Original

Thermoluminescent Characteristics of GR-200, TLD-700H and TLD-100 for Low Dose Measurement: Linearity, Repeatability, Dose Rate and Photon Energy Dependence

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ABSTRACT

Background: The dose values obtained from procedures of diagnostic radiology are relatively low. To accurately and precisely measure the dose values in this dose range, it is necessary to know the characteristics of dosimeters.

Objective: The aim of this study was to evaluate several thermoluminescent characteristics of GR-200, TLD-700H and TLD-100 for low dose measurement.

Material and Methods: In this experimental study, linearity, repeatability, dose rate and photon energy dependence of different TLD materials were investigated in a 0.05-10 mGy range dose. It is noteworthy that the data obtained from TLD-100 were considered as reference and the data obtained from two other types of TLDs were compared with them.

Results: For all three types of TLD materials, there are linear relations between absorbed dose values to TLDs and their responses. TLD-100 and TLD-700H have very low sensitivity than GR-200. For GR-200 and TLD-100, the coefficients of variation values (%) are 3.00% and 2.01%, respectively, that these values are within the tolerance limit (<7.5%). However, this value for TLD-700H is 10.85% which it is more than the reported tolerance limit. Furthermore, remarkable effects of dose rate and photon energy dependence on the responses of GR-200 are not observed in a 0.5-4 mGy dose range; nevertheless, remarkable effects of dose rate and photon energy dependence on the responses of TLD-100 and TLD-700H are found in this dose range.

Conclusion: The evaluated thermoluminescent characteristics for GR-200 are better than two other types of TLDs (TLD-100 and TLD-700H) for low dose values.

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Keywords

Thermoluminescent Dosimetry; Radiology; Radiation Dosage; GR-200; TLD-100; TLD-700H

Introduction

The radiation dosimetry in medical applications can be required for optimization of radiological techniques and X-ray equipment [1, 2]. It is also essential to investigate radiation dose values received to patients in medical procedures in order to estimate the risk associated with the received radiation dose values [3].

The one of most common dosimeters used in radiation dosimetry is thermoluminescent dosimeter (TLD). There are several types of TLDs, which are commercially available and applied for various applications, such as personnel, medical, environment dosimetry, etc. [4]. The main advantag-

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es of these dosimeters are as follows: **1)** small physical size, **2)** no requirement for cables or auxiliary equipment during dose assessment, **3)** tissue equivalent (it is essential for medical dosimetry), **4)** high sensitivity, **5)** stability under severe climatic conditions, **6)** very low dose measurement, and **7)** appropriate angular and energy response [3, 5, 6]. Other characteristics of TLDs (such as accuracy, precision, linearity, fading) have been reviewed by Rivera [3], and for more details about TLD, the readers can refer this article.

Dosimetric assessments in diagnostic radiology have received increasing attention in recent years [4]. Moreover, these assessments are needed to optimize the image quality as well as radiation protection purposes [3]. Since the dose values resulting from procedures of diagnostic radiology are relatively low, it is necessary to know the characteristics of TLDs in this dose range in order to accurately and precisely measure the dose values. Hence, the aim of this study was to evaluate several thermoluminescent characteristics of GR-200, TLD-700H and TLD-100 for low dose measurement (0.05-10 mGy). It is noteworthy that in the present study, the data resulting from TLD-100 were considered as reference and the data obtained from two other types of TLDs were compared with them.

Material and Methods

1. Materials

In the experimental present study, three types of TLDs were used as follows: **1)** GR-200 discs (LiF:Mg,Cu,P) produced by Solid Dosimetric Detector & Method Laboratory (Beijing, China) with the 5 mm diameter and 1 mm thickness, **2)** TLD-700H chips (LiF:Mg, Cu, P) generated by Harshaw Company (Solon, OH, USA) with the size of 3.3×3.3 mm^2 and 0.3 mm thickness, and **3)** TLD-100 chips (LiF:Mg,Ti) produced by Harshaw Company (Solon, OH, USA) with the size of 3×3 mm^2 and 1 mm thickness. The readout and analysis of TLDs was performed using 7200 TLD reader (RSD Co., Tehran, Iran) in the Medical Physics Laboratory (Kashan, Iran).

The exposure was done by a conventional X-ray radiology equipment installed at the Medical Physics Laboratory of Kashan, Iran. A UNIDOSE radiation dosimeter equipped with a calibrated type 77334 flat ionization chamber (PTW, Freiburg, Germany) was used to determine the radiation dose values exposed to the TLDs.

2. Methodology

In this study, thermoluminescent characteristics (linearity, repeatability, dose rate and photon energy dependence) of three types of TLDs for low dose values were evaluated. Before radiation exposure to the TLDs which depends on their type, they were annealed as follows: 1) 240 °C for 10 min to GR-200 discs, and 2) 400 °C for 60 min followed by 100 °C for 120 min to TLD-100 and TLD-700H chips. In addition, the reading cycles of the TLDs are listed in Table 1.

Linearity

Thirty dosimeters of each TLD material were divided into ten groups and irradiated to 0.05, 0.2, 0.5, 1, 2, 3, 4, 6, 8, and 10 mGy, respectively. The responses of TLDs were read 1 day

Table 1: Reading parameters used for various thermoluminescent dosimeters (TLDs).

Parameters of Time-temperature profile	GR-200	TLD-100 and TLD-700H
Preheating temperature	135 °C	50°
Preheating time	10 s	5 s
Preheating speed	10 °C/s	10 °C/s
Maximum temperature	240 °C	300 °C
Acquisition time	21 s	26 s
Annealing temperature	240 °C	300 °C

after irradiation process. To obtain the TLD response, as a function of absorbed radiation dose, the mean and standard deviation (SD) of TLD responses for each group were calculated and plotted versus the above-mentioned dose values.

Repeatability

To evaluate the repeatability of the TLDs at low dose values, ten dosimeters of each TLD material were used. This test was done for three consecutive cycles as irradiation, annealing and reading process were the same for each cycle. The irradiation process was carried out with a dose of 10 mGy, and annealing process was done in accordance with the conditions presented in *Section 2*. Next, process of readings was performed 1 day post-irradiation based on the same parameters listed in Table 1.

Then, the mean ($\bar{x}$) and SD (σ) of TLD responses for each material during the three cycles were calculated and finally, the repeatability (R) of the TLDs was calculated using the following equation [7]:

$$R = \frac{\delta}{\bar{x}} \times 100 \quad (1)$$

Dose rate dependence

To assess the dose rate dependence of TLDs, they were exposed with the same photon energy (80 kV) at various values of current tube 100 mA, 150 mA, 200 mA and 250 mA, which gave 0.5 mGy, 1 mGy, 2 mGy and 3 mGy, and 4 mGy dose values, respectively. Annealing process was done in accordance with the conditions presented in *Section 2*, and process of readings was performed 1 day post-irradiation based on the same parameters listed in Table 1.

It is noteworthy that in order to obtain the of the above-mentioned dose values through the applied voltage and current settings, the values of field size, focus-surface distance (FSD) and exposure time were varied.

Photon energy dependence

To evaluate the photon energy dependence of TLDs, they were irradiated to different photon energies of 60 kV, 80 kV, 90 kV and 100 kV at current tube 150 mA, which gave 0.5 mGy, 1 mGy, 2 mGy and 3 mGy, and 4 mGy dose values, respectively. Annealing process was done in accordance with the conditions presented in *Section 2*, and process of readings were performed 1 day post-irradiation based on the same parameters listed in Table 1.

Similar to the dose rate dependence experiments, for obtaining the above-mentioned dose values through the used voltage and current settings, the values of field size, FSD, and exposure time were varied.

Results

Linearity

The dose-response curves for different TLD materials at the low dose range are shown in Figure 1.

The findings obtained from these three curves demonstrate linear relations between absorbed dose values to TLDs and their responses in 0.05–10 mGy dose range. The following equations (2)–(4) represent the variation of the response (R_{TLD}) of the GR-200, TLD-700H and TLD-100, as a function from absorbed dose value, respectively. Furthermore, goodness of the fit parameters for these three curves are listed in Table 2. These results show an exact mono-polynomial fitting for these three types of TLDs in 0.05-10 mGy dose range.

$$R_{TLD} = 2.262 \times Dose + 55.540 \quad (2)$$

$$R_{TLD} = 0.028 \times Dose + 7.179 \quad (3)$$

$$R_{TLD} = 0.052 \times Dose + 5.004 \quad (4)$$

Repeatability

To obtain the repeatability of different TLD materials, the mean and SD of TLD responses for the ten TLDs during the three times were substituted in Equation (1). The results show that the coefficients of variation values (%) for GR-200, TLD-700H and TLD-100 were 3.00%, 10.85% and 2.01%, respectively.

Dose rate dependence

To assess the dose rate dependence of different TLD materials, four different dose rates were used and the obtained results are illustrated in Figure 2.

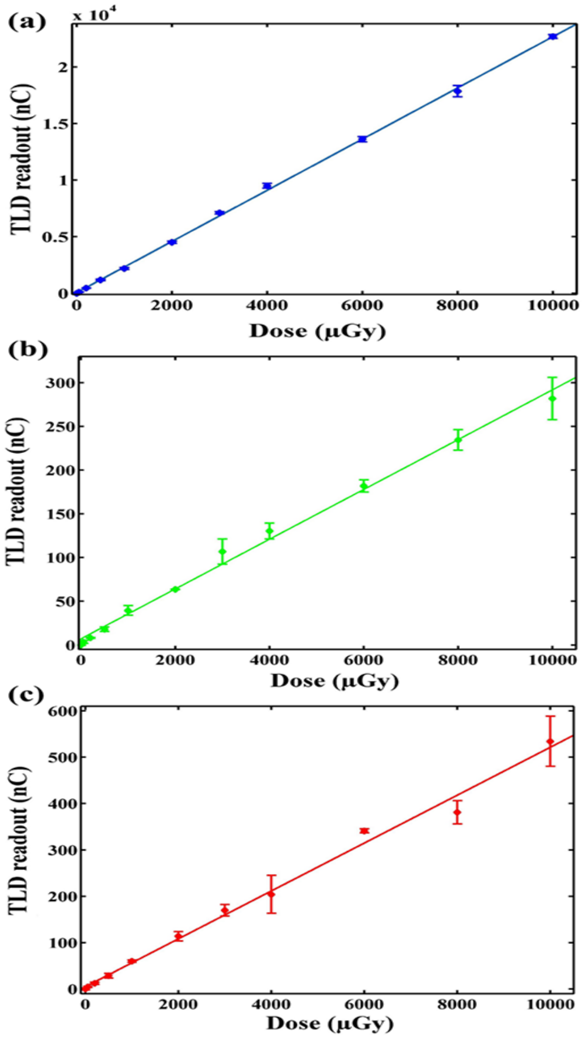

Figure 1: The responses of GR-200 (a), TLD-700H (b) and TLD-100 (c) as a function of absorbed dose in 0.05-10 mGy dose range at 1 day after irradiation. The standard deviations in a number of points are low; hence, the error bars are often not seen clearly.

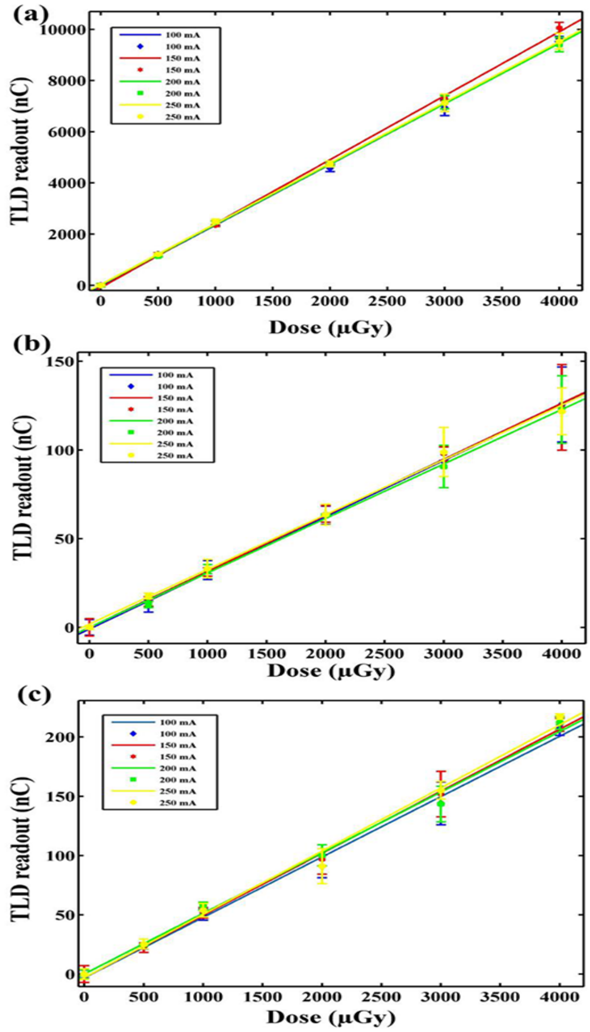

Figure 2: The dose-response curves of GR-200 (a), TLD-700H (b) and TLD-100 (c) for various values of current tube in 0. 5-4 mGy dose range at 1 day after irradiation. The standard deviations in a number of points are low; hence, the error bars are often not seen clearly.

Table 2: Goodness of the linear fit to dose-response data of GR-200, TLD-700H and TLD-100.

Parameters	GR-200	TLD-700	TLD-100
SSE	3.4×10^5	533.1	2453.0
R-square	0.999	0.995	0.992
Adjusted R-square	0.999	0.994	0.992
RMSE	195.50	7.70	16.51

SSE: Sum of Squares Error, RMSE: Root-Mean-Square Error

Photon energy dependence

The response dependence of different TLD materials to photon energies of 60 kV, 80 kV, 90 kV and 100 kV are plotted in Figure 3.

Discussion

Linearity

According to the equations (2)–(4), the dose-response sensitivities of GR-200, TLD-700H,

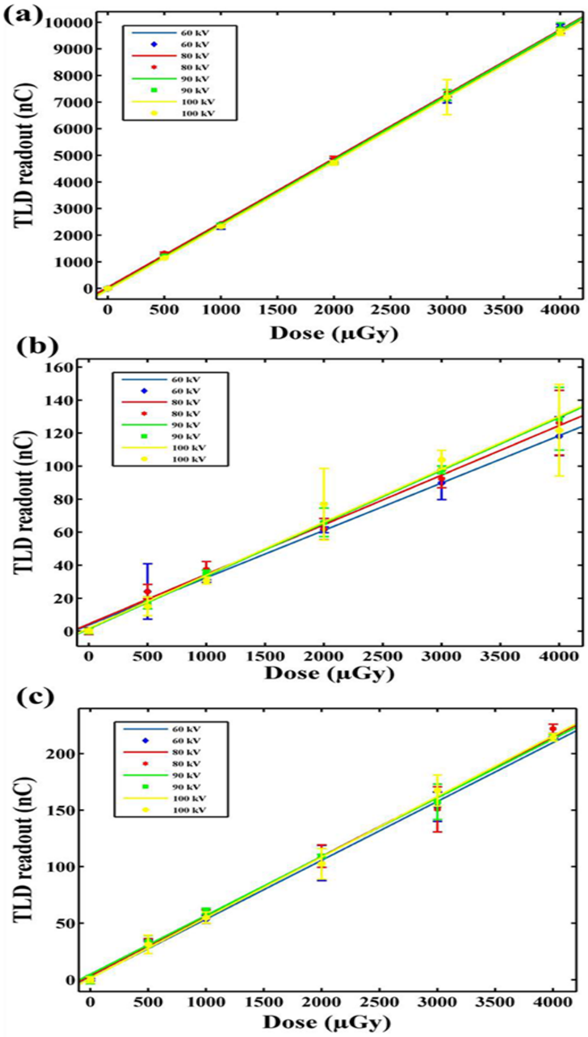

Figure 3: The dose-response curves of GR-200 (a), TLD-700H (b) and TLD-100 (c) for various photon energies in 0. 5-4 mGy dose range at 1 day after irradiation. The standard deviations in a number of points are low; hence, the error bars are often not seen clearly.

and TLD-100 are 2.262 ± 0.040, 0.028 ± 0.002 and 0.052 ± 0.003 $nC.Gy^{-1}$, respectively. TLD-700H and TLD-100 have very low sensitivity than GR-200; hence, GR-200 can be considered as a suitable dosimeter in low dose values. It has been previously reported that TLD-100 has some specifications, making it generally inappropriate for radiation dosimetry in low dose values such as low sensitivity, poor detection threshold, etc., [8-10].

Repeatability

According to the obtained data from GR-200 and TLD-100, the coefficients of variation values (%) are in agreement with the standard IEC 62387 limit of < 7.5% [11]. However, coefficient of variation value (%) for TLD-700H is more than the reported IEC 62387 limit. Finally, it can be mentioned that GR-200 and TLD-100 have very good repeatability for low dose value.

Dose rate dependence

As seen in Figure 2, remarkable effect of dose rate dependence on the response of GR-200 is not observed in a 0.5-4 mGy dose range since for most evaluated points, the response differences between the various values of current tube (100 mA, 150 mA, 200 mA and 250 mA) are less than 5%. Nevertheless, remarkable effects of dose rate dependence on the responses of TLD-700H and TLD-100 are found in the 0.5-4 mGy dose range so that the response differences between the various values of current tube are more than 5% for some evaluated points. In general, it can be stated that the response of GR-200 does not change under various dose rates; this means that, this dosimeter can be calibrated only for one dose rate and then utilized at four dose rates.

Photon energy dependence

As seen in Figure 3, remarkable effect of photon energy dependence on the response of GR-200 is not found in the 0.5-4 mGy dose range; as for most evaluated points, the response differences between the different photon energies are less than 5%. However, remarkable effects of photon energy dependence on the responses of TLD-700H and TLD-100 are observed in the 0.5-4 mGy dose range so that the response differences between the different photon energies are more than 5% for some evaluated points. In general, it can be stated that the response of GR-200 does not change under various photon energies. From practical point of view, if this dosimeter is used in low dose radiation dosimetry, one calibration is adequate for four photon energies evaluated in the present study.

Conclusion

In the current study, thermoluminescent characteristics (linearity, repeatability, dose rate and photon energy dependence) of GR-200, TLD-700H and TLD-100 for low dose measurement were investigated. The results show that for all three types of TLD materials, there are linear relations between absorbed dose values to TLDs and their responses in a 0.05-10 mGy dose range. TLD-700H and TLD-100 have very low sensitivity than GR-200. For GR-200 and TLD-100, the repeatability data show that these values are within the tolerance limit, however, this value for TLD-700H is more than the reported tolerance limit. Furthermore, remarkable effects of dose rate and photon energy dependence on the responses of GR-200 are not observed in the 0.5-4 mGy dose range. Nevertheless, remarkable effects of dose rate and photon energy dependence on the responses of TLD-700H and TLD-100 are found in this dose range.

Finally, it can be concluded that evaluated thermoluminescent characteristics for GR-200 are better than two other types of TLDs (TLD-700H and TLD-100) for low dose values.

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Authors' Contribution

B. Farhood conceived the idea. The original draft of the paper was written by M. Alizadeh. H. Moradi and A. Ramazani-Moghaddam-Arani gather the images and the related literature and also help with writing of the related works. The method implementation was carried out by M. Alizadeh. Results and Analysis was carried out by B. Farhood and A. Aliasgharzadeh. The research work was proofread and supervised by B. Farhood and M. Mohseni. All the authors read, modified, and approved the final version of the manuscript.

Ethical Approval

The Ethics Committee of Kashan University of Medical Sciences approved the protocol of the study (Ethic cod: IR.KAUMS.NUHEPM.REC.1398.009).

Conflict of Interest

None

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