Evaluation of TL response and intrinsic efficiency of TL dosimeters irradiated using different phantoms 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 can also alter the dosimeters response to different radiation types, so this fact should be considered in clinical dosimetry. The dosimeters were irradiated with doses ranged from 0.1 up to 5 Gy using a linear accelerator Clinac 2100C Varian of Hospital Israelita Albert Einstein - HIAE using a 10x10 cm^2 field size, 100 cm source-phantom surface distance and the dosimeters were positioned at the depth of maximum dose. The TL readings were carried out 24h after irradiation using a *Harshaw* 3500 TL reader. This paper aims to compare the TL response of the dosimeters for different phantoms used in radiotherapy dosimetry.

Keywords: Thermoluminescent Dosimetry, Electron Beams, Lithium Fluoride, Calcium Sulphate, Phantoms.

1. Introduction

In 1950's Daniels and his co-works made the first applications of TL to dosimetry when they used lithium fluoride (LiF) to made radiation measurements after bomb test (Cameron, Suntharalingam and Kenney, 1968). With the advancements in the use of nuclear technology for medical purpose, there was a major concern related to the detection and evaluation of radiation dose for control (Oberhofer and Scharmann, 1979).

In radiotherapy treatments is necessary to be sure that the patient is receiving the correct dose prescribed. For radiation dosimetry in oncology, a quality assurance program is fundamentally 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 precision the dose absorbed to the tumor. The clinical dosimetry main objectives 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 application 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) establish, 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 values for the uncertainty in the dose range of ± 5%. Considering the uncertainties in treatment planning, patient setup, and equipment calibration, this is certainly a very rigorous requirement (ICRU, 1976; Khan, 2010).

The thermoluminescent dosimeters have a long history of ionizing radiation dosimetry in radiotherapy and, in this area, most measurements have been done with lithium fluoride doped with 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).

The different phantom materials used to radiotherapy dosimetry can alter the dosimeters response according 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) to 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 - 400ºC/1h using a furnace Vulcan model 3-550 PD plus 100ºC/2h using a furnace FANEN model 315; $CaSO_4$:Dy - 300ºC/3h using a furnace Vulcan model 3-550 PD. The dosimeters were irradiated with 1,735 mGy using a ^{60}Co gamma radiation source of the GMR/IPEN (656.4 MBq) at electronic equilibrium conditions (3 mm PMMA thickness plates) and separated in groups according to their sensitivity. The TL readings were performed using a TL reader Harshaw model QS 3500.

To perform the irradiations in the clinical electron beam (12 MeV) using a linear accelerator Varian model Clinac 2100C of the Hospital Israelita Albert Einstein (HIAE) (Figure 3) the groups of dosimeters were positioned at the different phantoms at the depth of maximum dose, 2.4 cm, and the dose ranged from 0.1 up to 5 Gy. To ensure the adequate electrons backscatter 5 cm of water equivalent material was used. The PMMA and solid water phantoms consist of 30x30 cm^2 plates and the liquid water phantom is a PMMA cubic box with dimensions 40.0x40.0x40.0 cm^3 filled with distilled water. In the figures 1a, 1b and 1c are shown different views of the liquid water phantom positioned to irradiation. Figure 2 shows the PMMA phantom and TLDs electron beam irradiation set up. The radiation field size applied was 10 x 10 cm^2 with a source-detector distance of 100 cm.

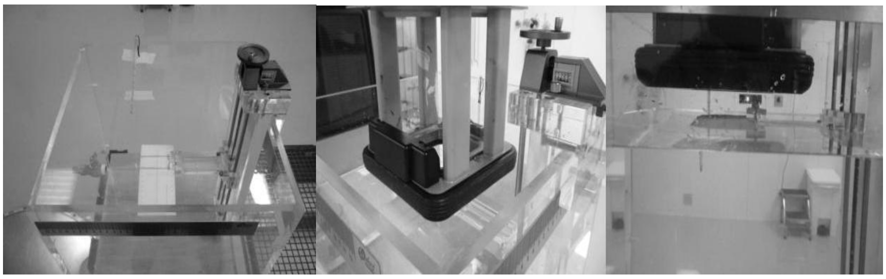
(a) (b) (c)

Figure 1: (a) Liquid water phantom before irradiation; (b) and (c) Liquid water phantom positioned to irradiation.

Figure 2: PMMA phantom and TLDs electron beam irradiation set up.

The TL responses were carried out 24 h after the irradiation and each presented value is the average of five TL readings of $CaSO_4$:Dy and micro LiF:Mg,Ti dosimeters of the same group and the error bars the standard deviation of the mean (1δ). The repeatability, lower detection limit (LDL) and intrinsic efficiency (IE) were calculated with the respective equations:

$$\text{Repeatability}\,(\%) = \frac{\sigma}{\sqrt{\text{n}} \cdot \overline{R}} \cdot 100 \qquad (1)$$

$$LDL = \overline{R(0)} + 3 \cdot \sigma \qquad (2)$$

$$IE = \frac{\overline{R}}{D \cdot m} \qquad (3)$$

where: σ is the standard deviation, n is the number of dosimeters, $\overline{R}$ is the average TL response (μC) of the dosimeters of each group to the absorbed dose D (Gy), $\overline{R(0)}$ is the average response (μC) of non-irradiated dosimeters and m the mass (mg) of the dosimeter.

3. Results

The table 1 presents the average TL sensitivity relative to ^{60}Co response and the repeatability (equation 1) of the $CaSO_4$:Dy and micro LiF:Mg,Ti dosimeters for liquid water, solid water and PMMA phantoms.

TABLE 1- TL sensitivity and repeatability of microLiF:Mg,Ti and $CaSO_4$:Dy for liquid water, solid water and PMMA phantoms.

	TL sensitivity relative to ^{60}Co					
	Liquid Water		Solid water		PMMA	
	$CaSO_4$:Dy	µLiF:Mg,Ti	$CaSO_4$:Dy	µLiF:Mg,Ti	$CaSO_4$:Dy	µLiF:Mg,Ti
sensitivity	0.88	0.74	0.84	0.67	0.95	0.69
deviation	0.010	0.030	0.020	0.030	0.030	0.040
Repeatability %	±0.66	±1.9	±1.3	±1.9	±1.5	±2.4

$CaSO_4$:Dy presents average relative TL response of 0.89 ± 0.56 (6.25%), the lower response is 0.84 to solid water phantom and the maximum 0.95 to PMMA phantom; the microLiF:Mg,Ti presents average relative TL response of 0.70 ± 0.036 (5.15%), the lower response is 0.67 to solid water phantom and the maximum 0.74 to liquid water phantom. For both materials the TL response was affected by the phantom material and in both cases the deviation is higher than 5%.

The repeatability of 5 TL readings for both materials and different phantoms is less than ≤ 1.5% for $CaSO_4$:Dy and ≤ 2.4% for microLiF:Mg,Ti.

The average intrinsic efficiency calculated (equation 3) was 0.058 ± 0.006 $\mu C.Gy^{-1}.mg^{-1}$ (10.34%) and 0.99 ± 0.09 $\mu C.Gy^{-1}.mg^{-1}$ (9.09%) to microLiF:Mg,Ti and $CaSO_4$:Dy dosimeters, respectively, for all phantoms, as expected, considering that the phantom material affects the TL response.

The lower detection limits were calculated for each material and phantom (equation 2), the obtained values are $(8.00\pm0.18)x10^{-4}$ Gy for $CaSO_4$:Dy and $(3.50\pm0.09)x10^{-4}$ Gy for microLiF:Mg,Ti for all phantoms studied.

Figure 3 shows the dose-response curves of microLiF:Mg,Ti and $CaSO_4$:Dy to liquid water, solid water and PMMA phantoms. From LDL up to 5 Gy the dose-response curves presented a linear behavior for the three phantoms studied. The LDL was $(8.00\pm0.18)x10^{-4}$ Gy for $CaSO_4$:Dy and $(3.50\pm0.09)x10^{-4}$ Gy for microLiF:Mg,Ti for all phantoms studied.

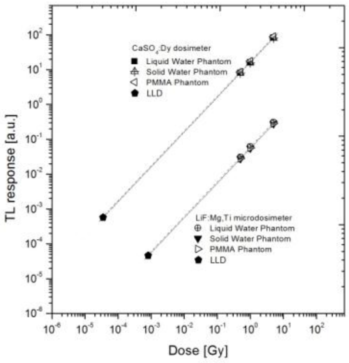

Figure 3- Dose-response curves of microLiF:Mg,Ti and $CaSO_4$:Dy for liquid water, solid water and PMMA phantoms.

4. Discussions and Conclusion

For the three phantoms studied, the dose-response curves presented a linear behavior for doses from LDL up to 5 Gy. All repeatability values are better than the recommended limit of ± 5%. $CaSO_4$:Dy dosimeters showed a TL sensitivity variation of 13% between solid water and PMMA and water phantoms and microLiF:Mg,Ti dosimeters showed a TL sensitivity variation of 9,5% to liquid water and solid water phantoms. Thus, the phantom materials can affect the results of the 12 MeV clinical electron beam dosimetry using microLiF:Mg,Ti e $CaSO_4$:Dy as thermoluminescent detector.

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