Testing mAs Reciprocity Law using a screen-film system and an exposure meter on a diagnostic x-ray machine

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Abstract. Reciprocity law states that the relationship between exposure and optical density (OD) should remain constant regardless of the exposure rate. In this experiment two different detectors were used to prove the reciprocity law using an exposure meter detector and a screen-film system. Four different values of kVps were used in this experiment which were 40 kVp, 50 kVp, 60 kVp, and 70 kVp. Different values of mAs were used from 1 mAs up to 50 mAs. Other factors used in this experiment were maintained constant such as the distance from focal spot to detector 100 cm and collimator opening 15 cm x 10 cm to make sure all contributions from the surroundings were approximately the same. In this experiment, acceptability range of the reciprocity law used for the screen-film OD was ±5% and acceptability range of the absorbed dose using the exposure meter was ±10%. From the result, it shows that at low kilovoltage which was 40 kV the OD and absorbed dose values disobeyed the reciprocity law, but at high kilovoltage, the OD and linearity value obeyed the reciprocity law.
Key words: mAs reciprocity law, diagnostic x-ray, exposure meter, screen-film system.

Introduction

Reciprocity law of film states that the relationship between the exposure and the optical density (OD) should remain constant regardless of the exposure rate. Theoretically, the response should be the same whether the photons delivered at low intensity over a long period of timer or at high intensity over a very short period. Thus, as long as all other exposure factors remain constant, any combination of mA and exposure time that give the same mAs should produce the same OD (Pizzutiello & Cullinan 1993). However, for very long or very short exposures, an exposure rate dependency between exposure and OD might be observed and this is called reciprocity law failure. This means that at the extremes of the exposure rate, the screen-film system becomes less efficient and gives lower OD (Bushberg 2002). This can result in reduced image quality and unnecessary patient exposure, especially when repeated images are required.

This study was done to check the mAs reciprocity of a diagnostic x-ray machine using a screen-film system and an exposure meter.

Materials and Method

For the screen-film exposures, a film (Konica Minolta AX Medical Film) was inserted into a film cassette (Konica SR-250) with intensifying screens and exposed with an X-ray machine (Toshiba KXO-15R) at focal-spot-to-film distance (FFD) of 100 cm. The field size was kept constant at 15 cm x 10 cm to make sure all contribution from surroundings like scattering were approximately the same. The exposures were carried out for kVp values of 40, 50, 60 and 70 kVp at 1, 2, 5, 6, 8, 10, 12, 20, 30, 40 and 50 mAs values. Multiple exposures were made, using the same kVp and mAs values, but the mA and time settings were varied for each exposure. A densitometer (RMI densitometer) was used to obtain the OD reading from the exposed film. If the corresponding optical densities of each exposure

for a particular kVp appeared to be of the same density, the mAs reciprocity law is obeyed. In an ideal situation, the reciprocity law will be in linear or constant reading. In reality, it is hard to get the exactly the same OD value for the same mAs but varies in tube current (mA) and time (s), so the values can be considered as within the acceptance tolerance. For visual reciprocity analysis, the acceptance tolerance for OD value is ±5% (Bushong 1993).

For the exposure meter (Victoreen 4000M+), the procedure was the same as the film-screen exposures. This detector was used to measure the radiation output from the X-ray machine. Multiple exposures were done, using the same kVp and mAs, but the mA and time settings were varied for each exposure. The detector read directly from the output of the X-ray machine in terms of absorbed dose in air (microGray) at FFD of 100 and 15 cm x 10 cm field size. To mathematically compare the mA stations, the mR/mAs values for each exposure were calculated. If the corresponding values of each exposure appeared to be the same, the mA is satisfactory and the mAs reciprocity law is obeyed.

Results and Discussion
a. mAs reciprocity using a screen-film system

Table 1 shows the OD values for 1 mAs and their ±5% tolerance. The red coloured OD values indicate that they are out of the acceptance tolerance. The variations of OD against exposure time can also be visually observed as in Figure 1. The dashed lines indicate the maximum and minimum acceptance tolerance levels for each particular kVp. At this x-ray quantity (1 mAs) and lower kVp values (40 kVp, 50 kVp and 60 kVp) the optical densities are out of the acceptability range, which means that the values are below or above than the ±5% acceptance tolerance. Only at the high tube potential of 70 kVp, the values of the optical densities are in the acceptability range. So it means that at 1 mAs, only a high kVp will give a good screen film OD.

Table 1: Results for the optical density values for 1 mAs at different kVp values.

kVp	Tube current (mA)	Time (s)	mAs	Optical density (X)	Average $\overline{X}$	0.95 $\overline{X}$ (-5%)	1.05 $\overline{X}$ (+5%)
70	100	0.01	1	2.10	2.14	2.04	2.25
	50	0.02	1	2.24			
	20	0.05	1	2.09			
60	100	0.01	1	1.62	1.66	1.58	1.75
	50	0.02	1	1.85			
	20	0.05	1	1.52			
50	100	0.01	1	0.78	0.81	0.77	0.85
	50	0.02	1	1.03			
	20	0.05	1	0.63			
40	100	0.01	1	0.04	0.12	0.12	0.13
	50	0.02	1	0.29			
	20	0.05	1	0.04			

Similar analysis was also carried out for x-ray quantities of 2, 5, 6, 8, 10, 12, 20, 30, 40 and 50 mAs. At lower mAs, as the kVp was increased, the OD also increased. As the quantity mAs is increased, the OD of the four kVp values increase until they reached saturation. Basically, this the characteristic curve of the diagnostic system at different mAs values. Higher kVp reaches OD saturation point earlier than the lower kVps (Figure 2).

At high mAs, all OD values are in the acceptance tolerance range as they reached their saturation value of the OD. For this screen film exposure, the OD saturation value of

each kVp is different. For 40 kVp the saturation OD value is 2.70 at 20 mAs, for 50 kVp the saturation OD value is 2.66 at 8 mAs, for 60 kVp and 70 kVp they reached the saturation values of 2.62 and 2.57 respectively at 5 mAs. The useful range of OD is approximately 0.25 to 2.5. Most radiographs however show good contrast in the OD range of 0.5 to 1.25. Hence, mAs reciprocity test for the four kVps should be confined to this OD range corresponding to about 1 to 8 mAs range.
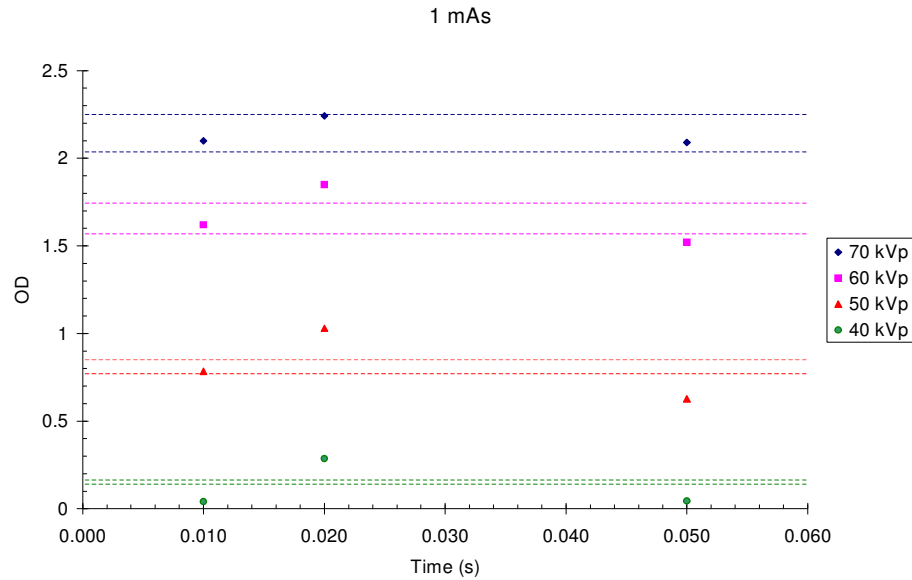

Figure 1: The visual analysis of the OD values for 1 mAs at the four kVp values. The dashed lines indicate the ±5% maximum and minimum acceptance tolerance levels for the respective kVp values.
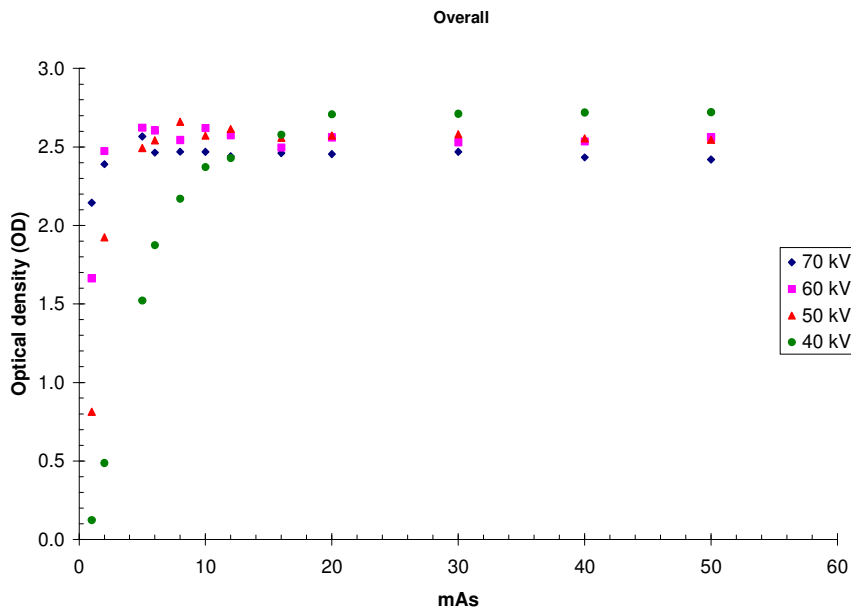

Figure 2: The OD values against mAs at four kVps for the screen-film system. Saturation point is reached by higher kVps at lower mAs values than for the 40 kVp.

b. mAs reciprocity using an exposure meter

Figure 3 shows that the dose response for the four kVp curves are linear with increasing mAs values in the 1 to 50 mAs range studied. No saturation point is observed in this mAs range. However, it is advisable for the mAs reciprocity study using the exposure meter to stick to the mAs range recommended for the screen-film system above. Figure 4 shows the absorbed dose in air of the exposure meter at 5 mAs. The dashed lines indicate the ±10% acceptance tolerance levels. It can be seen that only 70 kVp obeys the mAs reciprocity law. The same type of analysis was done at other 1 to 8 mAs values.
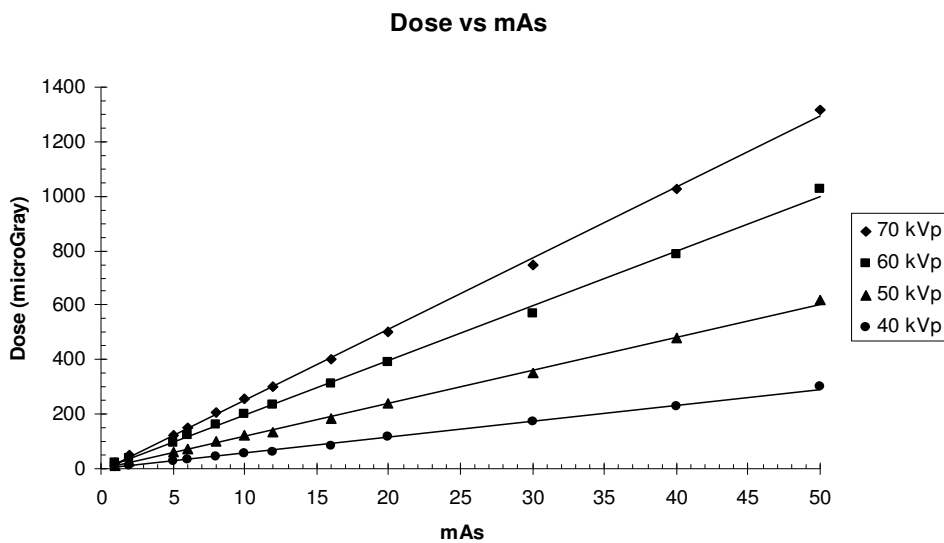

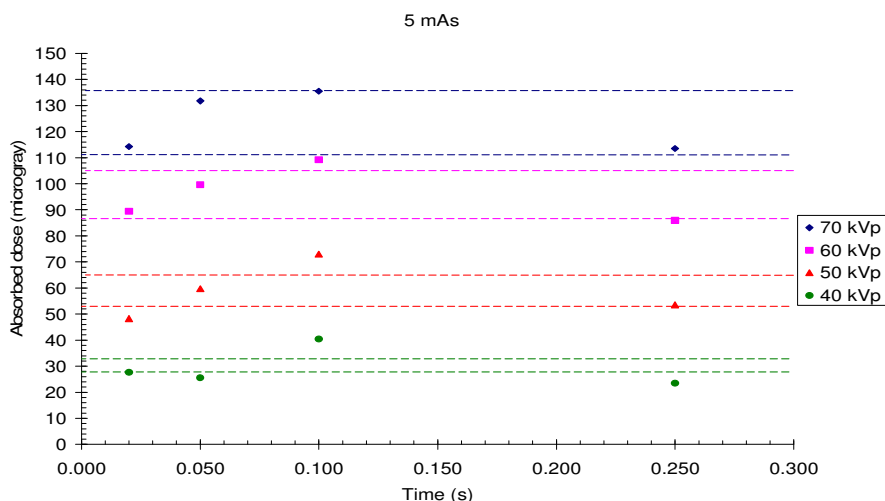Figure 3: Dose response of the exposure meter at four kVp values against mAs.

Figure 4: The absorbed dose in air of the exposure meter for 5 mAs at four kVp values against exposure time. The dashed lines indicate ±10% acceptance tolerance levels for that particular kVp.

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Conclusion
For mAs reciprocity study using screen-film system, the OD versus mAs or the characteristic curves for the whole range of parameters used should be conducted first. Then the mAs reciprocity study should be confined to the good contrast OD range of 0.5 to 1.25. The mAs reciprocity study using an exposure meter should also be confined to this OD range.

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