Dentomaxillofacial Radiology (2012) 41, 450–459

http://dmfr.birjournals.org

RESEARCH

Proximal caries detection accuracy using intraoral bitewing radiography, extraoral bitewing radiography and panoramic radiography

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Objective: To compare proximal caries detection using intraoral bitewing, extraoral bitewing and panoramic radiography.
Methods: 80 extracted human premolar and molar teeth with and without proximal caries were used. Intraoral radiographs were taken with Kodak Insight film (Eastman Kodak Co., Rochester, NY) using the bitewing technique. Extraoral bitewing and panoramic images were obtained using a Planmeca Promax Digital Panoramic X-ray unit (Planmeca Inc., Helsinki, Finland). Images were evaluated by three observers twice. In total, 160 proximal surfaces were assessed. Intra- and interobserver kappa coefficients were calculated. Scores obtained from the three techniques were compared with the histological gold standard using receiver operating characteristic analysis. Az values for each image type, observer and reading were compared using *z*-tests, with a significance level of $\alpha = 0.05$.
Results: Kappa coefficients ranged from 0.883 to 0.963 for the intraoral bitewing, from 0.715 to 0.893 for the extraoral bitewing, and from 0.659 to 0.884 for the panoramic radiography. Interobserver agreements for the first and second readings for the intraoral bitewing images were between 0.717 and 0.780, the extraoral bitewing readings were between 0.569 and 0.707, and the panoramic images were between 0.477 and 0.740. The Az values for both readings of all three observers were highest for the intraoral bitewing. Az values for the extraoral bitewing images were higher than those of the panoramic images without statistical significance ($p > 0.05$).
Conclusion: Intraoral bitewing radiography was superior to extraoral bitewing and panoramic radiography in diagnosing proximal caries of premolar and molar teeth *ex vivo*. Similar intra- and interobserver coefficients were calculated for extraoral bitewing and panoramic radiography.
Dentomaxillofacial Radiology (2012) **41,** 450–459. doi: 10.1259/dmfr/30526171

Keywords: dental caries; radiography; panoramic radiography; bitewing radiography

Introduction

Interproximal caries lesions develop between the contacting proximal surfaces of two adjacent teeth. They first appear clinically as opaque regions and are caused by the loss of enamel translucency at the outermost enamel between the contact point and the top of the free gingival margin.[1,2] Owing to the large size of the proximal surfaces of posterior teeth and the subtle mineral loss initially presented by lesions on these surfaces, proximal caries on posterior teeth are usually difficult to identify on radiographs.[3,4] The early and accurate diagnosis of a proximal caries lesion enables immediate operative therapy, thereby preventing extensive tooth loss.[5] In order to increase the frequency of detection of proximal caries, authors have recommended

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Received 11 September 2011; revised 4 November 2011; accepted 9 November 2011

that visual and clinical examination be combined with bitewing radiography.[6] The recommendation for a posterior bitewing examination is given because it should capture an image of the crowns of the teeth from the distal surface of the canine to the distal surface of the most posterior erupted molar without overlapping.[7] Intraoral bitewing radiographs can be obtained by either film or digital sensors. Digital systems offer reduced patient exposure, time savings, image enhancement and ease of image storage, retrieval and transmission. However, film still remains the most available method of choice for bitewing examinations.[7]

There are also numerous film-based and digital panoramic systems used in routine clinical practice. Panoramic radiography is a simple method of obtaining images by the synchronous rotation of the X-ray source and image receptor around the stationary patient. However, there is a magnifying factor associated with image formation, owing to the distances between the radiation source, object and image receptor. In addition, projection geometry causes image distortion and marked overlapping of tooth crowns. Accurate preparation and positioning of patients are needed to ensure that the image distortion is decreased and image quality is not affected by ghost images. Broad coverage of both jaws and teeth is obtained without the anatomical detail available through intraoral radiography.[8,9]

It was found that panoramic radiography alone is inferior to bitewing radiography in the diagnosis of proximal caries.[10,11] Recently, Planmeca (Helsinki, Finland) introduced a new concept called "extraoral bitewing" that can be used with the panoramic unit's optional Bitewing program. Extraoral bitewing images are easier to obtain than intraoral bitewings, and they may help to image challenging patients who have difficulties with intraoral imaging. According to company specifications, this system uses the improved interproximal projection geometry while also showing periapical information, similar to an intraoral bitewing image pair.

To our knowledge, no study has looked at the ability of extraoral bitewing images obtained by panoramic radiography to detect proximal caries. Therefore, the aim of the present study was to compare observers' abilities to diagnose proximal caries when using intraoral bitewing radiography, panoramic radiography and extraoral bitewing radiography obtained using a panoramic unit.

Material and methods

Our study used 80 human premolar and molar teeth with and without proximal caries that were extracted for periodontal or orthodontic reasons. The teeth of people who had given informed consent to donate their teeth for research and teaching were obtained from our hospital collection. Teeth were cleaned of calculus and debris, disinfected in 2% sodium hypochlorite solution for 20 min and stored in distilled water. Then, all teeth were split into crown and root sections using a low-speed saw (Isomet; Buehler Ltd, Evanston, IL). Teeth crowns were embedded in wax blocks in groups of four (two maxillary or mandibular premolars and two maxillary or mandibular molars, depending on the region in which they would be placed) with the proximal surfaces in contact, and all blocks and teeth were numbered. Each block of crowns was placed in the appropriate alveolar sockets of a dry human skull with a dry mandible in groups of 4, making a total of 20 groups. Crown blocks were placed in the maxillary right and left premolar–molar sockets and mandibular right and left premolar–molar sockets. The skull had natural maxillary third molars in place along with mandibular incisors and a maxillary left canine. The mesial and distal aspects of the 4 teeth in each group were assessed for caries, for a total of 160 surfaces of 80 teeth using 3 different radiographic methods (1, intraoral bitewing; 2, extraoral bitewing; and 3, panoramic radiography).

Intraoral radiographs were taken with Kodak Insight Film (Size 2, E/F sensitivity) (Eastman Kodak Co., Rochester, NY). Radiographic films were held in place with special holders during exposure. Teeth were radiographed at a 10° positive vertical angle using the bitewing technique (film-holder with a bitewing) to produce mesiodistal views (Figure 1). All images were exposed for 0.4 s using an Evaluation X 3000-2C X-ray unit (New Life Radiology Srl; Grugliasco, Turin, Italy) operated at 70 kVp and 8 mA with a focus–receptor distance of 30 cm. Films were automatically processed on the same day with fresh chemicals using an Extra-x Velopex (Medivance Instruments Ltd, London, UK) in accordance with the manufacturer's instructions. Panoramic images were also obtained using a Planmeca Promax Digital Panoramic X-ray (Planmeca, Inc., Helsinki, Finland) with a charge-coupled device (CCD) detector operated at 54 kVp and 8 mA with a 16 s imaging time. In addition, extraoral bitewing images were taken with the unit's optional Bitewing program. According to company specifications, the extraoral bitewing option uses the improved interproximal projection geometry and, similar to an intraoral bitewing image pair, also shows periapical information. Panoramic and extraoral bitewing images were adjusted by density and contrast enhancement tools and then printed by a high-resolution Fuji Medical Imager Drypix 2000 (Fujifilm Corporation, Tokyo, Japan) on Dry Film DI-HT in their original format. Figures 2 and 3 show the extraoral bitewing and panoramic images, respectively, of the same teeth shown in Figure 1.

For all three methods, the image acquisition exposure parameters used were determined based on pilot studies to ensure optimal image quality with good visibility of the pulpal root canal, enamel and dentine. All images were evaluated separately by three calibrated observers using a light box and magnifier (×2) in a dimly lit room

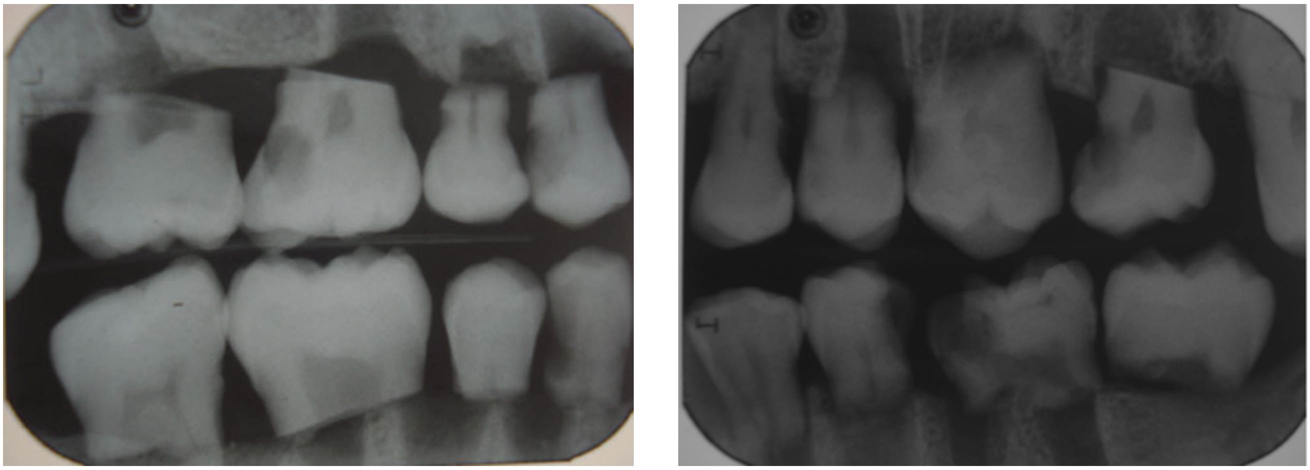

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Figure 1 Film radiographs obtained using Kodak Insight Film (Size 2, E/F sensitivity) (Eastman Kodak Co., Rochester, NY)

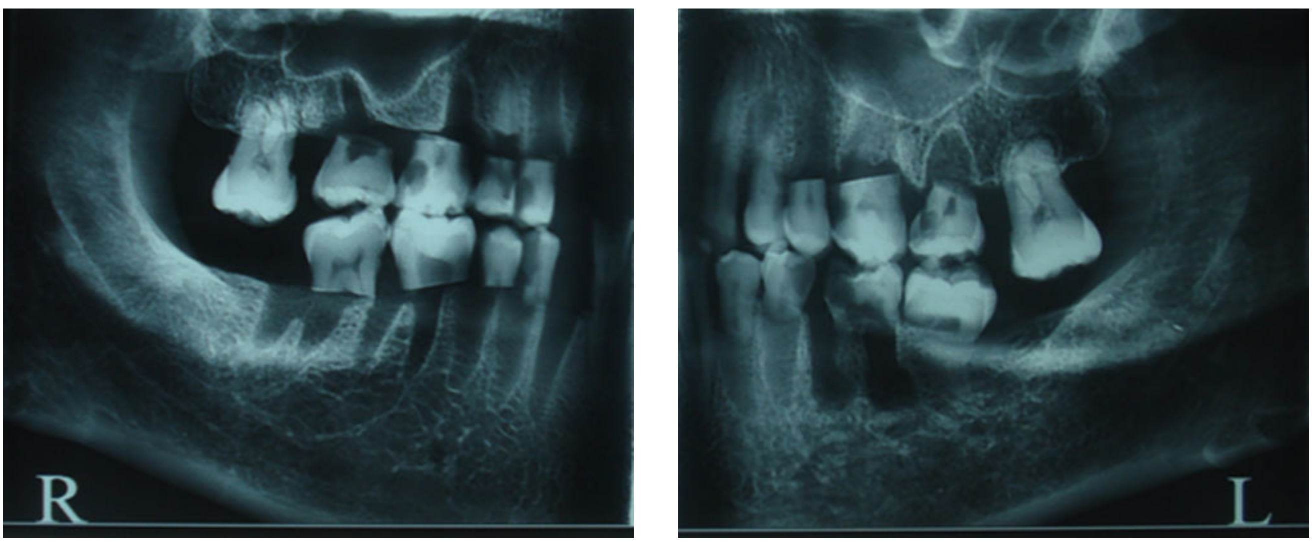

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Figure 2 Extraoral bitewing images taken with Planmeca Promax Digital Panoramic X-ray unit's (Planmeca Inc., Helsinki, Finland) Bitewing program

at random order. Observers were a doctorate student and two dentomaxillofacial radiologists with 10 and 15 years' experience. Image sets were viewed at 1 week intervals, and evaluations of each image set were repeated 1 week after the initial viewings. No time restriction was placed on the observers. The mesial and distal aspects of the four teeth in each group were randomly evaluated for the presence/absence of proximal 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 160 proximal surfaces of 80 teeth were assessed.

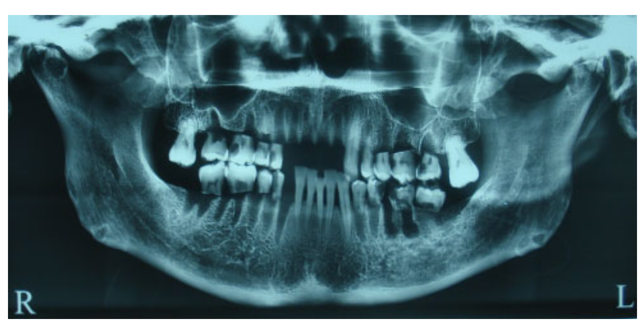

Figure 3 Panoramic images obtained using Planmeca Promax Digital Panoramic X-ray unit (Planmeca Inc., Helsinki, Finland)

Table 1 Intraobserver agreement calculated for each observer by image type

	Weighted kappa-SE		
	Observer 1	*Observer 2*	*Observer 3*
Intraoral bitewing	0.884–0.070	0.883–0.075	0.963–0.065
Extraoral bitewing	0.785–0.062	0.715–0.069	0.893–0.059
Panoramic	0.659–0.055	0.729–0.068	0.884–0.060

SE, standard error.

Histological validation of the status of caries was performed by serially sectioning each tooth mesiodistally in parallel to the long axis of the crown. Both sides of each section were examined under a stereomicroscope ($\times 10$) (Stemi 2000; Carl Zeiss, Jena, Germany) by one of the present study's authors, who recorded each tooth as either sound or as having a carious lesion, which was defined as a demineralized white or yellowish-brown discoloured area in the enamel or dentine. Histological sections were assessed using the following scale: 0, no caries lesion in the proximal surface; 1, proximal caries in enamel; 2, proximal caries extending to the enamel-dentine junction or in the outer half of the dentine; and 3, proximal caries in the inner half of the dentine (deep dentine). A histological examination of the 160 proximal tooth surfaces revealed no caries in 79 (49.4%) surfaces and caries in 81 (50.6%) surfaces. When analysed according to the level of caries, 23 (28.5%) surfaces were found to have enamel caries, 21 (25.9%) surfaces had dentine caries confined to the outer half of the dentine, and 37 (45.6%) surfaces had deep dentine caries extending to the inner half of the dentine.

Weighted kappa coefficients were calculated to assess the intra- and interobserver agreement for each image set. Kappa values were calculated to assess intra- 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. Kappa values were calculated using the MedCalc statistical software (MedCalc Software, Mariakerke, Belgium). Scores obtained from intraoral bitewing, extraoral bitewing and panoramic 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 proximal caries. The areas under the ROC curves (Az values) were calculated using the SPSS 15.0 (SPSS Inc., Chicago, IL) and the Az values for each image type, observer and reading were compared using z-tests, with a significance level of $\alpha = 0.05$. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) and false-positive ratio (FPR) for each observer were also calculated.

Results

Table 1 shows the intraobserver kappa coefficients calculated for each observer by image type. Higher intraobserver agreement was obtained from the intraoral bitewing images when compared with extraoral bitewing and panoramic images for all observers. Intraobserver kappa coefficients ranged from 0.883 to 0.963 for the intraoral bitewing images, from 0.715 to 0.893 for the extraoral bitewing images, and from 0.659 to 0.884 for the panoramic images, suggesting strong and excellent intraobserver agreement in general. Tables 2 and 3 show the interobserver kappa coefficients for both the first and second readings by image type, respectively. Higher interobserver agreement was obtained from the intraoral bitewing images when compared with the extraoral bitewing and panoramic images. Strong interobserver agreement was found for the first and second readings for the intraoral bitewing images (from 0.717 to 0.780). For the extraoral bitewing images, moderate and strong agreement was found for the first and second readings (from 0.569 to 0.707). In general, moderate interobserver agreement was found for the first and second readings for the panoramic images (from 0.477 to 0.740).

The 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 intraoral bitewing, and Az values of the extraoral bitewing images were higher than those of the panoramic images. Sensitivity, specificity, PPV, NPV and FPR for each observer and their two readings are presented in Table 5. Figures 4, 5 and 6 show the ROC curves for Observers 1, 2, and 3, respectively, for the second readings for each image type.

Comparisons between modalities are given in Table 6. No differences ($p > 0.05$) were found between

Table 2 Interobserver kappa coefficients among observers for the first readings

	Weighted kappa-SE		
	Observer 1–Observer 2	*Observer 1–Observer 3*	*Observer 2–Observer 3*
Intraoral bitewing	0.737–0.072	0.717–0.067	0.741–0.068
Extraoral bitewing	0.707–0.064	0.657–0.059	0.589–0.060
Panoramic	0.641–0.058	0.565–0.057	0.740–0.063

SE, standard error.

Table 3 Interobserver kappa coefficients among observers for the second readings

	Weighted kappa-SE		
	Observer 1–Observer 2	*Observer 1–Observer 3*	*Observer 2–Observer 3*
Intraoral bitewing	0.780–0.070	0.735–0.067	0.733–0.069
Extraoral bitewing	0.680–0.063	0.575–0.060	0.569–0.061
Panoramic	0.538–0.053	0.477–0.052	0.597–0.062

SE, standard error.

the Az values of the extraoral bitewing and those of the panoramic images for all observers. Statistically significant differences between Az values for the intraoral bitewing images and panoramic images were found for both readings of Observer 1 (first reading, $p = 0.012$; second reading, $p < 0.001$) and Observer 3 (first reading, $p = 0.037$; second reading, $p = 0.003$). Statistically significant differences were also found between the Az values for the intraoral bitewing and extraoral bitewing images for the second reading of Observer 1 ($p = 0.027$) and the second reading of Observer 3 ($p = 0.014$).

Discussion

To our knowledge, this study is the first to assess a new concept called "extraoral bitewing radiography" obtained by panoramic units. Through this new process, it is possible to obtain images similar to that of an intraoral bitewing image pair while also showing periapical information. This approach is claimed to be helpful especially for patients who have difficulties when obtaining intraoral bitewing images. The visibility of proximal caries in intraoral bitewing radiography may depend on various factors such as caries' depth, tooth position in jaw, angulation of the X-ray beam, superimposition of adjacent structures, artefacts and patient-related factors. Also, in panoramic radiography, shape and size of the dental arc and focal trough are important factors in assessing teeth and related structures. Superimpositions in the premolar region are an important drawback of panoramic radiography for detecting proximal caries. In the present study, crowns of different extracted teeth were placed in the alveolar sockets of a dry human skull and images were obtained. Therefore, it was not possible to produce a real dental arch and this could lead to superimpositions. On the other hand, images obtained without a soft-tissue equivalent might increase the observer's ability to detect caries in images obtained using all three methods.

It is recommended that a routine bitewing examination should be performed with only one film in each side of the mouth, and the film should be placed behind the premolars and the first and second molars, given that more than 90% of all radiographic caries lesions were found in those teeth.[12] Therefore, our study sample consisted of premolars and first and second molars, and only one film was used for each side of the dry skull.

Our results suggest that intraoral bitewing is the best method of choice in the diagnosis of proximal caries, considering the calculated Az values for all methods. With extraoral bitewing radiography, higher Az values were obtained than for panoramic; however, this was without statistical significance. We saw that superimpositions found in panoramic radiography were still present in extraoral radiography, which may explain higher false-positive ratios obtained by both systems than intraoral bitewings. In addition, in general, for all observers and readings, highest sensitivity, specificity, PPV and NPV were obtained by intraoral bitewing images followed by extraoral bitewing radiography.

Another study[10] compared panoramic and intraoral radiographic surveys in the evaluation of specific dental pathosis in air force personnel. The radiographs of 30 subjects were read singly and in various combinations: panoramic survey only; periapicals plus bitewings; panoramic survey plus bitewings; and panoramic

Table 4 Az values, their standard errors, 95% confidence intervals (CIs) and significance levels (p-value) for each observer

	Observer 1		*Observer 2*		*Observer 3*	
	First reading	*Second reading*	*First reading*	*Second reading*	*First reading*	*Second reading*
Intraoral bitewing						
Az-s.e.	0.918–0.024	0.929–0.023	0.819–0.035	0.832–0.034	0.861–0.030	0.877–0.028
95% CI	0.871–0.966	0.884–0.974	0.750–0.888	0.765–0.899	0.801–0.920	0.821–0.933
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Extraoral bitewing						
Az-s.e.	0.855–0.030	0.844–0.031	0.802–0.036	0.790–0.037	0.794–0.036	0.759–0.039
95% CI	0.796–0.914	0.782–0.906	0.731–0.873	0.717–0.862	0.724–0.864	0.683–0.835
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Panoramic						
Az-s.e.	0.816–0.033	0.753–0.039	0.768–0.038	0.763–0.038	0.760–0.038	0.729–0.041
95% CI	0.751–0.881	0.677–0.829	0.693–0.843	0.687–0.838	0.685–0.835	0.649–0.810
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Az, area under the receiver operating characteristic curve; SE, standard error.

survey plus periapicals plus bitewings. The panoramic survey by itself was shown to have the lowest correlation with the consensus radiographic standard when basic military trainees with generalized dental pathosis were evaluated.[10] Authors compared the diagnostic accuracy of panoramic and intraoral radiographic surveys in the diagnosis of proximal caries according to the different dental regions (maxillary and mandibular incisor, canine, premolar and molar).[11] The full mouth series was found to be the most efficient method in the diagnosis of caries for incisor and canine teeth. However, the full mouth series and the combination of panoramic plus bitewings had similar diagnostic accuracy for premolar and molar teeth. A panoramic survey alone was not sufficient for the diagnosis of proximal caries for the entire dentition. The combination of panoramic plus bitewing plus anterior periapical survey exhibited a diagnostic accuracy for proximal caries that was comparable with the full mouth series.[11] In the present study, we did not assess the combination of different methods because we were mainly interested in the diagnostic ability of each method separately. Specifically, the ability of observers to detect proximal caries with extraoral bitewing images compared with traditional methods was our main focus of interest. Also, we used only premolar and molar teeth because it was not possible to obtain extraoral bitewing images of incisors and canines. Our study also found panoramic imaging to be the least effective method in evaluating proximal caries.

The diagnostic accuracy of conventional bitewing, periapical radiographs, and unfiltered and filtered digital panoramic images were evaluated for proximal carious lesions in posterior teeth.[13] The digital panoramic unit used was the Orthoralix 9200 DDE machine (Gendex Dental Systems, Milan, Italy). Digital panoramic images were also assessed with the use of sharpened, smooth and embossed filters apart from unfiltered images. Intra- and interobserver agreement levels were found to be almost perfect compared with the readings of three experienced observers, similar to our results. The authors concluded that the diagnostic accuracy of the digital panoramic images was lower than conventional film-based bitewing and periapical radiographs, but it did have a value in the detection of posterior proximal carious lesions, especially for mandibular molar teeth. In addition, the embossed filter of panoramic images was found to have some value for the detection of proximal carious lesion in posterior teeth. However, one drawback of the mentioned study is that no histological validation of teeth could be performed.[13] The digital enhancements obtained by the different filters (inversion, histogram averaging, high pass, mean value, spreading of grey values) of the digitized radiographic images failed to result in any statistically significant improvement in the reproducibility or validity of interproximal caries depth measurements.[14]

Although we obtained extraoral bitewing and panoramic images by a digital system, proximal carious lesions were evaluated from panoramic film images, as

Table 5 Sensitivity, specificity, positive predictive value, negative predictive value and false-positive ratio for each observer and their two readings

	First reading	*Second reading*	*First reading*	*Second reading*	*First reading*	*Second reading*	*First reading*	*Second reading*	*First reading*	*Second reading*
	Se	*Se*	*Sp*	*Sp*	*PPV*	*PPV*	*NPV*	*NPV*	*FPR*	*FPR*
Observer 1										
Intraoral bitewing	0.80	0.84	0.97	0.99	0.97	0.99	0.82	0.86	0.03	0.01
Extraoral bitewing	0.64	0.69	0.91	0.89	0.88	0.87	0.71	0.73	0.09	0.11
Panoramic	0.64	0.59	0.85	0.81	0.82	0.76	0.69	0.67	0.15	0.19
Observer 2										
Intraoral bitewing	0.69	0.70	0.94	0.96	0.93	0.95	0.74	0.75	0.06	0.04
Extraoral bitewing	0.70	0.60	0.87	0.94	0.85	0.91	0.74	0.69	0.13	0.06
Panoramic	0.65	0.54	0.81	0.92	0.78	0.88	0.69	0.66	0.19	0.08
Observer 3										
Intraoral bitewing	0.69	0.69	0.96	0.96	0.95	0.95	0.75	0.75	0.04	0.04
Extraoral bitewing	0.57	0.57	0.90	0.90	0.86	0.86	0.67	0.67	0.10	0.10
Panoramic	0.51	0.51	0.95	0.96	0.91	0.93	0.65	0.65	0.05	0.04

FPR, false-positive ratio, Se, sensitivity, sp, specificity, PPV, positive predictive value; NPV, negative predictive value.

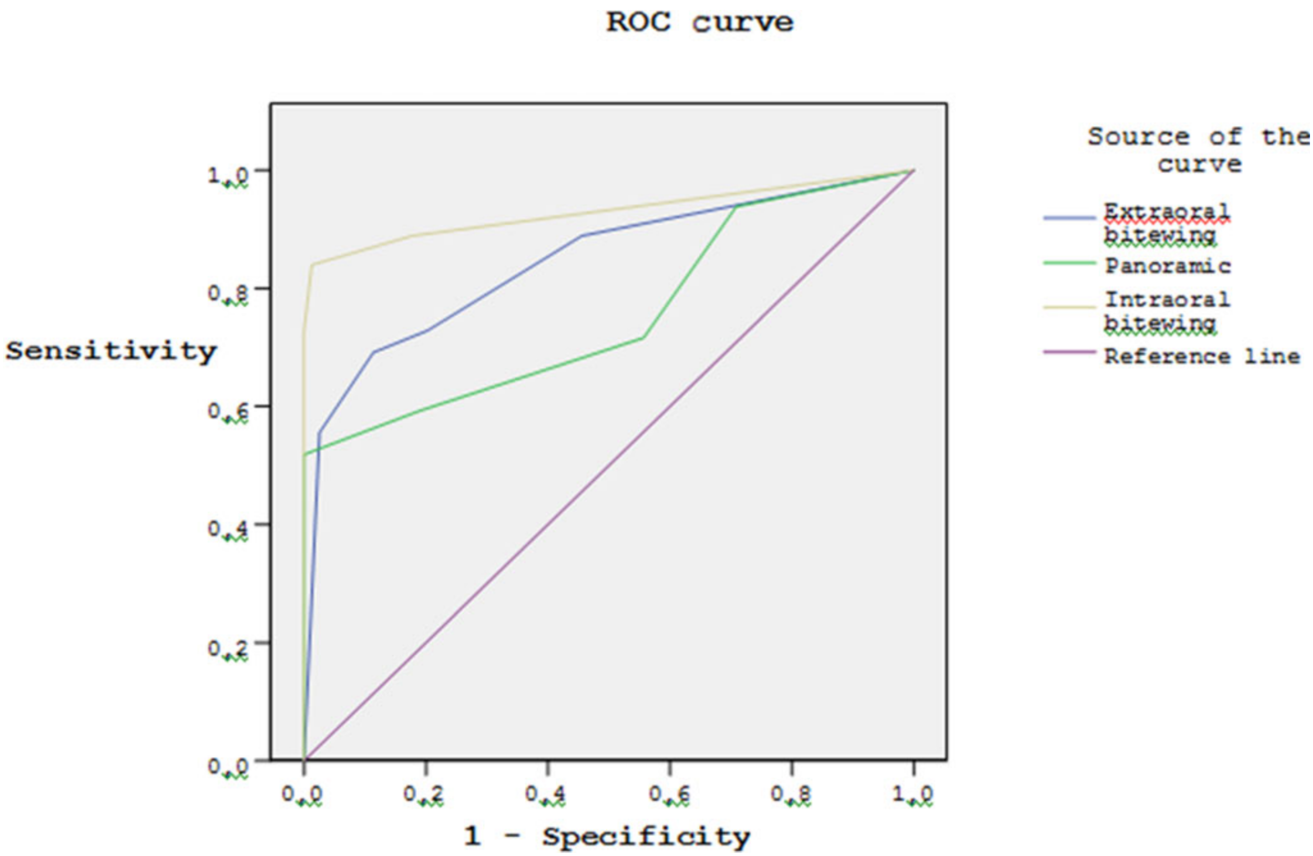

Figure 4 Receiver operating characteristic (ROC) curves for Observer 1 for the second reading for each caries detection method

with the intraoral bitewing film images. Therefore, all images were evaluated under the same conditions, against a light box with the use of a magnifier and digital enhancement tools, and monitors were not used for evaluation. It is our belief that, when comparing different radiographic projection techniques for proximal caries diagnosis as in the present study, inherent advantages and disadvantages of projection geometry of each technique are deterministic. It can be argued that assessing the digital panoramic images after printing may decrease their validity. Schulze et al[15] claimed that commonly available inkjet paper printers and glossy paper prints can reproduce digital intraoral radiographs sufficient for proximal carious lesion detection. No study was conducted to assess printed digital panoramic radiography for proximal caries diagnosis. However, authors of a previous study could not find any difference in diagnostic accuracy for assessment of position and morphology of mandibular third molars for digital panoramic radiographs, monitor-displayed images and printed images on glossy paper and transparent film.[16] In addition, subjective image quality of panoramic radiographs shown on a diagnostic computer monitor were compared with professional direct thermal prints and with common inkjet prints on different paper qualities. Monitor images and direct thermal prints performed similarly and better than inkjet prints. Although differences were observed, the average subjective image quality was sufficient for all modalities.[17]

Table 6 Modalities compared using a z-test, with a significance level of $\alpha = 0.05$. Statistically significant p-values are written in bold

Observer 1		*Observer 2*		*Observer 3*	
First reading	*Second reading*	*First reading*	*Second reading*	*First reading*	*Second reading*
Intraoral bitewing–extraoral bitewing $p > 0.05$	Intraoral bitewing – extraoral bitewing **$p = 0.027$**	Intraoral bitewing–extraoral bitewing $p > 0.05$	Intraoral bitewing–extraoral bitewing $p > 0.05$	Intraoral bitewing–extraoral bitewing $p > 0.05$	Intraoral bitewing–extraoral bitewing **$p = 0.014$**
Intraoral bitewing–panoramic **$p = 0.012$**	Intraoral bitewing–panoramic **$p < 0.001$**	Intraoral bitewing–panoramic $p > 0.05$	Intraoral bitewing–panoramic $p > 0.05$	Intraoral bitewing–panoramic **$p = 0.037$**	Intraoral bitewing–panoramic **$p = 0.003$**
Extraoral bitewing–panoramic $p > 0.05$	Extraoral bitewing–panoramic $p > 0.05$	Extraoral bitewing–panoramic $p > 0.05$	Extraoral bitewing–panoramic $p > 0.05$	Extraoral bitewing–panoramic $p > 0.05$	Extraoral bitewing–panoramic $p > 0.05$

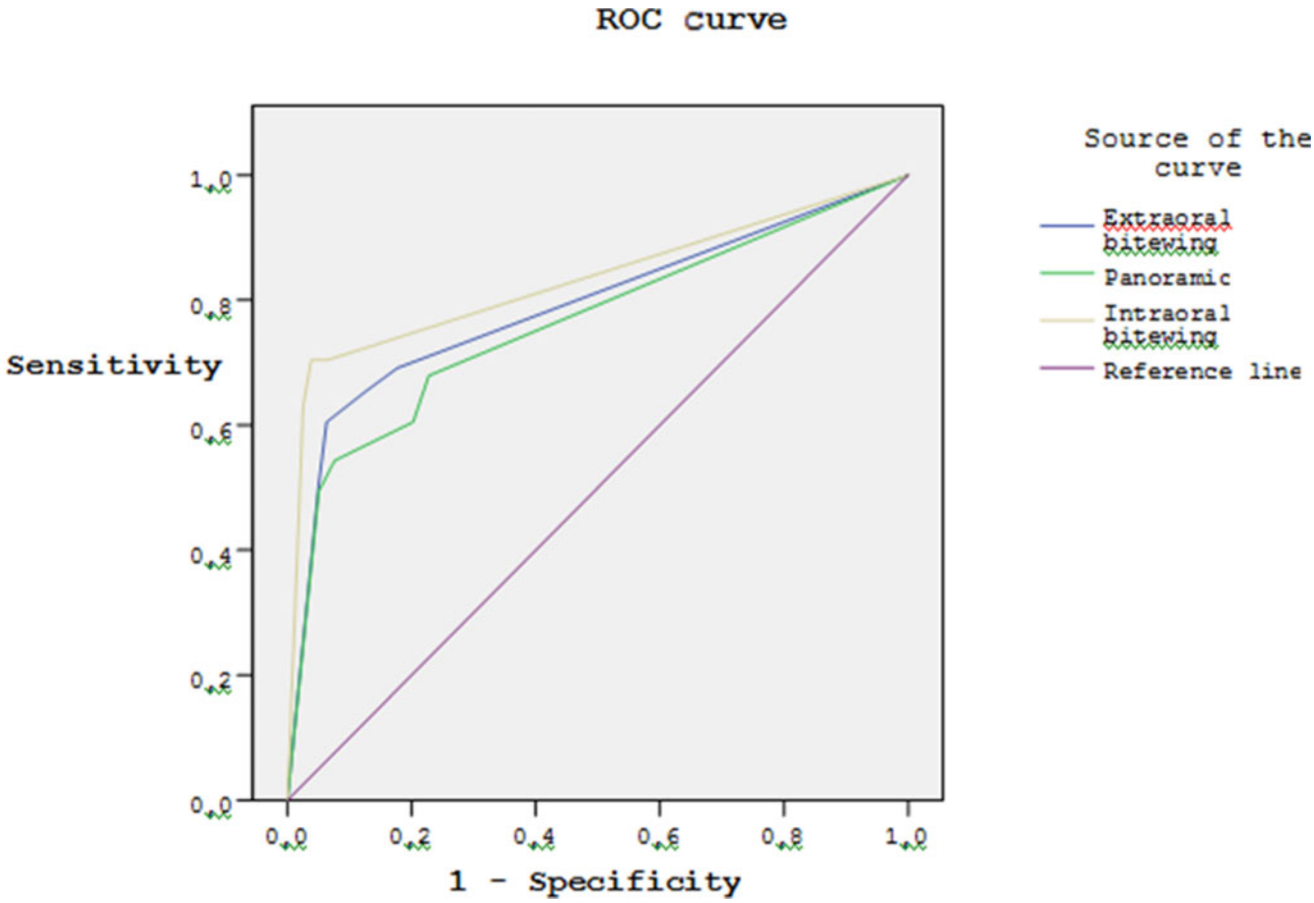

Figure 5 Receiver operating characteristic (ROC) curves for Observer 2 for the second reading for each caries detection method

Other studies assessed the effectiveness of task-specific enhancement filters in storage phosphor and solid-state intraoral receptors for proximal caries detection. No statistically significant difference was found between original and enhanced images in terms of diagnostic accuracy.[18,19]

Accuracy of the detection of proximal enamel caries lesions using three intraoral storage phosphor plate digital systems (DenOptix, Gendex Dental Systems) and Digora FMX with white and blue plates (Soredex, Helsinki, Finland) has been compared to that of Insight film.[20] There was no significant difference in the diagnostic accuracy among Insight film and the Digora and DenOptix digital systems for proximal enamel caries. The increase in depth of damage to the enamel layer by the carious lesion did not result in the increase in the number of surfaces correctly identified by the radiographic systems.[20] In our study, only Insight film was used for intraoral bitewing radiographs as we were mainly interested in comparing extraoral and intraoral bitewing images for proximal caries diagnosis. Film is still the major image receptor for obtaining bitewing radiography at most facilities due to rapid work flow.

A retrospective study compared bitewing radiographs taken with rectangular and circular collimators.[20] The use of film holders with circular collimation significantly reduced the incidence of cone cut errors from 21.7% to 3.3%. There was an increase in the incidence of cone cut errors from 3.3% to 20.9% when rectangular collimation was used, but the actual number that were considered "rejects" was very small, only 0.1–0.3%, when assessed for diagnostic yield. Therefore, the authors suggested that all practitioners should adopt rectangular collimation, and there is little justification for the continued use of circular collimation with film holding devices when taking bitewing projections.[20] Also, rectangular collimation reduces scatter and therefore improves image quality. However, in the present research, an X-ray unit with a circular collimator was preferred since this is the most available unit at our clinic and radiation dose was not an issue in this *ex vivo* study.

As an alternative to the two-dimensional nature of intraoral and panoramic radiography, cone beam CT (CBCT) was assessed for the diagnosis of proximal caries.[21] When compared with a CCD sensor (E2V Technologies Inc., Elmsford, NY), the detection of proximal dentine caries was improved by use of a limited CBCT 3DX Accuitomo (J Morita Corp., Kyoto, Japan) operated at 80 kVp and 5 mA with a 4 × 4 cm field of view. For proximal surface lesions extending into the dentine, the average sensitivity score when using 3DX images (0.61) was almost twice that of CCD images (0.33) and the difference was

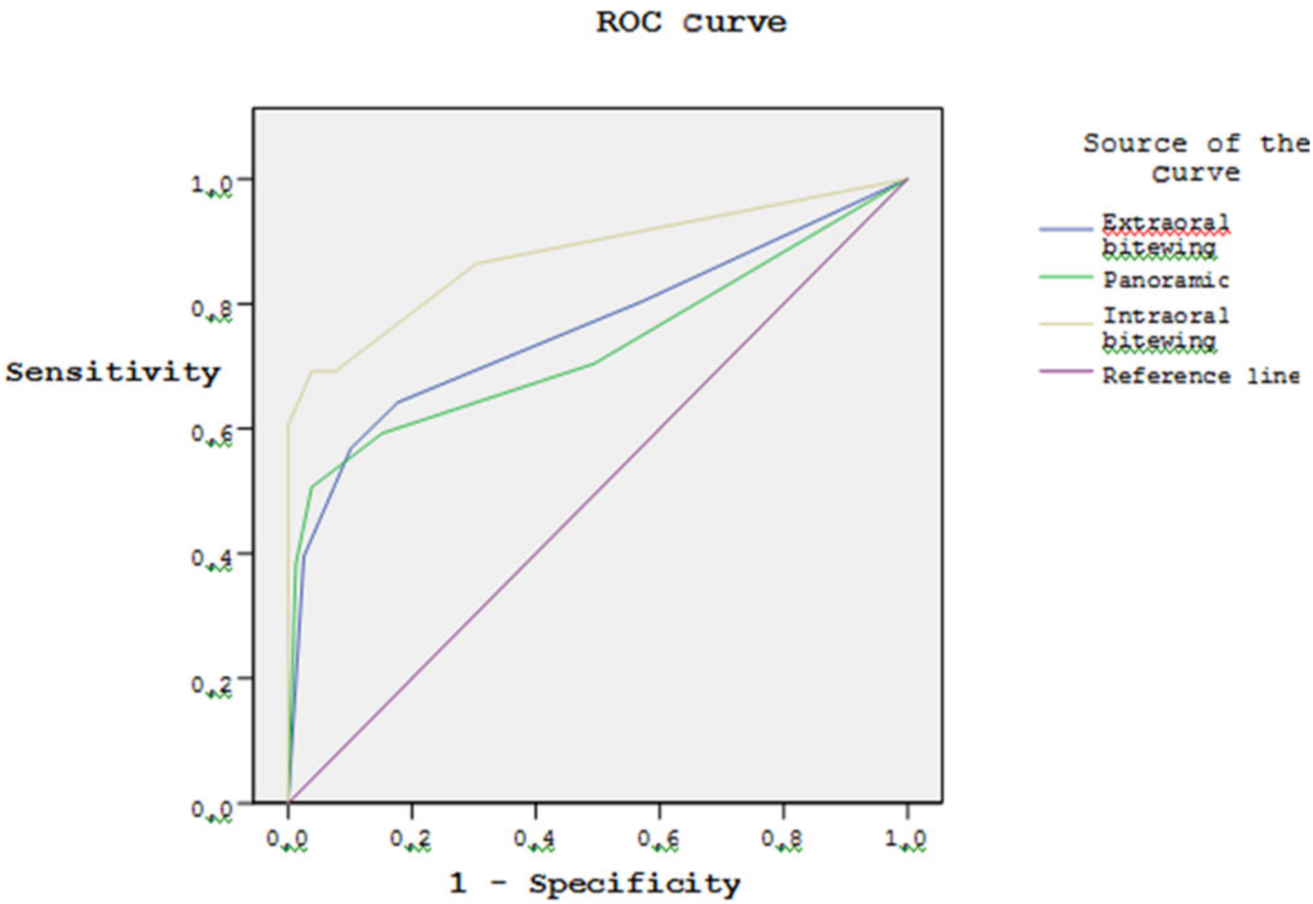

Figure 6 Receiver operating characteristic (ROC) curves for Observer 3 for the second reading for each caries detection method

significant. The specificity values for both systems were high and not significantly different from each other.[21] However, relatively higher patient doses given by CBCT than by conventional systems and the lack of availability should be taken into account. We obtained higher Az and sensitivity values than the study of Young et al.[21] Higher or lower Az values obtained from different caries methods are highly dependent on the depth of caries, and this difference may be because, in our study, 37 teeth with deep dentine caries which were easy to diagnose could have increased observer performance.

Although intraoral bitewing radiography is the best method of choice for proximal caries diagnosis, if it is impossible to obtain intraoral bitewing images then extraoral bitewing radiography may be an alternative to panoramic radiography in detecting proximal caries in challenging patients: such as patients who have a gagging reflex, patients who cannot open their mouths due to trismus and infection, and disabled or mentally retarded patients.

Conclusion

In the diagnosis of proximal caries in premolar and molar teeth, observer performance was best when using intraoral bitewing radiography followed by extraoral bitewing radiography.

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