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Dosimetry of gamma chamber blood irradiator using Gafchromic EBT film

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ABSTRACT

Gafchromic films are increasingly being used for dosimetry in medical and industrial applications of ionizing radiation because of their favorable characteristics such as self developing in nature, easy to handle, dose rate independent response, insensitivity to normal room lights, high resolution and insensitivity to variation in the environment conditions. The dosimetry measurements using Gafchromic EBT film, Fricke dosimeter and thermoluminescence (TL) dosimeter were carried out on gamma blood irradiators to establish the suitability of Gafchromic EBT film in such applications. The dose rates determined by Gafchromic EBT film, Fricke dosimeter and TL dosimeter powder are found in good agreement to one another within the uncertainty of measurement. The two-dimensional dose distributions determined using Gafchromic EBT film reflects the expected dose distribution inside the sample compartment of the blood irradiator. The results of this study establish Gafchromic EBT film a suitable dosimeter for routine dosimetry on gamma blood irradiators.

1. Introduction

Gafchromic films (HD810, MD55, HS and EBT) are increasingly being used for medical radiation dosimetry to generate two-dimensional (2D) dose profiles in external beam therapy (photon and electron beam), quality assurance and dosimetry in intensity modulated radiation therapy (IMRT), stereotactic radiosurgery (SRS), stereotactic radiotherapy (SRT), tomotherapy and brachytherapy (Butson et al., 2003; Chiu-Tsao et al., 1994 ; Niroomand-Rad et al., 1998; Sankar et al., 2006; Sharma et al., 2007, 2004; Su et al., 2007; Wilcox and Daskalov, 2007). Gafchromic films have also got wide applications in high dose dosimetry during food irradiation, spice irradiation and radiation processing of other products (Sharma et al., 2009). This is due to the fact that Gafchromic films are nearly tissue equivalent, dose rate independent, insensitive to normal room light, which provide convenience in handling, self developing in nature (no chemical or physical processing is required), post irradiation data analysis is easy, resolution is high and insensitive to the variation in the environment conditions (Chu et al., 1990).

Gafchromic EBT film has relatively favorable characteristics in comparison to earlier versions of this film supplied for medical dosimetry in terms of sensitivity, energy response in the range of kilovoltage to megavoltage, uniformity and temporal response in terms of after exposure optical density growth (Cheung et al., 2005; Chiu-Tsao et al., 2004, 2005, 2008).

The Board of Radiation and Isotope Technology (BRIT), Mumbai, and Best Theratronics, Canada, are the manufacturer and suppliers of different models of gamma chamber blood irradiators in India. These irradiators are being used to effectively irradiate blood and blood components in order to inactivate lymphocytes and to irradiate intraoperatively salvaged blood for the patients. The dose delivered to blood and blood components are in the range 25–30 Gy.

Dose rate at the centre of sample compartment and dose profile in the sample compartment of gamma chamber blood irradiator are usually measured by Fricke dosimeter and thermoluminescence dosimeters (TLDs) (Manjoor et al., 2009). The method based on Fricke dosimeter, in particular, is having very poor measurement resolution because of significant physical size of the dosimeter vial, which gives the dose rate at a point by averaging the dose rates from a volume. In essence, both Fricke dosimeter and TLDs are point detectors with limited resolution and methods of gamma chamber blood irradiator dosimetry based on these detectors are highly labor intensive. There is a need to explore the feasibility of using a dosimeter, which has more favorable characteristics for dosimetry of gamma cell blood irradiator. Gafchromic EBT film seems to be one of the dosimeters, which has the potential of replacing Fricke dosimeter and TLD in routine gamma chamber blood irradiator dosimetry. Dosimetry of two different gamma cell blood irradiators were carried out using Gafchromic EBT film with the objective of demonstrating its suitability for such applications.

This paper discusses the study carried out to measure the dose rate at the centre and dose profile in the sample compartment of

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the two gamma chamber blood irradiators using Gafchromic EBT film. Well established Fricke dosimeter and thermoluminescence dosimeter (TLD-700) were also used to measure the dose rate at the centre of the sample compartment to cross verify the Gafchromic EBT film measurements.

2. Materials and methods

2.1. Blood irradiators

The dosimetry measurements were carried out on two different gamma chamber blood irradiators namely BI2000 (BRIT, Mumbai, India) and GBI1000 (Best Theratronics, Canada). The BI2000 has four main components: source housing, radiation source(s), sample compartment and control panel. The source housing is a shielded container, which can hold 44 ^{60}Co source pencils arranged symmetrically along its cylindrical periphery. The gamma chamber available to us is containing four sources of total activity about 11.79 TBq (318.77 Ci) during the period of the experiment. The radiation source is a doubly encapsulated cylindrical pencil of outer/active diameter of 1.15/0.94 cm and total/active height of 20.9/19.54 cm. The sample compartment of this irradiator is cylindrical in geometry of 13.5 cm diameter and 20 cm height. The control panel consists of buttons for setting the irradiation parameters such as time of irradiation, dose, source ON/OFF.

The GBI1000 blood irradiator has four main components: radiation shield, radiation source(s), sample chamber and control system (consisting of control panel, primary control cabinet and computer control cabinet). The radiation shield is made of steel-encased lead, which houses either one or two radiation source(s). The GBI1000 blood irradiator has two doubly encapsulated sealed ^{137}Cs cylindrical source of total activity 0.50 TBq (13.55 Ci) as on March 2009. Each caesium-137 source capsule has total/active length of 27.15/26 cm and outer/active diameter of 1.75/1.28 cm. The sample chamber has a turntable and removable stainless steel beaker. The blood sample to be irradiated is placed in the beaker and the beaker is then placed on the turntable. On start of irradiation cycle, the turntable begins to rotate to deliver homogenous dose to the sample. The GBI1000 blood irradiator has a microprocessor-based control system to operate the unit through the control panel, which contains keypad and display, independent backup timer and beaker rotation sensing system.

2.2. Gafchromic EBT film

The Gafchromic EBT film was used as dosimeter and its dynamic range is about 1–800 cGy. Gafchromic EBT film (ISP Corporation, Wayne, NJ, USA) is a double sensitive layer self developing dosimetry media. Each of the sensitive layers is 17 μm thick and coated with 97 μm thick transparent polyester making total thickness of the film 0.234 mm. According to the manufacturer, overall atomic composition of Gafchromic EBT film is C (42.3%), H (39.7%), O (16.2%), N (1.1%), Li (0.3%) and Cl (0.3%). The unexposed Gafchromic EBT film is colorless and changes to shades of blue as a result of polymerization process induced by ionizing radiation. The calibration of the film was carried out at ^{60}Co reference beam (Theratron 780-E, Best Theratronics, Ontario, Canada) in the dose range 1.0–6.0 Gy. The calibration graph between net optical density and dose was generated and is shown in Fig. 1. A polynomial fit between absorbed dose and net optical density (NOD) was generated (Eq. (1)) to determine unknown dose values from the knowledge of NOD.

$$\text{Dose (Gy)} = 0.442 + 5.582(\text{NOD}) - 1.735(\text{NOD})^2 + 20.991(\text{NOD})^3 \quad (1)$$

This relation was used throughout the course of this study to determine dose from net optical density. Recommendations and standard instructions as prescribed by the manufacturer of Gafchromic EBT film were followed while handling the film. All experimental, calibration and background film samples were scanned in the central region of flatbed scanner (Epson Expression 10000XL) with transmission mode. The flatbed scanner (Epson Expression 10000XL) is a high quality scanner with a scanning area of $310 \times 437\ \text{mm}^3$. It can read film in transmission or reflection mode up to colour depths of 48 bits, a maximum of 2400 dpi resolution. These films were scanned in operating mode of 48 bits and a resolution of 200 dpi. Image J software was used to process the scanned image of all the film samples.

2.3. Fricke dosimeter

Fricke chemical dosimeter is an established primary reference standard and used for standardization of category-I irradiators such as gamma chamber, blood irradiators. A Fricke dosimeter sample contains solution of ferrous ammonium sulphate (1 mM) and sodium chloride (1 mM) prepared in 0.4 M aqueous sulphuric acids. The Fricke dosimeter vials each of length 5.5 cm outer diameter 1.3 cm and wall thickness 0.1 mm were exposed with 0.4 cm thick build up cap of unit density material. On irradiation to ionizing radiation the energy absorbed in the solution leads oxidation of ferrous ions (Fe^{2+}) into ferric ions (Fe^{3+}), whose

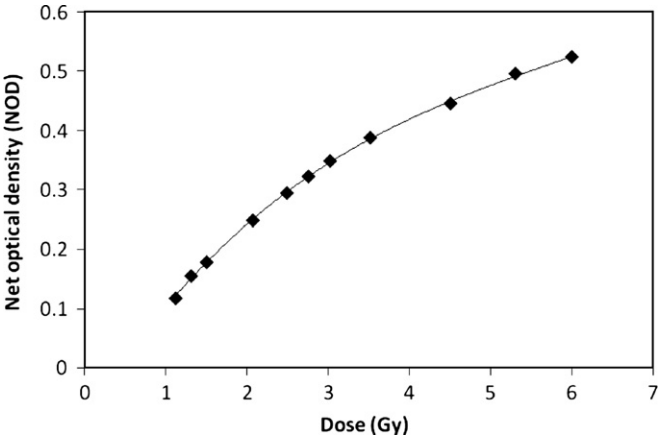

Fig. 1. Gafchromic EBT film calibration curve.

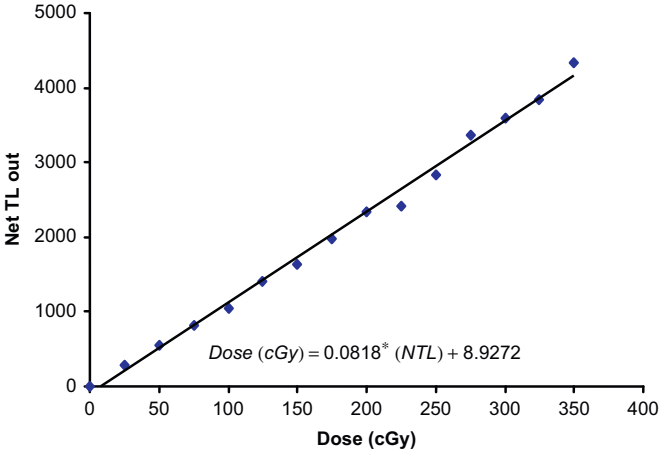

Fig. 2. Thermoluminescence dosimeter calibration curve.