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Photon Energy Dependence of the Sensitivity of LiF TLDs Loaded with Thin Material

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Purpose : An investigation has been carried out on the factors which affect the response reading of thermoluminescent dosimeters (TLD-100) loaded with thin material in high energy photon. The aim of the study was to assess the energy response of TLD-100 to the therapeutic ranges of photon beam.
Materials and Methods : In this technique, TLD-100 (abbreviated as TLD) chips and three different thin material (Tin, Gold, and Tissue equivalent plastic plate) which mounted on the TLD chip were used in the clinical photon beam. The thickness of each metal plates was 0.1 mm and TE plastic plate was 1 mm thick. These compared with the photon energy dependence of the sensitivities of TLD (normal chip), TLD loaded with Tin or Gold plate, for the photon energy range 6 MV to 15 MV, which was of interest in radiotherapy.
Results : The enhancement of surface dose in the TLD with metal plate was clearly detected. The TLD chips with a Gold plate was found to larger response by a factor of 1.83 in 10 MV photon beam with respect to normal chip. The sensitivity of TLD loaded with Tin was less than that for normal TLD and TLD loaded with Gold. The relative sensitivity of TLD loaded with metal has little energy dependence.
Conclusion : The good stability and linearity with respect to monitor units of TLD loaded with metal were demonstrated by relative measurements in high energy photon (6 15 MV) beams. The TLD laminated with metals embedded system in solid water phantom is a suitable detector for relative dose measurements in a small beam size and surface dose.

Key Words : TLD, Relative sensitivity, Energy dependence

INTRODUCTION

Thermoluminescent dosimeters are extensively used for dose determinations in industrial as well as in medical applications. In particular, LiF : Mg, Ti (TLD-100) has been commonly used in the medical environment because it is a nearly tissue equivalent material (effective atomic number of 8.2 compared to 7.4 for tissue). The thermoluninescent (TL) response of TLD-100 is not linear for large doses and its efficiency depends on the radiation energy. Studies of the thermoluminescent properties of TLD dosimeters exposed with x- or γ-rays have shown a dependence of the sensitivity of TLD and the supralinearity as function of the photon energy. It has been established that the degree of supralinearity increases when the photon energy increases.[1)]

There is necessity for making a detector which is not only smaller in size but also has more response for absorbed dose in small field sizes. One of the fundamental principles on which this study is based the relative importance of the Compton scattering and pair production process that depends on both the photon quantum energy and the atomic number Z of the absorbing medium. The probability of pair production resulting from interaction of the photon with the medium is more dominant for higher photon energy and higher Z media than lower Z ones. When the energy of the photon is greater than 1.02 MV, for 6, and 15 MV photon beams, the photon interacts with matter of high atomic number (Z) such as a metal plate (0.1 mm; Tin, Gold) on the TLD-100 chips through the mechanism of Compton

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scattering and pair production process. The physical density of metal is over ten times larger than the physical density of LiF. Taking into account the electron densities of Gold (19.29×10^{26} kg/m^3) and LiF (2.789×10^{26} kg/m^3), this results in about 4.7 times more electrons per unit volume in Gold than in LiF. In the range of therapeutic megavoltage x-rays where the Comton effect dominates the interaction between x-rays and matter, this leads also to about 4.7 times higher attenuation per unit linear thickness for Gold than for LiF. From the higher number of electrons per volume in Gold, one can also expect that the scattered electrons would increase. Therefore, it could be expected that the metal loaded on TLD influences TLD's response readings.[2)]

The aim of study was to assess the use of metal loaded TLD chips for the skin dose received for superficial treatments. An important prerequisite was the assessment of the energy response of TLD chips to the therapeutic energies. One of the two different metals (Tin or Gold) was mounted on a TLD chip for higher response in photon beam energies from 6 MV to 15 MV. Responses of the TLD over the dose range from 10 to 500 cGy was studied using TLD reader. In this work, a comparison was made of the photon energy dependence of the responses for TLD (normal chip), TLD loaded with Tin plate and TLD loaded with Gold plates.[3)]

MATERIAL AND METHODS

1. TLD Readout and Evaluation

In this study TLD-100 Harshaw chips (nominal dimensions of $3.16\times3.16\times0.89$ mm^2) for normal TLD chips and several thin material plates (Tin, Gold and TE plastic plate) were used. All the thin material plates have the same area as TLD. One of two different metal plate with thickness 0.1 mm and TE plastic plate of 1 mm thickness was simply loaded on TLD-100. TL dosimeter without any thin material plate (abbreviated as nc;normal chips) and TL dosimeter loaded with one of the metal plates (abbreviated as mc; TLD chip with one of metal plates, tc; TLD chip with Tin plate, gc; TLD chip with Gold plate) were investigated as dosimeter for evaluations of photon absorbed dose. TLD with TE (tissue equivalent) plastic plate was called pc. TLD was embedded in 1 mm depth and 3.2×3.2 mm^2 square hole of solid water phantom which just accommodate one chip. Then, One of the thin material was simply mounted on the TLD with vacuum tweezer.

The TL dosimeters were read in a TLD reader (Harshaw TLD reader 5500) in a two-step readout cycle after preread annealing at 100℃ for 10 mins (PTWO annealing oven). The readout cycle consisted of a linear heating rate of 11℃/sec (40 240℃), followed by and isothermal plateau for 25 sec. So, the dosimeters were read in a two-step process, the first being a 10 sec preread anneal and the second the readout step. The integral over all channels (channel width 0.1 sec) in the second step was used as the TLD reading. It was recorded as charge collected by the photomultiplier in nanocoulomb (nC). A Pernal Computer, on line, allowed the glow-curve analysis.[4)] The background dose during the investigation period of one year from about 0.4 nc to 0.6 nc. All chips were annealed (1h 400℃ followed by 2h 100℃) in a dedicated TLD annealing oven (PTW, TLDO) after each readout. Especially for this study all chips were annealed in a clean PYREX dish. It was noted that contact with any metal container may damage TLD chips crystal during annealing cycle according to the TLD manual of Harshaw/Filtrol Chemical company in 1990. In general TL phosphors give the best performance as dosimeters if they receive uniform, reproducible, and optimal (depending on the phosphor) heat treatment before and after use. Cleaning of the TLD chips was not found to be necessary between irradiations.

The response of individual chips was corrected for differences in their relative sensitivity, using a chip factor determined by previous measurements of the response of all chips to a common dose. Experimental and calibrating measurements are made using a total of 10 TLD chips, where each chip was individually calibrated for dose response.

2. TLD Surface Dose

All radiation was delivered by SIMENS MEVATRON accelerator. The accelerator was calibrated to give a dose of delivered 100 cGy per 100 monitor units (MU) at the depth of maximum dose (field size 10×10 cm^2, SSD 100 cm). The nc and mc dosimeters were embedded in a square hole on the surface of solid water phantom to fit single TLD chip. The Exposure of nc and mc chips were made in the 6, 10, and 15 MV photon beams on the surface of a 20 cm thick solid water phantom at a field size of 10×10 cm^2 and 100 cm SSD. In each TLD exposure, five TLD-100 chips were irradiated to reduce error. Surface dose response of TLD measurements of nc and mc chips were made following exposure to photon beam at various dose levels between 10 MU and 500 MU.[5)]

RESULTS AND DISCUSSIONS

1. Surface dose response curves

The TLD dosimeters (nc and mc) being embedded in the solid water phantom surface were given varied exposures in photon beams of each type measured, and families of surface dose response curves were plotted. The family of surface dose response of the nc, tc and gc for 6, 10, 15 MV photon beam is shown in Fig. 1, 2, and 3. All results are the average of 5 TLD chips measurements. These curves show the sensitivity of the nc and mc chips for doses between 10 to 500 MU and their variation of dose response. The degree of supralinearity increases as beam energy increases, except for tc which consistently shows a lower supralinearity than others. The sensitivities were caculated from the slopes of surface dose response curves. Sensitivity of TLD chip was taken as response per dose (μC/MU) in the approximately linear region. The different slopes of the curves show, however, that the sensitivity depends on photon energy, falling off somewhat as photon energy rises. It means that the photon beam with lower energy (6 MV) has the higher surface dose than that of higher energy (15 MV) naturally. The curves of tc in Fig. 2 have a good linearity of dose in 6, 10, and 15 MV photon beam. In Fig. 1 and Fig. 3, nc and gc show the similarity of slopes at 10 MV and 15 MV photon energies. However, mc signal intensity was higher than nc chips. TLD chips with a Gold plate was found to over response by a factor of 1.83 in 10 MV photon beam with respect to normal chip without any material.

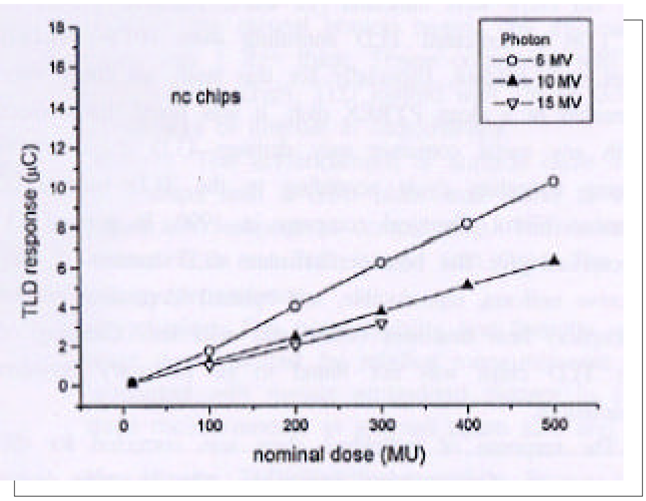

Fig. 1. Relative surface dose response curves for normal TLD chip. Each curve is for one photon energy.

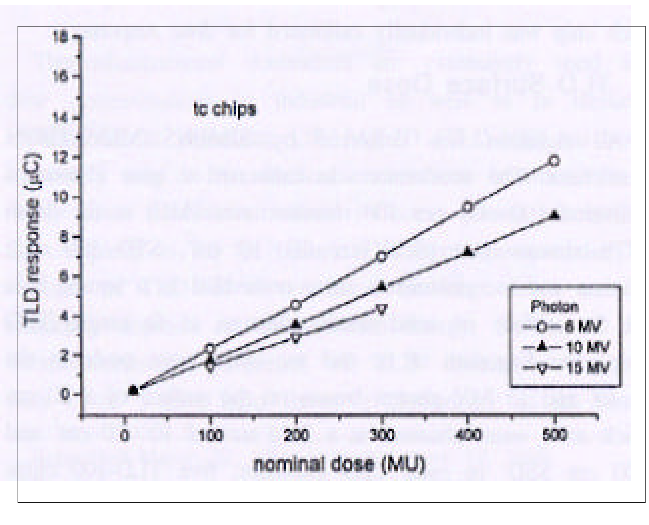

Fig. 2. Relative surface dose response curves for TLD with Tin plate. Each curve is for one photon energy.

2. Energy dependence

Fig. 4 shows the relative sensitivity of each TLD dosimeter of nc as a function of the photon beam energy. The energy response curve was determined using the relative sensitivities of each TLD chip of nc in Table 1. The sensitivities of each chip were calculated from the slopes of surface dose response curves in Fig. 1, 2, and 3. The vertical coordinate is relative sensitivity, and each curve is

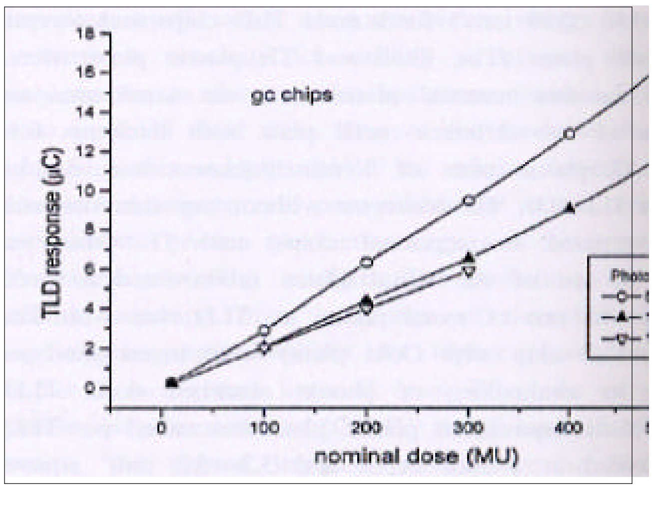

Fig. 3. Relative surface dose response curves for TLD with Gold plate. Each curve is for one photon energy.

Table 1. Chracteristics of TL Dosimeter with Thin Material

Type of TL dosimeter	nc	tc	gc	pc
Loaded thin material on TLD-100	None	Tin	Gold	TE Plastic
Thickness of loaded thin material (mm)	None	0.1	0.1	1
Equivalent thickness of thin material to tissue (mm)	None	0.53	1.4	1
Relative sensitivity to nc for 6 MV photon beam	1	1.28	1.67	1.39
Relative sensitivity to nc for 10 MV photon beam	1	1.5	1.83	
Relative sensitivity to nc for 15 MV photon beam	1	1.36	1.73	

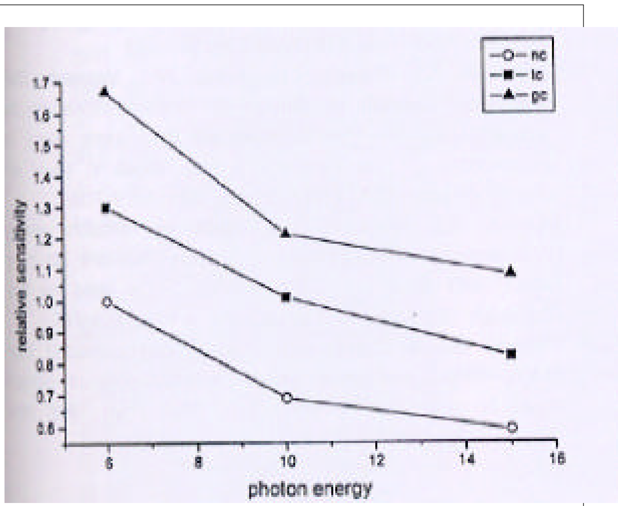

Fig. 4. Energy dependence plotted as photon beam energy against relative sensitivity to normal TLD.

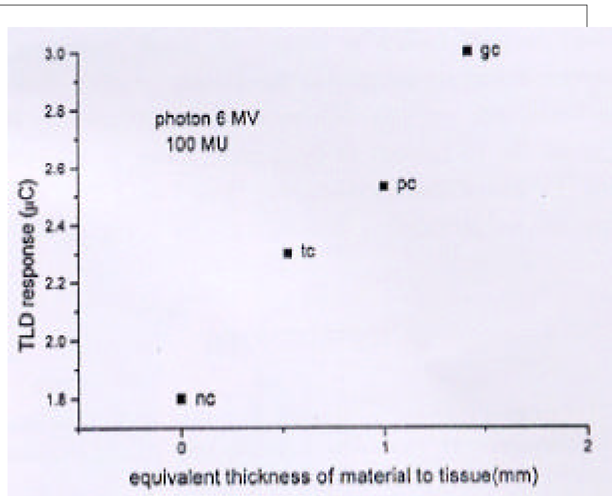

Fig. 5. Surface dose measurements plotted as equivalent thickness of thin material.

scaled to have a relative sensitivity respect to that of nc at each photon energy. In Fig. 4, the lower curve shows the results from nc measurements and the upper curves show the results of mc measurements, which gives a clearer depiction of the higher relative sensitivity of mc chips of nc. Fig. 4 shows that the relative sensitivity changes in tc and gc dosimeters are similar in magnitude as photon energy rises. The results shown in Fig. 4 suggest that the energy independence of the mc chips to be presented at the higher energy photons.

3. Equivalent thickness of metal plate

The relative reading of TLD chip with thin material is given as the charge collected in the photomultiplier during readout in μC as displayed in Fig. 1, 2, and 3. As the measured dose increases differently with the properties of thin material used, one can expect that the relative dose response (measured in a μC) should increase with the amount of electron density or equivalent thickness of thin material. This can be seen in Fig. 5. where the TLD response is plotted against the equivalent thickness of thin material plate to tissue of the four TLD chips shown in Table 1. The TLD response varies between the different types of chips. For 6 MV photon beam as the nominal dose was 100 MU, the increase in signal with equivalent thickness of thin material plate is almost linear. It is lowest for the nc chip and the highest for the gc chip. The results shown in Fig. 5 emphasize the role of Compton effect on metal plate in this range of beam energy. However, this may also be due in part the lower effective depth of measurement of nc (without any thin material plate) and build up effect for open fields.[6)]

CONCLUSION

In this paper to determine the metal loaded TLD response as a function of the photon energy, we show that the considerable increase in TLD response per unit dose at high photon energies by an ever-increasing relative contribution of Compton scattering and pair production to the total dose of clinical photon beam.[7] The response of gc is the most sensitive to the presence of the higher energy photons. TLD chip with a Gold plate was found to large response by a factor of 1.83 in 10 MV photon beam with respect to normal chip. The degree of supralinearity increases as beam energy increases, except for tc which consistently shows a lower supralinearity than others. Having relatively energy independence of response in the therapeutic x-ray range, mc is suitable for determination of dose distribution even when the photon spectrum varies somewhat with position.

Conclusions regarding mc chips are that energy dependence is small enough to require only small corrections for energy dependent spectra and the linearity of dose response is better with mc than with nc dosimeter. The results shall provide the background to the implementation of the technique for in vivo patient dosimetry. Metal loaded TLD technique has the potential to give the clinician a reading for the skin dose.

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국문 초록

얇은 박막을 얹은 TLD 반응감도의 광자 에너지에 대한 의존성

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목 적 : 얇은 박막을 위에 얹은 TLD 선량계의 반응 값에 영향을 미치는 인자를 조사하였고, 특히, 금속박막을 얹은 TLD 선량계의 광자에너지와 표면 흡수선량에 대한 의존성을 조사하였다.

방법 및 재료 : 본 연구에서는 TLD-100과 TLD-100 위에 얹은 얇은 물질로는 주석, 금, 그리고 TE 플라스틱 판을 사용하였다. 각 금속 박막의 두께는 0.1 mm, TE 플라스틱 판의 두께는 1 mm였고 각 박막의 면적은 TLD-100의 면적과 같이 하였다. 방사선치료에 많이 쓰이는 6 MV에서 15 MV사이의 광자에너지에 대한 TLD-100의 반응감도와 금 박막을 얹은 TLD-100의 반응감도, 그리고 주석 박막을 얹은 TLD-100의 반응감도를 비교해 보았다.

결 과 : 금속 박막을 얹은 TLD의 경우 표면 흡수선량의 증가가 명백히 나타나고, 금 박막을 얹은 TLD의 경우 10 MV에서 정상 TLD보다 약 1.83배 정도 과잉 반응하는 것으로 관측되었으며, 흡수선량에 따른 반응감도의 변화는 주석을 얹은 TLD의 경우가 가장 작았다. 금속 박막을 얹은 TLD의 일반 TLD에 대한 상대 반응감도는 에너지에 대한 의존성을 거의 나타내지 않았다. 그리고 얇은 박막의 조직에 대한 등가 두께에 따라 반응감도가 증가하였다.

결 론 : 금속박막을 얹은 TLD 선량계의 반응값이 고 에너지(6-15 MV)에 대한 의존성을 거의 나타내지 않았으며, 흡수선량에 대한 선형성도 뛰어난 것으로 관측되었다. 따라서 금속박막을 얹은 TLD 선량계는 매우 작은 크기의 광자 빔과 표면흡수선량의 측정에 매우 적합한 것으로 사료된다.

핵심용어 : 열형광선량계(TLD), 비교 감수성, 에너지 의존성

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