RESEARCH

Diagnostic accuracy of different imaging modalities in detection of proximal caries

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Objective: The purpose of this study was to assess the *in vitro* diagnostic ability of visual inspection, film, charge-coupled device (CCD) sensor, photostimulable phosphor (PSP) sensor and cone beam CT in the detection of proximal caries in posterior teeth compared with the histological gold standard.

Methods: Visual inspection, film, CCD, PSP and cone beam CT images were used to detect proximal caries in the mesial and distal surfaces of 138 teeth (276 surfaces). Visual inspection and evaluation of all intraoral digital and conventional radiographs and cone beam CT images were performed twice by three oral radiologists. Weighted kappa coefficients were calculated to assess intra- and interobserver agreement for each image set, and scores were compared with the histological gold standard using receiver operating characteristic (ROC) analysis to evaluate diagnostic ability.

Results: Intraobserver kappa coefficients calculated for each observer for each method of detecting caries ranged from 0.739 to 0.928. Strong interobserver agreement ranging from 0.631 to 0.811 was found for all detection methods. The highest Az values for all three observers were obtained with the cone beam CT images; however, differences between detection methods were not statistically significant ($P > 0.05$).

Conclusion: Visual inspection, film, CCD, PSP plates and cone beam CT performed similarly in the detection of proximal caries.
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Introduction

Dental caries are among the most common problems encountered in clinical dentistry, with a very high incidence of caries observed in the population.[1] Early and accurate diagnosis of caries is essential for clinicians, who require exact knowledge of the depth of caries in order to determine the appropriate type of restoration and treatment planning.[2,3]

Among the various types of methods used today in the diagnosis of caries, probing, visual examination, intraoral film and digital sensors are the ones most commonly used in routine clinical practice. Several studies have shown that between 25% and 42% of caries lesions remain undetected by clinical examination performed without radiographic examination.[4–6] Interproximal caries lesions develop between the contacting proximal surfaces of two adjacent teeth. They first appear clinically as opaque regions caused by the loss of enamel transparency at the outermost enamel between the contact point and the top of the free gingival margin.[7–9] As the caries lesion progresses through the enamel, it takes on a triangular configuration, with the top of the triangle located at the enamel–dentine border. When it reaches the enamel–dentine border, it expands laterally and towards the inner dentine, forming another triangle in the dentine, with the base of the triangle located in the enamel–dentine border and the top of the triangle pointing towards the pulpal space.[9]

Owing to the difficulties in detecting proximal caries lesions, clinical examination should be supplemented with radiographic examination. Radiographic diagnosis

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is based upon the amount of demineralization needed to create a change in radiographic density, with a minimum of 40% mineral loss needed for radiographic visibility.[1] 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 very difficult to visualize on radiographs. Conventional intraoral film, solid state detectors and photostimulable phosphor (PSP) plates are the image receptors most commonly used to diagnose proximal caries.[10] Solid state detectors consist of either a charge-coupled device (CCD) that uses a thin wafer of silicon as the basis for image recording or a light-sensitive complementary metal oxide semiconductor (CMOS) chip and a scintillator layer that converts X-rays to light.[10–12] A PSP plate consists of a polyester base coated with crystalline halide composed of europium-activated barium fluorohalide compounds.[13,14] All these systems are able to provide two-dimensional information about dental tissue and disease.

Cone beam CT dedicated to dentomaxillofacial imaging was introduced in response to the high demand for a technique that could provide three-dimensional data at a lower cost and with lower absorbed doses than the conventional CT used in medical radiology. Dental cone beam CT has since gained broad acceptance in dentistry, with the most promising results obtained in relation to caries diagnosis and endodontic applications.[15] The use of cone beam CT in clinical practice offers a number of potential advantages over conventional tomography, including easier image acquisition, higher image accuracy, reduced artefacts, lower effective radiation doses, faster scan times and greater cost-effectiveness.[16,17] Rather than the fan-shaped beam emitted by conventional CT technology, cone beam CT units, as the name implies, emit a cone-shaped X-ray beam that covers the entire region of interest, allowing images to be acquired in only one pass or less around the patient's head.[18]

In view of the importance of radiological diagnosis of proximal caries and the potential difference in diagnostic performance of different caries detection methods, the aim of the present study was to assess the *in vitro* diagnostic ability of visual inspection, film, CCD sensors, PSP sensors and cone beam CT in the detection of proximal caries in posterior teeth in comparison with the histological gold standard.

Materials and methods

Our study comprised 230 human premolar and molar teeth with and without caries that had been extracted for periodontal or orthodontic reasons. Teeth were cleaned of calculus and debris, disinfected in 2% sodium hypochlorite solution for 20 min and stored in distilled water. Teeth were embedded in acrylic blocks in groups of five, with the proximal surfaces in contact;

all blocks and teeth were numbered. The mesial and distal aspects of the 3 teeth located in the centre of each block were assessed for caries, for a total of 276 surfaces of 138 teeth embedded in 46 blocks. Detection of proximal caries was performed using visual inspection and film, CCD, PSP and cone beam CT images. Visual inspection was conducted under daylight using a mirror and probe, and surfaces were scored according to the following scale: 0, no caries lesion; 1, opacity or cavitation in enamel; 2, cavitation in dentine; 3, cavitation in dentine extending to pulp.

All blocks were imaged using three different intraoral radiography techniques and cone beam CT. Intraoral digital and conventional images were exposed 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. A 1 cm thick acrylic block was placed behind the teeth in each block in order to simulate soft tissue. Film radiographs were obtained using Kodak E speed (size 2) film (Kodak, Rochester, NY) with an image exposure time of 0.40 s (Figure 1). Films were processed immediately after exposure using a Velopex, Extra-X automatic processing machine (Medivance Instruments Limited, London, UK) and fresh chemicals according to the manufacturer's specifications. Direct digital images were obtained using a Progeny Vision DX (size 1) direct digital intraoral CCD sensor (Progeny Dental, Buffalo Grove, IL) with an image exposure time of 0.2 s. The Progeny CCD offers 1.25 million pixels, a pixel size of 22 μm $\times$ 22 μm and a theoretical resolution of 23 lp mm^{-1}) (Figure 2). Semi-direct 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 (super) pixel size, 14-bit greyscale, 12.5 lp mm^{-1} spatial resolution and an image exposure time of 0.20 s. A size 2 imaging plate was used, and the exposed phosphor plates were scanned immediately after exposure (Figure 3). Cone beam CT images were obtained using an ILUMA ultra cone beam CT scanner (Imtec Imaging, Ardmore, OK) with a 24.4 $\times$ 19.5 cm amorphous silicon flat-panel image detector and a cylindrical volume of reconstruction up to 21.1 $\times$ 14.2 cm. Images were obtained at 120 kVp, 3.8 mA and a voxel size of 0.3 mm, with an exposure time of 40 s. Volumetric data were reconstructed to provide serial coronal and sagittal sections (Figure 4).

Visibility of the pulpal root canal, dentine and enamel was used as an indication of optimal image quality for all images. All images were viewed at random in a dimly lit room. Images were evaluated separately by three oral radiologists experienced in image interpretation. Intraobserver agreement was assessed by having each observer view all images twice, with a 2 week interval between viewing to eliminate memory bias. Conventional film radiographs were evaluated using a light box and magnifier ($\times$ 2).
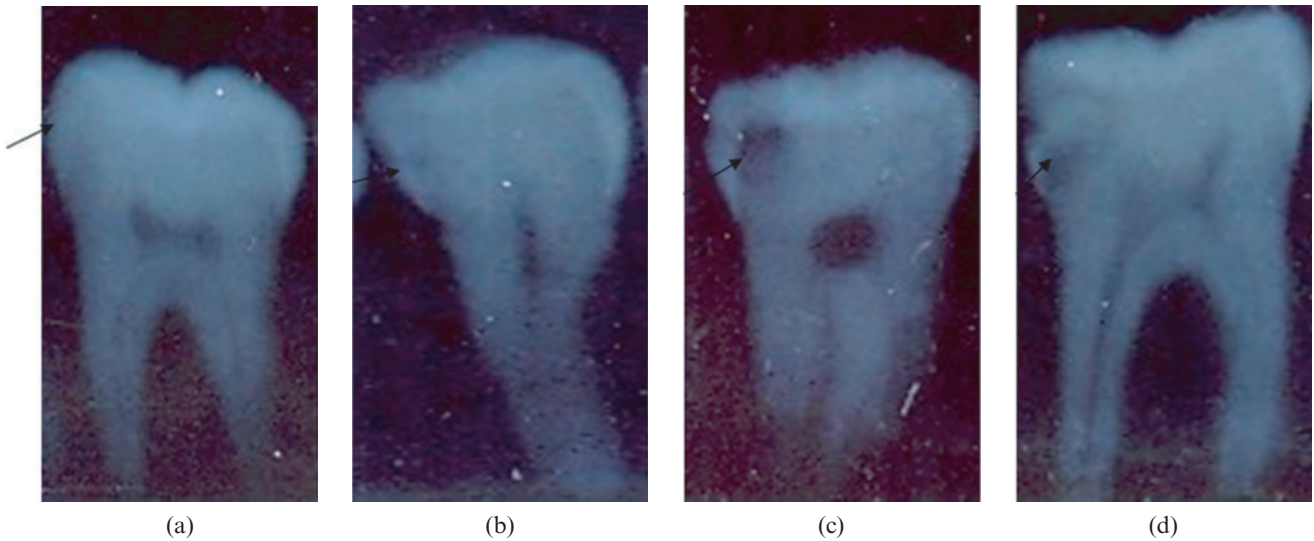
Figure 1 Film radiographs obtained using Kodak E speed: (a) score 0, (b) score 1, (c) score 2, (d) score 3 (indicated by arrows)

Digital images were viewed on a 22 inch LG Flatron monitor (LG, Seoul, Korea) set at a screen resolution of 1440×900 pixels and 32 bit colour depth using each system's own software. The presence or absence of proximal caries was assessed according to radiographic criteria using the following scale: 0, no caries detected in the proximal surface; 1, proximal radiolucency in enamel (enamel caries); 2, proximal radiolucency in dentine (dentine caries); 3, proximal radiolucency extending to pulp (deep dentine caries).

Histological validation of 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). The average thickness of the serial sections was 400 μm. The section with the deepest carious lesion was assessed using a high-resolution scanner (Epson Perfection V750-M Pro Scanner Epson, Nagano, Japan) at 600 dpi resolution and $\times 15$ magnification. Histological status was

determined by consensus of one of the researchers and a histology specialist. 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 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; 3, proximal caries in the inner half of the dentine. Histological examination of 276 proximal tooth surfaces revealed no caries in 142 surfaces (51.5%) and caries in 134 surfaces (48.5%). When analysed by caries level, 40 surfaces (14.5%) were found to have enamel caries, 45 surfaces (16%) had dentine caries confined to the outer half of the dentine and 49 surfaces (18%) had deep dentine caries extending to the inner half of the dentine.

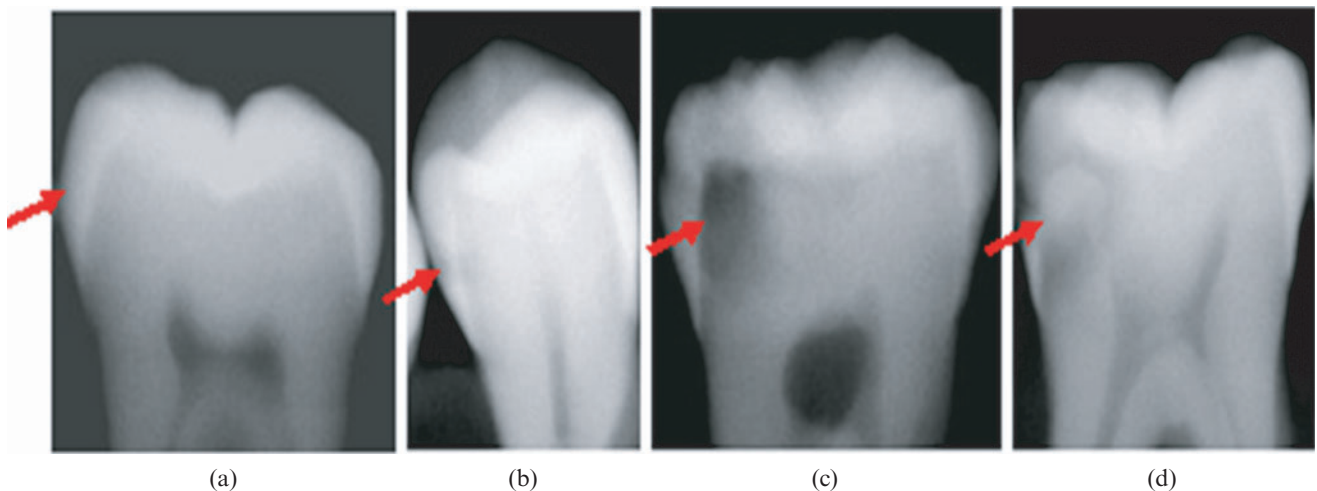Weighted kappa coefficients were calculated to assess intra- and interobserver agreement for each image set,

Figure 2 Images obtained by charge-coupled device sensor: (a) score 0, (b) score 1, (c) score 2, (d) score 3 (indicated by arrows)
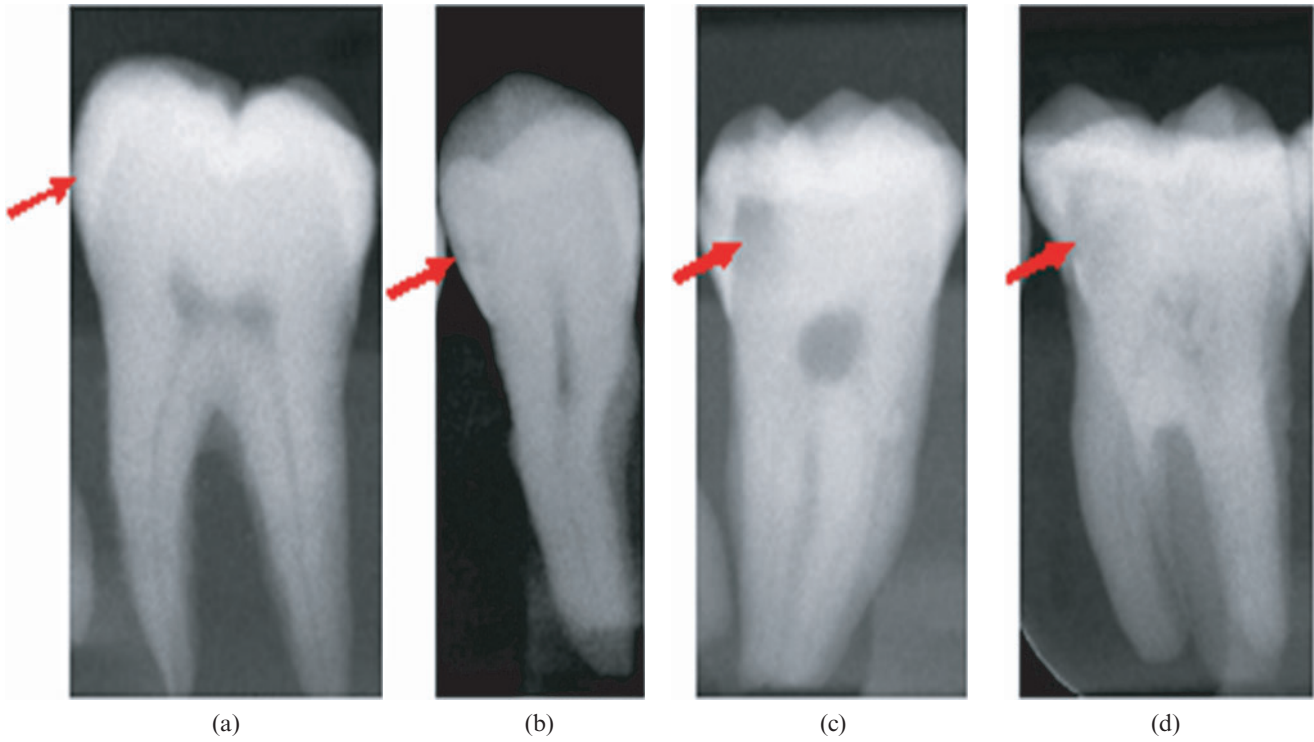
Figure 3 Images obtained by photostimulable phosphor plate sensor: (a) score 0, (b) score 1, (c) score 2, (d) score 3 (indicated by arrows)
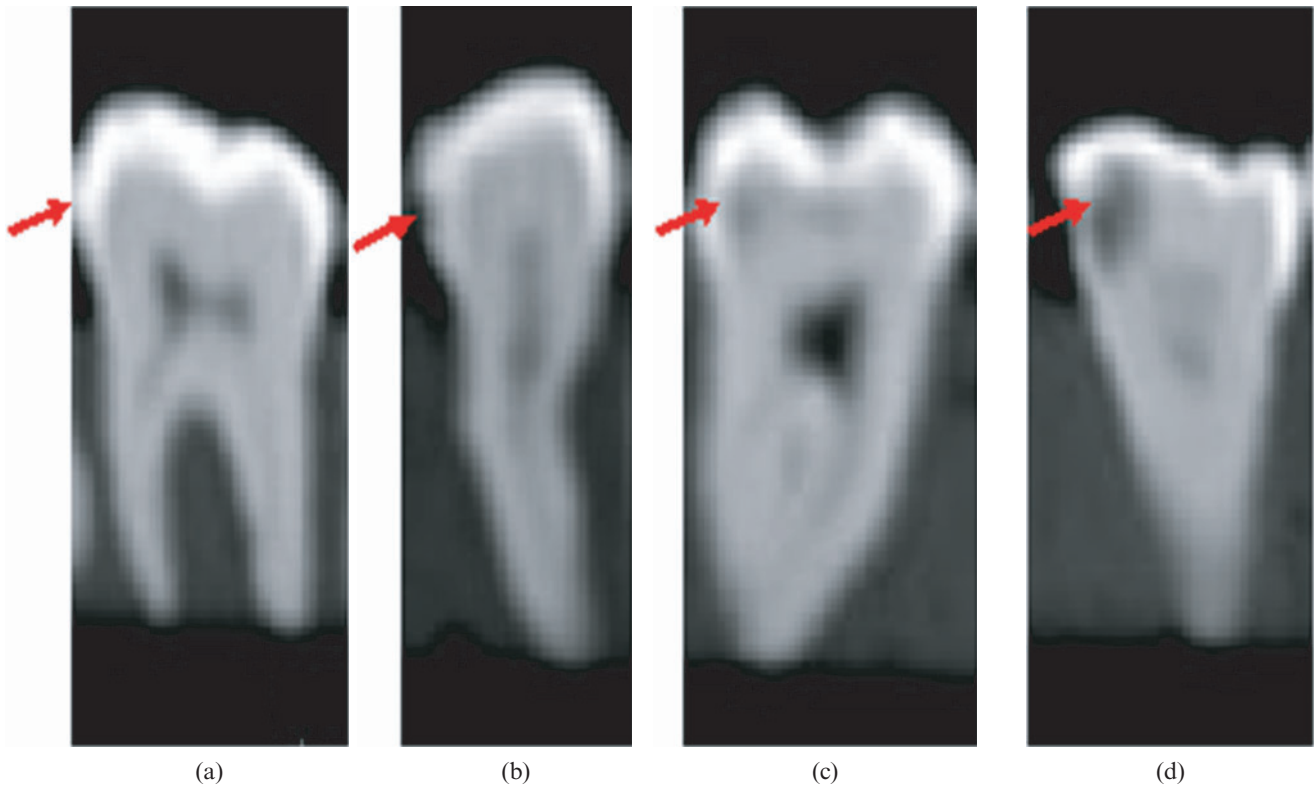

Figure 4 Images obtained by cone beam CT: (a) score 0, (b) score 1, (c) score 2, (d) score 3 (indicated by arrows)

Table 1 Intraobserver kappa coefficients calculated for each observer by caries detection method

	Observer 1	Observer 2	Observer 3
	Weighted kappa (SD)	*Weighted kappa (SD)*	*Weighted kappa (SD)*
Visual inspection	0.739 (0.052)	0.840 (0.031)	0.914 (0.029)
Intraoral film	0.827 (0.035)	0.868 (0.025)	0.893 (0.027)
Intraoral CCD sensor	0.810 (0.047)	0.856 (0.031)	0.794 (0.047)
Intraoral PSP sensor	0.819 (0.035)	0.878 (0.026)	0.827 (0.046)
Cone beam CT	0.846 (0.035)	0.759 (0.039)	0.928 (0.022)

CCD, charge-coupled device; PSP, photostimulable phosphor; SD, standard deviation

and scores were compared with the histological gold standard using receiver operating characteristic (ROC) analysis to evaluate diagnostic ability. The areas under the ROC curves (Az values) for each image type, observer and reading were calculated using the MedCalc statistical software. Az values were compared using t-tests, with a significance level of 0.05, and Bonferroni correction was applied. 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, significant agreement; 0.61–0.80, strong agreement; 0.81–1.00, excellent agreement. McNemar's test was applied to compare sensitivity and specificity values of radiographic methods obtained from each level of caries.

Results

Intraobserver kappa coefficients calculated for each observer by caries detection method ranged between 0.739 and 0.928 (Table 1). Considering the very high intraobserver kappa coefficients suggestive of strong and excellent intraobserver agreement, interobserver kappa coefficient and Az value calculations were based on the first readings only. Interobserver kappa coefficients by caries detection method ranged from 0.631 to 0.811, with strong interobserver agreement found for all detection methods (Table 2).

The areas under the ROC curves (Az values), their standard errors and significance levels for the first readings of each observer are given in Table 3. The highest Az values for all three observers were obtained with the Iluma cone beam CT images. The lowest Az values for Observers 2 and 3 were obtained with visual inspection, whereas the lowest Az value for Observer 1 was obtained with intraoral film; however, there were no statistically significant differences ($P > 0.05$)

between any of the Az values obtained with the different methods of caries detection. Figures 5, 6 and 7 show the ROC curves for the first reading for each method for Observers 1, 2 and 3, respectively.

Table 4 shows the average percentage of correct diagnoses for each observer for each caries detection method and each level of caries. Teeth free from caries, followed by teeth with caries in the inner half of the dentine, yielded the best diagnoses rates for all observers and all caries detection methods, whereas the worst diagnoses were obtained from teeth with enamel caries, followed by teeth with caries in the outer half of the dentine. Figure 8 shows the accuracy rates of the different detection methods in diagnosing different caries levels. Table 5 shows the true positive ratio and false positive ratio of the first readings of three observers obtained using different methods. When sensitivity and specificity values of radiographic methods obtained from each level of caries were assessed, no statistical significance ($P > 0.05$) was found.

Discussion

The present study found no differences in the diagnostic ability of visual inspection, film, CCD, PSP and cone beam CT images in the detection of proximal caries. Although observers obtained the highest Az values from cone beam CT images, the differences between modalities were not statistically significant ($P > 0.05$). It should be kept in mind that the cone beam CT images used in the present study were obtained at the lowest available resolution voxel size (0.3 mm) that is routinely used in clinical practice. Moreover, because of the beam hardening that occurs with the presence of metal such as amalgam, this study was limited to non-restored teeth.

Table 2 Interobserver kappa coefficients by caries detection method

	Observers 1 and 2	Observers 1 and 3	Observers 2 and 3
	Weighted kappa (SD)	*Weighted kappa (SD)*	*Weighted kappa (SD)*
Visual inspection	0.631 (0.062)	0.657 (0.064)	0.665 (0.057)
Intraoral film	0.699 (0.049)	0.750 (0.044)	0.759 (0.042)
Intraoral CCD sensor	0.746 (0.045)	0.769 (0.048)	0.777 (0.041)
Intraoral PSP sensor	0.774 (0.039)	0.790 (0.040)	0.811 (0.036)
Cone beam CT	0.695 (0.051)	0.802 (0.047)	0.802 (0.039)

CCD, charge-coupled device; PSP, photostimulable phosphor; SD, standard deviation

Table 3 *Az* values, standard errors and significance levels for each observer's first reading

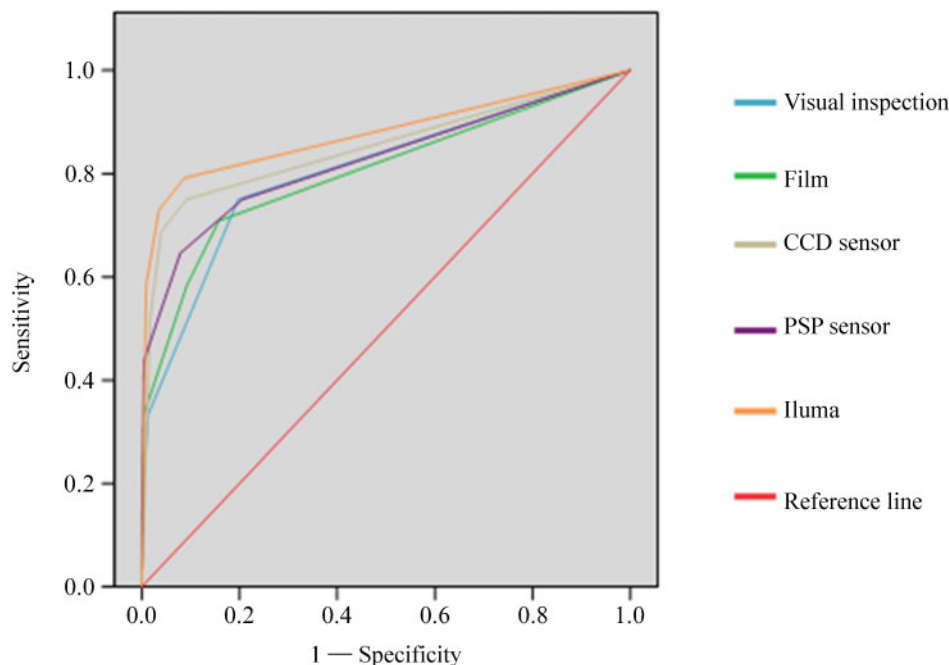|	Observer 1		Observer 2		Observer 3	
	Az (SE)	*P-value*	*Az (SE)*	*P-value*	*Az (SE)*	*P-value*
Visual inspection	0.805 (0.040)	<0.001	0.838 (0.039)	<0.001	0.792 (0.044)	<0.001
Intraoral film	0.803 (0.042)	<0.001	0.882 (0.032)	<0.001	0.819 (0.041)	<0.001
Intraoral CCD sensor	0.850 (0.039)	<0.001	0.914 (0.029)	<0.001	0.820 (0.042)	<0.001
Intraoral PSP sensor	0.825 (0.041)	<0.001	0.844 (0.039)	<0.001	0.801 (0.044)	<0.001
Cone beam CT	0.877 (0.036)	<0.001	0.920 (0.028)	<0.001	0.853 (0.040)	<0.001

CCD, charge-coupled device; PSP, photostimulable phosphor; SE, standard error

The very high intraobserver kappa coefficients found in the present study suggest excellent intraobserver agreement and strong interobserver agreement among experienced observers for all detection methods. Intraobserver kappa coefficients ranged from 0.739 to 0.928, and interobserver kappa coefficients ranged from 0.631 to 0.811. The level of intra- and interobserver agreement reported by previous studies examining the use of different intraoral radiography techniques in the detection of caries has varied.[19–23] Excellent interobserver agreement (kappa coefficient = 0.89) has been reported using bitewing film radiographs in the detection of proximal caries,[19] and a kappa coefficient of 0.79 was reported for intraobserver agreement using bitewing film in the *in vitro* detection of proximal caries.[20] In a study in which experienced observers assessed proximal caries depth using direct digital radiography and film, the average intraobserver kappa coefficient was 0.77 for digital and 0.78 for film, whereas the interobserver agreement was 0.44 for digital and 0.42 for film, suggesting no difference between the two modalities.[21] Intraobserver coefficients of 0.74 for film and 0.67 for digital radiography and

interobserver coefficients of 0.60 for film and 0.54 for digital radiography have been reported.[22] Similar interobserver agreement kappa coefficients ranging between 0.57 and 0.60 have been reported, suggesting significant agreement in the detection of proximal caries using bitewing film.[23] The differences in intra- and interobserver agreement kappa values among the different studies may be related to observer experience, radiographic quality, viewing conditions, study design and study material, all of which are important factors in determining observer agreement.

The use of visual examination and probing is a practical method for the clinical diagnosis of proximal caries. Although an earlier study found the use of visual inspection insufficient in the detection of superficial proximal caries,[24] the present study found no statistically significant differences ($P > 0.05$) between visual inspection and other caries detection modalities.

When film was used in the detection of caries in posterior teeth, 50% of proximal caries lesions were diagnosed correctly and 93% of caries-free surfaces were correctly identified.[25] Similarly, in our study, 89.2% of caries-free surfaces were identified correctly.

Figure 5 Receiver operating characteristic curves for Observer 1 for the first reading for each caries detection method. CCD, charge-coupled device; PSP, photostimulable phosphor

Figure 6 Receiver operating characteristic curves for Observer 2 for the first reading for each caries detection method. CCD, charge-coupled device; PSP, photostimulable phosphor
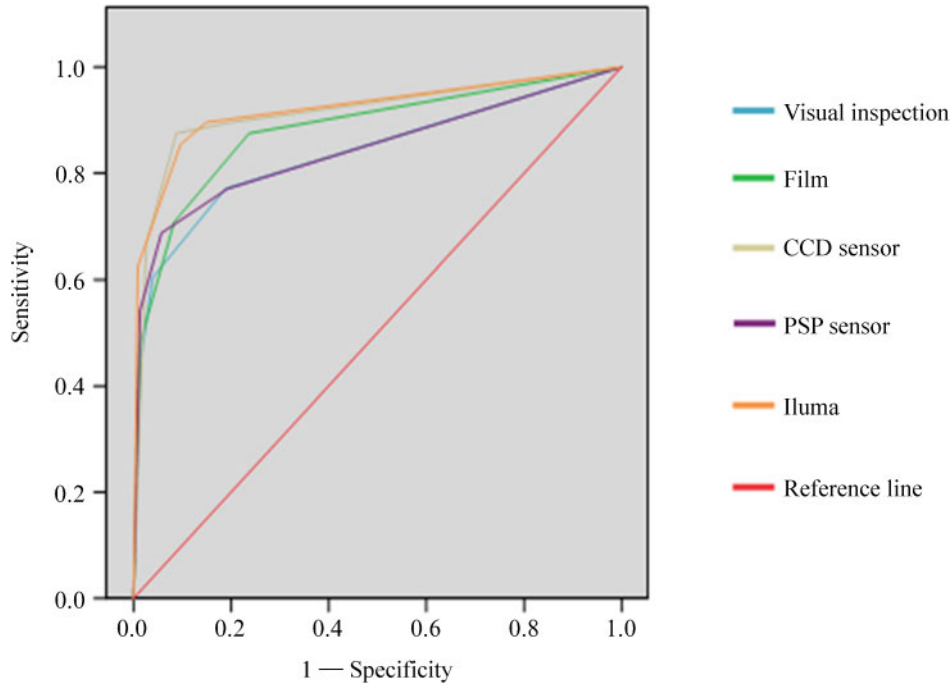
When looked at by the level of caries, correct diagnoses were found for 10.6% of enamel caries, 17.8% of dentine caries and 40.2% of deep dentine caries.

Several studies have compared the diagnostic ability of intraoral digital sensors with film in the detection of caries lesions.[26] In line with our results, most previous studies comparing film and CCD sensors in the detection of proximal caries have revealed similar results for both systems,[4,19,27–30] although some studies have found film to be more accurate than direct digital
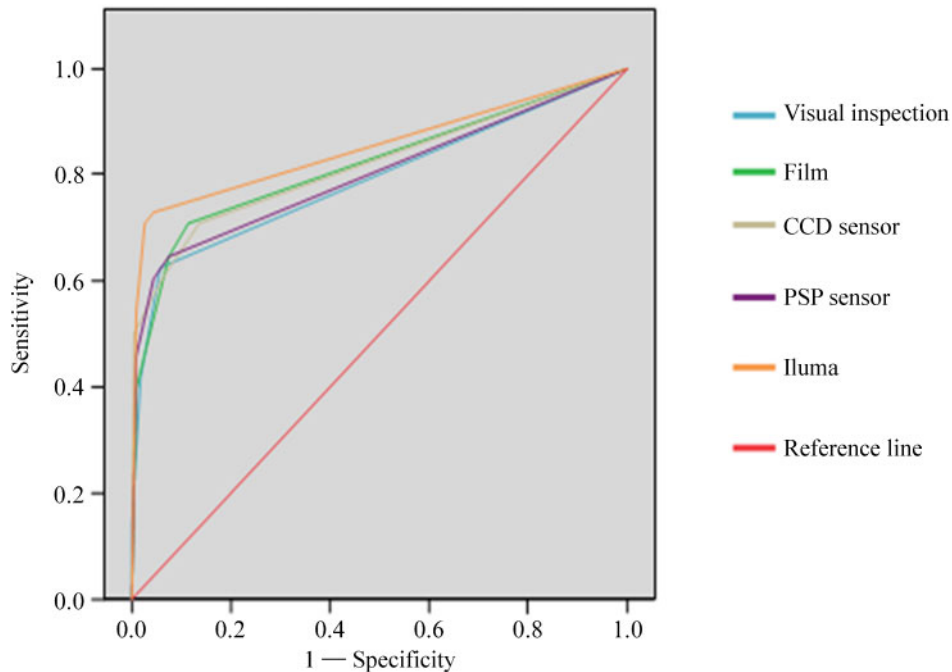

Figure 7 Receiver operating characteristic curves for Observer 3 for the first reading for each caries detection method. CCD, charge-coupled device; PSP, photostimulable phosphor
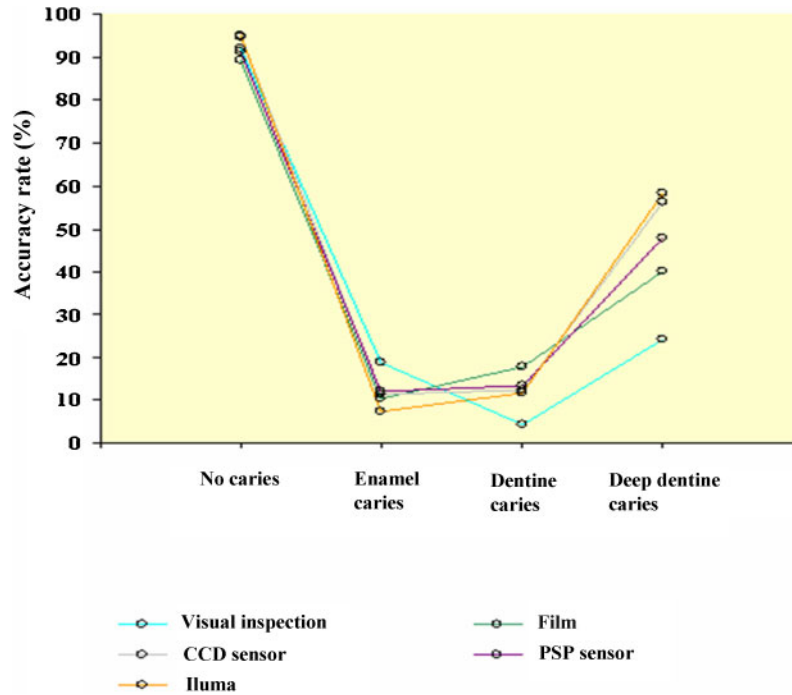
Figure 8 Accuracy rates of caries diagnosis obtained by different methods. CCD, charge-coupled device; PSP, photostimulable phosphor

radiography.[31,32] Our study found that CCD sensors (56.2%) had a higher rate than film (40.2%) and PSP plates (47.9%) but a lower rate than cone beam CT (58.3%) in correctly diagnosing deep dentine caries; however, the differences between methods were statistically insignificant. Four different intraoral storage phosphor plate systems (DenOptix, Denstply/Gendex, Chicago, IL; Cd-dent, DigiDent, Nesher, Israel; Digora blue plate and Digora white plate, Soredex, Helsinki, Finland) exposed with two different plate exposure times (10% and 25% of the film exposure time) were compared with traditional film images (Ektaspeed Plus, Eastman Kodak, Rochester, NY) in the detection of proximal caries.[33] A total of 365 surfaces were imaged. Using the longer exposure time, no significant differences in diagnostic accuracy were found among the DenOptix, Digora blue, Digora white and Ektaspeed Plus, all of which were significantly more accurate than the Cd-dent. Moreover, the accuracy of the DenOptix and Digora blue systems in diagnosing proximal caries improved significantly with the longer exposure time compared with the shorter exposure time.[33] It was found that, in comparison with film (Ektaspeed Plus) images, PSP (Digora) images using a caries-specific enhancement feature significantly improved accuracy and reduced observer variability in assessing the depth of caries in the outer half of the enamel.[34] In the present study, only one of three observers had better Az values with PSP (Digora) than with film images, although the difference was not statistically significant.

Several other studies have been conducted in order to evaluate and compare different intraoral radiographic modalities in the detection of proximal caries. 56

Table 4 Average percentage of true diagnoses of three observers using different detection methods

	Visual inspection	Film	CCD	PSP	Iluma
No caries (%)	92	89.2	94.6	91.3	94.8
Enamel caries (%)	18.7	10.6	11.3	12.2	7.3
Dentine caries (%)	4.4	17.8	12.6	13.3	11.8
Deep dentine caries (%)	24.3	40.2	56.2	47.9	58.3

CCD, charge-coupled device; PSP, photostimulable phosphor

Table 5 True positive ratio (TPR) and false positive ratio (FPR): percentage of the first readings of three observers obtained using different methods

	Observer 1		Observer 2		Observer 3	
	TPR (%)	FPR (%)	TPR (%)	FPR (%)	TPR (%)	FPR (%)
Visual inspection	14.6	9.9	43.8	10.6	14.6	3.5
Film	33.3	9.2	47.9	17.6	39.6	5.6
CCD	52.1	3.5	66.7	7.7	50	4.9
PSP	43.8	12.7	54.2	11.3	45.8	2.1
Cone beam CT	58.3	2.8	62.5	11.3	54.2	1.4

CCD, charge-coupled device; PSP, photostimulable phosphor

surfaces were radiographed using two different E-speed dental films (Ektaspeed Plus, Eastman Kodak, and Dentus M2 Comfort, Agfa-Gevaert, Mortsel, Belgium), two CCD systems (Sidexis, Sirona, Bensheim, Germany, and Visualix Gendex, Milan, Italy) and two PSP systems (Digora, Soredex, and DenOptix, Denstply/Gendex).[35] No significant differences were found in diagnostic accuracy between the two dental films and the Sidexis and Digora systems. Lesion depth was found to significantly affect observer performance and was, in general, underestimated. The authors concluded that, rather than imaging modality, the main factor affecting diagnostic accuracy was observer ability.[35] Extracted human teeth were radiographed using two CCD systems (Dixi, Planmeca, Helsinki, Finland, and Sidexis, Sirona) and two PSP systems (Digora, Soredex, and DenOptix, Gendex), and the Dixi and Digora systems were found to be more accurate than the Sidexis and DenOptix systems in measuring the depth of proximal caries lesions.[36] In the present study, no differences were found between the Digora Optime and the other systems tested. The accuracy of older and newer versions of a CMOS system (Schick CDR/Schick CDR Wireless, Schick Technologies, Long Island City, NY) and a PSP system (Digora FMX/Digora Optime, Soredex) were compared in the detection of proximal carious lesions.[37] The new systems (Digora Optime and Schick CDR Wireless) were found to have significantly higher sensitivities than their predecessors.[37] No significant differences in specificity were found among the Digora FMX, Schick CDR and Schick CDR Wireless systems, all of which had a significantly higher specificity than the Digora Optime ($P < 0.02$). Fewer false positive diagnoses occurred with the Digora FMX than with the Digora Optime, which also had a lower positive predictive value than that of both CCD systems assessed ($P < 0.02$). However, in terms of overall accuracy, the differences between the older and newer versions of the PSP and CCD systems were not statistically significant.[37]

The diagnostic accuracy of conventional tomograms has also been found to be similar to that of conventional bitewing and digital intraoral radiographs in the detection of proximal caries.[38] Although no difference was found between local CT (LCT) (Sirona Dental Systems, Bensheim, Germany) and conventional radiography in the detection of proximal caries, LCT was found to be more accurate in assessing lesion depth.[39]

A number of studies have compared the diagnostic ability of different dental cone beam CT systems and intraoral modalities in the detection of proximal caries.[40–42] The accuracy of proximal caries depth measurement using limited cone beam CT (3DX Accuitomo, J Morita MFG, Kyoto, Japan) was compared with PSP digital (Digora, Soredex) and F-speed film radiography (Eastman Kodak).[40] Significant differences ($P < 0.01$) were found between histological and film measurements and between histological and

PSP measurements, but no significant differences ($P > 0.05$) were found between histological and limited cone beam CT measurements. Interobserver agreement was 0.998 for the limited cone beam CT. The mean difference in measurements between observers using cone beam CT was approximately 0.02 mm, which was regarded as clinically insignificant.[40] The authors concluded that cone beam CT was a promising tool for the detection and monitoring of proximal caries lesions that provided highly accurate measurements of caries depth.[40] In contrast to Akdeniz et al's[40] study, the present study found no differences between cone beam CT and intraoral modalities. Differences in findings between the two studies may be due to differences in devices, settings and materials used.

The diagnostic accuracy of two cone beam CT systems, the NewTom 3G (Quantitative Radiology, Verona, Italy) and the 3DX Accuitomo (Morita), were compared with two intraoral receptors, one digital (Digora FMX, Soredex) and one film (Insight, Kodak).[41] Images were obtained with the NewTom 3G using three different fields of view (FOVs), 12 inches (0.36 mm pixel size), 9 inches (0.25 mm pixel size) and 6 inches (0.16 mm pixel size), and with the 3DX Accuitomo using a 4 cm FOV (0.125 mm pixel size). For proximal surfaces, the 3DX Accuitomo had significantly higher sensitivity ($P < 0.02$) than the NewTom 12 inch and 9 inch images, and the film and Digora FMX images had significantly higher specificity ($P < 0.04$) than the NewTom 9 inch and 6 inch images, whereas there were no significant differences among the film, Digora FMX and Accuitomo images for any of the variables tested ($P > 0.2$). For occlusal surfaces, the Accuitomo showed higher sensitivity than all the other systems tested, whereas specificity and overall true score did not differ ($P > 0.06$) among the modalities.[41] The authors concluded that the diagnostic accuracy of the NewTom 3G cone beam CT was lower than both intraoral modalities and the 3DX Accuitomo cone beam in the detection of caries lesions. Although the Accuitomo cone beam CT had a higher sensitivity than the intraoral systems in the detection of dentine lesions, the overall true score was not higher.[41] Although the cone beam CT Iluma system used in the present study does not offer different FOVs, it does offer different voxel sizes for image capture. We used a voxel size of 0.3 mm, which is the standard for routine clinical use.

The diagnostic ability of a limited cone beam CT imaging system (3DX Accuitomo, Morita) in detecting incipient proximal caries was assessed.[42] No difference was found in the accuracy of the cone beam CT system and traditional film (Insight, Eastman Kodak). Cone beam CT images of 100 surfaces from 50 extracted premolars detected a total of 71 proximal carious lesions, 47 of which were enamel caries and 24 of which were dentine caries. Analysis of variance showed no statistically significant difference between the 3DX Accuitomo and film images. Mean *A*z values were 0.63 ± 0.02 for 3D Accuitomo and 0.63 ± 0.03 for

film.[42] Compared with our study, the *Az* value of the cone beam CT system in this study was lower, which can be explained by the fact that most of the caries lesions in this study were confined to the enamel.

In the present study, none of the modalities tested showed both high sensitivity and high specificity, and none of the modalities significantly outperformed the others in the detection of proximal caries. Considering these results, digital intraoral systems can be recommended over film because of their lower levels of radiation exposure. The best diagnostic outcomes are likely to be achieved through the combined use of different caries detection modalities. Further research is also needed to assess the performance of newly developed cone beam CT systems in proximal caries detection and other sensitive diagnostic tasks.

In conclusion, visual inspection, film, CCD, PSP and cone-beam CT chosen for this study performed similarly in the detection of proximal caries *in vitro*.

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