RESEARCH

The effect of delayed scanning of storage phosphor plates on occlusal caries detection

E Soğur^{*1}, BG Bakır¹ and A Mert²

¹Department of Oral Diagnosis and Radiology, School of Dentistry, Ege University, Turkey; ²Department of Statistics, Faculty of Science, Ege University, Turkey

Objective: The aim of this study was to determine (1) the effect of various scan delays on pixel intensity measurements and (2) the diagnostic accuracy of occlusal caries detection.

Methods: 72 non-cavitated extracted human permanent molar teeth with sound and carious occlusal surfaces were radiographed using the DIGORA[®] storage phosphor plates (SPPs) (Soredex Corporation, Helsinki, Finland). Plates were scanned immediately and 10 min, 30 min, 60 min and 120 min after exposure. Three different plates were used for each scan delay. An aluminium (Al) wedge was used to evaluate the change in mean grey values (MGVs) for scan delays. Diagnostic accuracy for occlusal caries detection was performed by scoring all the digital images. The true presence of caries was determined by stereomicroscopy. Comparison of MGVs of the Al wedge for immediate and delayed scans was made using repeated measures analysis of variance (ANOVA) and Tukey–Kramer tests. The accuracy was expressed as the area under the receiver operating characteristics curves (A_z). A_z s were compared using two-way ANOVA and *t*-tests. Kappa was used to measure inter and intraobserver agreement.

Results: The mean A_z s of immediately scanned plates were higher than the A_z s of plates scanned with four different delays ($p < 0.05$). The A_z of immediately scanned images was significantly higher than the A_z s of images with 60 min and 120 min scan delays ($p < 0.05$) but not for 10 min and 30 min delays ($p > 0.05$). MGVs of immediately scanned plates were significantly higher than the plates scanned with four different delays ($p < 0.05$). Agreement decreased with increasing scan delays.

Conclusion: Scanning of DIGORA SPPs should not be delayed beyond 30 min for accurate occlusal caries diagnosis.

Dentomaxillofacial Radiology (2012) 41, 309–315. doi: 10.1259/dmfr/12935491

Keywords: radiography; dental; digital images; storage phosphor plates

Introduction

Storage phosphor plates (SPPs), having almost the same size and flexibility as that of conventional films, have been considered to be one of the most suitable substitutes for film radiography with high diagnostic accuracy¹ and wider dynamic range.^{2,3} Studies comparing the performance of SPP systems with that of conventional film and charge-coupled device (CCD) systems have reported similar or better image quality with SPPs.^{4,5} However, a major shortcoming of the SPP system is the handling and scanning of plates prior to the final viewing of the image.

After exposure, it is recommended that the SPPs should be scanned immediately to prevent any information loss that may occur owing to image degradation from either ambient light or decay of the trapped electrons.

Several studies have proved that delaying scan time and/or changing storage conditions adversely affects the quality of SPP images.^{6–9} Although the same SPP system was tested in many studies, the results with regard to the relationship between image quality loss and delay in scanning were contradictory. While some studies claimed a change in image quality within 30 min after exposure, others reported a change after a scan delay of up to 6 h.^{10,11}

Even though most of those studies measured pixel intensity along with subjective evaluations, they substantially

*Correspondence to: Dr Elif Soğur, Ege Üniversitesi, Dishekimliği Fakültesi, Oral Diagnoz & Rad AD, Bornova, 35100 İzmir, Turkey. E-mail: esogur@yahoo.com

Received 22 December 2010; revised 7 March 2011; accepted 11 April 2011

focused on the perception of main dental structures.^{6,10} Only one recent study evaluated the efficiency of caries detection using the DenOptix® system (KaVo Dental Gendex Imaging, Milan, Italy); however, the effect of various scan times, not scan delays, were tested.¹² So far, there have been no studies assessing both the objective and the subjective effect of delays in scanning with reference to the detection of occlusal caries. Therefore, the aims of the present study were to determine (1) the effect of various scan delays on pixel intensity measurements of DIGORA® (Soredex Corporation, Helsinki, Finland) SPP images and (2) the diagnostic accuracy of occlusal caries detection.

Materials and methods

Specimens

A total of 80 teeth were included in the study but 8 teeth were discarded owing to damage caused during the stereomicroscopic preparation. Therefore, 72 non-cavitated extracted human permanent molar teeth with sound or carious occlusal surfaces were included in the study for both objective and subjective evaluation.

The test tooth was mounted in a block of silicone with a non-test tooth on either side to create natural contact points. Contact teeth were provided to create a typical clinical image with natural anatomical noise. To ensure reproducible imaging geometry, one SPP and one silicon block were pressed into the vinyl polysiloxane putty while it was still soft. Once hardened, this allowed quick realignment of the blocks as well as the SPPs. In order to evaluate the change in pixel intensity measurements, an aluminum (Al) step-wedge made of 99.5% pure Al with 10 1 mm incremental steps was attached to the SPPs for pixel intensity measurements (Figure 1).

Figure 1 (a) Aluminum step-wedge, (b) test teeth and non-test teeth in contact mounted in a silicon block and (c) soft-tissue substitute

Radiographic technique

Digital images were acquired with the DIGORA Optime (Soredex Corporation) image plate system using Number 2 film size blue SPPs. All images were acquired using bitewing projection geometry. A 20 mm thick soft-tissue-equivalent material was placed close to the silicone blocks and facing the X-ray tube. A Gendex Oralix DC (Gendex Dental Systems, Milan, Italy) dental X-ray unit operating at 60 kVp, 7 mA and 1.5 mm Al equivalent filtration at a focus–receptor distance of 25 cm and a exposure time of 0.12 s was used for all exposures. After the plates were scanned the resulting images were transferred as 8-bit TIFF files to a personal computer (Toshiba Satellite 1900; Toshiba Corporation, Tokyo, Japan) for pixel intensity measurements.

Objective analysis

Before exposure, the plates were cleared of any background effect by means of the strong light source built into the scanner. This procedure removed any residual information that may have remained in the plates and thus brought the plates back to their original state, leaving no memory of previous exposures behind. Three plates were used for each scan delay. Plates were scanned immediately after exposure (to avoid any possible effects of time delay or storage) and 10 min, 30 min, 60 min and 120 min after they were exposed. This resulted in a total of 1080 exposures (72 teeth $\times$ 3 plates $\times$ 5 durations). Plates that were not immediately scanned were stored in their envelopes in a light-tight box and placed in a dark drawer to prevent any external light energy from affecting the trapped electrons. After all the plates were scanned, the grey level information in three different steps (1 mm step, the most radiolucent; 10 mm step, the most opaque; and 6 mm step, the middle grey) of the Al wedge and background of the image was sampled with three non-overlapping (40 $\times$ 40 pixels) regions of interest (ROIs) with a dental analysis software (Image Tool 3.0 SDK, University of Texas Health Sciences Centre, TX) (Figure 2).¹³ Black was assigned a value of 0 and white a value of 255 by the above-mentioned software. A mean pixel value for each step in each separate image was calculated from the three ROIs. In addition to the measurements on the Al wedge, pixel intensity was measured on enamel and dentine of the test teeth using standard sized three non-overlapping ROIs (20 $\times$ 20 pixels) (Figure 2). Mean grey values (MGVs) were then determined for three Al steps, background, enamel and dentine from the information in the three images obtained by repeat exposures. The MGVs from the immediately scanned plates provided the “gold standard” values.

Contrast was measured as grey level differences at various scan delays and compared on the basis of grey level differences between the highest and lowest values of the Al step-wedge and the differences in MGVs of background enamel and background dentine.

Subjective analysis

2 oral radiologists and 2 specialists in restorative dentistry, each with at least 5 years of experience in

Figure 2 Image of the assembly on Figure 1 demonstrating regions of interest used to measure pixel values

caries diagnosis, scored a total of 360 images for the presence/absence of occlusal caries using a 5-grade scale: (1) caries definitely absent; (2) caries probably absent; (3) unsure whether caries is absent or present; (4) caries probably present; and (5) caries definitely present (Figure 3). The images were displayed to observers at full size, 1:1 on a 17 inch high-resolution (super video graphics array) colour cathode ray tube monitor with a resolution of 1024×768 pixels and 256 grey levels (Toshiba Satellite 1900; Toshiba Corporation) in a room where the light was dimmed. Observation conditions were optimized through the use of the same computer monitor to display the images and the viewing distance was kept constant at about 50 cm for all observers. All images were presented in a randomized order. A moderator presented each image for viewing and maintained a proper random sequence order. 6 separate viewing sessions (60 images per session) were held with at least 1 week in between to minimize viewer fatigue and to decrease the chance of recalling previous decisions on similar images. The observers were not given

Figure 3 Storage phosphor plate images obtained with immediate scan and with various scan delays after exposure

the option to perform any image enhancements to avoid the production of a variety of different digital images. No time limit was set for the viewing procedure. At the end of the first evaluation procedure, evaluation was repeated in the same manner after 1 week for intra-observer agreement.

For the validation of the true presence of caries, the teeth were embedded individually in acrylic and serially sectioned (1000 µm thick sections) in the mesiodistal direction using a saw for hard tissues (Isomet saw, Buehler Ltd, IL). The tooth sections were fixed on microscope slides and examined from both sides under a stereomicroscope (Leica S8APO; Leeds, UK) at 10× magnification using the following scale: (1) sound, (2) caries in enamel, (3) caries in dentine. Caries was defined as present when an opaque–white demineralization or brown discoloration was observed in an area at risk of caries on an occlusal surface. If the observers' ratings varied, they were asked to perform a joint assessment to establish an agreement.

Data analysis

The accuracy of caries detection on images obtained with immediate scans and with four scan delays was expressed as the area under the receiver operating characteristic curves (A_z). A_z s were calculated for each observer and each scan delay. Comparison of mean A_z s was done with two-way analysis of variance (ANOVA), with the observers and scan delays as independent variables. Pair-wise comparisons were performed using post hoc *t*-test (SPSS package, GLM-version 10.0 for Windows; IBM Corporation, Armonk, NY). The level of significance was established as $p=0.05$. Cohen's kappa was used to measure the level of agreement in and between observers and the results were interpreted using the six-point scale as proposed by Landis and Koch.¹⁴

Pixel intensity values for enamel, dentine and background did not pass the normality test accordingly so comparisons among immediate and delayed scans were done using Friedman and Dunn tests ($p=0.05$). Repeated measures ANOVA and Tukey–Kramer tests were used to compare the differences in pixel intensity values of steps of the Al step-wedge for different scan delays ($p=0.05$).

Results

Histological examination revealed that of the 72 occlusal surfaces, 42 (58.3%) were sound and 30 (41.6%) showed enamel (12.5%) or dentine (29.1%) caries.

The mean A_z values for the detection of occlusal caries were 0.90, 0.88, 0.78, 0.71 and 0.69 for immediate, 10 min, 30 min, 60 min and 120 min delayed scans, respectively (Table 1). The A_z values obtained from

immediately scanned images were higher than the images scanned with four different delays ($p<0.05$). Pair-wise comparisons revealed that the A_z of immediately scanned plates was significantly higher than the A_z s of plates scanned with 60 min and 120 min delays ($p<0.05$) but not for the plates scanned with 10 min and 30 min delays ($p>0.05$) (Table 1). Pair-wise comparisons of A_z s of the delayed images with each other showed that A_z of 10 min delayed images were significantly higher than the A_z s of 60 min and 120 min delayed scans ($p<0.05$) (Table 1). No significant difference was found in the A_z s of 10 min vs 30 min, 30 min vs 60 min and 30 min vs 120 min delayed scans ($p>0.05$) (Table 1).

Figure 4 shows the MGVs of enamel, dentine, background and three steps of the Al wedge in immediately scanned plates and in those scanned after delays of 10 min, 30 min, 60 min and 120 min. Mean grey values $\pm$ standard deviations (SD) for three steps of the Al wedge for immediately scanned plates were 71 ± 17.5 (1 mm step), 136 ± 13.4 (6 mm step) and 178 ± 15.6 (10 mm step), the difference (107) being the contrast. After a delay of 120 min the corresponding MGVs were 88 ± 17.7 , 145 ± 18.2 and 186 ± 16.7 for steps of the step-wedge with a difference of 98. MGVs $\pm$ SD for enamel, dentine and background were 219 ± 9.7 , 194 ± 10.8 and 30 ± 12.6 for immediately scanned plates with a contrast of 189 for enamel and 164 for dentine. After a delay of 120 min, the corresponding MGVs $\pm$ SD were 229 ± 18.9 , 205 ± 16.2 and 43 ± 15.6 for enamel, dentine and background, respectively, with a contrast of 186 for enamel and 162 for dentine (Figure 4).

In general, MGVs increased with the scan delays. Increase in MGVs was larger for darker image areas (dentine and darker steps of the step-wedge). MGVs for enamel, dentine, background and three steps of the Al wedge of immediately scanned plates were significantly different from the plates scanned with all the delays used in this study ($p<0.05$). Pair-wise comparisons showed that the MGVs of plates scanned 10 min after exposure were not significantly different than the MGVs of immediately scanned plates ($p>0.05$). On the contrary, MGVs of plates scanned with delays of 30 min, 60 min and 120 min after exposure were significantly higher than the ones scanned immediately ($p<0.05$). Contrast decreased with increasing scan

Table 1 Mean area under the receiver operating characteristics curves (A_z) values $\pm$ SD at immediate scans and four different delays in scanning

Scan delays	Mean $A_z \pm SD$
Immediate	0.90 ± 0.21
10 min	0.88 ± 0.23
30 min	0.78 ± 0.30
60 min	$0.71^{a,b} \pm 0.32$
120 min	$0.70^{a,b} \pm 0.32$

SD, standard deviation.

^aIndicates significance with immediately scanned plates.

^bIndicates significance with plates scanned with 10 min delay.

Figure 4 Mean grey values of enamel, dentine, image background and three steps of aluminium step-wedge measured on immediately scanned images and on images scanned with various delays

delays for all measurements (three steps of the Al wedge, enamel and dentine) (Figure 5).

Kappa analysis showed that interobserver agreement for the detection of occlusal caries ranged between slight and moderate (range: 0.15–0.55), while intra-observer agreement ranged between fair and substantial (range: 0.23–0.79). Both intra- and interobserver agreement decreased with an increase in scan delays.

Discussion

According to the results obtained, MGVs for enamel, dentine, background and Al step-wedge increased with all scan delays used in this study. Increase in pixel values with the scan delay may be the result of image degradation owing to either loss of trapped electrons or ambient light which has been previously proved and discussed in many studies.^{7,9–11}

The results revealed that significant change in MGVs of the Al wedge were found with scan delays longer than 10 min. Although this finding is in accordance with a previous report by Akdeniz *et al*,⁷ it is different to the findings of Martins *et al* who reported a change in image density after a scan delay of 4 h and 6 h in two consecutive studies.^{6,10}

The quoted results of the aforementioned studies that have evaluated the effect of scan delays related to the first version of the DIGORA SPP system (FMX) operating with white phosphor plates.^{6,7,10} The kilovoltage, milli-ampere and exposure time they used were different to the exposure parameters used in this study. It has been already demonstrated that exposure is a major factor for the loss of image quality in SPPs.^{7,11} Therefore, in order to extrapolate our results to clinical settings, the plates in this study were exposed using the exposure time (0.12 s) recommended for patient exposure and the other exposure parameters (kilovoltage and miliampere) were selected with reference to the parameters previously preferred in caries detection studies that have used DIGORA SPPs.^{15–17} Owing to the differences in the type of SPP system, as well as the differences in exposure parameters, the present results cannot be directly compared with the above mentioned studies. However, it was proved once again that with the exposure times used in clinical practice the delays in scanning play a major role since it significantly affects the mean grey values, contrast and image quality for occlusal caries detection.

In addition to the increase in MGVs of the Al step-wedge, it was shown that pixel values of enamel and dentine—two major structures related to caries detection—have also demonstrated significant changes in

Figure 5 Change in contrast of enamel, dentine and aluminium step-wedge with various delays in scanning

density if scanning was delayed for more than 10 min. It was also revealed that this change in pixel values of dental structures affected the accuracy of occlusal caries detection after a 30 min delay in scanning. Decrease in intra- and interobserver agreement with increasing scan delays has further contributed to this result.

Recent studies testing the amount of image degradation on SPP images have mainly focused on the effect of various erasing times not scan delays.^{12,18,19} After evaluating the effect of different erasing times on proximal caries diagnosis, Melo et al¹² reported no significant difference in both pixel intensity values and diagnostic accuracy of observers. Since the effect of various erasing times was tested, the methods of the former and the presented study were basically not the same; therefore, the comparison of the results may not be relevant.

The increase in MGVs of enamel (from 219 to 223) and dentine (from 194 to 200) after a 30 min delay in scanning was approximately 2% and 3%, respectively. However, the increase in MGVs of background after a 30 min delay was approximately 23% (from 30 to 39). Even though there was a slight decrease in measured contrast for both enamel (from 189 to 184) and dentine (from 164 to 161) after a 30 min delay in scanning, it is well known that grey scales are perceptually altered by background lightness (fade of background).²⁰ Owing to a visual illusion named "background contrast effect", differences in background density affect the perception of adjacent structures.^{21,22} The true shading of the object in question appears altered as explained by a phenomenon called lateral inhibition of the eye.²⁰ Accordingly, as the background lightness diverges from the lightness of the target (caries in this study), the sensitivity of the eye to perceive this target decreases.²³ Therefore, the perception of caries by observers may be decreased owing to the brighter shade of the background resulting in lower diagnostic accuracy for scan delays of more than 30 min. This effect was previously proved for both CT images and head radiographs.^{20,24}

It was proved that signal-to-noise ratio (SNR) of SPP images deteriorated as the delay in scanning and accordingly duration of exposure of latent images to ambient light increased.²⁵ According to Molteni,²⁶ fading

of the latent image in SPPs occurs in a non-linear fashion owing to the remarkable decrease in SNR with greater time delays in scanning. It is well known that the ability to visualize subtle details is decreased as the SNR is decreased in SPP systems.²⁷ Accordingly, the increase in MGVs of the images obtained with delayed scans causes a relative increase in background noise that deteriorates the optimum level of brightness and contrast required for caries diagnosis, thereby decreasing the diagnostic accuracy of observers. This result partly corresponds to the results of Ang et al⁹ who reported a significant change in pixel intensity values but no effect of this change on diagnostic quality of the images. However, the clinical task performed by Ang et al was endodontic file length measurement. As already admitted by the authors, the level of difficulty in identifying a highly attenuated metallic file tip and tooth root apex was not as challenging as detection of caries to demonstrate a significant effect on diagnostic image quality resulting from signal fading.

This is the first study evaluating the effect of scan delays on pixel intensity measurements including enamel and dentine and detection efficiency of occlusal caries. It is generally recommended that the plates should be immediately scanned after exposure to prevent image degradation. However, if for some reason the scan was delayed by more than 30 min, the image can no longer be used for occlusal caries detection.

Although our study assessed both objective and subjective effects of delays in scanning of SPPs with reference to occlusal caries detection, it should be kept in mind that the present study was performed within the limits of *in vitro* conditions. Therefore, further clinical studies are needed to validate the presented results.

Acknowledgments

The authors wish to thank to all colleagues and co-workers who contributed to the evaluation of the images. This work was supported by the scientific research project branch office of Ege University (2006DIS021).

This study received the oral research award at the 12th European Congress of Dentomaxillofacial Radiology, 2–5 June, 2010, Istanbul, Turkey.

References

- Almeida SM, Oliveira AEF, Ferreira RI, Bóscolo FN. Image quality in digital radiographic systems. *Braz Dent J* 2003; **14**: 136–141.
- Berkhout WE, Beuger DA, Sanderink GC, van der Stelt PF. The dynamic range of digital radiographic systems: dose reduction or risk of overexposure? *Dentomaxillofac Radiol* 2004; **33**: 1–5.
- Farman AG, Farman TT. A comparison of 18 different x-ray detectors currently used in dentistry. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005; **99**: 485–489.
- Møystad A, Svanaes DB, Risnes S, Larheim TA, Gröndahl HG. Detection of approximal caries with a storage phosphor system. A comparison of enhanced digital images with dental X-ray film. *Dentomaxillofac Radiol* 1996; **25**: 202–206.
- Borg E, Attelman A, Gröndahl HG. Subjective image quality of solid-state and photostimulable phosphor systems for digital intra-oral radiography. *Dentomaxillofac Radiol* 2000; **29**: 70–75.
- Martins MG, Haite Neto F, Whaites EJ. Analysis of digital images acquired using different phosphor storage plates (PSPs) subjected to varying reading times and storage conditions. *Dentomaxillofac Radiol* 2003; **32**: 186–190.
- Akdeniz BG, Gröndahl HG, Kose T. Effect of delayed scanning of storage phosphor plates. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005; **99**: 603–607.
- Bramante CM, Bramante AS, de Souza RE, Moraes IG, Bernardineli N, Garcia RB. Evaluation of the effects of processing delays and protective plastic cases on image quality of a photostimulable phosphor plate system. *J Appl Oral Sci* 2008; **16**: 350–354.
- Ang DB, Angelopoulos C, Katz JO. How does signal fade on photo-stimulable storage phosphor imaging plates when scanned with a delay and what is the effect on image quality? *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2006; **102**: 673–679.

10. Martins MG, Whaites EJ, Ambrosano GM, Haiter Neto F. What happens if you delay scanning Digora phosphor storage plates (PSPs) for up to 4 hours? *Dentomaxillofac Radiol* 2006; **35**: 143–146.
11. Akdeniz BG, Gröndahl HG. Degradation of storage phosphor images due to scanning delay. *Dentomaxillofac Radiol* 2006; **35**: 74–77.
12. Melo DP, Pontual AA, Almeida SM, Campos PF, Tosoni GM. Alternative erasing times of the DenOptix system plate: performance on the detection of proximal caries. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2009; **107**: 122–126.
13. UTHSCSA ImageTool Version 3.0, image processing and analysis program. [Cited 20 May 2011.] Available from: <http://ddsdx.uthscsa.edu/dig/itdesc.html>
14. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–174.
15. Kaeppler G, Dietz K, Herz K, Reinert S. Factors influencing the absorbed dose in intraoral radiography. *Dentomaxillofac Radiol* 2007; **36**: 506–513.
16. Sakurai T, Kawamata R, Kozai Y, Kaku Y, Nakamura K, Saito M, et al. Relationship between radiation dose reduction and image quality change in photostimulable phosphor luminescence X-ray imaging systems. *Dentomaxillofac Radiol* 2010; **39**: 207–215.
17. Hintze H, Wenzel A, Frydenberg M. Accuracy of caries detection with four storage phosphor systems and E-speed radiographs. *Dentomaxillofac Radiol* 2002; **31**: 170–175.
18. Lopes SL, Cruz AD, Ferreira RI, Bóscolo FN, Almeida SM. Image quality in partially erased DenOptix storage phosphor plates. *Braz Oral Res* 2008; **22**: 78–83.
19. Melo DP, Dos Anjos Pontual A, de Almeida SM, Campos PS, Alves MC, Tosoni GM. Effect of alternative photostimulable phosphor plates erasing times on subjective digital image quality. *Dentomaxillofac Radiol* 2010; **39**: 23–27.
20. Daffner RH. Visual illusions affecting perception of the roentgen image. *Crit Rev Diagn Imaging* 1983; **20**: 79–119.
21. Daffner RH. Visual illusions in the interpretation of the radiographic image. *Curr Probl Diagn Radiol* 1989; **18**: 62–87.
22. Mandic L, Grgic S, Kos T. Color appearance models. In: *Recent trends in multimedia information processing - proceedings of the 9th international workshop on systems, signals and image processing*. New Jersey: World Scientific Publishing Co. Pte. Ltd.; 2002. pp. 542.
23. Ware C. *Information visualization: perception for design*. 2nd edn. San Francisco, CA: Morgan Kaufmann-Elsevier; 2004. pp. 88–94.
24. Imura H, Miyagawa T, Badono M, Takashima K, Hamada J. A study of the perception of radiographic density with magnitude estimation: density perception of high-density areas. *Nippon Hoshasen Gijutsu Gakkai Zasshi* 2004; **60**: 255–263.
25. Ramamurthy R, Canning CF, Scheetz JP, Farman AG. Impact of ambient lighting intensity and duration on the signal-to-noise ratio of images from photostimulable phosphor plates processed using DenOptix and ScanX systems. *Dentomaxillofac Radiol* 2004; **33**: 307–311.
26. Molteni R. Effect of visible light on photo-stimulated-phosphor imaging plates. In: Lemke HU, Vannier MW, Inamura K, Farman AG, Doi K, Reiber JHC (eds). *Computer assisted radiology and surgery*. Amsterdam: Elsevier Science; 2003. pp. 119–125.
27. Chotas HG, Floyd CE Jr, Dobbins JT 3rd, Ravin CE. Digital chest radiography with photostimulable storage phosphors: signal-to-noise ratio as a function of kilovoltage with matched exposure risk. *Radiology* 1993; **186**: 395–398.