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Article *in* Physics in Medicine and Biology · October 2015

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2015 Phys. Med. Biol. 60 8741

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Phys. Med. Biol. **60** (2015) 8741–8752 doi:10.1088/0031-9155/60/22/8741

Evaluation of Gafchromic EBT-XD film, with comparison to EBT3 film, and application in high dose radiotherapy verification

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Received 20 June 2015, revised 6 September 2015
Accepted for publication 25 September 2015
Published 29 October 2015

Abstract

There is renewed interest in film dosimetry for the verification of dose delivery of complex treatments, particularly small fields, compared to treatment planning system calculations. A new radiochromic film, Gafchromic EBT-XD, is available for high-dose treatment verification and we present the first published evaluation of its use. We evaluate the new film for MV photon dosimetry, including calibration curves, performance with single- and triple-channel dosimetry, and comparison to existing EBT3 film. In the verification of a typical 25 Gy stereotactic radiotherapy (SRS) treatment, compared to TPS planned dose distribution, excellent agreement was seen with EBT-XD using triple-channel dosimetry, in isodose overlay, maximum 1.0 mm difference over 200–2400 cGy, and gamma evaluation, mean passing rate 97% at 3% locally-normalised, 1.5 mm criteria. In comparison to EBT3, EBT-XD gave improved evaluation results for the SRS-plan, had improved calibration curve gradients at high doses, and had reduced lateral scanner effect. The dimensions of the two films are identical. The optical density of EBT-XD is lower than EBT3 for the same dose. The effective atomic number for both may be considered water-equivalent in MV radiotherapy. We have validated the use of EBT-XD for high-dose, small-field radiotherapy, for routine QC and a forthcoming multi-centre SRS dosimetry intercomparison.

Keywords: film, radiochromic, EBT3, EBT-XD, audit, dosimetry, SRS

(Some figures may appear in colour only in the online journal)

1. Introduction

Electronic array detectors are a convenient method for the verification of the accuracy of external beam radiotherapy delivery, particularly for relatively large treatment fields, and their use has become widespread. However, film is more suitable for the verification of treatments incorporating very small fields in which the resolution of the detector is of particular importance for accurate measurement (Wilcox and Daskalov 2007, Olding *et al* 2015, Cusumano *et al* 2015, Lee *et al* 2015). Stereotactic radiotherapy (SRS) in particular delivers extremely steep dose gradients to small volumes with very high doses. With close proximity to organs at risk, the safety and effectiveness of SRS relies on accurate treatment planning and treatment delivery. As with all radiotherapy techniques, it is essential that sufficient confirmation is sought that the intended treatment is actually delivered, however the optimisation of measurement methods for this task requires further research and development. Over the last decade much progress has been made with radiochromic film as a suitable dosimeter for the verification of the accuracy of external beam radiotherapy delivery (Slobodan 2011). Film dosimetry is suitable due to its high spatial resolution, low energy dependence, dose-rate independence, and near-water equivalence (Arjomandy *et al* 2010, Brown *et al* 2012).

However, film dosimetry methods, and results, vary widely in the published literature (Devic *et al* 2009, Slobodan 2011). While there have been several publications advocating triple-channel dosimetry as an optimum analysis methodology (van Hoof *et al* 2012, Hayashi *et al* 2012, Lewis *et al* 2012a, 2012b, Mendez *et al* 2014, Palmer *et al* 2014), further research is needed to establish best-practice approaches for specific applications. Gafchromic film (Ashland ISP Inc., Wayne, NJ, USA) is widely used (Dreindl *et al* 2014), however the current EBT3 film is limited in its recommended usable dose range to around 10 Gy in the red colour channel (Andres *et al* 2010). In order to measure and verify much higher dose treatments, Olding *et al* (2015) used a common approach of renormalizing the treatment plan (scaling down the monitor units) to accommodate the usable film dose range. However it is preferable to verify the actual treatment plan rather than a modified version, as scaled doses can change plan delivery parameters such as multileaf collimator speeds. Investigators have also attempted to extend the usable dynamic range of film by selecting different colour channels for different dose ranges (Andres *et al* 2010), or combining colour channels (Devic *et al* 2009, Mayer *et al* 2012). Other investigators have simply used EBT3 film with conventional single channel methodologies at doses exceeding the manufacturers' recommendation, due to an absence of alternatives.

Three research groups have published their results of film dosimetry measurements of small dimension, high dose photon fields during 2015, reflecting the interest and importance of this issue (Cusumano *et al* 2015, Lee *et al* 2015, Olding *et al* 2015). While film techniques were seen to be a valuable method in all three studies, the quantitative measures of agreement between planned and measured doses were perhaps below the anticipated level of agreement common in other applications, using larger field or lower doses. Olding *et al* (2015) considered the validation of VMAT stereotactic ablative body radiotherapy, using EBT3, scaling doses from 12 Gy to 2 Gy for measurement, even so, point differences were in the range 3.7 to 4.1% and gamma passing rates (at 3%, 3 mm) were 69.1 to 94.6%. Cusumano *et al* (2015) considered the verification of stereotactic radiosurgery/stereotactic radiotherapy up to 25 Gy using EBT3 single-channel dosimetry, with and without subtraction of the unexposed film. Average gamma passing rates (at 5% global normalisation, 1 mm) were 94.3% with film subtraction and 74.2% without film subtraction. Lee *et al* (2015) undertook a postal dosimetry audit of SABR lung plans at 21 centres in the UK during 2013–2014. Maximum doses were

up to 26.9 Gy, measured using EBT3 with conventional single red-channel dosimetry. The audit mean of the maximum difference between TPS-calculation and film-measurement at the 50% prescription isodose line was 3.4 ± 5.8 mm. Only 74% of audit measurements achieved gamma pass rates (at 3% local normalisation, 2 mm) above 75% with cut-off at 50% prescription dose level. While the authors stated EBT3 was found to be suited to a postal audit giving detailed information on geometric and relative dosimetric accuracy, they also stated gamma pass rates and mean gamma results varied, which may have been due to delivery/planning error or film dosimetry uncertainty.

There is a need to reduce further uncertainties in film dosimetry for small field, high-dose radiotherapy treatment verification compared to that reported in the above recent studies. This will provide confidence in the detection of lower magnitude treatment delivery errors which may currently be swamped by film uncertainty. The purpose of the present work was to evaluate a new Gafchromic film, which has been commercially available from spring 2015, type EBT-XD, specifically designed for high-dose radiotherapy measurements (Ashland ISP Inc. 2015). We provide an evaluation of this new film, with comparison to EBT3, in both conventional single-channel dosimetry and triple-channel dosimetry modes, for the verification of a typical high dose SRS treatment. Robust film dosimetry techniques are utilised including linear dose scaling with reference films and glass compression plate for film flatness at scanning.

2. Methods and materials

2.1. Structure of Gafchromic film

Information was obtained by personal communication with the manufacturer (Ashland ISP Advanced Materials, NJ, USA) on the structure and composition of Gafchromic EBT-XD and Gafchromic EBT3, which are the two films they recommend for external beam radiotherapy dosimetry. The chemical composition was compared and effective atomic number evaluated via a simple power-law method, acknowledging this is a simplification, appropriate for the comparison of the two film types (Taylor *et al* 2012).

2.2. Calibration and usage methodology for film dosimetry

Measurements were performed with Gafchromic film model EBT3® batch #12171303 and EBT-XD® batch #01081501. Films were scanned in red-green-blue (rgb) format using a 48 bit (16 bit per channel) scanner (Epson Expression 11000XL) at 72 dpi, in transmission mode, with no colour or sharpness corrections and consistent orientation. All calibration films and measurement films were scanned at a consistent 48 h post exposure. To ensure stabilised scanner response, three full-field scans were performed prior to scanner data acquisition after the in-built scanner warm-up time had elapsed. The procedure summary recommendations for handling radiochromic film as defined by Niroomand-Rad *et al* (1998) in AAPM TG-55 were adopted. All films were held physically-flat on the scanner plate using a glass compression plate (Palmer *et al* 2015), with consistent orientation of all films. The film response was calibrated in a conventional manner with ten EBT-XD and ten EBT3 film pieces exposed in the range 0–4000 cGy. The films were irradiated in a 10 cm × 10 cm field at 5 cm depth in Solid Water (model RMI457, Gammex, WI, USA), with a nominal 6 MV linear accelerator, traceably calibrated to a primary standard at the National Physical Laboratory (Teddington, UK). The scanned pixel value as a function of dose was determined as the average pixel value in a 4 × 4 cm region centred on the beam axis. Images were converted to dose maps using

FilmQAPro® software (Ashland ISP Advanced Materials, NJ, USA, version 5.0.5602.16030) using single (red)-channel dosimetry and using red-green-blue triple-channel dosimetry algorithm (Micke *et al* 2011). Film-dose linear scaling via FilmQAPro software was applied to both single- and triple-channel dosimetry, using reference films at zero dose and 80% of the maximum anticipated dose from the treatment plan, which were scanned simultaneously with the test films. This approach mitigates the effects of post-exposure darkening and variations of the scanner response, and stabilizes the calibration (forced into agreement) at the reference dose levels (Lewis *et al* 2012a, 2012b).

2.3. Evaluation of lateral scanner effect for Gafchromic films

A method similar to that proposed by Palmer *et al* (2014) was utilised to evaluate the lateral scanner effect for EBT-XD film with an Epson Expression 11000XL scanner. Films were exposed to doses of 0, 1300, 2000 and 4000 cGy, and cut into three to create identical samples. One piece of the film was positioned on the central axis of the scanner while the other pieces, that were irradiated at the same dose level, were moved laterally above and below the central axis, with scans acquired at various distances off-axis up to the edge of the scanner, at 15 cm displacement. The lateral direction is defined as being perpendicular to the direction of travel of the scanning lamp, with zero lateral displacement being the centre of the scan plane. The ratio of the laterally displaced to central film pixel values were calculated.

2.4. Verification of stereotactic radiotherapy (SRS) dose distribution using Gafchromic films

An EBT-XD film and an EBT3 film, both of 60 × 90 mm, were stacked together at 50 mm depth within a Solid Water® block (model RMI457, Gammex, WI, USA) of dimensions 30 × 30 × 30 cm. The films were placed between the slabs of Solid Water, rather than within specifically machined cavities of the film dimensions. (For a purpose-designed phantom, it would be preferable to use such cavities, however in this evaluation of the film performance the uncertainty associated with small air gaps each side of the film was considered insignificant as this did not coincide with any irradiation beam direction). The films were exposed to a typical stereotactic radiosurgery (SRS) radiotherapy treatment plan, with an approximately spherical target of 25 mm diameter, with maximum dose 2500 cGy, which had been inverse-planned on the Eclipse treatment planning system (version 13.5, anisotropic analytical algorithm (AAA) Varian Medical Systems). The films were positioned to intercept the maximum dose region of the treatment plan. The treatment was delivered three times, with new samples of EBT-XD and EBT3 for each exposure. The DICOM RTDose 3D dose cube was exported from the TPS, at 1 mm resolution in each dimension, to enable comparison between the intended dose distribution and the film-measured dose distributions, via the FilmQAPro software. The two dose distributions were aligned using the auto-alignment optimisation tool in FilmQAPro, hence any positional errors in treatment delivery compared to plan were mitigated and not studied in this work. Isodose overlay and gamma evaluation with various criteria (Low *et al* 1998) were used to compare the TPS-planned and film-measured dose distributions in 2D over a central region of the film 60 mm × 70 mm. The choice of gamma criteria was based on commonly used values in literature to enable comparison, typical dose gradients in small field, high dose radiotherapy treatments, and guidance that the distance to agreement (DTA) value should be numerically less than the dose value (Thwaites 2013). As a general rule, the evaluated distribution data spacing should be less than or equal to one-third of the DTA criteria in gamma. Therefore, to use a DTA criteria of 1.0 mm, film scanning resolution of at least 72 dpi

Table 1. Composition and structure of Gafchromic EBT-XD and EBT3 (personal communication with Ashland ISP Advanced Materials, NJ, USA).

Material	Thickness (microns)	Density (gcm^{-3})	Composition (Atomic percentage)								
			H	Li	C	N	O	S	Na	Cl	Al
EBT-XD											
Polyester film base	125	1.35	36.4		45.5		18.2				
Active layer	25	1.35	57.0	0.6	28.5	0.4	11.7	0.1	0.1	0.1	1.4
EBT3											
Polyester film base	125	1.35	36.4		45.5		18.2				
Active layer	25	1.20	56.8	0.6	27.6		13.3				1.6

is required (0.35 mm per pixel), as above. Increasing the film scan resolution further increases noise. The gamma calculation in FilmQAPro software uses the average film dose calculated to the same resolution as the TPS dose grid, hence eliminating film noise effects which may otherwise artificially improve the gamma score. The standard output of the linac (cGy mu^{-1}) was measured at the time of the film irradiation to account for any variation in the daily output of the machine from reference conditions modelled in the TPS.

3. Results

3.1. Structure of EBT-XD and EBT3 films

Table 1 shows the chemical composition and structure of Gafchromic EBT-XD and EBT3 films: composed of a central active layer with identical polyester films on either side. Values are given for the 'newer' EBT3 composition, in which alumina replaced the previous alkali metal halides for improved energy dependence and stability of the film. The effective atomic number of the polyester film base is 6.64, the same material for both films, 7.26 for EBT3 active layer and 7.37 for EBT-XD active layer, compared to 7.3 for water.

In examining the structure of the films, it was noted that in the small film sizes used in this work the EBT-XD samples exhibited a greater tendency for natural curl than with EBT3. This emphasised the importance of using a glass compression plate for accurate and consistent film dosimetry results (Palmer *et al* 2015).

3.2. Calibration of EBT-XD and EBT3 films

Figure 1 shows calibration curves for Gafchromic EBT-XD and EBT3 over a dose range 0–4000 cGy, in terms of scanned pixel value for the red, green and blue channels at 16 bits per channel. EBT-XD is consistently optically lighter (higher pixel value) than EBT3. At 200 cGy the gradient of the red channel curve for EBT-XD is −31.5, units of 'change in 16-bit pixel value per cGy', and is −44.4 for EBT3. At 800 cGy the gradients are −13.5 and −9.1, at 2000 cGy −4.7 and −2.2, and at 3000 cGy −2.6 and −1.1, for EBT-XD and EBT3 respectively. The red-channel gradient is greater for EBT-XD than EBT3 at doses greater than approximately 500 cGy. For the green and blue channel, the calibration curve gradient is greater for EBT-XD than EBT3 at doses greater than approximately 800 cGy. There is also a significant differential in the red and green pixel value for EBT-XD at high doses which is not present for EBT3, in which the curves tend towards saturation at the same pixel value.

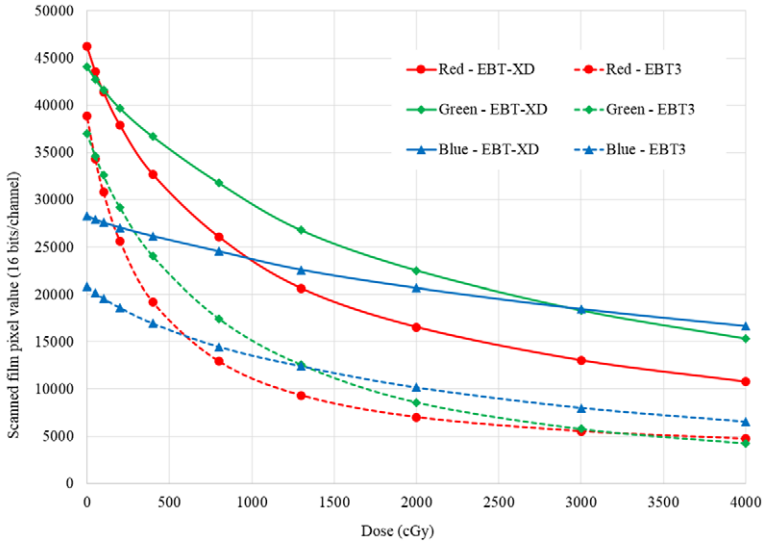

Figure 1. Calibration curves: scanned pixel value (rgb 16 bits per channel) as a function of dose exposure for Gafchromic EB-XD (batch #01081501) and EBT3 films (batch #12171303).

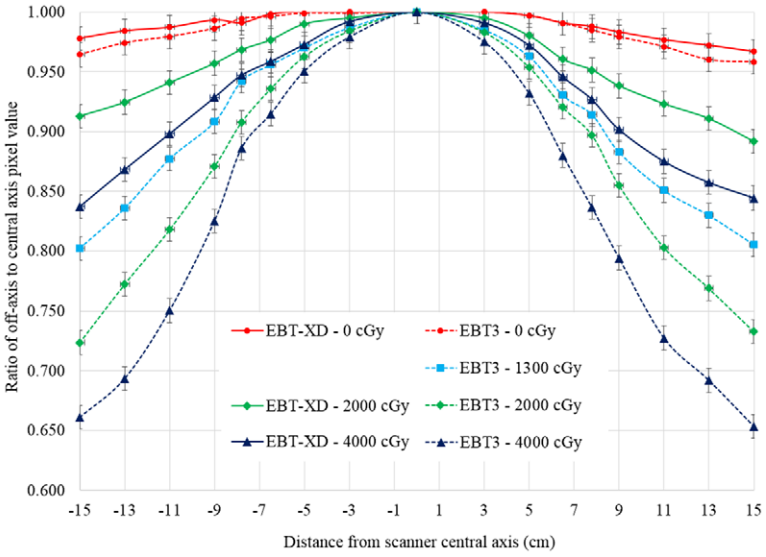

Figure 2. Lateral scanner effect for EBT-XD and EBT3 film for doses in the range 0–4000 cGy, over the full width of an Epson 11000XL scanner.

3.3. Lateral scanner effect for EBT-XD and EBT3 films

Figure 2 shows the relative change in pixel value with lateral distance away from the central axis (normal to the scan direction) of the Epson 11000XL scanner, termed the lateral scanner effect, for EBT-XD and EBT3 film. Data for films exposed to dose levels of 0, 2000 and 4000 cGy are presented for both film types, with an additional film at 1300 cGy for EBT3, chosen

to match the optical density of the 4000 cGy EBT-XD film. At high dose levels, the lateral scanner effect is very significant for film dosimetry, reducing the pixel value (increasing the reported dose) by 35% for EBT3 film in the extreme case of 4000 cGy at 15 cm off axis, the edge of the scanner plate. For SRS-type clinical applications, the high dose region will extend to around 30 mm width, for which the lateral effect is within 0.5% for EBT-XD film and 2.0% for EBT3 film at 4000 cGy. Across all of the data, the lateral effect for EBT-XD is smaller than for EBT3 film for an equivalent dose exposure, due to the EBT-XD films being of lower optical density than EBT3. The lateral effect is also smaller for EBT-XD film at 4000 cGy compared to EBT3 film at 1300 cGy, films which have the same optical density post irradiation.

3.4. Verification of stereotactic radiotherapy (SRS) dose distributions using EBT-XD and EBT3 films

Figure 3 shows isodose comparisons (200–2400 cGy) between TPS-calculated and film-measured dose for a typical SRS-type treatment delivery. Figure 3(a) shows the isodose comparison for three independent repeated exposures of EBT-XD film, analysed using triple-channel dosimetry with linear scaling (via simultaneously scanned reference dose films). The equivalent isodose comparison for one of the EBT3 films is shown in figure 3(b) with triple-channel dosimetry and figure 3(c) with single-channel dosimetry. The self-consistency between separate EBT-XD films, shown in the figure 3(a), was equivalent to that for EBT3 films (not shown). The repeatability between separate exposures may be affected by a combination of any treatment delivery variations and film dosimetry uncertainties; for both films isodoses were consistent within 1.0 mm away from low dose-gradient plateaux (in the region of the 200 and 2400 cGy isodose lines). With triple-channel dosimetry, the TPS-calculated and film-measured isodoses in the range 500–1500 cGy agreed within 2.0 mm for EBT-XD but only within 6.0 mm for EBT3, for all exposures. Relatively good agreement was seen for both film types at 1500–2200 cGy, isodose agreement within 1.5 mm for EBT-XD and 2.0 mm for EBT3, this is consistent with the linear dose scaling film dosimetry technique in which agreement is 'forced' at the reference doses, in this case 0 cGy and 2000 cGy were used as reference film doses.

Table 2 provides gamma passing rates for the comparison of TPS-calculated and film-measured dose distributions, for the cases presented in figure 3, over the full film 70 × 60 mm, using various gamma criteria, for both film types, with triple-channel dosimetry and single-channel dosimetry. Across all gamma criteria EBT-XD using triple-channel film dosimetry shows the highest gamma passing rates. At 3% (normalised to maximum dose) and 1.5 mm gamma criteria, average passing rate was 99.8%, and with 3% (locally normalised with dose cut off at 20%), 1.5 mm gamma criteria, the average passing rate was 97.0%. EBT-XD using single-channel performed well, with an average 3.1 percentage points lower passing rate than EBT-XD with triple-channel dosimetry across the gamma criteria considered. The difference was most significant at the most challenging gamma criteria, showing a 5.7 percentage point reduction in passing rate. EBT3 film with triple-channel dosimetry showed significantly reduced passing rates, 63.7% and 45.0% for the above gamma criteria, respectively. However the passing rates with EBT3 improved significantly when single-channel dosimetry was used, giving an average 4.3 percentage points below EBT-XD with triple-channel dosimetry, again the difference being larger at the most challenging criteria, increasing to 6.5 percentage point difference. Gamma criteria of 2% (locally normalised with dose cut off at 20%), 1.0 mm criteria show significantly reduced passing rates.

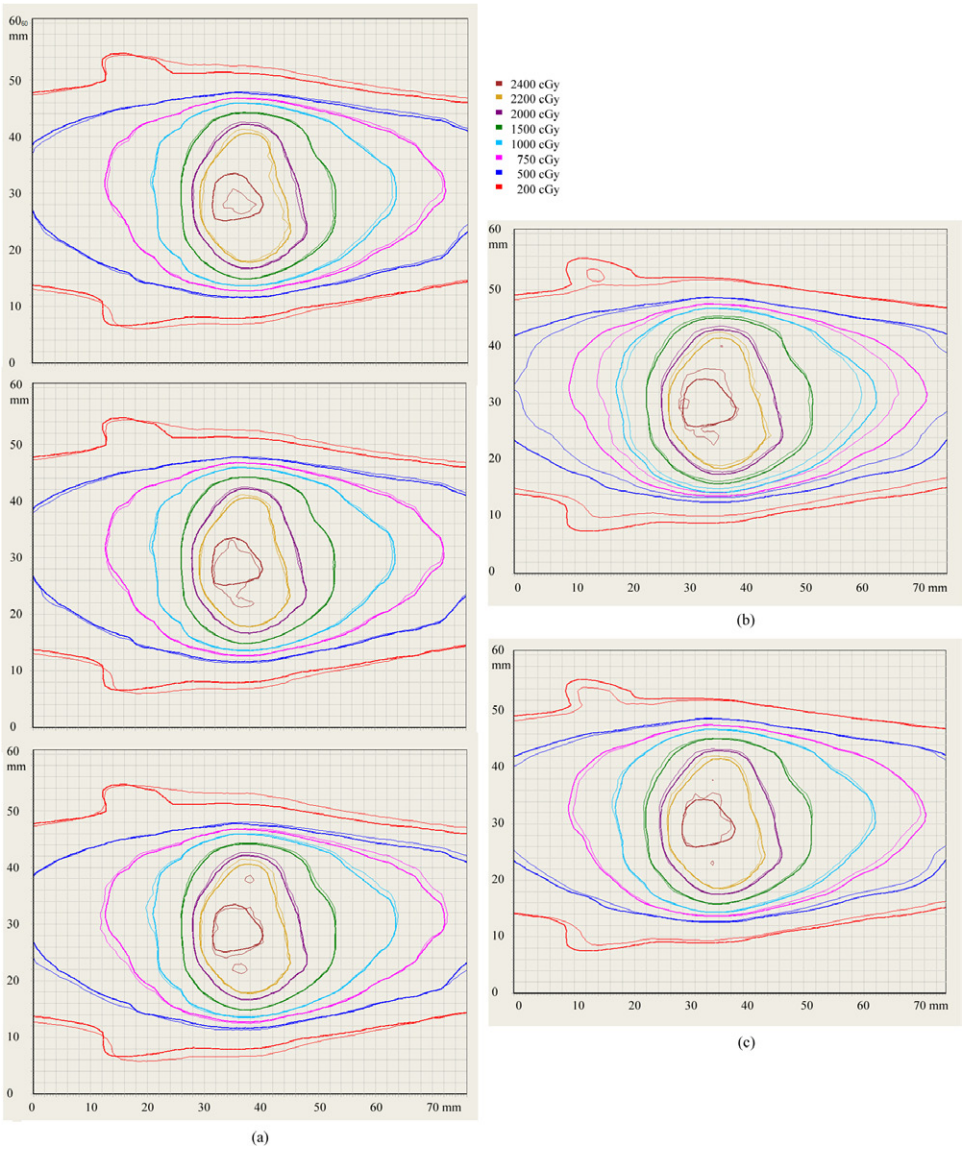

Figure 3. Comparison of treatment planning system isodose distribution (thick lines) and film-measured isodoses (thin lines) for a typical SRS-type radiotherapy treatment, for (a) EBT-XD film with triple-channel dosimetry (three repeated exposures shown), (b) EBT3 film with triple-channel dosimetry, (c) EBT3 film with single (red)-channel dosimetry, all using linear dose scaling with reference dose films, and a compression plate at scanning.

The standard output of the linac was 0.997 cGy mu^{-1}, only -0.3% from reference conditions within the TPS, and hence no correction was made either to the above results, nor the treatment plan or linac prior to delivery.

Table 2. Gamma passing rates, at various criteria, comparing TPS-planned dose and film-measured dose for EBT-XD and EBT3 films, using triple-channel and single (red)-channel dosimetry, with film-dose linear scaling via reference dose films unless otherwise stated, mean data over three separate treatment irradiations with 2500 cGy maximum dose.

	Gamma passing rate (evaluated over film region 60 mm × 70 mm, mean of three separate exposures)						
	Normalised to maximum dose, no dose cut-off			Normalised to local dose, cut-off at 20% of maximum dose			
Film type and dosimetry method	3%, 2.0 mm	3%, 1.5 mm	2%, 1.0 mm	5%, 2.5 mm	3%, 2.0 mm	3%, 1.5 mm	2%, 1.0 mm
EBT-XD, triple-channel	100.0	99.8	95.5	100.0	98.5	97.0	78.0
EBT-XD, red-channel	99.6	98.2	89.7	98.9	94.9	91.3	63.4
EBT3, triple-channel	71.0	63.7	38.9	69.1	55.6	45.0	30.4
EBT3, red-channel	98.0	96.9	89.1	96.5	94.2	90.5	59.9
EBT3, red-channel, with no film-dose scaling	97.6	95.2	84.9	96.6	93.9	88.0	51.6

4. Discussion

The physical structures of Gafchromic EBT-XD and EBT3 are equivalent, both 0.275 mm thickness with identical polyester layers. There are small differences in the atomic composition of the active layers for the two films, with both having effective atomic numbers close to water, considered water-equivalent for MV radiotherapy applications.

The calibration curves for the two films have similar appearance with EBT-XD showing less darkening than EBT3 for the same dose level. At the higher dose levels considered in this work (above 500–800 cGy), the gradients of the rgb calibration curves are greater for EBT-XD than for EBT3, which is important for improved accuracy with both single-channel dosimetry and triple-channel film dosimetry techniques. There is also greater separation of the red and green curves at high dose levels with EBT-XD, which is expected to be important for reduced uncertainties using triple-channel dosimetry algorithms, in which the differential between colours is utilised.

The lateral scanner effect can be a significant source of error in film dosimetry if not appreciated and controlled. The effect increases in magnitude with scanned optical density of the film, and hence for the same dose level, since EBT-XD has a lower optical density than EBT3, the lateral scanner effect is also lower, as verified in this work. Additionally, for the same optical density of film, the lateral scanner effect appeared to be lower for EBT-XD than for EBT3. According to Ashland (2015) the smaller physical particle size in the EBT-XD active layer compared to EBT3 is believed to reduce the effect, consistent with the explanation for lateral scanner effect provided by Schoenfeld *et al* (2014).

There was very good agreement between TPS-planned and film-measured dose distributions for a typical SRS-treatment, measured using EBT-XD with triple-channel dosimetry, dose linear scaling, removal of film curling at scanning, and other accepted good practice techniques for film dosimetry. While we have only investigated film responses for a single representative high dose treatment plan, it is assumed the results would be applicable for other similar cases. Isodoses in the range 200–2400 cGy, for a 2500 cGy maximum point dose treatment, showed agreement within 1.0 mm between TPS and film-measured isodoses. The gamma passing rate, with criteria locally normalised at 3% and 1.5 mm, omitting doses

lower than 20% of maximum, had a mean of 97.0% over three separate exposures. With criteria locally normalised at 2% and 1.0 mm, the gamma passing rates reduced significantly, indicating a limit of either film uncertainty, TPS calculation, or treatment delivery accuracy. The gamma passing rate, with criteria globally normalised 2% and 1.0 mm, no dose cut-off, had a mean of 95.5%. Whilst it is problematic to compare gamma results between studies, due to potential differences in results from the same data which may arise from using different software, specific calculation methods, investigation methodology, sensitivity to signal noise etc, the results presented in this work appear to demonstrate an improvement over several recent publications (Cusumano *et al* 2015, Lee *et al* 2015, Olding *et al* 2015), which may be attributed to the use of EBT-XD film rather than EBT3 at high doses, and the application of advanced film-dosimetry techniques. However, it is not possible to separate any real treatment delivery errors from the uncertainty of the film dosimetry process, when comparing across studies. In the current work, there were differences in the isodose comparison and gamma calculations between EBT-XD and EBT3 film, with the former showing superior results, which would likely be deemed clinically significant in the context of an application for the verification of radiotherapy treatment delivery. It was unexpected that EBT3 film would give significantly inferior results with triple-channel compared to single-channel dosimetry. This may be due to the reduced dose gradients and lack of separation of the red and green channels at high doses for EBT3 film, increasing the uncertainty in the application of the triple-channel algorithm. The good results obtained using single-channel EBT3 dosimetry in this study are likely to be influenced by the application of linear dose calibration scaling in FilmQAPro (Lewis *et al* 2012), usage of glass compression plate at scanning (Palmer *et al* 2015), and careful control of all film procedures (Palmer *et al* 2014) to mitigate and reduce uncertainties. Whilst the single-channel EBT3 and triple-channel EBT-XD give similar results in this work, with triple-channel EBT-XD superior, there are many advantages of utilising triple-channel for highest accuracy in film dosimetry, including the ability to mitigate small variations in the film active layer thickness, resilience to film contamination, mitigation of daily variations in scanner response. Hence EBT-XD with triple-channel dosimetry is advocated.

This system will be used for a multicentre SRS dosimetry intercomparison audit being developed by the University of Surrey in collaboration with the UK National Physical Laboratory. Based on the results of this work, it is proposed that gamma evaluation may be employed with criteria of 3% locally normalised dose difference (with 20% dose cut-off) and either 1.5 or 2.0 mm distance to agreement would be suitable for SRS treatment verification with EBT-XD film and advanced dosimetry analysis.

5. Conclusions

We have demonstrated that the new Gafchromic EBT-XD film is a suitable dosimeter for the verification of small-field, high-dose SRS-type radiotherapy treatments, with isodose comparisons and gamma passing rates exceeding recently published comparative work. In combination with triple-channel dosimetry and other process controls, film dosimetry is advocated as a robust method for treatment delivery verification. Both EBT-XD and EBT3 were found to be suitable dosimeters for the treatment delivery verification application considered, however EBT-XD reported moderately improved gamma passing rates and isodose line agreements over EBT3.

In this work, a mean gamma passing rate of 97.0% and 98.5% were achieved with EBT-XD at criteria of 3% locally normalised dose difference (with 20% dose cut-off) at 1.5 and 2.0 mm distance to agreement, respectively, for a typical high dose SRS treatment. The results indicate

the 'achievable' accuracy in the comparison between planned and delivered dose distributions for small-size, high-dose external bam radiotherapy treatment applications evaluated with advanced film dosimetry techniques.

Acknowledgments

The authors thanks A Micke, of Ashland ISP, for supply of EBT-XD film for clinical evaluation, and for review of the results in this paper.

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