Effects of digital grey-scale modification on the diagnosis of small approximal carious lesions

Department of Cariology and Endodontology, TRIKON: Institute for Dental Clinical Research, University of Nijmegen and *Faculty of Educational Technology, Technical University of Twente, The Netherlands

ABSTRACT
The aim of this study was to evaluate the accuracy of approximal caries diagnosis from digitized radiographs and digitally modified radiographic images, compared with conventional radiography. Twenty bitewing radiographs were digitized and from the digitized radiographs mirror-images were produced, resulting in 40 digital images. The caries progress at three approximal surfaces was graded by 12 dentists from conventional radiographs, digital unmodified images and digitally modified images. The image modifications were derived from the cumulative probability of grey values in the original digital image using one of five probability distributions: uniform, exponential, Rayleigh, hyperbolic cube root and hyperbolic logarithmic. Interobserver agreement was substantial. The unmodified digital images produced sensitivities comparable to radiographs but their specificities were lower. When the diagnostic task was to discriminate between 'caries' and 'no caries', the exponential, hyperbolic cube root and hyperbolic logarithmic modifications and radiographs performed equally well. With the decision cut off between 'dentinal caries' and 'no dentinal caries', the sensitivity of the hyperbolic logarithmic type of modification was statistically significantly superior to that of radiographs, but this modification was also associated with a statistically significant reduction of specificity. It is concluded that in particular the hyperbolic logarithmic modification can be an alternative to conventional radiography in incipient approximal caries diagnosis and restorative decision making.

KEY WORDS: Caries, Diagnosis, Digital radiology

INTRODUCTION
In dental radiography the use of digital imagery is increasing. Digital images were traditionally obtained from a radiograph through analogue to digital (A/D) conversion. Recently, a direct data acquisition technique was introduced in dental radiography. The first evaluations were promising (Benz et al., 1990; Horner et al., 1990), but many problems still have to be resolved before digital radiography can substitute for conventional radiography in dental practice. An important obstacle in this respect is the considerably smaller optical density range in digitized images when compared with radiographs. Hence, some valuable diagnostic information will become suppressed during digital image formation and}

disturbing information or noise will be introduced. Particularly, the display of subtle radiolucencies and radiopacities is affected by the digitization process. A major goal of digital radiography was, and still is, to restore or improve the diagnostic value of a digital image by enhancement of valuable information and suppression of noise. A successful introduction of digital radiography in dental practice can be achieved only when observer performance from enhanced digital images is at least comparable with observer performance from radiographs. In addition, the technique should be easy to apply. Digital subtraction techniques, which require two subsequent radiographs with equal geometry, were successfully applied in the detection of small periodontal lesions, but
due to the complexity of this method it is not yet suited for routine use in dental practice. However, recent research has shown that other, less complex, techniques can be employed to detect small periodontal lesions in digital images (Verdonschot et al., 1990; 1991).

Small approximal lesions cause subtle radiolucenties on bitewing radiographs. In radiographic diagnosis large numbers of false-positives and false-negatives are commonly introduced (Mejare et al., 1985; Thylstrup et al., 1986; Verdonschot et al., 1991b). It can be expected that the accuracy of approximal caries diagnosis from digitized images will be even worse due to a loss of valuable information during digitization (Ballard and Brown, 1982). Several image enhancements have been tested already to improve caries diagnosis from digital images. Regional image operators such as filters and edge detectors modify pixel values given the values of the surrounding pixels. Some of the high-pass filters had a positive effect on the estimation of the depth of occlusal caries lesions (Wenzel et al., 1990) and the detection of approximal caries (Pitts, 1986; Pitts and Renson, 1986a, b). Edge-detectors, which enhance those parts in an image where a gradient of grey values is found, were helpful in monitoring approximal caries (Klinger et al., 1989). Before the application of regional image operators, one or more full image operators are commonly used to reduce the general level of noise. The use of probability distributions has been suggested to conform with this noise and to enhance the image (Frieden, 1983; Swets, 1986) but their effect on diagnostic accuracy has not yet been determined.

In this study the accuracy of the diagnosis of small approximal carious lesions from digitized radiographs and from several enhanced image modalities was compared with the accuracy obtained from conventional radiography.

**MATERIALS AND METHODS**

**Radiographs and digital images**

Twenty bitewing radiographs were selected from a large supply. All radiographs were of excellent image quality as judged subjectively. Criteria for inclusion in this study were the presence of radiographically intact surfaces and surfaces with approximal radiolucencies reaching the amelodentinal junction. The radiographs were digitized from a light box using a CCD video-camera (MX-HTH, Eindhoven, The Netherlands; gamma = 1; manual gain control) and an imaging board (Matrox PIP-EZ 1024, Matrox Ltd, Dorval Quebec, Canada). The imaging board was hosted by a personal computer and could be addressed by Pascal programs. The A/D converter was capable of digitizing a maximum of 256 grey values. The resulting digital image had a spatial resolution of 512 by 512 pixels in which one pixel represents a film area of 0.06 by 0.08 mm. From each digitized image a reversed left to right image, denoted mirror-image, was produced.

During separate sessions 12 dentists, clinical teachers in operative dentistry, paedodontics and endodontics, were asked to grade the apparent lesion depth at three surfaces on each of the 20 radiographs (light box, masked viewing, no magnification). A four-point rating scale was used:

- 0 no carious lesion
- 1 lesion confined to the enamel
- 2 lesion reaching the dentino-enamel junction
- 3 lesion extending into the dentine

One month later the same dentists were asked to grade the surfaces on the digitized images and digitally modified images. Every digital image was presented with fixed monitor brightness and contrast. Unmodified and digitally modified images were presented alternately. All image modifications were derivatives of the cumulative probability histogram of the unmodified digital image. The cumulative probability of grey value (x) in the image is denoted by:

\[ \text{Cum}(x) = \sum_{j=0}^{x} \text{P}(j) \]

where \( \text{P}(j) \) is the probability of grey value (j) in the original digital image. The new grey value (\( y(x) \)), as a function of the original grey value x of a pixel, was obtained through application of the following functions, which are based on the probability distributions:

- **uniform:** \( y(x) = (b-a) \text{Cum}(x) + a \)
- **exponential:** \( y(x) = (a-1) \left[ c \log (1 - \text{Cum}(x)) \right]^{1} \)
- **Rayleigh:** \( y(x) = a + \left[ c^{-2} \log (1 - \text{Cum}(x)) \right]^{-1} \)
- **hyperbolic cube root:** \( y(x) = \left[ (b^{1/3} - a^{1/3}) \text{Cum}(x) + b^{1/3} \right]^{3} \)
- **hyperbolic logarithmic:** \( y(x) = b \left[ \frac{a}{b} \right] \text{Cum}(x) \]

in which a is the lower clipping, b is the upper clipping of the grey scale for the modified digital image and c is a constant value. The uniform probability function, also known as histogram equalization, will spread the grey-levels evenly between the lower and upper clipping. The exponential, Rayleigh and hyperbolic logarithmic probability functions emphasize the white end of the grey-scale, whereas the hyperbolic cube root function emphasizes the black end.

**Statistical methods**

To evaluate intraobserver reliability unweighted kappa statistics (Fleiss et al., 1979) between ratings from unmodified digital images and unmodified digital mirror images were calculated. Kappa values between radiographs and unmodified digital images and between radiographs and unmodified digital mirror images were
calculated to examine the influence of the digitization process on caries rating by observers.

'Gold standard' diagnoses for the approximal surfaces were provided by two dental radiologists, who individually graded the surfaces from radiographs. In a joint session of the two dental radiologists, all surfaces that were graded differently, were discussed until a unanimous decision was obtained. Decision cut-offs were applied between ratings 0 and 1 and between ratings 1 and 2. These thresholds were chosen to study observer performance in diagnosing approximal caries and dentinal caries respectively. Diagnostic accuracy was expressed in sensitivities, specificities, positive predictive values and negative predictive values (Douglass and McNeil, 1983) using expert diagnoses as the reference standard. To test statistically the difference between sensitivities and specificities of digital image modalities and radiographs, fourfold contingency tables were used (Berkey et al., 1990):

\[
\begin{array}{cccc}
\text{Truly decayed} & \text{Radiographs} \\
\text{Decayed} & a & b \\
\text{Sound} & c & d \\
\end{array}
\]

\[
\begin{array}{cccc}
\text{Truly sound} & \text{Radiographs} \\
\text{Decayed} & w & x \\
\text{Sound} & y & z \\
\end{array}
\]

In these tables observer performance from radiographs and digital images is related to the true status of decay, as obtained from the experts. The difference between the sensitivity of both diagnostic systems is reflected in the values of \(b\) and \(c\), whereas the difference between the specificities is reflected in the values \(x\) and \(y\). The error ratios (\(ER\)) for sensitivity and specificity are denoted by:

\[ER_{sens} = \frac{(a + b)}{(a + c)}\]  \[ER_{spec} = \frac{(w + x)}{(w + y)}\]

An error ratio value of 1 expresses that no difference between both diagnostic systems exists. The test-based 95 per cent confidence interval for the error ratio is defined by (Kleinbaum et al., 1982):

\[ER \exp \left[ \pm 1.96 \left( \frac{(\ln \frac{1}{1})^2}{\chi^2} \right)^{1/2} \right]\]

in which \(\chi^2\) is the McNemar chi square statistic, denoted by:

\[\frac{(b-c)^2}{(b+c)}\]  for sensitivity and \[\frac{(x-y)^2}{(x+y)}\]  for specificity.

A statistically significant difference between two sensitivities or specificities exists if the null value of \(ER\) (\(ER = 1\)) is outside the confidence interval.

Since both the positive predictive values (PPV) and negative predictive values (NPV) are prevalence dependent, they can be written in term of caries prevalence (Prev), sensitivity (\(\phi\)) and specificity (\(\psi\)) as follows (Espelid, 1987):

\[PPV = \frac{\text{Prev} \phi}{\text{Prev} \phi + (1-\text{Prev})(1-\psi)}\]

\[NPV = \frac{(1-\text{Prev}) \psi}{(1-\phi) + (1-\text{Prev}) \psi}\]

The effect of approximal caries prevalence on the positive and negative predictive values of the various image modalities will be studied using these functions.

RESULTS

The kappa values between caries ratings from radiographs are contained in Table I, unmodified digital images and unmodified digital mirror images for 12 observers. With the exception of observer 8 (kappa = 0.47) all kappa values in column 2 were between 0.60 and 0.82, indicating substantial intraobserver reliability. Because low intraobserver agreement will obscure the differences which may exist between the various image modalities, the ratings by observer 8 were excluded in the further analyses. Kappa values ranging from 0.30 to 0.71 (columns 3 and 4, Table I) indicate that, compared to radiographs, different ratings were frequently obtained from digitized images.

Almost equal sensitivity values for radiographs and unmodified digital images (Tables II and III, first two rows) indicate that, regardless of decision cut off, the sensitivities remained unaffected by the digitization process. The specificities of the unmodified digital images, however, were statistically significantly lower than those of radiographs. When the decision cut off was applied between ratings 0 and 1 (Table II) both the sensitivity and specificity of radiographs could not be improved by any of the modified digital images. When the cut off was applied between ratings 1 and 2 (Table III) the sensitivity of the hyperbolic logarithmic modification (\(\phi_{\text{digitat}} = 0.95\)) was significantly higher than the sensitivity of radiographs (\(\phi_{\text{radios}} = 0.83\)), but the specificities of all image modifications were significantly lower than those of radiographs.
Table I. Unweighted kappa values between caries ratings from radiographs, unmodified digital images and unmodified digital mirror images

<table>
<thead>
<tr>
<th>Observer</th>
<th>Unmodified digital Radiographs vs. unmodified digital mirror images</th>
<th>Radiographs vs. unmodified digital images</th>
<th>Radiographs vs. unmodified digital mirror images</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.71</td>
<td>0.40</td>
<td>0.53</td>
</tr>
<tr>
<td>2</td>
<td>0.76</td>
<td>0.47</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>0.64</td>
<td>0.56</td>
<td>0.67</td>
</tr>
<tr>
<td>4</td>
<td>0.82</td>
<td>0.58</td>
<td>0.71</td>
</tr>
<tr>
<td>5</td>
<td>0.78</td>
<td>0.58</td>
<td>0.51</td>
</tr>
<tr>
<td>6</td>
<td>0.60</td>
<td>0.47</td>
<td>0.51</td>
</tr>
<tr>
<td>7</td>
<td>0.64</td>
<td>0.60</td>
<td>0.64</td>
</tr>
<tr>
<td>8</td>
<td>0.47</td>
<td>0.56</td>
<td>0.49</td>
</tr>
<tr>
<td>9</td>
<td>0.71</td>
<td>0.67</td>
<td>0.58</td>
</tr>
<tr>
<td>10</td>
<td>0.73</td>
<td>0.38</td>
<td>0.42</td>
</tr>
<tr>
<td>11</td>
<td>0.76</td>
<td>0.49</td>
<td>0.60</td>
</tr>
<tr>
<td>12</td>
<td>0.82</td>
<td>0.51</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Table II. Sensitivity ($\theta_{\text{digital}}$, $\theta_{\text{radiog}}$) and specificity ($\psi_{\text{digital}}$, $\psi_{\text{radiog}}$) values for digital images and radiographs with decision cut off between caries ratings 0 and 1 and using expert ratings as 'gold standard', error ratios (ER) (film vs. digital image) and confidence intervals for error ratios

<table>
<thead>
<tr>
<th>Image modality</th>
<th>Number of observations</th>
<th>$\theta_{\text{digital}}$</th>
<th>$\theta_{\text{radiog}}$</th>
<th>$\psi_{\text{digital}}$</th>
<th>$\psi_{\text{radiog}}$</th>
<th>$\text{ER}_{\text{sens}}$</th>
<th>$\text{ER}_{\text{spec}}$</th>
<th>95% confidence interval for $\theta_{\text{digital}}$</th>
<th>95% confidence interval for $\theta_{\text{radiog}}$</th>
<th>95% confidence interval for $\psi_{\text{digital}}$</th>
<th>95% confidence interval for $\psi_{\text{radiog}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital unmodified</td>
<td>660</td>
<td>0.96</td>
<td>0.95</td>
<td>1.01</td>
<td>0.98, 1.04</td>
<td>0.72</td>
<td>0.85</td>
<td>2.13</td>
<td>1.55, 2.90</td>
<td>0.72</td>
<td>0.85</td>
</tr>
<tr>
<td>Digital unmodified mirror</td>
<td>660</td>
<td>0.95</td>
<td>0.95</td>
<td>1.00</td>
<td>0.97, 1.03</td>
<td>0.67</td>
<td>0.85</td>
<td>1.81</td>
<td>1.33, 2.47</td>
<td>0.76</td>
<td>0.85</td>
</tr>
<tr>
<td>Uniform</td>
<td>264</td>
<td>0.90</td>
<td>0.93</td>
<td>0.97</td>
<td>0.93, 1.02</td>
<td>0.67</td>
<td>0.89</td>
<td>3.00</td>
<td>1.40, 6.42</td>
<td>0.73</td>
<td>0.76</td>
</tr>
<tr>
<td>Exponential</td>
<td>264</td>
<td>0.96</td>
<td>0.96</td>
<td>1.01</td>
<td>0.97, 1.05</td>
<td>0.73</td>
<td>0.76</td>
<td>1.11</td>
<td>0.70, 1.75</td>
<td>0.76</td>
<td>0.77</td>
</tr>
<tr>
<td>Rayleigh</td>
<td>264</td>
<td>0.90</td>
<td>0.98</td>
<td>0.92</td>
<td>0.86, 0.97</td>
<td>0.76</td>
<td>0.90</td>
<td>2.42</td>
<td>1.42, 4.27</td>
<td>0.82</td>
<td>0.92</td>
</tr>
<tr>
<td>Hyperbolic cube root</td>
<td>264</td>
<td>0.95</td>
<td>0.92</td>
<td>1.04</td>
<td>1.00, 1.08</td>
<td>0.73</td>
<td>0.77</td>
<td>1.20</td>
<td>0.47, 3.09</td>
<td>0.82</td>
<td>0.92</td>
</tr>
<tr>
<td>Hyperbolic logarithmic</td>
<td>264</td>
<td>0.95</td>
<td>0.97</td>
<td>0.98</td>
<td>0.93, 1.02</td>
<td>0.84</td>
<td>0.84</td>
<td>1.05</td>
<td>0.66, 1.65</td>
<td>0.84</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Table III. Sensitivity ($\theta_{\text{digital}}$, $\theta_{\text{radiog}}$) and specificity ($\psi_{\text{digital}}$, $\psi_{\text{radiog}}$) values for digital images and radiographs with decision cut off between caries ratings 1 and 2 and using expert ratings as 'gold standard', error ratios (ER) and confidence intervals for error ratios

<table>
<thead>
<tr>
<th>Image modality</th>
<th>Number of observations</th>
<th>$\theta_{\text{digital}}$</th>
<th>$\theta_{\text{radiog}}$</th>
<th>$\psi_{\text{digital}}$</th>
<th>$\psi_{\text{radiog}}$</th>
<th>$\text{ER}_{\text{sens}}$</th>
<th>$\text{ER}_{\text{spec}}$</th>
<th>95% confidence interval for $\theta_{\text{digital}}$</th>
<th>95% confidence interval for $\theta_{\text{radiog}}$</th>
<th>95% confidence interval for $\psi_{\text{digital}}$</th>
<th>95% confidence interval for $\psi_{\text{radiog}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital unmodified</td>
<td>660</td>
<td>0.85</td>
<td>0.84</td>
<td>1.01</td>
<td>0.94, 1.08</td>
<td>0.79</td>
<td>0.87</td>
<td>1.68</td>
<td>1.34, 2.12</td>
<td>0.76</td>
<td>0.87</td>
</tr>
<tr>
<td>Digital unmodified mirror</td>
<td>660</td>
<td>0.85</td>
<td>0.84</td>
<td>1.02</td>
<td>0.95, 1.08</td>
<td>0.76</td>
<td>0.87</td>
<td>1.81</td>
<td>1.46, 2.24</td>
<td>0.71</td>
<td>0.83</td>
</tr>
<tr>
<td>Uniform</td>
<td>264</td>
<td>0.88</td>
<td>0.87</td>
<td>1.01</td>
<td>0.93, 1.09</td>
<td>0.71</td>
<td>0.90</td>
<td>2.73</td>
<td>1.73, 4.31</td>
<td>0.71</td>
<td>0.83</td>
</tr>
<tr>
<td>Exponential</td>
<td>264</td>
<td>0.88</td>
<td>0.81</td>
<td>1.10</td>
<td>0.97, 1.24</td>
<td>0.71</td>
<td>0.83</td>
<td>1.72</td>
<td>1.25, 2.36</td>
<td>0.65</td>
<td>0.82</td>
</tr>
<tr>
<td>Rayleigh</td>
<td>264</td>
<td>0.87</td>
<td>0.87</td>
<td>1.01</td>
<td>0.92, 1.12</td>
<td>0.82</td>
<td>0.92</td>
<td>2.14</td>
<td>1.31, 5.11</td>
<td>0.85</td>
<td>0.88</td>
</tr>
<tr>
<td>Hyperbolic cube root</td>
<td>264</td>
<td>0.92</td>
<td>0.81</td>
<td>1.15</td>
<td>1.04, 1.27</td>
<td>0.85</td>
<td>0.92</td>
<td>1.90</td>
<td>1.42, 5.94</td>
<td>0.85</td>
<td>0.88</td>
</tr>
<tr>
<td>Hyperbolic logarithmic</td>
<td>264</td>
<td>0.95</td>
<td>0.83</td>
<td>1.15</td>
<td>1.01, 1.30</td>
<td>0.82</td>
<td>0.88</td>
<td>1.57</td>
<td>1.07, 2.28</td>
<td>0.85</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Figs 1 and 2 depict the positive and negative predictive values for radiographs and the hyperbolic logarithmic modification, being the digital image modality with the highest sensitivities and specificities, as a function of approximal caries prevalence. Fig. 1 shows that in diagnosing approximal caries (decision cut off between 0 and 1) the curves for the positive predictive value of radiographs and the hyperbolic logarithmic modified images fully overlapped one another, while the curves for the negative predictive values were close to one another. When it was the observer's task to detect dentinal carious lesions (decision cut off between 1 and 2, Fig. 2) a very small difference between the positive predictive values of radiographs and the hyperbolic logarithmic modification was observed, but the negative predictive value of the hyperbolic logarithmic modification was superior to that of radiographs.
Fig. 1. Graph showing the relation between approximal caries prevalence and the positive predictive value (PPV) and negative predictive value (NPV) of diagnoses from radiographs and from radiographic images modified using the hyperbolic logarithmic probability function when the decision cut off was placed between ratings 0 and 1. 1, PPV radiographs; 2, PPV hyp. log. modification; 3, NPV radiographs; 4, NPV hyp. log. modification.

Fig. 2. Graph showing the relation between approximal caries prevalence and the positive predictive value (PPV) and negative predictive value (NPV) of diagnoses from radiographs and from radiographic images modified using the hyperbolic logarithmic probability function when the decision cut off was placed between ratings 1 and 2. 1, PPV radiographs; 2, PPV hyp. log. modification; 3, NPV radiographs; 4, NPV hyp. log. modification.

**DISCUSSION**

In this study the readings from two dental radiologists were used as a reference standard. The choice for this reference standard can be disputed because they can also produce false-positive or false-negative diagnoses. The results of the study should therefore be interpreted relative to the unanimous diagnoses from radiographs by experts.

The results from this study (Tables I, II and III) show that the original radiographs and their digitized equivalents lead to less accurate caries ratings, indicating that the process of digitization caused a loss of valuable information in the digital image. The loss of information had a deteriorating effect on, in particular the ability to correctly identify undecayed surfaces. This illustrates that image enhancements which compensate for the loss of information are indispensable. The exponential, hyperbolic cube root and hyperbolic logarithmic image modifications, evaluated in this study, reached the diagnostic accuracy of radiographs when the observers had to discriminate between ‘decayed’ and ‘undecayed’ (sound) surfaces (Table II). In addition, the positive predictive value of the best modification, i.e. the hyperbolic logarithmic, was comparable to film (Fig. 1). Thus, the aforementioned image modifications, but particularly the hyperbolic logarithmic modification, can be a suitable alternative to radiography in the detection of approximal carious lesions. If it was the observer’s task to discriminate between carious lesions with and without dentinal involvement (Table III), the hyperbolic logarithmic modification was associated with a statistically significant increase in sensitivity to $\phi_{\text{digital}} = 0.95$ and a small but statistically significant decrease in specificity to $\psi_{\text{digital}} = 0.82$ when compared to radiographs. In addition, the negative predictive value of the hyperbolic logarithmic modification was superior to that of radiographs (Fig. 2). These findings indicate that the hyperbolic logarithmic modification is an acceptable image enhancement method to support the diagnosis of approximal dentinal carious lesions. As restorative treatment is justified when caries has reached the dentine (Anusavice, 1988), this modification can be used in operative treatment decision making.

Compared with the other digital modifications, the performance of the hyperbolic logarithmic type of modification is remarkably good. This function stretches contrast particularly at the white end of the grey-scale, causing translucencies in enamel and dentine to be depicted somewhat larger than in the unmodified image. Dental radiologists, more than clinical teachers, are aware of the fact that radiographs consistently underestimate the true depth of a lesion and include this knowledge in their film readings. Since the readings from two dental radiologists were utilized to validate the readings by clinical teachers, it may explain the good performance of the hyperbolic logarithmic type of modification. Research using, for example, histology or microradiography as a validating criterion, should clarify the true value of this type of image enhancement.
In this study some common probability distributions were used to design probability functions, which were applied to pixel values of digitized radiographs. However, the probability functions could be applied more realistically if they were used to modify the density range of the transilluminated radiograph before each density was interpreted by the A/D converter. This can be achieved through physical alteration of the intensities by filtering and enhancement procedures, or by programmable A/D converters. Both options should allow for the light intensities in the low response region and the saturation region of the Hurter and Driffield (H-D) curve to be digitized with additional contrast, i.e., they should expand the range of digital grey values toward white and black. A digital grey value range of 7/6 may then, however, appear to be insufficient to record all different densities.

The viewing of the digital radiographs was conducted with fixed settings of monitor brightness and contrast to avoid monitor variables confounding the results. The digital values are converted by a digital to analogue converter and displayed on the black and white monitor screen. The supply of grey values which a monitor has available is very limited (Klinger et al., 1989), indicating that the monitor may not be able to display the 'real' digital image. Therefore, brightness and contrast should be secured in such a way that the monitor can display the entire range of its grey values in those regions of the image where diagnostic readings have to be made. Usually, this caused other regions in the image to be suppressed. In this study the monitor setting remained unchanged throughout all sessions, although the modified images might have caused this to present its grey value range to a full extent. This effect may, therefore, have caused an underestimation of the diagnostic performance of the digital modifications.

In conclusion, the results of this study indicate that digital radiographic images modified by a full image operator can be an alternative to conventional radiography in the diagnosis of small approximal lesions, but that their true validity has yet to be investigated using a more solid "gold standard" diagnosis. Further research is also required to investigate whether digital radiography can become superior to conventional radiography. In these efforts, emphasis should be placed on the improvement of the specificity of the digital image modalities.

References


Thylstrup A., Bille J. and Qvist V. (1986) Radiographic and observed tissue changes in approximal carious lesions at the time of operative treatment. Caries Res. 20, 75-84.


