Dentomaxillofacial Radiology (2007) 36, 138–142

http://dmfr.birjournals.org

RESEARCH

In vitro comparison of conventional film and direct digital imaging in the detection of approximal caries

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Objectives: To compare the diagnostic accuracy of conventional film, unenhanced direct digital and inversion grayscale direct digital imaging in the detection of approximal caries.
Methods: 150 approximal surfaces of extracted permanent molars and premolars were selected for the study on the basis of varying lesion depth. The teeth were radiographed using Ektaspeed Plus film; digital images were made with a Schick CMOS-APS sensor. 7 examiners evaluated 58 randomized images of each modality. Histological sectioning of the teeth was used to verify the presence and extent of decay.
Results: No significant difference was found between the diagnostic accuracies of the three imaging modalities ($P = 0.226$). Analysis of the diagnostic accuracy of the three modalities on lesion depth showed no statistically significant interaction; however, the main effect of the lesion depth was significant ($P < 0.001$, $\eta^2 = 0.936$).
Conclusions: The overall diagnostic accuracy of the three modalities in the detection of approximal carious lesions was comparable. All three modalities performed poorly in the detection of enamel lesions.
Dentomaxillofacial Radiology (2007) **36,** 138–142. doi: 10.1259/dmfr/15558921

Keywords: digital radiography, image processing, carious lesions, radiography

Introduction

Intraoral radiography has made a significant contribution as a diagnostic aid in the detection of carious lesions.[1] Conventional dental film is the most widely used image receptor for intraoral radiography. The introduction of digital radiography systems in dentistry has reduced radiation doses, as the sensors are more sensitive to radiation than film.[2]

Numerous studies have reported that digital images offer no diagnostic advantage over conventional film radiography in the detection of approximal carious lesions.[3–8] The majority of these studies found the diagnostic accuracy of conventional film and digital images to be comparable. However, neither modality satisfactorily detects incipient approximal lesions.[3,9] Consequently, digital image enhancements have been evaluated to improve the detection of approximal carious lesions.[9–13] Although several studies showed that digital enhancement may increase accuracy in detecting carious lesions, most studies showed poor detection of incipient enamel lesions with both conventional film and digital imaging.

An optimal digital image enhancement for the detection of incipient carious lesions has yet to be identified. The inversion grayscale mode has the potential to increase diagnostic accuracy in that the eye is better able to detect slight intensity changes in dark regions of an image than in light regions.[14] In an inversion grayscale dental image, the enamel will be dark and carious lesions will be light. Therefore, this modality may be particularly effective in improving the detection of incipient approximal lesions. Thus, the aim of the present investigation was to compare the diagnostic accuracy of conventional film, unenhanced direct digital and inversion grayscale direct digital imaging in the detection of approximal caries. The null hypothesis was that there is no statistical difference among the three modalities in the detection of approximal carious lesions.

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Received 8 July 2005; revised 5 April 2006; accepted 25 April 2006

Materials and methods

174 extracted permanent molars and premolars were selected for the study on the basis of varying caries depth. Teeth were evaluated clinically and radiographically for the presence of approximal caries. The roots of the teeth were embedded in plaster and arranged in groups of three. 150 mesial or distal surfaces were selected, including approximal surfaces with no decay and with carious lesions of varying depths. An Institutional Review Board (IRB) exemption was obtained for this study.

The teeth were radiographed using a GX-1000 dental radiographic unit (Gendex, Des Plaines, IL). An optical bench setup with a 40 cm focus-to-receptor distance was used, which included a 1.7 cm layer of acrylic that served as a soft tissue equivalent. Exposure factors for conventional film (Ektaspeed Plus; Kodak, Rochester, NY) were 70 kVp, 15 mA and 48 impulses. Digital images were made using a CMOS-APS sensor (Schick Technologies, Long Island, NY). Exposure factors for digital images were 70 kVp, 15 mA and 24 impulses. A third set of images was subsequently produced by inverting the unenhanced digital images using the Schick software.

Seven faculty members with equivalent clinical experience from the Department of General Dentistry, UMKC School of Dentistry, served as raters. Separate viewing sessions were used for each of the three modalities tested. Written and verbal instructions were given prior to each viewing session. Raters were shown sample images of each modality before each session to familiarize them with the types of images to be evaluated. Images were randomized for all three modalities. In a fourth viewing session, raters evaluated one of the modalities for a second time to assess intrarater reliability. Selection of the modality for the reread session was randomized. Rating sessions were separated by 1-week intervals. Raters evaluated the images using a continuous confidence-rating scale from 1 to 100, with 1 representing "lesion definitely not present" and 100 representing "lesion definitely present." A 100-point scale was used to decrease the probability of obtaining degenerate data.[15,16]

Conventional films were viewed under subdued lighting conditions on a conventional viewbox, which was masked to remove all ambient light around the radiographs. Raters were allowed to use a magnification device at $2\times$ magnification. Digital images were viewed on a 17 inch monitor (Gateway, North Sioux City, SD) with a resolution of 1024×768 and a grayscale of 0–255. Digital images were also viewed under subdued lighting conditions. No adjustment of contrast and brightness was performed by the raters.

Following acquisition of the radiographs, the teeth were sectioned mesiodistally along the long axis of the crown. The teeth were sectioned using a diamond blade mounted in a low-speed saw. The saw was used to cut the tooth structure adjacent to approximal lesions and caries-free approximal surfaces of the control teeth. Sectioned teeth were examined using a $16\times$ magnifying microscope by two observers who were familiar with the microscopic appearance of carious lesions. Tooth sections were evaluated for the absence or presence of approximal carious lesions, as well as for the depth of the lesions.

150 approximal surfaces were selected for the study: 75 surfaces were caries-free; 37 had carious lesions limited to the enamel; and 38 had carious lesions extending into the dentin. Of the enamel lesions, 19 were limited to the outer half of the enamel and 18 extended to the inner half of the enamel. Of the dentin lesions, 20 extended to the outer half of the dentin and 18 extended to the inner half of the dentin. A surface was recorded as carious if there were signs of demineralized white or discoloured (yellow/brown) areas and/or cavitation.

Receiver operating characteristic (ROC) analysis was used to assess the diagnostic accuracy of the three imaging modalities. The data were analysed using the ROCKIT software program (Charles Metz, Chicago, IL). The areas under the curves were used to compare the diagnostic accuracy of the three modalities in the detection of approximal carious lesions. Differences between areas under the curves were assessed using repeated measures analysis of variance (ANOVA). The level of significance was set at $\alpha = 0.05$. Pearson's correlation coefficient was used to measure intrarater reliability and Kendall's coefficient of concordance was used to measure interrater reliability.

Results

For the seven raters, Pearson's correlation coefficient was -0.02, indicating no intrarater reliability. One of the raters showed poor performance in the second reading session. When this rater was removed from the reliability calculation, the correlation between initial and retest data was 0.70, indicating higher intrarater reliability. Kendall's coefficient of concordance was 0.43, indicating good interrater reliability.

There was no statistically significant difference in the performance of the three imaging modalities ($P = 0.226$, $\eta^2 = 0.219$) when A_Z values were calculated from the six raters or from all seven raters, and the A_Z values shown in Table 1 were obtained from all seven raters. However, the η^2 of 0.219 suggests that the imaging modality does explain a meaningful proportion of variance in the area under the curve. The conventional film had a slightly higher level of diagnostic accuracy than the unenhanced direct digital and inversion grayscale direct digital imaging in the detection of approximal caries.

Table 1 reports the pooled A_Z values for all three imaging modalities including both enamel and dentin lesions. Figure 1 shows the ROC curve for the three modalities determined by the maximum likelihood

Table 1 Mean areas under the receiver operating characteristic curve (A_Z)* and standard deviations (SDs) for the three imaging modalities

Modality	*Mean*	*SD*
Film	0.7741	0.0502
Digital	0.7324	0.0919
Inversion	0.7181	0.0492

*Determined by maximum likelihood method

method. Repeated measures ANOVA showed no significant difference in the performance of the three modalities.

Table 2 reports A_Z values for the three modalities for enamel and dentin lesions separately. ROC curves for enamel and dentin lesions are shown in Figures 2 and 3, respectively. Repeated measures ANOVA of these data showed no interaction between modality and lesion depth; however, there was a statistically significant main effect for lesion depth, $F(1,6) = 87.51$, $P < 0.001$, $\eta^2 = 0.936$. No other significant effects were identified. Dentin lesions were identified with greater accuracy than enamel lesions regardless of the modality used.

Table 2 Mean areas under the receiver operating characteristic curve (A_Z)* and standard deviations (SDs) for the three imaging modalities for enamel and dentin lesions separately

	Enamel		*Dentin*	
Modality	*Mean*	*SD*	*Mean*	*SD*
Film	0.6565	0.0739	0.8863	0.0394
Digital	0.6167	0.0971	0.8482	0.1286
Inversion	0.6287	0.0817	0.8527	0.0670

*Determined by maximum likelihood methods

Discussion

The purpose of this study was to compare the three imaging modalities (conventional film, unenhanced direct digital and inversion grayscale direct digital images) in the detection of approximal caries. Analysis of the data revealed no significant differences between the three modalities. The null hypothesis that there is no statistically significant difference between the three modalities in the detection of approximal carious lesions was not rejected.

In the present investigation, the inversion grayscale images showed the same diagnostic accuracy for lesion detection as the other two modalities. A factor which may have affected this investigation was the observers' lack of familiarity with the image presentation. In an inversion grayscale image, a carious lesion will appear as a brighter area surrounded by a dark background rather than a dark area surrounded by a light background as is found in a conventional radiograph. Although the eye is more sensitive to slight intensity changes in dark regions of an image, the observers' familiarity with caries as a dark lesion may have negated the potential benefit of this enhancement.

When data were analysed for the detection of enamel and dentin caries, repeated measures ANOVA showed a statistically significant main effect for lesion depth. Dentin lesions were identified with greater accuracy than enamel lesions regardless of the imaging modality used. The detection rate for enamel lesions was close to chance for all three modalities. It was not until lesions penetrated into the dentin that observers were able to detect their presence more consistently. These findings are consistent with other studies reporting poor detection of incipient approximal lesions.[3,9] It has been reported that 40% demineralization of hard tissue is required before lesions are identified on radiographs.[2] Results indicate that the small decrease in density associated with incipient enamel lesions was not accurately identifiable with any of the modalities tested.

A search of the literature revealed a limited number of studies testing inversion grayscale enhancement in the detection of approximal caries. In an *in vitro* study, Haak and Wicht[17] compared direct digital images in normal and inversion grayscale modes. Different image sizes and types of monitors were also assessed. No significant differences were noted between normal and inversion grayscale images as a function of image-size group. For all image-size groups

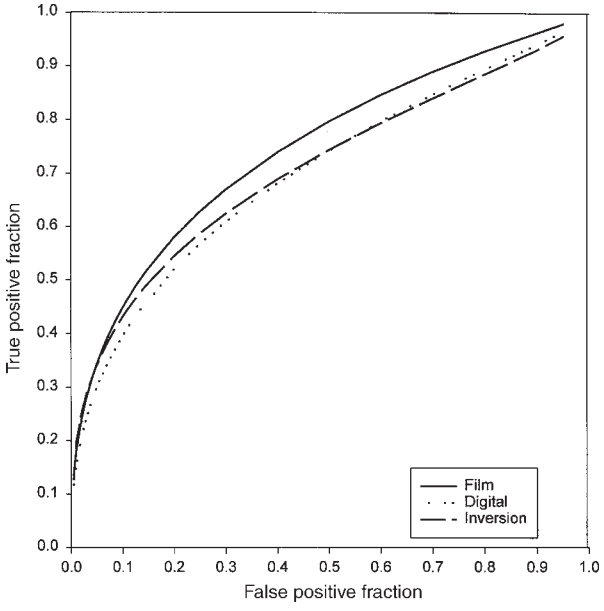

Figure 1 Receiver operating characteristic analysis for the detectability of all carious lesions

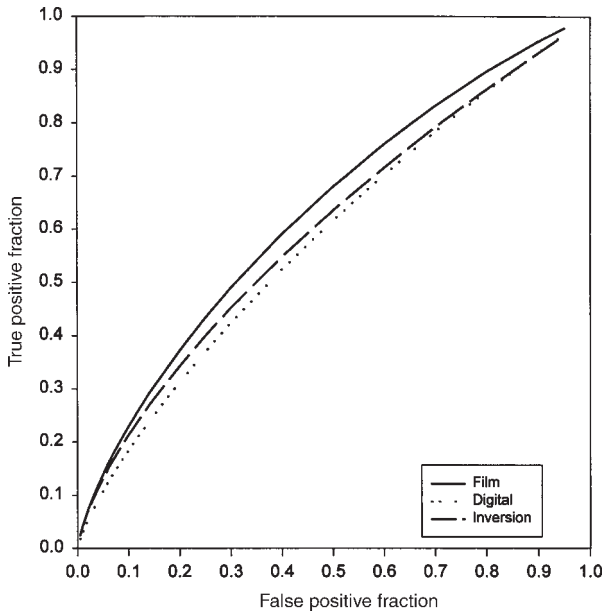

Figure 2 Receiver operating characteristic analysis for the detectability of enamel lesions

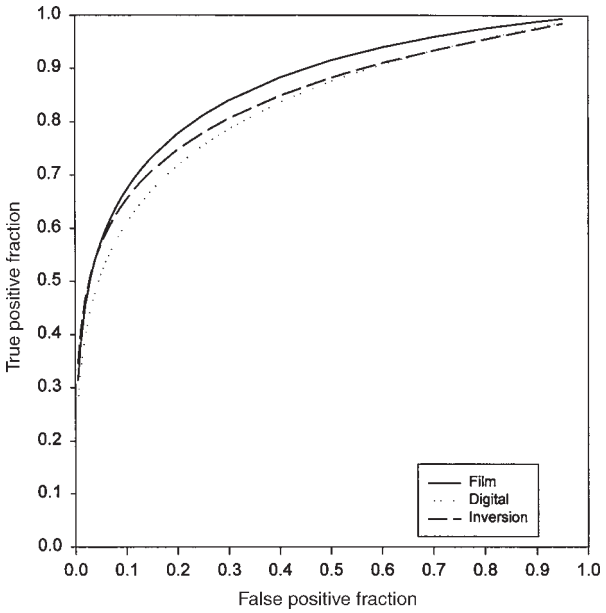

Figure 3 Receiver operating characteristic analysis for the detectability of dentin lesions

combined, inversion grayscale images were significantly less accurate in the detection of dentin lesions.

In another study, Dove and McDavid[10] compared conventional film with unenhanced digitized and enhanced digitized bitewing images for accuracy of caries detection. For caries detection without regard to depth, there was no significant difference between conventional film and digitized images, including inversion grayscale images. In the detection of actual caries depth, inversion grayscale images performed significantly worse than conventional film images. Although our study did not involve detection of actual caries depth, our findings are similar to those of the above-mentioned studies, indicating that inversion grayscale enhancement has not been beneficial in the assessment of approximal caries.

Inversion grayscale enhancement has been evaluated for other types of dental diagnosis, including endodontic working length and the detection of periapical lesions. In an *in vitro* study, Hedrick et al[18] found no significant difference between conventional film and inversion grayscale thermal print images in the determination of endodontic working length measurements. In another *in vitro* study, Ellingsen et al[19] reported greater accuracy in identifying small endodontic file tips using D-speed film compared with digital images, including inversion grayscale images. E-speed film and inversion grayscale images were comparable. In a similar study, Leddy et al[20] found no significant difference between conventional film and inversion grayscale digital images in determining endodontic file length. Barbat and Messer[21] compared conventional film with unenhanced and enhanced digital images in the detection of artificially created periapical lesions. Conventional film and unenhanced digital images were significantly more accurate than inversion grayscale images in detecting periapical lesions. Inversion grayscale images, however, demonstrated significantly greater accuracy in identifying controls. Thus, to date, inversion grayscale enhancement has generally not improved diagnostic accuracy compared with unenhanced digital or conventional film radiography.

In conclusion, the overall diagnostic accuracy of the three modalities tested was comparable in the detection of approximal caries. In that conventional film is the current standard image receptor in dental practice, this finding would suggest that direct digital radiography can be endorsed for clinical use, especially since radiation exposure is reduced. However, the inversion grayscale enhancement did not improve diagnostic accuracy compared with unenhanced direct digital images or conventional film. In addition, all imaging systems used in this study performed poorly in the detection of enamel lesions. Further investigation is needed to identify an imaging system or enhancement mode to improve the detection of incipient carious lesions.

Acknowledgment
The authors wish to express their gratitude to Dr Karen Williams, Department of Dental Public Health, for her valuable assistance in the preparation of this manuscript.

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