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Preliminary investigations of two types of silica-based dosimeter for small-field radiotherapy

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HIGHLIGHTS

- SiO_2–GeO_2 doped fibres and glass beads (GB) investigated as TLDs for their small field dosimetry.
- The maximum inter-difference between FWHM measurements was 1.8 mm.
- The maximum difference for penumbra measurements (80% to 20% beam fall off points) was < 1 mm.

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ABSTRACT

Two thermoluminescent dosimeters (SiO_2–GeO_2 doped fibres and glass beads (GB)) were used to measure small photon field doses and compared against GAFCHROMIC film, a small ionisation chamber (RK-018) and a p-type silicon diode (SCANDITRONIX, F1356), as well as Monte Carlo simulations with FLUKA and BEAMnrc/DOSXYZnrc. Ge-doped SiO_2 fibres have been shown by this group to offer a viable system for use as dosimeters. The fibres and GB offer good spatial resolution (~120 μm and 2 mm respectively), large dynamic dose range (with linearity from tens of mGy up to well in excess of many tens of Gy), are non-hygroscopic and are of low cost. Measurements of beam profiles for field sizes of 10 mm × 10 mm, 20 mm × 20 mm, 30 mm × 30 mm, 40 mm × 40 mm, and 100 mm × 100 mm were carried out. Through the use of a customised solid water phantom, doped optical fibres and GBs were placed at defined positions along the *x*-and *y*-axes to allow accurate beam profile measurement. The maximum difference between FWHM measurements was 1.8 mm. For penumbra measurements (measured between 80% and 20% isodoses), the maximum difference was < 1 mm. These measurements indicate good agreement, within measurement uncertainty, with Gafchromic film, data obtained from the use of two commonly used detectors and FLUKA and BEAMnrc/ DOSXYZnrc simulations.

1. Introduction

External beam radiotherapy techniques employing small photon fields ($\leq 4 \times 4$ cm^2) present several dosimetric challenges. These include partial occlusion of the direct-beam source (Zhu and Bjarngard, 1994; Sharpe et al., 1995; Zhu and Bjarngard, 1995; Zhu et al., 1995), loss of charge particle equilibrium (CPE) (Attix, 1986;

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Nahum, 1996) and steep fall-off in dose in the penumbra of small fields (Rice et al., 1987). Thus a small detector size is required compared to the field dimensions such that the maximum inner diameter should be smaller than the beam radius (Bjarngard et al., 1990; Higgins et al., 1995; Francescon et al., 1998; Sauer and Wilbert, 2007; Alfonso et al., 2008; Bassinet et al., 2013; Francescon et al., 2012). Measurements made with more than one detector type are recommended whenever possible (Aspradakis et al., 2010). The codes of practice are under development to propose a new formalism in order to standardise dosimetry techniques for small and nonstandard fields. For example work performed by the International Atomic Energy Agency (IAEA) in association with the American Association of Physicists in Medicine (AAPM) (IAEA, 2014; Palmans et al., 2012).

In order to obtain high accuracy and precision, various detectors have been used, notably with ionisation chamber uncertainties increasing for small radiation fields due to volume averaging of a high gradient radiation field (Rah et al., 2008). Although semiconductor diode detectors offer relatively good spatial resolution and radiation sensitivity, they show angular dependence (Araki et al., 2003, 2004). Films provide the best spatial resolution but can be influenced by the film processing procedures, room temperature, relative humidity and time elapsed after exposure (Heydarian et al., 1996; Ertl et al., 1998; Araki et al., 2004). Other detectors such as MOSFET-based devices and LiF TLDs offer smaller effective volumes than ionisation chambers. However, the former have the limitation of lifetimes (around one year) and energy dependency (Rah et al., 2011) and the latter are typically hygroscopic and fading effects are encountered (Araki et al., 2005).

Recent findings from studies of silica based TL materials such as doped silica glass optical fibres and glass beads report promising results that include minimal fading, increased sensitivity and reduced effective size, of the order of tens of μm in one dimension (Bradley et al., 2012); (Jafari et al., 2014, in press). This preliminary study makes use of Ge-doped SiO_2 optical fibres and glass beads (GB) for small field dosimetry, measurements being compared against those obtained using several well-established dosimetersGAFCHROMIC film, small ionisation chambers and photon diodes. Further comparison has been made against Monte Carlo simulations obtained using the FLUKA and BEAMnrc/ DOSXYZnrc codes.

2. Experimental materials and methods

2.1. Detectors

2.1.1. SiO_2–GeO_2 doped optical fibres

The SiO_2–GeO_2 doped fibres (CorActive, Canada) used herein have a doped core and cladding diameter of 50 μm and 124.7 ± 0.1 μm, respectively. A fibre stripper (Miller, USA) is used to remove the outer coating, and for irradiation the fibre is typically cut into lengths of 0.5 ± 0.1 cm. To mitigate against uncertainty in TL yield, the gross TL yield was normalised to unit mass of each fibre; the mean mass of a fibre was (4.55 ± 0.001) μg. Fibres selected by screening with a fixed dose provided a uniform response (≤ ± 1% of the group mean); details are provided elsewhere (Bradley et al., 2007). For uniform control of fading, optical fibre TL yield was measured 12 h post-irradiation.

2.1.2. Glass beads (GBs)

White GBs, 2 mm diameter and 1 mm thick (Mill Hill, Japan) were used to measure small field beam profiles. Prior to measurement, the beads were acid washed to remove the coating materials and calibrated using a nominal energy 6 MV clinical photon beam, field size 20 × 20 cm^2.

2.1.3. Gafchromic film EBT

GAFCHROMIC® EBT3 film was used in this study, the film comprising of a single active layer of approximately 27 μm thickness between two 120 μm thick transparent polyester substrates. It is water resistant and can easily be cut into smaller pieces. Care was taken in handling and storing the films, such that they were only handled at the edges and the irradiated films were stored together with the non-irradiated films at room temperature in a light proof envelope, separated by white paper. To calibrate the films, films were irradiated in a 30 × 30 cm^2 solid water phantom (Gammex, UK) with 5 cm of the build-up material above and 10 cm below the film. The source-to-surface distance was 100 cm, with a 10 × 10 cm^2 field size at the surface. Film samples, 5 × 5 cm^2 were irradiated perpendicularly in the 6 MV radiation beam from a dual-energy Varian linac (Varian Medical Systems, Palo Alto, CA). To obtain a calibration curve, films were irradiated with dose levels of 0 (background), 0.1, 0.3, 0.5, 1.0, 4.0, 6.0, 9.0, and 11 Gy. To read out the films, a flatbed scanner (Seiko Epson Corp., Nagano, Japan) was used, aided by OmniPro-I'mRT software (Qados, UK).

2.1.4. Ionisation chamber

Percentage depth doses were obtained using an ionisation chamber (RK-018, Wellhofer Dosimetrie, Germany), with an effective volume of 0.12 cc and active length of 10 mm.

2.1.5. Photodiodes

Beam profile measurements were measured with a p-type silicon photodiode (SCANDITRONIX, F1356, Wellhofer Dosimetrie, Germany) with an effective detection area of 2.5 ± 0.1 mm^2 and effective detection thickness of 60 μm.

2.2. TLD reader

A TOLEDO TL reader (Pitman Instruments, Weybridge, UK) was employed for the optical fibres and glass beads readout. The readout was carried out in the presence of N_2 gas flow to suppress oxidation and triboluminescence. The parameters providing an optimal glow curve were preheat temperature 160 °C for 10 s; readout temperature 300 °C for 25 s at a ramp rate of 35 °C /sec. The reading parameters were adjusted to provide a complete glow curve with minimum residual signal of 2%. An annealing temperature of 300 °C for 10 s was subsequently used to eliminate any residual signal.

2.3. Phantoms

The fibres and films were sandwiched between solid water phantom plates (30 × 30 × 0.2 cm^3 and 30 × 30 × 1.0 cm^3) (Gammex, UK), the fibres being located in superficial indentations to provide a range of positions. Additional solid water provided full scatter situations. GB measurements were obtained in a 25 × 25 × 0.5 cm^3 Perspex phantom sandwiched between additional solid water, with a 1.5 cm thick plate on top and 6 cm thick plate at the bottom for backscatter. The beads were located in the phantom such that the centre-to-centre distance was 2 mm.

2.4. Irradiation procedures

All dosimeters were irradiated with 6 MV photons from a Varian Clinac 2100C accelerator (Varian Medical Systems, Palo Alto, CA) to deliver 11 Gy dose at 1.5 cm depth, sufficient to ensure electronic build-up for the photon energy used, for each field size: 10 mm × 10 mm, 20 mm × 20 mm, 30 mm × 30 mm, 40 mm × 40 mm and 100 mm × 100 mm at the surface using a standard source-to-surface distance (SSD) of 100 cm. For percentage depth dose (PDD) measurements, the fibres were placed in the