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A comparison of older and newer versions of intraoral digital radiography systems

Diagnosing noncavitated proximal carious lesions

Francisco Haiter-Neto, DDS, PhD; Andrea dos Anjos Pontual, DDS; Morten Frydenberg, MSc, PhD; Ann Wenzel, DDS, PhD, dr odont

A number of digital systems are available for intraoral radiography in dental practices. In these systems, a solid-state receptor (that is, a charge-coupled device [CCD] or a complementary metal oxide semiconductor–active pixel sensor [CMOS-APS]) or a photostimulable storage phosphor (PSP) imaging plate replaces conventional film.^{1,2}

DIGITAL RADIOGRAPHY SYSTEMS

CCD and CMOS-APS systems. In CCD and CMOS-APS systems, a cable usually connects the sensor to the computer, and the image is displayed almost immediately on the computer monitor after exposure of the sensor. The CMOS-APS system has an active transistor built into each pixel and requires less system power to process the image in comparison with the CCD systems. The production costs are reduced for the CMOS-APS system, because it can be manufactured in mainstream silicon.³

A recently introduced digital radiography system (CDR Wireless, Schick Technologies, Long Island City, N.Y.) is manufactured with a wireless sensor. In this system, the wireless sensor captures the image

ABSTRACT



Background. The authors conducted a study to compare the accuracy of an older and newer version of two intraoral digital systems in terms of radiographic detection of proximal carious lesions.

Methods. Under in vitro and standardized conditions, the authors obtained radiographs of 160 noncavitated proximal surfaces using the Digora FMX (Soredex, Tuusula, Finland), the Digora Optime, the Schick CDR (Schick Technologies, Long Island City, N.Y.) and the Schick CDR Wireless (Schick Technologies) systems. Eight observers recorded proximal carious lesions on a five-point confidence scale. The presence of caries was validated histologically.

Results. The new digital systems (Digora Optime and Schick CDR Wireless) had significantly higher sensitivities than their predecessors. The authors found no significant differences in specificity among the Digora FMX, Schick CDR and Schick CDR Wireless systems, all of which had a significantly higher specificity than did the Digora Optime system ($P < .02$). The positive predictive value for the Digora Optime system was affected by its high sensitivity and low specificity, and it was lower than that for the two CDR systems ($P < .02$).

Conclusions. Regarding overall accuracy, the difference between the older and newer versions of the photostimulable storage phosphor and complementary metal oxide semiconductor systems was not statistically significant. However, the authors found more false-positive diagnoses made with the Digora Optime system than with the Digora FMX system.

Clinical Implications. Though the difference in specificities was statistically significant, the authors question whether the difference between the Digora Optime and the other systems is clinically relevant. Therefore, dentists can purchase any of these systems after considering factors other than those evaluated in this study.

Key Words. Radiography; digital radiography; dental caries; proximal caries; caries diagnosis.

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created when it is exposed to X-radiation, and it transmits the information over a wireless radio frequency link to a base station receiver. The base station receives the image from the sensor and sends it to a Universal Serial Bus (USB) interface unit that communicates with the computer hardware via a cable, enabling the acquired image to be displayed on a computer monitor.⁴

PSP systems. In PSP systems, when an image plate is exposed to X-radiation, the absorbed energy is stored temporarily within the phosphor crystals, and a latent image is created. The information contained in the plate is released by scanning the plate with a thin collimated helium-neon laser beam, and data are captured in the laser scanner. The information is converted to electrical signals, which subsequently are digitized.^{5,6} The first PSP system designed for intraoral dental radiography was the Digora FMX system (Soredex, Tuusula, Finland), which was introduced in the mid-1990s. It consists of imaging plates that have the same shape and dimensions of conventional film. The imaging plate in this system is more rigid than film and can be scanned in approximately 30 seconds.⁷

A few years ago, a new version of this system, the Digora Optime (OpTime in the United States), became available for dentistry. The imaging plates of this new version are thinner and more flexible than the previous ones. The readout time for the newly designed scanner is very short; the image is displayed on the computer monitor in approximately eight seconds.⁸

Noncavitated proximal carious lesions. The greatest difficulty in radiographic caries detection concerns the carious lesion in its initial stages, when the surface is noncavitated. Posterior proximal carious lesions traditionally have been diagnosed by clinical examination combined with radiography. Several caries detection studies using digital radiography have been conducted. Several authors have shown that the diagnostic accuracy of digital systems generally is comparable to that of conventional film radiography for the detection of proximal caries.^{7,9-18} The Digora FMX and Schick CDR are well-established among dental practitioners and have been shown to be as accurate as any conventional film for lesion detec-

tion.^{12,14,16,17} However, a comparative evaluation of the diagnostic accuracy of the older and newer versions of the Digora and Schick CDR systems for caries detection has not been performed to date.

The objective of this study, therefore, was to compare the accuracy of the older and newer versions of two intraoral digital systems for the detection of small proximal carious lesions. The null hypothesis was that no statistically significant differences existed between the imaging modalities for any parameter of diagnostic accuracy.

MATERIALS AND METHODS

We conducted the study using 100 extracted permanent human teeth (20 canines, 40 premolars and 40 molars). Clinically, the surfaces of the teeth were without cavitations, and they ranged from sound to varying degrees of demineralization appearing as chalky white or brown discolored areas. Two of us (F.H.-N., A.d.A.P.) mounted the teeth in 20 blocks of silicone with four test teeth (two premolars and two molars) and one nontest tooth (a canine). We assigned the teeth to a block disregarding the surface status and mounted them in an anatomical position from the apex to the cemento-enamel junction, with approximal surfaces in contact to simulate the clinical situation. We placed the nontest canine at the head of the block to secure approximal contact for the first premolar test tooth (Figure, A).

Three of us (F.H.-N., A.d.A.P., A.W.) obtained radiographs of the teeth using a radiographic unit (Gendex DC X-ray unit, Gendex Dental Systems, Lake Zurich, Ill.), with rectangular collimation operating at 65 kilovolts peak and 10 milliamperes. We stabilized the blocks of silicone on a positioning jig to create a focus-to-digital receptor distance of 32 centimeters, a central beam orientation and a tooth-to-receptor distance of 2 cm. We placed a 12-millimeter acrylic plate between the source of the X-radiation and the

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ABBREVIATION KEY. **CCD:** Charge-coupled device. **CMOS:** Complementary metal oxide semiconductor. **CMOS-APS:** Complementary metal oxide semiconductor–active pixel sensor. **PSP:** Photostimulable storage phosphor. **TIFF:** Tagged Image File Format. **USB:** Universal Serial Bus.

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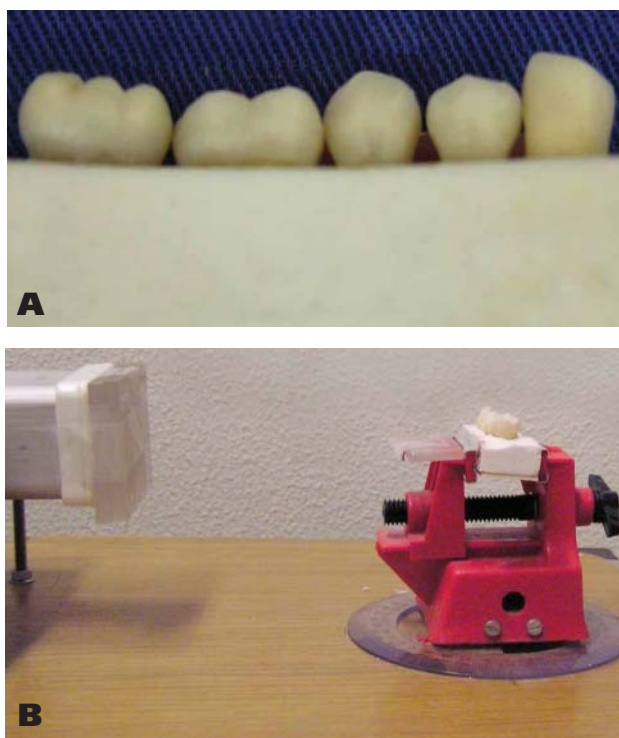


Figure. A. The tooth block. **B.** The tooth block is stabilized on the positioning jig to create a focus-to-digital receptor distance of 32 centimeters. A 12-millimeter acrylic plate is placed between the source of the X-radiation and the teeth to simulate soft tissue.

teeth to simulate soft tissue (Figure, B). We acquired the digital images by using the two PSP systems (Digora FMX and Digora Optime 8-bit resolution) and the two CMOS systems (Schick CDR and Schick CDR Wireless).

In a pilot test conducted before the study, we exposed one tooth block by using each of the four receptors at various exposure times (0.18, 0.22, 0.26, 0.30, 0.34, 0.42 and 0.50 seconds). For each receptor, two blinded observers (F.H.-N., A.W.) selected, in consensus, an image of each tooth (that is, first premolar, second premolar, first molar and second molar) that was of acceptable quality for caries detection. If the observers could not determine subjectively a difference in quality between two images obtained at different exposure times, they selected the image obtained at the lowest exposure time. The exposure times for the selected images were as follows: 0.34 seconds (molars) and 0.30 seconds (premolars) for Digora FMX, 0.42 seconds (both molars and premolars) for Digora Optime and 0.26 seconds (molars) and 0.22 seconds (premolars) for Schick CDR and Schick CDR Wireless.

We stored the PSP image plates in lightproof envelopes during the exposures. Immediately

after exposure, we scanned the exposed phosphor plates with their respective scanners by using the manufacturer's software and following the instructions. The Digora Optime system recorded images of the teeth in 8-bit high resolution. We exported and saved the image files for both the Digora and CDR systems in Tagged Image File Format (TIFF).

All observations took place in a quiet, windowless room with dimmed lighting. We coded the images and displayed them for observers in random order, in full size (1:1) on a 17-inch monitor. We used a software program (CaScO software, developed by Erik Gotfredsen, School of Dentistry, University of Aarhus, Denmark) with image enhancement features to adjust the contrast, brightness, gamma-curve function and magnification. After a practice session, eight independent observers with at least five years' experience with radiographic caries diagnosis assessed the digital images. They recorded the presence of proximal carious lesions by using a five-point confidence rating scale:

- 1 = caries definitely absent;
- 2 = caries probably absent;
- 3 = unsure if caries is present or absent;
- 4 = caries probably present;
- 5 = caries definitely present.

The reading order for the four imaging systems varied for each observer, and a period of at least one day separated each viewing session.

Histologic evaluation. To validate the presence of a true carious lesion, we embedded the teeth in acrylic (Viprcril, Vipi, São Paulo, Brazil) and, using a 200-micrometer diamond band, divided them serially into 700- μ m-thick sections in a mesiodistal direction. We cleaned the tooth sections of dust and glued them to microscope slides using transparent varnish. Two observers performed the histologic examination separately by using a light microscope at a magnification of $\times 12$ to $\times 16$ to look for the presence and extent of a carious lesion. In cases in which the observers' ratings differed, they performed a joint assessment to establish agreement.

We defined a carious lesion as being present when an opaque white demineralization or a brown discoloration was observed in an area at risk of developing caries on the proximal surface. We applied the following scale for the histologic validation:

- 0 = sound;
- 1 = caries in enamel;

TABLE 1

Sensitivity, specificity, accuracy and positive and negative predictive values for four digital radiography systems.

VARIABLE	MEAN (RANGE) PERCENTAGE			
	Digora FMX*	Digora Optime*	Schick CDR†	Schick CDR Wireless†
Sensitivity	15 (7-27)	22 (14-31)	19 (5-42)	23 (10-41)
Specificity	91 (86-99)	85 (68-97)	90 (68-99)	90 (76-99)
Accuracy	63 (61-66)	61 (53-66)	64 (59-68)	65 (61-68)
Positive Predictive Value	53 (41-83)	51 (33-73)	61 (44-89)	63 (45-86)
Negative Predictive Value	65 (64-67)	65 (62-66)	66 (64-67)	67 (65-69)

* Manufactured by Soredex (Tuusula, Finland).
 † Manufactured by Schick Technologies (Long Island City, N.Y.).

- 2 = caries one-third or less into dentin;
- 3 = caries more than one-third into dentin.

Data analysis. For each observer using each radiographic modality, we computed the sensitivity (that is, cumulative percentage of carious enamel lesions identified among those that had carious lesions), specificity (that is, cumulative percentage of sound surfaces identified among those that had sound surfaces) and accuracy (percentage of correct scores) from the results obtained by the radiographic and histologic examinations. We also computed the positive predictive values (that is, the probability that a surface with a positive test result has the disease) and negative predictive values (that is, the probability that a surface with a negative test result does not have the disease), which consider both the sensitivity and specificity of a system as well as the prevalence of the disease being detected. We calculated these values by using the following diagnostic threshold: sound surface equals caries definitely absent, caries probably absent and unsure if caries is present or absent; disease equals caries probably present and caries definitely present.

We estimated the differences in sensitivity, specificity, accuracy and positive and negative predictive values for the four modalities by analyzing the binary data assuming additive effects of observer and method in a generalized linear model using identity link. We adjusted for the correlation within surfaces by applying robust standard errors. The level of statistical significance was $P < .05$.

RESULTS

The true status of the 160 approximal surfaces according to the histologic examination was as follows: 100 (63 percent) were sound surfaces, 50 (31 percent) had enamel carious lesions and 10 (6 percent) had dentinal lesions extending one-third or less into dentin.

Table 1 shows the mean and range of sensitivities, specificities, accuracy and positive and negative predictive values for each digital system, and Table 2 shows the differences between the four systems.

The Digora Optime and Schick CDR Wireless systems exhibited the highest sensitivity values. The difference in sensitivity between the two Digora systems was statistically significant, with the Digora Optime system demonstrating higher sensitivity than the Digora FMX system ($P = .008$). The sensitivity of the Schick CDR Wireless system also was significantly higher than that of the Digora FMX system, but the sensitivity was not significantly higher than that of the Schick CDR system ($P = .13$).

Images obtained with the Digora Optime system exhibited significantly lower specificity values than did those obtained with the other systems ($P < .02$). We found no significant differences in specificity among the Digora FMX, Schick CDR and Schick CDR Wireless systems. The positive predictive value of the Digora Optime system was affected by its high sensitivity and low specificity, and the value was lower than that of the two Schick CDR systems ($P < .02$).

TABLE 2

Differences (95% CI*) in sensitivity, specificity, accuracy and positive and negative predictive values among four digital radiography systems.

VARIABLE	PERCENTAGE DIFFERENCE (95% CONFIDENCE INTERVAL) BETWEEN SYSTEMS					
	Digora FMX† Versus Digora Optime†	Digora FMX Versus Schick CDR‡	Digora FMX Versus Schick CDR Wireless‡	Digora Optime Versus Schick CDR	Digora Optime Versus Schick CDR Wireless	Schick CDR Versus Schick CDR Wireless
Sensitivity	-6 (-11 to -2)§	-3 (-6 to 1)	-6 (-11 to -2)§	4 (-1 to 8)	0 (-5 to 5)	-4 (-9 to 1)
Specificity	4 (1 to 7)¶	-1 (-3 to 1)	0 (-2 to 1)	-5 (-8 to -2)¶	-4 (-7 to -1)¶	1 (-1 to 2)
Accuracy	2 (-1 to 5)	-1 (-3 to 2)	-2 (-5 to 1)	-2 (-5 to 1)	-4 (-7 to -1)	-1 (-4 to 1)
Positive Predictive Value	4 (-6 to 15)	-6 (-16 to 5)	-8 (-18 to 2)	-10 (-18 to -1)#	-12 (-21 to -3)#	-2 (-12 to 7)
Negative Predictive Value	0 (-2 to 2)	-1 (-2 to 1)	-2 (-3 to 0)	-1 (-2 to 1)	-2 (-3 to 0)	-1 (-3 to 1)

* CI: Confidence interval.
 † Manufactured by Soredex (Tuusula, Finland).
 ‡ Manufactured by Schick Technologies (Long Island City, N.Y.).
 § P = .008.
 ¶ P < .02.
 # P < .02.

The overall accuracy of the digital radiography systems ranged from 0.61 for the Digora Optime system to 0.65 for the Schick CDR Wireless system. The difference between the older and newer PSP and CMOS systems was not statistically significant.

DISCUSSION

We conducted this study in vitro, which permitted the histologic examination of the approximal surfaces as the ultimate validation criterion. A thorough evaluation of new diagnostic methods always should precede their introduction to routine clinical practice. Laboratory studies are needed to determine whether the new digital imaging systems alter the diagnostic findings compared with well-established methods.

Sensitivity. The generally low sensitivities of all the digital systems evaluated in this study (ranging from 15 to 23 percent) indicate that they all failed to detect small initial lesions. This finding is in accordance with the results of earlier studies of the detection of approximal lesions.^{9,19} Our study results demonstrate that, for the diagnosis of proximal carious lesions, the sensitivity of the Schick CDR Wireless and Digora Optime systems was higher than the sensitivity of the

older Schick CDR and Digora FMX systems. Several studies have shown that the Digora FMX and Schick CDR systems possess a diagnostic accuracy comparable with that of conventional film radiography for the detection of proximal carious lesions.^{7,10,13,16-20}

Positive predictive values. We found no differences in positive predictive values between the two versions of the Digora system and between the older and newer versions of the Schick CDR system. These results suggest that the likelihood of attaining a positive test result with the newer Digora and CDR systems might be comparable with that of the recognized older systems in tooth samples with disease prevalence and lesion distribution similar to ours. The positive predictive values of the Schick CDR systems were significantly higher than that of the Digora Optime system.

Specificity. Our study results showed no statistically significant differences in specificity between the Schick CDR Wireless system and the Schick CDR system. However, we found a significant difference between the Digora systems in that the Digora Optime system exhibited significantly lower specificity than the Digora FMX system. The possible clinical implication for caries

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diagnosis is that the risk of a false-positive result may be higher when using the Digora Optime system than when using the Digora FMX system. Because this study was conducted on small carious lesions, the clinical implication of a higher false-positive outcome with the Digora Optime system probably will result in more resources being spent for improvements in oral hygiene rather than in increasing the risk of placing unnecessary restorations. The overall accuracy was virtually identical for the Digora Optime and Digora FMX systems, as well as for the Schick CDR Wireless and Schick CDR systems.

According to Tsuchida and colleagues,²¹ the physical properties of the wireless and wired Schick CDR sensors are essentially equal. One could speculate that when using radio wave transmission, the signal may be disturbed (for example, by mobile telephones), but, according to the manufacturer, the only evidence of a signal disturbance has been a turned-on microwave oven situated a short distance from the sensor.²² We did not experience transmission problems in this study; however, no published documentation seems to exist with regard to transmission efficiency with the wireless sensor.

The wireless sensor also may provide some functional improvements over its predecessor. Bahrami and colleagues² showed that bitewing recordings obtained with a wired sensor system gave rise to many more missing tooth surfaces and marginal bone crests compared with a PSP system, because the wired sensors are thicker than those of the PSP system and the wire is more difficult to position in the mouth. It may be that the wireless sensor causes less unpleasantness for the patient than do wired sensors. Future studies should evaluate intraoral recording procedures and patients' perceptions of the new digital systems in clinical settings.

In addition, other procedures, such as diagnosis of periodontal bone loss and periapical lesions, should be evaluated before clinicians and researchers can claim that the wireless sensor is as accurate as its wired version. The new generation of Digora PSP system—Digora Optime—also offers improvements over its predecessor, particularly with respect to waiting time for the dentist. In addition, more flexible plates covered in less sharp and less stiff envelopes are apt to be more pleasant for the patient. The scanning time of six to eight seconds for the Digora Optime scanner represents the fastest PSP plate scanner on the

market; however, fast scanning may be accompanied by more noise in the image. Further studies are needed to explore the apparently higher false-positive outcomes in caries detection with the Digora Optime system compared with the Digora FMX system. The Digora FMX system is obsolete and no longer sold by the manufacturer, while the two Schick CMOS systems are available.

CONCLUSION

The overall accuracies of the new Digora Optime and Schick CDR Wireless systems are comparable to their predecessor Digora FMX and Schick CDR systems for the diagnosis of small proximal carious lesions. It seems, however, that more false-positive diagnoses are made with the Digora Optime system than with the Digora FMX system. Although the result is statistically significant, we question whether the difference in specificities between the Digora Optime system and the three other systems is clinically relevant. Dentists should purchase whichever system they prefer, after considering factors other than those evaluated in this study. ■

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