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Electron beam energy monitoring using thermoluminescent dosimeters and electron back scattering

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HIGHLIGHTS

► Monitoring electron beam quality via electron backscattering was investigated.
► Different thermoluminescent materials were evaluated as detectors.
► A TLD100-TLD200 combination produced the most sensitive and reproducible results.
► An in-air jig was evaluated to allow measurements via postal dose audits.

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ABSTRACT

Periodic checks of megavoltage electron beam quality are a fundamental requirement in ensuring accurate radiotherapy treatment delivery. In the present work, thermoluminescent dosimeters (TLDs) positioned on either side of a lead sheet at the surface of a water equivalent phantom were used to monitor electron beam quality using the electron backscattering method. TLD100 and TLD100H were evaluated as upstream detectors and TLD200, TLD400 and TLD500 were evaluated as downstream detectors. The evaluation assessed the test sensitivity and correlation, long and short term reproducibility, dose dependence and glow curve features. A prototype of an in-air jig suitable for use in postal TLD dose audits was also developed and an initial evaluation performed. The results indicate that the TLD100-TLD200 combination provides a sensitive and reproducible method to monitor electron beam quality. The light weight and easily fabricated in-air jig was found to produce acceptable results and has the potential to be used by radiation monitoring agencies to carry out TLD postal quality assurance audits, similar to audits presently being conducted for photon beams.

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1. Introduction

Many modern linear accelerators have dual photon and multiple electron energies available for radiotherapy treatments. Conventionally, the beam quality of the photon beams is specified by the ratio of the absorbed doses at depths of 20 and 10 cm in a water phantom with a constant source to chamber distance of 100 cm and a 10 × 10 cm^2 field size. The fixed geometry facilitates regular measurements in water equivalent solid phantoms and allows the beam quality to be verified through thermoluminescent dosimeter (TLD) postal dose audit services. For electrons, the beam quality is specified by R_{50}, the depth in water at which the absorbed dose is 50% of its value at the absorbed dose maximum. As the beam quality may change over time, the AAPM Task Group 142 report recommends that the R_{50} be verified annually and the energy constancy checked monthly to ensure that it remains consistent with commissioning data (Klein et al., 2009). Verification of R_{50} requires measurement of the percentage depth dose (PDD) curve of each clinical electron beam in water. This is a laborious procedure which is not conducive to monthly constancy checks. It also cannot be used by a national or international radiation regulatory authority to conduct postal radiation quality assurance surveys using TLDs.

A number of methods have been proposed in literature to monitor electron beam energy without having to measure the full PDD curve (King and Anderson, 2001; Nelson et al., 2005; Woo and Videla, 2004). The electron backscattering method to estimate electron beam energy, proposed by Das and Bushe (1994), uses two detectors. An upstream detector to measure the backscattered electrons (Bs) and a downstream detector to measure the transmission (Tr) photons, separated by a high atomic number (Z) material such as lead. When the thickness of the high Z material is

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such that it stops all the electrons (saturation thickness, t_s), the downstream detector only measures photons produced by the electron interactions. The quantity of these bremsstrahlung photons is proportional to the energy of the electrons incident upon the high Z material and the ratio of the responses of the detectors can be expressed by Equation (1) (Das and Bushe, 1994).

$$\log\left(\frac{Tr}{Bs}\right) = \log\left(\frac{A_t}{A_b}\right) + k_1 t + E(k_2 t + \eta) \tag{1}$$

where, for a given electron energy E, A_t, k_1 and k_2 are transmission constants, A_b and η are backscatter constants, and t is the thickness of the interface material. E in the equation is the energy at the surface, E_0, calculated from the R_{50}. Equation (1) produces a straight line with respect to the electron energy as long as t is constant and greater than t_s. The gradient, representing the sensitivity of the test, is steep if there is large difference in the quantity of bremsstrahlung produced due to changes in incident electron energy.

The method proposed by Das and Bushe (1994) utilized ionisation chambers. Methods employing thermoluminescent dosimeters (Nelson et al., 2010; Pradhan et al., 1994) offer some advantages. Firstly, being a passive detection process, it requires minimal linear accelerator time to perform measurements. Secondly, TLDs can be incorporated into a holder which can be used for conducting quality assurance audits on megavoltage electron beams as proposed by Pradhan et al. (1994).

The aim of this work was to determine the viability of different TL materials to perform an electron beam quality check using the backscattering method and to assess if the method could also be performed using an in-air jig. This technique could then provide an alternative method for routine constancy checks and potentially be used by regulatory authorities to conduct external audits.

2. Methods

Two types of lithium fluoride TL materials with different dopants (TLD100 (LiF:Mg,Ti) and TLD100H (LiF:Mg,Cu,P) were used as the upstream detectors. A 0.5 cm thick sheet of lead was used as the high Z material as this is sufficiently thick to stop all the electrons for the beams used in this study, satisfying the condition $t > t_s$ (Pradhan et al., 1994). As the transmitted photon dose is much smaller than the dose from backscattered electrons, the downstream detector was required to have high sensitivity to low doses. Calcium fluoride based TL materials TLD200 (CaF_2:Dy), TLD400 (CaF_2:Mn) and the aluminium oxide based TLD500 (Al_2O_3:C) have a dose response approximately 30 times higher than TLD100 (Bassi et al., 1976), so these materials were used as downstream detectors. Several papers have reported on the energy dependence of the response for a variety of TL materials such as Bassi et al., 1976, and Mobit et al., 1996. While the energy dependence varies for the different TL materials used in this study, this is one of the characteristics that results in the differences in gradient for the plot of log (Tr/Bs) vs Electron Beam Quality for the different TL combinations.

The dimensions of the TLD chips were $3 \times 3 \times 0.9$ mm^3. For each batch of TLDs, a 6 MV photon beam was used to obtain chip calibration factors. Prior to each measurement, the TLDs were annealed according to manufacturer's recommendations. Four chips of each of the TLD200, TLD400 and TLD500 chips were placed near the central axis in indentations at the surface of a $30 \times 30 \times 20$ cm^3 water equivalent plastic slab phantom. The $30 \times 30 \times 0.5$ cm^3 lead sheet was placed above the phantom and the TLD 100 and TLD 100H were at a depth of 0.2 cm in a $10 \times 10 \times 0.6$ cm^3 Perspex tray placed above the lead sheet. A schematic diagram of the experimental setup can be found in Fig. 1. Measurements were performed

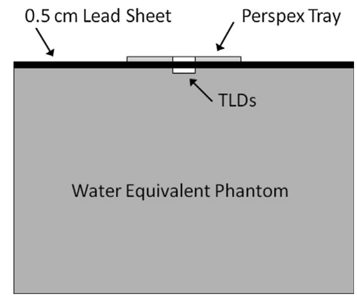

Fig. 1. Schematic diagram of the experimental setup.

on a Siemens Primus linear accelerator (Siemens Medical Solutions, Oncology Care Systems Group, USA) using a 100 cm source to surface distance, a field size of 10×10 cm^2 and 100 monitor units (MU). The dose delivered to the upstream TLDs was less than 1 Gy so that a supralinearity correction was not required for the TLD100 chips. Each measurement was performed three times, using six electron beams with nominal energies of 6, 8, 10, 12, 15 and 18 MeV. The TLDs were read using a Harshaw 5500 automatic TLD reader within 2 hours of irradiation. The time–temperature profile used for the readout also contained a low temperature 'pre-heat' treatment to minimise any effects of fading on the glow curves produced. Ratios of transmission to backscatter dose, for different combinations of TL materials, for all electron beams, were calculated to determine which combination was most sensitive to changes in electron beam quality.

Further tests were performed on the two TLD combinations which were determined to be the most promising based on the steepest gradient and highest correlation between log (Tr/Bs) and R_{50}. To check the short term reproducibility of the method, the TLDs were subjected to five cycles of irradiation and readout using a 10 MeV beam. The average value and standard deviation of the Tr/Bs ratio was recorded. To check the effect of dose variation, the TLDs were subjected to two irradiation and readout cycles, delivering 50 MU and 100 MU respectively, using an 8 MeV beam. The TLD combination with the best results for short term reproducibility and dose dependence was then assessed for long term reproducibility. The measurements were performed monthly for five months and compared to the R_{50} value determined from PDDs measured with an ionisation chamber.

Glow curve de-convolution software TLANAL®, developed by Chung et al. (2005), with the parameters proposed by Yazici and Haciibrahimoglu (2001), was also used to investigate any changes in the glow curve due to electron energy. Ratios of the individual peaks for glow curves produced from the 6, 12 and 18 MeV beams were calculated and analyzed for the downstream TL material which was determined to be the most suitable based on the prior testing.

To test the feasibility of the proposed method for quality control audits in air, three irradiations with the most suitable TL material combination were carried out using a locally fabricated prototype of an in-air jig. A stand was created to hold a mini-phantom 25 cm above the treatment couch surface. It consisted of three 15×25 cm^2 sheets of 0.2 cm thick cardboard taped together to form a triangular prism. The downstream TLDs were placed in indentations in a $10 \times 10 \times 1$ cm^3 Perspex sheet on the stand. A $10 \times 10 \times 0.5$ cm^3 lead sheet was placed above the Perspex sheet. The upstream TLDs were placed in a 0.6 cm thick Perspex tray at a depth of 0.2 cm above the lead sheet. 100 MU was delivered for the 6 MeV and 18 MeV beams with a 100 cm source to surface distance and a 10×10 cm^2 field size. The measurements were repeated with 0.2 cm and 2 cm Perspex beyond the downstream TLDs to

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