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ORIGINAL ARTICLE

On the evaluation of the relative sensitivity of commercial TLD readers using well characterized TLD chips

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Summary

Purpose: *To characterize a relative sensitivity or performance factor between two commercial thermoluminescent dosimeter (TLD) readers that can be used in inter comparing the thermoluminescent (TL) signals from the readers.*

Materials and methods: *The measurements were made with well-characterized TLD chips, TLD-100 (LiF: Mg; Ti). For illustrative purposes, we used the Harshaw TLD-5500 and the Victoreen 2800M TLD readers available in our department. A well-calibrated 6 MV beam linear accelerator was used as the source of radiation.*

Results: *A sensitivity factor between the two readers used in the illustration was measured as 3.40 ± 0.13 with the Harshaw TLD-5500 reader producing the superior sensitivity. In terms of measurement repeatability, we observed 2.32% ± 1.17% reproducibility with the Victoreen 2800M TLD reader and 1.86% ± 0.95% reproducibility with the Harshaw TLD – 5500 reader. The linearity properties of the two readers were comparable.*

Conclusion: *The sensitivity factor is to be interpreted as follows: when working with multiple TLD readers, in this case two, suppose the calibration of the TLD chip was performed with one of the readers, then we can use this calibration factor when measurements are made with the other reader provided we correct for differences in sensitivity with a relative sensitivity factor. This of course is true only if the TLD reader settings used at the time of measurement are similar to those used at the time of relative sensitivity characterization. Owing to a wide range of other factors that can affect the reader sensitivity, we recommend use of a relative sensitivity factor in protection level dosimetry only in situations where inaccuracies of up to 10% are acceptable.*

Key words: Harshaw TLD-5500, relative sensitivity, thermoluminescence, TLD-100, TLD reader, Victoreen 2800M

Introduction

The ability to efficiently record gammas, betas and neutrons coupled with their small size and tissue equivalent characteristics make TLDs very useful in the clinic for quality assurance purposes and for personnel dosimetry [1]. The two main crystal types used in TLD chips are CaF_2, useful for gamma detection and sometimes neutron detection depending on the impurity used, and LiF, useful for both gamma and neutron detection. The interaction of radiation with the crystal causes electrons in the atoms to be raised to higher levels where they are trapped due to impurity in the crystal, usually manganese or magnesium.

The thermoluminescence step involves heating the crystal at which point the trapped electrons jump back to the ground state and emit light [2]. This is performed using a TLD reader that is equipped with a photomultiplier tube (PMT) capable of measuring the emitted light. It has been verified that the light sum stored by individual capture levels depends not only upon the duration of the X-ray irradiation of the crystal, but also the preliminary heat treatment, and the activating impurities [3]. Therefore, the dosimeter type, TLD reader and annealing cycle used can affect the TL signal measured.

In this work, we focus on the component of the TL signal that is due to the TLD reader. The ultimate goal is

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to deduce a relative sensitivity/performance factor between readers that can be useful in comparing their TL signals. TLD-100 (LiF: Mg, Ti) TLDs (Thermo Scientific, Franklin, MA) were used for the study. This is the most commonly used TLD in clinical practice and despite its faults it has survived the competition with other TLD materials of higher sensitivity and superior signal-to-noise ratio [4]. The chips were used to characterize a relative sensitivity factor between two commercially available TLD readers used at our cancer center; the Harshaw TLD-5500 and the Victoreen 2800M. In addition, we also characterized the reproducibility and linearity of these readers.

The two readers used are for illustrative purposes rather than a real performance comparison as they are markedly different from each other. For example, the Harshaw TLD-5500 is a modern automatic TLD reader and far more superior to the Victoreen 2800M manual TLD reader (see appendix I for a summary of their properties).

It should be noted that the TLD reader performance can depend on a wide range of parameters including the workload handled, level of light signals detected by the PMT (fatigue), the reader settings and frequent changes in the settings and maintenance including cleaning of optical filters and the influence of other electronic components affecting the amplification of the PMT. This means that a relative sensitivity factor obtained between two readers in one laboratory can not necessarily be used in another laboratory with similar readers. Even in the same laboratory, a relative sensitivity factor measured in one session between two readers is applicable in another measurement session only if the factors outlined above have not changed considerably. Furthermore, owing to the many factors involved, long time use of the pre-established sensitivity factor should be limited to estimations of doses in quality control where inaccuracies of up to 10% may be acceptable. An example application is in quality control during Total Body Irradiation (TBI) procedure involving measurement of surface doses.

Materials and methods

Theory

Upon irradiating a given TLD chip and processing the chip using a TLD reader, the absorbed dose (D) and thermoluminescence (L) are linearly related for a given dose range. Neglecting background sources, one can write

$$D = k * L \quad (1)$$

where k is a proportionality constant (calibration constant) that converts L(C) to D(Gy), so k is measured in Gy/C. The constant k can be obtained by irradiating a chip to a known source and obtaining the luminescence. It is specific for a given TLD reader used owing to variations in reader sensitivities. Introducing a relative sensitivity factor offers the flexibility of using a single calibration constant across various TLD readers as this corrects for the variation in sensitivities. The following equation illustrates this idea:

$$D = k^a{}_b * k_a * L_b \quad (2)$$

where in equation 2 above, we have used the superscripts and subscripts to denote the TLD reader being used. In this case, the calibration step was obtained using TLD reader (a) and the thermoluminescence was obtained using TLD reader (b) so we have to introduce a relative sensitivity factor $k^a{}_b$ to obtain the absorbed dose. Observe that $k^a{}_b$ is the ratio of the two calibration constants (k_b / k_a) and can be obtained via an one time measurement.

Experiment

The TLD readers used for the investigation were the Harshaw TLD-5500

(Thermo Scientific, Franklin, MA) and the Victoreen 2800M (Victoreen Inc., Cleveland, OH). A brief discussion of the manufacturer specifications of these TLD readers is provided in the appendix section. The irradiation source used was a 6 MV beam linear accelerator, CLINAC 600 C (Varian Medical Systems, Palo Alto, CA), calibrated following the AAPM TG-51 protocol [5], to deliver a dose of 10^{-2} Gy per monitor unit (MU) at depth of maximum dose in water. A solid water phantom was used to hold the TLDs.

The chips to be irradiated were placed on top of a 10 cm thick back scattering phantom and a build up of 1.5 cm. The phantom with TLDs was set up such that the source-to-surface distance (SSD) was 100 cm. The linear accelerator's collimators (jaws) were set at 10 × 10 cm field size. Under this set up, the single energy (6 MV photons) linear accelerator has a depth of maximum dose at 1.5 cm. Further, by delivering a given number of MUs to the TLDs, the absorbed dose to the chips can be pre-determined. For example, by delivering 100 MUs to the chips using the set up, the absorbed dose is 1 Gy for a well calibrated Linac. In order to assure perfect calibration and stability of the Linac, an ion chamber, Exradin A1SL Shonka (Standard Imaging Inc., WI), was used to monitor the output prior to irradiating the TLDs. The output variations from one measurement to another were within 0.3%.

In particular, known doses were delivered to the TLDs depending on the process under investigation. The TLD readers were then used to obtain the signals stored in the chips. As was earlier mentioned, the signal strength depends to an extent on the settings on the readers, thus it is important to always state these settings (Table 1). We have included a glow curve example from the Harshaw TLD-5500 reader (Figure 1) that illustrates the notion of pre-heat and acquire temperature settings as stated in Table 1.

To prepare the TLDs for subsequent readings, they were annealed. Various annealing cycles are possible but to minimize the variation in TLD sensitivity owing to variation in annealing cycle [6] we used the following annealing cycle each time; heat at 400º C for one hour followed by 80º C for 24 hours. The chips were then cooled down to room temperature outside the oven after the 80º C treatment.

Reproducibility

For the relative sensitivity factor to be applicable it is important to demonstrate that, under similar experimental setups, both readers can reproduce the measured TL signals to within reasonable limits. To do this, we used 3 cycles and 13 TLD chips per cycle. Eleven TLDs were exposed at each stage and 2 were used for background monitoring and correction. By using more than one TLD chip in any given cycle and obtaining an average measured value we minimize the variation owing to TLD chips and focus on the variations associated with TLD reader behavior. The TLDs were irradiated to a known dose and their TL signals determined using the reader. TLD sensitivity has been shown to be affected by the duration of the anneal, and virtually independent of the various time delays between irradiation, pre-readout anneal, and readout [7]. Therefore, to minimize errors from external phenomena, the same irradiation conditions were set up each time and the process was repeated 3 times. Also, by keeping track of and maintaining each TLD location on the phantom at every irradiation, one minimizes the variation in known dose due to flatness and symmetry characteristics of the Linac beam.

Table 1. TLD reader settings for relative sensitivity measurement

	Harshaw TLD-5500	*Victoreen 2800M*
PM Tube bias voltage	801V	603V
Pre-heat temperature (° C)	55 - 104	60 -100
Acquired temperature (° C)	104 - 327	100 - 300
Cycle time	30s per chip	30s

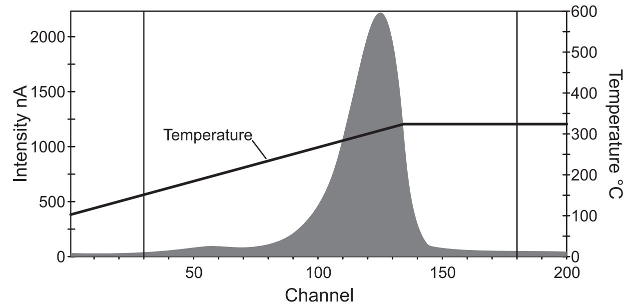

Figure 1. Glow curve example for a single chip read using the Harshaw TLD-5500 reader. The TL signal is the integrated charge (Coulombs) for the labeled region of interest (two vertical lines shown – channel 30 and channel 180).

Linearity

The dosimeter used for the study (TLD-100) has been observed to show supralinearity at all energies and modalities [8]. It deviates from linearity starting from 1.75 Gy with deviations approaching 5% at 3 Gy [9]. Therefore we used a range (0.1-1 Gy) to compare the reader's linearity performance at the given settings where we are sure that the dosimeters used exhibit linearity over this range.

Relative sensitivity evaluation

By irradiating the TLD to a known dose and obtaining a TL signal, one could obtain a calibration factor for a given TLD. The TLD is then prepared and the process is repeated with the other TLD reader. Again, the irradiations are done using all the TLD chips to properly account for or rule out any variations that may be otherwise attributed to dosimeter variation as opposed to TLD reader sensitivity variation.

Results

Reproducibility

We observed 2.32% ± 1.17% reproducibility with the Victoreen 2800M TLD reader and 1.86% ± 0.95% reproducibility with the Harshaw TLD – 5500 reader. We calculated the reproducibility for each TLD chip as the percent standard deviation of the repeated steps. The reproducibility stated above is the average across all the TLD chips used. This information is shown in Table 2.

Linearity

We used the R-squared concept to quantify the

Table 2. Reproducibility data for Harshaw TLD-5500 and Victoreen 2800M

TLD →	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
Trials (μC/Gy)					*Harshaw TLD-5500*						
Trial 1	4.530	4.332	4.423	4.679	5.041	4.408	4.472	4.735	4.193	4.880	4.636
Trial 2	4.434	4.383	4.365	4.626	5.015	4.260	4.389	4.589	4.080	4.871	4.488
Trial 3	4.594	4.334	4.480	4.792	5.060	4.477	4.496	4.788	4.314	4.903	4.650
					Victoreen 2800M						
Trial 1	1.348	1.297	1.278	1.293	1.440	1.365	1.216	1.255	1.265	1.233	1.296
Trial 2	1.402	1.288	1.318	1.296	1.418	1.358	1.234	1.259	1.296	1.245	1.316
Trial 3	1.427	1.337	1.200	1.320	1.465	1.428	1.243	1.296	1.319	1.325	1.333

index of linearity for the two TLD readers. The calculated R-squared value using the Harshaw reader was 99.96% and 99.98% for the Victoreen 2800M reader. The variation in R-squared between the two is not significant for us to associate any TLD reader factors in the linearity of the dosimeter used. The results are shown in Figure 2.

Relative sensitivity characterization

A relative sensitivity factor between the two TLD readers was determined as $k^a{}_b = 3.40 \pm 0.13$, where "a" represents the Victoreen 2800M TLD reader and "b" represents the Harshaw TLD-5500 reader. For each of the TLD chips, the relative sensitivity factor was calculated by taking the ratio of the calibration factors obtained using the TLD readers. This procedure was repeated 3 times per chip and an average value obtained. The final value stated above is the average across all the TLD chips used. The results are illustrated in Figure 3.

Discussion

We have characterized a relative sensitivity factor between two commercially available TLD readers routinely used for clinical applications. When compared to the Victoreen 2800M TLD reader, the Harshaw TLD-5500 reader produces sensitivity (μC/Gy) that is greater by a factor of 3.40 ± 0.13. In terms of measurement repeatability, we observed 2.32% ± 1.17% reproducibility with the Victoreen 2800M TLD reader and 1.86% ± 0.95% reproducibility with the Harshaw TLD – 5500 reader. Using a different TLD reader (the Harshaw TLD-3500 model), Harris et al. [9] observed a 3.64% reproducibility at a delivered dose of 1 Gy. They also showed reproducibility of the TLD chip

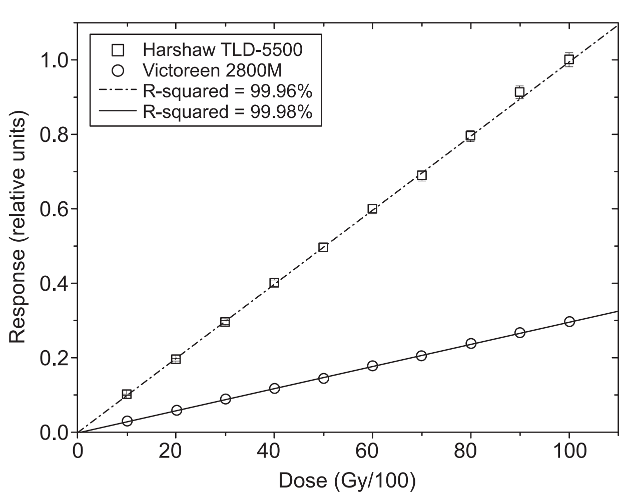

Figure 2. Linearity measurements for the Harshaw TLD-5500 and Victoreen 2800M readers.

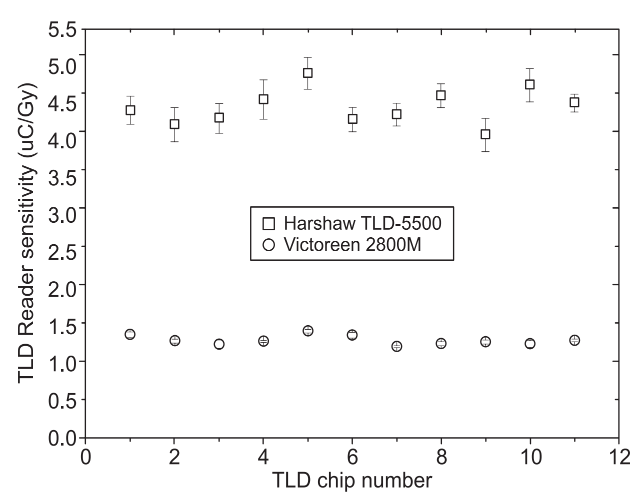

Figure 3. Relative sensitivity measurement between Harshaw TLD-5500 and Victoreen 2800M.

dependence on the dose used in the irradiation. This variation in reproducibility per TLD reader shows that, when quoted, it is important to state the TLD reader that was used in obtaining the TLD chip reproducibility. The linearity properties of the two readers were comparable. When quoting a relative sensitivity factor between two readers, reference to the reader settings must be made as different settings may produce different values. Also, owing to a wide range of other factors that can affect the reader sensitivity, routine use of a relative sensitivity factor should be limited to situations where inaccuracies of up to 10% are acceptable.

Appendix

The Victoreen 2800M TLD reader

The reader weighs 35 lbs (16 Kg) and can process only one TLD chip at a time making it a manual TLD reader. It is also designed to evaluate a variety of other TLDs including rod, bulb, glass encapsulated chips, powder, and teflon matrix configurations. The photomultiplier tube used was selected for its high gain, low dark current and long term stability. Heating is achieved by means of a heater pan (planchet) through which electric current is passed causing the metal to become hot (resistive heating) attaining a maximum temperature of 400º C. The resultant increased detectability makes it useful for evaluating TLDs in environmental applications.

The Harshaw TLD-5500 TLD reader

This is an automatic TLD reader as it has the capability of unattended automatic operation of up to 50 TLDs. Also available is an unattended automatic background subtraction capability. It is supplied with a thermoelectric PMT cooler for maximum gain stability. Heating is by hot nitrogen gas with temperature capability up to 600º C. It comes with a software (Win-REMS) which runs on a separate computer and provides a user interface, the reader control and application software.

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