



Short communication

Absorption spectra response of XRQA radiochromic film to x-ray radiation

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ABSTRACT

Gafchromic XRQA, radiochromic film is a high sensitivity auto developing x-ray analysis films designed and available for kilovoltage x-ray, dose and QA assessment applications. The film is designed for reflective analysis with a yellow transparent top filter and white opaque backing materials. This allows the film to be visually inspected for colour changes with a higher level of contrast than clear coated radiochromic films such as Gafchromic EBT version 1. The spectral absorption properties in the visible wavelengths have been investigated and results show two main peaks in absorption located at 636 nm and 585 nm. These peaks are located in the same position as EBT Gafchromic film highlighting a similar chemical monomer/polymer for radiation sensitivity. A much higher sensitivity however is found at kilovoltage energies with an average 1.55 OD units per 20 cGy irradiation variation measured at 636 nm using 150 kVp x-rays. This is compared to approximately 0.12 OD units per 20 cGy measured at 636 nm for EBT film at 6 MV x-ray energy. That is, the XRQA film is more than 10 times more sensitive than EBT1 film. The visual colour change is enhanced by the yellow polyester coating. However this does not affect the absorption spectra properties in the red region of analysis which is the main area for use using desktop scanners in reflection mode.

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1. Introduction

Utilization of radiochromic film has propagated in many areas of megavoltage radiation therapy (He et al., 2008; Butson et al., 1998a,b, 2002a,b; Klassen et al., 1997; Cheung et al., 2002) and kilovoltage therapy and diagnostic imaging applications (Giles and Murphy, 2002; Butson et al., 2007; Currie et al., 2007; Rampado et al., 2006) due to the every increasing range of films available. In recent years films have been created which have higher dose sensitivity allowing doses to be measured with minimal exposure levels. One such film is Gafchromic XRQA. International Specialty Products (Wayne, USA) has produced this film with quality assurance procedures in the kilovoltage energy range in mind. This film is a reflected type film where an opaque background material is used with a yellow coloured filter dye material over the active layer. This design is similar to the companies XR type R film (Butson et al., 2005a,b; Delle Canne et al., 2006) which is used extensively for dose verification during fluoroscopy imaging procedures. The active layer component of this film type has however changed from the XR-R film. As such the absorption spectra properties are also

different. The film has an increased sensitivity to low energy x-rays and can produce a significant colour change with as little as a few cGy of absorbed dose (Chu et al., 2007; Butson et al., 2009a,b; Rampado et al., 2006). In 2005, Chiu-Tsao et al. (2005) studied the energy dependence of XRQA film and found a significant variation in response at different kilovoltage energies. They also performed a basic study on the dose response of XRQA film. Chiu-Tsao's results showed a higher sensitivity compared to EBT film in general but unfortunately the analysis was performed at the 2 specific wavelengths of 665 nm (10 nm FWHM) and 520 nm (20 nm FWHM). These wavelengths were positioned near the absorption peaks of an older Gafchromic film types Gafchromic HS, MD-55-2 and XR-R. As such the measured sensitivity was significantly less than values if measured at the XRQA films absorption peaks. This note investigates the variations in absorption spectra of XRQA and the maximum dose response sensitivities achievable with specific wavelength as well as band pass light sources.

2. Materials and methods

Gafchromic XRQA radiochromic film (Lot No. 36124-002) was utilized for the measurement of absorption spectra changes due to ionising radiation. Information regarding the films construction is available on the manufacturers (ISP) web site (ISP accessed 2009).

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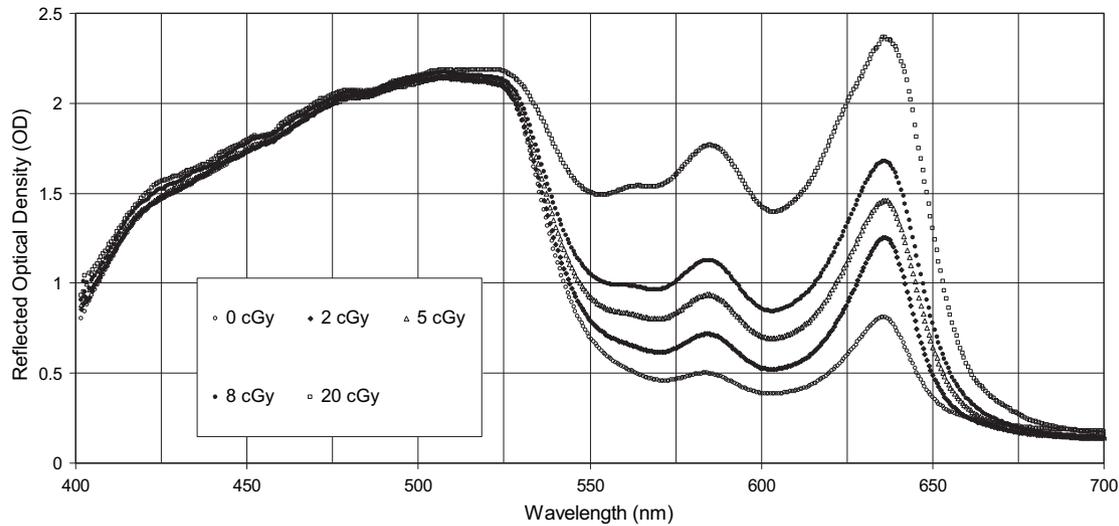


Fig. 1. shows the reflective absorption spectra of XRQA Gafchromic film when irradiated with kilovoltage x-rays. Of note is the 2 main absorption peaks at 636 nm and 585 nm as well as the band pass filter absorption starting around 525 nm and below.

For dose delivery, the films were positioned in a solid water (Constantinou et al., 1982) phantom of dimensions 30 cm × 30 cm × 30 cm. A Gulmay¹ D3300 orthovoltage films was used to deliver various absorbed doses up to 20 cGy at 150 kVp energy using a circular field size of 10 cm diameter. Irradiations were performed at the position of Dmax which is located at the surface. The phantom size used provided ample backscatter material for full scatter conditions. The effective energy of the 150 kVp beam was calculated from Half Value Layer measurements and found to be 69 keV photon equivalent. The radiation induced absorption spectra were measured with an Avantes AvaSpec-2048 reflectance photospectrometer (Avantes, Eerbeek, Netherlands). It is a fiber optic spectrometer with 300 lines/mm grating. The operational range is 327–1100 nm, and the instrument has an FWHM resolution of 2.4 nm. Measurements were made in absorbance mode which is defined as follows. Transmittance at pixel n is given by

$$T_n = 100 \times I/I_0,$$

where I is the net intensity of the sample film and I_0 is the net intensity of the reference film. The absorbance mode relates to the absorption of light within the film with the absorbance at pixel n given by

$$A_n = -\log(T_n).$$

The reference spectrum is the reflectance spectrum of a standard white background sheet. Subtracting this spectrum from the spectrum of the film after irradiation provides net absorption as a function of wavelength (nm). Wavelength range of analysis was from 400 nm to 700 nm in 1 nm steps with the resolution of FWHM = 2.4 nm. This wavelength range was chosen as it forms the most sensitive region of analysis for XRQA radiochromic film. Spectral data was analysed to measure the dose response at specific and broad band wavelengths.

Precautions in handling of radiochromic film outlined by Butson et al. (2003) were used. Film pieces of 4 cm × 4 cm were cut for experiments. 5 film pieces were exposed at each dose level and results show the average for this data set. The same orientation of

films pieces relative to the reflectance photospectrometer were used to minimise polarization or orientation effects on film absorption spectra assessment (Butson et al., 2009a,b). The film during storage and film analysis were kept in temperatures of $22 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$ to reduce any effects of time and temperature dependent evolution or readout of the absorption spectra (Meigooni et al., 1996). The film is only removed from a light tight envelope during irradiation and readout to reduce any effects of ambient light (Butson et al., 2002a,b). Films were left for 24 h before readout to minimize the effects of post irradiation colouration (Cheung et al., 2005).

3. Results and discussion

Fig. 1 shows the absorption spectra for Gafchromic XRQA film in the visible spectra region of 400 nm–700 nm when the film is exposed to radiation doses up to 20 cGy. Two distinct features are shown in the figure. They are the changing absorption spectra due to radiation induced effects and the yellow dye baseline absorption. As can be seen there is a significant absorption for all exposed films at wavelengths below 525 nm which is the effective band pass for absorption of the yellow dye utilized within the film type for enhanced visual color change. The two absorption peaks measured were located at 585 nm and 636 nm which is the same as EBT Gafchromic film (Butson et al., 2005a,b). This shows that similar active radiochromic components are used for both film types. The increased sensitivity to kilovoltage energies is a product of using high atomic number material in the substrates composition. After 20 cGy irradiation the optical density of the film at 636 nm was 2.5 OD which is near the saturation level of the reflectance spectrometer used. EBT 1 Gafchromic film at 6 MV x-ray energy has an optical density of approximately 2.2 after 500 cGy exposure at 636 nm (Butson et al., 2005a,b).

Fig. 2 shows the net absorption spectra of XRQA Gafchromic film. It was produced by the subtraction of absorption spectra for the non-irradiated films from the exposed films at each given dose level. As can be seen, a minimal response is seen at wavelengths below 525 nm. This is specifically due to the effects of the colored dye which acts as a band pass filter at wavelengths below this value. The absorption peaks show a highly sensitive radiochromic film with a non linear response to radiation at the absorption peak. The position of the absorption peak over these doses is unchanged remaining at the 636 nm position. A net OD change of 1.55 OD after

¹ Gulmay Limited, Chertsey, Surrey, KT16 9EH, United Kingdom.

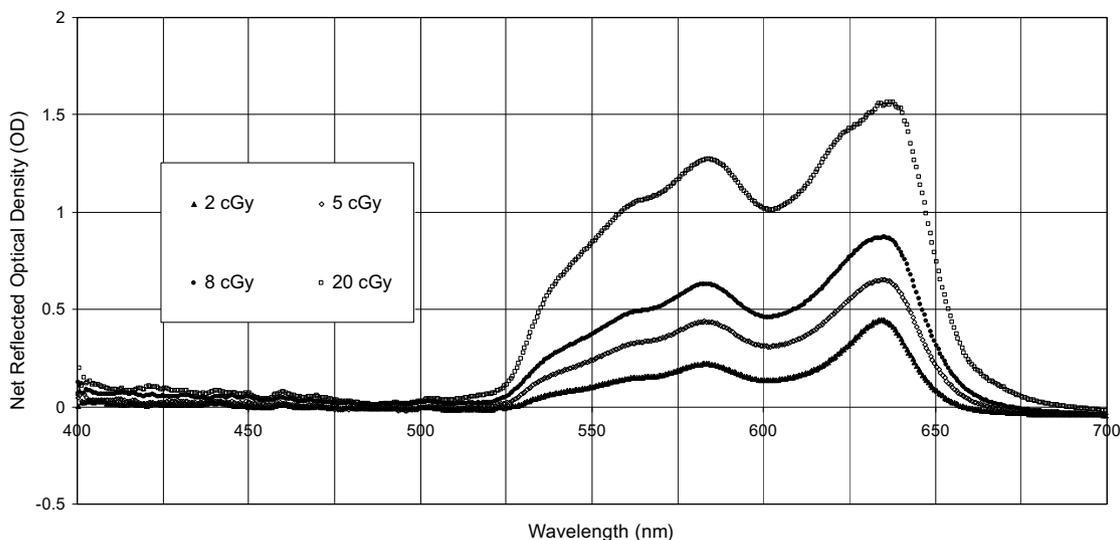


Fig. 2. shows the net Absorption of XRQA film for exposure levels up to 20 cGy.

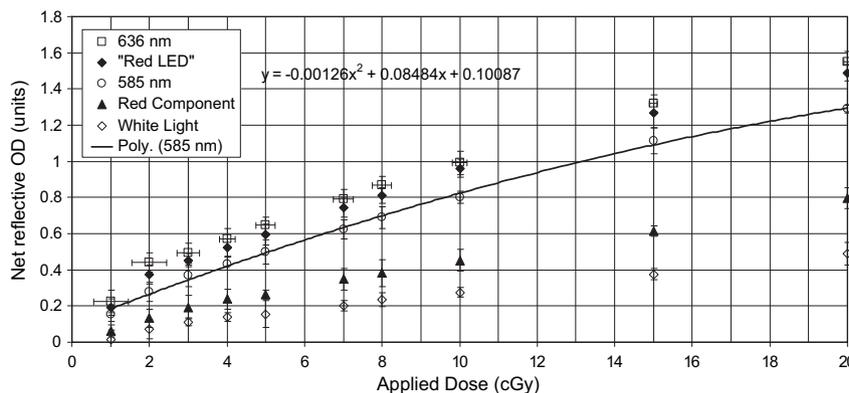


Fig. 3. shows the dose response of the XRQA film when analysed at various wavelengths and band passes. A polynomial fit to the 585 nm wavelength dose response data is included.

20 cGy irradiation is found at the peak wavelength. After 20 cGy irradiation the net OD change for EBT 1 film was found to be 0.12 OD at 636 nm. Thus the XRQA film was found to be more than 10 times more sensitive than EBT 1 Gafchromic film.

Fig. 3 shows the dose response of XRQA to 150 kVp x-rays when analysed at various wavelengths and band pass regions. At each wavelength of analysis or band pass, the dose response of XRQA is non linear but reproducible and in each case can be adequately fitted by a second order polynomial function for dose assessment if required. The use of a desktop scanner in reflective mode is an ideal tool for assessment of dose measured using XRQA film utilizing the red components of the image. This section of the response is not affected by the yellow dye with radiation exposure. XRQA film provides a highly sensitive radiation detection film for kilovoltage x-rays. The absorption spectra of the film shows very similar characteristics to EBT Gafchromic film in the position of the absorption peaks along with the extra filter dye used to enhance the colour change seen for visual inspection.

4. Conclusions

Gafchromic XRQA radiochromic film produces a change in its visible light absorption spectrum when irradiated with x-ray radiation. The absorption peaks are located at 636 nm and 585 nm

which are the same as for the EBT Gafchromic film. The use of a color dye enhances the visual color change seen at low applied doses. The dose sensitivity to 150 kVp x-rays is substantially higher than EBT at 6 MV x-ray energy producing an approximate 0.0775 OD per cGy color change as compared to 0.006 OD per cGy for EBT. With a high sensitivity this film is well suited for dosimetric comparisons at low applied x-ray exposures as would be seen in CT and some diagnostic procedures.

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