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OSL and TL response characterization of LiF:MG,Ti microdosimeters to be applied to VMAT quality assurance

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HIGHLIGHTS

- Applicability of LiF:Mg,Ti microdosimeters in dosimetry to VMAT Rapid Arc.
- Evaluation of TL and OSL response of LiF:Mg,Ti microdosimeters to VMAT technique.
- Comparison of results using TL and OSL techniques and data given by Eclipse 11.0.

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ABSTRACT

This paper aims to evaluate the feasibility of applying LiF:Mg,Ti microdosimeters as a new method of dosimetry to volumetric-modulated arc therapy (VMAT) RapidArc. The response of microdosimeters presented a maximum variation of $\pm 3.18\%$ and $\pm 0.510\%$ using optically stimulated luminescence (OSL) and thermoluminescence (TL) techniques, respectively. Although studies were conducted on LiF:Mg,Ti microdosimeters previously, the microdosimeters in this study showed precision and high potential of application in VMAT dosimetry and in the verification of treatment planning using the VMAT technique.

1. Introduction

Optically stimulated luminescence (OSL) is a luminescent signal emitted by a semiconductor or an insulator previously irradiated when exposed to light. The intensity of the OSL signal is a function of the radiation dose absorbed by the material. The process is similar to thermoluminescence (TL), but it differs in the stimulation: instead of thermal stimulation, the defects in the detector are stimulated by optical means in OSL (Botter-Jensen et al., 2003).

TL dosimeters are widely used in many hospitals for external dosimetry during radiotherapy treatment. However, the use of OSL is growing and OSL dosimeters have recently been studied and investigated for medical dosimetry applications (Yukihara and McKeever, 2011).

Volumetric-modulated arc therapy (VMAT) is a new method of treatment that has revolutionized radiotherapy, with benefits and lower toxicity in the treatment of patients. With this treatment, it is possible to minimize the radiation dose to the healthy tissues and escalate the dose to the target volume (tumor) (Hall, 1988; Mundt, 2005; Bortfeld, 2006). Quality assurance is essential to verify the operation of all components involved in the process of treatment planning and dose delivery. Several organizations have recommended the verification of patient dose for quality improvement in radiotherapy, with the recommended maximum values for the uncertainty in the dose range being $\pm 5\%$ (ICRU, 1976; AAPM, 1983).

The dosimetry of ionizing radiation is essential for radiological protection programs to ensure quality and license equipment. The conventional intensity-modulated radiation therapy (IMRT) and VMAT are new techniques responsible for transforming radiotherapy, with benefits and a lower toxicity in the treatment of patients (Hall, 1988; Mundt, 2005; Bortfeld, 2006).

Until recently, few well-established methods of quality assurance exist for IMRT. To guarantee that the IMRT services accord the highest clinical standards, each institution should invest in a quality assurance program for treatment planning and dose absorbed (Palta et al., 2008). As the VMAT equipment is still being deployed, it is important to optimize and facilitate quality control mechanisms to ensure that tests are performed in order to

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preserve above all the patient, but the equipment as well (Hancock, 2008). This paper aims to compare the behavior of the TL and OSL response of microLiF:Mg,Ti dosimeters to photon clinical beams and to evaluate the feasibility of applying this technique in a new method of dosimetry to VMAT RapidArc. The TL sensitivity relative to ^{60}Co, lower limit detection (LLD), and dose–response curves are analyzed.

2. Materials and methods

The LiF:Mg,Ti microdosimeters produced by the Hashaw Chemical Company employed a pre-irradiation heat treatment of 400 °C for 1 h using a VULCAN model 3-550PD furnace and 100 °C for 2 h using a FANEN model 315-IEA 11200 furnace. The dosimeters of repeatability $> \pm 5\%$ were selected and calibrated using a ^{60}Co gamma radiation source from the Centro de Tecnologia das Radiações (CTR-IPEN/CNEN). Three cycles of heat treatment, irradiation with ^{60}Co gamma radiation (656.4 MBq) in air under electronic equilibrium conditions, and TL/OSL reading were carried out. The individuals and average thermoluminescent and optically stimulated luminescent responses of the dosimeters were obtained, and the microdosimeters were separated into groups of five dosimeters according to their sensitivity.

The dose–response curves to 6-MV photon clinical beams were obtained using a linear accelerator (Clinac Varian 6EX) from the Hospital Israelita Albert Einstein (HIAE) with doses ranging from 30 up to 1400 cGy. The irradiations were carried out using a polymethacrylate (PMMA) phantom with absorbed doses corrected to the maximum dose depth by the planning system of the equipment.

To evaluate the viability of application of LiF:Mg,Ti microdosimeters in VMAT dosimetry, the microdosimeters were irradiated in the linear accelerator Truebeam STx of Varian Medical System of HIAE with a 6-MV photon beam. To perform these irradiations, a specific PMMA phantom containing five cavities with different geometric shapes was made. The project of this phantom is shown in Fig. 1a. Cavity 5 was defined as the target (tumor to be treated) and the other cavities as possible organs at risk. A group of eight microdosimeters were positioned inside each cavity, and a 10-cm-thick PMMA block was placed on the PMMA phantom (Fig. 1b). This PMMA block was used to ensure the backscattered radiation. All cavities were irradiated with homogeneous doses.

The obtained results using the LiF:Mg,Ti microdosimeters were compared with data from the planning system of the HIAE, Eclipse 11.0 of Varian Medical System. The planning ensured that no isodose line passes through cavities, therefore providing a homogeneous dose of radiation inside each cavity. The isodose lines provided by the planning system of the linear accelerator Truebeam STx of Varian Medical System of HIAE are presented in Fig. 2.

Each presented value of the dose–response curves and the phantom irradiation is the average of five and eight measurements of dosimeters of the same sensitivity, respectively. The error bars represent the standard deviation of the mean (1σ) with a confidence interval of 95%. The sensitivity (S) and LLD were calculated with Eqs. (1) and (2), respectively:

$$S\ (\text{units Gy}^{-1}) = \frac{\overline{R}}{D} \quad (1)$$

$$\text{LLD (Gy)} = \overline{R} + 3\,\sigma \quad (2)$$

where "$\overline{R}$" is the mean of the TL/OSL response of the dosimeters of each group, "D" is the absorbed dose, and "σ" is the standard deviation.

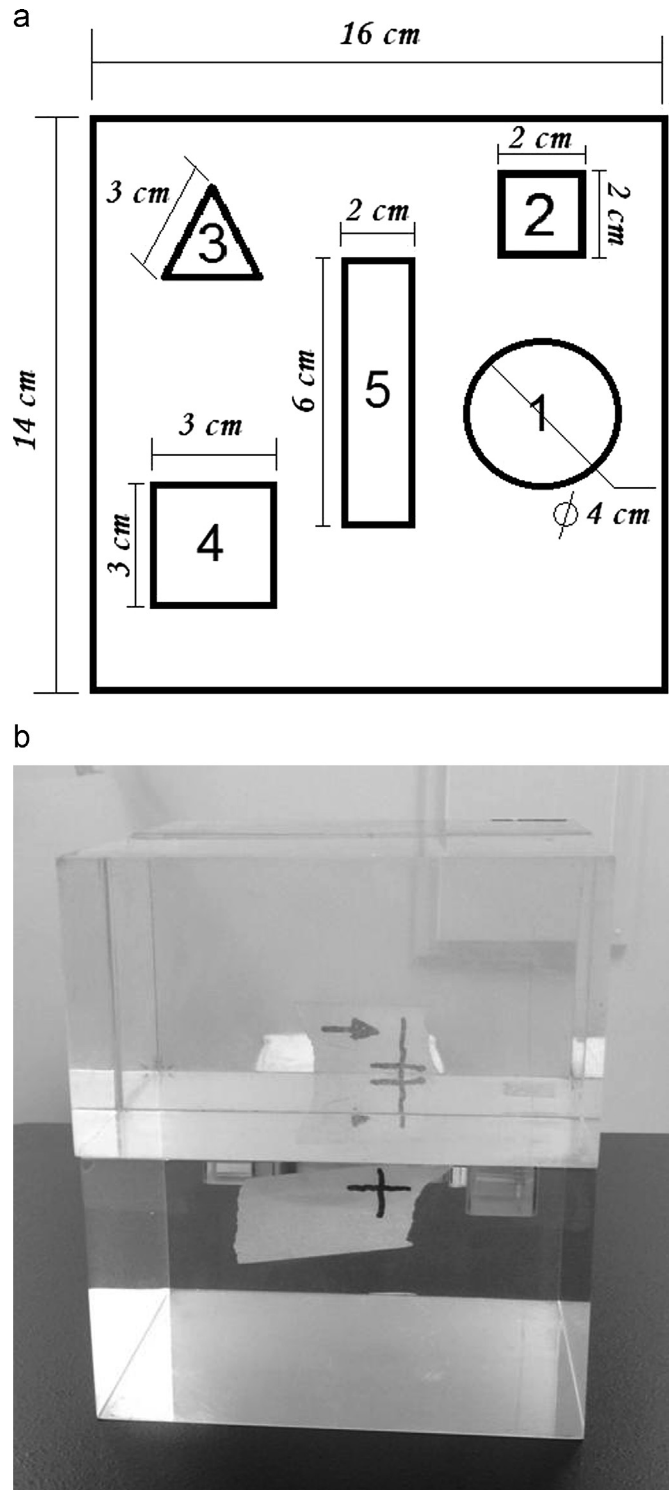

Fig. 1. (a) Project of PMMA phantom containing five cavities and (b) PMMA block used upon phantom with microdosimeters positioned to irradiation.

The thermoluminescent and optically stimulated luminescent responses were obtained using the TL reader Harshaw model 4500 and the OSL reader Risø model TL/OSL-DA-20, respectively. The OSL measurements of the microdosimeters were stimulated with Blue Led NICHIA – NSPB-500AS (470 nm) the Hoya U-340 filter was used for OSL signal readings.

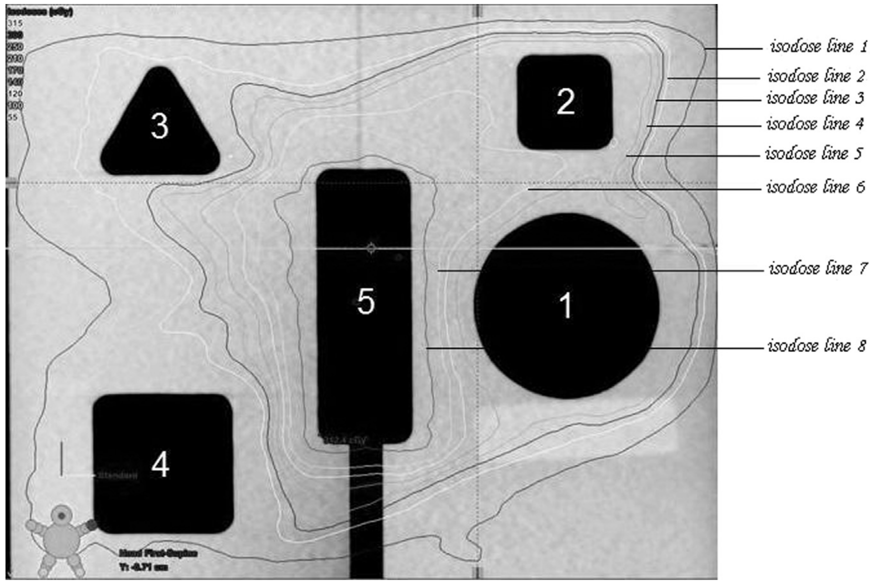

Fig. 2. Dose distribution in the phantom with five cavities – isodose lines provided by planning system.

3. Results

The TL and OSL dose–response curves of microLiF:Mg,Ti dosimeters to a 6-MV photon beam at the absorbed dose range studied (30–1400 cGy) are presented in Fig. 3.

A linear behavior from 30 up to 1000 cGy and a tendency of saturation of the OSL and TL response for doses higher than 1000 cGy were observed.

The TL sensitivity to the 6-MV photon beam relative to ^{60}Co (S_{6MV}/S_{60Co}) and the LLD of LiF:Mg,Ti microdosimeters obtained are shown in Table 1. The minimum, maximum, and average absorbed doses evaluated by the LiF:Mg,Ti microdosimeters and the average dose given by the planning system of HIAE to VMAT Varian RapidArc are shown in Table 2.

The agreement between the absorbed dose given by the planning system and that obtained by the LiF:Mg,Ti microdosimeters is shown in Fig. 4a and b.

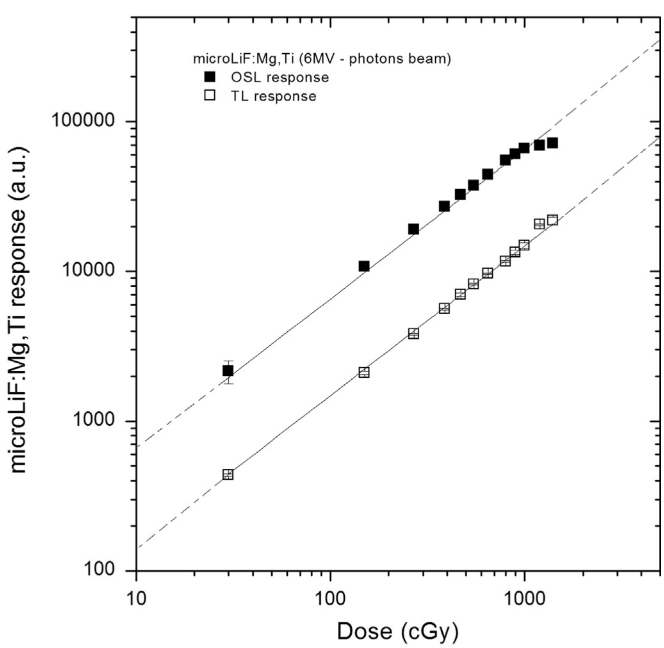

Fig. 3. OSL and TL dose–response curves of microLiF:Mg,Ti to 6-MV photon beam from linear accelerator Varian 6EX of HIAE.

Table 1
TL and OSL sensitivity to 6-MV photon beam relative to ^{60}Co and LLD of LiF :Mg,Ti microdosimeters to 6-MV photon beam.

S_{6MV}/S_{60Co}	OSL	TL
	0.06778	1019
LLD [Gy]	5.2×10^{-2}	4.7×10^{-4}

Based on the OSL measurements using microLiF:Mg,Ti, the minimum and maximum absorbed doses ranged from 299.9 up to 303.9 cGy for the target of cavity 5 ($\pm$0.0300%), from 149.5 up to 153.0 cGy for cavity 1 ($\pm$0.340%), from 197.9 up to 203.2 cGy for cavity 2 ($\pm$2.02%), from 99.90 up to 103.7 cGy for cavity 3 ($\pm$0.100%), and from 49.61 up to 54.14 cGy for cavity 4 ($\pm$0.780%).

The variation of the average dose inside each cavity measured with the LiF:Mg,Ti microdosimeters compared with the absorbed dose given by the planning system was $\pm$0.720%, $\pm$0.250%, $\pm$0.790%, $\pm$3.18%, and $\pm$0.620% in cavities 1–5, respectively.

For TL measures of LiF:Mg,Ti microdosimeters, the absorbed dose ranged from 296.4 up to 303.6 cGy for cavity 5 ($\pm$1.21%), from 147.8 up to 152.6 cGy for cavity 1 ($\pm$1.48%), from 198.4 up to 203.5 cGy for cavity 2 ($\pm$0.790%), from 97.96 up to 101.9 cGy for cavity 3 ($\pm$2.04%), and from 47.79 up to 52.02 cGy for cavity 4 ($\pm$4.42%). The variation of the average absorbed dose inside each cavity measured with the microLiF:Mg,Ti compared with the absorbed dose given by the planning system was $\pm$0.260%, $\pm$0.510%, $\pm$0.140%, $\pm$0.420%, and $\pm$0.160% in cavities 1–5, respectively.

In all cases, the TL and OSL experimental results were in agreement with the absorbed doses provided by the planning system of VMAT Varian RapidArc, as can be seen in Fig. 4a and b.

4. Conclusions

The LiF:Mg,Ti microdosimeters presented a linear dose–response behavior up to 1000 cGy for the OSL and TL techniques. The experimental results obtained using LiF:Mg,Ti microdosimeters showed maximum variation of punctual absorbed dose of $\pm$4.32% and $\pm$4.42% for cavity 4 (50 cGy) using LiF:Mg,Ti microdosimeters

Table 2
Minimum, maximum, and average absorbed doses obtained by LiF:Mg,Ti microdosimeters and the average dose given by the planning system of HIAE to VMAT Varian RapidArc.

Cavities at phantom	OSL (absorbed doses (cGy))			TL (absorbed doses (cGy))			Planning system
	*D*min	*D*max	$\bar{D}$	*D*min	*D*max	$\bar{D}$	$\bar{D}$
5 (target)	299.9	303.9	301.8 ± 1.4	296.3	303.6	300.5 ± 2.2	300.0
1	149.5	153.0	151.0 ± 1.4	147.8	152.6	150.4 ± 1.5	150.0
2	197.9	203.2	200.5 ± 1.9	198.4	203.5	201.0 ± 2.0	200.0
3	99.90	103.7	101.8 ± 1.2	97.96	101.9	99.86 ± 1.47	100.0
4	49.61	54.14	51.6 ± 1.3	47.79	52.02	49.79 ± 1.76	50.00

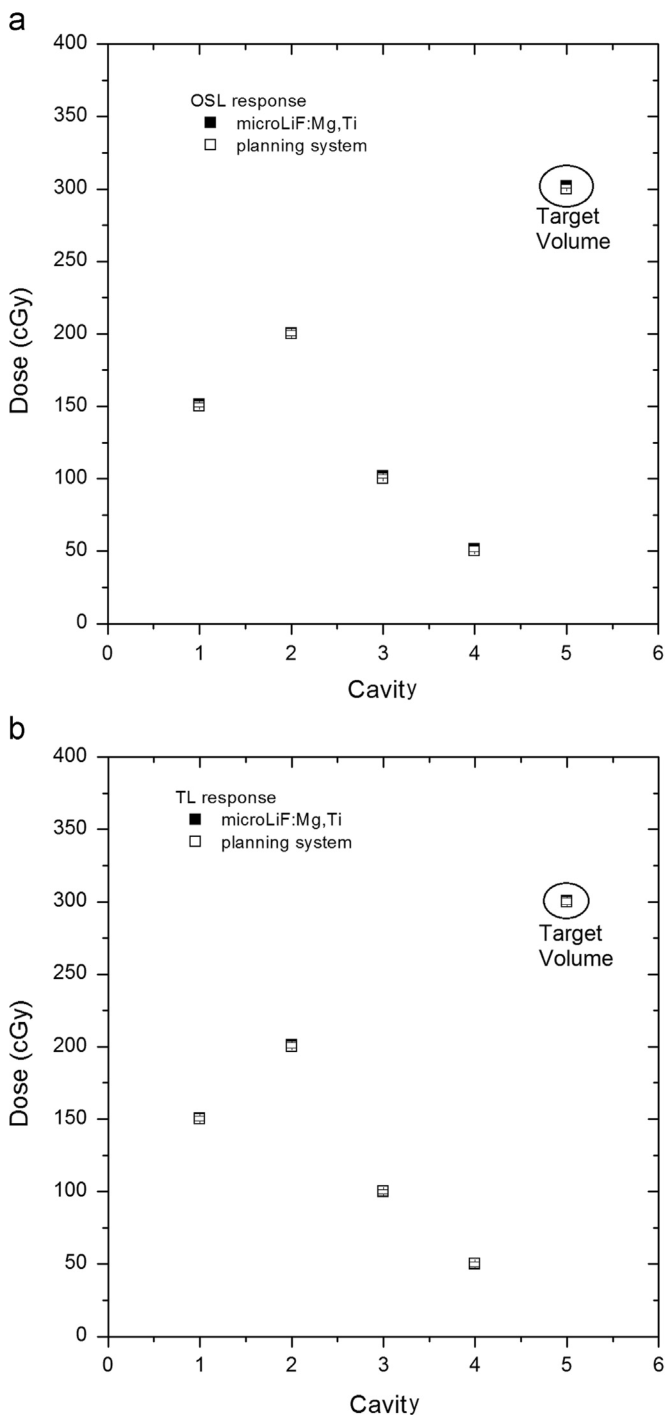

Fig. 4. Average absorbed doses measured by microLiF:Mg,Ti with (a) OSL and (b) TL techniques and provided by the planning system.

as OSL and TL dosimeters, respectively.

The maximum variation of the average absorbed dose of dosimeters inside each cavity was ±3.18% and ±0.510% using the OSL and TL techniques, respectively. For both techniques, OSL and TL, LiF:Mg,Ti microdosimeters presented results in accordance with the maximum variation acceptable in radiation therapy, ±5% (ICRU, 1973; AAPM, 1983).

Although these results were reported previously for LiF:Mg,Ti microdosimeters, the present study determines the absorbed dose in VMAT using OSL and TL techniques and PMMA phantom with precision. To enhance reliability, isodose lines with heterogeneous dose inside the cavities must be investigated further. Therefore, OSL and TL dosimetry using LiF:Mg,Ti microdosimeters are promising alternatives to quality control assurance for the absorbed dose by the VMAT Varian RapidArc technique.

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Further reading

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