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Characterisation of a plastic scintillation detector to be used in a multicentre stereotactic radiosurgery dosimetry audit

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ABSTRACT

Scintillation detectors are considered highly suitable for dosimetric measurement of small fields in radiotherapy due to their near-tissue equivalence and their small size. A commercially available scintillation detector, the Exradin W1 (Standard Imaging, Middleton, USA), has been previously characterised by two independent studies (Beierholm et al., 2014; Carrasco et al., 2015a, 2015b) but the results from these publications differed in some aspects (e.g. energy dependence, long term stability). The respective authors highlighted the need for more studies to be published (Beierholm et al., 2015; Carrasco et al., 2015a, 2015b).

In this work, the Exradin W1 was characterised in terms of dose response, dependence on dose rate, energy, temperature and angle of irradiation, and long-term stability. The observed dose linearity, short-term repeatability and temperature dependence were in good agreement with previously published data. Appropriate corrections should therefore be applied, where possible, in order to achieve measurements with low-uncertainty. The angular dependence was characterised along both the symmetrical and polar axis of the detector for the first time in this work and a dose variation of up to 1% was observed. The response of the detector was observed to decrease at a rate of approximately 1.6% kGy^{-1} for the first 5 kGy delivered, and then stabilised to 0.2% kGy^{-1} in the subsequent 20 kGy.

The main goal of this work was to assess the suitability of the Exradin W1 for use in dose verification measurements for stereotactic radiosurgery. The results obtained confirm that the detector is suitable for use in such situations. The detector is now utilised in a multi-centre stereotactic radiosurgery dosimetric audit, with the application of appropriate correction factors.

1. Introduction

Plastic scintillation detectors (PSD) have been investigated for their performance in medical radiation dosimetry for more than two decades (Beaulieu et al., 2013). They are considered suitable for radiotherapy applications, as they can be manufactured in small sizes, have tissue equivalent density and are capable of performing real-time measurements. As far as the authors are aware, there is currently only one commercially available PSD for small field photon dosimetry applications, the Exradin W1 (Standard Imaging, Middleton, WI, USA).

The Exradin W1 became commercially available in the UK in the summer of 2014. The sensitive volume of the detector is a 3 mm (length) by 1 mm (diameter) polystyrene cylinder, doped with scintillating agents. It is encased within an opaque enclosure made of epoxy resin and acrylonitrile butadiene styrene (ABS). The scintillator is coupled to an optical fibre with a 1 mm diameter polymethyl methacrylate (PMMA) core and a 2.2 mm diameter polyethylene jacket. The scintillator-fibre coupling is externally protected with a polyimide sheath. The fibre is 3 m long and is attached to a photodiode box. Although the manufacturer does not provide a detailed description of the contents of the photodiode box, it is understood to include instrumentation for the chromatic separation of light (dichroic filters and photodiodes). The other end of the photodiode box has two connectors for transmitting the electrical charges collected to a dual channel electrometer. Alternatively, two individual electrometers may be used, as long as they are able to detect the small charges produced by the PSD, which are in the pico-Coulomb range. Measurements with the PSD in two setup orientations, of maximum and minimum optical fibre in the radiation field, are used for the determination of the Cherenkov Light Ratio (CLR) correction. This is necessary to remove the stem signal produced by irradiation of the fibre. The manufacturer provides a 30×30 cm^2 polystyrene calibration slab that allows placement of the detector fibre in the minimum and maximum fibre orientations (Fig. 1).

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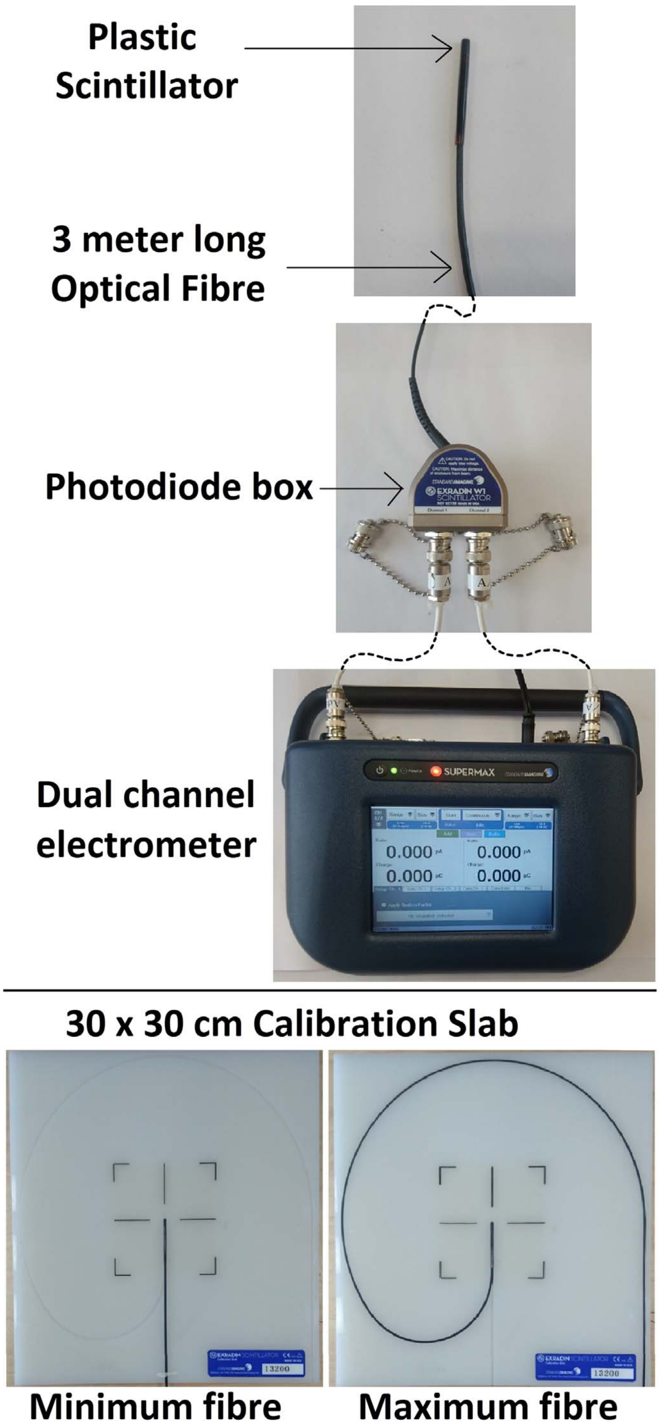

Fig. 1. Components of the Exradin W1 plastic scintillation detector, SuperMAX electrometer and calibration slab.

A previous study performed Monte Carlo simulations of different detectors in small fields, reported that the Exradin W1's response in small fields was expected to be within 1% of simulated output factors (Kamio and Bouchard, 2014). Similar findings were experimentally validated by another study in the measurement of small field output factors (Underwood et al., 2013) and the PSD was subsequently used to determine correction factors for other small field detectors. A third independent study, utilised a similar methodology and produced comparable results, further validating further the suitability of this detector for use in small fields (Silvestre et al., 2016). The detector was also used in an Italian multi-centre study for the measurement of output factors, which also confirmed its suitability for small fields (Pasquino et al., 2016). Although the available evidence supports the use of this detector in small fields, the dosimetric characteristics of the detector need to be further investigated to assess its suitability for patient-specific small field dose verification, such as used in clinical Stereotactic Radiosurgery (SRS).

The Exradin W1 has recently been recently characterised by two independent and almost simultaneously published studies (Beierholm et al., 2014; Carrasco et al., 2015a, 2015b). The results demonstrate promising dosimetric characteristics. However, slightly different results were observed for the energy dependence and the long term stability of the detector, which were highlighted and discussed in a letter to the editor (Beierholm et al., 2015). A response to this letter commented on the possibility that such differences may be inherent to the different detectors and highlighted the need for more studies investigating the dosimetric properties of the Exradin W1 (Carrasco et al., 2015a, 2015b).

There are limited published studies on the use of PSDs for dose verification purposes (Klein et al., 2012; Ottosson et al., 2015), although this limited evidence does not suggest their applicability in this area. In order to determine whether the Exradin W1 is suitable for SRS dose verification some additional investigations needed to be performed. These include the angular dependence of the detector along its polar axis and assessment of the manual collection mode for high dose measurements, which have not been previously been published.

The purpose of this study was therefore to conduct a full dosimetric characterisation of the Exradin W1 in order to verify previously published results, further investigate dosimetric characteristics where different results have been published, and extend the dosimetric characterisation with the aim of verifying the Exradin W1's suitability for use in the methodology of a national SRS dosimetry audit (Dimitriadis et al., 2016a).

2. Materials and methods

The W1 detector was connected to a SuperMAX dual channel (standard Imaging, Middleton, WI, USA). The readings from both channels were acquired in the low range (pC), using both triggered and manual collection modes. All factors and dose measurements were calculated manually using the spectral method (Guillot et al., 2011). Channel 1 of the electrometer collected signal produced mainly from the scintillator, and channel 2 collected signal mainly produced from Cherenkov in the stem. When trigger mode collection was used, channel 1 was automatically initiated and ended the measurement using the default threshold values of 0.4 pA (start) and 0.2 pA (stop) respectively. Manual collections were acquired by starting the collection immediately before the beam came on and stopping the collection after the beam went off and the dose-rate indications for both channels of the electrometer returned to zero. Leakage currents were occasionally noticed during the experiments. In order to minimise these, the detector was left to equilibrate for at least 10 min. It was then pre-irradiated with a dose of approximately 10 Gy and the electrometer was then corrected for background leakage. The photodiode box was positioned as from the primary beam as possible and shielded from scattered radiation, as there is evidence to suggest that similar instrumentation is susceptible to noise from scattered radiation (Liu et al., 2012). The irradiations were performed with a nominal 6 MV, 10 MV and 15 MV photon beam from an Elekta Versa HD linear accelerator (linac) and a Theratron ^{60}Cobalt unit.

The work reported here was undertaken with the PSD positioned in both perpendicular and parallel orientations to the radiation beam. For perpendicular irradiations, the detector was calibrated in its calibration slab (Fig. 1), using sufficient 30×30 cm blocks of water equivalent plastic material (WT1) to ensure full build-up and backscatter. The detector was placed at the radiation isocentre at 5 cm depth in WT1, 95 cm Source-to-Surface Distance (SSD), and with 15 cm WT1 for backscatter. A 40×40 cm field size was employed. Absolute dose