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Thermoluminescent chip detector for *in vivo* dosimetry in pelvis and head & neck cancer treatment

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ABSTRACT

Our aim is to show the TL dosimetry as a confident QA method for radiotherapy treatments. Before *in vivo* entrance dose measurements using TLD-100 chips, ECLIPSE TPS-simulated treatments for a Rando anthropomorphic phantom, two for pelvis and one head & neck. *In Vivo* measurements results with ^{60}Co beam remained within $\pm 5\%$ limits. Results for 6 and 15 MV are in conclusion. This is a National Cancer Institute/RJ/Brazil study under the 13.111—IAEA Coordinated Research Project.

1. Introduction

The success of radiotherapy, in terms of probability of local control of the tumor, depends upon an adequate high dose of radiation being delivered to the intended target volume. (ESTRO—Booklet no. 4, 2004). To achieve good results in the treatment, the accuracy in each part of the whole treatment planning and dose delivery process must be significantly high. Therefore, a quality assurance program is necessary to ensure the accuracy of the prescribed dose. *In vivo* dosimetry is an important step of such quality assurance program, which aid in an overall and ultimate check of the whole dosimetric process (Banjade et al., 2003).

Thermoluminescent dosimeters (TLD) are commonly used in assessing the dose from ionizing radiation, particularly to verify the calculated absorbed dose at specific sites in a radiation field.

This work presents initial results of an IAEA Coordinated Research Project-"Development of procedures for *in vivo* dosimetry in radiotherapy" (CRP13111), with which the Agency intends to elaborate its own *in vivo* dosimetry technical report. All measurements of entrance doses, calculations and data analyses here described were performed at the Radiotherapy Service and the Radiotherapy Quality Control Program (PQRT) of the National Cancer Institute (INCA), Rio de Janeiro, Brazil, from April 2005 to October 2007.

2. Material and methods

The chosen thermoluminescent material was LiF chip doped with Mg and Ti (TLD100), with dimensions of $3.2 \times 3.2 \times 0.9\,mm^3$. The TLDs were selected after following a careful initialization procedure suggested by IAEA (TRS398 Code of Practice, 2000).

2.1. Commissioning tests

The Agency provided a batch of 500 unsorted TLD chips and a printed procedure for *in vivo* dosimetry with solid state detectors. The initialization procedures suggested by IAEA consisted in irradiating all the TLDs five times with 100 cGy at the reference depth (d_{ref}) and then anneal them without taking any reading. Divided in groups of 25, each one of these TLDs groups were positioned between two slabs of solid water and irradiated under reference treatment geometry (^{60}Co beam, $10 \times 10\,cm^2$ field size, d_{ref}=5 cm and SSD at 80 cm) at a time. The annealing cycle was done with the ETT Fimel oven and the manufacturer recommendation for Harshaw TLD100 was followed: 400 °C for 1 h followed by 100 °C for 2 h. The interval between each annealing–irradiation cycle was at least 12 h. The following tests were performed in accordance with IAEA procedure.

2.1.1. Chip factor

The same setup described previously was used to determine the individuals chip sensibility factors (k_{chip}). From a batch of 500 TLDs, 226 were selected according to criterion of 3% maximum variation in the sensitivity factor. They were organized in a batch of 113 pairs (Fig. 1).

The calibration factor (N_{cal}) of the batch was determined using 5 pairs of TLDs randomly selected. The average calibration result is: $(4.03 \pm 0.04)10^{-5}$ Gy/TL signal.

Virtual water phantom (G211 standard imaging, $40 \times 40\,cm^2$) with 3 and 5 cm thickness, one specially drilled for PTW 30013 ion chamber was used for calibration and all correction factor measurements, including the plastic to water correction factor.

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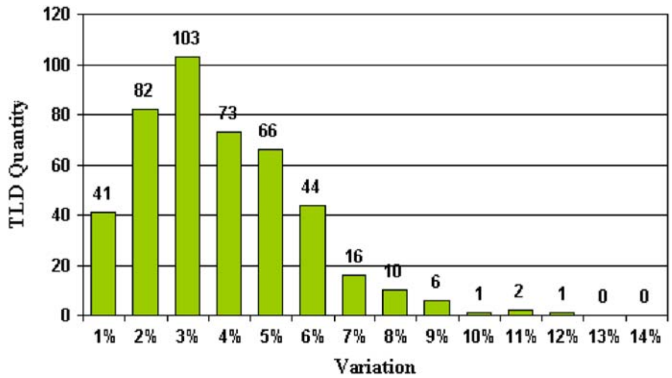

Fig. 1. Histogram of repeatability test to obtain the chip factors.

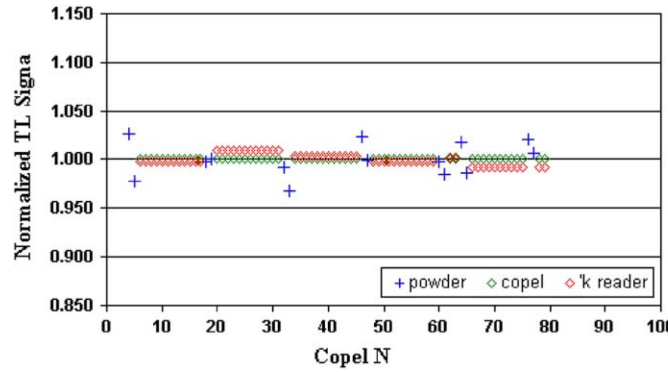

Fig. 3. Typical fluctuation of the TLD reader.

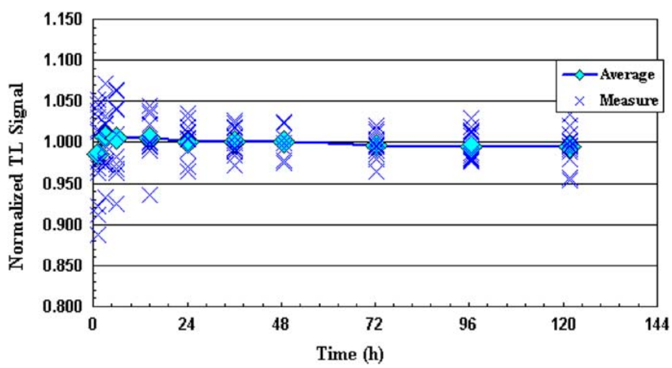

Fig. 2. Fading of the TLD chip readings up to 1-week post-irradiation.

k_{pl} was calculated both to Cobalto unit and Linac 6 MV Varian 600C. It was obtained as the ratio of $\overline{M}_W$ and $\overline{M}_{pl}$. Where $\overline{M}_W$ is the average of 5 ion chamber readings, at 5 cm depth in a water phantom and $\overline{M}_{pl}$ is the average of 5 ion chamber readings at the same depth in a plastic phantom. All ion chamber readings were corrected for the water temperature and atmospheric pressure. For both setup D_0=100 cGy was delivered at d_{max}. The k_{pl} value found was 1.0048 ± 0.0003 to ^{60}Co unit and 1.0138 ± 0.0003 to 6 MV Linac.

2.1.2. Fading

This intrinsic characteristic of the TLD consists in the spontaneous release of the electrons that were trapped during irradiation, into the crystal lattice (LiF:Mg, Ti). Fading correction factor, k_{fad}, was defined following the procedure. A test for 1-week period was performed. The results are shown in chart 2. Based on Fig. 2, we decided to read the detectors after 72 h.

The PCL3 TL reader (Fimel) was used to perform all the TL readings in this work. It is possible to read up to 93 TLD chip at once. As this process, lasts approximately for 1 h, we used a pre-irradiated stable TLD 100 powder to monitor reading fluctuations. To perform the measurements readout it was located before and after each group of 10 chips, 2 samples of TLD powder. For each 10 chips section a reader correction factor was determined, k_{reader}. Typical values for k_{reader} factors remained within ± 2%. This correction factor was included in the dose calculation. Fig. 3 shows a typical behaviour of the reader with a 1.2% fluctuation.

2.2. Study of the TLD response

All the studies of the TLD dependences were performed using a Cobalt unit – Theratron 780C – Theratronics AECL (THC) and a linear accelerator-Varian 600C (Linac 6 MV). These studies were performed with the reference treatment geometry. The chips were placed on the surface of the virtual water phantom covered by an aluminum (for ^{60}Co) or stainless steel (for 6 MV) buildup cap and the ionization chamber located at the reference position. The correction factors were also determined in accordance with IAEA procedure.

Table 1
Energy correction factor.

Beam	D_{20}/D_{10}	k_{engy}
^{60}Co	0.5016	1.0000
6 MV LINAC	0.5686	0.9711

2.2.1. Physical dependences

The relation between the response dose and the delivered dose is one of the most complex phenomenons intrinsic to the TLD (Claudio Viegas, 2003). Non-linearity dose response correction factor, k_{lin}, becomes significant when the measured dose differs from the reference dose. The TLDs were irradiated with the following doses: 20, 50, 100, 150, 200, 300 and 400 cGy.

The energy correction factor, k_{engy}, is applied when the quality of investigated beam differs from ^{60}Co reference beam. The reference calibration N_{cal} is based on measurements in the ^{60}Co beam. The ionization chamber was located at the appropriate reference depth for 6 MV beam energy. The result is shown in Table 1.

Angular dependence was performed following the procedures and the TLDs were irradiated with the gantry at 0°, 10°, 20°, 30°, 50° and 60°. It was irradiated, one beam at a time.

2.2.2. Geometric dependences

Almost every patient undergoing radiotherapy uses beam modifiers during their treatment sessions. Depending on the complexity of the treatment technique beam modifiers are required to guarantee an accurate irradiation of the target volume. Therefore, is extremely necessary for the determination of the correction factors correspondent to each one of these beam modifiers in order to include them in the dose calculation.

The radiation beam spectrum changes with field size. Therefore, is necessary to evaluate the possible effect of field size on the detector response. Field size correction factor, k_{field}, takes into account the effect of different field sizes on the detector response. Were performed measurements in the same setup for different field sizes.

The SSD correction measurements were performed as for the calibration setup at different SSDs: 70, 80, 90.2, 100 and 109.2.

The wedge filter correction factor, k_{wedge}, and the tray correction factor, k_{tray}, apply because the vast use of these modifiers during radiotherapy treatments. INCA radiotherapy service uses two types of tray and they have different influences in the TLD response. One is solid acrylic tray and another one has holes specially made (gaps) for fixing blocks used for all gantry angles (Fig. 4a, e and b). The correction factors for both trays were determined.

2.3. Calculation of expected dose

The expected dose for Rando measurements was calculated using the ECLIPSE treatment planning system (TPS) by placing a calculation point at the isocenter, the program also calculates the dose at the depth of d_{max}. Three treatments were simulated with a female Rando Alderson Anthropomorphic phantom, two for Pelvis (one 30° wedged) and one for head & neck (with and without mask). A manual verification was made as well for comparison with measurements. The expected dose for *in vivo* measurements was compared only with manual calculations.

$$D_0 = D/\mathrm{PDD} = (t - t_{err}).R_0.\mathrm{FF.WF.TF} \quad (1)$$

where t and t_{err} are the irradiation time (in minutes or monitor units) and its timer error, R_0 is the standard dose rate, FF is the field factor, WF, the wedge filter factor and TF, the tray factor. For patient measurements the entrance dose D is defined as the dose at the depth of maximum dose

$$D = M \cdot N_{cal} \cdot \prod_i k_i \quad (2)$$

where M is the detector readings and k_i are the relevant correction factors applicable for a given detector in a specific clinical setup.

2.4. Rando phantom measurements

The measurements with Rando were performed with the TLDs inside the buildup cap in the ^{60}Co unit. Doses were calculated by the TPS to deliver 50 cGy to the isocenter positioned at the center of one of the phantom slices.

For pelvis treatment, entrance dose measurements were made for a three-field beam arrangement (one anterior and two opposing lateral fields). For head & neck treatment, two parallel-opposed $6 \times 6\,\mathrm{cm}^2$ fields without wedges were irradiated. A dose of 100 cGy was delivered at the isocenter from each field, without the immobilization mask. The same setup was used for the measurements with the mask as well.

2.5. In vivo measurements

After validation of the *in vivo* dosimetry process with the irradiations on the Alderson, the patient measurements were started. All the patient measurements were performed for pelvis and head & neck during treatment with the ^{60}Co unit at the Cancer Hospital I of the National Cancer Institute. The measurements were performed with the TLDs pairs inside the buildup cap at the irradiation field center. There are a total of 237 fields from 100 patients treated with ^{60}Co beam.

3. Results

All Rando phantom measurements results presented that the difference between the doses calculated by the TPS and manually calculated remained within the acceptable limit of ±3% for a simulation. Fig. 5 summarizes the TLD measurements, $D_{m,}$ compared with TPS, D_{plan}, and manual calculations, D_c. The results from the measurements with 6 MV X-ray beam are being analyzed.

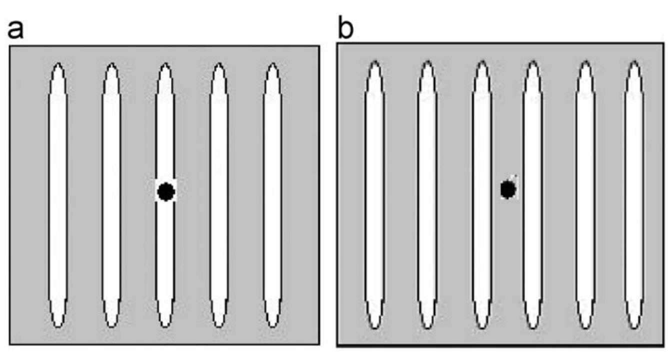

Fig. 4. (a) TLD in the center of the gap and (b) TLD under the solid acrylic.

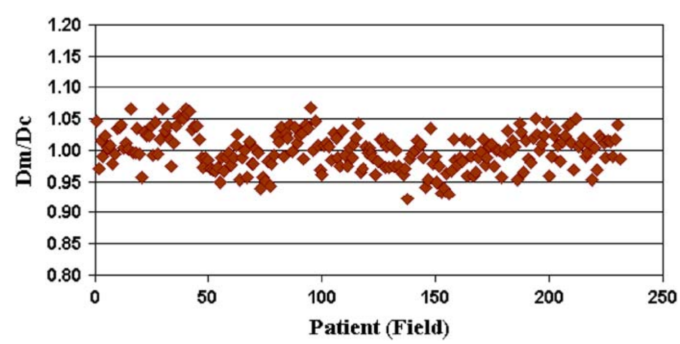

Fig. 6. *Invivo* measurements of patients treated in ^{60}Co unit.

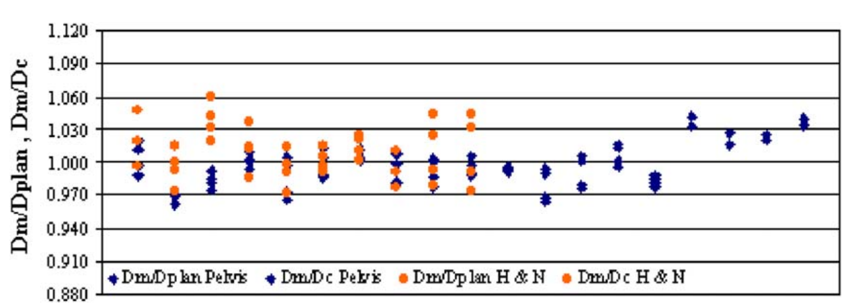

Fig. 5. Rando measurements with ^{60}Co beam.

Regarding *in vivo* measurements, 100 patients were irradiated and the vast majority of the analyzed fields remained within $\pm 5\%$ limit for *in vivo* dosimetry. Fig. 6 presents the results of the comparison between the TLD measurements, D_m and the manual calculation, D_c.

4. Conclusion

The physical and the intrinsic characteristics of the dosimeter were investigated in initial part of the work. As well as the system stability and reproducibility and the calibration of the TLD batch were performed.

All the results from Alderson phantom for different sites and setups remained within $\pm 3\%$ limit. Regarding to *in vivo* measurements, 90% of the analyzed fields remained within $\pm 5\%$ limit.

Radiotherapy involves a complex but well-established sequence of procedures that should be carefully studied and followed. It is important to analyze every step of the entire dosimetric process. With a good staff, well-trained, in order to decrease human errs and the proper use of all the correction factors, clinical studies for selected treatment sites could be preformed *in vivo*. The results obtained in our measurements are in accordance with other studies found in literature. Confirming that TL dosimetry can be used as a method to ensure the quality of the radiotherapy treatment.

Proceeding with our work, *in vivo* measurements in patients undergoing radiotherapy treatment with 6 MV beam will be the next step. Further in our work will determine all the correction factors for 15 MV Linac and perform *in vivo* measurements for patients treated with 15 MV beam.

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