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Dosimetric study of thermoluminescent detectors in clinical photon beams using liquid water and PMMA phantoms

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ABSTRACT

The purpose of this study was the dosimetric evaluation of thermoluminescent detectors of calcium sulphate doped with dysprosium ($CaSO_4$:Dy) produced by IPEN compared to the TL response of lithium fluoride doped with magnesium and titanium (LiF:Mg,Ti) dosimeters and microdosimeters produced by Harshaw Chemical Company to clinical photon beams dosimetry (6 and 15 MV) using liquid water and PMMA phantoms.

1. Introduction

Radiotherapy is one of three principal treatment modalities used in the treatment of malignant diseases such as cancer; the other two are chemotherapy and radiosurgery (IAEA, 2000). In contrast to other medical specialties that rely mainly on the clinical knowledge and experience of medical specialists, radiotherapy, with its use of ionizing radiation in treatment of cancer, relies heavily on modern technology and the collaborative efforts of several professionals whose coordinated team approach greatly influences the outcome of the treatment (IAEA, 2005).

Many institutions use megavoltage photon and electron beams for the treatment of malignant diseases. The decision of choosing particular beam energy depends on the depth of the tumor from the surface of the patient body (Chatterjee et al., 2009). The rapid fall of dose with depth allows sparing of the deep-seated organs at risk. Accurate and precise dosimetry of the clinical photon and electron beams, including measurement of beam energy, is fundamental in ensuring a patient's radiation safety and in optimizing radiation therapy practices. It is generally agreed that 5% accuracy in clinical dosimetry is required for radical radiation therapy (Nisbet and Thwaites, 1997; Nelson et al., 2010).

Thermoluminescent dosimetry, among relative dosimetry techniques, has gained a widespread use due to its simplicity, excellent spatial resolution and the ability for integrating the absorbed dose over extended periods of time without the need for a bias supply. The main use of thermoluminescent dosimetry is in personnel dosimetry and in studies of photon and electron beam dose distributions in phantoms (Robar et al., 1996; McKeever et al., 1995). In radiotherapy the aim of dosimetry is to make sure that the dose to the target volume is as prescribed while minimizing the dose to the surrounding normal tissue (Kron, 1999; Bilski et al., 2004).

In order to ensure the dosimetry accuracy of radiation techniques, national and international regulatory bodies conduct dosimetry audits using thermoluminescent dosimeters (TLDs) such as LiF:Mg,Ti (TLD 100). This work aimed the dosimetric study and applicability of the thermoluminescent dosimeters of $CaSO_4$:Dy produced at IPEN and LiF:Mg,Ti and LiF:Mg,Ti microdosimeters produced by Harshaw Chemical Company to be applied in clinical photon beams dosimetry (6 and 15 MV) using liquid water and PMMA phantom.

2. Materials and methods

To establish a consistent set of TL dosimeters, two hundred $CaSO_4$:Dy TLDs produced by Instituto de Pesquisas Energéticas e Nucleares (IPEN); two hundred LiF:Mg,Ti (TLD 100) and one hundred five microLiF:Mg,Ti (TLD 100) produced by *Harshaw Chemical Company* were used (Table 1). To perform the irradiations two different phantoms (Table 1) were used: a liquid water phantom and a PMMA phantom. The dimensions of three TLDs types are shown in Fig. 1.

The dose-response curves were obtained to the cobalt-60 gamma radiation source from Laboratory of Dosimetric Materials/LMD-IPEN (A=0.656 GBq on 09/12/2008). The TLDs were

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Table 1
Dosimetric materials—TLDs and irradiation phantoms.

Material	Composition	Dimensions
TLD type		
IPEN	$CaSO_4$:Dy	6 mm diameter × 0.8 mm thick
TLD-100	LiF:Mg,Ti	3.15 mm × 3.15 mm × 0.9 mm
Micro TLD-100	LiF:Mg,Ti	1 mm × 1 mm × 1 mm
Phantom	**Material**	**Dimensions**
Cubic liquid water	PMMA and distilled water	$30 \times 30 \times 30\ cm^3$
Polymethylmethacrylate (PMMA)	PMMA plates	$30 \times 30\ cm^2$

Table 2
Pre-irradiation heat treatment parameters.

Dosimeter type	Equipment	Heating Temperature	Period
$CaSO_4$:Dy	Furnace Vulcan	300 °C	3 h
LiF:Mg,Ti	Furnace Vulcan	400 °C	1 h
		+	+
	Surgical heater	100 °C	2 h

Fig. 1. Dimensions of the TLDs three types: $CaSO_4$:Dy, LiF:Mg,Ti and micro-LiF:Mg,Ti, respectively.

irradiated in air and positioned on PMMA plates to ensure the electronic equilibrium conditions. The dosimeters were selected and divided in groups according to their sensitivities ($\pm 5\%$). To protect the dosimeters to be irradiated in the liquid water phantom they were packed in plastic films and positioned at depth of maximum dose. The specifications followed for irradiation parameters were that recommended by the Technical Reports Series No. 398 (TRS 398) from International Atomic Energy Agency (IAEA): field size—$10 \times 10\ cm^2$; TLDs-source distance—100 cm and depth of maximum dose for 6 and 15 MV—1.5 cm and 2.9 cm, respectively.

The TLDs were irradiated in the linear accelerators VARIAN model Clinac 2100C of two different Hospitals: Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo (HC-FMUSP) and Sociedade Beneficente Israelita Brasileira – Hospital Albert Einstein (HAE).

The equipments for the TLDs pre-irradiation heat treatment used were a furnace Vulcan model 3-550 PD and a surgical heater Fanem model 315-IEA 11200. The pre-irradiation heat treatment parameters are presented in the Table 2. The thermoluminescent responses were taken in a TL reader Harshaw model 3500.

The TL responses were evaluated and the dose-response curves of each dosimeter type and its individual sensitivities were obtained to 6 and 15 MV and radiation doses: 0.1, 0.5, 1.0; 5.0 and 10.0 Gy. Each presented value represents the average of 10 TL responses and the error bars the standard deviation of the mean (1σ).

3. Results

Figs. 2–4 present the dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti to clinical photon beams (6 and 15 MV) for irradiation with liquid water and PMMA phantom for both hospitals' equipments. Fig. 5 presents the average TL sensitivity of each dosimeter type according to the dose, beam megavoltage and phantom.

According to the analysis of correlation coefficients (R) of Figs. 2–4 of the irradiations performed in the hospitals (with our reproducibility conditions) can be observed a linear behavior to the dose range from 0.1 to 5 Gy, dose higher than that reported

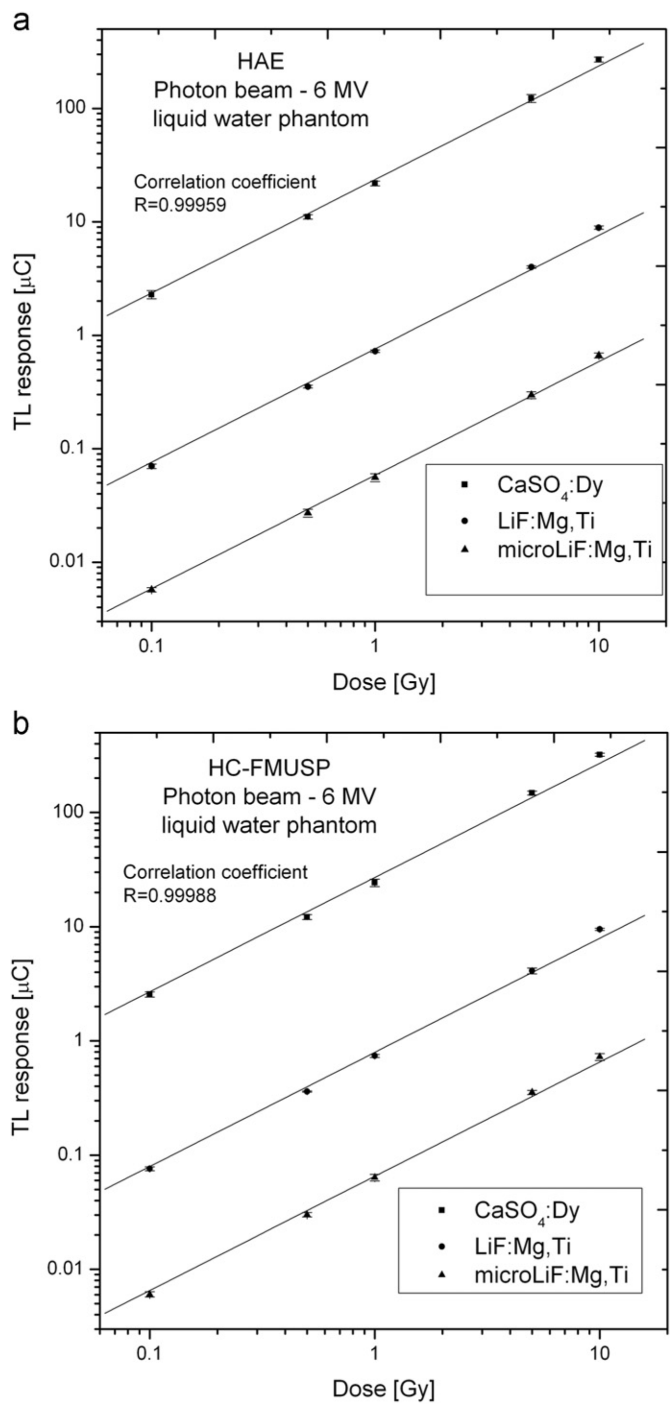

Fig. 2. Dose-response curves to 6 MV photons and liquid water phantom for irradiation: (a) at HAE; (b) at HC-FMUSP.

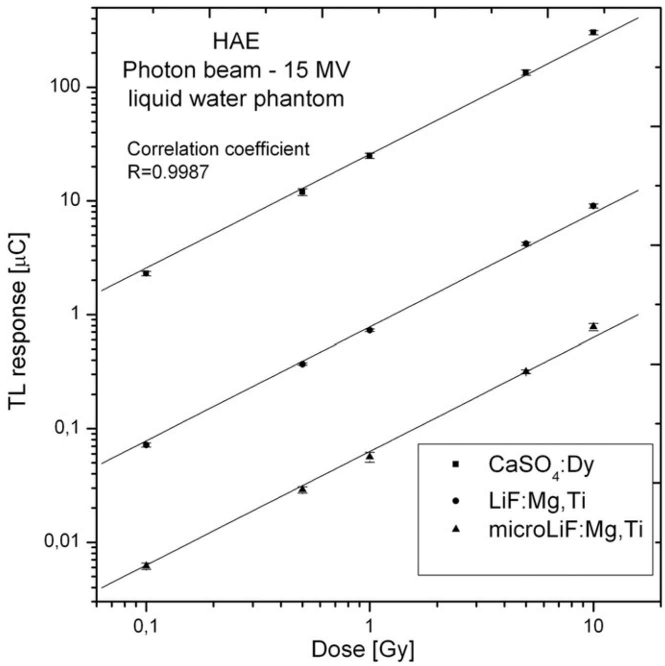

Fig. 3. Dose-response curves to 15 MV photons and liquid water phantom for irradiation at HAE.

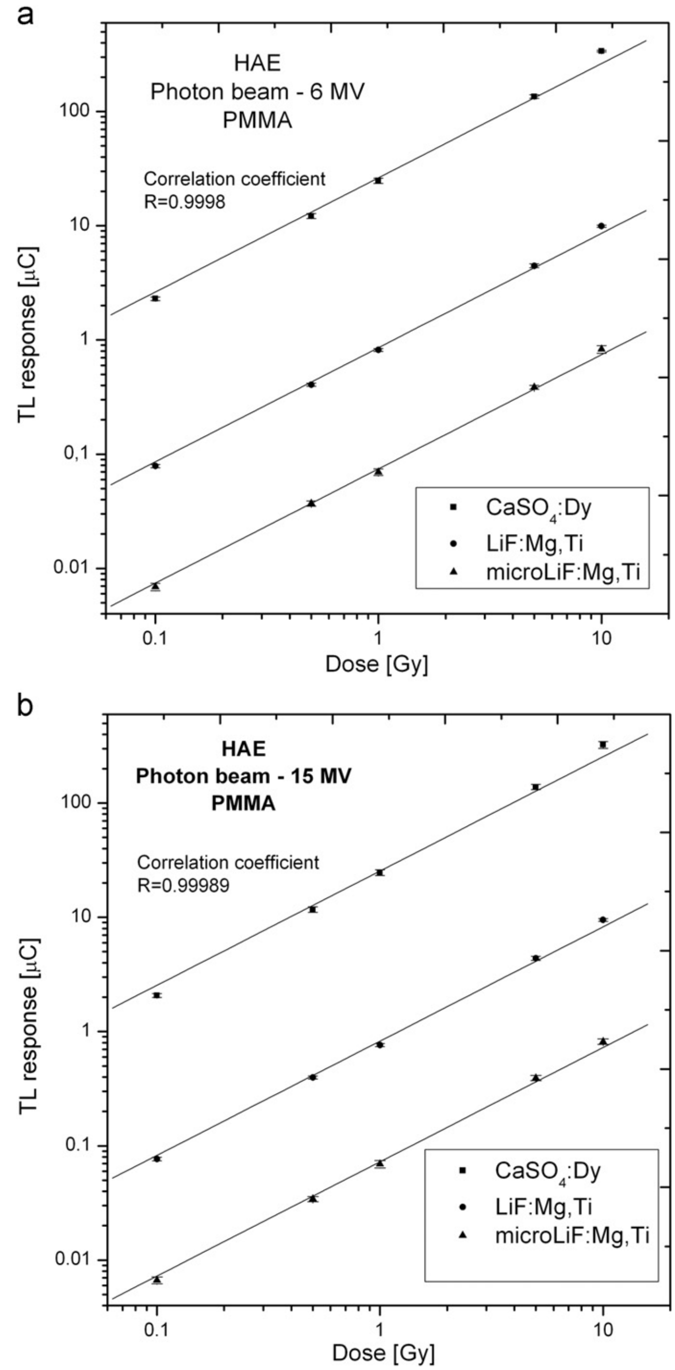

Fig. 4. (a) Dose-response curves to 6 MV photons and PMMA phantom for irradiation at HAE; (b) Dose-response curves to 15 MV photons and PMMA phantom for irradiation at HAE.

by other studies (Moscovitch et al. 1993; Moscovitch and Horowitz, 2007). These references showed a non-linear behavior with a supralinear tendency for doses above 1 Gy.

The TL sensitivities ($\mu C\, Gy^{-1}$) and the intrinsic efficiency ($\mu C\, Gy^{-1}\, mg$) since the TL response is an effect dependent on the mass and area of the dosimeter (Mahesh et al., 1989; McKeever et al., 1995) were calculated and the obtained results indicate that the $CaSO_4$:Dy dosimeters present relative TL sensitivity approximately 28 and 334 times higher than LiF:Mg,Ti and microLiF:Mg,Ti dosimeters, respectively, and relative intrinsic efficiency 330 and 7900 times greater than LiF:Mg,Ti and microLiF:Mg,Ti dosimeters, respectively.

The average TL responses reproducibility of the three dosimeters types was evaluated for 6 and 15 MV photon beams and liquid water and PMMA phantoms and is shown in the Table 3.

The TL reproducibilities varies from 4.34% to liquid water phantom to 2.32% to PMMA phantom for clinical photon beams (6 and 15 MV). Analyzing Table 3 it can be noted that the TL response variation was highest for the irradiations using water phantom for $CaSO_4$:Dy. This may be due to the difficulty in TLDs positioning submerged in water. In radiotherapy, these results were expected because errors greater than 5% can cause an accident in the treatment, affecting the estimated dose (Nisbet and Thwaites, 1997; Nelson et al., 2010). These results are in accordance with the references found in literature (McKeever et al., 1995; Bassinet et al., 2010).

4. Conclusions

The dose response curves obtained present linear behavior in the 6 and 15 MV photons dose range from 0.1 to 5 Gy (according to the correlation coefficients of the curves studied). For doses higher than 10 Gy can be observed the beginning of the supralinearity behavior.

The $CaSO_4$:Dy dosimeters presents intrinsic efficiency to 6 and 15 MV clinical photons approximately 330 and 7900 times greater than LiF:Mg,Ti and microLiF:Mg,Ti dosimeters, respectively.

No differences on the TL sensitivities were observed as a function of the irradiation equipments (HC and HAE). The average TL sensitivity calculated for each dose remains practically unchanged. Analyzing the Fig. 5 can be concluded that the $CaSO_4$:Dy TLDs have no energy dependence response in the energy range studied.

The TL response reproducibility of the three dosimeters type studied is better than $\pm 4.34\%$ for both 6 and 15 MV clinical photon beams to liquid water and PMMA phantom, lower than 5% required for radiation therapy.

The $CaSO_4$:Dy pellets developed and produced in commercial scale by the Laboratory of Dosimetric Materials/IPEN can represent

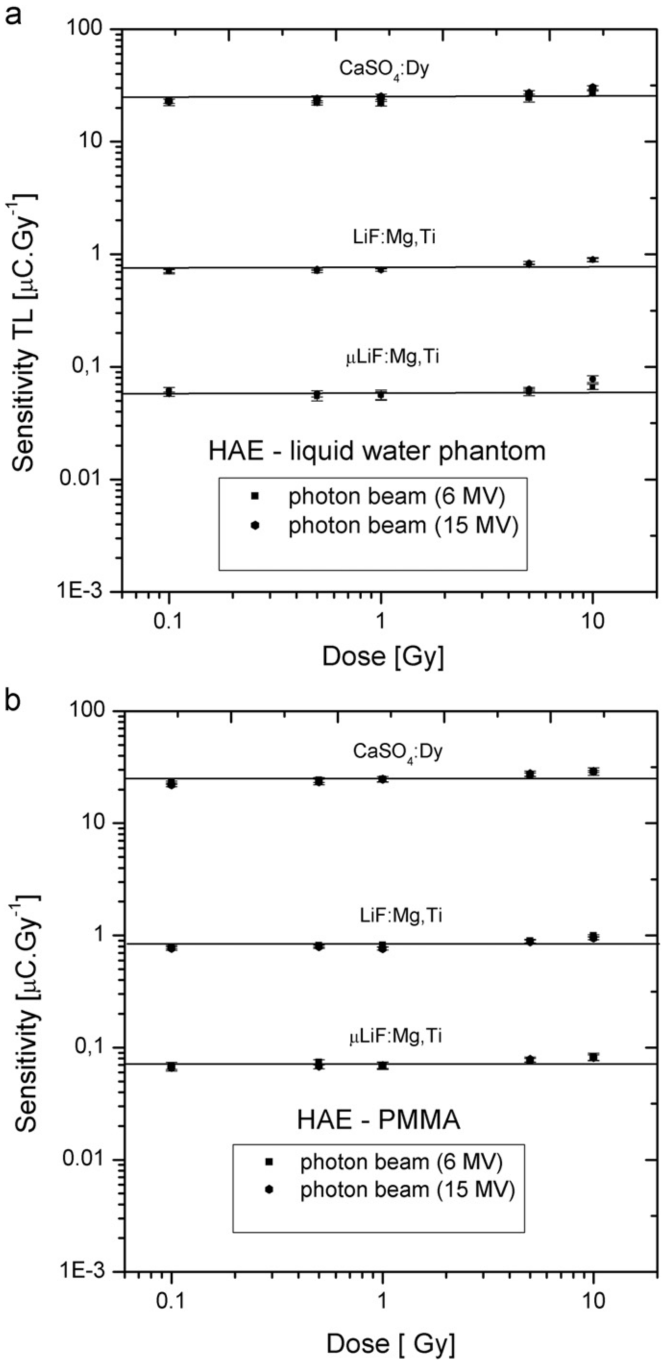

Fig. 5. Average TL sensitivity to 6 and 15 MV clinical photon beams for irradiation at HAE: (a) liquid water phantom; (b) PMMA phantom.

a cheaper alternative to the imported chips TLD-100 to be applied in clinical photon beams dosimetry and its main advantage is the high TL sensitivity.

Table 3
TL average reproducibility of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters according to the hospital, beam megavoltage and phantom.

Irradiation place	Photon beam	Phantom	Reproducibility (%)		
			$CaSO_4$:Dy	LiF:Mg,Ti	microLiF:Mg,Ti
HC-FMUSP	6 MV	Liquid water	4.34	1.21	2.23
HAE	6 MV	Liquid water	1.67	1.18	2.57
	15 MV	Liquid water	1.95	0.797	2.08
	6 MV	PMMA	2.07	1.22	2.32

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