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 thermoluminecent 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.

Key words: *In vivo* dosimetry, thermoluminescent dosimetry, photon beam, quality assurance, radiotherapy

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 inhomogeneties, on the dose calculation procedure. Various methods are available to obtain the the target dose from entrance plus exit dose measurements (Venables et al., 2004; Rodríguez et al., 2008).

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When detectors can be introduced in readily accessible body cavities, such as oesophageal tube, rectum, vagina and bladder, is possible to measure the intracavitary dose (Marcié 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, 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 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 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 thermoluminecent dosimetric system for performing *in vivo* entrance dose measurements in exter-

nal 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 a useful part of a quality assurance program in radiotherapy (Evans and Marinello, 2007). However, *in vivo* dosimetry as routine verification is currently still applied in a small numbers of institutions in Brazil (Viegas, 2003).

2 Materials and methods

A total of 45 thermoluminescent dosimeters (TLD) divided into 2 batches (one of 17 and other of 28 TLDs) were used. The thermoluminescent dosimeters are LiF:Mg,Ti (TLD 100) in the form of extruded square ribbons (about $3\times3\times0.9$ mm^3) manufactured by Harshaw. Thermoluminescent readouts were performed using an Harshaw model 2000B and 2000C manual TLD reader with a linear heating rate of 8 °C/s. Nitrogen flux was used. Readouts were taken within 25 s and temperature between 50°C and 250°C. An oven and a furnace were used for annealing procedures of the LiF:Mg,Ti. The annealing procedure used consists of two subsequent annealings: 1 h at 400°C and 2 h at 100°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 2 batches were annealed and irradiated to same dose. After readout, the procedure was repeated 3 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 of LiF:Mg,Ti after 1 Gy was investigated by determining the variation of TLD response with doses between 0.25 Gy 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 5 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 ($30\times30\times12.9$ cm^3) and delivering to them a dose which was chosen in the linear region of TLD response (80 cm source-surface distance, 10×10 cm^2 field size at surface).

A total of 49 treatment fields involving 11 patients randomly selected were 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 2 treatment sessions on every patient in every treatment field. The goal was to discover discrepancies larger than 5% between the expected dose and 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 to the 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 ±1.5%. The batch of 28 TLDs was found to have an intrinsic precision of ±1.6%. The thermoluminescent dosimetric system allow individual dose measurements with an expected overall uncertainty lower than ±3%. This overall uncertainty is less than ±5%, the action level recommended by ICRU (ICRU, 1976).

The TLD response with dose was plotted versus the dose for each batch. The data are presented in Figures 1 and 2. A formula proposed by Mayles et al. (2000) was applied to correct for the effect of supralinearity on the TLD response. Figures 1 and 2 show a linear region up to about 1 Gy, from 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 appllicability in clinical practice.

The results of *in vivo* entrance dose measurements are presented in Figure 3 and showed a mean percentual deviation of measured dose from expected dose of 99% with a standard deviation of ±2.6%. The comparison between the standard deviation of the mean percentual deviation of measured dose from expected dose (±2.6%) and the estimated overall uncertainty of individual dose measurementes (±3%) indicates that small 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 thermoluminecent 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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Fig. 1. Variation of TLD response with dose for the batch of 17 TLDs : □, raw TLD response; ∘, corrected TLD response; —, linear fit.

Fig. 2. Variation of TLD response with dose for the batch of 28 TLDs : □, raw TLD response; ∘, corrected TLD response; —, linear fit.

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

Figure 1

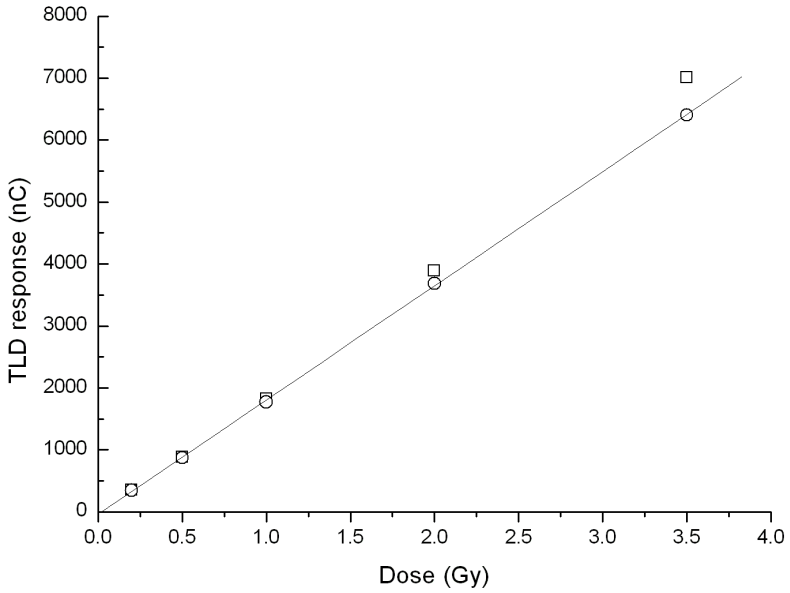

TLD response (nC)
Dose (Gy)
0
1000
2000
3000
4000
5000
6000
7000
8000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Figure 2

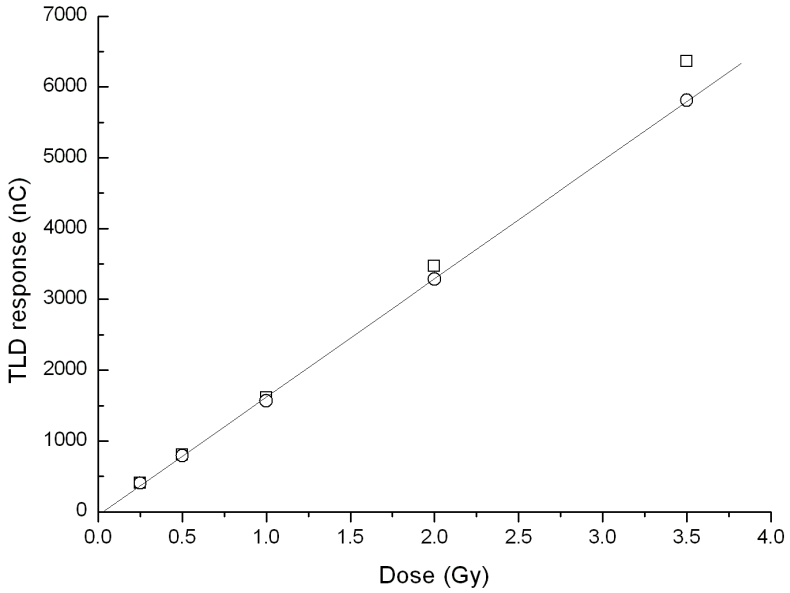
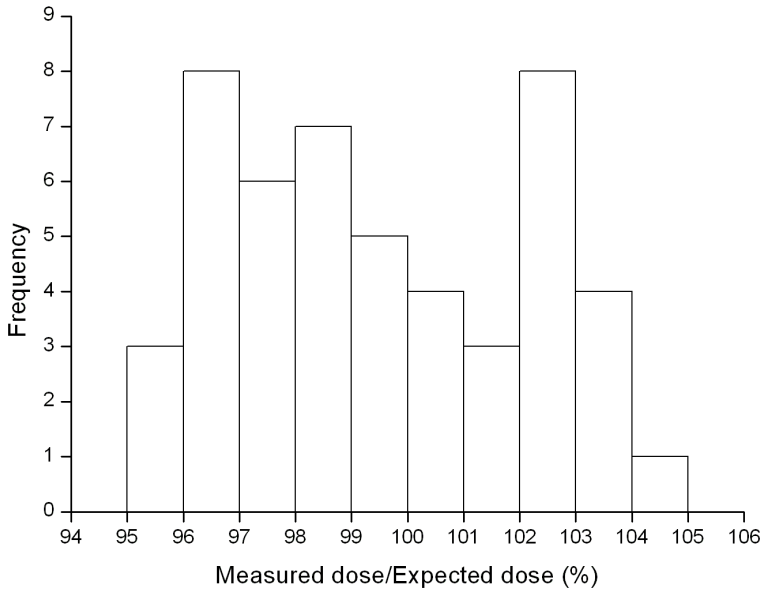

TLD response (nC)
Dose (Gy)
0
1000
2000
3000
4000
5000
6000
7000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

Figure 3


Frequency
0
1
2
3
4
5
6
7
8
9
94
95
96
97
98
99
100
101
102
103
104
105
106
Measured dose/Expected dose (%)