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Estimation of Clinical Axial Extension of Class II Caries Lesions with Ultraspeed and Digital Radiographs: An *In-vivo* Study

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Clinical Relevance

Both Ultraspeed and RVG-6000 radiographs underestimated the true clinical extension of Class II caries lesions; however, the RVG-6000 was more accurate in estimating the axial extension of a lesion than Ultraspeed films. Placement of Ultraspeed film was more pleasant for the patient than the RVG-6000 size 2 sensor.

SUMMARY

This study compared the newly introduced direct digital radiographic (DDR) system (RVG-6000) with conventional bitewing radiographs (D-speed film) to estimate the extension of Class II caries lesions. The patient's discomfort related to placement of each radiographic packet was also evaluated. Fifty-one Class II caries lesions were selected. Affected teeth were radiographed with D-speed film and the RVG-6000 size 2 sensor. Patients were asked to complete a one-page questionnaire regarding discomfort during the radiographic examination. The true caries depth was validated clinically from intra-operative photographs that captured the cross-sectional views of the lesion at its deepest point. During the operative procedures, the cavitation status was also recorded. A reference device was placed on the occlusal surface of the treatment or the adjacent tooth before taking radiographs and during the operative procedure. The caries lesion extension from the dentino-enamel junction (DEJ) was measured in mm on each radiograph and the results were compared to the true clinical depth. Both radiographs significant-

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ly underestimated the clinical depth (*p*<0.0001), but the RVG-6000 images were significantly closer to the actual depth of the lesion than the D-speed film (*p*=0.0031). All of the lesions which were diagnosed radiographically to be deeper than 1 mm into dentin were cavitated. Size, sharp edges of the sensor or both comprised the source(s) of most of the discomfort caused by D-speed film (64%) and RVG-6000 sensor (79%). The results of this study showed that both types of radiographic images tend to underestimate caries depth; however, the RVG-6000 image was more accurate than the D-speed film. This study also provides information about sources of the patient's discomfort associated with these radiographs.

INTRODUCTION

Correctly estimating the approximal caries extension for posterior teeth continues to be a difficult clinical task due to the limitations of direct examination of the approximal surfaces of these teeth. For more than 80 years, conventional bitewing radiography has been used to detect approximal caries lesions in posterior teeth. It is well documented in the literature that more approximal caries lesions were revealed radiographically than were discovered clinically.[1-4] Since 1955, D-speed film (Kodak Ultra-speed, Kodak, Rochester, NY, USA) has been manufactured and, because of its superior diagnostic quality, it has become the "gold standard" for bitewing radiographs to which most subsequent radiographs have been compared.

Since digital radiography was introduced, many clinicians are replacing conventional radiographs with digital radiography.[5] Intraoral digital radiographs offer the following advantages over conventional radiography: lower radiation exposure, elimination of film developing, immediate availability of the generated image for evaluation on the computer screen and digital manipulation of the image to enhance viewing. However, the primary disadvantages of digital systems include the rigidity and thickness of the sensors, the high initial system cost and unknown sensor lifespan.[6] The first intraoral digital x-ray sensor was introduced in the mid-1980s by Francis Mouyen (RVG, Trophy Radiologie, Croissy Beaubourg, France [now Trophy, a Kodak company]). RadioVisioGraphic (RVG) sensors have been refined over the past 25 years until Kodak recently launched its new RVG-6000 sensor with complementary metal oxide silicone (CMOS) technology using optical fiber.

The majority of the studies that compared the diagnostic efficacy of different digital radiographic systems with conventional radiographs to detect proximal caries lesions were conducted using *in-vitro* testing on extracted teeth. Most of these studies found different systems performed similarly.[7-11] Studies that measured proximal caries extension found both the conventional and digital systems underestimating the depth of caries.[11-14] However, a few studies found that the radiographs were more than 55% accurate in estimating the caries extension when compared to the depth of histological caries.[15-16]

The objectives of this study include:

1. Comparing the axial extension of Class II caries lesions in different diagnostic images (conventional D-speed film and digital RVG-6000) to the true clinical extension.
2. Evaluating the patient's discomfort, during exposure the two different radiographic sensors.

METHODS AND MATERIALS

Approval from the University of Michigan Health Sciences Institutional Review Board (IRB) was obtained before conducting the study. Written informed consent was obtained from all participants prior to treatment. The recruited subjects had at least one new approximal lesion that extended to or beyond the DEJ and was in proximal contact with an adjacent tooth. Teeth with frank cavitation, severe rotation or symptoms of pulpal inflammation were excluded.

Radiographic Examination and Patient's Questionnaire

Before any radiographs were taken, a measurement device (3-mm segment sectioned from the tip of a marked periodontal probe) was bonded to the occlusal surface of the decayed tooth using flowable composite without etching to act as a reference instrument. One radiograph was then taken using size 2 Kodak Ultraspeed (D-speed) double pack film (Kodak) exposed with the Gendex GX-770 x-ray unit (Gendex Corporation, Des Plaines, IL, USA) following the posted guidelines (70 kVp, 7 Ma, 25 pulses). An eight-inch round cone was placed in contact with the ring of the RINN XCP film holding system (Dentsply International, York, PA, USA) and the patient's cheek during exposure.

A digital image was then made of the same tooth by exposing the Kodak RVG-6000 size 2 digital sensor, Kodak) following the posted guidelines (70 kVp, 7Ma, 10 pulses) using the RINN XCP-DS sensor positioner (Dentsply International). All radiographic images and films were exposed by the primary investigator using the same x-ray unit. Conventional films were developed in an automatic roller-type processor (Gendex GXP Model, KaVo Dental Corporation, Gendex Dental Systems, Lake Zurich, IL, USA) with self-replenishing solutions (Supermax GX solutions, Gendex Dental Systems), while the digital radiographic images were saved directly to the electronic patient record. The order of exposing the radiographs was randomized between the tested radiographic systems.

After the radiographs were taken, the patient was asked to answer a one-page questionnaire to report any discomfort that either the sensor or the film packet had caused during the examination. The first question evaluated the difference between the two radiographs in terms of the patient's discomfort, while the second and the third questions investigated the sources of the patient's discomfort.

Operative Procedures

All of the restorative treatments were performed by the primary investigator. A dental local anesthetic agent was used for all procedures. A preoperative photograph was taken with a digital camera (Nikon D70 SLR, Nikon Corporation, Tokyo, Japan). The selected teeth were isolated with rubber dam, and the lesion was then accessed by a suitable carbide bur and carefully dissected in a step-wise manner cervically through the caries tissue. A series of occlusal intra-oral photographs were taken in an attempt to capture the cross-sectional views of the lesions at their deepest point. Before taking each photograph, the same measurement device used when radiographing the teeth was placed in the operative field as a reference instrument. The photographic sequence was repeated at approximately 1 mm intervals until the maximum depth of the caries was exposed. The tooth was then prepared and restored with the suitable restorative material using standard clinical procedures. During the operative procedure, the cavitation status of the external proximal surface of the affected tooth was viewed directly in multiple cross-sections and was recorded on the patient's data form as no cavitation, cavitation limited to enamel or cavitation extending to dentin. No recall visits were needed in this study.

Image Scoring

Each radiographic image was scored independently by two clinicians, each with more than 25 years of clinical teaching and private practice experience. A calibration exercise utilizing a subset of five radiographic sets out of the 51 lesions was carried out to standardize the radiographic scoring procedure with the two evaluators. Seven days following the calibration exercise, both examiners scored the radiographic sets and utilized consensus agreement to create the final radiographic score.

A standard fluorescent dental viewing box (8 in x 10 in) was used to examine the D-speed films, with all areas peripheral to the radiographic mounts blocked out to minimize glare. The RVG-6000 images were measured directly from a 19-inch computer monitor (Dell UltraSharp 1905FP, Dell Inc, Round Rock, TX, USA) with the RVG-6000 image being automatically enhanced (7x magnification). The distance between the centers of the notches of the reference device in each radiographic image was measured first using a clear plastic ruler and recorded to the nearest 0.5 mm. Next, the caries lesion was measured as an axial extension from the DEJ on the selected radiograph. Once the second value was recorded, the radiographic value of the lesion depth was obtained by dividing the measured value of the lesion by the measured value of the reference device. This calculation was necessary due to the difference in magnification between images generated by the two techniques.

The true clinical depth of the caries lesion was measured from the photographic images taken during caries removal. The photographic images at varying depths were examined carefully to identify the one that showed the lesion at its deepest extension in the axial direction. This process was performed twice, five days apart, and the same image was consistently selected both times. Measurements of the lesions and the reference device were made directly from the computer monitor by following the same procedure used with radiographic images. The deepest axial boundary of the caries lesion was measured from the DEJ, as evidenced by visual changes in dentin (Figure 1). The actual clinical value of the lesion depth was obtained by dividing the measured value of the lesion by the measured value of the reference device. The two measurements were made five days apart to avoid recall bias and the final measured value was the average of the two measurements.

Statistical Analysis

Multiple statistical tests were conducted to analyze the results using SAS 9.1.2 software. One-way ANOVA and Tukey Multiple Comparison tests were used to

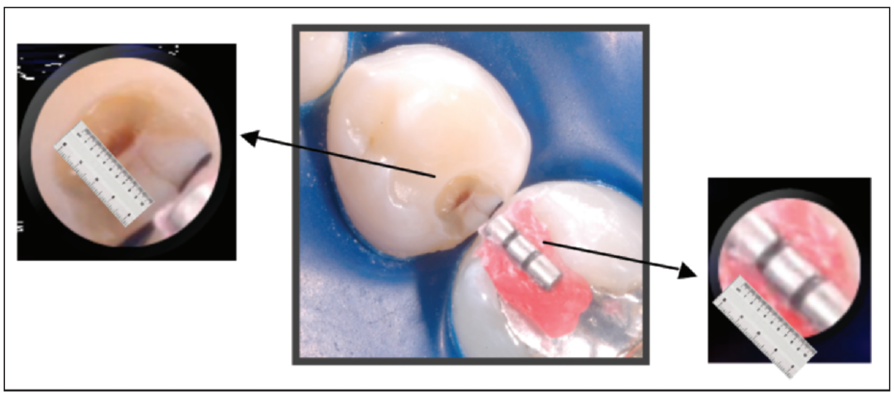

Figure 1. *Photographic image shows the clinical measurement of an approximal caries lesion (the actual clinical depth in mm = caries lesion depth from DEJ/reference device length).*

analyze the difference in the mean depth between the tested images. Pearson Correlation Coefficients were also calculated and used to assess the correlation of the caries depth on each radiographic image to the corresponding caries depth on the clinical images.

Twenty-one patients (15 female and 6 male), ranging in age from 20 to 54 years, requiring 51 Class II restorations (33 premolars and 18 molars), were recruited from the University of Michigan School of Dentistry clinics.

RESULTS

Diagnostic Quality

The lesion depths were classified, for convenience, into six depth categories at 0.5 mm increments, ranging from 0 mm (at the DEJ) to 2 mm into the dentin from the DEJ. All 51 lesions showed caries extending beyond the DEJ clinically. Radiographically, 33% (17/51) of the D-speed and 14% (7/51) of the RVG-6000 radiographic scorings were at the DEJ. Both radiographic sets were plotted against each other to compare the scores in each set (Table 1). The results showed that 31% (16/51) of the lesions were given the same categorical score for both radiographic sets. However, 57% (29/51) were given higher scores (deeper caries extension) for the RVG-6000 radiographic set compared to the D-speed set. The remaining 12% (6/51) were scored deeper in the D-speed radiographic set. Sensitivity of each radiographic modality was calculated at the level of clinical penetration of caries lesions into dentin. It was found that 86% of the RVG-6000 images and 67% of the D-speed radiographs were able to detect the dentinal lesions. The specificity could not be calculated, as all of the caries lesions were extended beyond the DEJ.

By comparing the D-speed scores to the clinical scores (Table 2), it was found that 29% (15/51) of the lesions were given the same depth category for both D-speed radiographs and clinical scores. Seventy-one percent of the lesions (36/51) were scored deeper into dentin clinically than radiographically and no lesion was scored deeper in the D-speed films than it was clinically.

For the RVG-6000 radiographic set, 43% of the lesions (22/51) were given the same depth category radiographically and clinically (Table 3). Forty-nine percent of the lesions (25/51) were scored deeper into dentin clinically and 8% (4/51) were scored deeper in the RVG-6000 images than what they were clinically.

The overall mean depth values from the DEJ for the D-speed films, RVG-6000 images and clinical scores were 0.40 mm, 0.53 mm and 0.83 mm, respectively. The mean differences of the caries depth between the radiographic and the clinical images for each radiographic set were 0.29 mm for the RVG-6000 and 0.42 mm for the D-speed images.

During the operative procedure, 18 of the 51 lesions were cavitated (35%). In 13 cases (25%), the cavitation was confined to enamel; whereas, in five lesions (10%), the cavitation extended into dentin. The distribution of cavitated lesions to the clinical, D-speed and RVG-6000

Table 1: *RVG-6000 Radiographic Scores Plotted against D-speed Scores*

		RVG-6000 Radiographic Scores						
	Category (in mm)	**0**	**0.1-0.5**	**0.6-1.0**	**1.1-1.5**	**1.6-2.0**	**>2.0**	**Total**
D-speed Radiographic Scores	**0**	4	11	2				17
	0.1-0.5	3	8	10				21
	0.6-1.0		2	3	1			6
	1.1-1.5			1	1	5		7
	1.6-2.0							0
	>2.0							0
Total		7	21	16	2	5	0	51

Table 2: *D-speed Radiographic Scores Plotted against Clinical Scores*

		D-speed Radiographic Scores						
	Category (in mm)	**0**	**0.1-0.5**	**0.6-1.0**	**1.1-1.5**	**1.6-2.0**	**>2.0**	**Total**
Clinical Scores	**0**							**0**
	0.1-0.5	9	5					14
	0.6-1.0	7	12	4				23
	1.1-1.5	1	4	2	6			13
	1.6-2.0				1			1
	>2.0							0
Total		17	21	6	7	0	0	51

Table 3: *RVG-6000 Radiographic Scores Plotted Against Clinical Scores*

		RVG-6000 Radiographic Scores						
	Category (in mm)	**0**	**0.1-0.5**	**0.6-1.0**	**1.1-1.5**	**1.6-2.0**	**>2.0**	**Total**
Clinical Scores	**0**							**0**
	0.1-0.5	6	8					14
	0.6-1.0	1	11	11				23
	1.1-1.5		2	5	2	4		13
	1.6-2.0					1		1
	>2.0							0
Total		7	21	16	2	5	0	51

Table 4: *Cavitated Lesions Per Scoring Category for Radiographic and Clinical Sets*

Category Depth	*D-speed Set*		Cavitated Lesions %	*RVG-6000 Set*		Cavitated Lesions %	*Clinical Set*		Cavitated Lesions %
	*N**	*T***		*N*	*T*		*N*	*T*	
0	3	17	18	0	7	0	0	0	-
0.1-0.5 mm	6	21	29	5	21	24	0	14	0
0.6-1.0 mm	2	6	33	6	16	38	6	23	26
1.1-1.5 mm	7	7	100	2	2	100	11	13	85
1.6-2.0 mm	0	0	-	5	5	100	1	1	100
>2.0 mm	0	0	-	0	0	-	0	0	-
Total	18	51	35	18	51	35	18	51	35

N=Number of cavitated lesions, T**=Total number of cases in depth category.*

depths is shown in Table 4. It was found that the percentage of cavitated lesions increased with lesion depth clinically and radiographically.

A one-way ANOVA analysis showed a highly significant difference (p<0.0001) between mean lesion depths of the three images (D-speed films, RVG-6000 images and clinical depth). Tukey multivariate analysis showed that RVG-6000 images were significantly closer in estimating the clinical caries depth than D-speed films (p=0.0031). Highly significant differences were also found between D-speed film and clinical images and between RVG-6000 and clinical images (p<0.0001). Pearson correlation coefficients (PC) showed that the clinical depth of decay was more highly correlated (PC= 0.8130) with the RVG-6000 images than with D-speed film (PC= 0.7409).

Two scatter plots were drawn. The first plot compared the D-speed film readings with the clinical depth (Figure 2). The second plot compared RVG-6000 radiograph readings with the clinical depth (Figure 3). For both comparisons, a greater scatter was associated with shallower lesions. It was observed that the larger the lesion, the better the linearity, especially for comparing D-speed films with clinical depth. When RVG-6000 readings were plotted against the clinical depth of the lesions, a slight curvature of the data was observed for larger lesions; therefore, RVG-6000 images tend to slightly overestimate the size of larger lesions. For small

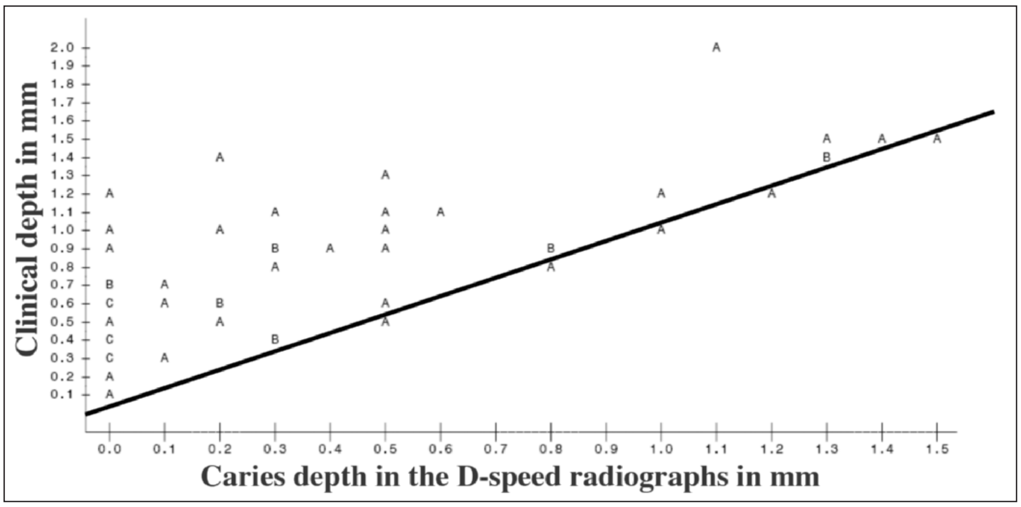

Figure 2: *Scatter plot for the clinical depth of caries against caries depth captured by D-speed radiographs. Letters represent the number of cases for each score (A=1 case, B=2 cases, C=3 cases). Line represents the area where the lesion is given the same depth score clinically and radiographically.*

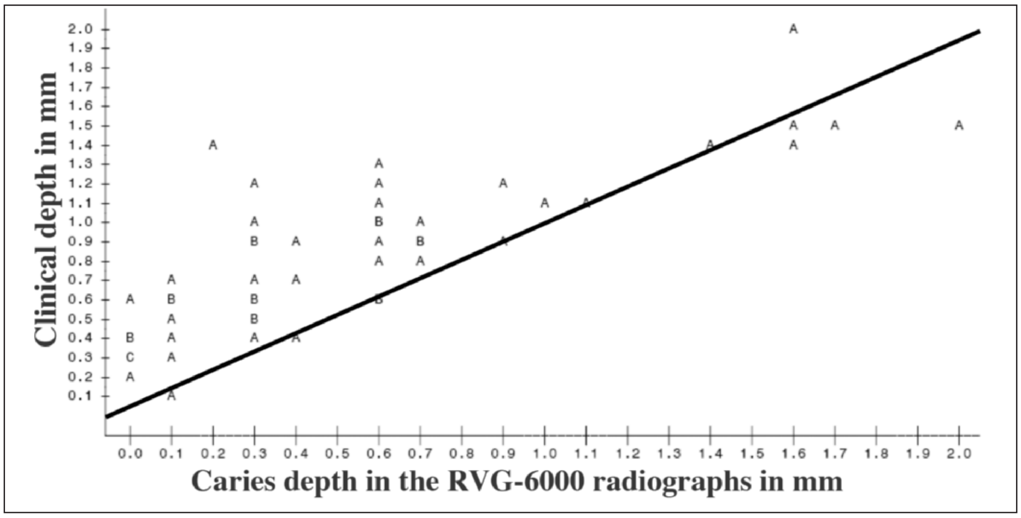

Figure 3: *Scatter plot for the clinical depth of caries against caries depth captured by RVG-6000 radiographs. Letters represent the number of cases for each score (A=1 case, B=2 cases, C=3 cases). Line represents the area where the lesion is given the same depth score clinically and radiographically.*

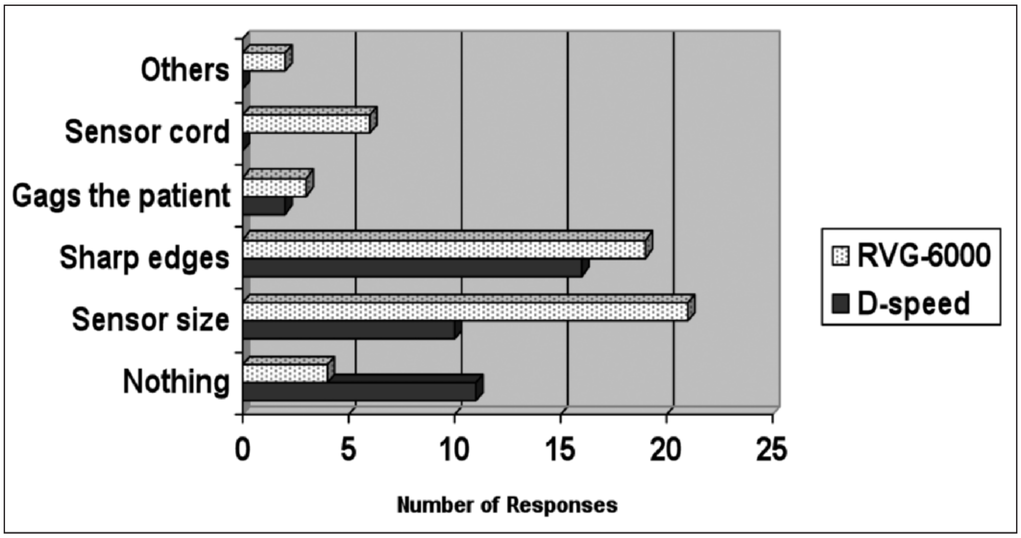

Figure 4: *Bar graph shows distribution of the type of radiograph to the sources of patient's discomfort.*

lesions, RVG-6000 was more accurate than D-speed film in estimating the caries depth. On both plots, most data points are above the equality line (reference line where clinical = radiograph), which means that when either D-speed film or an RVG-6000 image detects decay, the lesion is likely to be larger clinically.

Subject's Discomfort

Thirty-three questionnaire responses were collected from the 21 patients to evaluate the subject's discomfort during the radiographic procedure. Some patients who had caries lesions in different quadrants required two exposures with each radiographic system and, therefore, two responses were collected from those patients. The two radiographic exposures for each lesion were conducted independent of the other lesion and at different appointments. They were also treated independently in the database. Twenty-five out of 33 (76%) responses mentioned that the D-speed radiograph was less unpleasant than the RVG-6000 sensor. Only 15% (5/33) rated both sensors to be the same. Discomfort from either the sharp edges of the sensor, size of the sensor or both was reported in 64% of the cases (21/33) for the D-speed film and 79% (26/33) for the RVG-6000 sensor (Figure 4). However, 33% (11/33) reported no discomfort with the D-speed film and 12% (4/33) for the RVG-6000 sensor. One patient indicated what was most bothersome related to the RVG-6000 sensor was the difficulty in placing the sensor in the mouth, while another patient said that the RVG-6000 sensor pushed her tongue down and it was difficult to bite down completely.

DISCUSSION

The primary objective of the current study was to compare the use of RVG-6000 digital images and D-speed film to diagnose the axial extension of Class II caries lesions. Both were compared to the actual clinical extension measured *in-vivo*. Both radiographic sets underestimated the actual extension of the caries lesions (71% for the D-speed and 49% for the RVG-6000 images). Differences between the clinical and radiographic depths were found to be highly significant ($p<0.0001$). Similar results for conventional films were reported *in-vivo* by Kooistra and others (using F-speed films)[12] and *in-vitro* by Jesse and others (using D-speed films).[13] The level of agreement between the D-speed sets and the clinical set in this study was 29%. Jesse and others found that only 23.3% of the D-speed films agreed with the histological findings.[13] Another *in-vitro* study by Thylstrup and others found that 82% of the radiographic cases were scored the same as the clinical cases.[15] That study, however, included the participation of 263 dentists who were not standardized.

Gungor and others found, *in vitro*, that the D-speed films agreed in 55.8% of the cases with the histological measurements and only 26.8% of the films underestimated the lesions' depths.[16] The examiners did not quantify the lesion depth in mm and the true depth was validated histologically. In the current study, a quantitative measurement scale (+/- 0.1 mm) was used to measure the lesion extension radiographically and clinically.

In another *in-vitro* study, Jacobsen and others found that direct digital radiographic systems (Sidexis and Dixi) significantly underestimated the approximal caries lesion extension.[14] All but one of the four observers underestimated the caries lesions. However, the observers used a computer program to do the measurements, which were validated histologically. Syriopoulos and others found that both CCD and phosphor storage plate (PSP)-based digital radiographic systems underestimated the caries lesion depth *in vitro*.[11]

One of the objectives of the current study was to compare the diagnostic findings of D-speed film with that of RVG-6000 images. The results showed that 31% of the lesions were given the same categorical score for both radiographic sets, while 57% (29/51) were given higher scores (deeper caries extension) for the RVG-6000 radiographic set compared to the D-speed set (Table 1). Although the mean differences of the caries depth between the clinical images and each radiographic set were not very high (0.42 mm for the D-speed; 0.29 mm for RVG-6000), they were found to be statistically significant (p=0.0031). RVG-6000 images tended to slightly overestimate the size of larger lesions (Table 1 and Figure 3). However, that overestimation was not clinically significant in making a decision to restore the tooth, since large lesions would have been treated based on their clinical appearance. It can be concluded from these results that RVG-6000 images are more accurate in estimating small-to-medium size caries lesions than D-speed films. Part of this difference could be explained by auto-enhancement and 7x magnification, both of which were provided by the software program for the digital system.

The results of the current study showed that 86% of the RVG-6000 images and 67% of the D-speed radiographs were able to detect dentinal lesions. Although a significant effort was made to expose the radiographs at the right angle, it was difficult for some patients to bite down fully with the digital sensor in place. This was especially true when the lesion was located closer to the front of the mouth (first premolars) due to the size and rigidity of the RVG-6000 sensor. Hintze and others, using ROC curve analysis, found no significant difference in the area under the curves between the D-speed (p=0.61), E-speed (0.61) and RVG (0.59) systems.[9] However, the RVG system used in that study was the old system (1990) and the validation method was based on histological examination of the lesions. Uprichard and others, using ROC curve analysis, found that examiners were significantly more accurate in diagnosing the proximal surfaces of extracted teeth using either D-speed or E-speed Plus film (area under curve=0.7595, 0.7557) than they were using a CCD-based direct digital system (0.5928).[17] In that *in vitro* study, the examiners (five pediatric dentists) did not enhance the digital images.

In another *in vitro* study, Erten and others found the sensitivity of the new RVG system (0.49) to be higher than Ultraspeed, Ektaspeed Plus and Insight (0.39, 0.48, and 0.45, respectively).[18] Many dental professionals believe in remineralization therapy of incipient caries lesions, and the decision to treat or not to treat a caries lesion is greatly influenced by the presence of cavitation on the proximal lesion as well as the ability to accurately estimate the caries extension. In this study, the cavitated lesions had a clinical caries extension ranging from 0.7 to 2 mm from the DEJ. The results showed that the incidence of cavitation increases as the lesion depth increased both radiographically and clinically (Table 4).

For lesions with a radiographic depth ranging from 0.1 to 1 mm into dentin, 30% were cavitated (8/27 for D-speed and 11/37 for RVG-6000), compared to only 16% of cases with actual clinical lesion depth in the same range. Cases that scored as having a lesion depth between 1.1 and 2.0 mm radiographically were all cavitated. However, only 86% (12/14) of the lesions measured clinically in that range were cavitated. These results were similar to a study conducted by Kooistra and others, who reported that 26% of the 62 cases were cavitated, as were all the lesions that were diagnosed as being greater than 1.0 mm into dentin.[12] Also, Bille and Thylstrup found that 34% of the 158 tested lesions were cavitated and 52% of the lesions extending halfway through dentin radiographically were cavitated.[19]

A patient's discomfort while taking the radiographs may lead to some errors in the image or it may lead to an increase in the number of retakes, which subsequently increase radiation exposure to the patient. This study documented the patient experience after having two different radiographs taken at the same time in the same location. The order of exposing the radiographs was randomized between the two radiographic systems. For patients with more than one lesion in different quadrants, the first set was exposed starting with D-speed film, followed by the RVG-6000 sensor or vice versa. This order was reversed for the other quadrant at a later appointment.

Only a size 2 sensor was used in this study, which was obviously too large for some patients. Therefore, the differences in discomfort between the two systems might have been less if a smaller sized sensor had been available. More than one sensor size would need to be used to comfortably accommodate size variations among patients.

It was obvious from the results of the first question that D-speed film was less unpleasant in the patient's mouth than the RVG-6000 size 2 sensor (76%). Wenzel and others found that 58% of the patients preferred the Digora plate (PSP based digital radiographic system), 30% preferred the RVG sensor and 12% had no preference.[20]

Bahrami and others found no statistically significant difference in a patient's comfort level between the DenOptix (PSP based system) and conventional film, both of which were scored as more comfortable receptors than Planmeca, Trophy (CCD-based system) and Digora (PSP-based system).[21]

One of the difficulties in using a RVG-6000 size 2 sensor in this study was placing the sensor anteriorly and asking the patient to bite down with the sensor in place (33% reported no discomfort with the D-speed compared to only 12% reporting no discomfort with the RVG-6000 sensor). This problem was more prevalent with patients who had a small arch or bony exostoses. This was documented by Bahrami and others, who concluded that CCD sensors were the most difficult to position anteriorly sufficiently to display the canine and first premolar in a bitewing examination, compared to the PSP-based digital systems and conventional film.[21]

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn:

1. Both Ultraspeed (D-speed) film and an RVG-6000 super CMOS-based digital radiographic sensor significantly underestimated the actual clinical extension of Class II caries lesions. The mean radiographic differences in estimating caries depth compared to the true depth were 0.29 mm and 0.42 mm for the RVG-6000 and D-speed film, respectively.
2. RVG-6000 images were significantly more accurate in estimating the axial extension of caries in smaller sized lesions.
3. The incidence of cavitation increased as the lesion depth increased. For lesions diagnosed by either radiographic system between 0 and 1.0 mm into dentin from the DEJ, 25% were cavitated, while only 16% were cavitated for actual clinical lesions in that range. Beyond 1.0 mm, 100% radiographically and 86% clinically were cavitated.
4. D-speed film was more comfortable in the subject's mouth than the RVG-6000 size 2 sensor.

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