

Clinical Study of the Sensitivity and Dynamic Range of Three Digital Systems, E-speed Film and Digitized Film

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The objective of the present study was to clinically evaluate the sensitivity and dynamic range of three digital systems (Sens-A-Ray, CDR, Digora), digitized film and E-speed film. Five objects were submitted to three different kilovoltages and seven exposure times. In order to evaluate the relationship between exposure time and dosage, measurements were made in a dental x-ray unit with an ion chamber, X-ray timer and kVp meter. For each system, 105 radiographs were taken, totalling 525 images, that were evaluated by six trained observers by means of scoring from 0 to 4. The scores attributed to the images for each of the systems were submitted to analysis of variance and Tukey's test. The results showed statistically significant differences ($p < 0.01$) with the storage phosphor system producing the wider dynamic range, followed by the digitized film. The CDR system showed the greater sensitivity, followed by the Digora system.

Key Words: dental radiography, computer-assisted image enhancement.

INTRODUCTION

For almost a century, radiographic film was the only radiographic image receiving resource. However, radiographic technology is always seeking improvement in image quality, reduction of the dose of radiation to the patient, and a decrease in the time to take the radiography. Research reported good results with digitized radiograph film (1-3), and later with direct digital radiography, presenting digital sensors as photon-detectors replacing conventional film.

There are many advantages to digital images, such as the reduction in the patient's exposure dose (4-6) and the wider dynamic range of the storage phosphor plate (7-9). These conditions reduce the number of retakes when compared to film, because it is much less sensitive to exposure variations than both CCD systems and conventional film-based technology (4). Some authors point out that the dynamic range of the CCD digital sensors is narrow (10-12).

This study subjectively evaluates the image quality when submitted to different kilovoltages and exposure times of two CCD digital systems, one storage phosphor system, the E-speed film and the digitized film. The variation of these factors has allowed a comparative evaluation of the dynamic range and sensitivity of these systems.

MATERIAL AND METHODS

The radiographic systems used in this study were: 1) Sens-A-Ray 2000 (Reagam Medical System, Sundsvall, Sweden), 2) CDR (Schick Technologies Inc., Long Island, NY, USA) - Sensor No.2, 3) Digora (Soredex Orion Corporation, Helsinki, Finland) - optical plate size 30 x 40 mm, 4) E-speed Film - Kodak Ektaspeed Plus EP 21 (Eastman Kodak Co., Rochester, NY, USA), processed by the manual method, and 5) digitized film with the radiographs recorded by a Hewlett Packard Scanjet 4C/T scanner (Hewlett Packard,

Vancouver, WA, USA), associated with the Corel Photo-Paint software (Corel Corporation, Ontario, Canada). The images were stored in the TIFF format (Tagged Image File Format) without compression (8 bits with resolution of 600 DPI, a file of about 700 kB). The digital system monitor was a 17-inch S-VGA plane screen, with a screen configuration of 1024 x 768 resolution pixels.

The five objects analyzed were as follows: three dental anatomical areas - two sections of dry mandible (molar and premolar areas), one section of dry maxilla (incisor area) that were covered with a 4-mm thick silicon sheet to simulate soft tissue, an aluminum stepwedge and an aluminum block containing six 0.5-mm wide holes, varying in depth from 0.5 to 3 mm in increments of 0.5 mm.

The dental X-ray unit used was the GE 1000 (General Electric Company, Milwaukee, WI, USA), operating at 50, 60 and 70 kVp, and exposure times of 0.05, 0.08, 0.13, 0.2, 0.4, 0.8 and 2 seconds for each kVp, in 21 different exposure groups (Table 1). The

Table 1. Specifications of exposure groups based on dose, exposure time and kilovoltage.

Exposure Group	Dose (μGy)	Exposure time (s)
Kilovoltage 50		
1	85	0.05
2	135	0.08
3	220	0.13
4	340	0.2
5	680	0.4
6	1360	0.8
7	3400	2
Kilovoltage 60		
8	140	0.05
9	224	0.08
10	364	0.13
11	560	0.2
12	1120	0.4
13	2240	0.8
14	5600	2
Kilovoltage 70		
15	200	0.05
16	320	0.08
17	520	0.13
18	800	0.2
19	1600	0.4
20	3200	0.8
21	8000	2

lower exposure times of 0.05, 0.08 and 0.13 s were used to test the system's sensitivity; the intermediate times of 0.2, 0.4 and 0.8 s were used because these are the times mostly used in clinical practice, and the extreme time of 2 s was used to check the dynamic range of the systems. The focal spot to image receptor distance was 32 cm. An assessment of the beam entry dose was made in order to evaluate the relationship between exposure time and dose. For this purpose the following equipment was used: the "ion chamber" Victoreen 06-526, the "X-ray timer" Victoreen 07-457 (Victoreen Inc., Cleveland, OH, USA) and "kVp meter" (9002; Unfors Instruments, Billdal, Switzerland). The results showed that the dental x-ray unit used provided accurate results, in terms of exposure time, kilovoltage and dosage, with a good linear relationship between radiation dosage and exposure time.

Each object was exposed 21 times for each of the five systems, totalling 105 images for each object. As there were five objects, the total number of images was 525. In order to standardize the images, the three dental anatomical areas were placed in a Rinn holder (Rinn Corporation, Elgin, IL, USA) for exposure, while the metal objects were positioned in the central part of the photon-detector and exposed at a 90° vertical angle and 0° horizontal angle.

The radiographic analysis was done by six observers: three radiologists, two general practitioners and one senior dental student, making a total of 3150 evaluations. These observers used a scale from 0 to 4, to classify the images, where: 0 (zero) = without image; 1 = without possibility of diagnosis; 2 = poor quality for diagnosis; 3 = satisfactory diagnosis conditions, and 4 = ideal diagnosis conditions. To avoid different results among the observers, they were trained prior to analysis on how to work with the systems. After this training, an inter- and an intra-observers test for agreement was performed, involving 30 and 10 radiographs, respectively, and using the Kappa statistical method, which presented the values of 0.89 for the inter- and 0.91 for the intra-observers test. These tests were performed in order to evaluate the extent of assimilation of previous training, and the results were regarded as satisfactory. The evaluation was carried out disregarding the dimensional differences of the photon-detectors, and the number of images analyzed by each observer was limited to only one system per day, to avoid visual fatigue, which could impair the analysis. The observers were

blinded to the exposure time of the image evaluated.

The images were analyzed with the software inherent to their systems, and only the manipulation of brightness and contrast was allowed by means of the image manipulation tools at reduced room lighting and monitor brightness. The scoring record was filled out on previously prepared tables.

The data were submitted to analysis of variance and Tukey's test. The ratio of scores 3 and 4 was also calculated, because only these scores expressed diagnostic conditions for analyzing the dynamic range and sensitivity of the systems.

RESULTS

The scores given to the images by each observer, according to the system, exposure group and object, were submitted to analysis of variance in factorial outline. The results are presented in the Table 2.

The means of the scores given to each system, in decreasing order, are given in Table 3. The Digora system presented the largest number of images in diagnostic conditions, thus showing the wider dynamic range.

Table 2. Analysis of variance of the image scores.

Source	Degree of freedom	Sums of squares	Mean square	F
Systems	4	1292.00	323.02	768.23*
Groups	20	1401.60	70.08	166.66*
Objects	4	53.20	13.30	31.63*
S x D	80	1394.40	17.43	41.44*
Residue	3041	1277.22	0.42	
Total	3149	5418.42		

*significance at the level of 1%.

Table 3. Mean subjective image quality scores for each system.

Systems	Means ± SD	Tukey's test
Digora	3.25 ± 0.82	A
Digitized film	2.54 ± 1.12	B
E-Speed film	2.41 ± 1.06	C
CDR	1.67 ± 1.43	D
Sens-A-Ray	1.47 ± 1.20	E

P<0.01. Different letters indicate statistically significant difference.

The percentages of images with scores 3 and 4 were calculated according to the exposure group in each system, because these scores were the only ones that had diagnostic value. These data are presented in Table 4. The Digora System has the largest percentage of scores 3 and 4, followed by digitized film, E-speed film, CDR and the Sens-A-Ray.

In Table 4 it can be seen that the capacity to produce images with scores 3 and 4, at the lowest doses, is greater in the CDR followed by Digora. Therefore, these systems have greater sensitivity than the others. The Sens-A-Ray system presented the lowest number of images in diagnostic conditions, thus harming its sensitivity analysis, which was evaluated on the basis of image quality. Therefore, this low result (best percentage around 70%, compared to 100% in the other systems) made it difficult to determine the ideal exposure time

Table 4. Percentages of images scored 3 and 4 according to the dose, in each system.

Group	CDR	Digora	Digitized film	Film E-speed	Sens-A-Ray
Kilovoltage 50					
1	0	0	0	0	0
2	0	26.7	3.3	0	0
3	76.7	70.0	13.3	0	10.0
4	96.7	93.3	63.3	26.7	53.3
5	53.3	100.0	96.7	93.3	70.0
6	20.0	100.0	100.0	96.7	20.0
7	0	96.7	33.3	43.3	0
Kilovoltage 60					
8	3.3	26.7	3.3	0	0
9	80.0	70.0	16.7	0	20.0
10	96.7	96.7	83.3	20.0	70.0
11	56.7	100.0	100.0	86.7	50.0
12	20.0	100.0	100.0	100.0	20.0
13	3.3	100.0	60.0	70.0	0
14	0	96.7	13.3	20.0	0
Kilovoltage 70					
15	46.7	63.3	10.0	0	10.0
16	100.0	83.3	56.7	6.7	63.3
17	40.0	93.3	96.7	80.0	36.7
18	20.0	100.0	100.0	100.0	20.0
19	0	100.0	83.3	93.3	0
20	0	100.0	16.7	36.7	0
21	0	86.7	0	0	0
Mean	34.0	81.1	50.0	41.6	21.1

The exposure groups from 1 to 21 are reported in Table 1.

for reaching the best image quality. However, according to the results, it was deduced that Sens-A-Ray is a faster system than the E-speed film.

DISCUSSION

This study subjectively evaluated the sensitivity and dynamic range of five radiographic image systems, based on the number of images that offered diagnostic conditions after being submitted to different kilovoltages and exposure times. Seeking greater fidelity in the results, these exposure factors as well as the objects analyzed were diversified.

The results indicated Digora as the system with the largest number of images in diagnostic conditions. These results are in agreement with the literature (7-9,13).

The results of this study showed the digitized film as having a wider dynamic range and a greater sensitivity than the film analyzed in the light box, in agreement with other authors (1-3). This probably occurred due to the availability of digital manipulation tools, because some radiographs that would otherwise be discarded for poor diagnosis quality could be recovered, thus making radiographic diagnosis possible. However, this only occurred with under-exposed films. In case of over-exposed films, when attempts were made to recover some contrast, density alteration was noticed with an increase of image fog, identical to that presented by CCD systems. In spite of the results of digitized film, it could hardly be part of the dental clinic routine, due to the difficulty demonstrated in image acquisition.

The CCD, Sens-A-Ray and CDR systems showed the lowest number of the images in diagnostic conditions. These results are similar to those of Borg and Gröndahl (11) and are related to the great sensitivity and narrow dynamic range presented by these systems. Because 21 different exposure groups within a wide range were used in this study, many images became over-exposed, rendering them without the least possibility of making a diagnosis. It was observed that the use of 70 kVp is contra-indicated for these and other CCD systems, because it reduces the dynamic range even further. Some authors are in agreement about their considerations regarding the dark current of noise in the Sens-A-Ray system (14-16), which is introduced by them as a linear function of exposure time. They report

it as a condition that has a direct influence on decreasing the available gray scale of the image, harming the radiographic contrast by having a limiting effect on the dynamic range. It is believed that the limited CDR dynamic range can be justified in the same way by the fact that this system also uses the CCD as a photon-detector.

With regard to sensitivity, CDR presented the best results and its great sensitivity, as observed in this study, is in accordance with previous studies (10,17,18), as is also its reduced dynamic range (10). Therefore, in terms of decreasing doses to the patient, it is clear that this system is very advantageous. However, Welander et al. (15) pointed out that X-ray equipment should be adapted to work with a high sensitivity detector, because it was possible to verify that, according to the object, it may be necessary to use exposure times inferior to 0.1 s, as well as shorter time intervals than those usually used.

It is important to point out that the results of this study have not suffered any influence of possible saturation of the sensors through use or even manufacturer defects, because all equipment was tested at the time of installation, having been recently acquired when data collection for this study started. Another important consideration arising from the results found here is that in order to evaluate the diagnostic quality of a system, and to justify a result found, it is necessary to consider image quality, dynamic range, and sensitivity as intimately related concepts, and to recognize the direct influence of these factors on one another.

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RESUMO

Bóscolo FN, Oliveira AE, de Almeida SM, Haiter CFS, Haiter Neto F. Estudo clínico da escala dinâmica e sensibilidade de três sistemas digitais, filme E-speed e filme digitalizado. *Braz Dent J* 2001;12(3):191-195.

O objetivo do presente estudo foi avaliar clinicamente a sensibilidade e escala dinâmica de três sistemas digitais (Sens-A-Ray, CDR, Digora), filme digitalizado e filme E-speed. Empregou-se cinco objetos de análise que foram submetidos a três diferentes quilovoltagens e sete tempos de exposição. Foi

efetuada a avaliação do aparelho de raios X com câmara de ionização, *timer* de raios X e *kVp meter* visando verificar a relação entre tempo de exposição *versus* dose. Foram realizadas 105 radiografias para cada sistema, totalizando 525 imagens que foram avaliadas por seis examinadores que utilizaram uma escala de 0 a 4 para classificá-las. Os escores atribuídos as imagens de cada sistema foram submetidos à análise de variância e Teste de Tukey. Os resultados mostraram diferença estatisticamente significativa ($p < 0.01$), com o sistema de armazenamento de fósforo produzindo uma maior escala dinâmica, seguido pelo filme digitalizado. O sistema CDR apresentou a maior sensibilidade, seguido pelo Digora.

Unitermos: radiografia dentária, radiografia digital.

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