RESEARCH

Accuracy of direct digital radiography for detecting occlusal caries in primary teeth compared with conventional radiography and visual inspection: an *in vitro* study

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Objectives: The diagnosis of caries lesions is still a matter of concern in dentistry. The diagnosis of dental caries by digital radiography has a number of advantages over conventional radiography; however, this method has not been explored fully in the field of paediatric dentistry. This *in vitro* research evaluated the accuracy of direct digital radiography compared with visual inspection and conventional radiography in the diagnosis of occlusal caries lesions in primary molars.

Methods: 50 molars were selected and evaluated under standardized conditions by 2 previously calibrated examiners according to 3 diagnostic methods (visual inspection, conventional radiography and direct digital radiography). Direct digital radiographs were obtained with the Dixi3 system (Planmeca, Helsinki, Finland) and the conventional radiographs with InSight film (Kodak Eastman Co., Rochester, NY). The images were scored and a reference standard was obtained histologically. The interexaminer reliability was calculated using Cohen's kappa test and the specificity, sensitivity and accuracy of the methods were calculated.

Results: Examiner reliability was good. For lesions limited to the enamel, visual inspection showed significantly higher sensitivity and accuracy than both radiographic methods, but no significant difference was found in specificity. For teeth with dentinal caries, no significant differences were found for any parameter when comparing visual and radiographic evaluation.

Conclusions: Although less accurate than the visual method for detecting caries lesions confined to the enamel, the direct digital radiographic method is as effective as conventional radiographic examination and visual inspection of primary teeth with occlusal caries when the dentine is involved.

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As a result of modern minimal intervention dentistry, the diagnosis of dental carious lesions has become a real challenge. The conventional methods for lesion detection are well known; however, they present limitations, and for this reason researchers, dental practitioners and industry are always searching for more efficient techniques. Several diagnostic techniques are available, including visual, visual–tactile, radiographic, electrical conductance, fibre-optic transillumination, laser fluorescence and combination visual/radiographic methods.¹

Limitations of radiographic examination depend on the accuracy and precision of determining the extension

of the carious lesions.¹ There are several studies using different radiographic imaging modalities for detecting carious lesions at the contacting approximal dental surfaces.^{2–6} However, the detection of occlusal dental carious lesions is also challenging, and the determination of the extension of such lesions into enamel and dentine is crucial for the determination of the more appropriate treatment. Several studies have tested digital radiography for the detection of occlusal and approximal caries lesions in permanent teeth,¹ and a few researchers have investigated the performance of digital radiography in approximal caries lesions in primary teeth,^{7–9} but no studies have observed the performance of digital radiography in detecting occlusal caries in primary teeth. Because primary enamel is thinner than permanent enamel,¹⁰ the mineral content of primary enamel is lower, porosity is greater and

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caries lesions progress faster than in permanent teeth.¹¹ Thus, studies should be conducted to verify the advantages of using digital radiography in the detection of occlusal caries lesions in primary teeth.

Based on the limited information available on the accuracy of radiographic examination with digital modalities in primary teeth, this *in vitro* study aimed to investigate the performance of direct digital radiography in the diagnosis of occlusal caries lesions and to compare this with conventional radiography and visual inspection performance in primary molars.

Materials and methods

The ethics committee at the University of São Paulo's School of Dentistry approved the research.

50 first and second human primary molars (upper and lower) in the final process of exfoliation, or extracted for orthodontic reasons, were used. These teeth had been donated to the University of São Paulo, School of Dentistry Teeth Bank, which held the signed and informed consent of parents or guardians of all patients. After cleansing, the teeth were stored in refrigerated distilled water (4°C). The teeth presented pigmentation and at least one suspected site of occlusal carious lesion; the teeth had not been restored or had their surfaces sealed.

Each tooth was identified and the occlusal surface photographed in high resolution (Sony Super SteadyShot 5.1 megapixels, Tokyo, Japan). In the occlusal surface, among the sites more prone to developing caries lesions, one site per tooth was selected arbitrarily for the study. Using PowerPoint software (Microsoft, CA), the photograph of each tooth had the selected occlusal site covered by a black mark. This black mark would help the

examiners to locate the area to be examined in each of the methods (Figure 1).

Examination methods

Radiographs were taken using conventional film (InSight film; Kodak Eastman Co., Rochester, NY) and direct digital film by focusing on the marked area. The teeth were then inspected visually and the specimens were prepared for histological examination.

Radiographic examination

A dental X-ray unit (Odontomax, Astex, São Paulo, Brazil) operating at 7 mA and 70 kVcp was used for all exposures. The source-to-image receptor distance was maintained by using a device especially designed for this purpose (Figure 2). A soft-tissue equivalent phantom was not placed in the beam path during the exposures. Exposure times were selected individually for each system (film or digital) to provide adequate image densities. A radiologist other than the examiners determined the exposure times.

Film images were made with InSight film at 0.3 s. Films were processed with an automatic processor (Periomat; Durr Dental GmbH, Bietigheim-Bissingen, Germany) at 25°C, with a 5 min processing cycle. Radiographs were mounted in opaque plastic holders and coded for use later (Figure 3).

Digital radiographic images were obtained with a charge-coupled device sensor (Dixi 3; Planmeca, Helsinki, Finland) using an exposure time of 0.2 s. There was no manipulation of the images at any time. For those images that would later be displayed as unaltered digital images, only one projection was acquired using the periapical projection geometry and the optimizing filters were not activated. All digital images were coded and exported to a notebook (Toshiba Satellite A100-803; Toshiba, Tokyo, Japan) in a resolution of 1280 × 800 pixels where the examiners performed the diagnosis of the selected sites (Figure 4).

Two dental radiologists with minimum of 5 years' experience were recruited for this study. The viewing sessions took place in a quiet room with subdued ambient lighting. To ensure reader calibration, a training exercise was completed before each observation session. Instructions were provided and observers became familiar with the image scoring (modified from Dunkley and Ashley¹²) to be used for classifying the carious lesions, as follows:

0. No radiolucency
1. Radiolucency confined to the enamel
2. Radiolucency in the outer third of the dentine
3. Radiolucency in the middle third of the dentine
4. Radiolucency reaching the pulpal third of the dentine.

Visual examination

The visual inspection was performed using air/water spray and the criteria described by Ekstrand *et al*,¹³ as follows:

Figure 1 Photograph of occlusal surface of a primary tooth. The black mark indicates the site for further analysis for conventional and digital radiography

Figure 2 Device designed especially for maintaining the source-to-image receptor distance

0. Slight or no change in enamel translucency after prolonged air drying
1. Opacity or discolouration hardly visible on wet surface, but distinctly visible after air drying
2. Opacity or discolouration distinctly visible without air drying
3. Localized enamel breakdown on opaque or discoloured enamel and/or grayish discolouration from underlying dentine
4. Cavitations in opaque or discoloured enamel exposing dentine.

Histological validation

The teeth were embedded into acrylic resin and sectioned in a mesiodistal direction. Sections were obtained using a sectioning machine (Isomet; Buehler Ltd., Lake Bluff, IL) with a diamond disc (Extec, Enfield, CL) in low speed. The section surfaces were observed using a stereoscope

(Olympus, Tokyo, Japan) at $\times 40$ magnification and photographed with a video camera (CCD Sony Color Video, Tokyo, Japan) to determine the accurate extent of caries. The chosen occlusal surface area, which was previously scored by the conventional and digital radiographic methods, was observed by an oral pathologist. Histological sections containing the most profound lesions, where present, were used for scoring (Figure 5). The scores for histological analysis were:

- D0. No caries
- D1. Caries lesion limited to the outer half of the enamel
- D2. Caries extending into inner half of the enamel, but not to amelodentinal junction
- D3. Caries limited to the outer half of the dentine
- D4. Caries involving the inner half of the dentine.

Statistical analysis

The interexaminer reproducibility was calculated initially by considering all scores of visual inspection and radiographic methods using the intraclass correlation coefficient (ICC) and 95% confidence interval (CI). The interexaminer reliability was calculated using Cohen's kappa test (95% CI) after combining the results into two categories (sound *vs* decayed) using the D1 and D3 thresholds. All analyses were carried out using statistical software (MedCalc 9.3.0.0, Mariakerke, Belgium), and the level of significance was $P < 0.05$.

The sensitivity, specificity and accuracy values were calculated for each method at two different thresholds, D1 (all caries lesions) and D3 (dentine caries lesions). Accuracy was defined as the percentage of correct diagnosis in all samples (sound and decayed surfaces). Data were analysed separately for each examiner. For the radiographic methods, Score 1 represented the cut-off point for all lesions (D1 threshold) and Score 2 for lesions in dentine (D3 threshold). For visual inspection, Score 1 represented the cut-off point at the D1 threshold and Score 3 for dentine lesions (D3 threshold). The McNemar change test was applied to compare sensitivity, specificity and accuracy values of the different methods. The level of significance for the McNemar change test was $P < 0.05$.

Figure 3 Example of a conventional radiograph of a primary tooth. This is the radiograph of the tooth in Figure 1

Figure 4 Digital radiograph of a primary tooth. This is the radiograph of the tooth in Figure 1

Results

Histological examination revealed that most of the 50 selected sites were sound ($n = 22$) or presented carious lesions classified by the D4 ($n = 10$). Table 1 shows the distribution of the scores of sound and carious sites upon histological examination.

Figure 5 Example of the histological section of the primary tooth. This is a section of the tooth in Figure 1. The double arrow indicates the extension of the lesion inside the enamel (D2)

For lesions limited to enamel (D1 threshold), the visual inspection showed significantly higher sensitivity and accuracy than the two radiographic methods, while no significant differences were found in specificity. For teeth with dentinal caries (D3 threshold), no significant differences were found for any parameter when comparing visual and radiographic evaluation (Table 2).

The interexaminer reproducibility is presented in Table 3. When all scores were considered, ICC values were similar for all methods of caries diagnosis. When the samples were combined into sound and decayed categories, the kappa values for all diagnosis methods were similar.

Table 1 Distribution of the score of sound and carious sites upon histological examination of the teeth

Scores	Occlusal sites	Percentage (%)
D0	22	44
D1	4	8
D2	5	10
D3	9	18
D4	10	20
Total	50	100

D0, no caries; D1, caries lesions limited to the outer half of the enamel; D2, caries lesions extending into the inner half of the enamel, but not to the amelodentinal junction; D3, caries lesions limited to the outer half of the dentine; D4, caries lesions involving the inner half of the dentine.

Table 2 Sensitivity, specificity and accuracy of visual inspection, conventional and direct digital radiography at occlusal enamel caries lesion threshold (D1) and dentine caries lesion threshold (D3)

Method	Sensitivity		Specificity		Accuracy	
	D1	D3	D1	D3	D1	D3
Examiner 1						
Visual inspection	1.00 ^{a*}	0.89 ^a	0.77 ^a	0.77 ^a	0.90 ^a	0.82 ^a
Conventional radiography	0.68 ^b	0.74 ^a	0.68 ^a	0.87 ^a	0.68 ^b	0.82 ^a
Digital radiography	0.61 ^b	0.68 ^a	0.77 ^a	0.90 ^a	0.68 ^b	0.82 ^a
Examiner 2						
Visual inspection	0.96 ^a	0.74 ^a	0.77 ^a	0.87 ^a	0.89 ^a	0.82 ^a
Conventional radiography	0.68 ^b	0.79 ^a	0.77 ^a	0.94 ^a	0.72 ^a	0.88 ^a
Digital radiography	0.64 ^b	0.68 ^a	0.91 ^a	1.00 ^a	0.76 ^a	0.88 ^a

*Different letters indicate significant differences amongst the different caries detection methods ($P < 0.05$)

Discussion

The diagnosis of caries lesions is still a matter of concern in dentistry. Methods with the ability not only to detect lesions, but also to indicate the actual extension of the lesions inside the dental tissues, are not yet available. The radiographic digital method has been introduced with a series of advantages as an adjuvant tool for dental caries diagnosis; however, in the paediatric dentistry field, this method has not been fully employed for caries diagnosis.¹ Research in the use of digital radiographs for diagnosing dental caries in children is scarce despite the advantages this method could offer these patients. Moreover, the available literature concerning systems for occlusal caries detection in primary teeth is limited.¹ For this reason we evaluated the accuracy of direct digital radiography compared to conventional radiography in the analysis of the extension of occlusal carious lesions in primary molars. Taking into account sensitivity and specificity, this study showed that the direct digital radiography has a similar level of accuracy to conventional radiography; however, visual inspection was more accurate than both radiographic methods for enamel occlusal carious lesions in primary molars. For dentine caries lesions, digital radiography had a similar performance to conventional radiography and visual inspection.

The sample size in this study was similar to that of previous studies.^{12–14} Suspected carious lesions were chosen randomly at the occlusal surface of the primary molars. Histological examination showed that most sites were caries free (40%). This created a good parameter for testing the specificity of the radiographic imaging modalities, especially because the dental surfaces free of carious lesions presented pigmentation and at least one suspected site of occlusal caries lesion, which could have, in a visual inspection, led to a wrong diagnosis.

The presence of carious lesions classified by the Scores D1 to D4 in this study represented a variety of lesions with different extensions into the dental tissues, propitiating the conditions for testing not only the sensitivity of the radiographic imaging modalities, but also their capacity for predicting the depth of such lesions.

A soft-tissue equivalent phantom was not placed in the beam path during the exposures as this could have influenced the quality of the radiographs by artificially increasing the contrast. However, this methodology was applied for both radiographic modalities and, therefore, would minimize the effect of contrast enhancement in the results. Studies are required in order to test this hypothesis.

The level of sensitivity and specificity of the radiographic methods used indicate that these methods are appropriate for diagnosing occlusal carious lesions in primary teeth. They were able to detect the majority of the decayed surfaces and less than 25% of healthy occlusal surfaces were diagnosed as decayed.

The radiographic assessments were less accurate than visual identification for occlusal caries limited to enamel. However, in a systematic review of selected dental caries diagnostic and management methods, Bader *et al*¹ stated that the evidence did not support the superiority of either visual or visual–tactile methods. In fact, Pitts¹⁵ emphasized that the use of the dental probe (or explorer) has been controversial for many years. According to Pitts, in Europe the use of a sharp explorer tip as an adjuvant to visual signs of disease although provides tactile feedback, is believed to add little to diagnostic yield and might induce iatrogenic damage to the enamel surface and promote caries initiation or progression.¹⁵ In order to avoid such iatrogenic lesions, radiographic imaging modalities could be used for the diagnosis of occlusal carious lesions in primary teeth.

Table 3 Interexaminer reproducibility of visual inspection, conventional and digital radiography in detecting occlusal caries lesion in primary teeth

Methods	ICC (95% CI)	Kappa value (95% CI)	
		D1	D3
Visual inspection	0.795 (0.666 to 0.878)	0.780 (0.598 to 0.963)	0.515 (0.275 to 0.754)
Conventional radiography	0.862 (0.770 to 0.919)	0.760 (0.581 to 0.940)	0.760 (0.581 to 0.940)
Digital radiography	0.806 (0.686 to 0.883)	0.508 (0.266 to 0.751)	0.508 (0.266 to 0.751)

ICC, intraclass correlation coefficient; CI, confidence interval; D1, occlusal enamel caries lesion threshold; D3, dentine caries lesion threshold

It is known that general dental practitioners worldwide have switched from conventional film radiography to digital imaging (for a review refer to Wenzel¹⁶). In theory, at least, the main advantages of digital intraoral radiography systems are that they result in fewer errors in the image and fewer environmental problems, since there is no use of chemicals. They also save time and reduce dose to the patient because the receptors are more sensitive to radiation. These advantages are significant when dealing with children, especially working with a dynamic digital image. It is possible to improve images using image enhancement facilities; this could prove interesting for use with impatient children. According to the review by Wenzel,¹⁶ more radiographs are taken with a digital system compared to film, and there can be difficulties with positioning, particularly the sensors, leading to re-exposures with digital receptors.

Although the dynamics of digital imaging seem to be appreciated by dentists and dental students, only a small part of the image enhancement facilities are actually used.¹⁶ Several authors have studied the effect of image enhancement on diagnostic accuracy.^{17–22} Some enhancement procedures, for example compensation for exponential attenuation employed by Li *et al*¹⁷ for

processing images obtained with the Dixi sensor, or those available in the Digora system software,¹⁸ resulted in higher accuracy in the processed rather than the original images. On the other hand, no effect on diagnostic accuracy^{19,20} or a negative effect²¹ (lower accuracy) on detection of dentinal lesions was found when using various filter functions. Additionally, the use of two task-specific algorithms, a caries mode and a perio mode, included in the software system had no effect on the accuracy of caries diagnosis in RVGui images.²² Based on this controversy it was decided to work with raw digital images in the present study. More studies are needed to test the differences that can be observed when using digital image enhancement in primary teeth radiographs.

In conclusion, direct digital radiography is as effective as conventional radiographic examination and visual inspection for primary teeth occlusal caries detection when the lesion involves dentine. Visual inspection is better at detecting initial enamel caries lesions than radiographic methods. It is suggested that digital radiography be considered when selecting a method for diagnosing carious lesions in primary teeth owing to environmental concerns and patient health.

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