©Operative Dentistry, 2013, **38-2,** 197-207

Visibility of Artificial Buccal Recurrent Caries Under Restorations Using Different Radiographic Techniques

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Clinical Relevance

Considering the difficulties in detecting buccal recurrent caries under restorations due to the compression of structures in intraoral radiography and occurrence of metal artifacts in cone beam computed tomography (CBCT), it is clinically useful to assess the performance of intraoral film and digital radiography and two different CBCT systems in terms of the visibility of artificial buccal secondary caries lesions under various restorative materials.

SUMMARY

The aim of the present study was to assess intraoral images and two cone beam computed tomography (CBCT) systems for detection of artificial buccal recurrent caries under restorations. Class V cavities were made for composite (30 teeth) and amalgam (30 teeth). Full restorations with thermoplastic polymer (30 teeth) and nickel-chromium metal crown (30 teeth) were constructed. In 60 teeth, artificial buccal recurrent caries were simulated; 60 other teeth served as controls. Intraoral film, intraoral digital, Veraviewepocs 3D, and Kodak 9000 images were scored twice. κ Coefficients were calculated and Az values were compared using *Z*-tests, with a significance level of α=0.05. Higher interobserver agreement was obtained from the CBCT images compared with the intraoral images. The Az values of both readings of all three observers were highest for the Veraviewepocs 3D followed by Kodak 9000 except for the second reading of the third observer. CBCT outperformed intraoral radiography in detection of artificial buccal recurrent caries under restorations.

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DOI: 10.2341/12-158-L

INTRODUCTION

Development of recurrent caries under different types of restorations is considered a major cause of restorative failure and replacement. It is important to diagnose early lesions in order to prevent severe destruction of hard tissue and to enhance the prognosis for a successful treatment outcome.[1–3] Radiographic detection is the most useful method to diagnose recurrent caries adjacent to restorations in conjunction with clinical examination. Intraoral film and digital radiography are commonly available methods in routine clinical dentistry. Conventional intraoral film consists of silver halide crystals in order to produce analog images. On the other hand, digital intraoral systems include a solid state silicon chip or a photostimulable phosphor plate (PSP). Solid state detectors use a scintillator layer to convert x-rays to light and include a charge-coupled device or a complementary metal oxide semiconductor.[4–7] PSPs absorb and store energy from x-rays. This energy is then released as phosphorescent when stimulated by another light of an appropriate wavelength.[8]

Regardless of the intraoral system used, the two-dimensional (2D) nature of the images limits the information that can be obtained, and their diagnostic value is dependent upon beam angulation, superimposition of anatomical structures, and patient-related factors.[9] Due to their 2D nature, intraoral techniques may fail to provide enough information in certain cases.[4–9] For example, buccal recurrent caries lesions under restorations are difficult to detect in radiographic examination. Radiopacity, which is greater in amalgam restorations than in enamel, can interfere with the detection of lesions in the lingual and buccal areas.[10]

Introduction of cone beam computed tomography (CBCT) enabled dentists to visualize teeth in axial, coronal, and sagittal views with a reduced radiation dose compared with medical CT. CBCT uses a cone-shaped x-ray beam centered on a 2D sensor to scan a 180°-360° rotation around the patient's head to acquire a full three-dimensional (3D) volume of data.[11] CBCT systems offer different sensor types, fields of view (FOV), and exposure settings. However, beam hardening and metal artifacts that occur in CBCT images are thought to be a limiting factor in detection of recurrent caries under restorations.[12,13] Although CBCT eliminates many disadvantages of intraoral radiography, it must be taken into consideration that patients receive higher radiation doses compared with intraoral and panoramic radiography.[14,15] Therefore, available CBCT images obtained for different purposes should be used only if conventional methods are not useful for diagnostic accuracy.

Considering the difficulties in detection of buccal recurrent caries under restorations due to the compression of structures in intraoral radiography and occurrence of metal artifacts in CBCT, the goal of this *ex vivo* study was to assess the performance of intraoral film and digital radiography and two different CBCT systems for the visibility of artificial buccal recurrent caries lesions under various restorative materials. Our null hypothesis was that there was no difference between CBCT and intraoral radiography systems for detection of artificial buccal recurrent caries lesions under various restorative materials.

MATERIALS AND METHODS

A total of 120 caries-free teeth (mandibular premolars and molars) extracted for periodontal and orthodontic reasons were used. Teeth of people who gave informed consent to donate their teeth for research and teaching were obtained from our hospital collection.

Preparation of Specimens

In 60 teeth, Black Class V cavities were made in the middle third of buccal surfaces for composite (Valux Plus, 3M ESPE, St Paul, MN, USA; 30 teeth) and amalgam restorations (Cavex, Haarlem, Netherlands; 30 teeth). In the remaining 60 teeth, chamfer margin preparations were made and full restoration with a thermoplastic polymer (Meliodent, Heraeus Kulzer, Hanau, Germany; 30 teeth) and full nickel-chromium (Ni-Cr) metal crown (30 teeth) was completed. Artificial buccal recurrent caries were simulated with the aid of a 1-mm-diameter carbide bur, sealed with 1-mm-diameter red wax under the restorations on the buccal shoulder of 30 teeth with chamfer margin preparations and on the buccal shoulder of 30 teeth with buccal Black Class V cavities. Another 60 teeth with restorations were left without simulated caries lesions. Distribution of an equal number of teeth with and without buccal caries for all types of restorations was ensured (15 teeth with caries and 15 teeth without caries for each type of restoration).

Image Acquisition

All teeth were randomly placed in the alveolar sockets of a dry human mandible in groups of eight (two premolars and two molars on left and right

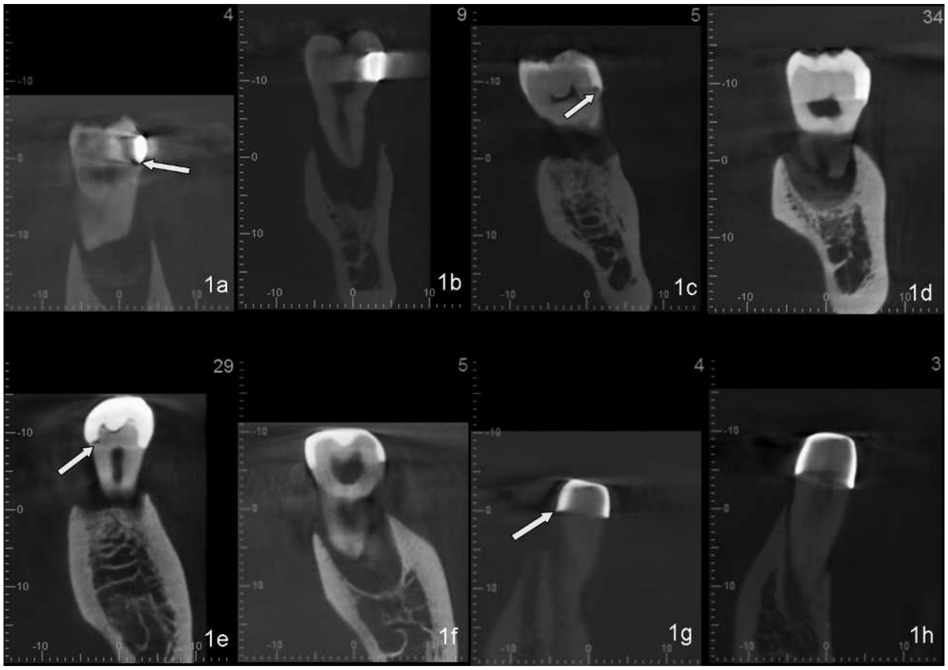

Figure 1. *Cross-sectional CBCT images obtained by Veraviewepocs 3D (Morita), 40 × 40 mm FOV (0.125-mm^3 voxel size). (a): Amalgam restoration with buccal recurrent caries. (b): Amalgam restoration without buccal recurrent caries. (c): Composite restoration with buccal recurrent caries. (d): Composite restoration without buccal recurrent caries. (e): Acrylic restoration with buccal recurrent caries. (f): Acrylic restoration without buccal recurrent caries. (g): Metal restoration with buccal recurrent caries. (h): Metal restoration without buccal recurrent caries.*

hemimandibles), and a 2-cm-thick plastic glove filled with distilled water was placed around the dry mandible in order to simulate soft tissue. Thereafter, teeth were imaged with intraoral conventional radiography, intraoral digital image receptors and two different CBCT units. Intraoral conventional radiographies and intraoral digital images were exposed ortho-radially with a Trophy Trex x-ray unit (Croissy, Beaubourg, France) operated at 65 kVp and 8 mA with a standardized paralleling technique and a focus-receptor distance of 20 cm. Repeated exposures after individual adjustment of the jaw/beam for each tooth were performed under reproducible conditions. Intraoral conventional radiographs were taken with Kodak Insight Film (size 2, E/F sensitivity, Eastman Kodak Co, Rochester, NY, USA) and an exposure time of 0.40 seconds. Films were automatically processed on the same day with fresh chemicals (Hacettepe, Ankara, Turkey) using an Extra-x Velopex (Medivance Instruments Ltd, London, England) in accordance with the manufacturer's instructions. Digital images were recorded using a Digora Optime (Soredex, Tuusula, Finland) PSP digital intraoral system, which includes a feature that automatically erases residual image signals. Image recording was set at a 40-μm pixel size, 14-bit grayscale, 12.5 line pairs per millimeter (lp/mm) spatial resolution and an image-exposure time of 0.20 second. A size 2 imaging plate was used, and the exposed phosphor plates were scanned immediately after exposure. Images of the teeth were obtained from two different CBCT units: 1) Veraviewepocs 3D model X550 (J Morita Mfg Corp, Kyoto, Japan) with a flat-panel detector offering digital 3D, panoramic, and cephalometric imaging options. With the Veraviewepocs 3D system, images were obtained at 60–90 kVp, 3 mA, and an exposure time of 9.4 seconds with a 40 × 40-mm FOV (0.125-mm^3 voxel size). 2) With the Kodak 9000 Extra-oral imaging system (Eastman Kodak), images were obtained at 60 kVp, 3 mA, and an exposure time of 13.2 seconds with an 50 × 37-mm FOV (76×76×76-μm voxel size isotropic voxel). Axial scans and multi-planar reconstructions were obtained, and volumetric data were reconstructed using the systems' software programs to provide serial cross-sectional views. A total of four image sets were obtained: 1) Veraviewepocs 3D (Morita), 40 × 40 mm FOV (0.125-mm^3 voxel size); 2) Kodak 9000, 50 × 37 mm FOV (76×76×76-μm voxel size); 3) intraoral digital images (Digora Optime PSP, Soredex); and 4) intraoral conventional film images (Kodak Insight Film). Figures 1 and 2 show examples of cross-sectional images obtained by Veraviewepocs 3D and Kodak 9000, respectively. Buccal recurrent caries–like lesions shown by arrows can be detected under each restoration. Figure 3 shows examples of intra-

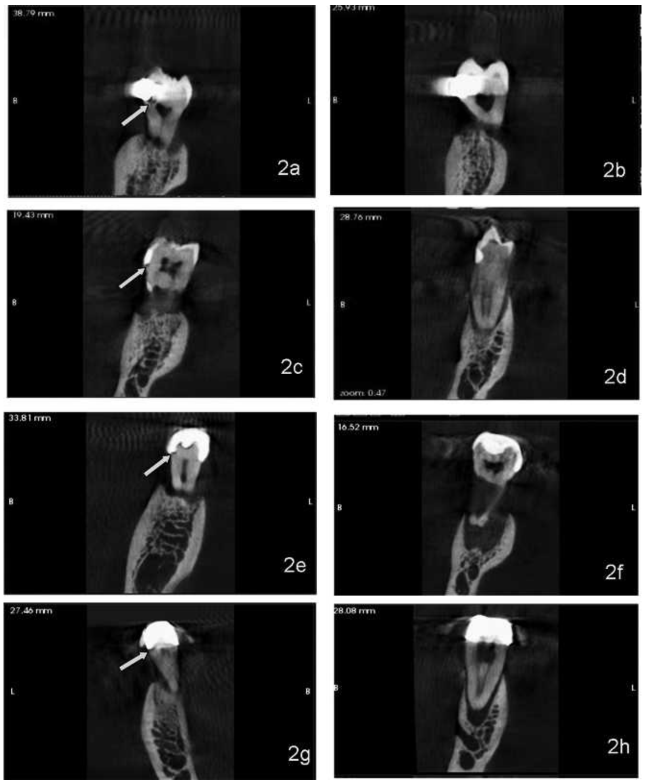

Figure 2. *Cross-sectional CBCT images obtained by Kodak 9000, 50 × 37 mm FOV (76×76×76-μm voxel size). (a): Amalgam restoration with buccal recurrent caries. (b): Amalgam restoration without buccal recurrent caries. (c): Composite restoration with buccal recurrent caries. (d): Composite restoration without buccal recurrent caries. (e): Acrylic restoration with buccal recurrent caries. (f): Acrylic restoration without buccal recurrent caries. (g): Metal restoration with buccal recurrent caries. (h): Metal restoration without buccal recurrent caries.*

oral images obtained by Digora Optime PSP (Soredex). Buccal recurrent caries–like lesions shown by arrows can barely be detected under each restoration. For all four methods, the exposure parameters used for image acquisition were based on pilot studies to ensure optimal image quality with good visibility of the pulpal root canal, enamel, and dentin.

Image Interpretation

A specific calibration session using 10 images was conducted prior to the study. Image sets were viewed separately by three calibrated and experienced observers (two dentomaxillofacial radiologists and a prosthodontist) in a dimly lit room. No time restriction was placed on the observers. Image sets were viewed at one-week intervals, and evaluations of each image set were repeated one week after the initial viewings. All radiographs were randomized within each imaging modality. All conventional intraoral images were evaluated using a light box and magnifier (2×). Digital intraoral and CBCT images were evaluated on a 22-inch LG Flatron monitor (LG, Seoul, Korea) set at a screen resolution of 1440 × 900 pixels and 32-bit color depth by using the systems' own software: DfW2.5 (Digora Optime, Soredex), i-Dixel (Veraviewepocs 3D, Morita), and Kodak Dental Imaging Software (Kodak 9000, Kodak). Built-in enhancement tools of the software were used if deemed necessary. Observers constructed cross-sectional images themselves. Cross-sectional images were not exported because by using the software, calibrated observers were able to identify buccal artificial lesions by scrolling through different cross-sectional images. One of the researchers who knew the study design and created artificial caries lesions guided viewing sessions by showing the observers which tooth in the arch would be scored. Also, the same researcher recorded the scores given by the observers. The buccal aspects of each restored tooth were randomly evaluated for the presence/absence of buccal caries 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 120 buccal surfaces of 120 teeth were assessed.

Statistical Analysis

Weighted κ coefficients were calculated to assess the intraobserver and interobserver agreement for each image set. κ Values were calculated to assess intraoberserver and interobserver agreement according to 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*. κ Values were calculated using the MedCalc statistical software (MedCalc Software, Mariakerke, Belgium). Scores obtained from intraoral film and two different CBCT images were compared with the gold standard using the receiver operating characteristic (ROC) analysis to evaluate the observers' ability to differentiate between teeth with and without buccal caries. The areas under the ROC curves (Az values) were calculated using SPSS 15.0 (SPSS Inc, Chicago, IL, USA), and the Az values for each image type, observer, and reading and restoration type were compared using Z-tests, with a significance level of α=0.05. Bonferroni adjustment was used to evaluate the statistically significance. Sensitivity (Se), specificity (Sp), positive predictive value (PPV), negative predictive value (NPV), and false positive ratio (FPR) for each observer and their two readings were also calculated for each restoration type.

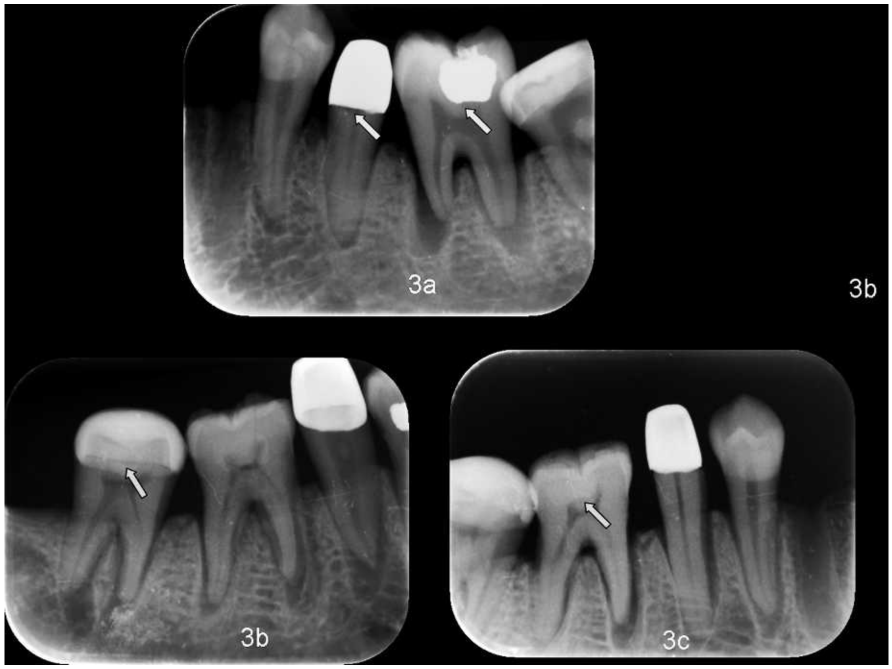

Figure 3. *Digital intraoral images obtained by Digora Optime PSP, (Soredex). (a): Digora Optime PSP image taken for the second premolar tooth. From left to right: first premolar without buccal recurrent caries under composite restoration, second premolar with buccal recurrent caries under metal restoration, and first molar with buccal recurrent caries under amalgam restoration. (b): Digora Optime PSP image taken for the first molar tooth. From left to right: second molar with buccal recurrent caries under acrylic restoration, first molar without buccal recurrent caries under composite restoration, and second premolar without buccal recurrent caries under metallic restoration. (c): Digora Optime PSP image taken for the first molar tooth. From left to right: first molar with buccal recurrent caries under composite restoration, second premolar without buccal recurrent caries under metallic restoration, and first premolar without buccal recurrent caries under composite restoration.*

RESULTS

Table 1 shows the intraobserver κ coefficients calculated for each observer by image type. Intraobserver κ coefficients ranged from 0.536-0.609 for the intraoral film (Kodak Insight), from 0.517-0.691 for the digital intraoral (Digora Optime), from 0.613-0.649 for the Veraviewepocs 3D, and from 0.582-0.628 for Kodak 9000 images, suggesting moderate and strong intraobserver agreement for observers 1 and 2 and strong intraobserver agreement for observer 3. Tables 2 and 3 show the interobserver κ coefficients for both the first and second readings by image type, respectively. Higher interobserver agreement was obtained from the CBCT images when compared with the intraoral images. Poor and moderate interobserver agreement was found for the first and second readings for the intraoral Kodak Insight film images (from 0.339-0.470) and for the digital intraoral Digora Optime images (from 0.337-0.522). In general, moderate interobserver agree-

Table 1: *Intraobserver Agreement Calculated for Each Observer by Image Type*

	Observer 1 Weighted κ–Se	Observer 2 Weighted κ–Se	Observer 3 Weighted κ–Se
Kodak Insight Film	0.583-0.058	0.536-0.074	0.609-0.062
Digora Optime	0.517-0.066	0.538-0.082	0.691-0.079
Veraviewepocs 3D (Morita)	0.647-0.079	0.613-0.092	0.649-0.086
Kodak 9000	0.590-0.078	0.582-0.082	0.628-0.085

Table 2: *Interobserver κ Coefficients Among Observers for the First Readings*

	Obs 1-Obs 2 Weighted κ–Se	Obs 1-Obs 3 Weighted κ–Se	Obs 2-Obs 3 Weighted κ–Se
Kodak Insight Film	0.339-0.069	0.355-0.052	0.363-0.054
Digora Optime	0.395-0.051	0.356-0.066	0.337-0.070
Veraviewepocs 3D (Morita)	0.603-0.069	0.536-0.068	0.545-0.069
Kodak 9000	0.458-0.069	0.617-0.069	0.466-0.076

Abbreviation: Obs, observer.

ment was found for the first and second readings for the Veraviewepocs 3D (from 0.465-0.603) and Kodak 9000 (from 0.458-0.617).

The areas under the ROC curves (Az values) for the different observers, readings, and image types were calculated and are given in Table 4. The Az values of both readings of all three observers were highest for the Veraviewepocs 3D followed by the Kodak 9000, except for the second reading of the third observer. Az values of the CBCT images were higher than those of the intraoral images. Se, Sp, PPV, NPV, and FPR for each observer and their two readings are presented in Table 5. Also, higher sensitivity values for CBCT systems compared with intraoral images were obtained.

Comparisons between modalities are given in Table 6. No differences ($p>0.05$) were found between the Az values of the Kodak Insight film and those of the digital intraoral Digora Optime images for all observers. Also, there was no statistically significant difference ($p>0.05$) between the two CBCT systems (Kodak 9000 and Veraviewepocs 3D). Statistically significant differences between Az values for the intraoral Kodak Insight film images and Veraviewepocs 3D images were found for both readings of observer 1 (first reading: $p=0.007$, second reading: $p=0.011$) and observer 2 (first reading: $p=0.003$, second reading: $p=0.023$). Statistically significant differences were also found between the Az values for the digital intraoral Digora Optime and Veraviewepocs 3D images for both readings of observer 1 (first reading: $p=0.001$, second reading: $p=0.027$), observer 2 (first reading: $p<0.001$, second reading: $p=0.001$), and observer 3 (first reading: $p=0.002$). There was only a significant difference for the second reading of observer 2 between Kodak 9000 and Kodak Insight film ($p=0.027$) and between Kodak 9000 and the digital intraoral Digora Optime system ($p<0.001$).

When visibility of buccal recurrent caries under four different restorative materials for each imaging modality was taken into consideration for all observers, no statistically significant difference ($p>0.05$) was found among different restorative materials for each imaging modality except for the comparison of composite and amalgam restorations

Table 3: *Interobserver κ Coefficients Among Observers for the Second Readings*

	Obs 1-Obs 2 Weighted κ–Se	Obs 1-Obs 3 Weighted κ–Se	Obs 2-Obs 3 Weighted κ–Se
Kodak Insight Film	0.470-0.051	0.428-0.064	0.438-0.053
Digora Optime	0.446-0.066	0.440-0.083	0.522-0.082
Veraviewepocs 3D (Morita)	0.465-0.078	0.494-0.082	0.486-0.094
Kodak 9000	0.509-0.078	0.521-0.088	0.525-0.081

Table 4: *Az Values, Their Standard Errors (SE), 95% Confidence Intervals (CI), and Significance Levels (*p*) for Each Observer*

	Observer 1		**Observer 2**		**Observer 3**	
	1st Reading	**2nd Reading**	**1st Reading**	**2nd Reading**	**1st Reading**	**2nd Reading**
Kodak Insight Film						
Az (SE)	0.597 (0.060)	0.592 (0.060)	0.575 (0.058)	0.524 (0.063)	0.647 (0.061)	0.558 (0.063)
95% CI	0.504- 0.685	0.499-0.680	0.484-0.757	0.431-0.616	0.555-0.732	0.465-0.648
p	0.063	0.663	0.003	0.041	0.113	0.427
Digora Optime						
Az (SE)	0.538 (0.064)	0.590 (0.062)	0.509 (0.064)	0.587 (0.062)	0.558 (0.063)	0.542 (0.060)
95% CI	0.426-0.647	0.478-0.697	0.397-0.619	0.474-0.693	0.445-0.666	0.530-0.744
p	0.266	0.246	0.849	0.383	0.485	0.034
Veraviewepocs 3D (Morita)						
Az (SE)	0.815 (0.048)	0.744 (0.056)	0.896 (0.036)	0.815 (0.048)	0.777 (0.052)	0.583 (0.065)
95% CI	0.711-0.895	0.631-0.836	0.805-0.954	0.710-0.894	0.667-0.864	0.465-0.694
p	$<$0.001	$<$0.001	$<$0.001	$<$0.001	$<$0.001	0.215
Kodak 9000						
Az (SE)	0.720 (0.058)	0.677 (0.061)	0.760 (0.062)	0.810 (0.049)	0.681 (0.060)	0.681 (0.060)
95% CI	0.606-0.816	0.561-0.780	0.643-0.764	0.704-0.890	0.564-0.782	0.565-0.783
p	0.001	0.008	0.017	$<$0.001	0.007	0.007

obtained from Veraviewepocs 3D images (observer 1; p=0.011 and observer 2; p=0.003).

DISCUSSION

To our knowledge, up until now, no previous study has compared CBCT and intraoral radiography in detecting buccal recurrent caries under different types of restorations. In the present study, composite restorations and thermoplastic polymer were used as nonradiopaque restorations, whereas amalgam and full crown were used as radiopaque restorations. Comparison between radiopaque and nonradiopaque restorations was considered useful in terms of assessing beam hardening and metal artifacts. Metal artifacts, which are seen as dark and light streaks on tomographic images, can seriously degrade the visual quality and interpretability of CBCT images. 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.[16] Although metal artifacts seen in CBCT images are claimed to be limiting factors in the diagnosis of caries under restorations, we found better Az values for CBCT images compared with intraoral images. This can be explained by the fact that with CBCT, it is possible to view teeth and related structures in axial, coronal, and cross-sectional views. Besides, in the present

Table 5: *Sensitivity (Se), Specificity (Sp), Positive Predictive Value (PPV), Negative Predictive Value (NPV), and False Positive Ratio (FPR) for Each Observer and Their Two Readings*

	1st Reading Se	2nd Reading Se	1st Reading Sp	2nd Reading Sp	1st Reading PPV	2nd Reading PPV	1st Reading NPV	2nd Reading NPV	1st Reading FPR	2nd Reading FPR
Observer 1										
Kodak Insight Film	0.588	0.265	0.605	0.814	0.602	0.587	0.598	0.526	0.395	0.186
Digora Optime	0.676	0.765	0.209	0.372	0.458	0.546	0.388	0.606	0.791	0.628
Veraviewepocs 3D (Morita)	0.853	0.853	0.698	0.581	0.739	0.669	0.823	0.794	0.302	0.419
Kodak 9000	0.853	0.647	0.535	0.721	0.648	0.698	0.782	0.672	0.465	0.279
Observer 2										
Kodak Insight Film	0.588	0.421	0.767	0.814	0.719	0.688	0.652	0.582	0.233	0.186
Digora Optime	0.382	0.421	0.605	0.698	0.493	0.583	0.495	0.546	0.395	0.302
Veraviewepocs 3D (Morita)	0.912	0.882	0.698	0.647	0.752	0.715	0.886	0.844	0.302	0.353
Kodak 9000	0.735	0.912	0.581	0.674	0.637	0.733	0.690	0.881	0.419	0.326
Observer 3										
Kodak Insight Film	0.235	0.206	0.930	0.953	0.774	0.807	0.550	0.547	0.07	0.047
Digora Optime	0.441	0.529	0.698	0.837	0.594	0.768	0.555	0.641	0.302	0.163
Veraviewepocs 3D (Morita)	0.765	0.676	0.721	0.535	0.733	0.591	0.757	0.623	0.279	0.465
Kodak 9000	0.735	0.647	0.558	0.698	0.627	0.684	0.682	0.666	0.442	0.302

study, CBCT units with limited FOVs and small voxel sizes were chosen that could reduce metal artifacts. With the Veraviewepocs 3D, slightly higher values were found compared with the Kodak 9000. This difference, although without significance, may be due to sensor, software, or hardware specifications. In our notion, digital intraoral and CBCT systems must be evaluated by using their dedicated software as in the present study because software is probably the most important component of the digital systems. Software capability can not be detached from digital radiographic imaging systems. In addition, when the visibility of buccal recurrent caries under four different restorative materials for each imaging modality was taken into consideration for all observers, no statistically significant difference ($p>0.05$) was found.A study[17] found no difference between intraoral film (Ekstraspeed Plus, Eastman Kodak) and direct digital radiography (Sidexis, Siemens, Bensheim, Germany) in the detection of small artificial lesions induced by a demineralization buffer gel system at the crown margin, similar to our findings. Authors recommended the use of hydroxyethyl cellulose for creating artificial caries lesions. Also, artificial cementum and dentin lesions were slightly easier to diagnose than enamel lesions. Authors concluded that radiography was not considered a reproducible and safe method for characterization of the demineralization process localized at the crown margin—especially in enamel—due to the

Table 6: *Modalities Compared by Using Z-Test, With a Significance Level of α = 0.05 (Statistically Significant* p *Values Are Written in Bold*)

	Obs 1		Obs 2		Obs 3	
	1st Reading, *p*-Value	2nd Reading, *p*-Value	1st Reading, *p*-Value	2nd Reading, *p*-Value	1st Reading, *p*-Value	2nd Reading, *p*-Value
Kodak Insight Film-Digora Optime	0.273	0.869	0.225	0.072	0.210	0.479
Kodak Insight Film- Veraviewepocs 3D (Morita)	***0.007***	**0.011**	**0.003**	**0.023**	0.065	0.978
Kodak Insight Film- Kodak 9000	0.254	0.077	0.594	**0.027**	0.370	0.277
Digora Optime- Veraviewepocs 3D (Morita)	**0.001**	**0.027**	<**0.001**	**0.001**	**0.002**	0.426
Digora Optime- Kodak 9000	0.070	0.215	0.085	<**0.001**	0.056	0.818
Kodak 9000- Veraviewepocs 3D (Morita)	0.162	0.405	0.301	0.929	0.287	0.304

Abbreviation: Obs, observer.

low interexaminer agreement among three calibrated observers. Therefore, the importance of a thorough visual and tactile examination was emphasized.[17] In the present study, a standard 1-mm-diameter red wax was used under restorations in order to simulate small buccal recurrent caries that are difficult to diagnose in routine clinical and radiographic examination. A similar method in an attempt to create artificial caries lesions was used in a previous study.[18] Standardization of artificial buccal caries lesions was thereby provided to some extent, because our aim was only to compare different radiographic techniques in detecting artificial lesions, instead of histological validation of caries. In the present study, higher Az values for CBCT images compared with intraoral images may be attributed to the sharp round margins of the defects; however, sharp-margined defects were imaged by all systems assessed.

Another study[19] found that a thorough clinical examination was more reliable than intraoral radiography in detecting recurrent interproximal caries at crown margins of full restorations. This may be due to the masking effect of full restorations and limited information gathered from intraoral radiography. On the other hand, for nonrestored teeth, radiographs often rendered evidence of caries lesions that were not diagnosed during the clinical examination.[19] However, findings of the mentioned study are debatable because only one observer clinically and radiographically evaluated teeth. Therefore, it is not possible to assess the reproducibility of the results. The present study only compared different radiographic systems in detecting artificial buccal recurrent caries under different restorations. Visual and clinical examination findings were not in the scope of the present research.

It has been postulated that the marginal gap between the restoration and dentin is the main reason for recurrent caries' development, despite the fact that even with highly sophisticated technology, there is always a marginal gap.[1] However, existence of a clinical marginal defect alone is not a reason to replace a restoration, given that not all defective margins cause recurrent caries under restorations. Of the 822 teeth with defective restorations in the total sample, 86% (709 of 822) were free of radiographic recurrent caries.[1] On the other hand, an increased likelihood of defective over intact restorations to display radiographic recurrent caries was found. Approximately 14% of the defective restorations were associated with radiographic recurrent caries, compared with 5% for the intact restorations.[20] Similarly, colors next to restorations are not always predictive of secondary caries. Stained composite margins and ditched amalgam margins are not necessarily signs of decay, although they indicate a greater risk.[21,22] In light of these findings, radiographic diagnosis of caries under restorations is an important aid to clinical examination.

It must be taken into consideration that patients receive higher radiation doses with CBCT compared with intraoral and panoramic radiography. Radiation doses from CBCT scans vary substantially among devices, FOVs, and other technical factors.[14,15] In view of concerns regarding radiation exposure, a smaller FOV results in a less effective dose and should be used for dental images, whereas a larger FOV should be restricted to cases in which a wider view is required.[23] Although radiation exposure was not an issue for this *ex vivo* research, we used CBCT with a limited FOV and small voxel sizes in order to assess teeth that could possibly increase the observer's ability to detect artificial buccal recurrent caries lesions under restorations. Values produced in the present study may not apply to CBCT images taken for other indications and with different settings.

CONCLUSION

Higher Az and sensitivity values were obtained with Veraviewepocs 3D and Kodak 9000 images compared with both intraoral images, which performed similarly in the diagnosis of artificial buccal recurrent caries under restorations. Available CBCT units and images can be useful in the diagnosis of buccal recurrent caries under restorations.

Acknowledgements

The authors are grateful to Dentistomo Dentomaxillofacial Imaging Center, Ankara, Turkey, for providing the Kodak 9000 unit and Ayrıntı Dentomaxillofacial Imaging Center, Ankara, Turkey, for providing the Veraviewepocs 3D unit used in the present study. Authors also thank our prosthodontic laboratory technician Mustafa Dikmen for his invaluable assistance during production of the crowns.

Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

(Accepted 13 June 2012)

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