Evaluation of PSPL Plate Erasing Time of a Digital Dental Radiology System

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ABSTRACT

Denoptix (CEDH Gendex Dental System, Milan, Italy) dental imaging system uses photo-stimulable phosphor luminescence (PSPL) plates to store energy during X-ray exposure, being later processed by a laser reader and digitizer. Afterwards the plate is erased and re-used. The cleaning process described by the manufacturer consists of exposing the PSPL plates to negatoscope light for 5 minutes. Proper light intensity and exact erasing time must be considered in order to guarantee good quality procedures in its re-utilization. X-ray exposed plates were submitted to four negatoscopes with different measured light intensities for several periods of light exposure, until the Denoptix system was unable to process the latent image in the plates, and we considered then that the plates were cleaned. We have found the relationships between erasing time, exposed dose and negatoscope light intensity. We have also measured the relative plate image fading with negatoscope light exposure time. We have concluded that a Poisson process governs plate erasing. Considering clinical situations, we have shown that it was possible to largely reduce erasing time and increase plate re-utilization. The exponential decay of image data also suggested a still smaller erasing time, representative of a partial cleaning status assuming that residual noise presence in the erased plate is clinically acceptable.

Keywords: Digital dental radiology, quality assurance in radio diagnostics, photo-stimulable phosphorus luminescence.

1. INTRODUCTION

X-ray imaging is the oldest and perhaps the most common medical imaging method. The optimization of radiological image quality has been a strong motivation for researchers in developing alternative X-ray techniques. Continuous development of inherently digital X-ray imaging systems has been favored over film-screen radiology[1-4]. The most important methods are based on amorphous selenium (a-Se) and amorphous silicon (a-Si) photoconductive solid-state detector, selenium drum, charge-coupled device (CCD) and PSPL detectors[5]. However, the influence from clinical environment and user operation procedures on image quality is not yet fully established. The photo-stimulable phosphorus luminescence technology (PSPL) has been widely used in digital dental radiology systems.

The PSPL technology is based on europium-doped barium flurohalide plates[6], called storage phosphor or PSPL plates. When the storage phosphor plate is exposed to X-rays, electrons are excited to the conduction band, creating electron/hole pairs in the crystalline lattice. Half of stimulated electron/hole pairs preserve a metastable state, forming a latent image. The latent image can be recovered by a stimulated luminescence of these trapped electrons. Denoptix (CEDH Gendex Dental System, Milan, Italy) system uses PSPL plates to store energy during the X-ray exposure, being later processed by a laser reader (latent image recovering) and digitizer. Once the storage phosphor plate is read, it is flooded with light to erase any remaining image and prepare the plate to the next X-ray exposure.

The cleaning process described by the manufacturer consists of exposing the Denoptix PSPL plates to negatoscope light for 5 minutes[7]. Proper light intensity and exact erasing time must be considered in order to optimize the cleaning process of

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these plates and guarantee good quality procedures in its re-utilization. In this investigation, the erasing process characteristics are evaluated in an attempt to reduce the demanded erasing time and promote an increase in plates utilization.

2. MATERIAL AND METHODS

2.1. ERASING TIME

We have carried out an experiment to evaluate the dependence of the cleaning process on the time necessary to erase all previous plate information, taking the time proposed by the manufacturer as first parameter and seeing if it could be reduced. X-ray exposed plates to a fixed dose were submitted to four negatoscopes with different measured mean light intensity (275, 316, 474 and 502 mW/cm^2) for several time durations. Two negatoscopes were based on common fluorescent lamp (502 and 275 mW/cm^2) and two were based on LCD backlight (474 and 316 mW/cm^2). All negatoscopes were turned on for 5 minutes before any experiment. In this study, erasing time is defined as the minimum time that the Denoptix system needs to become unable to process images, showing that the plates were cleaned. In a second experiment, we have observed the dependence of the erasing time to X-ray absorbed dose using a fixed negatoscope. All exposures were made using the same dental X-ray unit, a GE 1000 (General Electric Company, Milwaukee, USA), operated at 60 kV_p, 10 mA, 32 cm focus-to-receptor distance and varying exposure times. The system has an inherent 2.7mm Al pre-filtration plate. To provide a clinically comparable beam quality at the receptor, the beam was filtered with an extra 0.1mm Cu plate. All X-ray exposure measurements were carried out using a Victoreen 06-526 ionization chamber (Nuclear Associates, New York).

2.2. IMAGE FADING

The Denoptix system uses a photomultiplier tube to amplify the luminescence signal and convert it to an electrical signal. The photomultiplier tube gain is adjusted in a pre-scan in order to optimize the quantization process. This procedure maximizes the image contrast, but loses the relationship between the image pixel gray level and the corresponding local concentration of holes in the PSPL plate. This poses a problem when one tries to measure the fading of the image in the plate (the image just become ever more noisy). To overcome this problem, we have designed a specific phantom (figure 1). The phantom has three sections: 1) a non X-ray exposed area (figure 1-D); 2) a directly X-ray exposed area (figure 1-C) and 3) an area submitted to a 0.1 mm Cu filter (figure 1-A and 1-B). The sections 1 and 2 are called markers and will define the maximum and minimum gray levels respectively. This has ensured that the gray scale was correctly positioned between the fixed maximum and minimum limits of the X-ray absorbed dose range.

To measure the relative image fading for each negatoscope, half of PSPL plate (containing the markers) was protected against light by a plastic cover. This procedure guarantees that the gray scale calibration is not lost. So we have two different regions: 1) a non-exposed to negatoscope light (figure 1-A), used as initial X-ray dose reference, and 2) an exposed to negatoscope light (figure 1-B), used do measure the fading process. All measurements were normalized in terms of radiation intensity (luminance), defined in this study as the complement of the image gray level ($S = 255$ - gray level).

Afterwards, the acquired images (figure 1) were exported in TIFF file format to a specific developed program, which segments a marker at the border between exposed and non-exposed to light regions (figure 1-E). The program automatically selects regions of interest (ROI) in both regions (figure 1) and calculates the average (S) and standard deviation (σ_S). The program also calculates the ratios $S(t)/S(t=0)$ and $\sigma_S(t)/\sigma_S(t=0)$, with the user supplying the negatoscope exposure time (t).

3. RESULTS

Figures 2 and 3 present the experimental relationships between erasing time, exposed dose and negatoscope light intensity. As we can see the erasing time is linearly dependent to the exposed X-ray dose (Figure 3) and logarithmically dependent to the light intensity (Figure 2). Figure 4 shows the complete relationship between erasing time, exposed X-ray dose and negatoscope light intensity. Note that erasing times are equal to or smaller than the time suggested by the manufacturer (300s), so it may be possible to create routines to reduce the plate erasing time.

Figure 5 shows a Denoptix PSPL plate fading characteristic (S(t)/S(t=0)) for a special case (Negatoscope N4). We can see an exponential-like decay in the image fading process. The general analyses of S(t)/S(t=0) and $\sigma_S(t)/\sigma_S(t=0)$ can be seen in Figure 6 and Figure 7. We can observe that the S(t)/S(t=0) and $\sigma_S(t)/\sigma_S(t=0)$ curves correspond to an exponential-like decay for each negatoscope, with time constant dependence on its light intensity profile. The time constant increases with negatoscope light intensity. Note that the plates normalized mean image fading S(t)/S(t=0) tends to zero faster than the normalized standard deviation image fading $\sigma_S(t)/\sigma_S(t=0)$.

Figure 8 shows that Denoptix PSPL plates normalized mean is coincident to the variance of the image fading. This indicates that the erasing process of PSPL plates by negatoscope light obeys a Poisson random process[8]. The coincidence between normalized mean and variance is confirmed by the ANOVA[8] analyses results shown in Table 1.

4. DISCUSSION

As shown in Figure 4, it was possible to determine the alternative erasing time (always lower than 5 minutes) due to its dependence on the X-ray dose and negatoscope light intensity. We noted that the manufacturer suggested erasing time (300s) is reached at 2800 μGy X-ray dose and 275 mW/cm^2 negatoscope light intensity. This condition represents a very high dose for digital dental radiology purposes and a weak negatoscope light intensity. In spite of this possible clinical situation, it demands a large plate occupation time. The Denoptix system has a carrousel capable of processing up to 29 plates simultaneously. These considerations inspire Denoptix use in a picture archiving and communication systems (PACS) being a base for multiple attendance service. In such cases, the erasing time can be a factor of severe limitation of the quality of the process. Reducing the demanded erasing time and promoting an increase in plate utilization may improve the service economic viability.

Alternative erasing times can be established by the negatoscope and/or X-ray dose standardization. Figure 4 also shows that it is possible to reduce the plate erasing time to 198s (66% of the manufacturer suggested erasing time) if we assure that the negatoscopes have 500 mW/cm^2 light intensity and the plate be exposed to a maximum of 2800 μGy X-ray dose. Digital dental radiology can reduce the X-ray dose compared to that used for conventional films. Reductions in erasing time to 80s (26% of the manufacturer suggested erasing time) can be achieved if we assure a maximum X-ray dose of 600 μGy that is usually enough in dental clinical situations.

Another proposal of this research was to analyze the image fading through the erasing process. This study revealed an exponential-like decay with time constant dependence on the negatoscope light intensity profile. It has been shown that the erasing process obeys a Poisson distribution. This result was expected, considering the typical quantum characteristics of the light incident photons. The Poisson process is characterized by variance equal to mean. The signal to noise ratio, considering the most important quantum mottle, can be described as the mean to standard deviation ratio[8-11] . Note that the signal to noise ratio tends to infinity for a complete blank plate, S(t)=0 and $\sigma_S(t)=0$, condition of minimum signal (no image at all in our case). To measure how much the plate has been erased, we then use the gray level and the signal to noise ratio is given by Equation 1:

$$SNR(t) = \frac{G(t)}{\sigma_G(t)} = \frac{255 - S(t)}{\sigma_S(t)} \tag{1}$$

Where, G(t) is the mean gray level, S(t) is the mean radiation intensity; $\sigma_G(t)$ is the gray level standard deviation and $\sigma_S(t)$ is the radiation intensity standard deviation;

Figures 9 presents erasing SNR increase with negatoscope exposure time, showing an exponential-like grow. Figure 10 shows Denoptix PSPL signal exponential-like decay fading process, suggesting an alternative use of a partial erasing time, inferior to the complete erasing time. Further experiments may show that we can use the near zero S(t) mean point as a partial clean status, assuming that residual noise presence is clinically acceptable, since the real influence of a low background noise for diagnosis is still not well established. For instance, in Figure 11 we can see the effect of plate re-utilization after 40s partial erasing time (remember that the manufacturer suggests 300s for total erasing). It is noted that there is not much visual influence of the possible added noise due to the non-totally cleaned plate before the next X-ray exposure.

5. CONCLUSION

We have studied the influence of X-ray dose to PSPL plates and the negatoscope light intensity on the erasing time for re-utilization of PSPL plates and have shown that it was possible to reduce erasing time up to 74%. Greater improvements can be achieved if we use a partial clean status assuming that the residual noise presence is clinically acceptable.

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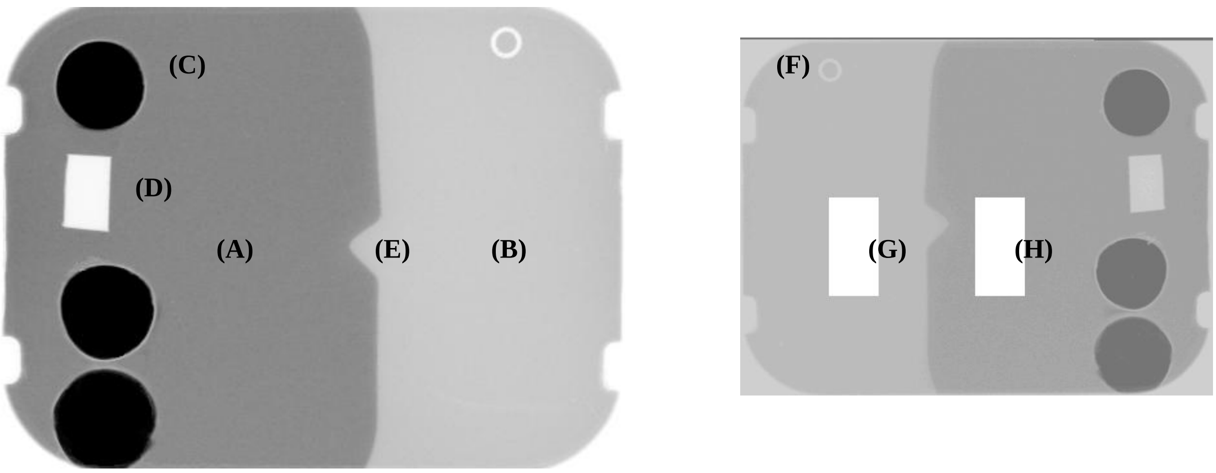
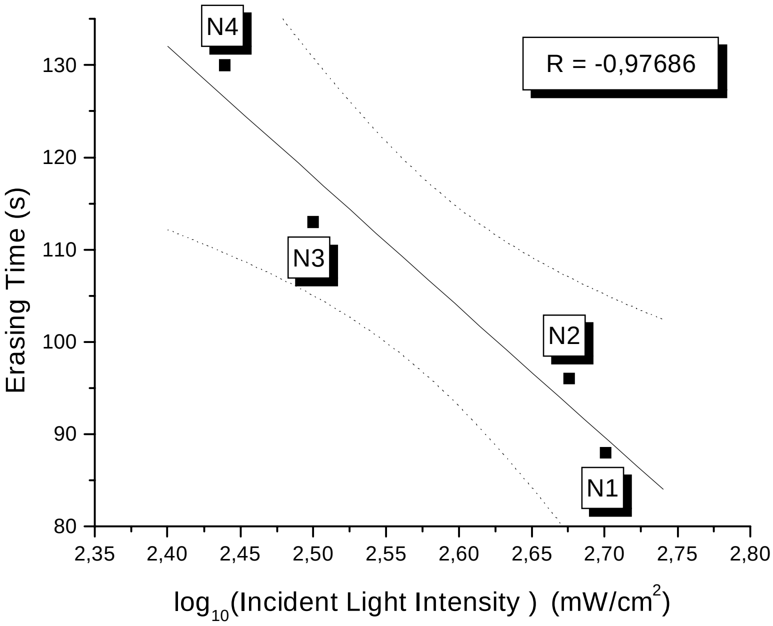


Figure 1. Phantom image after exposure to negatoscope light: (A) phantom region protected against light, (B) erased region, (C) maximum dose marker, (D) high absorption (minimum dose) marker, (E) ROI reference marker. (F) developed software ROI segmentation, (G) selected erased ROI, (H) selected initial reference ROI.



Negatos-cope	Mean luminous power (mW/cm^2)	erasing time(s)
N1	502	88
N2	474	96
N3	316	113
N4	240	130

Figure 2. Denoptix PSPL plates erasing time as function of negatoscope light i ntensity after 840 uGy X-ray exposure.

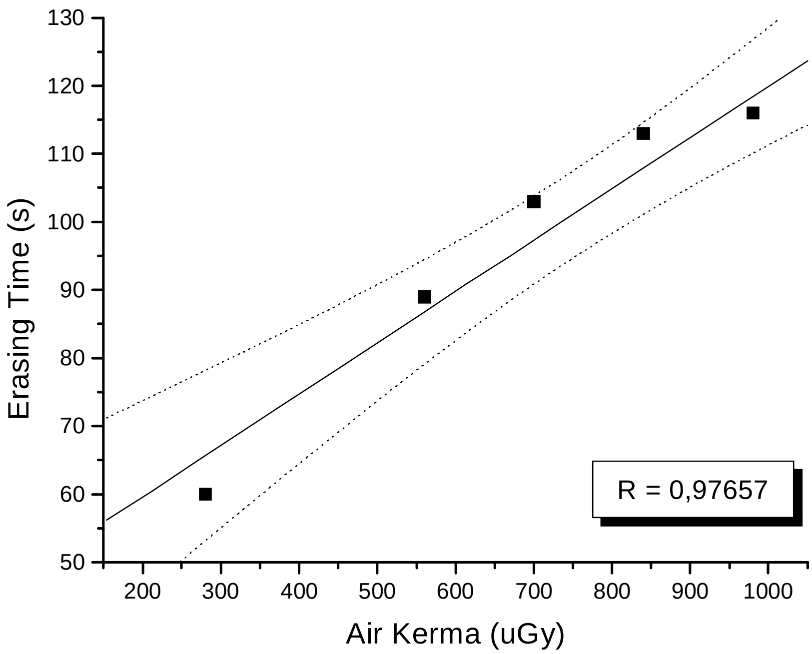


Figure 3. Denoptix PSPL plates erasing time as function of absorbed dose using a 316 mW/cm ^{2} light intensity negatoscope.

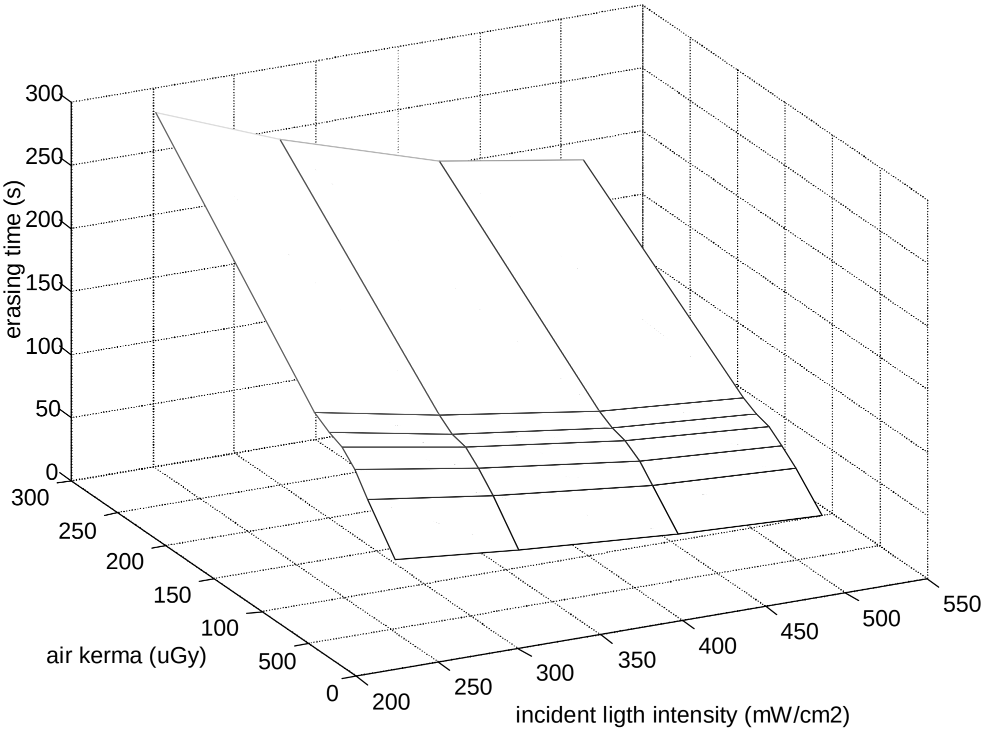


Figure 4. General Denoptix PSPL plates erasing time relationships.

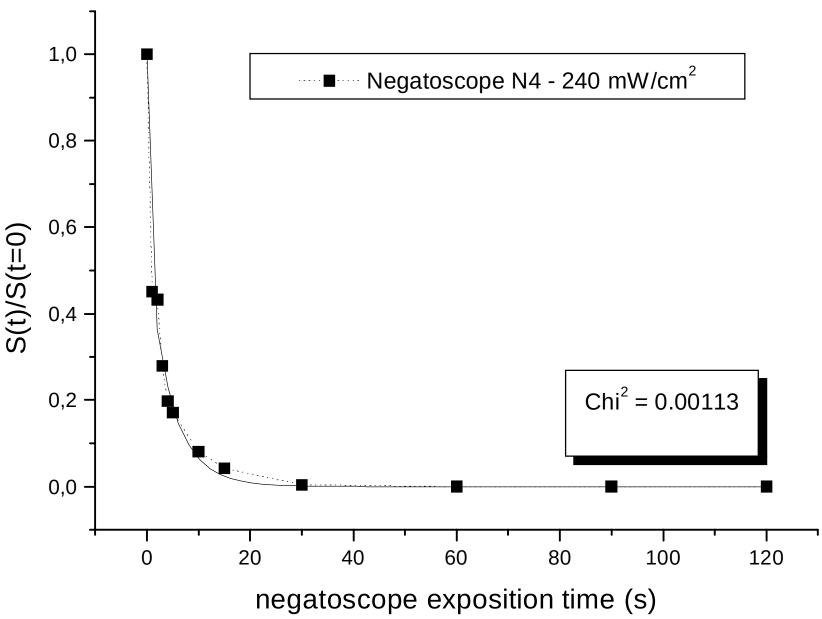


Figure 5. Denoptix PSPL plates fading characteristics. The solid line shows a exponential decay fitting.

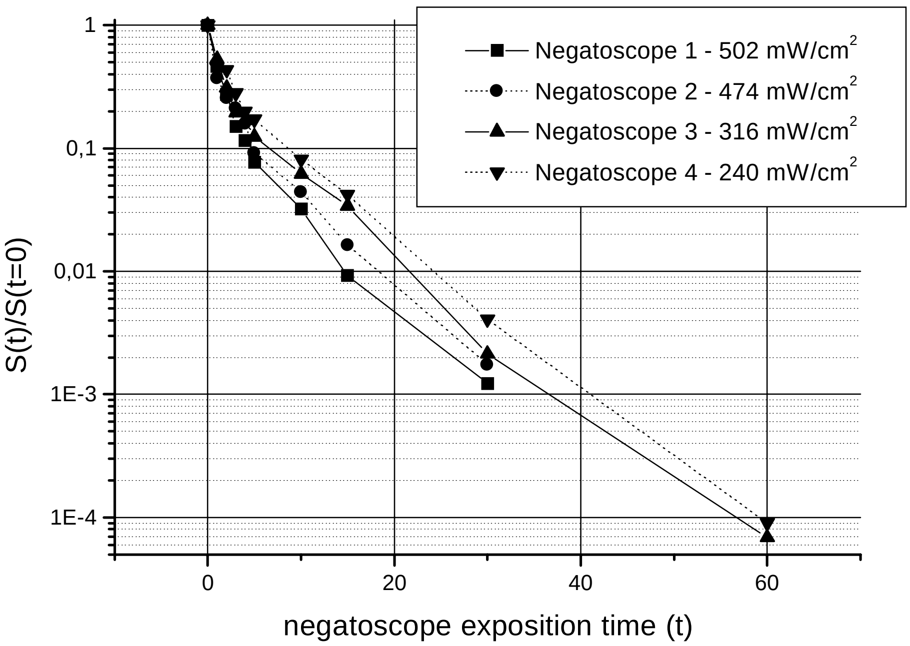


Figure 6. Denoptix PSPL plates normalized mean image fading for all negatoscopes. An exponential-like decay is apparent.

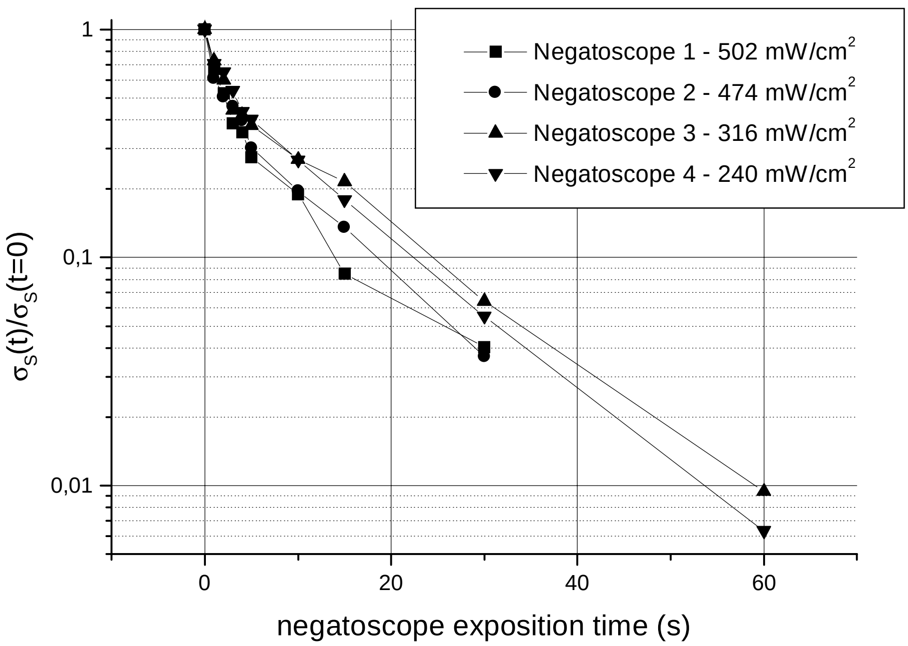


Figure 7. Denoptix PSPL plates normalized standard deviation image fading for all negatoscopes. An exponential-like decay is apparent.

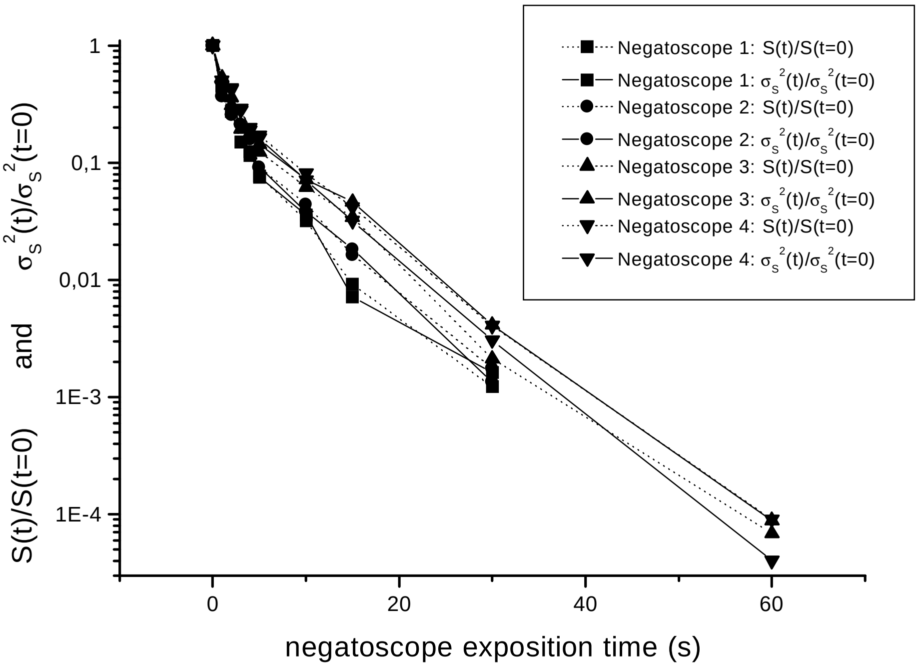


Figure 8. Denoptix PSPL plates normalized mean and variance image fading for all negatoscopes.

Negatoscope	Measurement	N	Mean	Variance	F	p	At the 0.05 level, the means are significantly different.
N1	S(t)/S(t=0)	10	0,21206	0,09790	$1,96962.10^{-4}$	0,98896	NO
	$\sigma_S^2(t)/\sigma_S^2$ (t=0)		0,21010	0,09714			
N2	S(t)/S(t=0)	11	0,19581	0,08634	$6,33362.10^{-4}$	0,98017	NO
	$\sigma_S^2(t)/\sigma_S^2$ (t=0)		0,19896	0,08647			
N3	S(t)/S(t=0)	12	0,20212	0,88550	$6,04000.10^{-3}$	0,93878	NO
	$\sigma_S^2(t)/\sigma_S^2$ (t=0)		0,21161	0,08994			
N4	S(t)/S(t=0)	12	0,22155	0,08689	$2,98301.10^{-5}$	0,99569	NO
	$\sigma_S^2(t)/\sigma_S^2$ (t=0)		0,22222	0,08967			

Table 1. ANOVA analysis table showing that there are no significant differences between normalized mean and variance image fading.

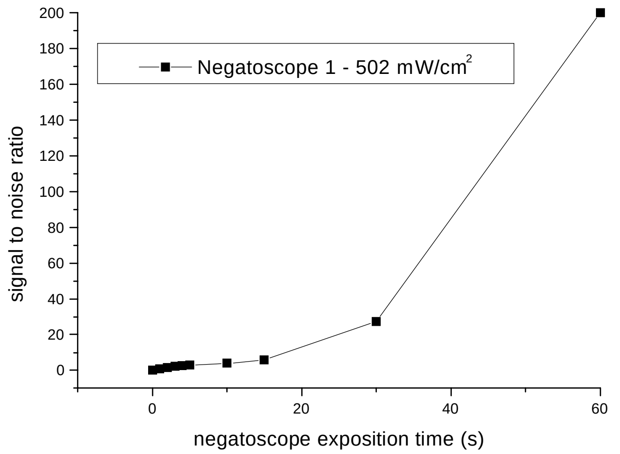


Figure 9. Denoptix PSPL erasing SNR as a function of negatoscope exposure time.

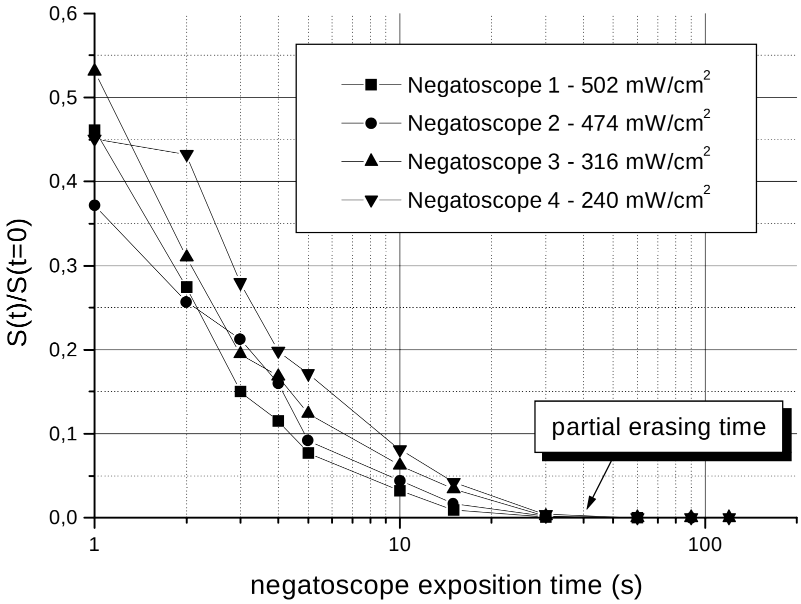
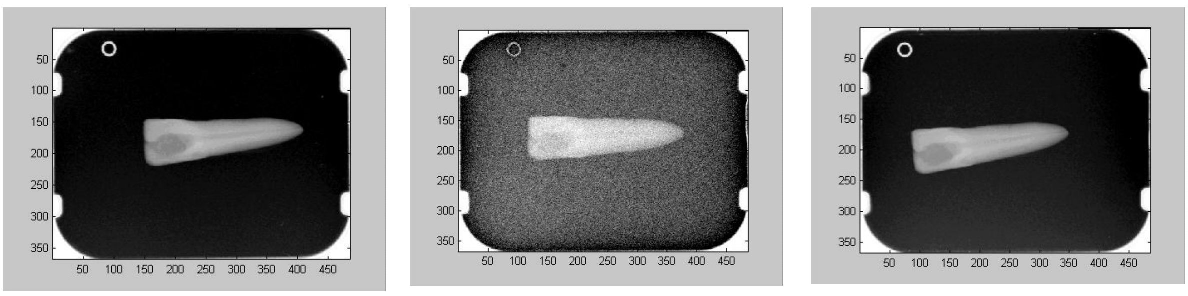


Figure 10. Denoptix PSPL exponential-like decay fading process suggesting an alternative use of a partial erasing time.



(a) original image

(b) Image residue after 40s partial erasing time.

(c) X-ray re-exposed and revealed image over the previous (b) image residue.

Figure 11. Illustration of Denoptix PSPL partial erasing time.