Effects of filtration, collimation, and target-receptor distance on artificial approximal enamel lesion detection with the use of RadioVisioGraphy

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RadioVisioGraphy is an imaging modality that uses a charge-coupled device electronic sensor. Dental charge-coupled device imaging can be used to detect dental caries; however, it was not known what effect beam collimation, added filtration, or variable target-receptor distance has on this task. The purpose of this investigation was to study these effects and to compare RadioVisioGraphy images with E-speed radiographs. Human teeth with mechanically created proximal defects were imaged by conventional radiography and RadioVisioGraphy varying exposure time, target-receptor distance, collimation, and filtration. Printed RadioVisioGraphy images without enhancement and E-speed radiographs were evaluated by five viewers. The number of true-positives and false-positives were compared as were sensitivity, specificity, positive and negative predictive values, accuracy, and entrance level radiation exposure. Added filtration reduced the false-positives regardless of collimation or target-receptor distance. True-positives and false-positives were greater at a target-receptor distance of 8 inch at exposures < 0.10 seconds (P < 0.015). E-speed radiographs had a greater specificity and positive predictive value than RadioVisioGraphy images without image enhancement; however, no significant differences were found between RadioVisioGraphy images and E-speed radiographs in true-positive or false-positive identifications without image enhancement.

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RadioVisioGraphy (RVG) (TrophyRadiology, Vincennes, France) uses a charge-coupled device (CCD) as the image receptor. The CCD is a solid-state, area array detector for light from a scintillation screen that is constricted with a fiberoptic bundle. The CCD converts light photons into an electric charge that is stored in the electron potential wells. Light photons from the scintillation screen strike the silicon base in the CCD, break covalent bonds, and release electrons. These electrons are stored in potential wells in the CCD in proportion to the incident x-ray photons that struck the scintillation screen. The wells correspond to pixels and the electron charge in these wells is converted to a gray level for each pixel, which is also proportional to the charge. The charge along a horizontal row of the parallel register is transferred sequentially by electronic gates (circuits) in the silicon to a serial register for a readout. The readout or charge is then amplified and sent to the central processing unit. An analog to digital converter and frame store produces a visible gray scale image that can be displayed on a video screen or printed on thermal paper.1-6 The x-ray tube provided with the RadioVisioGraphy 32000-ZHR (RVG) unit operates at 70 kVp and 8 mA with an exposure range of 0.02 seconds to more than 1 second. RVG 32000-ZHR is equipped with an 8 inch round position-indicating device, and filtration is 1.5 mm of aluminum equivalence. The RVG image is displayed on the video monitor immediately after exposure. The RVG 32000-ZHR requires significantly less radiation than E-speed film to produce an acceptable image.2-7 RVG is designed to allow the operator to enhance the recorded image by manipulating the gray scale, by magnifying part or all of the image, or by using a high resolution zoom mode (later RVG models are not equipped with this mode).

Caries detection has been compared among traditional radiographs, digitized radiographs, and RVG images.8 RVG images that have been enhanced after exposure have also been compared with conventional images.8 The results of these studies indicate that the task of caries detection with RVG images is compa-
Table I. Experimental groups

<table>
<thead>
<tr>
<th>Receptor</th>
<th>Collimation</th>
<th>Filtration</th>
<th>TRD (inches)</th>
<th>Exposure range (seconds)</th>
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<tbody>
<tr>
<td>E-speed film</td>
<td>Round</td>
<td>Aluminum</td>
<td>8</td>
<td>0.02-0.40</td>
</tr>
<tr>
<td>RVG</td>
<td>Round</td>
<td>Aluminum</td>
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<td>0.02-0.16</td>
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<tr>
<td>RVG</td>
<td>Rectangular</td>
<td>Aluminum</td>
<td>8</td>
<td>0.02-0.22</td>
</tr>
<tr>
<td>RVG</td>
<td>Round</td>
<td>Aluminum/gadolinium</td>
<td>8</td>
<td>0.02-0.28</td>
</tr>
<tr>
<td>RVG</td>
<td>Rectangular</td>
<td>Aluminum/gadolinium</td>
<td>8</td>
<td>0.02-0.28</td>
</tr>
<tr>
<td>E-speed film</td>
<td>Round</td>
<td>Aluminum</td>
<td>12</td>
<td>0.02-0.40</td>
</tr>
<tr>
<td>RVG</td>
<td>Round</td>
<td>Aluminum</td>
<td>12</td>
<td>0.02-0.22</td>
</tr>
<tr>
<td>RVG</td>
<td>Rectangular</td>
<td>Aluminum</td>
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</tr>
<tr>
<td>RVG</td>
<td>Round</td>
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<td>12</td>
<td>0.02-0.28</td>
</tr>
<tr>
<td>RVG</td>
<td>Rectangular</td>
<td>Aluminum/gadolinium</td>
<td>12</td>
<td>0.02-0.28</td>
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Table II. Sensitivity, specificity, positive and negative predictive values, and accuracy for exposure parameters

<table>
<thead>
<tr>
<th>Exposure parameter</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>Filtration</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.821</td>
<td>0.792</td>
<td>0.798</td>
<td>0.815</td>
<td>0.806</td>
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<tr>
<td>Aluminum/Gadolinium</td>
<td>0.788</td>
<td>0.842</td>
<td>0.833</td>
<td>0.798</td>
<td>0.815</td>
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<tr>
<td>Collimation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Round</td>
<td>0.792</td>
<td>0.808</td>
<td>0.805</td>
<td>0.795</td>
<td>0.800</td>
</tr>
<tr>
<td>Rectangular</td>
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<td>0.821</td>
<td>0.815</td>
<td>0.798</td>
<td>0.806</td>
</tr>
<tr>
<td>TRD</td>
<td></td>
<td></td>
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<tr>
<td>8 inch</td>
<td>0.775</td>
<td>0.863</td>
<td>0.849</td>
<td>0.793</td>
<td>0.819</td>
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<tr>
<td>12 inch</td>
<td>0.775</td>
<td>0.821</td>
<td>0.812</td>
<td>0.785</td>
<td>0.798</td>
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Table III. Sensitivity, specificity, positive and negative predictive values, and accuracy for imaging modalities at the highest true positive identification

<table>
<thead>
<tr>
<th>Imaging modality</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>Positive predictive value</th>
<th>Negative predictive value</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>8Ron</td>
<td>0.800</td>
<td>0.808</td>
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<td>8Ren</td>
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<td>0.835</td>
<td>0.779</td>
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<td>0.908</td>
<td>0.899</td>
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<td>0.863</td>
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<td>8Ref</td>
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<td>0.850</td>
<td>0.839</td>
<td>0.797</td>
<td>0.817</td>
</tr>
<tr>
<td>12Ron</td>
<td>0.825</td>
<td>0.783</td>
<td>0.792</td>
<td>0.817</td>
<td>0.804</td>
</tr>
<tr>
<td>12Ren</td>
<td>0.817</td>
<td>0.800</td>
<td>0.803</td>
<td>0.814</td>
<td>0.808</td>
</tr>
<tr>
<td>12Rof</td>
<td>0.817</td>
<td>0.867</td>
<td>0.860</td>
<td>0.825</td>
<td>0.842</td>
</tr>
<tr>
<td>12Ref</td>
<td>0.792</td>
<td>0.850</td>
<td>0.841</td>
<td>0.803</td>
<td>0.821</td>
</tr>
<tr>
<td>12Film</td>
<td>0.858</td>
<td>0.992</td>
<td>0.990</td>
<td>0.875</td>
<td>0.925</td>
</tr>
</tbody>
</table>

8, 8 inch TRD.
9, 12 inch TRD.
ro, round collimation.
re, rectangular collimation.
n, no added filtration.
f, added gadolinium filtration.

Although postexposure enhancement has been explored with respect to caries detection, no studies have been performed to evaluate the effects of x-ray beam modification on this task. One type of beam modification that has been used with conventional radiography is gadolinium filtration. Gadolinium is a rare earth material. When used as a filter material, gadolinium is often referred to as a k-edge filter, which hardens the radiation beam. Beam hardening is achieved by removing the lower wavelength photons and permitting the passage of photons with energies comparable to the k-shell electron-binding energy for the particular filter material. In addition, filter materials such as gadolinium have been reported to signif-
significantly reduce patient exposure during radiographic procedures.\textsuperscript{10, 11}

The value of collimating the x-ray beam to reduce both patient exposure and image degradation caused by scattered radiation has been extensively reported.\textsuperscript{12-17} Although the reduction of patient exposure can be extrapolated from radiographic film studies to CCD imaging, the effects of scattered radiation on image quality cannot.

Updegrave\textsuperscript{18} and Biggerstaff and Phillips\textsuperscript{19} discussed the use of a long target receptor distance (TRD). Reduced patient exposure and improved image quality are advantages provided by the use of a long TRD.\textsuperscript{18, 19} Again, patient dose reduction with CCD imaging can be deduced from studies performed using radiographic film. However, the effects of TRD on image quality cannot be extrapolated from radiographic film to CCD imaging.

The purpose of this study was to evaluate the effects of gadolinium filtration, collimation, and TRD on approximal artificial enamel caries detection with the use of the RVG 32000-ZHR compared with imaging with E-speed film (Eastman Kodak Co., Rochester, N.Y.). In addition, exposure comparable to skin surface dose was measured and compared between the techniques.

\textbf{METHODS}

Six groups of three extracted posterior teeth with mechanically induced enamel defects of various sizes were imaged with a RVG 32000-ZHR. Twenty-four approximal surfaces were imaged, 12 with defects and 12 with no defects. Three different size defects were created with no. 2, 4, and 6 round burs in a high-speed handpiece. Three surfaces had defects with a mean depth of 0.23 mm (SD 0.15) and were classified as defects less than half the depth of enamel. Seven surfaces had defects with a mean depth of 0.63 mm (SD 0.06) and were classified as lesions half the depth of enamel. Two surfaces had mean depths of 1.04 mm (SD 0.042) and were classified as lesions greater than half the depth of enamel. Although not reproducing the histologic condition of dental caries, mechanically created defects or "artificial dental caries" have been used in a number of recent studies.\textsuperscript{20-23}

The teeth were approximated and mounted in stone. All images were exposed with a 2.5 cm. acrylic soft tissue equivalent phantom. The experimental groups are shown in Table I E-speed film was exposed with the Trophy x-ray generator (70 kVp, 8 mA) and processed according to manufacturer's specifications in an AT-2000 (Air Techniques Inc., New Hyde Park, N.Y.) with fresh chemistry. RVG images were printed on a 4.5 by 6.5 cm frame with UPP-110HD Sony printing paper (Sony Corp., Park Ridge, N.J.). No postexposure enhancement was performed on the RVG images. The x-ray beam size was limited in half the exposures by attaching a Rinn (Rinn Corp., Elgin, Ill.) snap-on rectangular collimator to the face of the position-indicating device. Six mil of Gd2SO4S:Tb (Lanex regular screen) was placed over the aluminum filter in the tube head for half the exposures.

Four diplomates of the American Board of Oral and Maxillofacial Radiology and one additional person with more than 15 years of radiology teaching experience viewed the RVG images and the film images twice with a minimum of a week between viewings to reduce learning bias. The evaluators were unaware of the experimental groups. Radiographs were viewed in subdued light on a masked viewbox. RVG printed images were viewed in conditions of the evaluator's choosing. Figs. 1 and 2 show typical RVG and film images that were evaluated. The evaluators were instructed to identify the number and location of artificial carious lesions seen on the approximal surfaces of the extracted teeth. Perceptibility curves were constructed that plotted the number of lesions perceived versus the exposure time.\textsuperscript{24, 25} True positive (TP) and false positive (FP) identifications were compared among the imaging modalities at each exposure time using a one-way ANOVA (F < 0.05). Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated for each modality at each exposure time.\textsuperscript{26, 27}

Radiation exposure at the receptor was measured using an ionization chamber (Nuclear Associates Inc., Westbury, N.Y.). Five readings for each expo-
RESULTS

Filtration

The TP values both with and without added gadolinium filtration for RVG images were within one TP of E-speed radiographs at exposure times of 0.12 and 0.16 (Fig. 3). The FP values were lower for added gadolinium filtration RVG images than for those without added filtration by at least one FP at each exposure time (Fig. 4). However, no significant differences were determined between the two filtration modalities with respect to either TP or FP values.

Collimation

The TP and FP values for round and rectangular collimation with RVG were not significantly different from each other or from E-speed radiographs (Figs. 3 and 4). However, the rectangular collimation method used in this study did not appreciably collimate the x-ray beam (see Discussion section).

Target-Receptor Distance

The TP values for the 8 inch TRD were significantly higher than those for the 12 inch TRD at exposure times less than 0.10 seconds (F < 0.015)(Fig. 3). The TP values for the 8 and 12 inch TRDs were not significantly different for exposure times 0.10
Fig. 3. Effects of collimation, added gadolinium filtration, and TRD on TP identifications with RVG and E-speed radiographic film.

seconds or greater. No significant differences were determined among FP values for 8 and 12 inch TRD RVG modalities and E-speed radiographs (Fig. 4).

**Exposure**
Gadolinium filtration, rectangular collimation, and 12 inch TRD all decreased radiation exposure when compared with the 8 inch TRD with no added filtration using round collimation (Fig. 5). The exposure values were measured independently of the image receptor.

**Sensitivity, specificity, PPV, NPV, and accuracy**
Table II compares the sensitivity, specificity, PPV, NPV, and accuracy for each exposure parameter. Gadolinium filtration improved specificity and PPV over images made with no additional filtration. This improvement seemed to be at the expense of sensitivity and NPV. Overall, gadolinium filtration had minimal effect on the enamel defect detection use of RVG. Rectangular collimation produced no differences in caries detection use over round collimation techniques. Eight inch TRD techniques produced higher specificity, PPV, and accuracy than 12 inch TRD techniques. Table III illustrates the sensitivity, specificity, PPV, NPV, and accuracy at the highest TP value for each RVG imaging technique. RVG images with gadolinium filtration had higher specificity than comparable nonfiltered RVG images. E-speed radiographs had higher specificity and PPV than any of the RVG images. However, several of the RVG techniques had comparable sensitivity, NPV, and accuracy with E-speed film. Added gadolinium filtration with round collimation with 8 inch and 12 inch TRD produced the best overall RVG detection use profile.

Intra- and interobserver reliability was evaluated with the use of an ANOVA of TP and FP identifications over the range of exposure times. Interobserver reliability for TP identifications was quite high (no significant differences among observers at 6 of 9 exposure times). Interobserver reliability for FP identi-
Fig. 4. Effects of collimation, added gadolinium filtration, and TRD on FP identifications with RVG and E-speed radiographic film.

Discussions was low. Significant differences were found at each exposure time. One observer accounted for over 88% of the FP identifications. When data from this outlier were excluded from the analysis, differences were found at only four exposure times. Intraobserver reliability for TP identifications was high. No differences were found at any exposure times. Intraobserver reliability for FP identifications was again influenced by one observer (differences in all but three exposure times). When these data were excluded from the analysis, no differences at any exposure times were noted.

Discussion

Added filtration and use of a 12 inch TRD decreased the number of FPs detected with the use of RVG. Although gadolinium filtration decreased the number of FPs, it also appreciably decreased the image density. This effect improved specificity, PPV, and accuracy but decreased sensitivity. Cervical burnout became a significant artifact on the RVG images produced at higher exposures (Fig. 2, C). One evaluator consistently identified areas of cervical burnout as carious lesions. The number of these false identifications was appreciably decreased for the images exposed with gadolinium filtration. Because the RVG unit operates at 70 kVp, only a small portion of the beam spectrum would be selectively modified by gadolinium (k-edge 50kV). A filter material with a lower k-edge may produce comparable effects on specificity and accuracy without detrimental effects on sensitivity.

Rectangular collimation used in this investigation did not influence artificial caries detection. This is probably due to the fact that the "collimation" neither approximated the size of the receptor or appreciably restricted the shape of the x-ray beam. This was determined by placing an extra oral film cassette behind the RVG image receptor and exposing the cassette. The resultant image on the film cassette was round regardless of the shape of the collimation used (Fig. 6). In addition, the rectangular collimation did not approximate the size of the CCD image receptor but rather the size of a No. 2 film.

The use of a 12 inch TRD improved the sensitivity of lesion detection over 8 inch TRD techniques. Varying the TRD did not seem to affect detection with RVG. Because the use of a 12 inch TRD did not af-
fect lesion detection but did decrease patient exposure, a 12 inch TRD should be routinely used when imaging with RVG. Exposure at the RVG receptor was decreased by the use of 12 inch TRD, gadolinium filtration, and rectangular collimation.

As with all studies with multiple observers, intra- and interobserver reliability is a concern. The $\kappa$ statistic is most commonly used to evaluate observer reliability. Recently, the limitations of the $\kappa$ statistic with respect to observer reliability have been discussed.28,29 The greatest deficiency of the use of the $\kappa$ statistic is that it reduces observer reliability to a single value.29 Because of the wide range of exposure times and multiple imaging modalities, ANOVA was used to compare the TPs and FPs by observers and by viewing to provide a more complete evaluation of inter- and interobserver reliability.

Significant differences in TP identifications were noted among viewers at three exposure times. Differences between two observers (high and low value) accounted for this finding. Different combinations of observers were responsible for the differences at the different exposure times. Significant differences in FP identification were found at each exposure time. One observer accounted for 88% of the FP identifications. Because of this outlier, data were also evaluated ex-

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Fig. 5. Comparison of radiation exposure among the imaging modalities.

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Fig. 6. Resultant image with the use of the experimental "rectangular" collimation technique. Exposure factors were 70 kVp, 0.08 seconds, rectangular collimation, no added filtration, 8 inch TRD. The outline of the aperture of the "collimator" is denoted with white arrows.
cluding this observer. Statistically significant differences were found at only four exposure times (as compared with nine).

No differences between TP identifications were noted between viewings. Differences in FP identifications were found in six of nine exposure times. When data generated by the viewer who identified the majority of the FP identifications were excluded, no differences in either TP or FP identifications were found.

Observers had difficulty identifying the defects classified as less than half the depth of enamel independent of imaging modality. Both film and RVG modalities displayed comparable detection of defects half the depth of enamel or larger.

The RVG images were read from printed copies of the image, consequently, the operators were not able to enhance the image by manipulating the gray scale, magnification, or high resolution modes. Wenzel et al.30 have cited a study that indicates a significant difference between the quality of the paper image and the video image with RVG. This quality difference plus the novelty of reading a nontranslucent image may have influenced lesion detection.

Further study is needed to determine if adequate collimation to approximate the dimensions of the image receptor will influence RVG lesion detection and if filter materials other than gadolinium will decrease the number of FPs without degrading image density. The use of artificially induced carious lesions in place of mechanically created defects will provide more accurate information with respect to the detection of small incipient carious lesions using either E-speed film or CCD imaging. The influence of postexposure operator enhancement of the RVG image on proximal caries detection also needs to be evaluated.

REFERENCES


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