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Independence of calibration curves for EBT Gafchromic films of the size of high-energy X-ray fields

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Abstract

The EBT Gafchromic radiochromic film is a relatively new product designed specifically for dosimetry in radiation therapy. Due to the weak dependence of its response on the photon energy (variations are below 10% in the 50 kVp–10 MVp range), the film is ideal for dosimetry when the photon energy spectrum may be changing or unknown. In order to convert a map of optical densities into a map of absorbed radiation doses, a calibration curve constructed on the basis of standard calibration films is necessary. Our results have shown that, with the EBT Gafchromic film, one can use the same calibration curve for 6-MV X-ray fields of any size in the range from $5 \times 5\,cm^2$ up to $40 \times 40\,cm^2$. This is not the case for radiographic films, such as Kodak X-Omat V, whose response to the same dose varies approximately by 10% depending on the field size in this range. This insensitivity of the EBT Gafchromic film to size of the radiation field makes it possible to assess doses delivered by small radiation fields. With the help of this film, it was shown that the output factor for a $0.5 \times 0.5\,cm^2$ field is 0.60 ± 0.03 (2SD) relative to the $10 \times 10\,cm^2$ field.

Keywords: Radiochromic film; Gafchromic; EBT; Calibration; Energy dependence; Field size; Scatter; Radiotherapy

1. Introduction

Over the years, two-dimensional dosimetry in radiotherapy has been performed primarily with films (Palm and LoSasso, 2005; Butson et al., 2004, 2005b; Suchowerska et al., 1997; Tangboonduangjit et al., 2004). This type of dosimetry requires construction of calibration curves, which are then used to convert measured optical densities into radiation doses. In the past, this was performed with silverhalide radiographic films, which exhibit a strong photon energy dependence of their response to doses (Kron et al., 1998) and are, therefore, not ideal. As treatment parameters, such as field size, change, so does the X-ray spectrum at the target, because of the changed scattering conditions. As a result, film calibration was a formidable task requiring construction of multiple calibration curves for radiation fields of different sizes. Radiochromic films in general exhibit weaker energy dependences than radiographic films because they do not contain silver (Butson et al., 2005a; Cheung et al., 2004). Response to a dose of a relatively new dosimetric film, Gafchromic EBT, varies by less than 10% in the wide range between 50 kVp and 10 MVp (Butson et al., 2006), which should significantly simplify the calibration procedure. It should also make it possible to measure small field output factors accurately (Westermark et al., 2000; Martens et al., 2000; Laub and Wong, 2003), thus providing a "point" dosimeter. In this work, we have investigated dependence of the response of this film to the same doses delivered by fields of different sizes.

2. Materials and methods

Studies of the effect of the X-ray field size on dose calibration curves were performed with the EBT Gafchromic radiochromic film in comparison with the Kodak X-Omat V radiographic film. EBT films are multilayered:

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the active polymer is protected by polyester coatings, which allows the film to be handled easily and minimizes ultraviolet exposure of the active polymer (Butson et al., 1998, 2003). The effective atomic number of the EBT film (Z_{eff}) is 6.98, which is not very far away from Z_{eff} for water (7.3) (ISP web site, 2005). Because of this similarity and the relatively weak energy dependence of the film response to dose, one can expect that the effect of the field size on calibration curves (optical density vs. dose) will be small or even negligible, provided that the energy of the X-rays in the beam does not change and is relatively high. The films were irradiated in a solid water (Constantinou et al., 1982) phantom ($30 \times 30 \times 30\,\text{cm}^3$), which rested on the linear accelerator couch (SSD = 100 cm). The films were given the same number of monitor units (approximately 3 Gy). The delivered dose depended on the used field size, which ranged from $5 \times 5\,\text{cm}^2$ to $40 \times 40\,\text{cm}^2$. The analysis of the EBT radiochromic films was delayed until at least 6 h after the irradiation in order to minimize effects of post-irradiation coloration (Cheung et al., 2005). The Gafchromic films were analyzed with a flatbed computer scanner (Hewlett Packard ScanJet) and the Image J software. The scanning resolution was 75 pixels per inch, and the images were stored in the 16-bit RGB format. The colors were not separated, and the full RGB values were used in the analysis.

Experiments with the Kodak X-omat V film were similar. The films were irradiated to smaller doses (approximately up to 66 cGy) according to the range of their sensitivity. The films were analyzed on a VidarVX-12 fluorescent light scanner.

For both the types of the films, net OD values were plotted vs. radiation doses.

Experiments were also performed to evaluate relative output values of the EBT Gafchromic film for small fields (down to $0.5 \times 0.5\,\text{cm}^2$). The results were compared with measurements performed with small-volume and standard-volume ionization chambers.

3. Results and discussion

Fig. 1a shows calibration curves for EBT Gafchromic film exposed to 6-MV X-ray radiation fields of various sizes, ranging from $5 \times 5\,\text{cm}^2$ to $40 \times 40\,\text{cm}^2$. For any given dose, variation of the optical density over this range of field sizes is very small and insignificant as compared with the uncertainties of film analysis (~3%). Irradiations to the same number of monitor units, but with increasing field size, result in increasing doses because of the increasing scatter. These results are very interesting because they show that a single calibration curve can be used for processing of all radiochromic films of this type regardless of the sizes and configurations of the radiation fields used for their irradiation. This can be particularly useful for analysis of small fields, individual calibration curves for which are hard to produce. A standard calibration curve constructed with a $10 \times 10\,\text{cm}^2$ field can be used for analysis of doses delivered with small fields, like those used in intensity-modulated radiation therapy (IMRT). For comparison, Fig. 1b shows a similar set of calibration curves for the Kodak X-Omat V radiographic film, although for lower doses appropriate for the sensitivity range of that film. One can see a measurable difference between the calibration curves for fields of different sizes: larger fields produce higher net optical densities for the same dose. This is not surprising because increasing radiation field changes the X-ray spectrum: the lower-energy X-rays become more intense due to the increased scatter. As the energy dependence of the response of the radiographic film to a dose is significantly stronger in the lower-energy range, one should expect a higher optical density per unit dose for larger fields. This dependence requires that the radiation fields used in construction of the calibration curve and in experiments using the curve would be of the same size. It also means that radiographic film is not ideal for relative dosimetry in situations where the radiation spectrum may vary, e.g. at beam edges. EBT Gafchromic film has minimal field-size effects and is, therefore, superior for film calibrations.

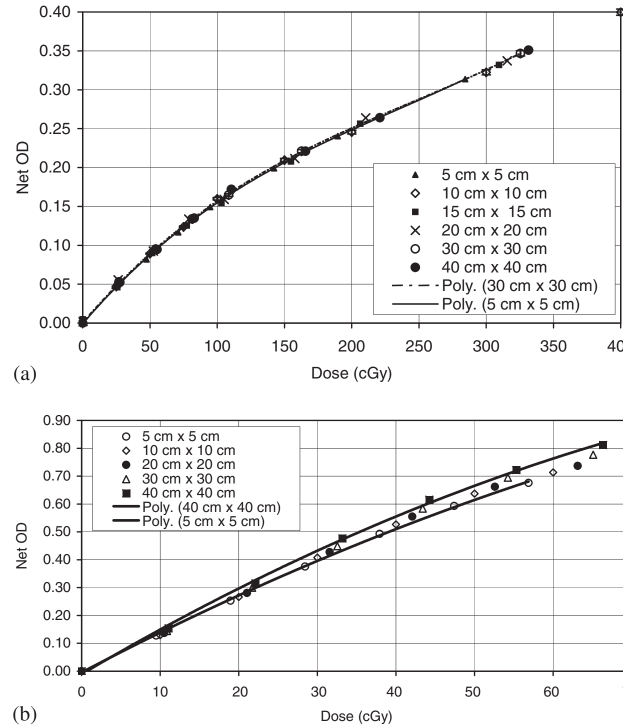

Fig. 1. Standard calibration curves for assessing doses in radiation fields of various sizes: (a) EBT Gafchromic radiochromic film; (b) Kodak X-omat V radiographic film. Second order polynomials are used to fit data.

Fig. 2 shows the dependence of the dose output on the size of a 6-MV X-ray field measured by different techniques. The EBT Gafchromic film results are shown for fields down to $0.5 \times 0.5\,\text{cm}^2$, where the relative field output factor was found to be 0.60 ± 0.03 (2SD). EBT seems to be a nearly ideal detector for small field measurements as its spatial resolution is very high and it

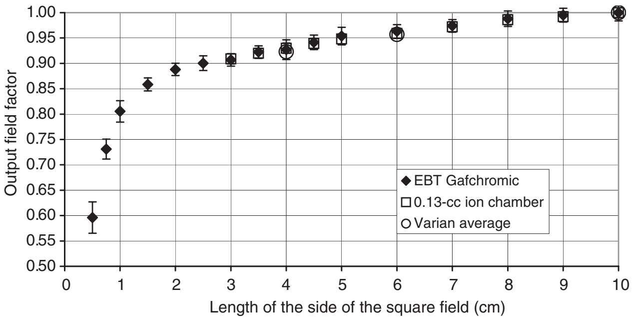

Fig. 2. Relative radiation output factors for 6-MV X-ray beams of various sizes.

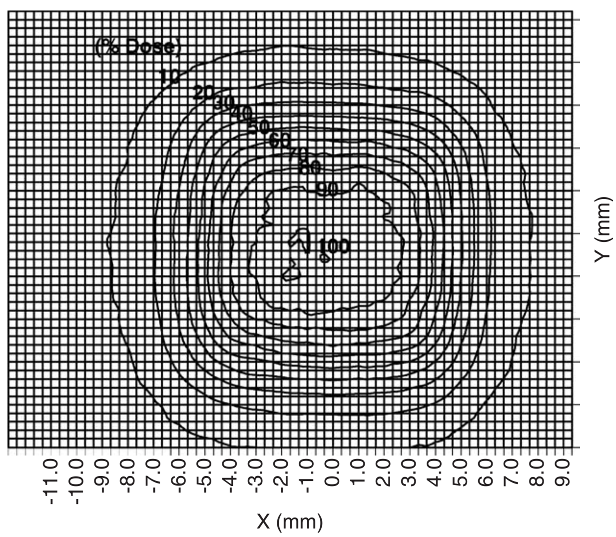

Fig. 3. A map of a $1 \times 1\,\mathrm{cm}^2$ field obtained with the EBT Gafchromic radiochromic film.

does not suffer from significant energy-dependence effects. The error bars shown are the relative uncertainties in measured output factors for each given field size. Measurements on similar machines with photon diodes produced values of 0.6 for a $0.5 \times 0.5\,\mathrm{cm}^2$ field and 0.89 for a $2 \times 2\,\mathrm{cm}^2$ field, although the fields on those machines were defined by both jaws and MLC collimation (Chow et al., 2005). The quoted results for larger fields were also compared with standard ionization chamber measurements of the same beam. The figure also shows average results obtained on 2100C Varian linacs across the United States (Cho et al., 2005). The agreement is very close. Fig. 3 shows an isodose plot for the $1 \times 1\,\mathrm{cm}^2$ beam, which demonstrates that the EBT Gafchromic film is not only suitable for dose measurements in small fields, but can also provide high-resolution maps of radiation fields. The 10% step in the isodose curves is used merely for illustrative purposes in this picture; much finer dose resolution can be used in accurate field size assessments. The important point is that isodose levels in such small fields can be determined with this film accurately based on calibrations made with larger fields.

4. Conclusion

Calibration curves for the EBT Gafchromic film (film response vs. absorbed dose) are independent of the size of the radiation field produced by high-energy X-ray beams. This minimizes uncertainties in doses measured in small or irregular radiation fields. The response of the EBT Gafchromic film to a dose depends on the radiation field size to a much lesser extent than the response of the X-Omat V film. Therefore, the EBT film will be useful for measurements in small fields, where ionization chambers do not work. It can also provide two-dimensional dose maps of such small fields, if required.

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References

Butson, M.J., Yu, P., Metcalfe, P., 1998. Effects of readout light sources and ambient light on radiochromic film. Phys. Med. Biol. 43, 2407–2412.

Butson, M.J., Yu, P.K.N., Cheung, T., Metcalfe, P.E., 2003. Radiochromic film for medical radiation dosimetry. Mater. Sci. Eng. R: Reports 41, 61–120.

Butson, M.J., Cheung, T., Yu, P.K.N., 2004. Radiochromic film: the new X-ray dosimetry and imaging tool. Australas. Phys. Eng. Sci. Med. 27, 230.

Butson, M.J., Cheung, T., Yu, P.K.N., 2005a. XR type R radiochromic film X-ray energy response. Phys. Med. Biol. 50, N195–N199.

Butson, M.J., Cheung, T., Yu, P.K.N., 2005b. Absorption spectra variations of EBT radiochromic film from radiation exposure. Phys. Med. Biol. 50 (13), N135–N140.

Butson, M.J., Cheung, T., Yu, P.K.N., 2006. Weak energy dependence of EBT Gafchromic film dose response in the 50 kVp–10 MVp X-ray range. Appl. Radiat. Isot. 64 (1), 60–62.

Cheung, T., Butson, M.J., Yu, P.K.N., 2004. Experimental energy response verification of XR type T radiochromic film. Phys. Med. Biol. 49, N371–N376.

Cheung, T., Butson, M.J., Yu, P.K.N., 2005. Post irradiation coloration of Gafchromic EBT radiochromic film. Phys. Med. Biol. 50, N281–N285.

Cho, S.H., Vassiliev, O.N., Lee, S., Liu, H.H., Ibbott, G.S., 2005. Mohan R Reference photon dosimetry data and reference phase space data for the 6 MV photon beam from Varian Clinac 2100 series linear accelerators. Med. Phys. 32 (1), 137–148.

Chow, J.C., Seguin, M., Alexander, A., 2005. Dosimetric effect of collimating jaws for small multileaf collimated fields. Med. Phys. 32 (3), 759–765.

Constantinou, C., Attix, F.H., Paliwal, B.R., 1982. A solid water phantom material for radiotherapy X-ray and gamma-ray beam calibrations. Med. Phys. 9 (3), 436–441.

International Specialty Products Inc., 2005. Web site: www.ispcorp.com

Kron, T., Duggan, L., Smith, I., Rosenfeld, A., Butson, M., Kaplan, G., Howlett, S., Hyodo, J., 1998. Dose response of various radiation detectors to synchrotron radiation. Phys. Med. Biol. 43, 3235–3259.

Laub, W.U., Wong, T., 2003. The volume effect of detectors in the dosimetry of small fields used in IMRT. Med. Phys. 30 (3), 341–347.

Martens, C., De Wagter, C., De Neve, W., 2000. The value of the PinPoint ion chamber for characterization of small field segments used in intensity-modulated radiotherapy. Phys. Med. Biol. 45 (9), 2519–2530.

Palm, A., LoSasso, T., 2005. Influence of phantom material and phantom size on radiographic film response in therapy photon beams. Med. Phys. 32 (8), 2434–2442.

Suchowerska, N., Davison, A., Drew, J., Metcalfe, P., 1997. The validity of using radiographic film for radiotherapy dosimetry. Australas. Phys. Eng. Sci. Med. 20 (1), 20–26.

Tangboonduangjit, P., Metcalfe, P., Butson, M., Quach, K.Y., Rosenfeld, A., 2004. Matchline dosimetry in step and shoot IMRT fields: a film study. Phys. Med. Biol. 49 (17), N287–N292.

Westermark, M., Arndt, J., Nilsson, B., Brahme, A., 2000. Comparative dosimetry in narrow high-energy photon beams. Phys. Med. Biol. 45 (3), 685–702.