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Technical note

Energy response of the new EBT2 radiochromic film to x-ray radiation

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ABSTRACT

Gafchromic EBT2, Radiochromic film is assessed for its change in optical density response to x-ray radiation over a broad energy range, from low energy kilovoltage to megavoltage x-rays. A small energy dependence was found with variations in the change in optical density when scanned in the red component of a desktop scanner light source per unit dose of 6.5% from 50 kVp to 10 MV. This produces a slightly smaller and thus even more energy independent film than its predecessor, EBT film whose response varied by 7.7% over the same energy range. The energy response peaked at 100 kVp with a 5% over response compared to 6 MV x-rays and the minimum response found at both 50 kVp and 250 kVp being a 1.5% under response. It should be noted that the shape of the energy dependence response curve increases from 50 kVp up to 100 kVp followed by a decrease through to higher energies whilst the original EBT was found to increase in response from 50 kVp through to 10 MV. A reflected net optical density change of 0.215 ± 0.006 OD for the first Gray of radiation was found for EBT2 analysed in reflection mode at 6 MV x-ray energy. The minimal energy dependence of the EBT2 film provides further enhancement compared to EBT for its accuracy with respect to spectral changes in the beam to measure beams such as IMRT where complex field and multileaf collimator configurations exist causing small spectral changes to occur over the treatment field or at depth where spectral changes also occur.

1. Introduction

Energy dependence of radiation sensitive film products is a significantly important property for film dosimetry for radiation absorbed dose determination (Butson et al., 2003, 2005, 2006; Cheung et al., 2004; M.J. Butson et al., 2005; Butson et al., 2006a, b; Cheung et al., 2006; Cheung et al., 2007; Butson et al., 2008). Historically silver halide based radiographic films produced what could now be considered a poor energy dependant, net change in optical density to unit dose relationship with up to 15 or 16 times variation seen within the medical application x-ray energies of 50 kVp–20 MVp (Kron et al., 1998). In more recent times, with the introduction of more tissue equivalent radiochromic film products, the energy dependence reduced towards the ideal dosimetry relationship of energy independent sensitivity response. Films used clinically such as Gafchromic MD55-2, and HS (Cheung et al., 1999; Meigooni et al., 1996; Butson et al., 2000, 1999, 2002) were the precursors to the higher sensitivity film products like EBT (M. Butson et al., 2005) from International speciality products. In an effort to provide a more robust but flexible, lower UV sensitive and higher accuracy radiochromic film product, ISP has recently released EBT2 Gafchromic film. Of interest for this study, is its completely new construction geometry and inclusion of a yellow marker dye within the active layer. The combination of these two property changes along with any other proprietary changes will affect the energy dependence to x-rays of the EBT 2 Gafchromic film. This short note investigates these effects and the dose response at given kilovoltage and megavoltage x-ray energies.

2. Materials and methods

Gafchromic EBT2, radiochromic film (Lot No. F02060902B) has been utilized for the measurement of optical density change per unit radiation energy response measurements for x-ray energies from 50 kVp to 10 MV x-rays. The new EBT2 film has changed in physical design from EBT film with the design changes shown on ISP's website. The most significant changes in the design are the inclusion of the yellow dye into the films active component layer which acts as a "visible band pass filter" and the changed thickness of the substrate (50 microns for EBT2 compared to 97 microns for EBT) and over-laminate material (175 microns for EBT2 compared

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to 97 microns for EBT). The yellow dye, the redesigned over laminate and substrate layers and any other proprietary changes are expected to affect the energy response characteristics of EBT 2 film compared to the original EBT film.

To test for energy dependence, EBT 2 films were irradiated to doses of 50 cGy, 100 cGy and 200 cGy using beam energies of 50 kVp, 75 kVp, 100 kVp, 125 kVp, 150 kVp, 200 kVp, 250 kVp, 6 MV and 10 MV x-rays. Results for energy dependence quoted were the average of the results from the 3 dose levels. Irradiations were performed in a 30 × 30 × 30 cm^3 solid–water phantom (Constantinou et al., 1982) using a GULMAY D3300 orthovoltage machine and a Varian 2100C linear accelerator. The absorbed dose calibrations were performed with a Farmer thimble-type ionization chamber according to the IPEMB protocol for kilovoltage x-rays (Ipemb, 1996) and IAEA TRS-398 protocol for megavoltage x-rays (Andreo et al., 2002). The delivered doses were dose to water and no corrections were applied for the influence of solid–water or EBT2 film material on absorbed dose. The equivalent photon energy of each beam was calculated from half value layer (HVL) measurements. These values are quoted within the results.

All EBT2 Gafchromic films were analysed using a PC desktop scanner and Image J software on a PC workstation at least 24 h after irradiation to minimize effects from post irradiation colouration (Cheung et al., 2005). The scanner used for quantitative analysis was an Epson Perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 50 pixels per inch in reflection mode. The images produced were 48 bit RGB colour images. An area of 5 cm × 5 cm was used to analyse the pixel values of the film. No filters or correction functions were applied to raw pixel value results. These images were analysed using the red component. Net Reflective optical density (ROD) for all films was calculated to evaluate energy and dose responses. Net ROD is defined as equation (1):

$$\text{Net ROD} = \log(P_u/P_t) \quad (1)$$

Where P_u is the pixel value of the reflected intensity through an unexposed film at an orientation whereby the maximum pixel value is found and P_t is the pixel value of the reflected intensity at any other film orientation or irradiation level. Ohuchi (2007) produced a similar definition for reflected optical density.

3. Results and discussion

Fig. 1 shows the relative energy response curve for Gafchromic EBT 2 radiochromic film when normalised to 1 at the equivalent photon energy of 1.4 MeV which corresponds to a 6 MV x-ray beam. Equivalent photon energies for the x-ray beams were 25.2 keV (50 kVp), 30 keV (75 kVp), 36 keV (100 kVp), 54 keV (125 kVp), 69 keV (150 kVp), 95 keV (200 kVp), 123 keV (250 kVp), 1400 keV (6 MV) and 2200 keV (10 MV) respectively. In terms of energy response, Gafchromic EBT appears to have the least energy dependence of any radiation film product available, surpassing the low energy dependence of its predecessor, EBT film. ISP quotes on its website that it has and will continue to attempt to improve the energy dependence of their film product range. It is expected that this will be achieved by the addition of proprietary compounds to produce the least energy dependence possible whilst retaining Gafchromic's other radiation accuracy features. EBT2 produced a 6.5% ± 1% variation in its energy response over the energy range of 50 kVp to 10 MV. The response in one sense is similar in shape to traditions radiographic films with a lower response at low energy and peaking in response around the 100 kVp energy. However the variations are much smaller. Following on from 100 kVp the energy response decreases again with 200 kVp beams and above all within 1.5% of each others response. It should be noted that for kilovoltage x-ray absolute dosimetry in our centre, most beams have an uncertainty of 1%–2%. Thus the response at 250 kVp could be defined as equivalent to 6 MV and 10 MV due to the level of accuracy attainable in dose delivery.

Table 1
Comparison of energy Dependence of EBT2 film to the original EBT film.

Photon equivalent energy (keV)	EBT2	EBT
	Normalised to 1 at 1400 keV (6 MV)	
25.5	0.985	
28		0.923
30	1.04	
32.5		0.926
36	1.05	
39		0.93
53		0.929
54	1.03	
68		0.928
69	1.02	
94		0.946
95	1.00	
119		0.956
123	0.985	
1400	1.000	
1500		1.00
2200	1.00	
5500		1.00

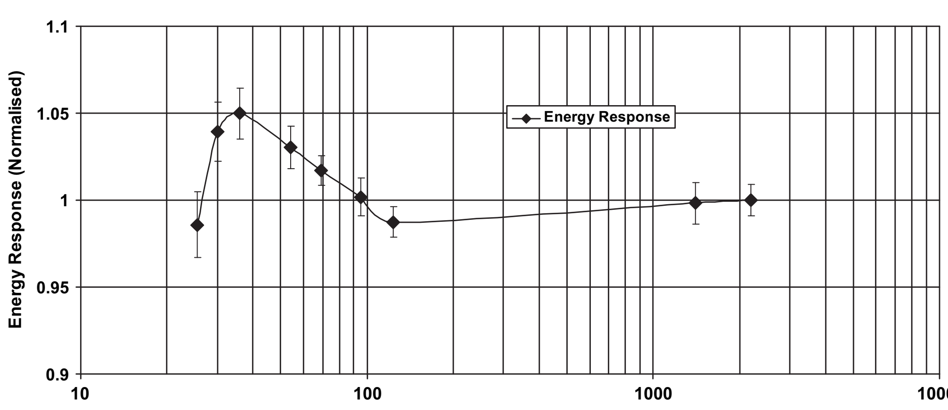

Fig. 1. Change in Optical density to Dose response curve for varying x-ray energies from 50 kVp to 10 MV for EBT2 Gafchromic film.

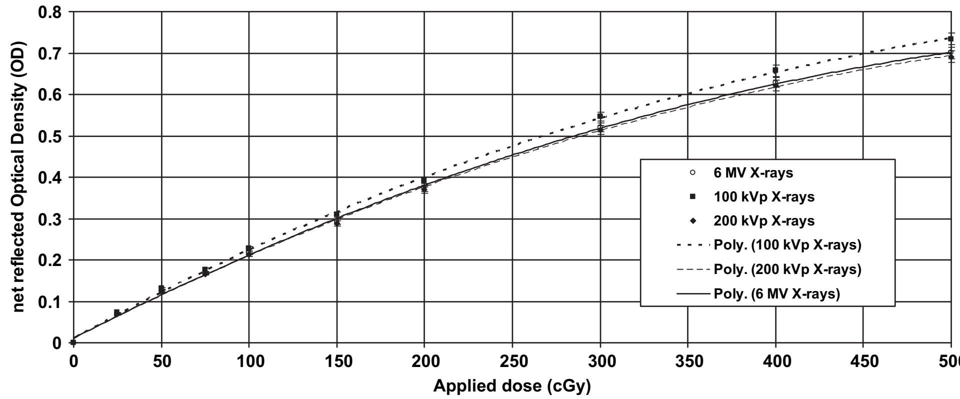

Fig. 2. Dose response curve for EBT 2 Gafchromic film for x-ray energies of 100 kVp, 250 kVp and 6 MV. These energies represent the largest variation in dose response for energies tested between 50 kVp and 10 MV.

Table 1 compares these results to the original EBT film highlighting the decrease in energy dependence of the film. Results calculated for energy dependence of EBT were analysed using the change in film optical density within the spectral range of 500 nm–700 nm by photo spectroscopy. This was compared to the utilization of the red component (550 nm–700 nm) on a desktop scanner for EBT2 results. We acknowledge that different scanners are used for the original and current model EBT/EBT2 films however as the wavelength range of analysis is similar, we have assumed that no significant difference in energy response should pertain to the results. EBT produced a 7.7% ± 2% variation in response over the same energy range as the results quoted in this note. Thus EBT 2 has achieved a small but measurable decrease in energy dependence. These results are highlighted in Fig. 2 which shows the dose response curves for EBT2 which have been irradiated with 100 kVp, 250 kVp and 6 MV x-rays for comparison. These results being the largest variation in dose response measured with our available x-ray beam energies. Results show the relatively close dose response at all these energies. Whilst these results are close it would still be expected that calibration curves be produced for dose assessment at each beam energy used to provide the highest level of accuracy achievable. It can however be stated that the low energy dependence of EBT2 film will minimize uncertainties in dose assessment using the same beam energy which may have arisen from spectral changes due to beam configuration changes (eg. MLC fields) or spectral changes due to beam attenuation and depth of measurement. The figure shows that using the red component of the beam that a 0.227 OD units per Gray radiation dose is achieved for 100 kVp x-rays, 0.214 for 250 kVp and 0.215 for 6 MV x-rays. The absorption spectra of EBT2 film has been shown to be similar to EBT (Butson et al., 2009) with the same absorption peaks located at 636 nm and 585 nm. The main differences of coarse being the high absorption at wavelengths lower than 500 nm due to the yellow dye and slightly changed OD characteristics in the higher wavelengths from the changes to the substrate and over-laminate thickness and adhesive materials. It is important to note that these design changes have produced an effect on energy response which has been shown to improve the energy independent nature of this film type compared to its predecessor, Gafchromic EBT.

4. Conclusion

EBT 2 Gafchromic has been shown to have a very low energy dependence with a 6.5% ± 1% variation in optical density to absorbed dose response for x-ray beam irradiations with energy from 50 kVp up to 10 MV. These results are slightly better than it predecessor film EBT which had a 7.7% ± 2% variation over the same energy range. Low energy dependence is an important feature for film radiation dosimetry as it reduces the response changes in 2 dimensional or even 3 dimensional dosimetry caused by the spectral changes to beams from small IMRT style fields or beam attenuation at depth.

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