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Detection of proximal caries in conventional and digital radiographs: an *in vitro* study

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SUMMARY

Objectives. To compare digital images to conventional film radiography in the diagnosis of proximal caries.

Methods. Fifty-one molars and 24 premolars were studied and divided in groups of three teeth. They were fixed in silicone and radiographed using InSight film (Kodak) and the digital systems Digora (Soredex), DenOptix (Gendex) and CygnusRay MPS (Progeny). Twenty-five radiographs were obtained in each modality and four proximal surfaces were analyzed in each radiograph. Radiographs were interpreted individually by one observer at three different sessions for each imaging modality. Caries lesions were classified according to their depth: (0) absent; (1) restricted to enamel; (2) reaching the dentino-enamel junction; and (3) reaching the dentin. The teeth were sectioned and ground in order to obtain the gold standard and were examined histologically by stereomicroscopy.

Results. The Kendall test was employed and showed a good intra-observer agreement among the three evaluations implemented. The sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were all calculated, and there were no significant differences observed among the four imaging modalities studied (ANOVA, $p \leq 0.05$). Besides, the ROC curve was determined for each modality and no statistically significant differences were observed when comparing the areas under the ROC curve at the 5% level of significance.

Conclusions. The results demonstrate that the diagnostic accuracy of digital images is similar to that of conventional film radiography in the detection of proximal caries.

Keywords: dental caries; radiography; diagnostic imaging; microscopy.

INTRODUCTION

The introduction of digital radiographs providing various possibilities of manipulating the radiographic image and allowing the image to be easily obtained, stored and transmitted consisted in an important advance in the area of imaging diagnosis was However, studies found in the literature are divergent in relation to the quality of the images when comparing digital systems and conventional film radiographs. Some works consider the image quality of the radiographic films comparable to that of the systems with charge-coupled devices (CCD) [1-3] and to the ones that use storage phosphor plates [4-6]. Other studies reported the superiority of the systems with storage phosphor plates over conventional radiographs and over systems with charge-coupled devices [7-10]. There are also works that demonstrated a greater diagnostic accuracy of conventional film radiographs in relation to digital systems [11].

According to White and Yoon [2], the diagnosis of carious lesions is a very difficult task, even with the radiographs. Wenzel and Hintze [12] found that radiography is far from being an accurate method for caries diagnosis, particularly for small proximal lesions. On the other hand Møystad et al. [13] emphasized the need for the development of methods that can correctly discriminate sound surfaces from those with carious lesions, especially in the outer half of enamel. Therefore, because of the need of better methods for proximal caries diagnosis, mainly with

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the aim of detecting early lesions, it is necessary to verify if the introduction of digital systems provided a significant contribution to the radiographic caries diagnosis.

MATERIALS AND METHODS

The material was consisted of 75 human teeth, extracted due to clinical indication. They included 51 molars and 24 premolars, sound or with small proximal cavities, and without restorations. The teeth were scraped to remove residual organic matter and disinfected in 2% glutaraldehyde for 24 h. They were stored in physiological sodium chloride afterwards (NaCl 0.9%).

For radiographic exposures the teeth were divided in groups with three elements. The teeth were positioned vertically with proximal contacts to simulate clinical conditions and were affixed in blocks of silicone (Express™ STD, 3M ESPE, St Paul, USA) surrounded by an approximately 10 mm thick layer around the roots. Dental wax of 10 mm thickness was placed in front of the teeth to simulate soft-tissue [14]. The teeth were radiographed with their long axes perpendicular to the central ray, utilizing a Timex-70X DRS (Gnatus, Ribeirão Preto, SP, Brazil) X-ray machine, operating with 70 kVp, 7 mA and with HVL of 2.5 mm Al. The focus-film distance was 40 cm. The exposure times were determined by a pilot study.

The conventional film radiographs were obtained utilizing periapical film no. 2, IP-21 InSight (Eastman Kodak Co., Rochester, NY, USA). The exposure time used was 0.40 s. The films were simultaneously processed in an automatic processor (A/T 2000® XR, Air Techniques Co., Hicksville, NY, USA) according to the manufacturer's instructions.

Twenty-five digital radiographs were also acquired utilizing storage phosphor plates (31×41 mm) of the DenOptix™ system (Gendex®, Des Plaines, IL, USA). The exposure time used was 0.50 s. The images were processed in the system's scanner and analyzed employing the VixWin™ 2000 program (Gendex®, Des Plaines, IL, USA).

Another series of 25 digital radiographs was obtained utilizing the digital system Digora® (Soredex, Orion Co., Helsinki, Finland) which also used storage phosphor plates. The exposure time used was 0.32 s. The imaging plates (30×40 mm) were scanned in the Digora® scanner. Analysis of the images was carried out with the Digora® program for Windows version 2.1.

A series of 25 other digital radiographs were acquired using the CygnusRay MPS system (Progeny, Buffalo Grove, IL, EUA) with a charge-coupled device (CCD) which has the dimensions 39.5×25×5.7 mm. The exposure time used was 0.12 s. This system is accompanied by the Cygnus program Imaging® for Windows®.

This study involved 25 conventional film radiographs and 75 digital radiographs, a total of 100 radiographs. Four proximal surfaces were analyzed in each radiograph.

The radiographs were interpreted individually by one examiner in three different viewing sessions considering all imaging modalities. A period of at least one week separated each viewing session and the radiographs were selected randomly. Only the proximal surfaces in contact with the adjacent tooth were analyzed. The free proximal, occlusal and cervical surfaces lesions were not considered. The results showed average values of the observer's three readings.

The evaluations were carried out in a room with the light dimmed that was reproducible between viewing sessions. The conventional film radiographs were examined with a 4× magnification lens in a viewbox with a masking frame which has a central opening corresponding to no. 2 film. The digital images were examined in a monitor set at 1024×768 resolution, with the use of tools to adjust the brightness and contrast, inversion and amplification of the image.

The lesions were classified according to their depth, employing the ordinal caries depth rating scales [15], where: 0 – no carious lesion; 1 – caries restricted to enamel; 2 – caries reaching the dentino-enamel junction; and 3 – caries extending into the dentin.

For the validation of the caries true absence or presence (gold standard) the teeth were sectioned and polished and then examined by stereomicroscopy. They were hemi-sectioned with a diamond saw (Extec® Labcut 1010, Enfield, CT, USA) perpendicular to the occlusal and buccal surfaces. Two halves were thereby obtained, each one representing a proximal surface. They were polished in the bucco-lingual direction utilizing a polisher (Politriz DPU-10, Panambra, São Paulo, SP, Brazil) and wet sandpapers with granulations of 200 to 600. During this process the proximal surfaces were examined with a 10× magnification lens and were polished up to the center of contact point/area or lesion or up to the center of the lesion [8].

The histological examination was performed with a stereomicroscope (Olympus DF Planapo IX SZH10, Japan) at 15 and 30 times magnification. The images were captured utilizing the program *Image-Pro plus*. The image program *Windows Picture Manager* was also used for this analysis. Microscopic analysis was performed by two observers, both experienced in his-

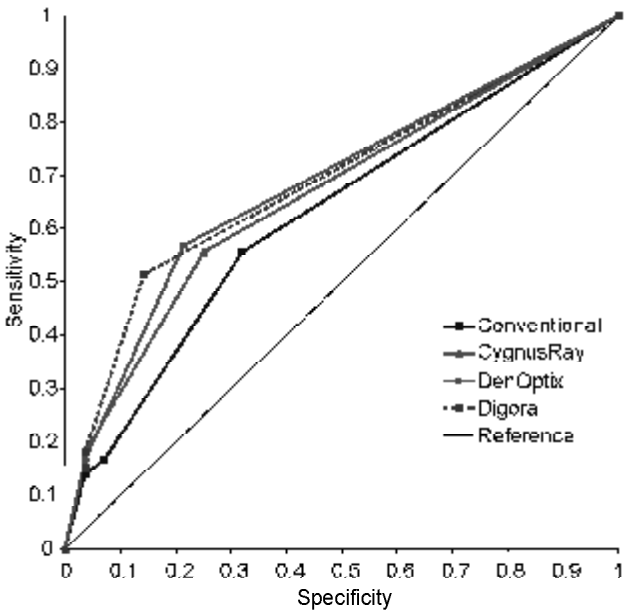

Fig. ROC curves of all imaging modalities studied

tological examination and disagreements were settled by consensus. Caries was defined as present when there was a cavity or when demineralization, demonstrated by a change in opaque- white to dark brown color, was observed in an area at risk of caries [16].

RESULTS

An evaluation of intra-observer agreement using Kendall's test showed intra-observer agreement ranging between 0.795 and 0.859, this is considered a good reliability (Table 1).

A table to compare the results with those from the validation method was constructed. The absence of caries was determined when the teeth surface received a score of 0, on the other hand caries was defined as present if the score was 1 or higher. Sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV) were calculated from this table. The results are presented in Table 2.

There was no statistically significant difference in sensitivity, specificity, PPV and NPV, for the diagnosis of proximal caries among the four imaging modalities (ANOVA, $p \leq 0.05$). Albeit not statistically significant, the DenOptix system exhibited the highest sensitivity and the highest NPV values when compared with the other modalities. In turn, the Digora system showed the highest specificity and PPV among the imaging modalities studied. The conventional film radiography showed the lowest values for all indices except for the sensitivity.

Table 1. Intra-examiner agreement

Method	Kendall´s W
Conventional (film)	0.853
CygnusRay	0.820
DenOptix	0.795
Digora	0.859

Analysis of the receiver operating characteristic (ROC) curves were also used to compare the radiographic modalities studied (Figure). The area under the ROC curve was determined and was not found to differ statistically among the four imaging modalities at the 5% level of significance (Tables 3 and 4).

The radiographic modalities were also compared through Friedman test and it was complemented by his multiple comparison test. No statistically significant difference was observed among the four radiographic modalities in relation to the different depths of the lesions studied. Although all methods were statistically different from the microscopic analysis which was the gold standard employed in this study (Table 5).

DISCUSSION

Digital systems are becoming more available to dental practice. However these systems need to provide images whose diagnostic value is at least comparable to the one of the conventional film radiographs in order to replace the images obtained with the radiographic films [1,7]. In the present study no significant difference between the digital systems and the conventional film modality in the radiographic proximal caries diagnosis was observed.

Table 2. Values for sensitivity, specificity, PPV and NPV for radiographs with InSight film, CygnusRay, DenOptix and Digora systems

Method	Sensitivity		Specificity		PPV		NPV	
	Proportion	Standard error	Proportion	Standard error	Proportion	Standard error	Proportion	Standard error
Conventional%	55.6	0.059	67.9	0.090	81.6	0.056	37.3	0.068
CygnusRay%	55.6	0.059	75.0	0.083	85.1	0.052	39.6	0.068
DenOptix%	56.9	0.059	78.6	0.079	87.2	0.049	41.5	0.068
Digora%	51.4	0.059	85.7	0.067	90.2	0.047	40.7	0.065
p*	0.919		0.466		0.695		0.975	

*ANOVA: Values differ significantly if p 0.05

Table 3. Area under the ROC curves for radiographs with all imaging modalities studied

Method	Area	Standard error	P	Confidence interval (95%)	
Conventional	0.626	0.060	0.051	0.508	0.744
CygnusRay	0.665	0.057	0.011	0.553	0.778
DenOptix	0.685	0.056	0.004	0.575	0.796
Digora	0.689	0.055	0.003	0.580	0.797

In the radiographic modalities studied measures of accuracy were low. One explanation for these low values is the quality of the sample, due to the high representation of caries in the enamel (46 lesions). The same occurred in the work of Li et al.[18]. Initial lesions in the proximal surfaces are histologically visible in the enamel but are not radiographically detected. In similar studies deeper lesions were more easily detected than the superficial lesions [2,3,18]. However it was observed that the severity of proximal caries was radiographically underestimated. This also occurred in the present study where many lesions histologically characterized in the dentin were visualized in radiographs as a more superficial lesion localized in the enamel. According to Ricketts et al. [19] the low sensitivity, which was also noted by Russell and Pitts [20], demonstrates the difficulty of diagnosing demineralized tooth tissue when X-ray have to pass through intact buccal and lingual enamel.

In this study the imaging modalities presented higher specificity (67.9% to 85.7%) than sensitivity (51.4% to 56.9%). The same was found in the study of Svanaes et al. [10]. In clinical practice, in examinations with bitewings radiographs, a greater specificity is important, that is, a greater detection of intact surfaces and a low rate of false-positives, when dealing with an irreversible treatment to assure that there is no over-treatment. Although there was no statistical significance a lower specificity was found corresponding to the conventional film radiographs. A combination of the diagnostic methods makes it possible to increase sensitivity while maintaining a high specificity, thereby resulting in a more effective diagnosis.

The analysis of the ROC curves presented no significant difference in area under the curves (Az) among the four imaging modalities indicating that the digital systems had a diagnostic accuracy comparable to the conventional film radiographs in the detection of proximal caries. The area under the ROC curves varied between 0.626 and 0.689. The greatest area corresponds to that of the Digora system and the least to the conventional film radiography. Therefore diagnostic accuracy defined by Az values was relatively low. These low values as already mentioned can be explained by the over-representations of carious lesions in the enamel. In the study by Li et al. [17] the Az values were also low, being 0.57 for original images and 0.66 for processed images.

These findings are in line with other similar works utilizing various imaging modalities, which also found no significant differences in the area under the ROC curves between the conventional film radiographs methods and digital systems. However, the mean Az areas on the proximal surfaces did vary considerably among the different works. Wenzel et al. [21] obtained values lower than those found in the present study, while Hintze et al. [22] found similar results, unlike Nair and Nair [3] and Haak et al. [23] who obtained higher values.

The ROC curve is frequently constructed with data from a sample on a rank scale which measures the likelihood [24]. However, Verdonschot et al.[15] verified the applicability of ROC curve with data derived from diagnostic systems which employ an ordinal scale of severity based on the caries depth and demonstrated that this rating scale yielded more comprehensive measures of diagnostic performance and can be adequate for studies of diagnostic systems. Therefore this study to classifies the lesions according to their depth,

Table 4. Comparison of area under the ROC curves among all imaging modalities studied

Method	p
Conventional x CygnusRay	0.553
Conventional x DenOptix	0.306
Conventional x Digora	0.279
CygnusRay x DenOptix	0.707
CygnusRay x Digora	0.710
DenOptix x Digora	0.942

Table 5. Friedman test, complemented by multiple comparison test, for gold standard and imaging modalities

Score	Method				
	Gold Standard	Conventional	CygnusRay	DenOptix	Digora
0	28	51	53	53	59
1	46	35	33	34	27
2	3	3	1	0	2
3	23	11	13	13	12
Total	100	100	100	100	100
Mean Rank	3.75 ^{A}	2.86 ^{B}	2.86 ^{B}	2.84 ^{B}	2.70 ^{B}

* Mean ranks followed by different letters are significantly different. Significance level at 5%.

beginning at the external portion of the proximal surface.

One of the most important criteria in the evaluation of accuracy of a diagnostic method is to determine the validation method that expresses the true state of the disease. In carrying out the histological examination in this work the teeth were hemi-sectioned and the halves were later polished to determine the depth of the lesion without excessive loss of dental tissues. According to Hintze and Wenzel [16] the results obtained with histological validation should be regarded as more reliable. Therefore, although the areas under the ROC curves obtained with histological validation were lower, as occurred in the present study, the results obtained are more trustworthy.

The number of examiners is another important factor in the design of laboratory studies. Bader et al. [25] believe that a small number of observers is a limiting factor to those studies which evaluate methods for the identification of caries lesions. However it is more productive to compare the findings of one observer to the gold standard than to those of other observers when evaluating the diagnostic methods using images accuracy. According to Correa [26] the evaluations carried out by single well-calibrated observer with good intra-observer agreement is the ideal situation. In the present study the intra-observer agreement was determined by Kendall's test where the values ranged between 0.795 and 0.859, indicating a good concordance among the evaluations performed by the observer.

The manipulation of digital images is another variable that differs in works that compare digital systems to conventional film radiographs. This study was designed to simulate clinical conditions as much as possible, where the observer was allowed to alter the brightness, contrast and size, as well as reverse the image. Another reason was the possibility of enhancing the image and compensating the lower resolution in the digital systems, thereby obtaining an image of good diagnostic quality [3,5,8,21].

Several studies compared digital radiographic systems to conventional film radiographs to detect caries lesions. As observed in the present investigation, most of these works concluded that the accuracy of digital systems is comparable to that of the conventional film radiographs in the detection of proximal caries [2,3,5,16,18,21,27-30].

Thus digital bitewings radiographs can be indicated as radiographic examination in the diagnosis of proximal caries because of the various advantages that digital systems demonstrate. However more clinical studies are warranted with the aim of determining the accuracy of different digital systems in the routine of the clinical practice, as well as intra-oral manipulation of the image receptors of these systems.

CONCLUSIONS

- The diagnostic accuracy of digital images in the detection of proximal caries is similar to that of the conventional film radiography.
- The digital systems with storage phosphor plates (DenOptix and Digora) are comparable to the system with a charge-coupled device (CygnusRay) in caries radiographic diagnosis of proximal surfaces.
- The carious lesions were underestimated by the radiographic modalities studied when compared to the histological examination.

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