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NOTE

Absorption spectra variations of EBT radiochromic film from radiation exposure

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Abstract

Gafchromic EBT radiochromic film is one of the newest radiation-induced auto-developing x-ray analysis films available for therapeutic radiation dosimetry in radiotherapy applications. 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 absorption peaks are different to many other radiochromic film products such as Gafchromic MD-55 and HS film where two peaks were located at 676 nm and 617 nm respectively. The general shape of the absorption spectra is similar to older designs. A much higher sensitivity is found at high-energy x-rays with an average 0.6 OD per Gy variation in OD seen within the first Gy measured at 636 nm using 6 MV x-rays. This is compared to approximately 0.09 OD units for the first Gy at the 676 nm absorption peak for HS film at 6 MV x-ray energy. The film's blue colour is visually different from older varieties of Gafchromic film with a higher intensity of mid-range blue within the film. The film provides adequate relative absorbed dose measurement for clinical radiotherapy x-ray assessment in the 1–2 Gy dose range which with further investigation may be useful for fractionated radiotherapy dose assessment.

1. Introduction

Radiochromic film has in the last ten years provided many advances and achievements in radiotherapy radiation dosimetry (Klassen *et al* 1997, Butson *et al* 2002, Chiu-Tsao *et al* 2004). One of the major advances has been the continual increase in available dose sensitivity within the megavoltage as well as kilovoltage range. Products such as FWT-60 radiochromic film produced by Far West technologies (Young *et al* 1999) provide accurate x-ray dosimetry for doses in the kGy range (Miller *et al* 2003), and products such as Gafchromic MD-55-2 and

HS provide accurate dosimetry within the few Gy to 100 Gy region. Radiochromic films have also been developed for increased sensitivity in the lower kVp range (Giles and Murphy 2002) for dosimetry purposes in diagnostic procedures. International Specialty Products has recently released a new radiochromic film which can measure doses within the cGy to Gy region. This reported ability will make the film ideal for dosimetry in clinical radiotherapy applications, with the doses delivered during routine radiotherapy fractions matching the effective range of this new product called EBT Gafchromic. Manufacturers' specifications report that the visual absorption spectra properties of this film differ from their original products. The visible absorption spectra of the film product can significantly affect the dosimetry characteristics of the film detector providing a large variation in the dose to optical density relationship. This change in visual absorption spectra may also affect the ability to accurately use existing scanners owned by radiochromic film users. This note investigates the absorption spectra of EBT Gafchromic film and investigates the dose response in the 0 to 5 Gy dose range for high-energy x-rays.

2. Materials and methods

Gafchromic EBT radiochromic film (Lot no 34267-004) was investigated for this visible absorption spectra study. For dose delivery, the films were positioned in a solid water (Constanitinou *et al* 1982) phantom of dimensions 30 × 30 × 30 cm^3. The films were irradiated using a standard 10 × 10 cm^2 6 MV x-ray field at 100 cm source to surface distance at the d_{max} position of 1.5 cm depth. The films were irradiated placed perpendicular to the central axis of the beam. Results are given for films ranging in applied doses of 0 cGy to 500 cGy produced by a 6 MV linear accelerator x-ray beam. Precautions in handling of radiochromic film outlined by Butson *et al* (2003) were used. Film pieces 4 × 4 cm^2 were cut for experiments. Five film pieces were exposed at each dose level and results show the average for this data set. The film during storage and film analysis were kept in temperatures of 22 ± 2 °C to reduce any effects of time- and temperature-dependent evolution or readout of the absorption spectra of the film as is the case found for MD-55 Gafchromic film (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* 2002). The absorption spectra results were measured using a Shimadzu UV-160 UV-visible recording spectrophotometer (Butson *et al* 2002). Wavelength range of analysis was from 450 nm to 800 nm in 5 nm steps except at the absorption peaks where the maximum was found using a step size of 1 nm. The Shimadzu UV-160 has a spectral bandwidth of 3 nm with an accuracy of ±0.5 nm. The film was held in a quartz holding container. Spectra data were then analysed to calculate sensitivity values at various specific wavelengths and various band passes relating to various densitometry light sources.

3. Results and discussion

Figure 1(a) shows the absorption spectra for Gafchromic EBT film in the visible and partly into the infrared region (450–800 nm). The results show the average for the five films at each dose level with an overall standard deviation in measurements of 0.008 OD units calculated. As can be seen the absorption spectra for the film produce two pronounced peaks which are located at 636 nm and 585 nm. The position of these peaks did not change within the measured dose levels of up to 5 Gy. There seems to be a minor peak located at 560 nm. Also shown in the figure is the increase in absorption, albeit to a lesser extent, with absorbed dose covering a

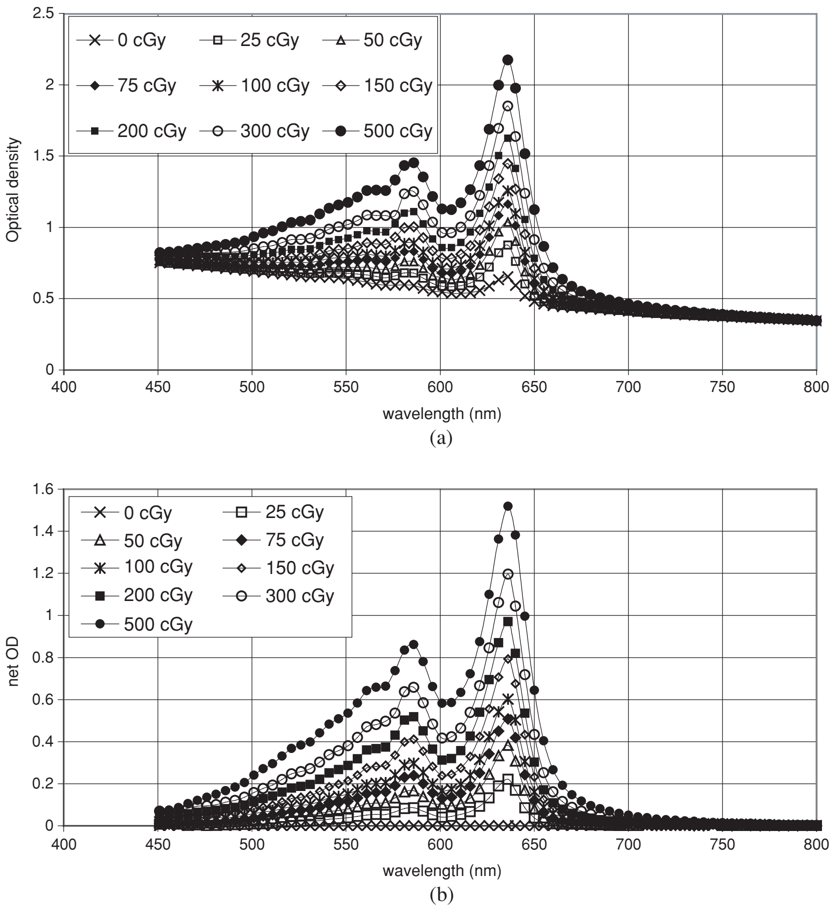

Figure 1. (a) Visible absorption spectra for Gafchromic EBT radiochromic film when exposed to 6 MV x-rays. Of interest are the absorption peaks located at 636 nm and 585 nm. (b) Net optical density change for Gafchromic EBT radiochromic film when exposed to 6 MV x-rays up to 5 Gy absorbed dose.

larger bandwidth of wavelengths. This range of wavelength response seems to be much larger than MD-55-2 Gafchromic film which produces a lesser effect with different wavelength peaks. Figure 1(b) shows the net optical density increase when EBT film is exposed to 6 MV x-rays. These results are the subtraction of 0 Gy measured absorption spectra from radiation-exposed results. These results highlight the sensitivity of the film to high-energy x-ray dose. Results show that at the main absorption peak a net sensitivity is found to be approximately 0.6 OD units per Gy within the first Gy of applied dose with a non-linear response reaching on average 0.3 OD units per Gy over 5 Gy applied dose. The non-linear relationship over this range of applied doses is easily modelled using a second-order polynomial function. The position of the visible absorption peaks for EBT film is different from older versions of Gafchromic film such as MD-55-2 and HS Gafchromic. Their peaks are located at 676 nm and 618 nm respectively (Butson *et al* 2003). As such the EBT film's visible colour is different, producing what we describe as a richer, lighter blue upon irradiation compared to MD-55-2 and HS film.

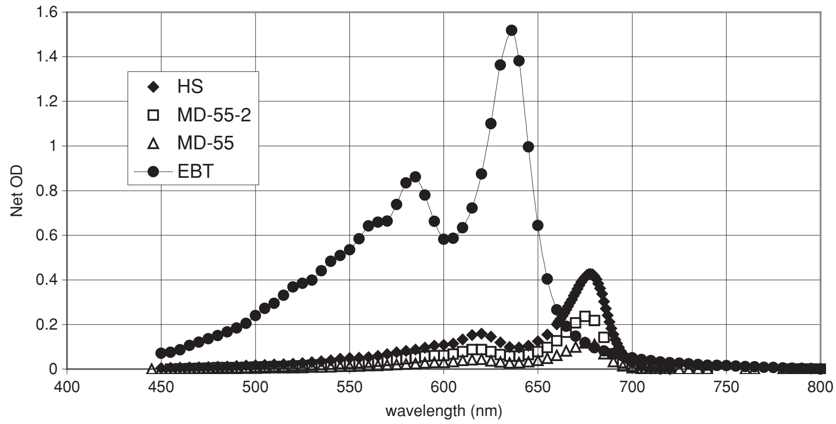

Figure 2. Comparison of visible absorption properties of Gafchromic EBT film with MD-55, MD-55-2 and HS film when exposed to 5 Gy absorbed dose.

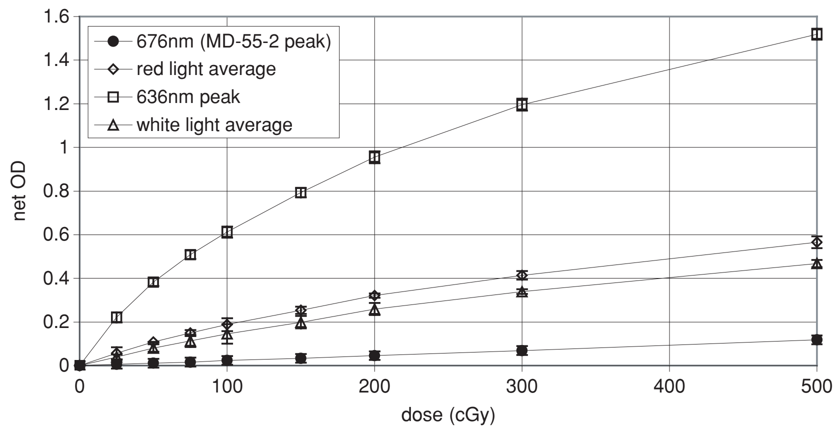

Figure 3. Dose response of EBT radiochromic film when analysis performed at various wavelengths matching absorption peak and common wavelength band passes.

Figure 2 compares the absorption spectra for EBT radiochromic film to the absorption spectra of older Gafchromic film types, MD-55, MD-55-2 and HS film. All films were exposed to 5 Gy applied dose at 6 MV x-ray energy and results showed a net increase in optical density. As can be seen, the EBT produces a far more sensitive result at its absorption peak compared to the MD-55, MD-55-2 and HS film at their respective absorption peak. At this dose level the EBT is approximately 4×, 7× and 12× more sensitive than HS, MD-55-2 and MD-55 film to 6 MV x-rays. Figure 3 shows the dose response of EBT film at specific wavelengths and band passes. Results show the non-linear relationship of the dose response which is modelled adequately by a second-order polynomial function. Due to the absorption characteristics of the new EBT film, the response of the film is significantly higher, not only at a selected peak wavelength but also higher as a white light (0.468 OD/5 Gy), or red light average (0.565 OD/5 Gy) as would be the case if analysis occurred using a fluorescent light densitometer in normal mode or Red–Green–Blue split analysis. For comparison, over the same wavelengths, the net OD change for 5 Gy dose at 6 MV energy would be 0.1 OD, 0.17 OD and 0.04 OD, 0.09

OD (MD-55-2) at white light average and red light average. Thus EBT film produces a more sensitive film result for commonly used densitometers and desktop scanners. An important point to note with this new film is its response at and around the absorption peak (676 nm) of the older film types. At this wavelength the response is quite low producing, only a 0.118 net OD change for 5 GY absorbed dose (approximately 13 times lower). Thus a densitometer which was optimized for use with MD-55-2 or HS film using a narrow band light source around the 676 nm would not be suitable for high sensitivity dosimetry using the newer EBT film. Common radiotherapy fractionated dose regimes delivered to patients normally range from approximately 100 cGy to 200 cGy per fraction. In the past no film product could provide accurate (within 5%), immediate and automated dose assessment for this type of radiation exposure. Gafchromic EBT film does, however, possess the characteristics to produce all of the above for conventional radiotherapy *in vivo* dose assessment as well as the ability to do this in a two-dimensional manner. That is, a dose map could be produced in an area in question if required by the radiation oncologist for quantitative analysis.

4. Conclusions

Gafchromic EBT 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 differs from the older style MD-55-2 and HS Gafchromic films. The dose sensitivity to 6 MV x-rays is substantially higher than older style films at this energy, producing a 0.6 OD unit increase within the first Gy of absorbed dose. As this film's visible light absorption spectra have changed from older versions of Gafchromic film a reader with a narrow band pass wavelength located at or near the old absorption peak of 676 nm would not be useful for high sensitivity analysis of EBT film. The larger sensitivity over the entire range of visible light does make the film more ideal for analysis with white light/fluorescent light densitometers or desktop scanners. It is also ideal for dose analysis within typical ranges of delivered doses during a conventional radiotherapy x-ray treatment.

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