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Dosimetric evaluation and comparation of TL responses of LiF:Mg,Ti and μLiF:Mg,Ti in the clinical electron beams dosimetry applied to total skin irradiation (TSEB) treatments

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ABSTRACT

The Total Skin Electron Beam (TSEB) irradiation is a radiotherapeutic technique that aims to provide the patient's skin surface with a more homogeneous dose, in order to treat cutaneous T-cell lymphomas, both for curative and palliative purposes. Electron irradiation penetrates a few millimeters into the skin, reaching the affected parts completely, without penetrating the internal organs. In vivo dosimetry has become an important role for the treatment of total skin irradiation within a rigorous quality assurance program that should be an integral part of the radiotherapy departments. The use of TLDs *in vivo* can identify variations in the prescribed dose because its measurement accuracy and great precision. The LiF:Mg,Ti is the most used TL material and widely studied in radiotherapy dosimetry due to near tissue-equivalence of the material, along with its overall reliability. The dosimeters of μLiF:Mg,Ti have been gaining considerable importance in the radiotherapy departments. These detectors allow measurements *in vivo* with great advantages due to their minimum dimensions of $1 \times 1 \times 1$ mm^3. This paper reports a comparative study of the TL responses of both materials to dose evaluation in TSEB treatments. The TL response of both materials in several TSEB parameter tests and in clinical application were evaluated, analyzing the dose distribution in a treatment simulation using AldersonRando anthropomorphic phantom. The results showed that the μLiF:Mg,Ti presented greater variation of the response in relation to LiF dosemeters in some parameters analyzed, due to the small dimensions and to evaluate doses absorbed in the surface over a large area in the treatment plan.

1. Introduction

Mycosis fungoides (MF) is a rare type of persistent, slow-growing non-Hodgkin's lymphoma that originates from mature T lymphocytes that affect the skin, with a chance of progressing to lymph nodes and internal organs (Chowdhary et al., 2016; Kamstrup et al., 2015). This neoplasia begins in a small region of the skin that then thickens and develops into a pruritic and prolonged eruption, which may subsequently develop nodules and spread slowly in area and depth. In more severe cases it can progress to leukemia (Sézary's syndrome), where it is possible to see abnormal lymphocytes in the bloodstream. MF presents difficulties in the early diagnosis due to the early stages of the disease because they present similarity with benign diseases of the skin (Jawed et al., 2014).

Treatment for MF has been used in patients since 1902 (Silveira, 2010). In the first instance, low doses absorbed from low-voltage X-ray photons were used. These equipment did not allow large fields to irradiate large areas and overdoses could occur at adjacent field interfaces. Having significant penetration, the photon bundles could radiate tissues that did not need to be irradiated. The use of electrons was suppressed for the treatment of MF in the year 1940. The first patient was treated with electron beams in 1952, with a linear accelerator of Van der Graaff (Silveira, 2010; Hinds et al., 2013).

The treatment technique used for cutaneous T-cell lymphoma, for either curative or palliative purposes is the Total Skin Electron Beam (TSEB) irradiation. The modality aims to deliver a homogeneous electron-beam dose distribution over the entire skin surface of the patient. The electrons penetrates a few millimeters into the skin, reaching the affected parts completely, without penetrating the internal organs. In some anatomical regions, the absorbed dose may vary widely due to the angle of treatment, or even the skin surface itself, which is often significantly curved and oblique to the plane of treatment. (Karzmack

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et al., 1987; Strohl, 1994; Jones et al., 1999; Podgorsak, 2005; Bao et al., 2012).

This technique aims to use a configuration where the patient is treated with six dual fields (anterior, posterior and four oblique fields) having a position 60° separated from the scope of the patient, or the patient is situated in a strategic geometry, so that can achieve better beam prestance (Reisner et al., 2010; Nevelsky et al., 2017). The patient is arranged standing on a turntable for irradiating to complete a round, ending six different positions. Each field is composed of two elements of the beam, detailing for a favorable angle to the horizontal (Khan, 2010), in this way the patient is irradiated with two electron beams having an angulation of 20° in relation to the waist line, up and down. For irradiation is used an acrylic plate, being placed in front of the patient so that it can mix the dose distribution across the extent of the skin surface (Karzmack et al., 1987).

Our group has been performing research on the use of thermoluminescent dosimeters (TLDs) for *in vivo* dosimetry, and it is been noticed that TLDs can identify variations in the prescribed dose because its measurement accuracy and great precision (Platoni et al., 2012; Almeida et al., 2018; Almeida et al., 2019). The LiF:Mg,Ti is the most used TL material and widely studied in radiotherapy dosimetry due to its near tissue-equivalence, along with its overall reliability (Mckeever et al., 1995). The dosimeters of μLiF:Mg,Ti have been gaining considerable importance in the radiotherapy departments. These detectors allow measurements *in vivo* with great advantages due to their minimum dimensions of $1 \times 1 \times 1\ mm^3$. Thus, this paper reports a comparative study of the TL responses of both materials LiF:Mg,Ti to dose evaluation in TSEB treatments. Measurements were performed using the six-dual-field "Standford" technique (Karzmack et al., 1987) and an Alderson Rando anthropomorphic phantom.

2. Experimental

2.1. Dosimetric materials

The thermoluminescent dosimeters used in this work (Fig. 1) were selected for repeatability and reproducibility better than ± 5.0% and separated into six groups, five for dosimetric measurements and one for background dose control. The TLDs are better specified below.

2.2. Dosimeters readout and annealing treatment

The TL measurements were performed using a Harshaw 4500 TLD reader in nitrogen atmosphere. The reading procedure of LiF:Mg,Ti and μLiF:Mg,Ti was performed with Time Temperature Profile (TTP) of preheating at 80 °C, linear heating hate of $5\ °C.s^{-1}$ with maximum temperature of 400 °C. Both types of TLDs were annealed in a Vulcan® 3–550 PD furnace at 400 °C for 1 h, followed by rapid cooling to ambient temperature and then placed at a 100 °C preheated Fanen® 315-IEA 11200 surgical stove for 2 h (Mckeever et al., 1995).

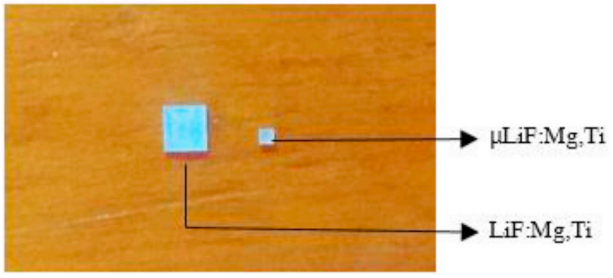

Fig. 1. Thermoluminescent dosemeters used in this study. From left to right: LiF:Mg,Ti TLD-100 and μLiF:Mg,Ti TLD-100.

- LiF:Mg,Ti (TLD-100) TLDs produced by Thermo Scientific: 3.15 × 3.15 × 0.9 mm and mass of 24.4 ± 0.3 mg;
- μLiF:Mg,Ti TLDs produced by Thermo Scientific: 1 × 1 × 1 mm and mass of 3.5 ± 0.1 mg.

2.3. Irradiation systems

The ^{137}Cs 4 π geometry gamma irradiator (Activity of 38,11 GBq in 17 April 2014) from Dosimetric Materials Laboratory – LMD/IPEN was used to test the TLDs repeatability into limits of response of ± 5.0%. The clinical measurements were carried out using the High Dose Rate Total Skin electron mode (HDTSe-) and 6 MeV beam of the linear accelerator Varian Clinac 23EX (Varian Medical Systems, Inc., Palo Alto, California) from the Radiotherapy Center of the Hospital Israelita Albert Einstein (HIAE). The collimator was opened $36 \times 36\ cm^2$ after the insertion of a specific tray dedicated for the TSEB practice, providing a great field size over distance.

2.4. Characterization of the TLDs

The TL dosimeters were characterized for the HDTSe-6 MeV electron beam of the Clinac 23EX. Irradiations were performed positioning all dosimeters between two polymethylmethacrylate (PMMA) plates 0.3 cm thick and depth of 1.30 cm obtained with solid water bolus for electronic equilibrium conditioning. It can be found more details over this characterization in Almeida et al. (2018). The characterization set-up is shown in Fig. 2.

2.5. Experimental set-up and irradiations

Real conditions of TSEB treatment were simulated by using an AldersonRando® anthropomorphic phantom, arranged on a turntable and a large PMMA sheet of 0.5 cm thickness used to module the electron fields with clinical irradiation of 420MU. The experimental set-up of field parameters and treatment dosimetry is shown in Fig. 3.

The TLDs dosimeters were placed over different parts of the phantom, waistline and the abdomen point was used as reference (z_{Ref}) as recommended by AAPM (1987). Six LiF:Mg,Ti TLD-100 and three μLiF:Mg,Ti were used in each point of measurement. The measurements were performed on alternate days, as reported by AAPM, allowing greater study of sub- and over-dosage. The LiF:Mg,Ti TLD-100 dosimeters were used as reference and compared with μLiF:Mg,Ti.The experimental results of the absorbed doses are presented as the average of three dosimeter measurements located in each region studied, and the error bars are the standard deviation of the mean. Where the dose and the standard deviation are written in cGy.

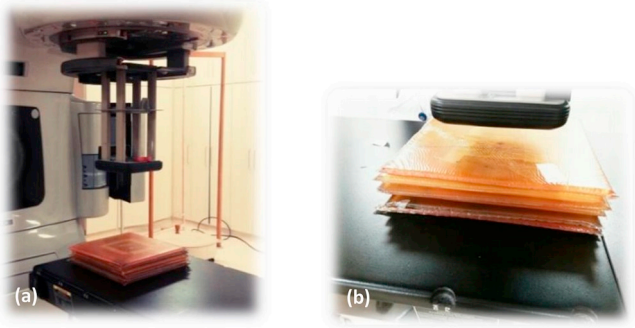

Fig. 2. Positioning of the dosimeters to perform the dosimetric characterization. (a) Accommodation of the TLDs between the two PMMA plates and irradiation; (b) set-up for dosimetric characterization with Varian Clinac 23EX.

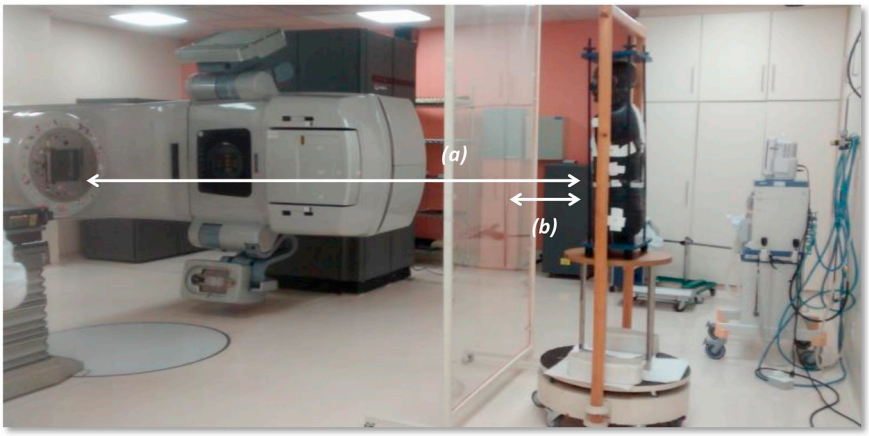

Fig. 3. TSEB experimental set-up of irradiation using the AldersonRando® anthropomorphic phantom. Distance *a* between the phantom and the field isocenter is 3 m; and distance *b* between the phantom and the PMMA sheet is 50 cm.

3. Results

3.1. Performance tests and characterization of the TLDs

The repeatability measurements were performed free in air at electronic equilibrium conditions placing the TL samples between two 0.3 cm PMMA plates. Irradiation with absorbed dose of 2 mGy, readout and thermal treatments were repeated five times to screen the samples with repeatability better than ± 5.0%. The calibration factors obtained after TL characterization of each sample to HDTSe- 6 MeV electron beam varied between 0.167 ± 0.005 C cGy^{-1} for LiF:Mg,Ti TLD-100 and 88.51 ± 0.9 μC cGy^{-1} for μLiF:Mg,Ti. More results on dosimetric characterization can be found in Almeida et al. (2018).

3.2. Dose distribution over z_{Ref} and the waist line

Table 1 shows the absorbed dose of different points in the waist line and at the reference point for each TLD type. The results of the waistline were compared with the dose at the z_{Ref}. The right lateral (RL) showed a greater percentage difference because the incident beam is not directed to this position, obtaining in this way a smaller dose in this place. The posterior region also received a smaller dose because of the anatomical asymmetry. Other point to be observed were the right anterior oblique (RAO) and right posterior oblique (RPO).

3.3. Treatment simulation

For treatment simulation, 470 MU were selected in the console control of the Varian Clinac 23EX to deliver 210 cGy to z_{Ref}. TLDs were positioned at z_{Ref} and disperse in 10 other points throughout the anthropomorphic phantom to evaluate the hole-body dose distribution and compare the LiF:Mg,Ti with the μLiF:Mg,Ti results. Table 2 presents the obtained experimental results and Fig. 4 shows agreement between them.

Table 1
Absorbed doses evaluated at z_{Ref} and throughout the waistline of the AldersonRando® anthropomorphic phantom.

Position	LiF:Mg,Ti		μLiF:Mg,Ti	
	Absorbed Dose (cGy)	% Difference from z_{Ref}	Absorbed Dose (cGy)	% Difference relative to LiF:Mg,Ti
z_{Ref}	214.5 ± 1.2		230.9 ± 6.4	7.6
Posterior	199.8 ± 1.2	7.4	213.1 ± 3.8	6.6
RAO	212.6 ± 1.1	0.9	219.4 ± 13.6	3.2
RPO	210.1 ± 0.9	2.1	241.9 ± 1.5	15.1
RL	196.7 ± 1.0	9.1	221.0 ± 6.1	12.4

The absorbed doses measured with μLiF:Mg,Ti varied up to 15% compared with LiF:Mg,Ti. This can be explained by the different radiation scattering and absorption due to such small dimensions of the dosimeters.

Table 2
Experimental results using LiF:Mg,Ti TLD-100 and μLiF:Mg,Ti dosimeters.

Position	LiF:Mg,Ti		μLiF:Mg,Ti	
	Absorbed Dose (cGy)	% Difference from z_{Ref}	Absorbed Dose (cGy)	% Difference relative to LiF:Mg,Ti
(1) z_{Ref}	205.0 ± 1.0		224.3 ± 1.3	9.4
(2) Thorax Center	205.30 ± 1.2	4.0	211.3 ± 1.6	2.9
(3) Thorax Right	189.6 ± 1.1	12.6	199.6 ± 1.0	5.2
(4) Thorax Left	193.2 ± 1.7	10.5	213.3 ± 6.1	10.4
(5) Posterior	206.4 ± 0.9	3.5	207.0 ± 2.8	0.39
(6) Right Lateral	196.6 ± 1.8	8.6	210.2 ± 0.1	6.9
(7) Right Thigh	204.4 ± 2.6	4.5	229.4 ± 1.7	12.2
(8) Perineum	202.2 ± 0.9	5.6	217.3 ± 2.2	7.5
(9) Forehead	200.9 ± 0.7	6.3	224.1 ± 1.2	11.51
(10) Scalp	155.8 ± 2.8	37.0	159.8 ± 7.5	2.6
(11) Right Axilla	86.2 ± 2.4	142.7	85.8 ± 0.1	0.5

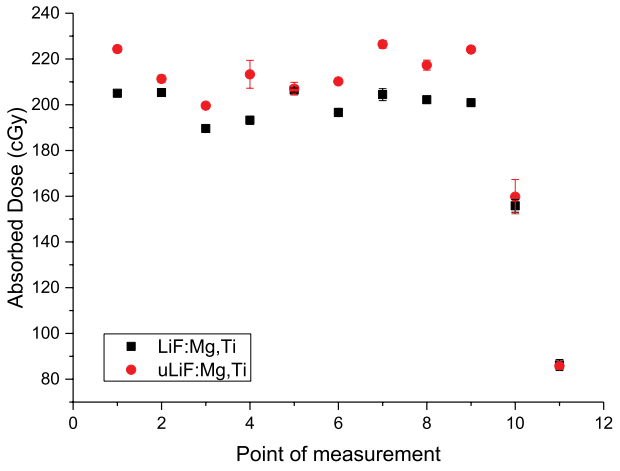

Fig. 4. Agreement between experimental TL dosimetry obtained.

4. Discussion

The dose distribution on the skin may vary widely due to the large

radiation incident angles on the skin surface, often curved and oblique to incident radiation plane. Regions such as thorax, posterior region, right lateral and right thigh has statistically small dose variations. However, for many other parts of the body, doses are measured with more than 20% different to abdomen (z_{Ref}). The TSEB six-dual-field technique is quite complex, and measurement of absorbed doses in the skin of the patient can present variations up to 10% (Karzmack et al., 1987).

For the abdomen region (z_{Ref}), the agreement with the prescribed 210 cGy dose was 97.62% for LiF,Mg,Ti and 93.61% for μLiF,Mg,Ti. Over the waistline, the right lateral (RL) showed the greater percentage difference (up to 15.0%) and all the deviations can be explained by anatomical asymmetry and field's incident angles. For the clinical simulation, the dose distribution varied within the expected 20% reported by AAPM (Karzmack et al., 1987) at almost all points measured. The greater deviations were at scalp and right axilla, the resulting sub dosage can also be explained by the incident angles and phantom's anatomy. The experimental results obtained with μLiF:Mg,Ti were slightly different compared to TLD-100, even though they differ only by their dimensions. Differences on their absorbed doses can be explained by the lower TL intrinsic efficiency and reduced dimensions of μLiF:Mg,Ti, as predicted as well by Bravim et al. (2012). Dosimeters with such small dimensions are extremely useful for assessing differences in isodose lines. However for application in the TSEB treatment the field measurements are relatively large for such a small dosimeter. In this way it is recommended to use this material in smaller fields and to perform a lower dosimeter characterization to improve measurement accuracy.

5. Conclusion

From the experimental results, it can be concluded that for the dose at the calibration point, a small variation was observed in comparison to the other points studied. In some anatomical regions, some dosimeters presented higher doses, being explained by their location where one group received more doses than others due to overlays and irradiation angles. The use of μLiF:Mg, Ti, required a more precise dosimetric characterization, adding more attention to individual or batch sensitivity correction factors and proper positioning for measurements. Taking into account the aspects of repeatability, reproducibility, sensitivity, beam energy and type of radiation that will be employed to improve accuracy in measurements.

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