The use of the TLD-100 for quality assurance in Total Body Irradiation (TBI)

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Abstract: Total body irradiation (TBI) is a radiotherapy treatment of significant complexity. The planning of this type of treatment aims at ensuring the homogeneous distribution of the prescribed dose over the entire volume of the patient, which will inevitably present various thicknesses and densities. In order to verify the quality of a TBI during its accomplishment it is recommended to use thermoluminescent dosimeters to measure the doses delivered to the patient. This work explored the use of TLD-100 in vivo dosimetry during a TBI by developing a calculation method to find the doses deposited on the medium of the DAP in various regions of a patient's body. The thermoluminescent dosimetry required a rigorous selection of the TLDs, followed by the calibration of the same ones in the same conditions practiced in the TBI. The results of the measurements showed a good agreement between the values planned to meet the medical prescription and the values measured in-vivo. In addition, the variation between dose values overestimated for the various regions studied showed good dose homogeneity over the entire patient volume.

Key–Words: TBI, TLD-100, surface dosimetry, TBI dosimetry, TBI measurements.

1 Introduction

Total body irradiation (TBI) is a radiotherapeutic technique frequently employed, in conjuction with chemotherapy, before bone marrow transplantation. The procedure involves the application of large external beams over the whole, aiming the immunosuppress the patient [1][2]. According to [3], quality assurance is essential for the proper application of more complex techniques in radiotherapy. In TBI treatments, in vivo dosimetry is recommended because it makes it possible to ensure the accuracy and quality control of dose delivery during irradiation [4].

There are several dosimetry techniques available for in vivo dosimetry but, the use of semiconductors and thermoluminescent dosimetry are the most commonly to ensure doses in TBI [3] [5] [6]. In this work, the use of thermoluminescent dosimeters was chosen. The importance of thermoluminescence for radiation dosimetry is due to the fact that the amount of light emitted is proportional to the absorbed dose by the irradiated material, which requires sensitive detection and accurate measurements of ionizing radiation. Under favourable conditions, emitted TL light intensity by a solid is proportional to the absorbed dose, and thus, using an appropriate calibration, one can evaluate the applied dose in the radiation field [7].

2 Methodology

2.1 Procedures for termoluminescent dosimetry

A group of 170 commercial LiF:Mg,Ti (TLD-100) chips were preselected from a larger group by exposing the examined samples to 100 mGy of gamma rays with photon energies of 662 keV, from a 137Cs gamma sources at room temperature (RT). This process was repeated three times and the chips with TL response higher than 4.0% were discarded. The measurements of TL glow curves were performed in a Harshaw-Bicron 3500 TLD reader, operating under a linear temperature profile over the range of 50 to $300°C$, in the resistive mode, by using a heating rate of $10°C/s$ and reading cycles of 35s. Annealing was performed at $400°C$ (1 h) and $100°C$ (2 hs) before each irradiation. Pre-reading annealing was done by heating at $100°C$ during 15 min.

2.2 TLD-100 calibration

Since thermoluminescent dosimeters do not provide absolute dose values, it was necessary to calibrate the dosimeter set to perform any measurement. According [8], the quality of the calibration should be appreciated because it is directly linked to the accuracy and precision of the results.

Calibration should be done by irradiation with known doses, produced by a beam of energy similar to the one to which the dose is to be evaluated. Therefore, this calibration process was used the same linear accelerator used in TBI. The calibration setup followed the recommendations of TRS-398 [9]. The measurements were performed in a solid water phantom to reproduce the conditions of electronic equilibrium and the results were intercompared with the values recorded by a Farmer ionization chamber of $0,6cm^3$ at the reference conditions. Figure 1 shows the calibration set up.

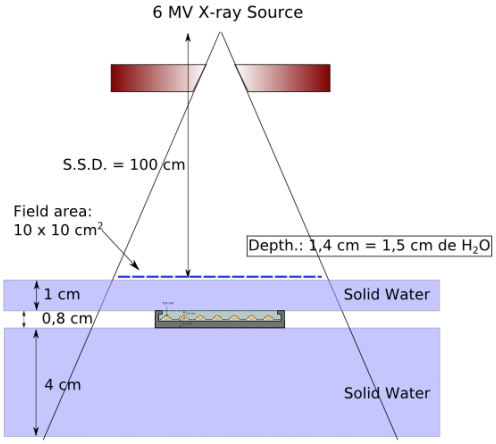

Figure 1: Schematic diagram showing the TLD-100 calibration setup using solid water.

The calibration of the TLD-100 was made from the irradiation of groups of TLDs positioned in the reference conditions for several doses. Four dosimeters were detached and read without being irradiated to obtain the mean TL reading for the 0 cGy dose. Another 40 dosimeters were separated into 10 groups. Each group was allocated within the carrier in the calibration setup and irradiated with a specific dose. Table 1 shows the dose at which each group of TLDs was irradiated.

Table 1: Correspondence between the group and the dose irradiated in the calibration configuration.

TLD Group	1	2	3	4	5	6	7	8	9	10
Dose (cGy)	25	50	75	100	125	150	175	200	225	250

2.3 Evaluation of supralinearity of TLD-100

According to [10], the thermoluminescent dose-response relationship can be described by:

$$f(D) = \frac{F(D)/D}{F(D_1)/D_1} \quad (1)$$

Where D is the dose and $F(D)$ is the signal intensity TL. The terms D_1 and $F(D_1)$ refer to the low dose situation.

According to [10]), most TL materials, including LiF: Mg, Ti, have the term $F(D_1) = D_1$ equal to 1, in other words, have an approximately constant dose-response at low doses. However, from 1 Gy, a supralinear behavior of the TLD-100 is reported, meaning a dose-response factor that changes from this threshold. In order to avoid incorrect evaluations of the absorbed dose, a quadratic adjustment was made to obtain the calibration curve.

2.4 TBI treatment protocol

There are many different TBI techniques being practiced around the world. The choice of a technique in a particular hospital depends on many factors like available equipment, photon beam energy, maximum possible field size, patient dimension, and treatment distance [5]. In the in-vivo dosimetry discussed in this work, the Elekta Precise Linear Accelerator was used, with nominal energy of 6 MV. The patient was placed in lateral decubitus on a vacuum cushion at a source to surface distance (SSD) of 354 cm. The vacuum cushion was proposed to guarantee the immobilization of the patient during the treatment. Collimator jaws were opened to a maximum field size of 40 40 cm^2, with the collimator rotated to 45° to produce the largest possible longitudinal coverage in the projection of the treatment field. Cerrobend blocks were used to compensate for the lower electron density of the lung. The blocks were glued onto an acrylic screen arranged between the source and the patient. The correct position of the blocks was acquired through the generation of portal images before the start of the TBI.The acrylic screen, made of polymethylmethaacrylate (PMMA) of thickness 2 cm, was also introduced with the aim of avoiding the skin-sparing effect. Total prescribed dose of 12 Gy (200 cGy per fraction) was delivered to the patient over six fractions of treatment in 3 days. On each day, two fractions were intervaled in at least 6 hours. The treatment was delivered in two fields, one pair AP-PA, with dose rate controlled by the device of 150 monitor units (MU)/min. Number of MUs required to deliver the per field prescription dose of 100 cGy was 1511 MUs. Several anterior posterior (A-P) thickness was measured, among which: the head; neck; thorax; abdomen; thigh; calf and feet. Dose was prescribed to the midplane depth of this calculated average thickness.

2.5 The disposition of TLDs on the patient's surface

The disposition of TLDs on the patient's surface was made from the choice of five representative axes, in which TLDs were positioned on the anterior and posterior surface of the patient. The figure 2 shows the approximate position of each TLD positioned on the patient.

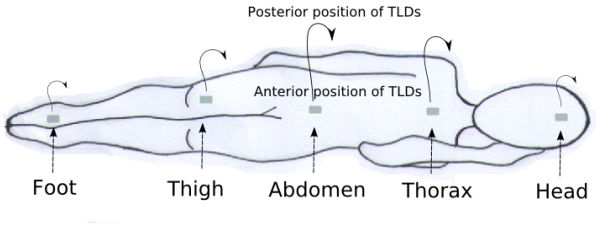

Figure 2: Illustration with the arrangement of TLDs positioned on the patient's surface.

3 Results and Discussion

3.1 TLD-100 Calibration Curve

After obtaining the TL reading in μC of the irradiated dosimeters, it was possible to establish a relation with the absorbed dose expected in the reference conditions. From a quadratic adjustment, the calibration curve of the TLDs was obtained, as shown in figure 3.

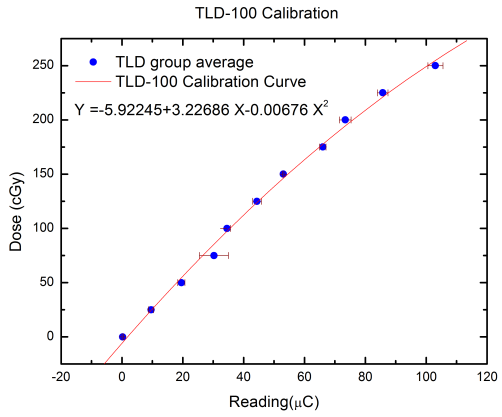

Figure 3: Calibration curve of TLD-100.

3.2 Dose evaluation of TLDs used in TBI

The TLDs placed on the points specified in figure 2 were, after the TBI, submitted to the TL process in order to obtain the doses absorbed by each of them. The tables 2 and 3 gives the results for mean dose at each dose evaluation point.

Table 2: Average dose without corrections obtained by reading the TLDs positioned on the anterior surface of the patient

Anterior Surface		
Tld position	TLD reading (uC)	Dose (cGy)
Foot	58,73	162,75
Thigh	65,87	180,41
Abdomen	65,97	180,65
Thorax	64,30	176,57
Head	54,14	151,14

Although the TLDs were positioned on the anterior and posterior surface of the patient only once in the procedure, during the application of the treatment fields the patient was repositioned by inverting the faces facing the source. This caused the results measured by the TLDs at each chosen point to contain a portion of the input dose and another portion of the exit dose in that treatment region. In order to estimate the dose distributed in the midline of the patient, in addition to the consideration of DAP and the percentage of deep dose (PDD) in the treatment conditions, it was necessary to make a correction for non-backscattering in the situation of TLD in exit dose measurement. This correction was made based on studies done by [3], which estimated a loss of 4 to 16% of dose caused by the absence of backscattering.

Based on the above considerations, the following equations were taken to obtain doses in the midline of the patient:

$$\overline{D_{1C}} = \frac{D_1 \times PDD(Z_{mid}) + D_1 \times PDD(Z_{mid})/PDD(Z_{exit})}{2} \quad (2)$$

$$\overline{D_{2C}} = \frac{D_2 \times PDD(Z_{mid}) + D_2 \times PDD(Z_{mid})/PDD(Z_{exit})}{2} \quad (3)$$

Table 3: Average dose without corrections obtained by reading the TLDs positioned on the posterior surface of the patient

Posterior Surface		
Tld position	TLD reading (uC)	Dose (cGy)
Foot	60,71	164,37
Thigh	59,33	161,07
Abdomen	61,75	166,84
Thorax	58,7	159,56
Head	53,65	147,22

$$D_{mid} = (\frac{\overline{D_{1C}} + \overline{D_{2C}}}{2}) \times 1,1 \quad (4)$$

Where the equation 2 represents the calculation of the dose mean D_{1C} corrected from the PDD to the depth located in the middle of the DAP of the assessed region. If the D_{1C} dose is that recorded by the TLDs positioned on the patient's anterior surface, then the D_{2C} dose corresponds to the dose on the posterior surface, and vice versa. Equation 4 determines the mean dose in the midline for each evaluated region correcting the lack of backscattering with multiplication by factor 1.1.

Thus, it was possible to obtain the dose in the midline for each of the regions studied from the surface doses recorded by the TLD-100. The doses are set out in table 4.

Table 4: Dose calculated for the center of the DAP in the regions evaluated from the dose measured by the TLDs on the anterior and posterior surface of the patient.

Dose in the middle of the DAP	
Tld position	Dose (cGy)
Foot	183,42
Thigh	191,48
Abdomen	210,80
Thorax	202,80
Head	182,39

Therefore, from the values shown in table 4, the mean dose value in the DAP medium of 194.18 cGy was obtained. Since the prescription dose for treatment is equal to 200 cGy, 194.18 cGy corresponds to 97% of the desired dose. This result shows a good agreement between the planned values before the therapy and the values observed in the in-vivo measurements.

Another important discussion is the observation of the standard deviation between the doses calculated for the center of the DAP in the various treated and measured regions. TBI aims to distribute the prescription dose homogenously over the whole volume of the patient, being important for this reason to guarantee a small variance between the dose values of each region. The standard deviation between the values obtained in this study resulted in an average variation of 6% around the mean dose. Considering the complex TBI planning condition in which a large volume with various densities and thicknesses is irradiated, an average deviation of 6% indicates good dose homogeneity in the patient's body.

4 Conclusion

The use of thermoluminescent dosimetry for the evaluation of the doses distributed in the TBI technique has been very reported in the literature. The advantages of TL dosimetry are in the good reproducibility of the dosimeters, their excellent stability, their adequate sensitivity and even in their electronic density approximately close to the electronic density of human tissue. This last advantage makes the TLD-100 an excellent dosimeter to be used for quality control of treatments when being positioned on patients' skin. In this work, the use of the TLD-100 for the measurement of the doses distributed in the whole body irradiation technique (TBI) was studied. The process of selection and calibration of TLD-100 was described before being used for in-vivo dosimetry. The TLDs were arranged on some representative points of the patient and from the reading of the TL signal it was possible to find the doses absorbed on the surfaces of the patient. By applying the necessary corrections to avoid disregarding some physical phenomena that contribute to the increase of the dose, it was possible to find the dose for the center of the patient's DAP in the various evaluated axes. The results showed a good agreement with the values planned to satisfy the medical prescription. In addition, the small mean deviation between values found in each region indicated good dose homogeneity in the patient's body.

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