



In vivo dosimetry with thermoluminescent dosimeters in external photon beam radiotherapy

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ABSTRACT

The ultimate check of the actual dose delivered to a patient in radiotherapy can only be achieved by using *in vivo* dosimetry. This work reports a pilot study to test the applicability of a thermoluminescent dosimetric system for performing *in vivo* entrance dose measurements in external photon beam radiotherapy. The measurements demonstrated the value of thermoluminescent dosimetry as a treatment verification method and its applicability as a part of a quality assurance program in radiotherapy.

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1. Introduction

The ultimate check of the actual dose delivered to a patient in radiotherapy can only be achieved by using *in vivo* dosimetry (ICRU, 1976). This is perhaps the most obvious way to check the accuracy of patient treatment (Mayles et al., 2000).

In vivo dosimetry can be divided into three classes: entrance dose measurements, exit dose measurements and intracavitary dose measurements.

Entrance dose measurements (Van Dam and Marinello, 1994; Huyskens et al., 2001) are a verification of the output and performance of the treatment unit. Entrance dose measurements can also be used to check the accuracy of patient set-up. Exit dose measurements (Piermattei et al., 2006) serve, in addition, to verify the dose calculation algorithm and to determine the influence of patient's parameters, such as shape, size and tissue inhomogeneities, on the dose calculation procedure. Various methods are available to obtain the target dose from entrance plus exit dose measurements (Venables et al., 2004; Rodríguez et al., 2008).

When detectors can be introduced in readily accessible body cavities, such as esophageal tube, rectum, vagina and bladder, are possible to measure the intracavitary dose (Marcicé et al., 2005; Engström et al., 2005).

In vivo dosimetry is applied to assess the delivered dose to critical organs (Kalapurakal et al., 2000) or in difficult geometries where the dose is hard to predict from the treatment plan (Chow and Grigorov,

2008). *In vivo* dosimetry can also be used to monitor the dose delivered in special treatment techniques (Su et al., 2008).

The principal techniques used for *in vivo* dosimetry are semiconductor diodes and thermoluminescent dosimetry (Van Dam and Marinello, 1994; Kron, 1999; Mayles et al., 2000; Huyskens et al., 2001). Some other techniques have also been used for *in vivo* dosimetry, such as metal oxide semiconductor field effect transistors dosimetry, alanine dosimetry, plastic scintillators dosimetry, radiochromic films dosimetry, conventional portal films or electronic portal imaging devices dosimetry and gel dosimetry (Evans and Marinello, 2007). The choice between these techniques may depend on many factors such as availability, intrinsic characteristics of the detector type, measurement type, training of personnel, financial considerations and, of course, personal preference (Van Dam and Marinello, 1994; Evans and Marinello, 2007).

The introduction of thermoluminescent dosimetry in radiotherapy has already a long history and its use for *in vivo* dose measurements has been well documented in the literature (Cameron et al., 1968; Rudén, 1976; McKinlay, 1981; Van Dam and Marinello, 1994; Kron, 1999; Mayles et al., 2000).

This work reports a pilot study to test the applicability of a thermoluminescent dosimetric system for performing *in vivo* entrance dose measurements in external photon beam radiotherapy. *In vivo* dosimetry was applied for treatments of head and neck cancers at a radiotherapy department in a public hospital of Ribeirão Preto, Brazil. The aim is the implementation of *in vivo* dosimetry as a part of a quality assurance program in radiotherapy.

Presently, *in vivo* dosimetry is considered as a useful part of a quality assurance program in radiotherapy (Evans and Marinello,

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2007). However, *in vivo* dosimetry as routine verification is still only applied in a small numbers of institutions in Brazil currently (Viegas, 2003).

2. Materials and methods

A total of 45 thermoluminescent dosimeters (TLD) divided into two batches (one of 17 and the other of 28 TLDs) was used. The thermoluminescent dosimeters are LiF:Mg, Ti (TLD 100) in the form of extruded square ribbons (about $3 \times 3 \times 0.9 \text{ mm}^3$) manufactured by Harshaw. Thermoluminescent readouts were performed using Harshaw Model 2000 thermoluminescence (TL) analyzer. The system consists of two components: the Model 2000-B automatic integrating picoammeter and the Model 2000-C TL detector set to a heating rate of $8 \text{ }^\circ\text{C/s}$, with nitrogen flow to suppress chemiluminescence. Readouts were recorded over the 25 s interval between 50 and $250 \text{ }^\circ\text{C}$. An oven and a furnace were used for annealing the LiF:Mg, Ti dosimeters. The annealing procedure used consists of two subsequent annealings: 1 h at $400 \text{ }^\circ\text{C}$ and 2 h at $100 \text{ }^\circ\text{C}$.

The irradiations were carried out using a ^{60}Co unit (Siemens model Gammatron S-80) with polymethylmethacrylate serving as buildup material (5 mm thick). The reference standard system consists of a cylindrical ionization chamber (Farmer type) model TN30013 (0.6 cm^3) and an electrometer model UNIDOS E T10010, both from PTW-Freiburg. The International Atomic Energy Agency code of practice (IAEA, 2000) was followed in the determination of absorbed dose to water.

All TLDs of the two batches were annealed and irradiated to the same dose. After readout, the procedure was repeated three times. A sensitivity factor was determined for each TLD. The intrinsic precision of each batch was evaluated calculating the pooled standard deviations (Mayles et al., 2000).

Supralinearity of response with dose for LiF:Mg, Ti beyond 1 Gy was investigated by determining the variation of TLD response with doses between 0.25 and 3.5 Gy (Van Dam and Marinello, 1994; Mayles et al., 2000).

A calibration was performed during each series of *in vivo* dose measurements using five TLDs selected at random from each batch (Van Dam and Marinello, 1994; Mayles et al., 2000). Calibration coefficients were determined by putting TLDs on the entrance surface of a polymethylmethacrylate phantom ($30 \times 30 \times 12.9 \text{ cm}^3$) and delivering to them a dose which was chosen in the linear region of TLD response (80 cm source-surface distance, $10 \times 10 \text{ cm}^2$ field size at surface).

A total of 49 treatment fields involving 11 patients randomly selected was included in the pilot study. These patients were patients treated for head and neck cancers. *In vivo* entrance dose measurements were performed during at least two treatment sessions on every patient in every treatment field. The goal was to discover discrepancies larger than 5% between the expected dose and the measured dose (ICRU, 1976). The expected dose was defined as the dose at the depth of dose maximum and was calculated manually from the prescribed tumor dose (Van Dam and Marinello, 1994). Each patient was treated with an immobilization mask with reference marks at entrance points in each field. TLDs were positioned on these reference marks in the center of every treatment field.

3. Results and discussion

The batch of 17 TLDs was found to have an intrinsic precision of $\pm 1.5\%$. The batch of 28 TLDs was found to have an intrinsic precision of $\pm 1.6\%$. The thermoluminescent dosimetric system

enables individual dose measurements to be made with an expected overall uncertainty lower than $\pm 3\%$. This overall uncertainty is $< \pm 5\%$, the action level recommended by ICRU (1976).

The TLD response (integrated output current from TLD reader in nanoCoulombs) with dose was plotted versus the dose for each batch. The data are presented in Figs. 1 and 2. A formula proposed by Mayles et al. (2000) was applied to correct for the effect of supralinearity on the TLD response. Figs. 1 and 2 show a linear region up to about 1 Gy, above which the TLD response becomes supralinear, consistent with the literature (Van Dam and Marinello, 1994; Mayles et al., 2000). The linear fits to the experimental data corrected by the formula proposed by Mayles et al. (2000) showed a correlation coefficient equal to 1, showing its applicability in clinical practice.

The results of *in vivo* entrance dose measurements are presented in Fig. 3 and showed a mean percentage deviation of measured dose from expected dose (dose at the depth of dose maximum calculated

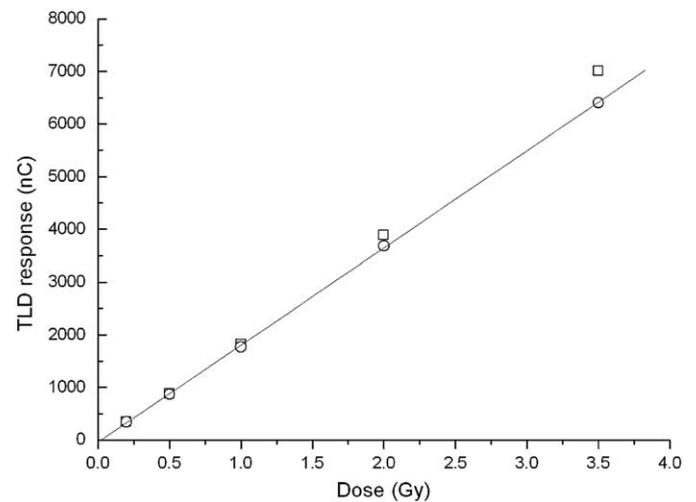


Fig. 1. Variation of TLD response with dose for the batch of 17 TLDs: \square , raw TLD response; \circ , corrected TLD response; —, linear fit. The slope of the linear region is $1828 \pm 10 \text{ nC/Gy}$.

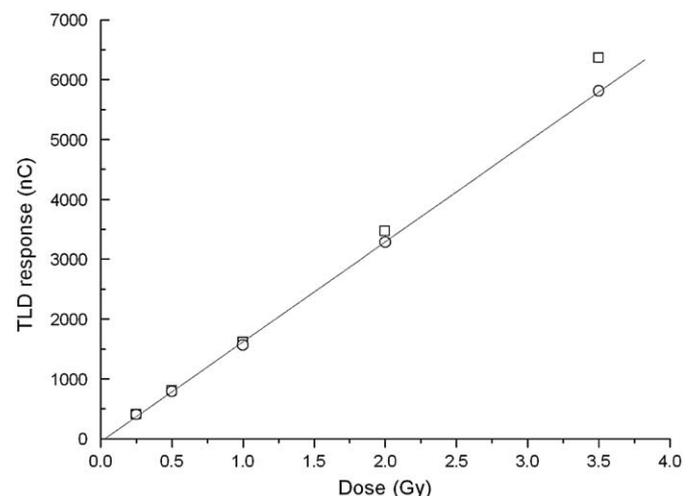


Fig. 2. Variation of TLD response with dose for the batch of 28 TLDs: \square , raw TLD response; \circ , corrected TLD response; —, linear fit. The slope of the linear region is $1642 \pm 10 \text{ nC/Gy}$.

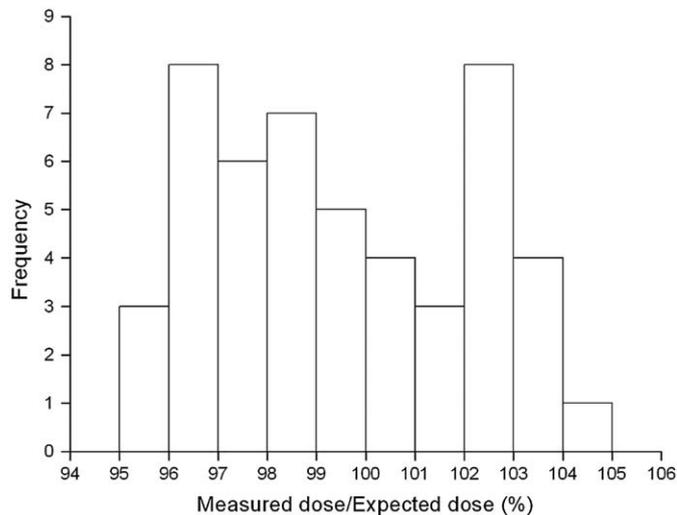


Fig. 3. Percentage deviation of measured dose from expected dose.

manually from the prescribed tumor dose) of 99% with a standard deviation of $\pm 2.6\%$. The comparison between the standard deviation of the mean percentage deviation of measured dose from expected dose ($\pm 2.6\%$) and the estimated overall uncertainty of individual dose measurements ($\pm 3\%$) indicates that small residual discrepancy between the measured and expected mean value (-1%) was due to limitations of the dosimetric system. In this pilot study no discrepancies larger than 5% between the expected dose and measured dose (ICRU, 1976) were detected.

4. Conclusions

The pilot study to test the applicability of a thermoluminescent dosimetric system for performing *in vivo* entrance dose measurements in external photon beam radiotherapy presented good results. These measurements demonstrated the value of thermoluminescent dosimetry as a treatment verification method and its applicability as a part of a quality assurance program in radiotherapy.

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References

- Cameron, J.R., Suntharalingam, N., Kenney, G.N., 1968. Thermoluminescent Dosimetry. University of Wisconsin, Madison.
- Chow, J.C.L., Grigorov, N.G., 2008. Surface dosimetry for oblique tangential photon beams: a Monte Carlo simulation study. *Med. Phys.* 35 (1), 70–76.
- Engström, P.E., Haraldsson, P., Landberg, T., Hansen, H.S., Engelholm, S.A., Nyström, H., 2005. *In vivo* dose verification of IMRT treated head and neck cancer patients. *Acta Oncol.* 44 (6), 572–578.
- Evans, P., Marinello, G., 2007. Quality control of treatment delivery. In: Mayles, P., Nahun, A., Rosenwald, J.C. (Eds.), *Handbook of Radiotherapy Physics: Theory and Practice*. Taylor Francis, New York, pp. 867–895.
- Huyskens, D.P., Bogaerts, R., Verstraete, J., Löff, M., Nyström, H., Fiorino, C., Broggi, S., Jornet, N., Ribas, M., Thwaites, D.I., 2001. Practical Guidelines for the Implementation of *In Vivo* Dosimetry with Diodes in External Radiotherapy with Photon Beams (Entrance Dose). ESTRO, Brussels.
- IAEA (International Atomic Energy Agency), 2000. Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water. Technical Reports Series no. 398, IAEA, Vienna.
- ICRU (International Commission on Radiation Units and Measurements), 1976. Determination of dose in patient irradiated by means of X or gamma rays in radiotherapy procedures. ICRU Report no. 24, ICRU, Bethesda.
- Kalapurakal, J.A., Sathiseelan, V., Bista, T., Marymont, M.H., 2000. Adverse impact of multileaf collimator field shaping on lens dose in children with acute leukemia receiving cranial irradiation. *Int. J. Radiat. Oncol.* 48 (4), 1227–1231.
- Kron, T., 1999. Applications of thermoluminescence dosimetry in medicine. *Radiat. Prot. Dosim.* 85 (1–4), 333–340.
- Marcé, S., Charpiot, E., Bensadoun, R.-J., Ciais, G., Héroult, J., Costa, A., 2005. *In vivo* measurements with MOSFET detectors in oropharynx and nasopharynx intensity-modulated radiation therapy. *Int. J. Radiat. Oncol.* 61 (5), 1603–1606.
- Mayles, W.P.M., Heisig, S., Mayles, H.M.O., 2000. Treatment verification and *in vivo* dosimetry. In: Williams, J.R., Thwaites, D.I. (Eds.), *Radiotherapy Physics: In Practice*. Oxford, New York, pp. 220–246.
- McKinlay, A., 1981. Applications of TLD in medicine. In: Oberhofer, M., Scharmann, A. (Eds.), *Applied Thermoluminescence Dosimetry*. Adam Hilger, Bristol, pp. 271–287.
- Piermattei, A., Fidanzi, A., Stimato, G., Azario, L., Grimaldi, L., D'Onofrio, G., Cilla, S., Balducci, M., Gambacorta, M.A., Di Napoli, N., Cellini, N., 2006. *In vivo* dosimetry by an aSi-based EPID. *Med. Phys.* 33 (11), 4414–4422.
- Rodríguez, M.L., Abrego, E., Pineda, A., 2008. Implementation of *in vivo* dosimetry with Isorad™ semiconductor diodes in radiotherapy treatments of the pelvis. *Med. Dosim.* 33 (1), 14–21.
- Rudén, B.I., 1976. Evaluation of the clinical use of TLD. *Acta Radiol. Ther. Phys. Biol.* 15 (5), 447–464.
- Su, F.-C., Shi, C., Papanikolaou, N., 2008. Clinical application of GAFCHROMIC® EBT film for *in vivo* dose measurements of total body irradiation radiotherapy. *Appl. Radiat. Isot.* 66 (3), 389–394.
- Van Dam, J., Marinello, G., 1994. Methods for *in vivo* Dosimetry in External Radiotherapy. ESTRO, Brussels.
- Venables, K., Miles, E.A., Aird, E.G.A., Hoskin, P.J., and on behalf of the START trial management group, 2004. The use of *in vivo* thermoluminescent dosimeters in the quality assurance programme for the START breast fractionation trial. *Radiother. Oncol.* 71 (3), 303–310.
- Viegas, C.C.B., 2003. Dosimetria *in vivo* com uso de detectores semicondutores e termoluminescentes aplicada ao tratamento de câncer de cabeça e pescoço. Master's Thesis, Universidade Federal do Rio de Janeiro, COPPE, Rio de Janeiro.