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NOTE

Visible dye light absorption properties of processed radiographic film

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Abstract

The visible absorption spectra of Kodak X-Omat V film, which had been exposed to various doses of radiation, have been investigated to analyse the dosimetry characteristics of the film with various densitometers. Common densitometers can use fluorescent light (broad band visible), helium–neon (632 nm) or other spectra of specific bandwidth. The visible absorption spectra show a slight peak in absorption at approximately 580 nm and another at 630 nm caused by the base material of the film. The optical density of the film is shown to increase almost equally at all wavelengths within the visible region with increases in applied dose. By evaluating the results for the broad band spectra and specific wavelength optical density it is shown that a relatively uniform response is expected for all densitometers that work within the visible region as well as in selected infrared wavelengths. Thus similar optical density to dose response curves for X-Omat V radiographic film should be produced for all types of densitometers, no matter what type of light source is used for illumination. Thus it is most efficient to have a densitometer with a light source suitable for radiochromic film, which can also be used with radiographic film.

1. Introduction

Film dosimetry in radiotherapy can depend on many parameters. Some of these include the energy or beam quality of the irradiation beam (Johns and Cunningham 1983), whether the exposure is performed parallel or perpendicular to the film (Suchowerska *et al* 1999) or the chemistry involved in the processing of the film (Khan 1992). Another area that can affect film dosimetry is the densitometer used and the type of light source it uses for analysis.

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Infrared light sources are often used for radiographic film densitometers to avoid interference with the room lighting (Metcalfe *et al* 1997). Fluorescent, visible light densitometers have also become widely used (Mersseman and de Wagter 1998) partly due to the introduction of radiochromic film dosimetry in radiotherapy where the optimal light source required for dosimetry should lie in the ‘red’ region of the visible spectrum. Radiochromic film is predominantly sensitive in the red region with two absorption peaks located at approximately 600 nm and at 660 nm (Niroomand-Rad *et al* 1998). Thus a visible light densitometer can be used for both applications. This note studies the absorption spectra in the visible region for Kodak X-Omat V radiographic film after irradiation with 6 MV x-rays and provides a comparison of absolute optical density results for various common light sources used in these visible light densitometers.

2. Materials and methods

Kodak X-Omat V radiographic film was used for the study of visible absorption spectra. For absorbed dose delivery, the films were positioned in a solid water (Constantinou *et al* 1982) phantom of dimensions 30 cm $\times$ 30 cm $\times$ 30 cm. The phantom was placed on a Varian 2100C linear accelerator treatment couch with the upper surface at the isocentre (100 cm). The film was positioned at a depth D_{max} of 1.5 cm for 6 MV x-rays and doses of 0 cGy, 10 cGy, 20 cGy, 30 cGy and 50 cGy were given with the film perpendicular to the central axis of the beam. The film was processed in a Kodak M35 X-Omat processor in a single batch. The absorption spectra results were measured using a Shimadzu UV-160 UV–visible recording spectrophotometer. Its wavelength range is 200 nm to 1100 nm and it has a spectral bandwidth of 3 nm with an accuracy of $\pm$0.5 nm. The films were scanned five times each and results showed a mean error of less than 0.5%. The films were held in quartz holding containers. Measurements were made at 5 nm intervals from 400 nm to 750 nm. Optical density measurements were also made on four different densitometers for comparison using the same pieces of exposed film. These include:

(a) A 660 $\pm$ 20 nm LED system (converted Scanditronix) (Carolan *et al* 1997).
(b) A 670 $\pm$ 5 nm band pass filtered Gafchromic film reader.
(c) A Vidar VXR-12 fluorescent light densitometer.
(d) A Vidar Lumiscan 75 632.8 nm helium–neon laser scanner.

The films were scanned five times each at a well-defined point in the centre of the film for each densitometer. Comparisons are made of optical density for these various visible light source densitometers.

3. Results and discussion

Figure 1 shows the absorption spectra for Kodak X-Omat V film in the visible and just into the infrared region (400–750 nm). Increases in absorption with dose are broad band in the visible region as expected due to the optical black body nature of the film; however, two nominal peaks in the absorption spectra are located at approximately 580 nm and 630 nm. Upon further examination, it was found that these two peaks are due to the inherent absorption characteristics of the base material of the radiographic film. The emulsion was totally removed from the film using bleach. The absorption properties of the base were measured and produced two nominal peaks of the same magnitude at the same wavelengths. Figure 2 shows the net optical density of the film after irradiation up to 50 cGy applied dose. Results show that the net increase in optical density with dose is approximately linear (within 10%) over all wavelengths from 400 nm to 750 nm. The largest net change in OD was recorded at the lower wavelengths around

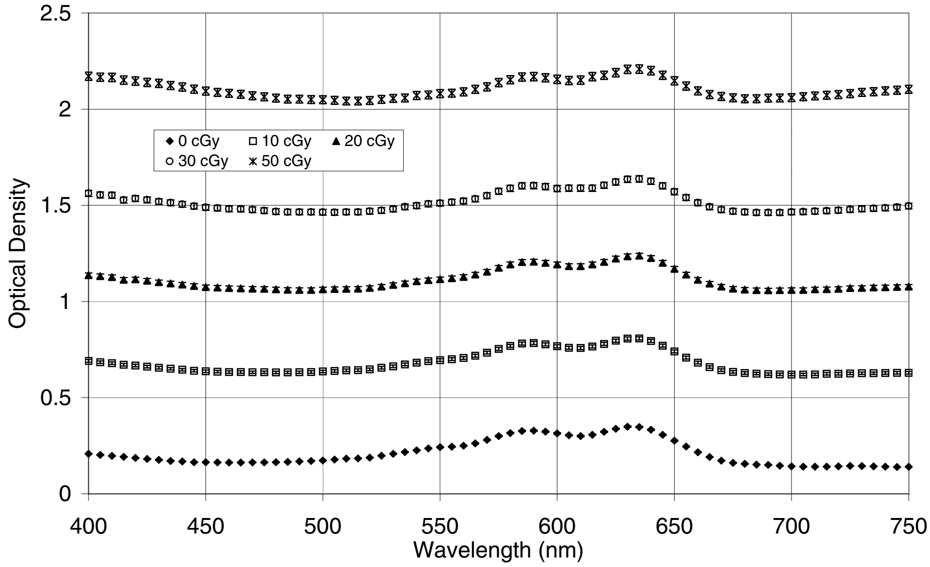

Figure 1. Dye light absorption spectrum for radiographic film irradiated to various dose levels up to 50 cGy.

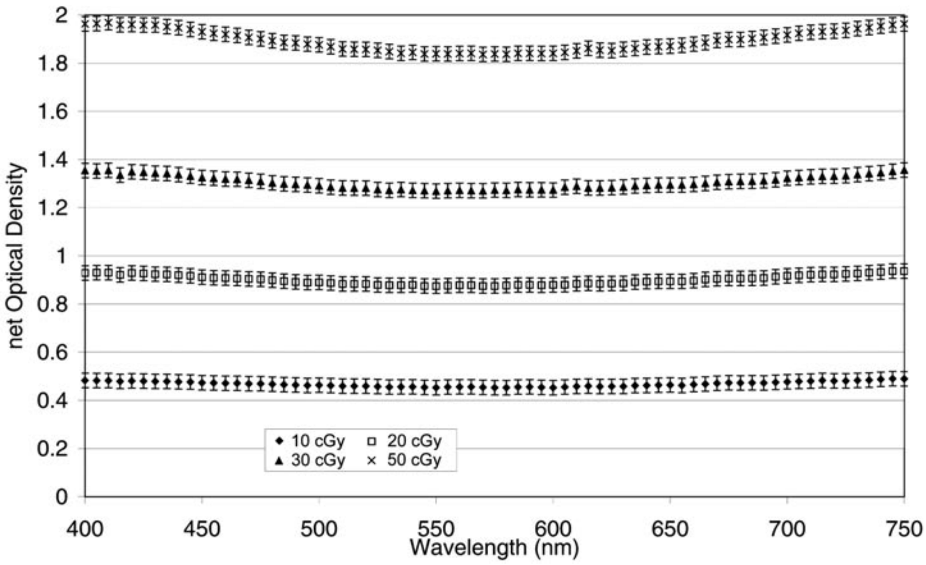

Figure 2. Net optical density of radiographic film as a function of wavelength for various absorbed doses up to 50 cGy.

400 nm. These results show that any visible light densitometer used for analysis of X-Omat V radiographic film should produce similar results for net OD measurements. This is different from the results for radiochromic film where the film produces a major absorption peak in the 'red' region and thus the readout wavelength for the densitometer used can produce significant differences in the measured optical density. To quantify these assumptions four commonly

Table 1. Optical density results for exposed Kodak X-Omat V film at specific wavelengths.

Densitometer light source	Absolute optical density				
	0 cGy	10 cGy	20 cGy	30 cGy	50 cGy
Fluorescent	0.203 ± 0.007	0.679 ± 0.011	1.112 ± 0.010	1.509 ± 0.013	2.105 ± 0.015
660 ± 20 nm	0.229 ± 0.009	0.695 ± 0.013	1.128 ± 0.012	1.528 ± 0.017	2.110 ± 0.015
670 ± 5 nm	0.175 ± 0.010	0.645 ± 0.013	1.079 ± 0.014	1.479 ± 0.021	2.067 ± 0.023
632 nm	0.348 ± 0.0142	0.808 ± 0.0135	1.237 ± 0.0153	1.636 ± 0.0178	2.208 ± 0.028
Densitometer light source	**Net optical density**				
	0 cGy	10 cGy	20 cGy	30 cGy	50 cGy
Fluorescent (broad band)	0	0.476 ± 0.013	0.909 ± 0.012	1.31 ± 0.015	1.90 ± 0.017
660 ± 20 nm	0	0.467 ± 0.016	0.899 ± 0.015	1.30 ± 0.019	1.88 ± 0.017
670 ± 5 nm	0	0.471 ± 0.016	0.904 ± 0.017	1.31 ± 0.023	1.89 ± 0.025
632 nm	0	0.460 ± 0.02	0.889 ± 0.021	1.29 ± 0.023	1.86 ± 0.031

used light sources were evaluated and the results are quoted in table 1. As can be seen, the absolute optical density recorded on each densitometer varies slightly due to the characteristic wavelength of each light source. Also shown are the results for net optical density of each film with the four densitometers. Results show a close match for change in net optical density for all densitometers. There was a variation of less than 5% between all densitometers. These results highlight the fact that radiographic film is not wavelength sensitive in its densitometry output. This is unlike radiochromic film, which is highly wavelength specific. Thus it is most efficient to have a densitometer with a light source suitable for radiochromic film, which can also be used for radiographic film.

4. Conclusions

X-Omat V radiographic film has nominal absorption peaks at approximately 530 and 630 nm in the visible region. Upon irradiation, there is less than 10% variation in net optical density over the visible spectral region. All four visible light densitometers tested for use with radiographic film produced results for net optical density in close agreement with each other. Radiographic film is predominately not sensitive to wavelength in the visible region. Radiochromic film *is* wavelength sensitive. Consequently, it would appear to be most efficient to have a densitometer with a light source suitable for radiochromic film, but which can also be used for radiographic film.

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