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Reproducibility of pixel values for two photostimulable phosphor plates in consecutive standardized scannings

Reprodutibilidade dos valores de "pixels" de duas placas de fósforo fotoestimuláveis em leituras padronizadas consecutivas

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ABSTRACT: The objective of the present study was to determine the reproducibility of the pixel values obtained with the Digora system (Soredex, Finland). Exposures were standardized, with variation in exposure and scanning time of two photostimulable phosphor plates containing a stepwedge image. The smallest variation in pixel values ranged from 50 to 75%, with the widest variations being observed in less dense steps. A significant difference in pixel values was observed in terms of X-ray exposure and scanning times and between the two plates themselves (ANOVA, $p < 0.01$). Using the present methodology, the reproducibility of pixel values was not satisfactory for the tested white photostimulable plates. This wide variation in digitalization might be influenced by the amount of X-rays that sensitized the plates. It may be important to establish the reproducibility of the pixel values in quantitative studies using digital image.

DESCRIPTORS: Radiography, dental, digital; Reproducibility of results.

RESUMO: O objetivo do presente trabalho foi determinar a reprodutibilidade dos valores de "pixels" obtidos com o sistema Digora (Soredex, Finlândia). As exposições foram padronizadas, com variação no tempo de exposição e leitura de duas placas de fósforo fotoestimuláveis contendo a imagem de um penetrômetro. A menor variação nos valores de "pixels" foi de 50 a 75%, sendo as maiores variações oriundas nas faixas mais claras. Uma diferença significante nos valores de "pixels" foi observada em relação ao tempo de exposição e leitura das placas e entre as duas placas (ANOVA, $p < 0,01$). Utilizando a presente metodologia, a reprodutibilidade dos valores de "pixels" das placas testadas do sistema Digora não foi satisfatória. Essa grande variação na digitalização pode ter sido influenciada pela quantidade de Raios X que sensibilizou as placas. Isso pode ser importante para estabelecer a reprodutibilidade dos valores de "pixels" em estudos quantitativos usando imagem digital.

DESCRITORES: Radiografia dentária digital; Reprodutibilidade dos resultados.

INTRODUCTION

Some digital radiographic systems use photostimulable phosphor plates, materials that emit light when exposed to another energy source (light, X-rays). Commercially, this method was introduced in 1981 during the International Congress of Radiology, and the first study was published in 1983[16]. Since then, there have been great advances in imaging systems in general[2].

Photostimulable plates have some advantages over conventional radiographic film, including the efficient formation of the latent image because these plates absorb more energy than conventional film, and thus require a shorter exposure time[10]. Finally, the image is obtained electronically, eliminating chemical processing, and the plates are also reutilizable[6,11].

The signal resulting from a digital photostimulable phosphor imaging system might be affected by a low incidence of photons (short exposure) and thus generate a smaller number of luminescence centers, which in turn leads to a low signal. Con-

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sequently, there is an increase in photon noise, which causes a non-uniform density distribution. Another factor that might cause a reduction in the signal of this system is fainting of the latent image over time due to phosphorescence[2,10,12,15,17]. These two types of signal loss can compromise the pixel values attributed to a radiographic image.

Direct digital dental radiological systems offer the potential to radically change the way dentists diagnose and treat dentomaxillofacial diseases[5,8,9,14,20].

The aim of this study was to determine the reproducibility of pixel values obtained with two plates from the Digora system (Soredex, Finland) in consecutive standardized scannings.

MATERIALS AND METHODS

Two photostimulable white plates (1 and 2) of the Digora system (Soredex, Orion Corporation, Tuusula, South Finland, Finland) measuring 35 x 45 mm, with an active area of 30 x 40 mm and a specification of 416 x 560 pixels, were used. Each pixel possessed a specific spatial resolution of 71 x 71 μm (6 lp/mm)[3,18]. All plates were immediately scanned before each test to exclude any residual signal caused by environmental light during storage. The plates were kept protected from light throughout the process[13]. The Digora scanner must be calibrated at installation in order to relate the output of the X-ray unit to the scanner response. For the calibration, an imaging plate has to be exposed with the maximum exposure that will be tested, which in our situation was 0.5 s^1. No extra pre-processing was used for the scanned radiographs. Furthermore, no image processing was done to enhance image quality other than the standard pre-processing provided by the system under investigation.

All exposures were done with the same X-ray device (Yoshida, Tokyo, Honshu, Japan) operating at 70 kVp, 7 mA, with a filtration of 2.2 mmAl. The exposure time was varied for each photostimulable plate as shown in Table 1. The focus-plate distance was 20 cm and five radiographic images and five readings were obtained for each plate. The plates were exposed with a stepwedge and soft tissue simulator (Figure 1). The soft tissue simulator was done using red wax (17 mm thick, 45 mm wide and 35 mm high).

Calculation of the reproducibility of pixel values (RP)

The radiographic step image was digitized five times under identical conditions for the two plates in order to determine the inherent RP when assigning pixel values to the same grayscale steps[7]. After digitization, the standard deviation (SD) and mean pixel value were obtained using the ImageJ software (NIH, Washington, Maryland, USA). The histogram tool measured an area of 14,000 pixels for each step in every image (Figure 2). The calculation applied was (largest difference/mean) x 100. The largest difference was chosen between the largest number obtained from the difference between mean pixel value

TABLE 1 - Variation in X-ray exposure and scanning times.

Exposure time (s)	Scanning time
0.05	5 min, 30 min, 1 h and 8 h
0.1	5 min, 30 min, 1 h and 8 h
0.2	5 min, 30 min, 1 h and 8 h
0.3	5 min, 30 min, 1 h and 8 h
0.4	5 min, 30 min, 1 h and 8 h
0.5	5 min, 30 min, 1 h and 8 h

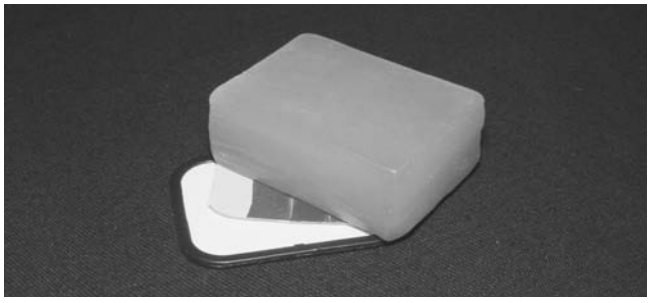

FIGURE 1 - A stepwedge and soft tissue simulator.

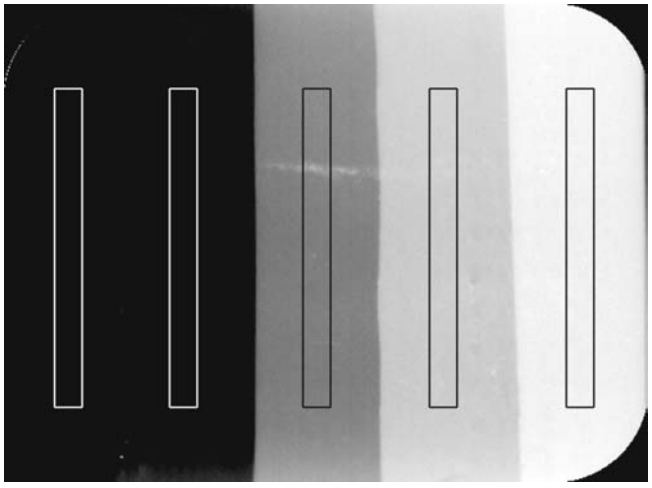

FIGURE 2 - Representation of the reading areas for the Digora plates.

(of the five images) minus the smallest pixel value (of the five images) and the largest pixel value minus the mean. The smallest and the largest pixel values were obtained after five consecutive scannings of the plates. The mean pixel value was obtained from the five images scanned under the same conditions.

RESULTS

The final mean pixel values and the RP coefficient using different exposure and scanning times obtained for plates 1 and 2 are shown in Tables 2, 3, 4 and 5. The steps represent the five optical densities of the stepwedge, the mean corresponds to the five scannings of the photostimulable plates (plate 1 and plate 2), and RP is reported as a percentage.

Three-way ANOVA revealed a significant difference for scanning time of the plates ($p < 0.000001$), X-ray exposure time ($p < 0.000001$), and between plates ($p < 0.01$). Pairwise comparison of the above variables was significant for the scanning time and exposure time combination ($p < 0.01$). The other combinations were not significant at the 5% level.

TABLE 2 - Mean pixel values and the reproducibility of pixel values (RP) coefficient obtained for plates 1 and 2 using 5 minute scanning time and different X-ray exposures.

Scanning - 5 min	Step	Mean plate 1	RP plate 1 (%)	Mean plate 2	RP plate 2 (%)
Exposure time - 0.5 s	1	11.37	97.00	6.41	100.00
	2	34.25	76.00	19.02	100.00
	3	85.53	85.00	50.45	82.00
	4	203.48	25.00	156.70	22.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.4 s	1	17.90	59.00	9.46	133.00
	2	41.37	43.00	30.49	110.00
	3	91.74	51.00	76.98	92.00
	4	190.27	34.00	176.39	45.00
	5	254.99	0.00	255.00	0.00
Exposure time - 0.3 s	1	6.37	100.00	1.21	400.00
	2	23.25	100.00	5.28	400.00
	3	59.07	74.00	27.77	137.00
	4	153.21	17.00	151.88	8.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.2 s	1	4.10	100.00	0.00	0.00
	2	21.31	116.00	0.00	0.00
	3	65.02	95.00	21.60	26.00
	4	178.18	43.00	141.54	8.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.1 s	1	2.07	175.00	1.19	400.00
	2	11.58	154.00	5.64	400.00
	3	42.99	75.00	32.38	124.00
	4	151.47	14.00	143.52	16.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.05 s	1	1.29	400.00	0.00	0.00
	2	5.86	400.00	0.00	0.00
	3	26.99	274.00	12.80	100.00
	4	130.30	30.00	126.10	82.00
	5	255.00	0.00	209.10	0.00

TABLE 3 - Mean pixel values and the reproducibility of pixel values (RP) coefficient obtained for plates 1 and 2 using 30 minute scanning time and different X-ray exposures.

Scanning - 30 min	Step	Mean plate 1	RP plate 1 (%)	Mean plate 2	RP plate 2 (%)
Exposure time - 0.5 s	1	13.52	47.00	19.25	29.00
	2	45.30	47.00	54.54	29.00
	3	104.43	40.00	128.73	32.00
	4	206.29	24.00	242.04	21.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.4 s	1	14.35	100.00	5.40	131.00
	2	39.80	100.00	21.63	146.00
	3	92.05	98.00	62.34	109.00
	4	214.35	32.00	175.66	43.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.3 s	1	14.40	59.00	14.31	107.00
	2	38.98	47.00	39.06	100.00
	3	89.29	45.00	99.72	79.00
	4	185.07	38.00	207.02	36.00
	5	247.02	0.00	255.00	0.00
Exposure time - 0.2 s	1	28.16	50.00	19.15	100.00
	2	66.59	42.00	48.68	100.00
	3	138.99	40.00	126.33	35.00
	4	236.35	32.00	225.84	23.00
	5	255.00	0.00	249.52	0.00
Exposure time - 0.1 s	1	8.11	100.00	0.00	0.00
	2	30.79	100.00	0.00	0.00
	3	81.09	72.00	14.95	44.00
	4	184.17	38.00	140.98	15.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.05 s	1	3.64	170.00	1.39	400.00
	2	12.56	163.00	5.98	400.00
	3	42.19	90.00	24.52	198.00
	4	156.76	18.00	147.43	15.00
	5	255.00	0.00	255.00	0.00

DISCUSSION

No studies were available in the literature evaluating the digitalization variability or reproducibility of pixel values in direct or semidirect digital systems such as the Digora system. The present study demonstrated a systematic error in the consecutive digitalization of photostimulable plates which increased in value with decreasing X-ray exposure time.

The studies evaluating images over time, for example, bone healing[8,9,14], digital subtraction[5] and densitometry[20], all based on differences in the pixel values of images obtained at different times, may be affected by the variability of the digitalization process. A digitalization error (causing lack of reproducibility) of pixel values would be deleterious in these situations because it would attribute pixel values that differ from those corresponding to a true change that occurred in the patient.

Apparently, photon noise originating from X-rays may be one factor that could contribute to the large digitalization error observed for photostimulable plates of the Digora system[4,6,17,18]. As observed

TABLE 4 - Mean pixel values and the reproducibility of pixel values (RP) coefficient obtained for plates 1 and 2 using 1 hour scanning time and different X-ray exposures.

Scanning - 1 h	Step	Mean plate 1	RP plate 1 (%)	Mean plate 2	RP plate 2 (%)
Exposure time - 0.5 s	1	19.80	34.00	21.13	33.00
	2	53.80	37.00	59.84	44.00
	3	123.21	37.00	137.93	45.00
	4	222.84	25.00	236.66	31.00
	5	241.80	22.00	241.80	22.00
Exposure time - 0.4 s	1	17.14	51.00	16.61	36.00
	2	50.98	37.00	51.52	40.00
	3	118.21	35.00	122.17	38.00
	4	222.07	24.00	237.96	29.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.3 s	1	12.19	100.00	13.41	51.00
	2	45.71	100.00	53.08	40.00
	3	133.05	27.00	129.29	39.00
	4	255.00	0.00	238.83	27.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.2 s	1	18.10	36.00	13.04	39.00
	2	62.87	15.00	47.97	21.00
	3	146.39	9.00	115.04	27.00
	4	254.98	0.00	228.71	18.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.1 s	1	3.70	216.00	5.44	100.00
	2	20.13	100.00	23.06	100.00
	3	60.52	89.00	63.07	61.00
	4	171.48	48.00	160.09	12.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.05 s	1	6.58	100.00	1.74	400.00
	2	25.17	100.00	6.17	400.00
	3	64.44	81.00	32.14	142.00
	4	166.55	8.00	146.32	17.00
	5	255.00	0.00	254.99	0.00

in Table 2 through Table 5, the lower exposure times (0.3; 0.2; 0.1; 0.05 s) showed, in general, higher pixel variability. It may be possible that using a larger amount of soft tissue in the tests to absorb secondary radiation would improve these results, since a greater exposure time would be necessary. Another possible factor contributing to pixel value variability could be the kVp used, as stated by Tucker, Rezentes[19] (1997). According to them, the largest variation in pixel values occurred at the lowest kVp, thus the X-ray beam quality has a significant effect on the pixel value.

Another finding of the present study was that the two photostimulable plates behaved differently in terms of the pixel values attributed to the same image. This result calls attention because it is possible that plates, although submitted to the same situation, could yield different results.

CONCLUSIONS

Using the present methodology, it was not possible to establish a satisfactory reproducibility of pixel values for the white photostimu-

TABLE 5 - Mean pixel values and the reproducibility of pixel values (RP) coefficient obtained for plates 1 and 2 using 8 hour scanning time and different X-ray exposures.

Scanning - 8 h	Step	Mean plate 1	RP plate 1 (%)	Mean plate 2	RP plate 2 (%)
Exposure time - 0.5 s	1	20.74	19.00	22.96	44.00
	2	55.79	27.00	65.14	37.00
	3	122.52	30.00	143.24	38.00
	4	227.91	22.00	241.47	22.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.4 s	1	17.67	100.00	20.15	108.00
	2	51.54	100.00	56.07	63.00
	3	135.27	42.00	122.95	38.00
	4	254.96	0.00	226.80	21.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.3 s	1	17.17	100.00	12.96	100.00
	2	46.70	100.00	40.88	100.00
	3	114.31	76.00	98.44	77.00
	4	222.25	33.00	199.68	32.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.2 s	1	20.05	65.00	7.39	141.00
	2	57.73	47.00	25.65	100.00
	3	132.08	40.00	66.45	66.00
	4	239.94	25.00	166.69	15.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.1 s	1	12.11	104.00	10.34	118.00
	2	36.23	100.00	34.36	100.00
	3	91.00	82.00	85.27	64.00
	4	202.72	26.00	192.09	35.00
	5	255.00	0.00	255.00	0.00
Exposure time - 0.05 s	1	7.21	205.00	1.25	400.00
	2	23.06	150.00	5.24	400.00
	3	66.88	106.00	28.38	135.00
	4	176.77	44.00	144.06	9.00
	5	255.00	0.00	255.00	0.00

lable plates tested. Those plates, under the circumstances tested, showed a wide variation in pixel values attributed to the same image even under standard conditions. These differences were statistically significant in terms of scanning time, X-ray exposure time and between the plates themselves. It is possible that photon noise originating from X-rays may be the factor that contributed to the large digitalization error in this study.

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