyscale display*	*Screen size (inches)*	*Screen type*	*Colour*	*Resolution*	*Software*
Toshiba	Toshiba (Tokyo, Japan)	Qosmio F75 5-3D350 Laptop	No	15.6	LED	Colour	1920 × 1080	Nvidia GeForce GT 540M Core™ i7 processor Software: Picasa
MacBook	Apple Inc. (Cupertino, CA)	MacBook Laptop	No	12	LED	Colour	2304 × 1440	1.1-GHz dual-core Intel Core M processor 4 MB shared L3 cache Intel HD Software: Picasa
iPhone	Apple Inc.	A1524 Smart phone (iPhone 6 plus)	No	5.5	LED	Colour	1920 × 1080	iOS v. 9.0.1, Software: Mail app
Vestel	Vestel (Manisa, Turkey)	32PH3125D Consumer monitor	No	32	LED	Colour	1366 × 768	Mac mini, preview, Intel HD graphics 4000 1536 MB graphics Software: Picasa
Medical	NEC (Tokyo, Japan)	Md213mg Diagnostic monitor	Yes	21.3	LED	Greyscale	2048 × 1536	Windows 8 i5 3330 CPU 3 GHz 64 bit, ATI Radeon HD 4800 Software: Picasa
Software	NEC	Md213mg Diagnostic monitor (with software)	Yes	21.3	LED	Greyscale	2048 × 1536	Windows 8 i5 3330 CPU 3 GHz 64 bit, ATI Radeon HD 4800, Software: Planmeca Romexis
iPad	Apple Inc.	A1474 Tablet (iPAD Air)	No	9.7	LED	Colour	2048 × 1536	iOS v. 9.0.1, Software: Mail app

CPU, central processing unit; HD, high definition; LED, light-emitting diode.

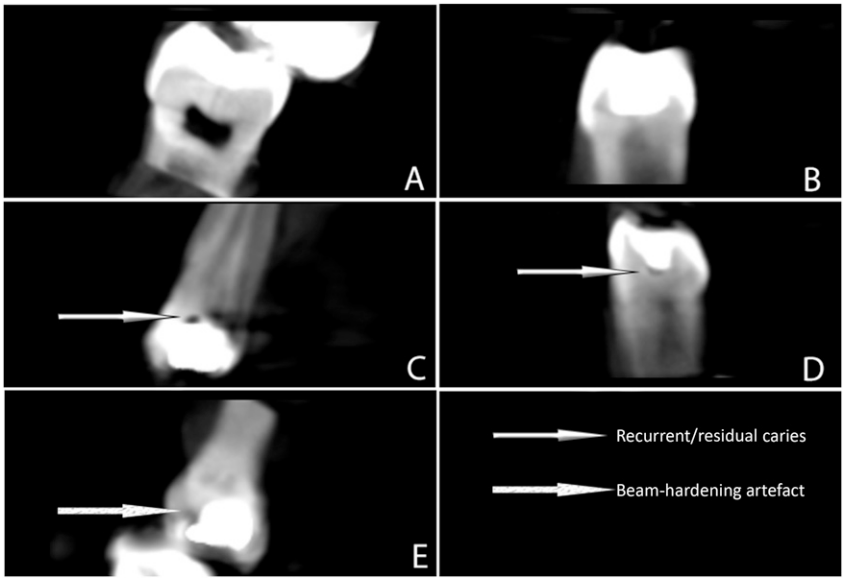


Figure 1 Cross-sectional CBCT images obtained using Romexis software (Planmeca Romexis®, Helsinki, Finland) in normal resolution mode at 96 kV, 10 mA and an exposure time of 12.3 s using 0.200 mm^3 voxel size displayed on medical monitor: (a) amalgam restoration without caries, (b) composite restoration without caries, (c) amalgam restoration with recurrent caries, (d) composite restoration with recurrent caries, (e) amalgam restoration with beam-hardening artefact.

by consensus of the researchers. Histological examination of 128 tooth surfaces confirmed our first examination and revealed dentin caries in 64 surfaces and no caries in 64 surfaces.

Statistical analysis

Weighted kappa coefficients were calculated to assess the intra- and interobserver agreement for each display type. Kappa values were interpreted as the following criteria: <0.10 = no agreement; 0.10–0.40 = poor agreement; 0.41–0.60 = moderate agreement; 0.61–0.80 = strong agreement; and 0.81–1.00 = excellent agreement.[13] Scores obtained from different CBCT display types were compared with the gold standard using the receiver operating characteristic analysis to evaluate the observers' ability to differentiate between teeth with and without recurrent caries. The area under the receiver operating characteristic curve (AUC) (Az) with standard error and 95% confidence interval was calculated using SPSS® v. 11.5 (IBM Corp., New York, NY; formerly SPSS Inc., Chicago, IL). Thus, the Az value 1 corresponds to perfect discrimination, whereas values <0.5 correspond to scores with no discrimination ability. Therefore, Az values for each image display type, observer, reading and restoration were compared using *z*-tests against Az = 0.5. The significance level was set at $p = 0.05$. The main purpose of this study was to determine the effects of different display types on diagnosis of secondary caries. A sample of 55 from the positive group and 55 from the negative group achieve 80% power to detect a difference of 0.1500 between the AUC under the null hypothesis of 0.5000 and an AUC under the alternative hypothesis of 0.6500 using a two-sided *z*-test at a significance level of 0.05000. The data are discrete (rating scale) responses. The AUC is computed between false-positive rates of 0.000 and 1.000. The ratio of the standard deviation of the responses in the negative group to the standard deviation of the responses in the positive group is 1.000. Sensitivity (Se), specificity (Sp), positive-predictive value and negative-predictive value for each observer were also calculated for each display type. For Se categories, Scores 1 and 2 were collapsed, and for Sp categories, Scores 4 and 5 were collapsed.

Results

Table 2 shows the intra- and interobserver Kappa coefficients calculated for the observers by display type. In general, we found poor and moderate agreements. The AUC values for observers, display types and voxel sizes (modes) were calculated and are given in Table 3. In general, the highest AUC (Az) values were found when software and medical diagnostic monitor were utilized. For Observer 2, Az values were statistically significantly higher when software was used on medical monitor [$p = 0.036$, $p = 0.015$ and $p = 0.002$, for normal-resolution mode (0.200 mm^3 voxel size), high-resolution mode (0.150 mm^3 voxel size) and low-resolution mode (0.400 mm^3 voxel size), respectively]. No statistically significant differences were found among other display types for all modes ($p > 0.05$). In general, no difference was found among the three different voxel sizes (modes) ($p > 0.05$). Therefore, only scores obtained from the normal-mode (0.2 mm^3 voxel size) images were taken into consideration for the comparison of different tooth types, restorative materials and restoration location.

Table 2 Intra- and interobserver agreement

Display type	*Observer 1 First–second reading Weighted κ-Se*	*Observer 2 First–second reading Weighted κ-Se*	*First reading Observer 1–Observer 2 Weighted κ-Se*	*Second reading Observer 1–Observer 2 Weighted κ-Se*
Toshiba	0.255–0.056	0.519–0.062	0.386–0.048	0.284–0.057
MacBook	0.382–0.055	0.491–0.063	0.433–0.046	0.343–0.056
iPhone	0.375–0.060	0.369–0.068	0.359–0.046	0.358–0.057
Vestel	0.496–0.060	0.329–0.064	0.177–0.047	0.274–0.054
Medical	0.367–0.062	0.436–0.064	0.384–0.045	0.273–0.059
Software	0.308–0.074	0.378–0.067	0.203–0.045	0.407–0.063
iPad	0.392–0.073	0.382–0.067	0.270–0.065	0.310–0.058

When Az values were calculated for amalgam and composite restorations separately for each display type, for Observer 1, Az values with MacBook (Apple Inc., Cupertino, CA), iPhone (Apple Inc., Cupertino, CA), medical monitor and software assessments were statistically significant >0.50 ($p = 0.003$, $p = 0.043$, $p = 0.031$ and $p = 0.045$, respectively). When visibility of recurrent caries under two different restorative materials for each display type was taken into consideration, in general, higher Az values were obtained for composite restorations than for amalgam restorations for all observers. For Observer 1, Az values for composite restorations were statistically significantly higher than those of amalgam restorations for MacBook and iPhone assessments ($p = 0.002$ and $p = 0.048$, respectively) (Table 4).

Se, Sp, positive-predictive value and negative-predictive value for each observer and their first readings are presented in Table 5.

Discussion

To our knowledge, no previous study has compared different display types using CBCT images in detecting recurrent caries under different types of restorations. In general, we obtained low Az, Se and Sp values due to the fact that CBCT is not the ideal imaging technique for the detection of recurrent caries. However, dentists are often asked to assess caries under restorations in the available CBCT images taken for other reasons. We found that medical monitor with or without using the inbuilt software showed the highest Az values. In addition, we found significant difference between software on medical monitor and other display types for the second observer. These findings suggest that when evaluating available CBCT images for the detection of recurrent caries under restorations, using their dedicated software along with a medical greyscale monitor would

Table 3 The Az values for both observers, display types and voxel size

	Observer 1			*Observer 2*		
Display type	*Mode 1 (0.20 mm^3)*	*Mode 2 (0.15 mm^3)*	*Mode 3 (0.40 mm^3)*	*Mode 1 (0.20 mm^3)*	*Mode 2 (0.15 mm^3)*	*Mode 3 (0.40 mm^3)*
Toshiba						
Az (SE)	0.544 (0.051)	0.539 (0.051)	0.521 (0.051)	0.543 (0.051)	0.501 (0.051)	0.543 (0.051)
95% CI	(0.444–0.644)	(0.439–0.639)	(0.420–0.621)	(0.443–0.643)	(0.401–0.602)	(0.443–0.643)
p-value	0.393	0.446	0.687	0.403	0.979	0.399
MacBook						
Az (SE)	0.575 (0.050)	0.496 (0.051)	0.579 (0.051)	0.494 (0.051)	0.522 (0.051)	0.575 (0.051)
95% CI	(0.476–0.674)	(0.396–0.597)	(0.479–0.678)	(0.394–0.595)	(0.422–0.623)	(0.474–0.673)
p-value	0.145	0.945	0.125	0.907	0.666	0.151
iPhone						
Az (SE)	0.551 (0.051)	0.531 (0.052)	0.556 (0.051)	0.498 (0.051)	0.465 (0.051)	0.566 (0.051)
95% CI	(0.452–0.651)	(0.430–0.632)	(0.456–0.656)	(0.398–0.598)	(0.364–0.565)	(0.467–0.665)
p-value	0.316	0.543	0.275	0.970	0.489	0.198
Vestel						
Az (SE)	0.504 (0.051)	0.496 (0.052)	0.510 (0.051)	0.527 (0.051)	0.529 (0.051)	0.521 (0.051)
95% CI	(0.404–0.605)	(0.395–0.597)	(0.410–0.610)	(0.427–0.628)	(0.429–0.630)	(0.421–0.622)
p-value	0.932	0.935	0.845	0.595	0.567	0.680
Medical						
Az (SE)	0.592 (0.050)	0.518 (0.051)	0.581 (0.051)	0.501 (0.051)	0.533 (0.051)	0.597 (0.050)
95% CI	(0.494–0.691)	(0.417–0.618)	(0.481–0.680)	(0.401–0.602)	(0.433–0.634)	(0.498–0.695)
p-value	0.072	0.730	0.116	0.983	0.515	0.059
Software						
Az (SE)	0.572 (0.051)	0.553 (0.051)	0.551 (0.051)	0.608 (0.050)	0.624 (0.050)	0.657 (0.048)
95% CI	(0.472–0.672)	(0.452–0.653)	(0.452–0.651)	(0.510–0.705)	(0.527–0.721)	(0.562–0.751)
p-value	0.160	0.303	0.316	**0.036**	**0.015**	**0.002**
iPad						
Az (SE)	0.445 (0.051)	0.528 (0.051)	0.543 (0.051)	0.555 (0.051)	0.571 (0.051)	0.542 (0.051)
95% CI	(0.345–0.546)	(0.427–0.628)	(0.443–0.644)	(0.455–0.655)	(0.472–0.671)	(0.442–0.642)
p-value	0.287	0.590	0.396	0.283	0.164	0.412

Az, the highest area under the receiver operating characteristic curve; CI, confidence interval; SE, standard error.
Bold values indicate significant difference $p < 0.05$.

Table 4 Az values, their standard error (SE), 95% confidence interval (CI) and significance levels (*p*-value) for each observer's first reading at 0.2 mm^3 voxel size

	Observer 1			*Observer 2*		
Display type	*Amalgam*	*Composite*	p-*value*	*Amalgam*	*Composite*	p-*value*
Toshiba						
Az (SE)	0.531 (0.071)	0.553 (0.074)	0.830	0.463 (0.071)	0.628 (0.072)	0.102
95% CI	(0.392–0.670)	(0.408–0.699)		(0.324–0.602)	(0.487–0.769)	
p-value	0.661	0.475		0.603	0.086	
MacBook						
Az (SE)	0.426 (0.070)	0.725 (0.065)	0.002	0.418 (0.070)	0.552 (0.075)	0.188
95% CI	(0.288–0.564)	(0.597–0.853)		(0.281–0.555)	(0.404–0.699)	
p-value	0.298	0.003		0.249	0.488	
iPhone						
Az (SE)	0.454 (0.071)	0.651 (0.070)	0.048	0.418 (0.070)	0.578 (0.074)	0.117
95% CI	(0.315–0.593)	(0.513–0.789)		(0.281–0.555)	(0.432–0.723)	
p-value	0.518	0.043		0.249	0.298	
Vestel						
Az (SE)	0.436 (0.071)	0.588 (0.073)	0.135	0.564 (0.072)	0.476 (0.075)	0.390
95% CI	(0.297–0.575)	(0.445–0.732)		(0.423–0.704)	(0.330–0.623)	
p-value	0.370	0.236		0.370	0.751	
Medical						
Az (SE)	0.520 (0.071)	0.661 (0.071)	0.158	0.462 (0.071)	0.538 (0.074)	0.459
95% CI	(0.381–0.659)	(0.521–0.800)		(0.323–0.601)	(0.393–0.684)	
p-value	0.778	0.031		0.594	0.608	
Software						
Az (SE)	0.492 (0.071)	0.650 (0.073)	0.115	0.602 (0.069)	0.602 (0.073)	1.00
95% CI	(0.353–0.632)	(0.508–0.792)		(0.466–0.739)	(0.459–0.746)	
p-value	0.915	0.045		0.149	0.170	
iPad						
Az (SE)	0.431 (0.070)	0.455 (0.077)	0.814	0.501 (0.071)	0.609 (0.073)	0.288
95% CI	(0.293–0.569)	(0.305–0.605)		(0.361–0.640)	(0.467–0.752)	
p-value	0.331	0.549		0.990	0.143	

Az, the highest area under the receiver operating characteristic curve.

increase the possibility of correct diagnosis. By using systems' own software, observers were able to scroll through different image sections which probably increased their diagnostic ability. User friendly software along with a high quality monitor is an important component of a CBCT system for the diagnosis of recurrent caries. However, we found highest Sp, positive-predictive value and negative-predictive value values for the software at the cost of Se. This phenomenon should be also taken into consideration when assessing CBCT images for recurrent caries detection under restorations.

Although we found higher Az values for medical monitor than for other display types, these differences were not statistically significant. Recently, the importance of mobile devices as work tools in dentistry has become greater. Tablets have recently come to be used in hospitals for different purposes. They provide access to acquired images where a regular computer display may not be available, and patient's information may be

Table 5 Sensitivity (Se), specificity (Spe), positive-predictive value (PPV) and negative-predictive value (NPV) for each observer and their first reading

Display type	*First reading Se*	*First reading Spe*	*First reading PPV*	*First reading NPV*
Observer 1				
Toshiba	0.790	0.258	0.505	0.567
iPhone	0.710	0.379	0.518	0.581
Vestel	0.597	0.409	0.487	0.519
Medical	0.742	0.409	0.541	0.628
Software	0.419	0.788	0.650	0.591
iPad	0.306	0.727	0.514	0.527
MacBook	0.677	0.424	0.525	0.583
Observer 2				
Toshiba	0.710	0.348	0.518	0.605
iPhone	0.774	0.242	0.487	0.533
Vestel	0.500	0.364	0.492	0.571
Medical	0.758	0.227	0.500	0.577
Software	0.677	0.485	0.553	0.627
iPad	0.677	0.455	0.538	0.600
MacBook	0.597	0.409	0.487	0.529

accessed remotely by connection to a picture archiving and communication system. A study[9] compared the detection of interproximal caries in digital intraoral images presented in a 24-inch LCD monitor and iPad 2 (Apple Inc.). For iPad 2 and the LCD monitor, Az values were 0.87 and 0.86, respectively. For the tablet, the mean values of Se, Sp and accuracy were 0.75, 0.86 and 0.83, respectively. For the LCD monitor, these values were 0.77, 0.82 and 0.80, respectively. Authors concluded that the second generation iPad can effectively display images comparably to the evaluated LCD monitor for interproximal caries detection under bright light conditions. Furthermore, image size did not affect the ability to identify dental caries on the iPad 2 compared with the 24-inch LCD monitor.[9] These findings are similar to ours in terms of display type size. In our study, the monitor size ranged between 5.5 and 32 inches among different display types; however, no significant effect of monitor size was found for the different display types. Generally, higher Az values obtained in the mentioned study compared with ours were probably due to the absence of restorations and CBCT artefacts. In general, we found poor and moderate agreements. It is generally accepted that the diagnosis of recurrent caries lacks consistency for observers,[14–17] and the diagnostic variations among clinicians are great.[18] Authors compared observer performance in the detection of anatomical structures and pathology in panoramic radiographs using an uncalibrated consumer-grade display and a tablet (3G iPad; Apple Inc.) under suboptimal lighting conditions (bright lighting) and a 6-MP display under dim lighting. The type of display did not significantly affect the performance of the more experienced observer.[12] This finding was analogous to our study in which we obtained no statistical difference according to the type of display for the two experienced and calibrated observers.

In the present study, we utilized Black classification as the standard method of cavity preparation and classification. Obviously, Black classification has been abandoned in the preparation of restorations nowadays. Our methodology is substantiated by the fact that a huge number of clinicians still use this classification all around the world, and there are a number of old restorations with recurrent caries.

In the present study, composite restorations were used as non–radio-opaque restorations, whereas amalgam restorations were used as radio-opaque restorations. Comparison between radio-opaque and non–radio-opaque restorations was considered useful in terms of assessing the effects of beam-hardening artefacts on the detection ability of observers for recurrent caries. Metal artefacts, which are seen as dark and light streaks on tomographic images, can seriously degrade the visual quality and interpretability of CBCT images. When visibility of recurrent caries under two different restorative materials was taken into consideration, we found higher Az values for composite restorations than for amalgam restorations. It is accepted that image degradation increases with the number of metal restorations in the jaws, whereas small voxel size, limited beam and true alignment of X-ray beam decreases image degradation.[19] In the present study, we could not show any difference between different voxel sizes used, and therefore, we decided to make the calculations only for 0.200 mm^3 voxel size at 100×90 mm FOV which is a common setting utilized for most dental diagnostic purposes. We also presumed that beam-hardening and scatter artefacts from amalgam restorations would limit the diagnostic ability of CBCT for recurrent caries detection. We found relatively fair detection rates for CBCT images specifically for amalgam restorations. Observers frequently confused caries and beam-hardening artefacts and *vice versa*.

A pervious study found no difference between composite and amalgam restoration when detecting secondary caries by using the same CBCT unit used in the present study. This might be due to usage of artificial caries lesions created by round burs which were easy to detect in the mentioned study.[20]

Authors evaluated the diagnostic performance of a storage phosphor plate system Digora® Optime (Soredex, Helsinki, Finland) with two types of LCD monitors in the detection of artificial caries when compared with Ultraspeed (D), Ektaspeed Plus (E) and Insight (F) radiographic films.[21] Digital images were scored on a LCD computer monitor (170S; Philips, Amsterdam, Netherlands) and a medical monitor—3-megapixel monochrome display (ME355i2; Totoku, Tokyo, Japan). Storage phosphor images with the medical monitor demonstrated higher mean Az values (0.70 ± 0.08) than digital images with the computer monitor and conventional films. Storage phosphor images with the medical monitor presented the highest scores: 0.97, 0.90 and 0.94 for each observer, respectively.[21] We also found higher Az values for medical monitors when compared with other display types without statistical significance. The differences between the different display types were attributed to differences between LCD monitors in terms of resolution, contrast ratio and luminance. Another study[22] also assessed the influence of the display monitor on observer performance. Artificial enamel lesions were created in 40 extracted teeth, and their radiographic images were viewed on the following monitors: (1) AlphaScan 711 (Sampo Corp., Taoyuan City, Taiwan); (2) Multiscan 17 Se II (Sony Electronics Inc., Tokyo, Japan); (3) DS 2000 (Clinton Electronics Corp., Lores Park, IL); and (4) Latitude CP Laptop (Dell Computer Corp., Round Rock, TX). Mean receiver operating characteristic curve areas ranged from 0.8728 for the Sampo monitor to 0.8395 for the Sony monitor. No significant difference was found between monitors suggesting that observer performance was independent of the visual characteristics of the display monitor. Further research is essential to compare the diagnostic ability of newly developed monitors with various technical specifications.

Authors recommended the use of hydroxyethyl cellulose for creating artificial caries-like lesions.[23] Also,

some studies used standard red wax under restorations in order to simulate small artificial recurrent caries.[3,24] Due to their sharp margins, artificial caries lesions are easier to diagnose when compared with real caries lesions and their appearance may not reflect the real clinical conditions. Therefore, in the present study, we used real carious lesions under restorations which were clinically, radiographically and histologically validated.

Human eye and contrast resolution is important in the detection of carious lesions. Experienced observers can differentiate approximately 150–170 shades of grey. In the present study, the two observers had almost the same level of experience in assessing caries and CBCT images. Low ambient light level of the evaluation room is another important factor which was proven to enhance observer performance in the detection of caries. However, almost always high ambient light level is present in routine dental clinical environment.[25,26] Authors claimed that the ability to detect carious lesions by experienced clinicians can be enhanced by hooding laptop displays in bright clinical environments.[25] In a previous study,[26] seven observers evaluated teeth for proximal carious lesions on standardized intraoral digital radiographs using three setups as follows: (1) precalibrated monitor for high ambient light (>1000 lux), (2) precalibrated monitor for low ambient light (<50 lux) and (3) Barten calibration (digital imaging and communication in medicine) on the monitor in dimmed ambient light (<50 lux). Authors found no difference in diagnostic accuracy for the detection of any type of proximal carious lesions between the different calibration modes of the monitor according to different ambient light levels. Authors concluded that monitor calibration according to ambient light level eliminates the negative effects of ambient light in detection of carious lesions in digital radiographs.[26] In the present study, ambient light was not an issue, as we assessed all types of images under dimmed light and no calibration was applied to display modes prior to viewing sessions.

The marginal gap between the restoration and dentine is thought to be the main reason for recurrent caries' development.[27] However, the existence of a clinical marginal defect alone is not a reason to replace a restoration, since not all the defective margins cause recurrent caries under restorations.[27] A study found that approximately 14% of the defective restorations were associated with radiographic recurrent caries compared with 5% for the intact restorations.[28] In addition, stained composite margins and ditched amalgam margins are not necessarily signs of decay, although they indicate a greater risk.[29,30] In light of these findings, radiographic diagnosis of caries under restorations is an important aid to clinical examination.

Unlike intraoral images, by using available CBCT images, it is possible to view restorations and carious lesions in axial, coronal and cross-sectional views. However, it must be taken into consideration that patients receive higher radiation doses with CBCT than with intraoral and panoramic radiography.[31] Although radiation exposure was not an issue for this *ex vivo* research, we used CBCT with medium FOV and 0.2 mm voxel size, as they are the most preferred settings for most diagnostic tasks. Our findings may not apply to CBCT units and images taken with different settings.

Conclusion

Our study revealed generally rather low Az values as well as a low interrater agreement. This may be attributed to the fact that CBCT is not an appropriate technique for assessment of (recurrent) caries. Within the limitations of this study, higher Az values were observed with medical monitors when used with dedicated software than with other display types, which performed similarly in the diagnosis of recurrent caries under restorations. In addition, observers performed better in detection of recurrent caries when assessing composite restorations than when assessing amalgams.

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