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Assessment of the Effects of Radiation Type and Energy on the Calibration of TLD-100

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ABSTRACT

Introduction: In radiation therapy, knowing the dose rates to healthy organs and tumors is beneficial, and thermoluminescent dosimeter (TLD) allows for this possibility. This study was aimed at determining the dose-response differences of TLDs in various types of radiation, energy levels, and dose rate calibrated with other types of radiation beams and energy and dose levels.
Materials and Methods: In this study, LiF:Mg,Ti (TLD-100) was used for dosimetry. Photon and electron irradiation was performed by Elekta Precise Linear Accelerator. First, TLDs were calibrated in three different groups of 6 MV photon, 6 MeV electron, and ^{60}Co teletherapy photon beam with 50 cGy dose. Next, each group was irradiated with 6 MV photon, 6 MeV electron, and ^{60}Co teletherapy photon beam separately at three different dose levels of 20, 60, and 100 cGy.
Results: TLDs calibrated with electron were significantly different at all dose levels and with all types of radiation from TLDs calibrated with photon or ^{60}Co teletherapy photon beam (P=0.000). P-value of the TLDs calibrated with 6 MV photon versus ^{60}Co was less than 0.94. The maximum standard deviation belonged to 100 cGy irradiation, while the least pertained to 20 cGy irradiation.
Conclusion: Calibration of TLDs depends on the type of radiation.

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Introduction

In radiotherapy, the radiation dose to tumors or the surrounding healthy organs is determined by dosimetry of these regions. Thermoluminescent dosimeter (TLD) is one of the common means of dosimetry due to its small size. This device shows the dose each point received. Selecting the type of TLD depends on its application.

Dosimetry with TLD has been one of the most important techniques in medical radiation procedures for many years. TLDs have created opportunities for advancement in novel radiotherapy techniques because of being tissue equivalent and small, as well as having proper sensitivity [1, 2]. Various types of TLDs have been used for different usages such as LiF:Mg,Cu,P and LiF:Mg,Ti. LiF:Mg,Ti TLD is appropriate for radiotherapy because of having suitable properties such as high sensitivity, small size, and tissue equivalence [2].

The thermoluminescent (TL) response of LiF:Mg,Ti is extremely sensitive to the various thermal treatments involved in TL processing including high temperature, pre-irradiation annealing, cooling rate, low temperature annealing, heating rate during readout, and maximum readout temperature [3].

Amols et al. in 1987 found that 22% of the reported dose levels had a 10% error, while the acceptable error of radiation therapy applications is as low as 3–5% [4]. Thus, proper calibration and use of TLD can bring these uncertainties well within the acceptable limits [3].

In low-energy photons, under a few hundred KeV, the ratio of the mass energy absorption coefficient of most TL material increases relative to air with decreasing energy [3]. The over-response of LiF:Mg,Ti TLD is larger than what could be expected from the ratio of the mass-energy absorption coefficients and that is because the microscopic dose distribution within photon induced secondary electrons, represented by supralinear region of the dose-response curve [3]. No supralinearity is observed for LiF:Mg,Cu,P TLD ,and the dose-response is linear–sublinear rather than linear–supralinear as is the case for LiF:Mg,Ti TLD[3].

The photon energy dependence of LiF:Mg,Cu,P is lower than expected just from the ratio of the mass-energy absorption coefficients, and it is consistent with the lack of supralinearity in this material [5].

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For electron beams, the correction factors of LiF TLDs depend on the average electron energy incident on the phantom surface, the electron energy spectrum incident on the dosimeter surface, the size and density of the TLD material, the phantom material, and the depth of irradiation of the TLDs [6].

Banaee et al. in 2013 evaluated the effect of energy on ^{7}LiF:Mg,Cu,P calibration. They exposed three tested TLDs at various energies, that is, 120 kVp, 200 kVp, 6 MV, and 18 MV, and ^{60}Co photon beams. After that, they drew calibration curves. Energy dependence was obtained in the tested TLDs by exposing to 50 cGy, 100 cGy, and 200 cGy. Next, the dose response of TLDs was normalized to the ^{60}Co photon beam. Finally, they concluded that this type of TLD does not have the same dose response at different energy levels, and the reference dose affects the amount of energy dependence. They also confirmed that energy dependence of this type of TLD is more significant at lower energies compared to megavoltage beams. The relative response to ^{60}Co illustrated that GR-207A did not have uniform response to different energy levels, and energy dependence was totally different at various dose levels [7].

TLDs must be calibrated before use. What TYPE of radiation and energy should be used for TLD calibration? In other words, is it possible to calibrate TLDs at a specific energy or with a particular radiation beam and use them for dosimetry in other energies or other types of radiation beams? In this study, we responded to these controversial questions. In fact, the major objective of this study was to evaluate the role of radiation type (photon or electron) in calibration of TLDs. On other words, this study indicates that: can TLDs be calibrated with ^{60}Co, but then exposed to photon and conversely?

Materials and Methods

We irradiated 6 MV photon and 6 MeV electron by Elekta Precise Linear (Elekta Precise model, Germany). Lithium fluoride TLDs with the cross-section of 3 × 3 mm^2 and thickness of 0.9 mm (TLD-100, Harshaw-Bicron, Cleveland, OH, USA) were used for dosimetry. A 3500 TLD reader (Harshaw-Bicron, USA) was used to read the TLD chips. The TLDs were calibrated in three different groups of 6 MV photon, 6 MeV electron, and ^{60}Co teletherapy photon beam. Before irradiating the TLDs, they were annealed based on the manufacturer's instructions to reduce the background radiation (1 h at 400°C, 15 min at room temperature, and 2 h at 100°C).

To maintain the high-quality performance of a TLD system, both the dosimeter and reader are commonly calibrated [6]. TLD calibration consists of three steps: generation of calibration dosimeters, reader calibration, and dosimeter calibration.

At the first step of photon and electron calibration, 20 TLD chips were selected and irradiated with 50 cGy of the same type of radiation that we aimed to calibrate. For ^{60}Co photon beam, 50 chips were irradiated for 1.06 min that was equivalent to a dose of 50 cGy. TLDs were read out after 24 h of irradiation due to the elimination of low-temperature peaks. These dosimeters are named Element Correction Coefficient (ECC), which is the relative response of irradiated dose (L) from the mean and is generated for each element of these calibration dosimeters. This calibration process is performed only once at the TLD system start-up [8].

$$ECC_j = \frac{<Q>}{qj} \quad (1)$$

Secondly, 50 cGy irradiation with the same type of radiation being calibrated was performed. After reading out the TLDs, Reader calibration factor (RCF) coefficient was calculated. RCFis defined as the average of the calibration TLDs per irradiated dose (L):

$$RCF = \frac{<Q>}{L} \quad (2)$$

Each dosimeter is calibrated before being put into the TLD reader system. The purpose of this calibration is to find a TL efficiency correction factor for each element [9].

$$ECC_j = \frac{RCF*L}{qj} \quad (3)$$

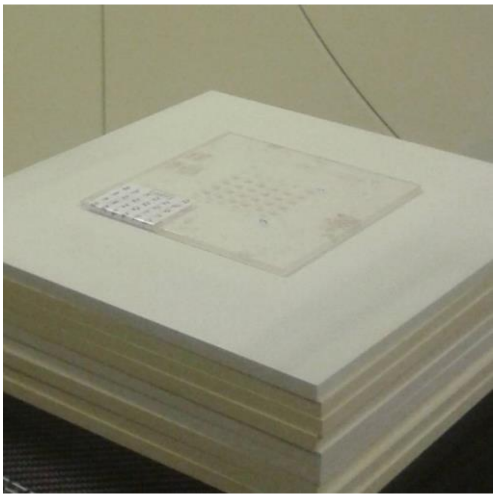

Figure 1. Thermoluminescent dosimeters container on 10 cm polymethylmethacrylate plates

TLDs were set in a polymethylmethacrylate (PMMA) plate, which had slots for putting TLDs. Over this plate, a 1.5-cm bolus was placed and a 30*30*10-cm^3 PMMA phantom was set under it (Figure 1). The calibration conditions of 6 MV photon were as follows: 50 cGy irradiation, field size=15*15 cm^2, and SSD=100 cm. The calibration conditions. The calibration conditions for 6 MeV such as irradiation and SSD for 6 MeV electron were the same as the photon experiment the difference was the thickness of the bolus which was 0.5 Cm, also using a 20-cm^2 applicator instead of field size of 15 cm^2 and radiated by 6 MeV electron rather than 6 MV photon as shown in Figure 2.

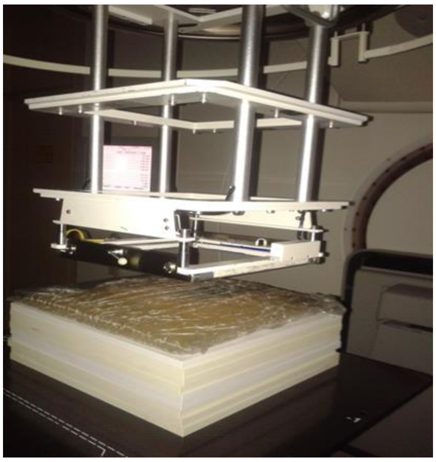

Figure 2. Left side, photon irradiation set-up; right side, electron irradiation set-up

Figure 3. The 60Co photon beam irradiation conditions

The calibration conditions for ^{60}Co photon beam were: 1.06 min exposure to ^{60}Co photon beam that was equivalent to 50 cGy, field size=15*15 cm^2, SSD=100 cm, and using a 0.5-cm bolus over the TLD plate and a 20*20*10 water phantom under it (Figure 3).

These conditions were repeated in three steps of calibration. After calibration, TLDs with less than 3% variation in the three steps of calibration were selected. Overall, 18 TLDs calibrated with photons, 18 TLDs calibrated with electrons, and 35 TLDs calibrated with ^{60}Co photon beam had less than 2% variations.

For drawing the calibration curve, several groups of TLDs, each containing three chips, were exposed to different doses from 10 to 200 cGy of 6 MV photons. The result of the trial showed that for up to 120 cGy dose the TLD response is linear and for higher doses it is supralinear (Figure 4). Thus, we chose 100 cGy as the maximum and 20 and 60 cGy were selected for evaluating TLD responses to low and average doses, respectively.

TLDs calibrated with 6 MV photon, 6 MeV electron, and ^{60}Co photon beam were irradiated at three different dose levels of 20, 60, and 100 cGy of 6 MV photon, 6 MeV electron, and ^{60}Co photon beam. Irradiation conditions for each energy were in accordance with the calibration conditions with the same energy but a different delivered dose.

Statistical analysis

All the data were distributed normally; therefore, to analyze the dose difference in the three different radiation types and three different dose levels, independent t-test was run in SPSS, version 21.

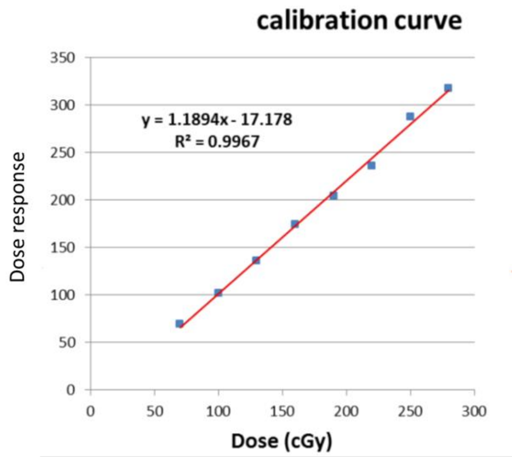

Figure 4. The calibration curve of thermoluminescent dosimeters

Results

Tables 1, 2, and 3 present the mean dose and standard deviations of TLDs and the Figures 5,6 and 7 present the dose response curves in the three different radiation types and three different dose levels.

Table 1. The dose response of thermoluminescent dosimeters calibrated in three groups when irradiating with 6 MV photon with different doses

Dose levels of Photon 6 MV	dose cGy 20	dose cGy 60	dose cGy 100
The average of thermoluminescent dosimeters (TLDs) calibrated with 6 MV photon	0.67 (cGy)± 20.62	1.9 (cGy)± 61.4	4.18 (cGy)±101.28
The average of TLDs calibrated with 6 MeV electron	0.52 (cGy)±21.71	2.21 (cGy)±67.87	3.88 (cGy)±111.07
The average of TLDs calibrated with the 60Co photon beam	0.69 (cGy)±20.37	2.13 (cGy)±61.04	4.07 (cGy)±103.50

Table 2. The dose response of thermoluminescent dosimeters calibrated in three groups when irradiating with 6 MeV electron with different doses

Dose levels of 6 MeV electron	Dose cGy 20	dose cGy 60	dose cGy 100
The average of thermoluminescent dosimeters (TLDs) calibrated with 6 MV photon	0.66 (cGy)±18.00	2.45 (cGy)±55.18	3.73 (cGy)±94.88
The average of TLDs calibrated with 6 MeV electron	0.55 (cGy)±20.82	1.79 (cGy)±57.10	3.29 (cGy)±104.84
The average of TLDs calibrated with the 60Co photon beam	0.43 (cGy)±18.62	1.74 (cGy)±55.10	2.94(cGy)±98.89

Table 3. The dose response of thermoluminescent dosimeters calibrated in three groups when irradiating with the 60Co photon beam with different doses

Dose levels of ^{60}Co	(0.43 min) equivalent to 20 cGy dose	(1.33 min) equivalent to 60 cGy dose	(2.15 min) equivalent to 100 cGy dose
The average of thermoluminescent dosimeters (TLDs) calibrated with 6 MV photon	0.88 (cGy)±19.36	2.49 (cGy)±58.75	4.49 (cGy)±99.80
The average of TLDs calibrated with 6 MeV electron	0.46 (cGy)±21.38	1.85 (cGy)±63.47	4.39 (cGy)±108.23
The average of TLDs calibrated with the 60Co photon beam	0.62 (cGy)±19.85	1.87 (cGy)±58.56	4.07 (cGy)±100.97

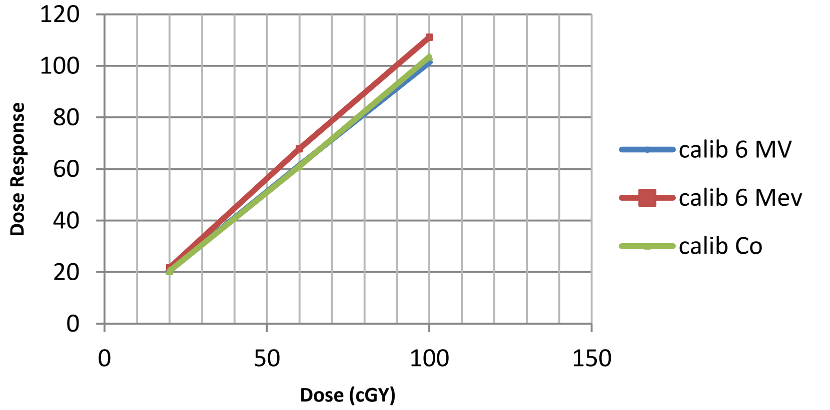

Figure 5. The dose response of thermoluminescent dosimeters calibrated in three groups, when irradiating with 6 MV photon in different doses
Abbreviations: calib 6 MV= TLDs calibrated with 6 MV photon, calib 6 MeV e= TLDs calibrated with 6 MeV electron, and calib Co= TLDs calibrated with the 60Co photon beam.

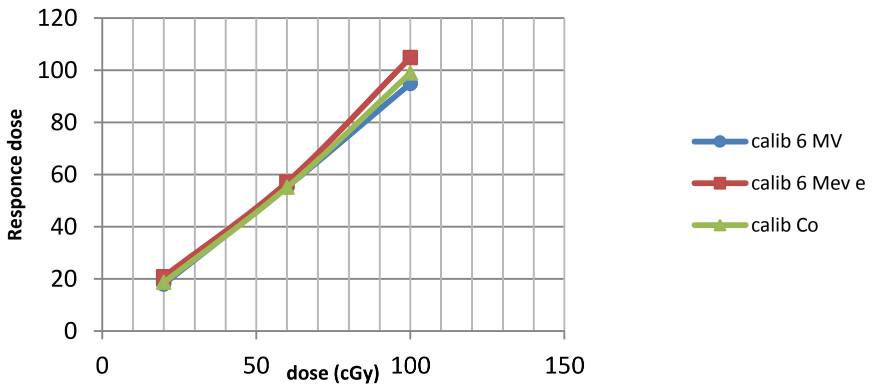

Figure 6. The dose response of thermoluminescent dosimeters calibrated in three groups when irradiating with 6 MeV electron in different doses
Abbreviations: calib 6 MV= TLDs calibrated with 6 MV photon, calib 6 MeV e= TLDs calibrated with 6 MeV electron, and calib Co= TLDs calibrated with the 60Co photon beam

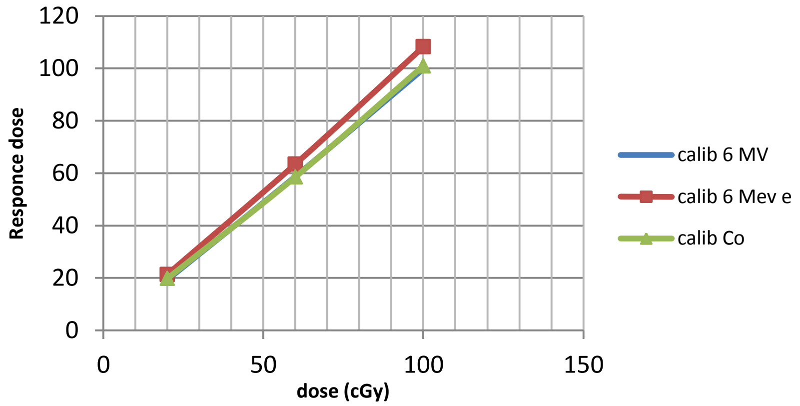

Figure 7. The dose response of thermoluminescent dosimeters (TLDs) calibrated in three groups, when irradiating with the 60Co photon beam in different doses.
Abbreviations: calib 6 MV= TLDs calibrated with 6 MV photon, calib 6 Mev e= TLDs calibrated with 6 MeV electron, and calib Co= TLDs calibrated with the 60Co photon beam

Standard deviation for the three types of radiation and three dose levels ranged from 0.43 to 4.49 for TLDs calibrated with ^{60}Co photon beam and irradiated with 20 cGy dose of electron radiation and TLDs calibrated with 6 MV photon and irradiated with 100 cGy dose of ^{60}Co photon beam, respectively (tables 1, 2, and 3). The maximum standard deviation belonged to 100 cGy irradiation, whereas the least one pertained to 20 cGy irradiation.

The averages of TLDs calibrated with 6 MV photon or ^{60}Co photon beam irradiated with 60 cGy of 6 MV photon or ^{60}Co photon beam were close to one another except at dose of 100 cGy (Figure 5). P-value of the TLDs calibrated with 6 MV photon versus ^{60}Co was less than 0.94. TLDs calibrated with 6 MV photon or ^{60}Co photon beam and irradiated with 60 cGy dose of electron were not significantly different (P-Value=0.993), but they were significantly different at doses of 20 and 100 cGy (P-Value=0.000).

TLDs calibrated with electron were significantly different at all doses (i.e., 20, 60, and 100 cGy) with TLDs calibrated with photon or ^{60}Co when irradiated with all types of radiation (i.e., photon, electron, and ^{60}Co photon beam) (P-Value=0.000). The difference was less for TLDs calibrated with photon and ^{60}Co that irradiated with the 60 cGy dose of electron (P-Value<0.017).

Discussion

Herein, we sought to assess the effects of radiation type and energy on the calibration of TLD-100. In doing so, TLDs were calibrated in three different groups of 6 MV photon, 6 MeV electron, and ^{60}Co teletherapy photon beam, and they were irradiated at three different dose levels (i.e., 20, 60, and 100 cGy).

Based on the obtained results (tables 1, 2, and 3), at lower doses (e.g., 20 cGy), dose response of TLDs is in a narrower range for higher doses (e.g., 100 cGy), that is, the dose responses of TLDs at lower doses are closer to one another than at higher doses. Banaee et al. showed that energy dependence of 7-LiF:Mg,Cu,P (GR-207A) is too significant at kilovoltage energies compared to megavoltage beams. They also declared that energy dependence is totally different at various dose levels [5].

Mobit et al. [6] determined the energy correction factor of TLD-100 calibrated in cobalt-60 gamma ray and irradiated with megavoltage electron beams (using Monte Carlo simulations). They showed that the energy correction factor increases, especially for low energies of electron beams, which is consistent with the present findings indicating that TLDs that are supposed to be exposed to electron must be calibrated with electrons (Table 2).

The present study also revealed that TLDs can be calibrated with 6 MV photon or ^{60}Co photon beam when they are supposed to be irradiated with 6 MV photon at all dose levels, which also applies to ^{60}Co photon beam, that is, TLDs calibrated with 6 MV photon can be irradiated with ^{60}Co photon beam at all doses; therefore, calibration does not depend on energy.

The dose responses of TLDs calibrated with 6 MV photon or ^{60}Co photon beam and 60 cGy radiation are more comparable than the other doses (tables 1 and 3), which could be due to calibrating TLDs with the 50 cGy dose level. Accordingly, we suggest calibrating TLDs with the same dose level they are supposed to be exposed to.

Conclusion

Calibration depends on the type of radiation when it is supposed to be irradiated with electron; however, photon energy does not play a role (6 MV photon or ^{60}Co photon beam) when it is supposed to be irradiated with photon (6 MV photon or ^{60}Co photon beam). Therefore, TLD calibration is hinged upon the type of radiation.

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