RESEARCH

Comparison of digital systems and conventional dental film for the detection of approximal enamel caries

AA Pontual^{*,1}, DP de Melo², SM de Almeida², FN Bóscolo² and F Haiter Neto²

¹Department of Oral Medicine, Division of Oral Radiology, Pernambuco Dental School, Pernambuco University, UPE, Camamragibe, Recife, Brazil; ²Department of Oral Diagnosis, Division of Oral Radiology, Piracicaba Dental School, Campinas University, UNICAMP, Piracicaba, São Paulo, Brazil

Objectives: The aims of this study were (1) to compare the accuracy of the detection of approximal enamel caries lesions using three intraoral storage phosphor plate digital systems and one conventional film-based radiographic system; and (2) to determine whether there is a correlation between the histological and radiographic measurements of enamel caries.

Methods: 160 approximal surfaces were radiographed under standardized conditions using three storage phosphor stimulable systems (DenOptix and Digora FMX with white and blue plates), and one film system (Insight film). 17 observers scored the images for the presence and depth of caries using a 4-point scale. The presence of caries was validated histologically (gold standard). Two-way analysis of variance was used to test the differences in sensitivity, specificity and overall accuracy (TP+TN). The data from the radiographic and histological measurements were statistically analysed by Spearman's rank correlation coefficient.

Results: Two-way analysis of variance and the *post hoc t*-test demonstrated that Digora (white plate) had higher specificity and overall accuracy values than DenOptix ($P = 0.021$); there was no statistically significant difference among the other imaging modalities ($P > 0.05$). There was no significant correlation between the histological depth measurements and the radiographic measurements from Digora (blue plate) ($P = 0.43$), Digora (white plate) ($P = 0.15$), DenOptix ($P = 0.17$) and Insight film ($P = 0.06$).

Conclusions: The results suggest that (1) the performance of the three storage phosphor image plate systems was similar to that of the Insight film for detection of approximal enamel caries, and (2) the increase in histological depth of enamel caries was not significantly correlated with radiographic measurements.

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Introduction

The prevalence and the behaviour of approximal caries have changed during the last decades, probably because of the scientific advances in preventative dentistry. These changes have had a profound impact on the treatment philosophy of this pathology, resulting in immediate operative therapy for a carious lesion being replaced by non-invasive treatment. Currently, the greatest difficulty in caries detection concerns the carious lesion in the initial stages, when it is confined to the enamel layer.^{1–3} As it has become more difficult to diagnose caries in clinical practice, several diagnostic

methods are being improved and others developed. Examples include laser fluorescence, transillumination, electrical conductance measurement (ECM), electrical impedance measurement, digital imaging and imaging processing for caries detection.^{4,5}

Clinical examination of contacting approximal surfaces, even under ideal circumstances, results in an unacceptable proportion of false-negative results, especially in the presence of tight contact points that impair inspection.⁵ Thus, caries in approximal surfaces has traditionally been diagnosed by clinical examination combined with radiography.

Developments have made it possible to use computer technologies to acquire and display digital radiographic images.⁶ Several digital radiographic systems are

*Correspondence to: Andrea dos Anjos Pontual, Rua Guerra de Holanda, 79, Casa Forte, Recife PE 52061-010, Brazil; E-mail: pontual.andrea@gmail.com
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currently used in dental practice as an alternative to film-based radiography. Several studies have shown that direct digital systems have a number of advantages when compared with conventional film.^{2,7-13} For example, the exposure dose should, in principle, be reduced since digital images are less likely to show the high frequency of exposure or processing artefacts often experienced with conventional film; working time from image exposure to image display is reduced (no wet processing is involved) and image communication is easier. Another potential advantage of digital imaging is the ability to perform image quality enhancements such as contrast and density modulation, which may increase diagnostic accuracy.^{2,8-13}

There are two different approaches to direct digital image acquisition: the solid state-based system (charge-coupled device and complementary metal oxide semiconductor active pixel image sensors) and the photo-stimulable phosphor (PSP) plate systems. In storage phosphor imaging systems (SPIP), an image plate is exposed to X-radiation, the absorbed energy is temporarily stored 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 capturing it in a laser scanner. The information is converted to electrical signals, which are subsequently digitized.^{8,10,12,14,15}

Lesion type has an influence on radiographic estimation of caries lesion. It has been shown that enamel lesions are less underestimated than dentine lesions.¹⁶ Previous studies have focused on lesion detection, whether caries lesion is present or not, but none of them has evaluated the influence of enamel caries depth. The aims of the present study were (1) to evaluate the diagnostic accuracy of enamel caries lesion detection using one conventional film system and three SPIP systems and (2) to determine whether there is a correlation between the histological depth measurements of enamel caries and the radiographical measurements from each of the imaging modalities.

Materials and methods

After approval by Piracicaba Dental School Ethics Committee, a sample of 80 unrestored extracted human permanent teeth, 40 premolars and 40 molars, was used in this study. Clinically, the approximal surfaces of the teeth were without cavitations and ranged from sound to varying degrees of demineralization, appearing as chalky white or brown areas of discolouration. The teeth were divided into 20 groups, disregarding the surface status. Four test teeth, two premolars and two molars, and one non-test canine were mounted in a block of silicone in an anatomical position from the apex to the cemento-enamel junction with approximal surfaces in contact to simulate clinical conditions. The

non-test tooth was placed at the beginning of the row to create approximal contact for the first test tooth.

Bitewing projection geometry was used, as each block was stabilized on a positioning jig to provide a target-to-film distance of 40 cm and a central beam orientation. The teeth were radiographed with Insight film (Eastman Kodak, Rochester, NY) and with the phosphor plates of two intraoral digital systems: Digora, blue and white plates (Soredex Medical Systems, Helsinki, Finland), no longer on the market, and DenOptix (Gendex, Milan, Italy). The X-ray unit was a GE 1000 X-ray machine (General Electric Company, Milwaukee, WI), operating at 70 kVp, 10 mA. A 15 mm acrylic plate was placed between the tube and the teeth to simulate soft tissue. Optimal exposure times were determined by a pilot study. The exposure time used for the Insight film was 0.35 s, which resulted in a density of 1.0 for the step 3 image of an 8-step aluminium step-wedge, 16 mm in total thickness with a 2 mm increase per step.¹⁷ Before the study, all digital receptors were exposed using various exposure times (ranging from 0.06 s to 0.50 s). For each SPIP, three maxillofacial radiologists, working in consensus and blinded to the exposure times, selected which image had an acceptable quality for caries detection. If no difference in quality between two images with different exposure times could be determined, the lowest exposure time was selected. For each digital system, the exposure time was as follows: 0.25 s for Digora (blue plate), 0.13 s for Digora (white plate) and 0.20 s for DenOptix.

The conventional films were processed in an automatic GPX processor (Gendex Dental Systems, Milan, Italy), using fresh Kodak RP X-OMAT processing solutions (Eastman Kodak). The phosphor image plates of the digital systems were stored in lightproof envelopes during the exposure. The exposed phosphor plates were scanned in their scanners (Digora FMX Scanner and DenOptix Scanner) using the manufacturer's software and the files were exported and saved in tagged image file format (TIFF).

All observations took place in a quiet, windowless room with dimmed lighting. Mounted conventional films were displayed one at time in a random sequence on a conventional masked viewbox with fixed light intensity. A $\times 2$ magnification viewer was used to assess the conventional films. Digital images were displayed to the observers on a 17 inch monitor in random order using the EMAGO/Advanced 3.43 software (Acta Oral Diagnostic Systems, Louwesweg, Amsterdam, the Netherlands). 17 observers viewed the conventional and digital radiographs and recorded their diagnosis for the presence and depth of approximal enamel caries using a 4-point scale: 0, sound; 1, caries restricted to the outer half of the enamel; 2, caries in the inner half of the enamel up to the enamel-dentine junction; 3, caries in dentine. The observers included six oral and maxillofacial radiologists, two restorative dentists, three periodontists, two

pedodontists and four general practitioners. Verbal and written instructions were made available to the observers. The reading order for the four different image modalities varied for each observer, and a period of at least 3 days separated each of the four viewing sessions.

For validating the presence of true caries, the teeth were individually embedded in acrylic (Vipcril, Vipi, São Paulo, Brazil) and serially sectioned into 700 µm thick sections in the mesiodistal direction, using a 200 µm diamond band. The tooth sections were cleaned of dust and glued to microscope slides using transparent varnish. Histological validation was performed by two observers using a light microscope at $\times 12.5$ –20 magnification. Caries were defined as present when an opaque-white demineralization or brown discoloured area was observed on the surface. For histological validation, the same 4-point rating scale used in the radiographic assessment was applied to the approximal surfaces. For the validation, the observers individually assessed the teeth. If the observers' ratings varied, they were asked to perform a joint assessment to establish agreement. The histological examination of the sample showed that eight of the carious lesions extended into the dentine. These eight surfaces were excluded from the sample, since the purpose of the present study was to evaluate the radiographic detection of enamel approximal caries.

The surfaces with enamel caries were submitted to another histological examination to measure the extent of the enamel layer and the depth of the carious lesion. These histological measurements were performed by two observers under a light microscope connected to a millimetric ocular (Axiolab, Zeiss, Germany). The observers measured the depth of the lesion and the extent of the enamel layer in the histological section in which the caries lesion was deepest. The scale values of this ocular were established in millimetres by an object micrometer (Axiolab). The mean of the two observers' measurements was used to determine the proportion between the caries lesion and the enamel layer (histological depth measurements).

Data analysis

For each observer and each radiographic modality, the sensitivity (cumulative per cent of carious enamel lesions identified among those that had carious lesions), specificity (cumulative per cent of sound surfaces identified among those that had sound surfaces) and accuracy (per cent of correct scores) were computed. Two-way analysis of variance tested differences in sensitivity, specificity and accuracy. Pair-wise comparisons of the systems were made by Tukey's honestly significant difference (HSD) test. The relation between the histological measurements of the depth of enamel caries and the mean of the measurements from 17 observers of radiographs from each of the imaging modalities was analysed using Spearman's rank order correlation coefficient (SAS software, SAS System Release 8.02, SAS Institute, Cary, NC).

Results

The true status of the approximal surfaces according to histology was 88 sound surfaces; 38 surfaces with caries restricted to the outer half of the enamel and 26 surfaces with caries in the inner half of the enamel up to the enamel–dentine junction.

Table 1 shows the mean sensitivities, specificities and overall accuracy for each imaging modality. DenOptix and Insight film displayed higher sensitivity values than the other imaging modalities, whereas Digora (blue plate) had the lowest sensitivity of all modalities, although these differences were not statistically significant ($P = 0.779$).

The specificities were generally higher for all imaging modalities. Two-way analysis of variance revealed significant differences in specificity between the imaging modalities ($P = 0.023$). *Post hoc* paired comparisons of each of the modalities using Tukey's HSD test demonstrated that DenOptix showed significantly lower specificity than Digora (white plate) ($P = 0.018$). There were no differences between the remaining digital systems and conventional film ($P > 0.05$) (Table 2).

Table 1 Sensitivity, specificity and accuracy for each imaging modality: Digora blue plate, Digora white plate, DenOptix and Insight film

Descriptive statistics	n	Mean	Standard deviation	Standard error	Minimum	Maximum
<i>Sensitivity</i>						
Digora blue plate	17	0.14	0.082	0.020	0.047	0.328
Digora white plate	17	0.15	0.079	0.019	0.031	0.297
DenOptix	17	0.16	0.075	0.018	0.047	0.281
Insight film	17	0.16	0.070	0.017	0.031	0.250
<i>Specificity</i>						
Digora blue plate	17	0.93	0.052	0.013	0.830	1.000
Digora white plate	17	0.94	0.040	0.010	0.874	1.000
DenOptix	17	0.89	0.055	0.013	0.807	0.977
Insight film	17	0.92	0.053	0.013	0.818	1.000
<i>Accuracy</i>						
Digora blue plate	17	0.59	0.020	0.005	0.559	0.632
Digora white plate	17	0.61	0.022	0.005	0.556	0.649
DenOptix	17	0.58	0.023	0.006	0.546	0.632
Insight film	17	0.60	0.020	0.005	0.559	0.632

ANOVA demonstrated a significant difference among the modalities ($P = 0.021$). The overall accuracy (true positive + true negative) was significantly higher for Digora (white plate) than DenOptix ($P = 0.021$); there were no significant differences among the other imaging modalities ($P > 0.05$) (Table 2).

Spearman's rank order correlation coefficient (r_s) established that there was no statistically significant correlation between histological depth measurements of enamel approximal caries and their radiographic measurements from Digora (blue plate) ($r_s = 0.1$; $P = 0.43$), Digora (white plate) ($r_s = 0.18$; $P = 0.15$), DenOptix ($r_s = 0.17$; $P = 0.17$) and Insight film ($r_s = 0.2$; $P = 0.06$).

Discussion

The sensitivity values are virtually identical for digital systems and conventional film in the present study. The finding that the storage phosphor digital systems and the Insight film are diagnostically similar for detection of approximal enamel caries suggests that they may be used in dental practice for this task. This supports the conclusion of previous studies that there are no statistically significant differences between conventional film and digital systems for diagnosis of approximal caries.^{18–24,26,27}

A previous study by Hintze *et al*¹⁰ indicated that the reduction in exposure with the digital systems from 25% to 10% of the exposure time needed for E-speed film resulted in statistically significant differences among the phosphor plate systems; Digora (white plate) was as accurate as conventional E-speed film and was more accurate than DenOptix and Digora

(blue plate). These authors suggested that these differences were a result of the reduction in the thickness of the phosphor layer in the blue plates compared with those of the white plates. In the present study, there was no statistical difference between Digora (white plate) and Digora (blue plate), since for each storage phosphor plate the exposure time that generated acceptable image quality for caries detection was chosen. Furthermore, Digora (white plate) was found to be significantly more accurate and specific than the DenOptix.

The low sensitivities of imaging modalities, ranging from 0.14 to 0.16, suggest that all radiographic systems failed to detect enamel approximal caries. These low sensitivities may not be unexpected, since it has been shown that natural enamel lesions have an irregular shape and relatively low contrast and are not sharply defined. These results are consistent with those that have been reported in the literature.^{15,25,27} Hintze and Wenzel,¹⁵ using the criteria of “definitely” and “probably present” to define caries as present, found that only 18% of carious lesions were detected by radiography. In the present study, the observers reported the caries depth of each approximal surface and there were no scores of uncertainty.

The increase in histological depth was not significantly correlated with the radiographic measurements, since Spearman's correlation revealed rather weak coefficients for all imaging modalities, showing a lack of consistency for the radiographic measurements of enamel approximal caries. There seems to be no increase in detection of radiographic caries with increased depth of the enamel caries. In accordance with Syrioupoulos *et al*,²⁶ White and Yoon²⁷ and Castro *et al*,²⁸ deeper caries lesions were easier to detect by radiographic systems than relatively superficial ones. The material in these studies consisted of sound surfaces, enamel and dentine caries; in the present study, the caries sample was composed of natural enamel caries.

Castro *et al*²⁸ observed that the detection rate for enamel lesions was close to chance in all digital modalities evaluated in their study, and, as the lesions penetrate dentine, observers are able to detect their presence more consistently. Enamel lesions detection has been an issue in dental radiography, as its clinical diagnosis is even harder to perform than radiographic diagnosis. Methods have been improved in order to overcome radiographic limitation in this area. The increase in enamel lesion extension does not interfere with the correct diagnosis of the carious lesions, as shown in our results.

It seems that high contrast is a prerequisite for interpretation of radiographic approximal caries. Radiographs need to be quite dark with good contrast to provide an optimal basis for caries detection. Diagnosis of caries on radiographs occurs when the difference in density between the dental hard tissues and the demineralization in tissues by caries is detected

Table 2 Comparison of mean sensitivity, specificity and accuracy with three digital systems and one film system for approximal caries

Modalities	Mean difference	P-value
<i>Sensitivity</i>		
Digora blue vs Digora white	−0.010	0.981
Digora blue vs DenOptix	−0.025	0.782
Digora blue vs Insight film	−0.021	0.853
Digora white vs DenOptix	−0.015	0.944
Digora white vs Insight film	−0.011	0.975
DenOptix vs Insight film	0.004	0.999
<i>Specificity</i>		
Digora blue vs Digora white	−0.011	0.912
Digora blue vs DenOptix	0.041	0.094
Digora blue vs Insight film	0.006	0.985
Digora white vs DenOptix	0.052*	0.018*
Digora white vs Insight film	0.017	0.746
DenOptix vs Insight film	−0.035	0.192
<i>Accuracy</i>		
Digora blue vs Digora white	−0.009	0.642
Digora blue vs DenOptix	0.013	0.282
Digora blue vs Insight film	−0.005	0.880
Digora white vs DenOptix	0.022*	0.021*
Digora white vs Insight film	0.003	0.972
DenOptix vs Insight film	−0.019	0.062

*Paired comparisons of the modalities using Tukey's honestly significant difference test demonstrated significant differences ($P < 0.05$)

by radiographic methods as a result of the different interactions between X-rays and the mineral present in the exposed structures. In enamel approximal caries, the boundary between sound and diseased tissue may present relatively low radiographic contrast for it to be detected by radiographic systems. The extent of change over time of carious lesions can be assessed and monitored by measuring the linear distance *in vitro*.^{29,30} Even if the technician takes precautions during radiographic exposure geometry, the resulting radiograph tends to underestimate the extension of the lesion compared with the histological examination.^{2,31,32}

Specificities were generally higher for film and digital systems (ranging from 0.89 to 0.94). A caries diagnostic method which emphasizes specificity at the expense of some loss of sensitivity seems preferable, as the consequences of false-positive results in clinical terms

may be the unnecessary filling of sound teeth and the initiation of a continuous and increased repair cycle. Since incipient caries not detected by diagnostic methods develop slowly, arrest or remineralize with the use of fluoride dentifrices, radiography may be used in combination with clinical examination for caries diagnosis until new diagnostic methods are developed. The clinical decision whether to excavate caries should be made based on cavitation rather than histological lesion depth.³²

In conclusion, there was no significant difference in the diagnostic accuracy among Insight film and Digora and DenOptix digital systems for approximal 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.

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