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Improvement of Precision in TL Response with an Automated TLD Reader

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Abstract

Background: Whilst TLD is one of the most convenient methods of dosimetry, it is a somewhat imprecise technique with several draw-backs. An increase in the variability of TLD dose measurements prompted a study of the precision of dose measurements with an automatic TLD reader. An optimum calibration procedures decreasing the effects of uncertainties should be determined.

Methods: The dependence of sensitivity of the TLD response to calibration techniques and repeated cycles of irradiation was investigated. Measurements were performed using a batch of twenty seven TLDs, chosen at random from the stock. They were irradiated to 1 Gy with a 6 MV photon beam placing the dosimeter inside a PMMA solid phantom under a thickness of 15mm (full build-up depth). TLD readings of the responses were measured directly in the TLD reader.

Results: When TLDs were selected homogeneously in the batch, our data indicate a large improvement of precision in TLD sensitivity, up to a factor of 2. When TLDs are calibrated with sensitivity factor in a TLD reader, precision levels of 3.7% and 1.4% of the sensitivities are for large batch and for a small batch respectively. Two different batches of TLD-100 showed a similar regression in sensitivity with increasing cycles of irradiations and readouts.

Conclusion: Two calibration techniques of homogenization and sensitivity factors have been examined in order to improve the precision of TLDs by elimination random error.
An application of homogenization and sensitivity calibration techniques has allowed us to reach a standard deviation of less than 1.4% in the small batch. This study allows us to state that an application of both calibration techniques is the best one for obtaining better precision, reproducibility of TL signal.

Key Words: TLD sensitivity, homogeneity, calibration, precision

Introduction

Throughout the last decade TL(thermoluminescence) dosimetry has developed into a well established method for both in vivo and phantom measurements. Whilst being one of the most convenient methods of dosimetry, since its use in the clinical environment is simple, speedy and unobtrusive, it is a somewhat imprecise technique with several drawbacks. While TL process depends on the crystal itself and the impurities concentration, other factors like TLD sample manipulation, use of photomultiplier to convert emitted light into current, annihilation and stockage, are additional stages that increase the uncertainties in the dose estimation from thermoluminescence.[1]

To obtain high quality dose measurement data, it is therefore most important to minimize both systematic and random uncertainties in the experimental system. According to van Dam and Marinello, a standard deviation in the intrinsic precision of the TLD signal of 2% or less is required. Larger standard deviations either indicate TLD material of non-acceptable quality, or an inadequate procedure. In a paper by Kirby et al., they report the necessity of detecting uncertainties in dose of less than ±2%, which require a standard deviation in TL readings of less than 1.5%.[2]

One method for decreasing the effects of uncertainties is to homogenize the batch of TLD chips and apply the sensitivity factors to each chip in the batch. The goal of this study is to investigate dependence of sensitivity of the TLD response to calibration technique and repeated cycles of irradiation. This paper reports a detailed statistical analysis of a set of data obtained from measurements on two group of TLD dosimeters. The effect of calibration factor to precision of two different batch of lithium fluoride TLD-100 chips has been studied.

Materials and Methods

A. TLD system

The chips used throughout were LiF: Mg,Ti(Harshaw TLD-100) hot press extruded ribbon chips of dimensions 3.2㎜×3.2㎜×0.9㎜. The experiment was carried out irradiating with a 6 MV Linac unit in the

Dong-A Hospital (Pusan) placing the dosimeter inside a PMMA solid phantom under a thickness of 15mm(full build-up depth). All these chips were irradiated to the same dose (1 Gy) using 6 MV x-rays. The TL signal was analysed with the 5500 Harshaw/Bicron automated reader. A preheating to 50℃ was performed in the reader in order to eliminate the unstable low temperature peaks of lithium fluoride. The TL signal was acquired at 300℃ during 20 sec. This tinge temperature profile resulted in the integration of dosimetric peaks characterized by a long half-life if compared to the time between irradiation and evaluation. Using a computer-controlled oven (hot air stream method, PTW), the annealing procedure recommended for the crystal was adopted 400℃ for 1 h followed by cooling at 100℃ for 2 h. This procedure was repeated on a number of occasions.[3)]

B. TLD homogenization

Measurements were performed using a batch of twenty seven TLDs (R27), chosen at random from the stock. They were irradiated to 1 Gy with a 6 MV photon beam placing the dosimeter inside a PMMA solid phantom under a thickness of 15mm (full build-up depth). TLD readings of the batch R27 responses were measured directly in the TLD reader without prereadout annealing by the oven. From that results of R27 responses, seven TLDs were excluded which were far from mean response of the batch R27. The twenty TLD chips selected from R27 was named batch L20. Means, standard deviations(SD), and relative standard deviations(100 · SD/mean value) were computed for the distributions of readings for each group, R27 and L20.

C. Sensitivity factors

The differences in the physical properties of the TLDs are encountered by using chip correction factors(SFi).[4)] For each detector, an individual sensitivity factor, SFi, was determined with respect to the mean value of the readings of the group:

$$SFi = X/Xi$$

where X is the group mean value and Xi is the reading of detector i when the whole batch is irradiated to the same dose(e.g., 1 Gy).

The sensitivity factors of the batch were used for correction of the TLD responses, which have been irradiated to an unknown irradiation field to improve the statistical quality of the measured data. SFi was multiplied by the original reading of the TLD to give a final corrected reading. This method of individually calibrating the TLDs is called the sensitivity calibration technique.[5)]

The experiment was carried out using two fixed groups H5 and L20. Batch H5 of five TLDs has a higher sensitivity than the other batch L20 of twenty TLD chips. All these chips were irradiated to the same dose(1 Gy) using 6 MV x-rays and then read out in a Harshaw TLD reader. A statistical analysis was performed in order to test the effectiveness of the sensitivity factor to different batches in size and sensitivity.

D. Sensitivity change to repeated cycles of irradiation

For two batches of H5 and L20, 5 subsequent irradiation and readout cycles were performed to investigate the reproducibility of TLD. Individual TL signals were recorded, and linear regression analysis was applied to find TL sensitivity change. Sensitivity stability of the each batch of dosimeters was assessed by evaluation of the slope of the curve showing the sensitivity dependence on the number of cycles.

Results and Discussion

1. Batch homogeneity effect

A batch R27 of 27 dosimeters , chosen at random from the stock, was irradiated to 1 Gy with 6 MV photon beam. The dosimeters were not annealed before readout in the oven and their readings were not corrected for individual sensitivity factors. A quantitative and statistical analysis of TLD sensitivity was performed for the batch R27, compared with those L20 of 20 TLDs selected uniformly in sensitivity from R27. Means, standard deviations(SD), and relative standard deviations(100 · SD/mean value) were computed for the distributions of sensitivity for each group. The histogram representing statistical distribution of 27 independent TLDs sensitivity (R27) is shown in Fig.1. The TL sensitivity of L20 of 20 TLDs selected uniformly from R27 follows a Gaussian distribution with a mean value of 4.9 μC/Gy in Fig.2. As expected the mean sensitivity of R27 are nearly the same as the mean sensitivity of L20. These results are presented in Table 1. which shows the average number of counts obtained as μC per Gy (sensitivity) along with the variation.

The relative standard deviations of R27 and L20 (Table 1.) are 7% and 3.3% respectively. The relative standard deviations of R27 was unacceptably large for precise dosimetric measurements. Thus, ICRU recommended tolerances for absorbed dose delivery of ±5% may not be unequivocally detectable without homogeneity treatment.[6)]

Table 1. Comparison of the sensitivity between homogenized batch (L20) and not homogenized batch (R27) of TL dosimeters.

Batch character	Mean value (nC/Gy)	SD (nC/Gy)	relative SD (%)
homogernized (L20)	4.9	0.34	7.0
not homogernized(R27)	4.9	0.16	3.3

2. Sensitivity calibration to characteristic batches

A quantitative and statistical analysis of TLD sensitivity was performed for the both batches L20 and H5 applied with sensitivity factors to TLD responses, compared with those that were not applied. It was shown in Table 2. When sensitivity factors were not applied to both batches, for 6 MV X-ray beams the deviation of sensitivity was almost the same in both batches as ±3.85% for L20 and 3.58% for H5. Using the sensitivity calibration procedure to apply individual relative sensitivity factors to scale the original test readings dramatically improves the coefficients of variation to less than 1.4 % for batch H5.

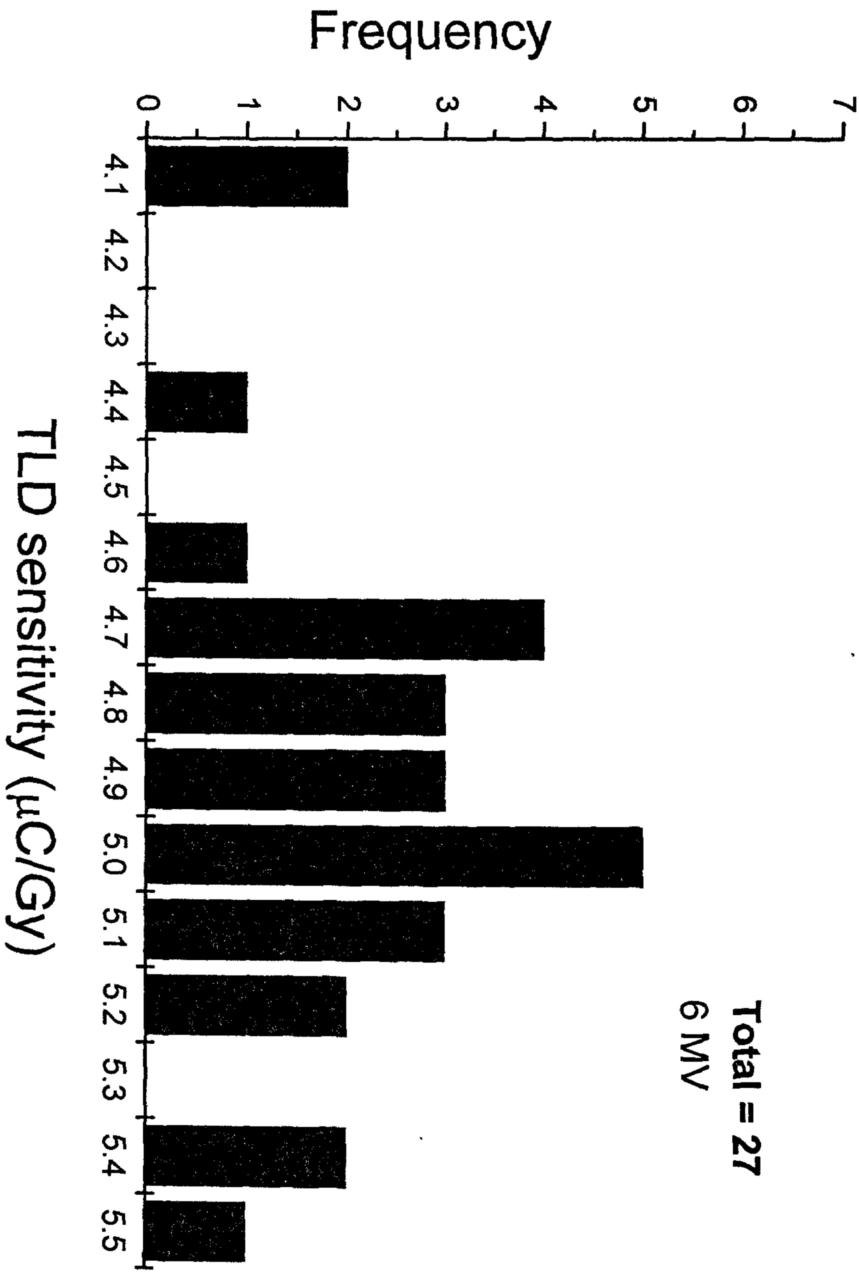

Fig.1. The sensitivity distribution of batch R27 of 27 TLD chips chosen at random with a mean value of 4.9 μC/Gy and relative standard deviation of 7 %.

However, when the readings of H5 are corrected for individual sensitivity the coefficient of variation improves to 1.4 % (Table 2.), which is not consistent with the coefficients variation for the corrected reading of L20. The larger coefficients of variation for the L20 than H5 even using the individual relative sensitivity factor in both batches may be explained by the difference of their batch sizes. A lot of chips in a batch could be mixed up easily while handling them during the course of the experiment. The results presented in table 2 show that, in our hands, it is essential to compute individual sensitivity factors for the TLD-100 in order to obtain reasonably precise dose values.

Table 2. Mean TLD sensitivity, standard deviation(SD) and relative standard deviation (SD/Mean value(%)) for applied sensitivity factor(SF) or not applied SF to two different batches.

	Batch L20		Batch H5	
	applied SF	not applied SF	applied SF	not applied SF
No. of dosimeters	20	20	5	5
Mean value(μC/Gy)	4.4	4.4	4.9	4.9
SD(μC/Gy)	0.16	0.17	0.07	0.18
relative SD(%)	3.7	3.9	1.4	3.6

Various calibration techniques have been examined in order to improve the sensitivity of TLDs by elimination random error. Among these procedures, there are two more calibration techniques of homogenization and sensitivity factors. Our results indicate that when both techniques applied together, it reduces the distribution of TLD sensitivity from about 7% to 1.4% at an absorbed dose of 1 Gy.

3. Sensitivity as function of irradiation and readout cycles

Two different batches of LiF TLD-100 chips, L20 and H5 were subjected to investigation of their radiation sensitivity after subsequent cycles of irradiation readouts. For both batches, 5 subsequent irradiation and readout cycles were performed. Individual TL signals were recorded, and linear regression analysis was applied to investigate reproducibility of TL sensitivity.

The plots of TL sensitivity as a function of the repeated cycles, are reported in Fig.3. The batch L20 containing twenty TLD-100 chips with lower sensitivity had shown initial sensitivity of approximately 4.46 (μC/Gy). Another batch containing five TLDs (H5) had shown an initial sensitivity more than a factor of 1.1 higher than the other batch L20. Both batches showed a slight tendency to decrease in sensitivity with increasing cycles of irradiations and readouts. The decrease of the TL sensitivity had almost same linear regression in both batch. The variation of TL sensitivity was always of the order of a few parts per hundred.

Conclusion

This paper has investigated an optimum calibration methodology when TL materials are analysed using conventional calibration techniques for the purposes of patient dosimetry. Two calibration techniques of homogenization and sensitivity factors have

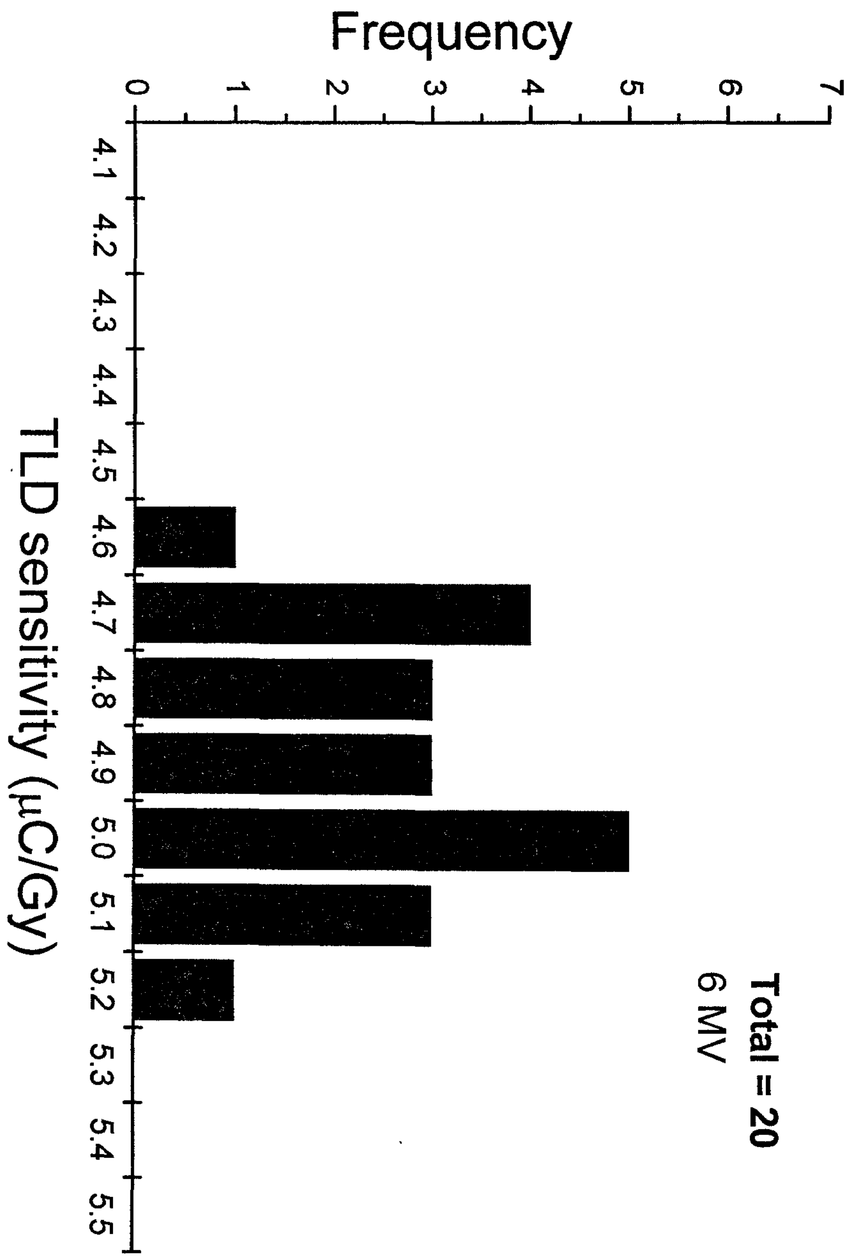

Fig.2. The sensitivity distribution of homogenized batch L20 with a mean value of 4.9 μ C/Gy and relative standard deviation of 3.3 %.

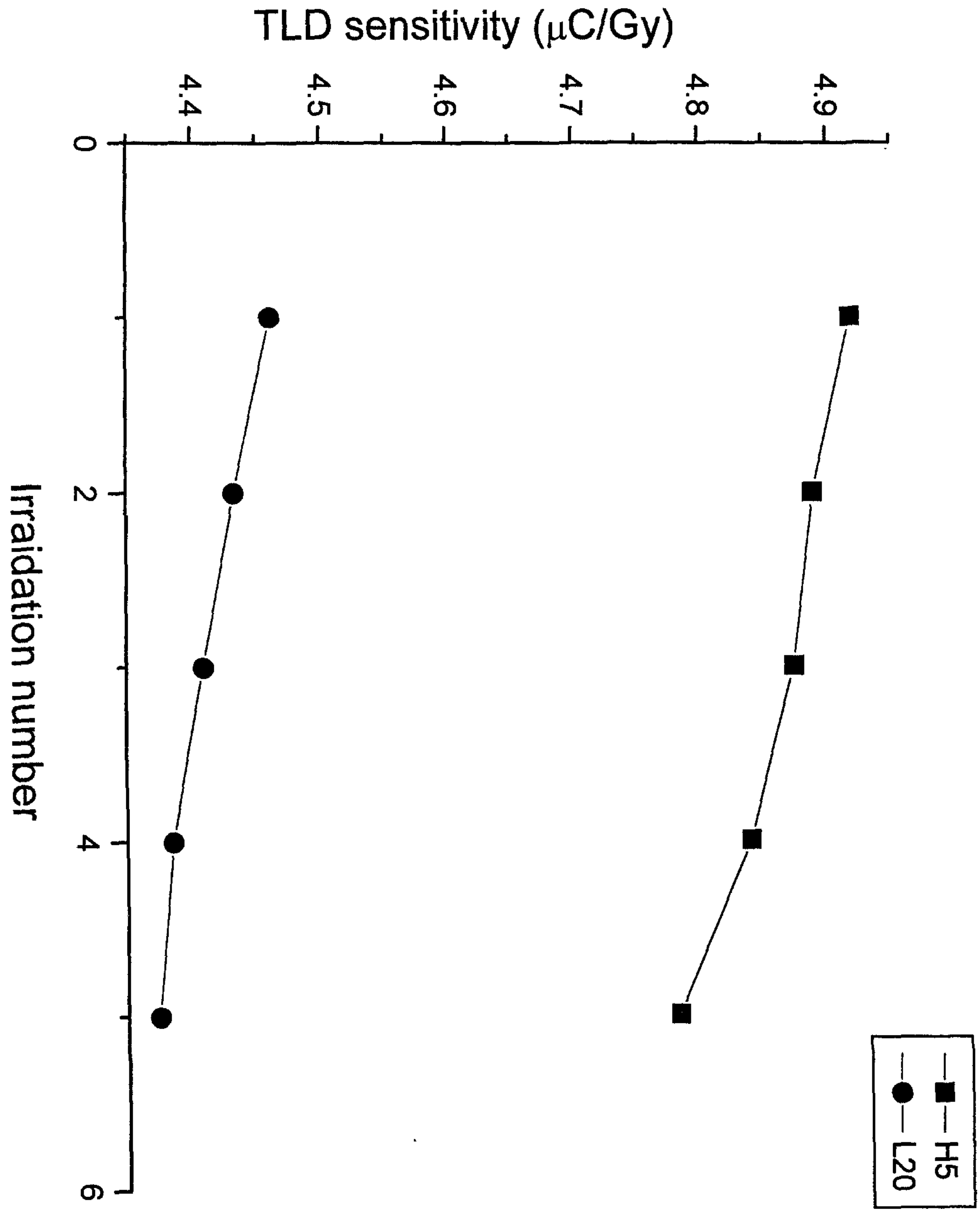

Fig.3. The TLD sensitivity for two different batches, measured in five consecutive irradiation at 1 Gy: squares are mean values of batch H5 of five detectors and circles are mean values of batch L20 of twenty detectors.

been examined in order to improve the sensitivity of TLDs by elimination random error.

When TLDs were selected homogeneously in the TLD batch, our data indicate a large improvement of TLD precision, up to a factor of 2. At precision levels of 3.7% and 1.4% of the sensitivities are for large batch and small batch respectively, if TLDs are read with sensitivity factor in the TLD reader. A batch of TLD-100 showed a significant change in sensitivity with increasing cycles of irradiations and readouts. An application of homogenization and sensitivity calibration techniques has allowed us to reach a standard deviation of less than 1.4% in batch H5.

This study allows us to state that an application of both calibration techniques is the best one for obtaining better precision and reproducibility of TL signal. It was also found that for determining the reader calibration factors (RCF), the calibration chips should be chosen at random from the batch and then returned to the batch for further use because the sensitivity of the batch was found to change with use.[7]

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국문초록

목적 : TLD가 선량 측정 시 가장 편리한 반면에 그 측정값이 다소 정확하지 못한 단점을 가지고 있다. TLD 선량 측정이 다양하게 증가하는 중이므로 자동 TLD 계측기를 이용해서 정확한 선량측정 방법을 연구할 필요가 있다. 적절한 보정 방법을 찾아 TLD의 정밀도를 높이고자 한다.

방법 : 총 30개의 TLD 기판을 세 종류의 TLD 군으로 분류하여 실험을 행하였으며, TLD-100 기판을 하나씩 PMMA 고체팬텀 내의 15㎜ 깊이에 넣어 6MV의 X선을 1Gy 조사하였고, 균질화와 반응감도 인자 보정 방법을 TLD에 적용하여 그 반응값을 자동 TLD 반응 계측기를 이용하여 구하였다.

결과 : TLD군을 균질화 한 뒤 측정한 TLD군의

반응감도의 정확도는 2배로 증가하였고, 반응감도 인자로 TLD군을 보정하여 반응감도를 계측한 경우, 큰 TLD군과 작은 TLD군의 정확도는 각각 3.7%와 1.4%였다. 방사선조사와 계측의 횟수 증가에 따른 각자 다른 TLD 특성군의 반응감도변화는 유사한 감소추세를 보였다.

결론 : 오차를 줄이고 정확도의 개선을 위하여 균질화와 반응감도 인자 보정 방법을 TLD에 적용하여 조사하였고, 적은 TLD군의 경우 표준오차가 1.4%까지 줄어들었다. 이 보정방법을 TLD의 선량측정에 적용할 경우 반응감도의 정확도와 재현성을 높일 수 있음을 보였다.

중심단어 : TLD반응감도, 균질화, 보정, 정확도