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Clinical application of GAFCHROMIC® EBT film for *in vivo* dose measurements of total body irradiation radiotherapy

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Abstract

The GAFCHROMIC® EBT film model is a fairly new film product designed for absorbed dose measurements of high-energy photon beams. *In vivo* dosimetry for total body irradiation (TBI) remains a challenging task due to the extended source-to-surface distance (SSD), low dose rates, and the use of beam spoilers. EBT film samples were used for dose measurements on an anthropomorphic phantom using a TBI setup. Additionally, *in vivo* measurements were obtained for two TBI patients. Phantom results verified the suitability of the EBT film for TBI treatment in terms of accuracy, reproducibility, and dose linearity. Doses measured were compared to conventional dosimeter measurements using thermoluminescent dosimeters (TLDs), resulting in an agreement of 4.1% and 6.7% for the phantom and patient measurements, respectively. Results obtained from the phantom and patients confirm that GAFCHROMIC® EBT films are a suitable alternative to TLDs as an *in vivo* dosimeter in TBI radiotherapy.

Keywords: Total body irradiation; Radiochromic film; GAFCHROMIC® EBT; Radiation dosimetry; *In vivo* dosimetry

1. Introduction

In radiation oncology, total body irradiation (TBI) is generally part of the conditioning regimen for applications such as bone marrow or cord blood donor transplants. TBI treatments are usually given with a 6 MV photon beam at an extended source-to-surface distance (SSD). The technique is thoroughly described in AAPM report no. 17 (AAPM, 1986). The goal of the TBI technique is to deliver a uniform dose to the entire body, with no more than +10% dose heterogeneity in reference to the dose to the prescription point (Dusenbery and Gerbi, 1999; Khan, 2003). At the same time, some selected parts of the body (e.g. lungs and kidneys) can be partially shielded, depending on the protocol used. In contrast to conventional external beam radiotherapy, the extended SSD, the larger field size (usually maximum available field size of the linac), the lower dose rate, and the use of a spoiler to increase surface dose make the TBI dosimetry a challenging task (AAPM, 1986; Dusenbery and Gerbi, 1999; Khan, 2003). Therefore, there is a clear demand for *in vivo* dose validation, which has to be reliable and suitable for the TBI treatment delivery.

Traditionally, thermoluminescent dosimeters (TLDs) are used to verify the homogeneity of dose throughout the treatment field and to evaluate the doses along the central axis of the patient. However, handling TLDs is labor intensive and requires expensive equipment and dedicated workspace to house it (Best et al., 2005). Additionally, uncertainties associated with the TLD handling procedure such as readout and annealing might compromise their accuracy of dose measurements.

The newly developed GAFCHROMIC® EBT film is a commercially available radiochromic film designed for the measurement of absorbed dose of high-energy photon beams and is particularly attractive for IMRT dosimetry. It also has a potential application as an *in vivo* dosimeter in TBI dosimetry. GAFCHROMIC® EBT films are laminated with two film coatings, resulting in an active layer of

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approximately 17 μm thickness. The nominal thickness of 234 μm (ISP, 2006) is ideal for patient dosimetry with minimal perturbation of the delivered dose. The maximum light absorption band is centered at 633 nm, and the Z_{eff} is 6.98 (ISP, 2006), which is very close to the Z_{eff} of water (7.30). Irradiation of GAFCHROMIC® EBT films with ionization radiation induces a polymerization effect, which changes the originally colorless film to shades of blue. The measured dose is directly correlated to the absorbed spectrum (Gamble et al., 2003).

GAFCHROMIC® EBT films have advantages over conventional dosimetry methods (i.e., TLDs) used for TBI dose validation because they are easy to handle and flexible in shape to fit the patient's body contour. Compared to radiographic films such as Kodak extended dose range (EDR2) films, GAFCHROMIC® EBT films have the advantages of being insensitive to room light and being self-developing, thus reducing uncertainties in optical density that are typical for film processing. Furthermore, consistent and uniform responses (better than 1.5%), the almost water-equivalent density, and the water resistance of this film make it a uniquely qualified *in vivo* dosimeter (ISP, 2006).

Although dosimetric characteristics of GAFCHROMIC® EBT films for high-energy photon and electron beams have been reported in the literature (Devic et al., 2004, 2005; Butson et al., 2006; Cheung et al., 2006; Todorovic et al., 2006; Su et al., 2007), their application for *in vivo* dosimetry of TBI has not been investigated. Butson et al. (2006) have shown that the GAFCHROMIC® EBT film is independent of photon beam energy ranging from 50 kVp to 10 MVp. Cheung et al. (2006) have demonstrated that the calibration curve of GAFCHROMIC® EBT films does not depend on the field size of the photon beam. General dosimetric characteristics of the EBT radiochromic film have been described by Todorovic et al. (2006), who reported the versatility of this film for dose verification in external beam radiotherapy. Additionally, Devic et al. (2004, 2005) indicated limitations on the calibration procedure for the GAFCHROMIC® EBT films using different scanners and introduced a procedure that uses EBT radiochromic films for accurate measurements of the skin dose using 6 MV photon beams. In this work, we evaluate the feasibility of the GAFCHROMIC® EBT film for dose measurements with the TBI treatment technique. Measurements were obtained in a phantom and *in vivo* for two patients who received TBI using a lateral treatment setup technique. We specifically assessed the accuracy, reproducibility, dose linearity, and *in vivo* performance of the film in TBI irradiation conditions.

2. Methods and materials

The TBI procedure in our facility is such as to deliver 12 Gy to the patient mid-plane in six fractions over 3 days with parallel-opposed lateral fields of 6 MV photon beams. *In vivo* dosimetry is performed using TLDs on several anatomical sites for relative dose verification. The acceptance criterion is within ±10% spread from the prescription dose at the mid-plane as measured with TLDs. The 6 MV photon beam for the TBI was produced by a Varian 600 (C1) accelerator (Varian Medical Systems, Palo Alto, CA) operating in the low-dose rate (approximate by 200 MU/min). The phantom used for the measurements was a water-equivalent solid phantom.

Measurements were performed with GAFCHROMIC® EBT film (ISP Corp., Wayne, NJ) samples ($2.5 \times 1.5\,cm^2$ in size), which were cut from the same batch (Lot #: 36306-002I). After the irradiation, the film pieces were scanned 6 h post irradiation (Butson et al., 2006) with a Canon PIXMA MP160 flat-bed scanner (Canon USA, Inc., Lake Success, NY). Net optical densities (NetOD) of the irradiated films were converted to the absorbed dose using the calibration procedure described by Devic et al. (2005). Absolute doses were determined using the PTW Farmer-type ionization chamber (PTW-Freiburg, Freiburg, Germany) connected to a Keithley 602 Electrometer (Cleveland, OH).

The TLD dosimetry system consisted of a TLD reader (Model 5500, Harshaw Chemical Company, Solon, OH) and dosimeters made of lithium fluoride (LiF) crystal in the form of TLD chips (1 mm in thickness). All TLDs were calibrated by exposing them to a known dose at the depth of dose maximum in solid water using an SSD irradiation setup (SSD = 100 cm).

2.1. Accuracy and reproducibility

2.1.1. Entrance dose evaluation

Ten GAFCHROMIC® EBT film samples were placed on the front surface of a cylindrical SolidWater™ phantom (30 cm in diameter) and irradiated to 80 cGy (corresponding to a mid-plane dose of 50 cGy). Ten packs of TLDs were positioned on the front surface of the phantom using the same setup as for the EBT film pieces, and readings of these TLDs were compared with the values obtained from GAFCHROMIC® EBT films. Dose readouts of GAFCHROMIC® EBT films were also compared to ionization chamber measurements at a depth of 5 mm under the same irradiation conditions while applying a depth correction. We used the clinical tissue-maximum ratio (TMR) of the same field size under TBI condition to correct the depth difference.

2.1.2. Exit dose evaluation

Exit doses were evaluated under TBI conditions with the same cylindrical phantom. Ten GAFCHROMIC® EBT film samples and packs of TLDs were positioned equidistantly around the central axis on the exit surface of the phantom and irradiated to 30 cGy (corresponding to a mid-plane dose of 50 cGy). The readouts of GAFCHROMIC® EBT films were compared to TLD readings as well as ionization chamber measurement at a depth of 295 mm under the same irradiation conditions.