

# Evaluation of GafChromic EBT prototype B for external beam dose verification

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The capability of the new GafChromic EBT prototype B for external beam dose verification is investigated in this paper. First the general characteristics of this film (dose response, postirradiation coloration, influence of calibration field size) were derived using a flat-bed scanner. In the dose range from 0.1 to 8 Gy, the sensitivity of the EBT prototype B film is ten times higher than the response of the GafChromic HS, which so far was the GafChromic film with the highest sensitivity. Compared with the Kodak EDR2 film, the response of the EBT is higher by a factor of 3 in the dose range from 0.1 to 8 Gy. The GafChromic EBT almost does not show a temporal growth of the optical density and there is no influence of the chosen calibration field size on the dose response curve obtained from this data. A MatLab program was written to evaluate the two-dimensional dose distributions from treatment planning systems and GafChromic EBT film measurements. Verification of external beam therapy (SRT, IMRT) using the above-mentioned approach resulted in very small differences between the planned and the applied dose. The GafChromic EBT prototype B together with the flat-bed scanner and MatLab is a successful approach for making the advantages of the GafChromic films applicable for verification of external beam therapy. © 2006 American Association of Physicists in Medicine. [DOI: 10.1118/1.2188077]

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## I. INTRODUCTION

Radiographic films are widely used to detect ionizing radiation. In fact, photographic plates have been used since x rays were discovered.<sup>1</sup> Today, films are routinely used for imaging as well as for dosimetry in radiotherapy and radiation protection applications. The dosimetry with silver-halide films has the advantage that a two-dimensional dose distribution can be obtained from a single exposure. Films offer a high spatial resolution and they can easily be used in solid phantoms. As radiographic films have to be processed before evaluation, the sensitivity of the film is individually dependent on the developing process. Furthermore, as digital imaging is continuously expanding in radiological applications, the availability of developing machines is vanishing. In addition, films have an increased sensitivity to x rays below 200 keV, so that the response varies with the field size and the depth in the phantom.<sup>2,3</sup> The response of the film also depends on the orientation of the film with respect to the incident radiation.<sup>4</sup> Finally, it was shown that the envelope material also has a slight influence on the dosimetric results obtained with films.<sup>5</sup> The recent development of EDR2 films has compensated for some of the restrictions mentioned above,<sup>6,7</sup> but the sensitivity of the type of film is still limited to only a few Gy.

Some of the problems related to radiographic film do not exist if radiochromic films are used. The radiation sensitivity of these films is based on a solid solution of colourless polydiacetylene coated on a flexible polyester film base. When exposed to ionizing radiation the color changes to blue due to polymerization effects,<sup>8,9</sup> so there is no need for develop-

ing the film. The radiochromic films commercially available today are the GafChromic films manufactured by ISP (International Speciality Products, Wayne, NJ). The chemical compositions of the films are nearly tissue equivalent, so the energy dependence of the response can be kept low compared to radiographic films. Therefore these films have extensively been used for brachytherapy with  $\gamma$  and  $\beta$  sources and have recently been used for the analysis of small beamlets for IMRT.<sup>8,10-13</sup> One possible restriction to the use of GafChromic film is the low sensitivity. This makes the film suitable for dosimetric investigations where high doses are applied, as in brachytherapy and radiosurgery, but unsuitable for measurements with normal fractionation scheme as in external beam therapy.<sup>14</sup> Recently a new type of GafChromic film has become available.<sup>15</sup> This GafChromic HS (high sensitivity) film has a dynamic range for doses ranging from 0.5 to 40 Gy. Therefore, it is suitable for verification of stereotactic radiosurgery with prescribed doses of 20 Gy, but still not suitable for normal fractionated external beam therapy. To overcome this deficiency, the prototype of a new GafChromic film was introduced. The sensitivity of this EBT (external beam therapy) GafChromic film has increased considerably.

In this paper the new EBT film prototype B is compared to the common GafChromic HS film and the radiographic film Kodak EDR2 in terms of the dose linearity in a 6 MV x-ray field. As the intensity of the blue color of the common GafChromic films (e.g., HS) changes with the time (postirradiation coloration), these films need to be stabilized using a rapid color stabilization technique (RCS).<sup>16</sup> The effect of

postirradiation coloration was also investigated for the GafChromic EBT prototype B. The absorption spectra for the GafChromic films contain two peaks. The peaks of the spectrum of the HS have wavelengths between 610 and 676 nm. The spectrum of the EBT is shifted towards shorter wavelengths with peaks at 575 and 640 nm. For the old types of GafChromic films like the HS film, it is generally recommended to use a densitometer for analysis with a light source operating in the range of the absorption peaks (e.g., HeNe laser scanners), but the use of color document scanners with a broad light spectrum was also considered.<sup>9,17,13</sup> Due to the shifted spectrum, readers with a narrow-band-pass wavelength located at or near the old absorption peak of 676 nm are of no use for the EBT films.<sup>18</sup> The use of a commercial document scanner with a broadband light source was investigated. To demonstrate the applicability of this new GafChromic EBT prototype B film for verification measurements for typical dose schemes used in IMRT and stereotactic radiotherapy (SRT; 1.8 Gy per fraction), the measurements of a SRT and an IMRT fraction compared to the treatment plan data are illustrated.

## II. MATERIALS AND METHODS

### A. Kodak EDR2

EDR2 film has become a popular choice for performing IMRT verifications.<sup>19</sup> The film consists of two active layers, each approximately 30  $\mu\text{m}$  thick adhered on a 180  $\mu\text{m}$  cellulose base. The active layer consists of high-Z silver halides embedded in glucose. The active layers are covered by an approximately 8  $\mu\text{m}$  thick cellulose layer to protect them against environmental impact.

### B. GafChromic HS

The HS film consists of three layers. Here an active layer of 40  $\mu\text{m}$  containing only low Z elements (C, H, N, and O) is sandwiched between two sheets of clear, transparent polyester of 97  $\mu\text{m}$  thickness. So the total thickness is 0.234 mm. The effective Z of the film is 6.5. The HS film is suitable for doses from 0.5 Gy up to 40 Gy. For the experiments described here the films were taken from Lot No. K0223HS.

### C. GafChromic EBT prototype B

According to the specification of the manufacturer ISP the GafChromic EBT Film prototype B consists of two active layers; each is 17  $\mu\text{m}$  thick and coated with a layer of transparent polyester of 67  $\mu\text{m}$ . These two layers are laminated together with an adhesive tape, consisting of two adhesive layers of 15  $\mu\text{m}$  sandwiching a 25  $\mu\text{m}$  thick transparent polyester base. So, the total thickness of the EBT prototype B film summarizes to 0.229 mm. According to the manufacturer, the overall atomic composition of the prototype B is C (41.7%), H (41.2%), O (15.6%), N (0.9%), Li (0.2%), and Cl (0.3%). The prototype B has an effective Z of 6.90. This slightly varies from the overall atomic composition of the commercially available GafChromic EBT film, which is C (42.3%), H (39.7%), O (16.2%), N (1.1%), Li (0.3%), and Cl

(0.3%). The commercially available EBT film (former prototype A) has an effective Z of 6.98 and only one sensitive layer in the middle of the film.

Though both film types (HS and EBT prototype B) are comparable with respect to the total thickness, the thickness of the active layer of the EBT prototype B is 34  $\mu\text{m}$ , whereas the HS has an active layer thickness of 40  $\mu\text{m}$ , so the increased sensitivity of the EBT compared to the HS does not result from the thickness of the sensitive layer. It results from the changed chemical composition of the active layer. The presence of a minor amount of the moderate Z element chlorine in the atomic composition of EBT prototype B film suggests that photoelectric absorption of keV photons in this film will be boosted. For the experiments described here the films were taken from Lot No. 34196-07. The EBT is suitable for doses ranging from 0.1 to 8 Gy.

### D. Color document scanner

For two-dimensional scanning, a commercially available document scanner Model ScanMaker 8700 (Microtek, Hsinchu, Taiwan) was used. The scanner operates a cold cathode lamp and a tri-linear CCD with 10 600 pixels. The sample depth is 42 bits, i.e., 14 bit per color; the optical resolution is 1200  $\times$  2400 dpi. The connection to a PC is performed either with a USB (universal bus) or IEEE 1394 (FireWire) interface. The films were scanned on the glass tray provided for film transparencies. The applied resolution was 72 dpi. All films were scanned as grayscale TIFF images. The EBT prototype B and HS films were additionally digitized as RGB TIFF images.

### E. Phantom

For all experiments we used the Easy Cube (Euromechanics, Schwarzenbruck, Germany) solidwater phantom. The Easy Cube is a multi-purpose phantom suitable for stereotactic and IMRT validation, consisting of 16  $\times$  16  $\times$  1  $\text{cm}^3$  slabs made of a water-equivalent material (RW3). These slabs are housed in RW3 walls of 1 cm thickness. The Easy Cube is designed for measurements with various dosimeters, e.g., radiographic and radiochromic films, ionization chambers, and TLD.

### F. Ionization chamber

Two different types of ionization chambers were used. For absolute dose measurement and to specify the dose applied to the film irradiated using a 10  $\times$  10  $\text{cm}^2$  field size, two ionization chambers were used. Both chambers were flexible chambers of the type 23323-flex provided by PTW (PTW, Freiburg, Germany). The active volume of this chamber is 0.1  $\text{cm}^3$  with an acrylic wall material. For field sizes of 2  $\times$  2  $\text{cm}^2$  and the plan verification, all measurements have been done using a small thimble type chamber (CC03, Wellhofer Dosimetry, Schwarzenbruck, Germany) with air-equivalent wall material. This chamber is small enough (0.028  $\text{cm}^3$  active volume) to avoid volume effects and to resolve steep dose gradients.

## G. Irradiation

### 1. Characteristics of the EBT prototype B film: Dose response and postirradiation coloration

For the determination of the general characteristics of the new EBT prototype B film, all measurements were performed on Siemens linear accelerators using 4 (Meatron), 6 and 15 MV (Primus) photon spectra. The Easy Cube was positioned with its top surface at the isocenter of the linear accelerator using a SSD of 100 cm; the films were positioned perpendicular to the top surface at a depth of 5 cm. The film measurements were acquired during three sessions. Within the first session both film types were irradiated in several steps up to a dose of 8 Gy using a field size of  $10 \times 10 \text{ cm}^2$ . For the second session, measurements were performed using field sizes of  $2 \times 2 \text{ cm}^2$ , applying different doses up to approximately 3.5 Gy. During the third session one film was irradiated using a special sequence. This sequence consists of a pattern of 9 separate  $2 \times 2 \text{ cm}^2$  fields, each field irradiated with a different amount of monitor units. These segments are arranged in a  $3 \times 3$  pattern with 1 cm space between them. This method enables us to create a calibration curve with a single film. Within all three sessions, the films were marked related to their coating direction using a fine tipped marker. They were positioned inside the phantom on the central beam at a depth of 5 cm using these marks. The dose at this position was measured using two ionization chambers. One was positioned at exactly the same position as the film and a second chamber was positioned 3 cm below the other. Underneath the Easy Cubes was a slab of 10 cm RW3, to provide enough backscatter. During film measurements, the first chamber was replaced by the film and the other chamber stayed within the phantom. In this way, we were able to calculate the dose applied to the film by measuring the dose 3 cm below with the ionization chamber.

### 2. External beam dose verification

As examples for the external beam dose verification a fraction of a stereotactic radiotherapy (SRT) and an IMRT fraction are chosen. For the SRT, the treatment plan was created using the 3D Line Ergo++ treatment planning software (3D Line, Milano, Italy). The treatment plan consists of ten fields with two different table angles. The total dose for this fraction was 1.8 Gy and was applied using 6 MV. To verify this, the treatment plan was transferred to the Easy Cube using the same angles and MU. The Easy Cube was loaded with 4 GafChromic EBT prototype B films. The size of each film was  $10 \times 10 \text{ cm}^2$ . The films were positioned parallel to the top of the EasyCube with one film at the isocenter. The radiation was delivered using the 3D Line micro-mlc DMLC attached to the linear accelerator. The IMRT treatment planning was done using XiO (CMS, St. Louis, USA). It consists of seven fields with a total of 76 segments. The total dose for this fraction was 1.8 Gy and was applied using 6 MV. The complete fraction was measured, using the Easy Cube filled with 4 GafChromic EBT

prototype B films (size:  $10 \times 10 \text{ cm}^2$ ). The films were positioned perpendicular to the rotation axis of the gantry with one film at the isocenter.

## H. Postprocessing and readout

The radiochromic films were carefully handled using cotton gloves to avoid soiling. During the storage, irradiation, and readout, the films were kept at a temperature of  $22 \pm 2 \text{ }^\circ\text{C}$  and  $50 \pm 10\%$  humidity controlled by the cooling system of our laboratory. This was done to reduce the effects of temperature-dependent evolution and readout. Additionally the films were kept together to avoid differences in thermal histories. To reduce the effect of ambient light, they were kept in light-tight envelopes and were only removed from them for irradiation and readout.<sup>20</sup> For the HS films, the use of the RCS technique was investigated:<sup>16</sup> After irradiation, the films were cut into halves. Within 30 min after irradiation one half was brought into an oven and stayed there for 2 h at  $45 \text{ }^\circ\text{C}$ . The other half was kept directly in a light-tight envelope. Afterwards the warmed up films were kept in a light-tight envelope, like the EBT films and the other halves of the HS films.

All films (HS, EDR2, and EBT) were scanned using the flat-bed scanner. The obtained digital data [14 bit grayscale tagged image file format (TIFF) and 42 bit RGB (14 bit per color) TIFF for the EBT, resolution 72 dpi] were evaluated using self-written routines in MatLab (Math Works Inc., Natwick, MA). To avoid polarization effects during the readout process,<sup>21</sup> the films were positioned on the glass tray of the document scanner in exactly the same way, using the marks made before the irradiation.

## III. RESULTS

### A. Dose response curves

In Fig. 1, the dose response curve between 0.1 and 8 Gy for the new GafChromic film EBT prototype B is shown in comparison with the response of the GafChromic HS, which used to be the GafChromic film with the highest sensitivity and the response of the widely used Kodak EDR2 film for IMRT verification. Before scanning, the HS films were stabilized using the RCS method. To ensure that there is no effect resulting from different scan times, a time gap of exactly 3 h between irradiation and read-out was applied for all film types.

Both GafChromic film types were scanned as 42 bit RGB TIFF images using the Microtek Scan Maker 8700, while the digital data obtained for the EDR2 was 14 bit grayscale TIFF. To show the influence of the chosen datatype, the GafChromic EBT prototype B was also scanned as a 14 bit grayscale image. If the grayscale image is used, the determined response of the EBT prototype B film is comparable to the response of the HS derived from the red channel of the RGB TIFF. The red channel of the HS was applied to improve the response of the film, due to the position of the absorbance maximum. When evaluating the data obtained by the red channel of the 42 bit RGB TIFF of the EBT proto-

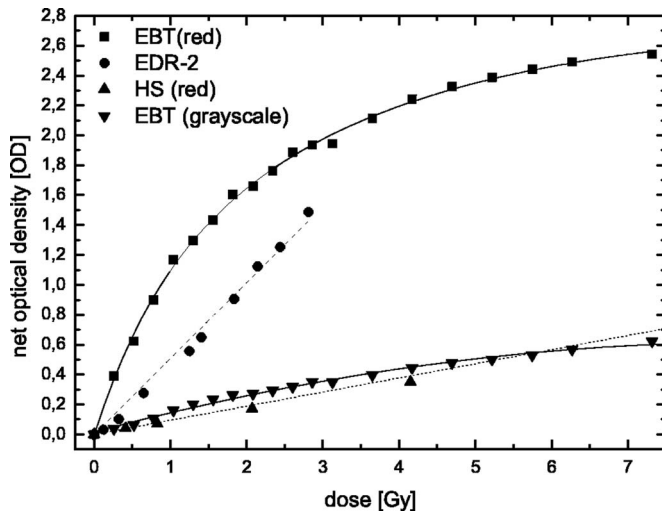


FIG. 1. Response of the GafChromic EBT compared with the GafChromic HS and the Kodak EDR2. If the red channel of the EBT RGB TIFF image is used, the response of the EBT is ten times higher than the response of the HS. Compared to the response of the Kodak EDR2 the response of the EBT is three times higher.

type B, the response is almost ten times higher than the response of the GafChromic HS. Compared to the response of the Kodak EDR2, again the response of the EBT prototype B is superior. The response of the EBT prototype B is three times higher than the response of the Kodak EDR2.

## B. Postirradiation coloration

The optical density of all GafChromic film types prior to the EBT was unstable with time. They had a temporal growth of the readout. To investigate this, each film was scanned multiple times, at different times after irradiation. The dose ranged from 1 Gy up to 31 Gy. Figure 2 shows the calibration curves derived from the different scan moments. The optical density increases with the time between irradiation

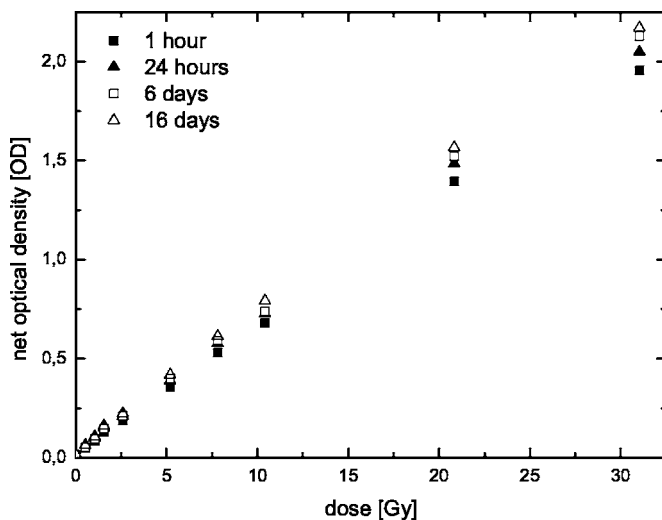


FIG. 2. Dose response curves for the GafChromic HS at different times after irradiation. A postirradiation coloration of the GafChromic HS can be observed.

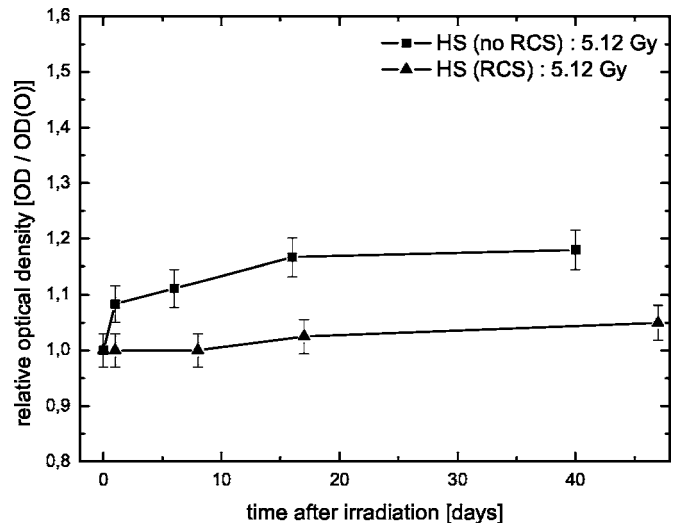


FIG. 3. Postirradiation coloration of the scan values for the GafChromic HS. The HS shows a time-based growth of the scanvalue. This behavior is typical for all previous GafChromic film types. During the first 24 h the OD increases by 8%, and within 15 days it increases by another 3%. When the RCS technique is applied, the OD stays almost the same (0.5% difference within 48 days).

and readout. To make this clear, Fig. 3 shows this postirradiation coloration effect for the HS film irradiated with 5.12 Gy. During the first 24 h the optical density increases by 8%. Within the next 15 days the optical density increases again by another 3%. Due to this postirradiation coloration, it is impossible to evaluate the films directly after irradiation. So it is recommended to wait for 24 h until the films are nearly stable. Also, this impedes the reproducibility of measurements. Based on different scan moments, the obtained optical density values will vary. Therefore Reinstein *et al.*<sup>16</sup> introduced the RCS for the GafChromic MD-55. It was investigated to determine if the RCS method is also suitable for GafChromic HS. After the RCS method was applied, during the first 24 h, there was no change in the optical density observed. After 48 days, the optical density only changed slightly from 1.0 to 1.05 (5%). So, it is possible to stabilize the GafChromic HS by using the RCS technique first invented for the MD-55.

The commercially available EBT film produces a postirradiation coloration effect of approximately 9%–11% within the first 6 h.<sup>22</sup> To investigate if this also occurs for the GafChromic EBT prototype B, several films were irradiated with different doses (0.2 Gy up to 3.2 Gy). Figure 4 indicates that the postirradiation coloration effect that influences the readout of the older GafChromic film, does not occur for the new EBT prototype B. The same film was evaluated at different times during an interval starting 15 min after irradiation and terminating 3 days after irradiation. To illustrate this, Fig. 5 depicts the results for one film. A dose of 1.67 Gy was applied to this film, which is within the typical dose range used for external beam therapy. The solid line indicates the mean value for the relative scanvalues. Within the first 3 h, the decrease in scan values is 5%, and then it nearly stays the same. A decrease in scan values

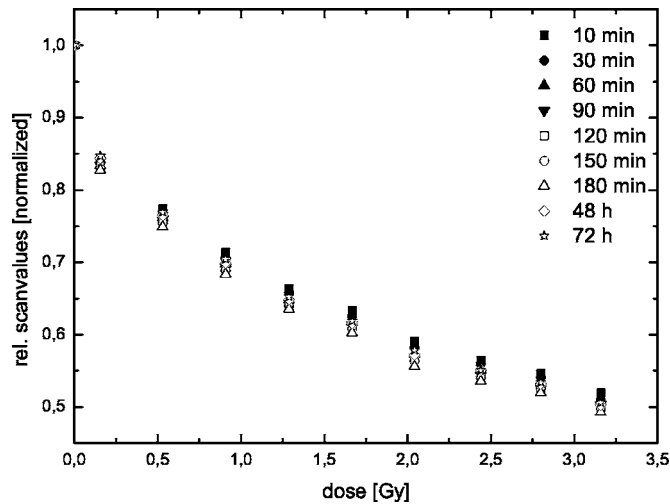


FIG. 4. Dose response curves for the GafChromic EBT prototype B at different times after irradiation. A weak postirradiation coloration can be observed.

means that there is a postirradiation coloration effect for the EBT prototype B. However, compared to the HS and the commercially available EBT film, the increase is much smaller and occurs within the first 3 h after irradiation. Therefore no RCS method has not to be applied to stabilize the films, and the films can be evaluated 3 h after irradiation.

### C. Energy dependence for megavoltage radiation energies

The energy dependence of the dose response of the commercially available EBT film in the 21 kV to 10 MV range was investigated by Butson *et al.*<sup>23</sup> and Chiu-Tsao *et al.*<sup>24</sup> and was found to be within 10%. To prove that this also is true for the EBT prototype B, two different approaches were made. The energy dependence for megavoltage radiation en-

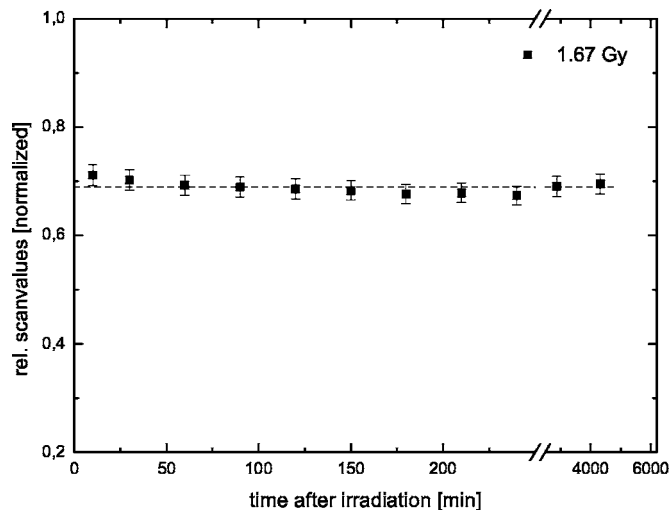


FIG. 5. Postirradiation coloration of the scan values for the EBT film derived from the red channel of the RGB TIFF file in dependence of the time between irradiation and read out. Within the first 3 h, the scan values decrease by 5%.

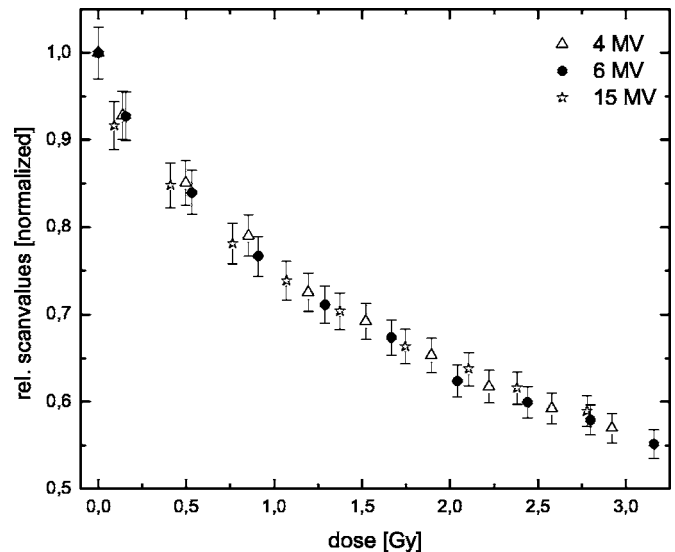


FIG. 6. Energy dependence of the dose response curve for megavoltage irradiation energies. Dose response curves for the EBT prototype B were determined for 4, 6, and 15 MV photon spectra. There was no influence of the energy on the response.

ergies was determined by using three different photon energies. Films were irradiated using 4, 6, and 15 MV photospectra and the special  $3 \times 3$  pattern. Figure 6 shows the response curves derived from this measurements. There was no influence of the megavoltage radiation energy on the dose response curve found. The second approach was to investigate if the calibration field size has an influence on the dose response.

### D. Influence of the calibration field size

Radiographic films, like the Kodak EDR2, usually consist of high Z silver halides. Therefore the response of these film is energy dependent.<sup>6</sup> The size and geometry of the radiation field used for calibration can have an influence on the dose response curve obtained.<sup>2</sup> Different field sizes result in different dose response curves, and IMRT consists of multiple small beamlets. To fit the requirements for IMRT, we use a special pattern of nine small fields ( $2 \text{ cm} \times 2 \text{ cm}$ ) arranged in a  $3 \times 3$  matrix around the central beam for film calibration, for IMRT verification with Kodak EDR2.

To investigate if there is also an influence of the chosen field size on the calibration curve for the GafChromic EBT prototype B, we irradiated EBT films with different field sizes of  $10 \times 10 \text{ cm}^2$  and  $2 \times 2 \text{ cm}^2$ . The corresponding dose response curves are illustrated in Fig. 7. If the response of the EBT prototype B film was energy dependent, different field sizes would result in different dose response curves. This fact, together with the information that the effective Z for the GafChromic EBT prototype B is 6.9 and the energy independence for megavoltage radiation energies, leads to the conclusion that the films are energy independent within the inspected energy range. It is possible to calibrate the EBT

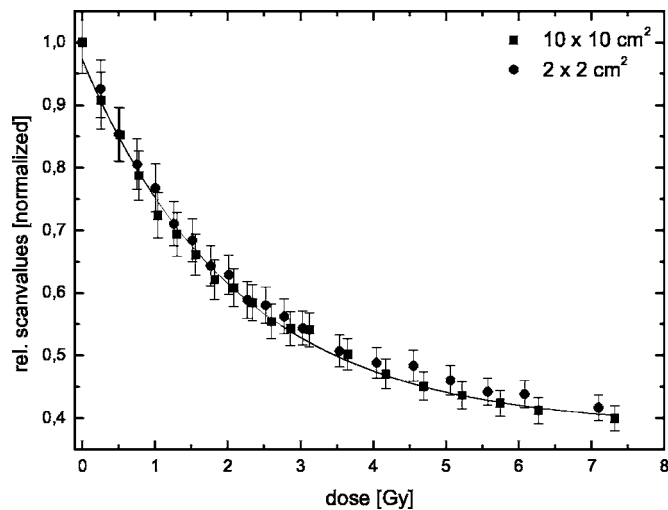


FIG. 7. Influence of the chosen calibration field size. The EBT film was calibrated using two different field sizes ( $2 \times 2 \text{ cm}^2$  and  $10 \times 10 \text{ cm}^2$ ). The EBT film does not show an influence of the calibration field size on the dose response curve (scan values). It is possible to use different field sizes for calibration and measurement.

prototype B film using  $10 \times 10 \text{ cm}^2$ , field sizes and then evaluate dose distributions resulting from very small fields like IMRT or stereotactic radiotherapy.

### E. Homogeneity of the filmsheets

Homogeneity of the film sheets is an important point when dealing with film dosimetry. To check the homogeneity of the GafChromic EBT prototype B filmsheets, unirradiated films were scanned. To identify effects resulting from scanner noise, the same films were scanned multiple times with four different orientations ( $0^\circ$ ,  $19^\circ$ ,  $180^\circ$ , and  $270^\circ$ ) on the glass tray. If there is an evidence for effects resulting from the scanner, averaging of multiple scans of the film with the same orientation can be done, to remove the scanner noise.<sup>25</sup> To evaluate the influence of the scanner noise the whole film was chosen as the region of interest (ROI). The difference between the maximum and minimum of all readouts was 2%, and the relative standard deviation was 0.9%. The sensitive layer of the GafChromic EBT prototype B film is homogeneous within 2%, and therefore the film fulfills all criteria for film dosimetry.

### F. External beam dose verification

After investigating if the GafChromic EBT prototype B film theoretically is a reasonable detector for dose verification of external beam therapy, a SRT fraction and an IMRT fraction, both with 1.8 Gy at the isocenter, were measured with the EBT prototype B film. To compare the planned dose with the actually applied dose, the dose matrix of the treatment planning system was exported using an ASCII-format. This data was imported to the self-written MatLab routine. In order to match with the measured data, the plan data were interpolated to the resolution of the measured data (72 dpi). The measured data is semiautomatically matched to the

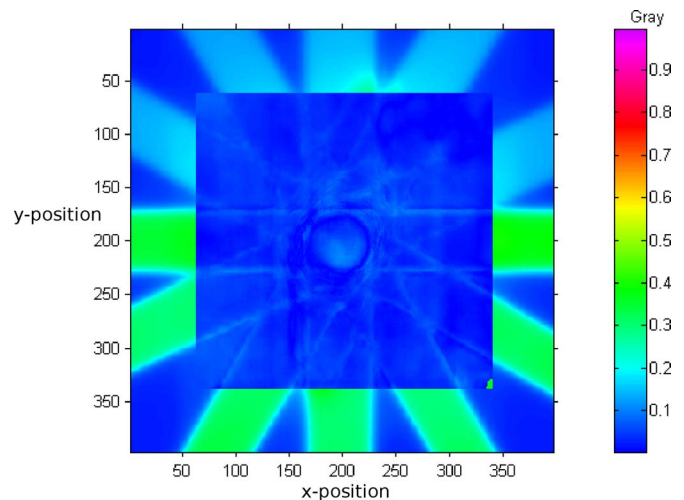


FIG. 8. External beam therapy verification for a SRT fraction. Comparison of the measured dose distribution and the dose distribution (smaller region in the middle) provided by the treatment planning system Ergo++. The color bar ranges from 0 to 1.0 Gy. There are some differences at the edges of the beams.

planned data until the deviations between both are minimized. This is done in three steps. First the middle of the quadratic film is assumed to be positioned in the isocenter during the irradiation. This isocenter is positioned on the real isocenter of the plan data. In the second step, the deviations between measured data and the data provided by the treatment planning system are minimized. This is done by moving the film pixelwise over the planned data and calculating the deviation between both by subtracting the film data from the planned data. Only translations were taken into account. After finding a minimum for the deviation, the results were examined. If necessary, the film data will be rotated by hand. In this way, all deviations resulting from possible positioning errors of the phantom can be eliminated.

#### 1. Stereotactic radiotherapy (SRT)

Figure 8 depicts the output of the self-written MatLab program. Illustrated is the difference between the planned and the measured data (smaller region in the middle). The color bar on the right ranges from 0 to 1.0 Gy. An absolute evaluation of the obtained data is possible. The maximum deviation of 0.1 Gy (approximately 5% of the prescribed dose) is found at the edges of the beams, and possibly results from the tolerance of the leaf positions, the table rotation, and the gantry positioning. Due to the steep dose gradients at the field edges, minimal deviations in positioning result in large errors. Considering this, the plan and measurements are in good agreement.

#### 2. Intensity-modulated radiotherapy (IMRT)

The difference between the planned and measured data for the IMRT case is shown in Fig. 9. For the SRT and IMRT verification, the deviations are in the same dimensions. The maximum deviation is 0.1 Gy and can be found in regions with a steep dose gradient. Again, minimal deviations in po-

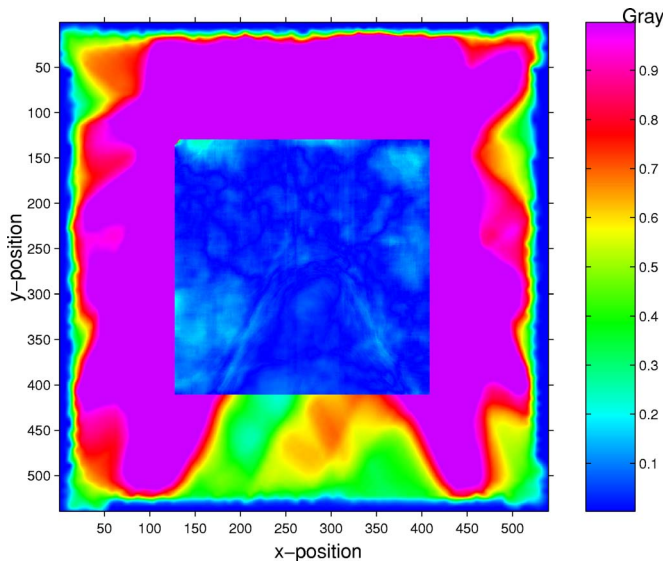


FIG. 9. External beam therapy verification for an IMRT fraction. Comparison of the measured dose distribution and the dose distribution (smaller region in the middle) provided by the treatment planning system XiO. The color bar ranges from 0 to 1.0 Gy. There are some small deviations.

sitioning result in large errors. Also, the accuracy of the MLC must be taken into account. The treatment plan consists of seven fields with a total of 76 subfields. Small deviations in leaf positions can also result in dose differences, especially in areas with steep dose gradients. Considering this, the plan and measurements are in good agreement.

#### IV. CONCLUSIONS

In this paper the application of the GafChromic EBT prototype B for external beam therapy such as SRT and IMRT was demonstrated. The general characteristics such as dose response, postirradiation colouration, energy dependence, and the influence of calibration field sizes were determined. It was shown that the EBT prototype B film has to be scanned as a RGB TIFF image, and the red channel of this file has to be evaluated for maximum sensitivity. Using the red channel, for doses ranging from 0.1 to 8 Gy, the GafChromic EBT prototype B has a response that is ten times higher than the response of the GafChromic HS and three times higher than the response of the Kodak EDR2, which so far is the standard film for IMRT verifications. The EBT prototype B film is energy independent; there is no influence of the calibration field size on the dose response curve. Previous GafChromic films (e.g., the HS) showed a time-dependent growth of the scanvalues (8% within the first 24 h for the HS). They needed to be stabilized using the rapid color stabilization technique (RCS). The EBT prototype B does not show this effect. The readout is almost constant and does not increase much with time. The films can be analyzed within 3 h after irradiation.

The GafChromic EBT prototype B is a successful approach for making the advantages of the GafChromic film applicable for the verification of external beam radiotherapy. As the films are self-developing and need not be developed

using chemicals and a developing machine, the calibration has to be done only once per film batch. Together with the fact that the phantom need not be loaded in the darkroom, the very time consuming process of IMRT verification can be speeded up by a factor of 2. At our department, the GafChromic EBT replaced the EDR2 film for all kinds of external beam therapy verification measurements. For all measurements the observed deviations were within 5%.

Based on this work, the European Society for Therapeutic Radiology and Oncology (ES-TRO) has recently adapted the use of EBT prototype B films and the scanning and analyzing procedures presented in this paper for the IMRT quality assurance program of the EQUAL-ESTRO laboratory.

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