TL AND OSL DOSE RESPONSE OF LiF:Mg,Ti AND AL_2O_3:C DOSIMETERS USING A PMMA PHANTOM FOR IMRT TECHNIQUE QUALITY ASSURANCE

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Abstract

The principle of IMRT is to treat a patient from a number of different directions (or continuous arcs) with beams of nonuniform fluences, which have been optimized to deliver a high dose to the target volume and an acceptably low dose to the surrounding normal structures (Khan, 2010). This study intends to provide information to the physicist regarding the application of different dosimeters type, phantoms and analysis technique for Intensity Modulated Radiation Therapy (IMRT) dose distributions evaluation. The measures were performed using dosimeters of LiF:Mg,Ti and Al_2O_3:C evaluated by techniques of thermoluminescent (TL) and Optically Stimulated Luminescence (OSL). A polymethylmethacrylate (PMMA) phantom with five cavities, two principal target volumes considered like tumours to be treated and other three cavities to measure the scattered radiation dose was developed to carried out the measures.

Keywords: LiF:Mg,Ti, Al_2O_3:C, TL dosimetry, OSL dosimetry

1. INTRODUCTION

The clinical implementation of Intensity Modulated Radiation Therapy (IMRT) requires at least two systems: a treatment-planning computer system that can calculate nonuniform fluence maps for multiple beams directed from different directions to maximize dose to the target volume while minimizing dose to the critical normal structures and a system of delivering the nonuniform fluences as planned. Each of these systems must be appropriately tested and commissioned before actual clinical use (Khan, 2010).

Available evidence for effectively treating certain types of cancers points to the need for an accuracy of approximately ±5% in dose delivery. This is indeed a very stringent requirement, considering the uncertainties in equipment calibration, treatment planning and patient setup (Khan, 2010).

Intensity Modulated Radiation Therapy (IMRT) treatments involve the delivery of complex dose distribution shapes that place steed dose gradients near critical structures in an optimized 3D configuration. The use of fluence modulation allows the radiation beam orientations to be decoupled from the tumor and critical structure geometries so that the radiation beams can be aimed directly through critical structures and the fluence modulation optimization process will limit the critical structure doses (Boyer *et al*., 2001; Low *et al*., 2011).

The IMRT dose quality assurance measurements need to explicit and include a quantitative registration process for independently validating the spatial location of the dose gradients (McNiven *et al*., 2004). The spatial location of measurement points must be known to high accuracy to enable quantitative evaluation of the calculated doses at those points. The position of the calculated doses must also be known. Because IMRT provides very nonintuitive fluence distributions, and no mechanism currently exists for independently verifying that the delivered fluence yields the desired dose distribution, and independent determination of the measured and calculated dose distribution coordinates is essential (Boyer *et al*., 2001). High sensitivity, precise delivery of light, fast readout times, simpler readers and easier automation are the main advantages of OSL in comparison with thermoluminescent dosimetry (TLD) (Akselrod *et al*., 2007; Yukihara and McKeever, 2011).

This study intends to provide information to the physicist regarding the application of different dosimeters type, phantoms and analysis technique for Intensity Modulated Radiation Therapy (IMRT) dose distributions evaluation. The measures were performed using dosimeters of LiF:Mg,Ti and Al_2O_3:C evaluated by techniques of thermoluminescent (TL) and Optically Stimulated Luminescence (OSL). A polymethylmethacrylate (PMMA) phantom with five cavities, two principal target volumes considered like tumours to be treated and other three cavities to measure the scattered radiation dose was developed to carried out the measures.

2. MATERIALS AND METHODS

Two types of dosimeters were used: a batch of one hundred of LiF:Mg,Ti (TLD-100) dosimeters (3.15 mm x 3.15 mm x 0.9 mm) produced by Harshaw Chemical Company and a batch of fifty Al_2O_3:C provided by Rexon TLD System (0.9 mm thick and 5 mm diameter).

The LiF:Mg,Ti dosimeters were previously selected with repeatability better than ±5% and calibrated using ^{60}Co gamma radiation were used to doses evaluation. The pre-irradiation heat treatment adopted was one hour for 400ºC in the furnace Vulcan model 3-550 PD and two hours for 100ºC in the surgical heater Fanem model 315-IEA 11200.

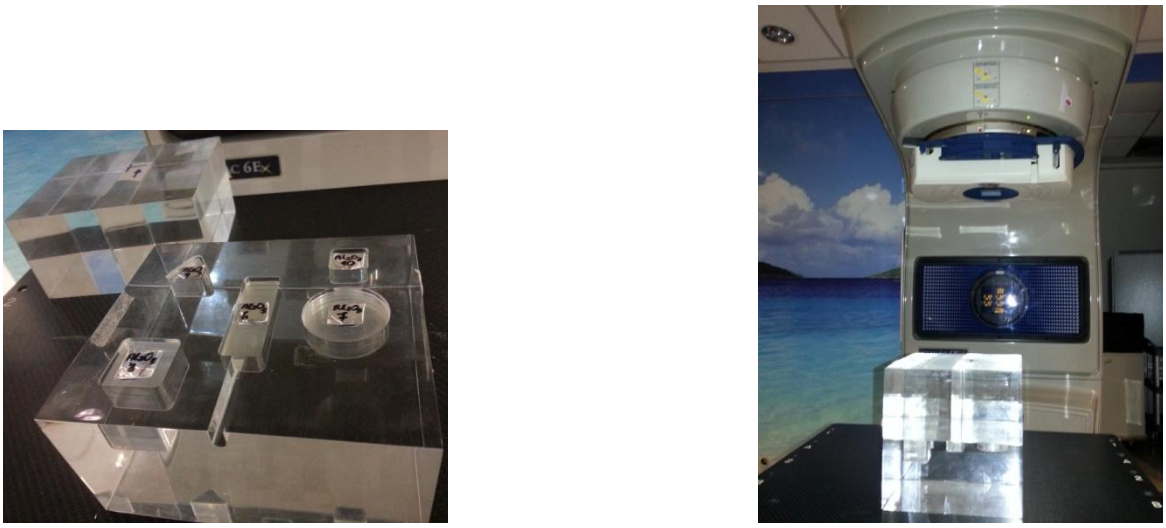
Before irradiation the Al_2O_3:C dosimeters were treated optically (illuminated) for 24 hours with a blue LED lamp for achieve the signal bleaching, the dosimeters were accommodated in a dark box completely sealed with a blue LED lamp at the top (Matsushima *et al.*, 2013).

The dose-response curves to 6 MV photons from a linear accelerator Clinac Varian 6EX of the Sociedade Beneficente Israelita Brasileira-Hospital Albert Einstein was obtained using a PMMA phantom for the following absorbed doses: 0.05; 0.5; 1; 3.5 and 7 Gy corrected to the maximum dose depth by planning system.

For dose assessment ten LiF:Mg,Ti and five Al_2O_3:C dosimeters were irradiated with photon beams (6 MV) positioned in a PMMA phantom specially designed and constructed to perform this measurement, containing five cavities (Fig. 1-a). Two cavities considered the tumors to be treated (cavities 1 and 2, Fig. 3); the other cavities (3, 4 and 5, Fig. 3) considered organs at risk; both dosimeters were individually identified and were positioned inside each of the five cavities. The IMRT irradiations were performed in the target volumes with multileaf modulated synchronously with the fluence of the radiation beam. A PMMA block of 10 cm thickness positioned on the top of the PMMA phantom was used to ensure the backscattered radiation (Fig. 1-b).

Two target volumes were irradiated simultaneously (cavities 1 and 2) and the scattered radiation dose distribution in the surrounding areas near to the tumors (cavities 3, 4 and 5) were evaluated. The obtained results were compared with the isodose curves provided by the planning system of Hospital Albert Einstein.

The TL responses for the LiF:Mg,Ti were obtained using a reader TL Harshaw model 4500. The OSL readings for the Al_2O_3:C were performed using an automated RisØ TL/OSL DA-20 reader. The Al_2O_3:C dosimeters were stimulated with the blue LED (NICHIA, type NSPB -500AS), in a constant illumination intensity mode (CW), with an emission peak of 470 nm and it was used an Hoya U-340 filter at the detection window. Each presented value represents the average of 10 TL responses (for the LiF:Mg,Ti) and 5 OSL responses (for the Al_2O_3:C) and the error bars the standard deviation of the mean (1σ) with a confidence interval of 95%.

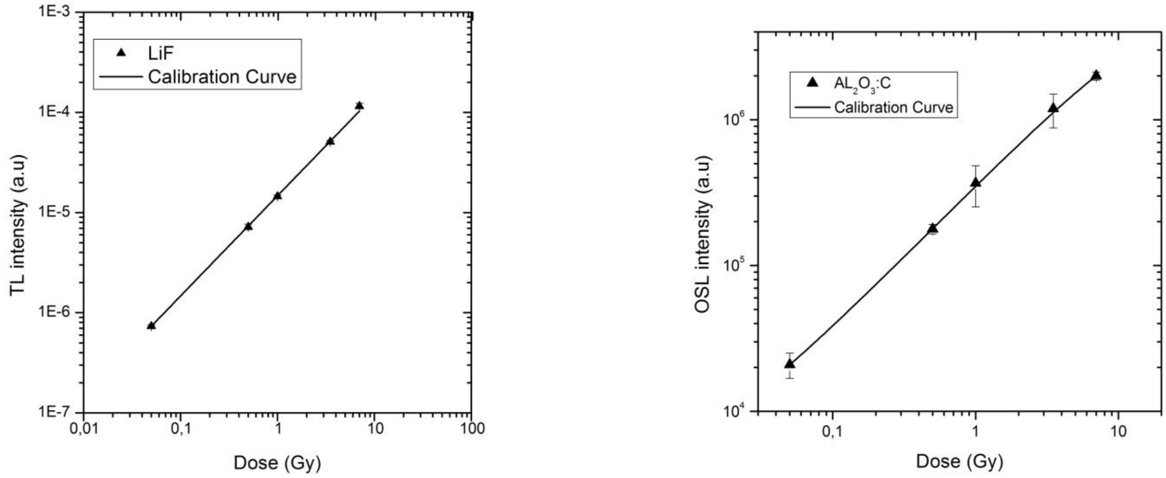


(a) (b)

Figure 1 - (a) PMMA phantom containing five cavities and PMMA block; (b) Dosimeters positioned inside the phantom's cavities and PMMA block positioned on top of the phantom to ensure backscattering.

3. RESULTS

Figure 2 (a) presents the TL dose-response curve of the LiF:Mg,Ti and Fig. 2 (b) the OSL dose-response curve of Al_2O_3:C to 6 MV photon beam radiation. It can be observed the linear behaviour in the dose range studied, from 0.05 to 7 Gy, for both dosimeters.



(a) (b)

Figure 2 - Dose-response curves to 6 MV photon beam from linear accelerator VARIAN 6EX of: (a) LiF:Mg using TL technique, Ti; (b) Al_2O_3:C using OSL technique.

The isodose curves provided by planning system are presented in Fig. 4.

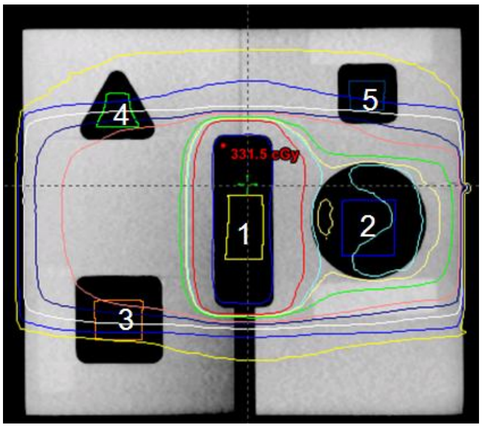


Figure 3 - Isodose curves given by planning system showing the dose distribution in the five phantom cavities.

The data provided by the planning system and the measured using LiF:Mg,Ti and Al_2O_3:C dosimeters using TL ou OSL techniques, respectively, to the five cavities are presented in Tables 1, 2 and 3 and summarized in Figure 4.

Table 1: Dose distribution provided by the planning system

Structure	Min Dose (cGy)	Max Dose cGy)	Mean Dose (cGy)	Std Dev (cGy)
1	323.7	329.0	326.7	0.9
2	221.5	228.2	224.2	1.6
3	9.6	140.5	72.0	42.7
4	14.9	129.7	65.3	38.0
5	14.1	45.8	20.9	6.2

Table 2: Dose distribution measured by LiF:Mg,Ti dosimeters using TL technique

Structure	Min Dose (cGy)	Inter Dose (cGy)	Max Dose (cGy)	Mean Dose (cGy)	Std Dev (cGy)
1	324.71 ± 6.29	---	346.33 ± 6.81	337.07	13.03
2	215.87 ± 1.86	---	228.07 ± 2.32	221.10	6.79
3	24.90 ± 0.51	55.75 ± 2.52	99.35 ± 5.16	65.25	29.85
4	20.48 ± 2.40	40.04 ± 4.12 [(a)] 85.22 ± 0.19 [(b)]	104.86 ± 13.27	60.14	35.06
5	19.72 ± 2.37	---	29.46 ± 2.37	22.64	5.21

Table 3: Dose distribution measured by Al_2O_3:C dosimeters OSL technique

Structure	Min Dose (cGy)	Inter Dose (cGy)	Max Dose (cGy)	Mean Dose (cGy)	Std Dev (cGy)
1	282.7		300.3	288.7	8.187
2	282.7		297.2	292.3	6.785
3	52.2		144.2	113.0	42.98
4	30.4	85.1	124.3	79.4	40.2
5	12.8	28.4	66.3	17.5	6.41

According the analysis of TL responses of LiF:Mg,Ti dosimeters the mean doses measured in the cavities 1 and 2 were 337.07 ± 13.03 cGy and 221.10 ± 6.79 cGy, respectively. The TL results agree, considering the standard deviations, with the expected by the planning system.

Regarding the doses evaluated by TL responses of LiF:Mg,Ti dosimeters for the structure 3 the minimum dose was 24.90 ± 0.51 cGy, the maximum dose 99.35 ± 5.17 cGy, can be observed an intermediate isodose line of 55.75 ± 2.52 cGy and mean dose of 65.25 ± 29.85 cGy. For structure 4 the minimum dose was 20.48 ± 2.40 cGy, the maximum dose 104.86 ± 13.27 cGy, can be observed two intermediate isodoses lines of 40.04 ± 4.12 cGy (a) and 85.22 ± 0.19 cGy (b) and mean dose 60.14 ± 35.06 cGy. For structure 5 the minimum dose was 19.72 ± 2.37 cGy, the maximum dose 29.46 ± 2.37 cGy and mean dose 22.64 ± 5.21 cGy. In all cases the experimental results agree with the isodose curves provided by the planning system. In the case of scattered radiation the experimental doses evaluated presents standard deviations lower than the calculated.

According the analysis of OSL responses of Al_2O_3:C dosimeters the mean doses measured in the cavities 1 and 2 were 288.7 ± 8.18 cGy and 292.3 ± 6.78 cGy, respectively. These values are underestimated and overestimate for the cavities 1 and 2, respectively.

Regarding the doses evaluated by the Al_2O_3:C dosimeters, for the structure 3, the minimum dose was 52.2 cGy, the maximum dose 144.2 cGy, it can be observed two isodose lines that agree with the planning system. For structure 4 the minimum dose was 30.4 cGy, the maximum dose 124.3 cGy, it can be observed an intermediate isodose line of 85.1 cGy and mean dose of 79.4 ± 40.2 cGy. For the structure 5 the minimum dose was 12.8 cGy, the maximum dose 66.3 cGy and the mean dose 17.5 ± 6.41 cGy. It can be observed an intermediate isodose line of 28.4 cGy that agree with the isodose curves provided by the planning system.

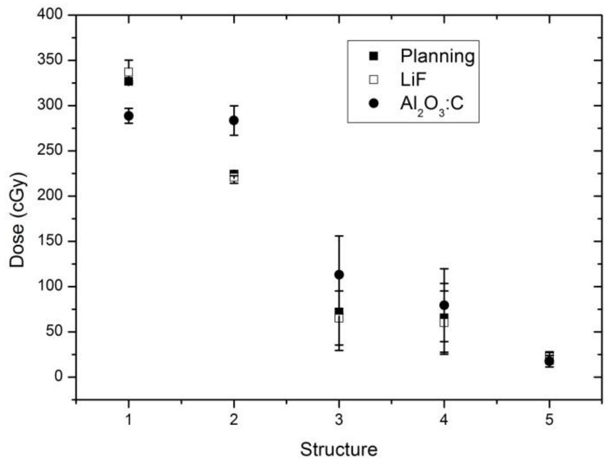


Figure 4 - Mean doses given by the planning system and measured by LiF:Mg,Ti and Al_2O_3:C.

4. DISCUSSION AND CONCLUSIONS

The doses evaluated to the tumor simulators using LiF:Mg,Ti dosimeters corresponding to the estimated doses given by IMRT planning and the repeatabilities of TL responses is better than 4.12%, lower than 5% acceptable for radiation therapy [AAPM, 1983; Podgorsak, 2005]. The scattered radiation doses received by structures 3, 4 and 5 corresponded on average to 16.14% of the highest dose received by the structure 1, according to the planning. The LiF:Mg,Ti dosimeters demonstrated have good accuracy in all measures of IMRT planning.

Comparing the doses calculated by Al_2O_3:C dosimeters using OSL technique with the doses provided by the planning system it can be observed that the dose for the cavity 1 was underestimated and the dose for the cavity 2 was overestimated (Fig. 4). This result may be explained due to the fact that Al_2O_3:C dosimeters are more sensitive than LiF:Mg,Ti and extremely sensible to any ambient light. Further studies will be done to confirm and evaluate the use of Al_2O_3:C in dosimetry in IMRT, although the scattered doses for the cavities 3, 4 and 5 agree with the doses given by the planning system.

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