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Evaluation of TL response and intrinsic efficiency of TL dosimeters irradiated using different phantoms in clinical electron beam dosimetry

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HIGHLIGHTS

- TL dose response curves of the dosimeters for clinical electron beams.
- Evaluation of dosimeters for different phantoms.
- Sensitivity and intrinsic TL efficiency of the dosimeters for clinical electron beams.
- Effect of phantom materials in clinical electron beam dosimetry.

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ABSTRACT

The TL response of LiF:Mg,Ti microdosimeters and $CaSO_4$:Dy dosimeters were studied for 12 MeV electron beams using PMMA, liquid water and solid water (SW) phantoms. The different phantom materials affect the electron spectrum incident on the detector and it can alter the response of dosimeters to different radiation types, so this fact should be considered in clinical dosimetry. The dosimeters were irradiated with doses ranging from 0.1 up to 5 Gy using a Varian Clinac 2100C linear accelerator of Hospital Israelita Albert Einstein – HIAE using a 10 × 10 cm^2 field size and 100 cm source-phantom surface distance, with the dosimeters positioned at the depth of maximum dose. The TL readings were carried out 24 h after irradiation using a *Harshaw* 3500 TL reader. This paper aims to compare the TL response relative to ^{60}Co of the dosimeters for different phantoms used in radiotherapy dosimetry. $CaSO_4$:Dy dosimeters presented higher TL sensitivity relative to ^{60}Co and intrinsic efficiency than microLiF:Mg,Ti dosimeters for all phantoms.

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1. Introduction

In radiotherapy treatments it is necessary to verify that the patient is receiving the correct dose prescribed. For radiation dosimetry in oncology, a quality assurance program is a set of policies and procedures to preserve the quality of patient maintenance (Khan, 2010). The main objective of radiotherapy dosimetry is to determine with great accuracy the dose absorbed to the tumor. The main objectives of clinical dosimetry are to promote the radiation protection of individuals (patients and staff) and establish a radiation beam quality control (Oberhofer and Scharmann, 1979).

The high energy electron beams have broad applications in medicine, especially in the treatment of various cancers. Several organizations recommended the verification of patient dose for quality improvement in radiotherapy and the International Committee of Radiation Units and Measurements (ICRU) established, in 1976 that "all procedures involved in planning and execution of radiotherapy may contribute to a significant uncertainty in the dose administered to the patient". The recommended maximum value for the uncertainty in the dose is ±5%. Considering the uncertainties in treatment planning, patient setup, and equipment calibration, this is certainly a very rigorous requirement (ICRU, 1976; Khan, 2010).

Thermoluminescent dosimeters have a long history of ionizing radiation dosimetry in radiotherapy and, in this area, most measurements have been completed with lithium fluoride doped with

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magnesium and titanium (LiF:Mg,Ti). However, another thermoluminescent material, calcium sulfate doped with dysprosium ($CaSO_4$:Dy), has been studied for application in the same area (Robar et al., 1996; Nunes and Campos, 2008; Bravim et al., 2011; Matsushima et al., 2012).

Up to now studies showed that the correction factors in electron beams of LiF TLDs depend on some factors including the electron energy spectrum incident on the dosimeter surface, the average electron energy incident on the phantom surface, the size and density of the TLD material, the phantom material and the depth of irradiation of the TLDs. Mobit et al. (1996) determinated experimentally and theoretically (using Monte Carlo simulations) the energy correction factors of TLD-100 in megavoltage electron beams. For mono-energetic and broad spectrum didn't present significant difference in the energy correction factor comparing with Monte Carlo simulation and principally to low-energy electron beams using 5 mm thick TLD irradiated at a depth different of d_{max} the energy correction factor will increase (Mobit et al., 1996).

In routine dosimetry solid phantoms are normally used but in the majority protocols water is the reference material. There are some epoxy-resin materials manufactured commercially – Solid Water™, Virtual Water™, Plastic Water™ and WTe – McEwen and Niven characterized Virtual WaterTM in megavoltage photon and electron beams and determinated the fluence correction factor. This material can be considered water equivalent and presented a level of uncertainty that enables it to perform dosimetry in solid phantoms (McEwen and Niven, 2006). The different phantom materials used in radiotherapy dosimetry affect the electron spectrum incident on the detector and it can alter the response of dosimeters to different radiation types, so this fact should be considered in clinical dosimetry.

This paper aims to compare the TL response of LiF:Mg,Ti microdosimeters (TLD-100 from Harshaw) and $CaSO_4$:Dy dosimeters (produced and marketed by Laboratory of Dosimetric Materials of the Instituto de Pesquisas Energéticas e Nucleares – IPEN/CNEN) for 12 MeV clinical electron beams for different phantoms used in radiotherapy dosimetry.

2. Materials and methods

Before irradiation, 15 dosimeters of each type were heat-treated: LiF:Mg,Ti-microdosimeters – 400 °C/1 h (McKeever et al., 1995) using a furnace Vulcan model 3-550 PD plus 100 °C/2 h using a furnace FANEN model 315; $CaSO_4$:Dy – 300 °C/3 h (Campos and Lima, 1986) using a furnace Vulcan model 3-550 PD. The dosimeters were irradiated with absorbed dose in water of 1735 mGy using a ^{60}Co gamma radiation source of the Laboratory of Dosimetric Materials (LMD/IPEN-CNEN/SP) (656.4 MBq) in electronic equilibrium conditions (3 mm PMMA thickness plates) and separated into groups according to their sensitivity. The TL readings were performed using a TL reader Harshaw model QS 3500.

To obtain a dose response curve to ^{60}Co gamma radiation the dosimeters were irradiated in PMMA phantom with absorbed dose ranging from 5×10^{-4} to 10 Gy in the Laboratory of Instrument Calibration (LCI/IPEN-CNEN/SP) in electronic equilibrium conditions. To obtain a dose response curve to clinical electron beam (12 MeV) the groups of dosimeters were positioned in the different phantoms at the depth of maximum dose, 2.4 cm, and irradiated with nominal standard absorbed doses in water ranging from 0.1 up to 5 Gy using a Varian model Clinac 2100C linear accelerator of the Hospital Israelita Albert Einstein (HIAE) (Fig. 1). The depth of maximum dose used was the same for all phantoms considering that the variation of 1 mm in the depth maximum dose as function of the phantom material results in a difference in the absorbed dose smaller than 0.5% (Varian Medical System, 2011).

Fig. 1. Varian model Clinac 2100C linear accelerator of the Hospital Israelita Albert Einstein.

To ensure adequate electron backscatter, 5 cm of water equivalent material was used under the dosimeters. The PMMA and solid water phantoms consisted of 30×30 cm^2 plates and the liquid water phantom was a PMMA cubic box with dimensions $40.0 \times 40.0 \times 40.0$ cm^3 filled with distilled water. Fig. 2 shows the PMMA phantom and TLD electron beam irradiation setup. The radiation field size applied was 10×10 cm^2 with a source-detector distance of 100 cm.

The TLDs were read out 24 h after the irradiation and each presented value is the average of five TL readings of $CaSO_4$:Dy and microLiF:Mg,Ti dosimeters of the same group and the error bars are the standard deviation of the mean (1σ) and the TL responses relative for each phantom was obtained. The TL sensitivity is given by Eq. (1) and the relative response to ^{60}Co per unit dose obtained by Eq. (2). The repeatability (R), lower detection limit (LDL) and intrinsic efficiency (IE) were calculated with the Eq. (3)–(5) respectively:

$$\bar{S} = \frac{\overline{M}}{D} \tag{1}$$

$$\bar{S}_{12\ \mathrm{MeV}/60\mathrm{CO}} = \frac{\bar{S}_{12\ \mathrm{MeV}}}{\bar{S}_{60\mathrm{Co}}} \tag{2}$$

Fig. 2. PMMA phantom and TLDs electron beam irradiation setup.

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