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In Vitro Comparison of Four Different Dental X-ray Films and Direct Digital Radiography for Proximal Caries Detection

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Clinical Relevance

F-speed films and digital technologies provide remarkable radiation dose reduction and have equal diagnostic performance with E-speed films for proximal caries detection.

SUMMARY

This study investigated the efficiency of different speeds of conventional intraoral films and a direct digital system for proximal caries detection. In this study, 48 extracted human posterior permanent teeth were used. Conventional bitewing radiographs and direct digital radiographs were obtained from the teeth. Three observers independently assessed 96 proximal surfaces, each observer had 10 years of experience. The presence or absence of caries was scored according to a five-point scale. True caries depth was determined by histological examination. The diagnostic accuracy of each radiographic system was assessed by means of a receiver operating characteristic (ROC) curve analysis. The mean of areas under the ROC curve (Az) was analyzed by pairwise comparison of ROC curve. The interobserver agreement was evaluated by using ANOVA analysis. The statistical analysis of Az scores exhibited no significant difference for the five imaging modalities ($p>0.05$). There was no statistically significant difference between interobserver agreements ($p>0.05$). The results of this study showed that the diagnostic performance of E- and F-speed films and direct digital radiography are similar for proximal caries detection.

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INTRODUCTION

A variety of test methods are available regarding the diagnosis of proximal tooth surfaces.[1] In clinical caries

care, bitewing radiographs form an indispensable addition to the visual inspection of the teeth.[2] The combination of visual inspection and bitewing radiographic images is accepted as a standard procedure in proximal caries diagnosis.[1]

Clinicians strive to reduce the exposure of patients to radiation in an effort to decrease radiation's damaging effects on the human body. A potential strategy for achieving this goal is the use of high-speed films that require less exposure to radiation to form a diagnostic image.[3]

Radiographic film manufacturers continually attempt to produce faster films without decreasing image quality in order to reduce radiation exposure.[4] For many years, D-speed film (Ultra-speed, Eastman Kodak Co, Paris, France) has been considered the "gold standard" for analyzing images. Newer generations of faster E-speed films were introduced (Ektaspeed, Ektaspeed Plus, Eastman Kodak Co), with several studies showing a statistically similar diagnostic capacity to D-speed film.[5-6] The latest generation of radiographic film, F-speed (Insight, Eastman Kodak Co) was introduced in the summer of 2000. With a speed 60% faster than Ultra-speed and at least 20% faster than Ektaspeed Plus, Insight has been recommended as the film choice by some researchers.[4] Sensitometric laboratory evaluations of Insight have shown that the film is 20% to 25% faster than Ektaspeed Plus, with no statistically significant reduced diagnostic efficacy.[7-8] Two other studies found Insight to be less affected when processed in used and depleted developing solutions.[9-10]

The rapid advances in computer technology have had a significant impact on dental radiography. In 1987, the first direct digital system became commercially available as an alternative to conventional radiography. Since then, several systems have been introduced to the market.[11] Many digital intraoral radiographic systems are now commercially available and are expected to replace film radiography.[12] Conventional radiographic films have disadvantages, such as processing errors and varying images, based on the chemical products used, and it is impossible to enhance the image after the films are processed. Additionally, the radiographic image requires a developing, fixing and drying time until it is ready to be interpreted.[13] On the other hand, digital imaging systems eliminate processing disadvantages. Moreover, the radiation dose for digital systems is approximately 20% to 25% of that required for D-speed film and 50% of that required for E-speed film, providing another advantage for digital systems.[14] An advantage of using digital radiographic systems is that the quality of the radiographs can be kept to an acceptable level irrespective of possible exposure variations by adjusting brightness and contrast to their optimum using digital image processing techniques.[12]

This study compared the efficiency of two types of E-speed films (Ektaspeed Plus, Eastman Kodak Co; Agfa Dentus M2 Comfort, Heraeus Kulzer GmbH & Co, Hanau, Germany), two types of F-speed films (Insight, Eastman Kodak Co; Flow X ray FV 58 F speed, Flow X-ray Corp, West Hempstead, NY, USA) and direct digital radiography (Radiovisiography, Marne La Vallee, France) for proximal caries detection.

METHODS AND MATERIALS

The study was based on 48 extracted human posterior permanent teeth, 24 molars and 24 premolars. The clinical appearance of the tooth surfaces after cleaning ranged from sound to discolored, with white/brown discoloration or small cavitations. The teeth were mounted in dental stone models, three in a row (either two premolars and one molar or one premolar and two molars), with proximal surfaces in contact.

The teeth were radiographed with the bitewing technique using Ektaspeed Plus, Agfa Dentus M2 Comfort, Insight and Flow x-ray FV 58 F-speed film. The direct digital radiography system to be evaluated was radiovisiography (RVG). All radiographs of the teeth were obtained using standardized bitewing projection geometry, with an object-to-film distance of approximately 0.5 cm simulating the intraoral clinical condition and a source-to-image receptor distance of 32 cm. The CCX intraoral unit (Trophy, Instrumentarium), with a 0.8 mm focal spot size, operating at 70 kVp and 8 mA, was used for the exposures and had 2.5 mm of aluminum-equivalent filtration. One centimeter of soft tissue equivalent material was used to simulate scatter radiation and beam attenuation from facial tissues. E-speed films (Ektaspeed plus and Agfa dentus M2 comfort) were exposed for 0.24 seconds and F-speed films (Insight and Flow x ray FV 58) were exposed for 0.16 seconds. All film radiographs were developed in an automatic film processor with fresh solution (Velopex, Extra-X, Medivance Instruments Ltd, London, UK and NW107A). Digital images were obtained with a 32-cm sensor to focal spot distance with a 0.08-second exposure time. Figure 1 shows examples of radiographic images evaluated in the study.

Two oral and maxillofacial radiologists and one specialist in restorative dentistry with at least 10 years of experience independently evaluated all the images. The film radiographs were interpreted using a light box and a 2x magnification X-viewer (Luminosa, CSN Industrie, Italy) in a darkroom. Images from the digital system were displayed on a 17-inch monitor. Brightness and contrast features of the software were standardized before assessing the images.

The presence or absence of caries was assessed in the proximal surfaces of the teeth by using a 5-point confidence scale, where 1=caries being definitely absent,

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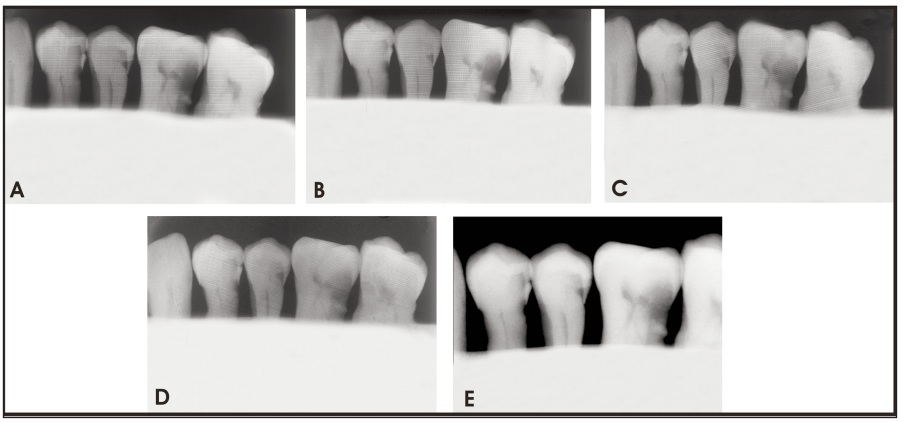


Figure 1: *Examples of images evaluated in the study. A: An example of Ektaspeed Plus; B: An example of Agfa Dentus M2 Comfort; C: An example of Insight; D: An example of Flow X-ray FV 58; E: An example of RVG.*

2=caries probably absent, 3=unsure whether caries is absent or present, 4=caries probably present and 5=caries is definitely present.[15] Observers were instructed to assess only the proximal surfaces coronal to the cementoenamel junction.

After all assessments were completed, the teeth were histologically prepared. The proximal surfaces were first colored with a solution of propylene glycol with added basic fucsin (0.5%) for 10 seconds and rinsed in tap water. The teeth were then hemisectioned perpendicular to the proximal surfaces from their central fossas by a diamond disc under water-cooling. Two sections were obtained, each section was examined under a stereomicroscope (Olympus SZ 60, Japan) at 10x magnification by three observers.

For histological validation, the following scale was applied:[16]

1= Sound

2= Caries in enamel

3= Caries in dentino-enamel junction

4= Caries in the outer-half of the dentin

5= Caries in the inner-half of the dentin

Data Analysis

Histological validation served as the "gold standard" for all tested methods. The diagnostic accuracy of the five radiographic systems was assessed from the area under the receiver operating characteristic (ROC) curve (Az). Med-Calc (version 7.3) was used for ROC analysis. Az values were calculated for each observer for each diagnostic method. The Az values were analyzed by pairwise comparison of ROC curves. One-way analysis of variance (ANOVA) was performed for comparison of observers. SPSS-version 13.0 for Windows (Northwestern University Information Technology, Evanston, IL, USA) was used for all calculations. The level of statistical significance was α=0.05.

Table 1: *Histological Examination of the Teeth*

Scores	# of Tooth Surfaces	Percent (%)
Score 1	61	63.54
Score 2	3	3.12
Score 3	12	12.5
Score 4	2	2.09
Score 5	18	18.75

RESULTS

The status of the 96 proximal surfaces in 48 posterior teeth was assessed. Histological examination of the teeth confirmed that 61 (63.54%) of the proximal surfaces were caries free; whereas 35 (36.46%) of the proximal surfaces determined caries lesions of different depths. According to histological examination, the number of proximal surfaces for each score is shown in Table 1. The distribution of caries depth in accordance with histology diagnosed by each radiographic system is shown in Table 2.

Table 2: *The Proportion of Sound and Carious Proximal Surfaces Assessed by Histology*

Methods	Score 1 (%)	Score 2 (%)	Score 3 (%)	Score 4 (%)	Score 5 (%)
Ektaspeed Plus	100	0	16.7	100	77.8
Agfa Dentus	100	0	16.7	100	77.8
Insight	100	0	8.3	50	77.8
Flow X-ray	100	0	16.7	50	77.8
RVG	98.4	0	16.7	100	88.9

No statistically significant difference was found between observers at the 95% confidence interval (p>0.05) according to ANOVA (Table 3).

Table 3: *Results of ANOVA*

	Sum of Squares	df	Mean Square	F	Sig
Between Groups	4.210	2	2.105	1.012	0.364
Within Groups	2989.290	1437	2.080		
Total	2993.499	1439			

Figure 2 illustrates the ROC curve for radiographic methods. Areas under the ROC curve (Az) and standard errors are shown in Table 4. The Az values were 0.843, 0.811, 0.800, 0.796 and 0.793 for Ektaspeed plus, Agfa dentus M2 comfort,

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Insight, Flow x ray and RVG, respectively. Analysis of Az values are shown in Table 5. No statistically significant difference was found between radiographic systems in the 95% confidence interval according to pairwise comparison ($p>0.05$).

DISCUSSION

In this study, the efficiency of four types of dental films with different speeds and a direct digital radiographic system were compared by using ROC analysis for proximal caries detection.

Several studies have compared conventional films and direct digital systems, and diagnostic performance of these systems was found to be equal for proximal caries diagnosis.[11,13,16-17] Digital intraoral systems are reported to produce diagnostically-comparable images with conventional films by providing a radiation dose reduction of 25%-50%, and these systems allow for image quality enhancements to increase diagnostic accuracy.[18-19] Wenzel reviewed studies assessing the diagnostic accuracy of radiographic caries detection in digital methods, and the majority of these studies did not demonstrate significant differences in accuracy between enhanced and unenhanced images.[14] Moystad and others[20] and Gotfredsen and others[21] reported better results in the interpretation of digital images with brightness and contrast enhancement. However, Tyndall and others[22] reported that brightness and contrast enhancement features were not properly used and may actually reduce diagnostic accuracy in digital systems. This result was confirmed by Ohki and others.[23] Interpretation of the digital image presented less sensitivity than the conventional radiographic image, but it provided equal diagnostic performance for the majority of the observers.[24] The observers were not allowed to change the brightness and contrast features of the software used in this study. The assessments were carried out under standardized conditions, providing optimal diagnostic performance, and no statistically significant difference was found between conventional and digital intraoral radiographs used in this study.

Depletion of developer and fixer solutions had an adverse effect on the speed of all types (D, E, F) of films.[9] Syriopoulos and others[25] investigated the effect of age of solutions on the different developing sys-

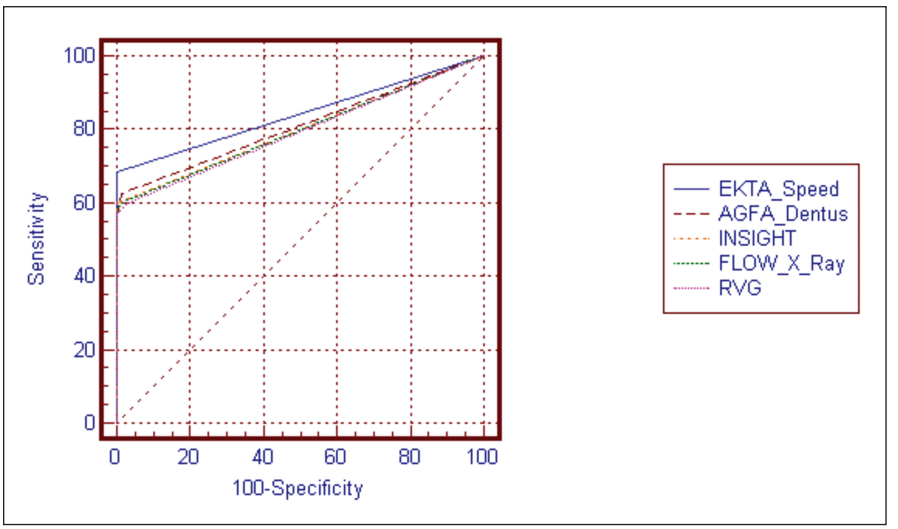


Figure 2: *ROC curve of radiographic methods.*

Table 4 : *The Mean of Areas Under the ROC Curve (Az)*

Test Result Variable(s)	Area	Std Error	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
Ektaspeed plus	0.843	0.045	0.754	0.909
Agfa dentus M2 comfort	0.811	0.049	0.718	0.883
Insight	0.800	0.050	0.706	0.875
Flow X ray FV 58	0.796	0.050	0.702	0.872
RVG	0.793	0.051	0.698	0.869

Table 5: *Pairwise Comparison of Az Scores*

Pairwise	Difference Between Area	Std Error	P	Asymptotic 95% Confidence Interval	
				Lower Bound	Upper Bound
Ektaspeed-Agfa dentus	0.032	0.051	0.530	-0.068	0.132
Ektaspeed-Insight	0.043	0.052	0.408	-0.059	0.144
Ektaspeed-Flow x-ray	0.046	0.052	0.372	-0.055	0.148
Ektaspeed-RVG	0.050	0.053	0.350	-0.055	0.154
Agfa dentus-Insight	0.011	0.052	0.837	-0.092	0.113
Agfa dentus-Flow x-ray	0.014	0.005	0.007	0.004	0.025
Agfa dentus-RVG	0.018	0.053	0.739	-0.087	0.123
Insight-Flow x-ray	0.004	0.053	0.947	-0.100	0.107
Insight-RVG	0.007	0.054	0.896	-0.099	0.113
Flow x-ray-RVG	0.004	0.054	0.948	-0.102	0.109

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tems and found that a decrease in speed varied widely over different lengths of time and for different developers. The Agfa film, M2 Comfort, is also classified in speed group E when it is processed automatically in system-compatible chemistry or manually in fresh chemistry. Under other processing conditions, it is classified in speed group D.[26] Since film speed is properly categorized according to ISO (International Organization for Standardization) protocol, the films should be developed with a roller-type automatic processor and fresh solutions.[8-9,26] Conventional films with different speeds (E and F) were used in this study. All conventional films were developed in this study with an automatic film processor and fresh solutions in order to obtain each film with the correct speeds.

Previous studies[27-29] reported that the diagnostic performance of F-speed films is not any different from D- and E-speed films for caries detection. However, one study[5] has shown that F-speed film (Insight) had poorer image quality than E-speed film (Ektaspeed plus). Farman and Farman[30] reported that the diagnostic performance of another F-speed film (Flow x ray) is almost equal to that of D- and E-speed films. These different results may have been due to differences among the samples and/or rating scales, depth of carious lesions and experience of the observers. In this study, F-speed films (Insight and Flow x-ray FV 58) were found to have adequate image quality, and the diagnostic performance of E- and F-speed films were found to be equal for proximal caries diagnosis.

Recent studies[11,31] that evaluated the accuracy of radiographic methods showed differences in diagnostic performance between individual observers. These studies reported that this condition might have been due to differences in experience, training or visual perception.[32] Stookey and others[33] reported these differences in diagnostic performance as a limitation of the radiographic interpretation of the high degree of variability of intra- and inter-observers. Dunn and Kantor[34] mentioned the radiographic interpretation as an activity of high cognitive level based on the knowledge and experience of the examiner. Syriopoulos and others[11] emphasized that diagnosis of the radiologists was significantly closer to actual lesion depth than that of the general practitioners. In this study, three observers were specialists (two oral and maxillofacial radiologists and a specialist in restorative dentistry), each having approximately 10 years of experience. No statistically significant difference was found between observers in this study.

Receiver operating characteristic (ROC) analysis is well established as a method of comparing the diagnostic accuracies of imaging systems and will continue to be a reliable method.[35] The area under the ROC curve (Az value) provides useful information to measure the accuracy of a diagnostic system.[36] The highest Az value was found to be 0.843 for Ektaspeed plus film, and the Az values in this study were 0.811, 0.800, 0.796 and 0.793 for Agfa dentus M2 comfort, Insight, Flow x-ray FV 58 and RVG, respectively. The difference in ROC curve areas among the four conventional films and digital radiographs was not statistically significant.

CONCLUSIONS

No statistically significant difference was found between four types of conventional films with different speeds and digital radiography according to ROC analysis for proximal caries detection in this study. F-speed films with approximately a 20% dose reduction and digital systems with approximately a 50% dose reduction had produced similar quality images when compared with E-speed films. Ionizing radiation burden was relatively small in dental radiology; patients should be exposed to as little radiation as possible according to the ALARA principle. Because F-speed films and digital technologies provide remarkable radiation dose reduction and have equal diagnostic performance with E-speed films for proximal caries detection, dentists should consider these factors when choosing a radiographic technique.

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Corrections

Changes/corrections have been made and are posted online for the following articles, which were published in *Operative Dentistry* **32-4** and **32-5**:

In Vitro Inhibition of Bacterial Growth Using Different Dental Adhesive Systems (R Walter, WR Duarte, PNR Pereira, HO Heymann, EJ Swift Jr & RR Arnold) **4** 388-392.

The Effect of Light Curing Source on the Residual Yellowing of Resin Composites (MG Brackett, WG Brackett, WD Browning & FA Rueggeberg) **5** 443-450.

In Vitro Comparison of Four Different Dental X-ray Films and Direct Digital Radiography for Proximal Caries Detection (MT Alkurt, I Peker, O Bala & B Altunkaynak) **5** 504-509.