DOSIMETRIC EVALUATION OF TL RESPONSE, SENSITIVITY AND INTRINSIC EFFICIENCY OF TL DOSIMETERS IN 4 MeV CLINICAL ELECTRON BEAM USING LIQUID WATER PHANTOM

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Abstract: This paper aimed to study the TL response, sensitivity and intrinsic efficiency of thermoluminescent dosimeters of $CaSO_4$:Dy, LiF:Mg,Ti e microLiF:Mg,Ti to 4 MeV clinical electron beam and liquid water phantom. The three types of detectors showed a linear behavior of TL response in the dose range, energy and phantom material studied. The $CaSO_4$:Dy exhibited a higher behavior about sensitivity and intrinsic efficiency.

Keywords: thermoluminescence, dosimetry, radiotherapy, electrons.

1. INTRODUTION

In accordance with Portaria 453 of June 1, 1998 of Healthy Ministry, the exposure for health purposes is the main source of population exposure to artificial sources of ionizing radiation. A patient dose verification has been recommended for quality improvement in radiotherapy for several organization [1-2].

In radiotherapy treatments is necessary to be sure that the patient is receiving the correct dose prescribed. The main objective of radiotherapy dosimetry is to determine with great precise the dose absorbed to the tumor. This can be done by calibrating the radiation beam and routine dosimetry to quality assurance control [3]. As there is a difficult in making in vivo dosimetry, refers to calculations that relate measured dose in phantoms with the patient dose [4].

The International Comission on Radiation Units and Measurements (ICRU) established in 1976 that *"all procedures involved in the planning and execution of radiotherapy may contribute to a significant uncertainty in the dose administered to the patient"* and *"the evidence available for some types of tumors indicates to the need for accuracy in the release of 5% of the dose to the target volume if the primary tumor eradication is desired"*. Thus, the maximum values recommended for the uncertainty in the dose range of ±5% [5].

The high energy electrons beams have a wide application in medicine, especially in the treatment of various types of cancer. The electron application in therapy requires a great accuracy in the absorbed dose to the tumor, as a minor variation is highly determinant in the risk of recurrence and sequelae [5]. This fact requires measurements and rigorous control of the patient absorbed dose by dosimeters with great accuracy and precision.

In radiotherapy the most applied measure technique is thermoluminescent dosimetry, that has been done using lithium fluoride doped with magnesium and titanium, LiF:Mg,Ti (TLD-100) dosimeters marketed by Harshaw [6-8]. Recently the LiF:Mg,Ti microdosimeters, which are similar a TLD-100 but with a smaller size [9], have been characterized and used. This phosphorus presents some features that justify its popularity. Among them are their effective atomic number similar to human tissue, its good sensitivity and a high reliability in measurements [10]. Its application in radiotherapy is recommended because with them is possible to obtain, in clinical practice, accuracy better than ±5% in the measures [11].

The $CaSO_4$:Dy dosimeter was developed and manufactured by the Dosimetric Materials Laboratory of the Insituto de Pesquisas Energéticas e Nucleares (LMD/IPEN). Still little explored in the radiotherapy, this dosimeter is already used in radiation protection measures and beta and photon radiation monitoring. There are a great interest in the use of $CaSO_4$:Dy dosimeters in radiotherapy dosimetry not only for its characteristics of sensitivity and linearity of the TL response to radiation, but also because it can be easily acquired by IPEN. Although its effective atomic number is higher than human tissue, this dosimeter presents TL performance similar to LiF:Mg,Ti on the energy dependence with the dose rate and temperature of use and storage [12].

The performance of the $CaSO_4$:Dy dosimeters applied to high energy electron beam dosimetry was studied by Chatterjee et al (2009) Nunes e Campos (2008), Matsushima (2010) e Bravim et al (2011) that analyzed the properties of the TL response of these TLDs and estimated doses received by patients in the skin and whole body [13-16].

The measurements taken with liquid water phantom presented in this paper aim to study the TL response, the sensitivity and the intrinsic efficiency of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to 4 MeV clinical electron beam and analyze also the applicability of $CaSO_4$:Dy in radiotherapy dosimetry.

2. MATERIALS AND METHODS

The pre-irradiation heat treatments of different types of dosimeters (Fig.1) were: $CaSO_4$:Dy - 300ºC/3h using a furnace VULCAN model 3-550 PD; LiF:Mg,Ti and microLiF:Mg,Ti - 400°C/1h using a furnace VULCAN model 3-550 PD plus 100°C/2h using a furnace FANEN, model 315-IEA 11200. For the selected batch, the dosimeters were irradiated in air under electronic equilibrium with a ^{60}Co gamma source (0.953 GBq) of the Instruments Calibration Laboratory of IPEN. After TL responses evaluation, they were separated into groups according to their sensitivity (± 5%).

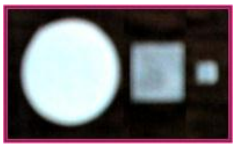
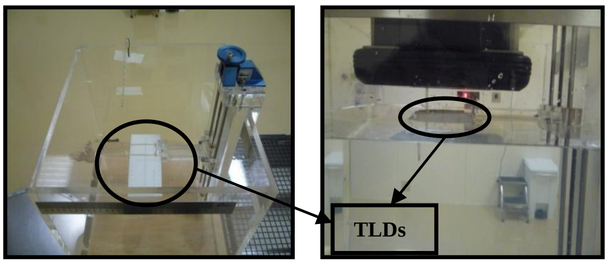


Fig.1. Thermoluminescent dosimeters of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti respectively.

To 4 MeV clinical electron beam irradiations in the linear accelerator VARIAN model Clinac 2100C of the Hospital Albert Einstein, the TLDs were positioned at the depth of maximum dose (1.0 cm) in the liquid water phantom with dimensions 40.0 x 40.0 x 40.0 cm^3 (Fig.2). To ensure the backscatter of the beam, 5 cm from the same phantom material was used under the TLDs. For this type of irradiation followed the specifications recommended by the TRS-398 of the International Atomic Energy Agency (IAEA): radiation field size - 10 x 10 cm^2, distance source/TLDs – 100 cm [17].



(a) **(b)**

Fig.2. (a) Liquid water phantom; (b) Electron beam irradiation in liquid water phantom set up.

The TL readings were performed between 24 and 32 hours after the irradiation using a TL reader Harshaw model 3500 .

To obtain the TL dose response curves 5 TLDs for each of the following dose values: 0.5, 1 e 5 Gy were used. Each point represents the average of five readings and error bar are their respective standard deviations of the mean (1σ) with 95% confidence level.

The intrinsic efficiency is given by equation 1:

$$IE = \frac{A}{m} \qquad (1)$$

where: 'A' is the slope of the adjusted straight line provided by the Origin 7.0 program and 'm' is the dosimeter mass.

3. RESULS AND DISCUSSION

The dose-responde curves of the $CaSO_4$:Dy, LiF:Mg,Ti e microLiF:Mg,Ti dosimeters to 4 MeV electrons beam and liquid water phantom are showed in Figure 3.

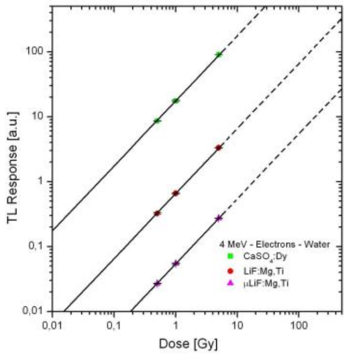


Fig. 3. Dose-response curves of $CaSO_4$:Dy, LiF:Mg,Ti e microLiF:Mg,Ti dosimeters to 4 MeV electrons beam in liquid water phantom.

For the three types of dosimeters can be observed a linear behavior of the TL response in the dose range of 0.5 to 5 Gy, the same behavior was observed in recent studies using 6 MeV clinical electron beam and PMMA and solid water phantoms [14].

Figure 4 is presents the average sensitivity of $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters to the electron dose range from 0.5 to 5 Gy.

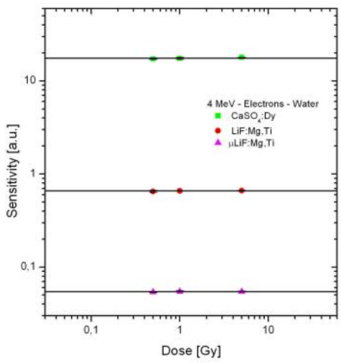


Fig.4. Average TL sensitivity of $CaSO_4$:Dy, LiF:Mg,Ti e microLiF:Mg,Ti dosimeters to 4 MeV electrons and liquid water phantom.

The average sensitivity obtained to 4 MeV electrons beam was 17,54±0,37 $\mu C.Gy^{-1}$, 0,6569±0,0069 $\mu C.Gy^{-1}$ and 0,0544±0,0004 $\mu C.Gy^{-1}$ to $CaSO_4$:Dy, LiF:Mg,Ti and microLiF:Mg,Ti dosimeters respectively.

The obtained results agree with previous studies to the same materials and different phantom materials (PMMA and solid water) [14] between ± 92% to 4 MeV electrons.

In the Table 1 are presented the slope of the adjusted straight line of the different dosimeters used to calculate the intrinsic efficiency.

Tabela 1. Slope of the adjusted straight line of TL response to 4 MeV electron beam and liquid water phantom.

TLD	A [$\mu C.Gy^{-1}$]
$CaSO_4$:Dy	17.91
LiF:Mg,Ti	0.6625
microLiF:Mg,Ti	0.05404

The intrinsic efficiencies obtained were (1.08±0.11) $\mu C.Gy^{-1}.mg^{-1}$ to $CaSO_4$:Dy, (0.331±0.033) $\mu C.Gy^{-1}.mg^{-1}$ to LiF:Mg,Ti and (0.054±0.005) $\mu C.Gy^{-1}.mg^{-1}$ to microLiF:Mg,Ti.

3. CONCLUSION

The dose-response curves of the three types of dosimeters to 4 MeV electron beam radiation showed a linear behavior in the dose range studied. The $CaSO_4$:Dy dosimeter are 26 and 322 times more sensitivity than LiF:Mg, Ti and microLiF:Mg,Ti respectively. The intrinsic efficiency of the $CaSO_4$:Dy is 3 and 20 times higher than LiF:Mg, Ti and microLiF:Mg,Ti respectively, for the energy and a kind of beam analyzed. The results indicates that the TDL of $CaSO_4$:Dy can be a new alternative of detector to clinical electron beam dosimetry. As this dosimeter is a national product, manufactured at IPEN, has a lower cost and facility in its acquisition.

ACKNOWLEDGMENTS

The authors are thankfull to CNPq and FAPESP for financial support and to the radiation therapy staff of the Hospital Israelita Albert Einstein for the electrons irradiations.

REFERENCES

[1] G. Kutcher; L. Coia; M. Gillin; W.F. Hanson; S. Leibel; R.J. Morton; J.R. Palta; J.A. Purdy; L.E. Reinstein; G.K. Svensson; M. Weller; L. Wingfield. *"Comprehensive QA for Radiation Oncology: Report of AAPM*". Med. Phys**.** 21:581-618, 1993.

[2] J. Van Dam, G. Marinello. *"Methods for In Vivo Dosimetry in External Radiotherapy. Physics for Clinical Radiotherapy Booklet"*, 1; ESTRO: Brussels: Belgium. 1994.

[3] International Commission On Radiation Units And Measurements - ICRU Report 24: "*Determination of Absorbed Dose in a Patient Irradiated by Beams of X or Gamma Rays in Radiotherapy Procedures".* Bethesd, Maryland. 1976.

[4] P. Metcalfe; T. Kron; P. Hoban. *"The Physics of Radiotherapy X-rays from Linear Accelerators".* Madison, WI: Med. Phys. 2007.

[5] H.E. JOHNS; J.R. CUNNINGHAM. "*The Physics of Radiology"*. 3.ed. Illinois: Charles C. Thomas, 1974.

[6] P. Olko; B. Marczewska; L. Czopyk; M. A. Czermak; M. Kłosowski; M. P. R. Waligórski. *"New 2-d dosimetric technique for radiotherapy based on planar thermoluminescent detectors".* Radiation Protection Dosimetry. v. 118, nº 2, p. 213–218, 2006.

[7] J. Livingstone; S. Horowitz,Y; L .Oster; H. Datz; M. Lerch; A. Rosenfeld; A. Orowitz. *"Experimental investigation of the 100 keV x-ray dose response of the high-temperature thermoluminescence in LiF:Mg,Ti (TLD-100):theoretical interpretation using the unified interaction model.*" Radiation Protection Dosimetry**.** v. 138, nº. 4, p. 320–333, 2010.

[8] V. K. Nelson; I. D. Mclean; L. Holloway. "*Thermoluminescent dosimetry (TLD) for megavoltage electron beam energy determination".* Radiation Measurements. v. 45, p. 698-700, 2010.

[9] M. Moscovitch; Y. S. Horowitz. "*Thermoluminescent materials for medical applications: LiF:Mg,Ti and LiF:Mg,Cu,P".* Radiation Measurements. v. 41, n. 1, p. S71-S77, 2007.

[10] S.W.S. Mckeever; M. MOSCOVITCH; P.D. TOWNSEND. "*Thermoluminescence dosimetry materials: Properties and uses."* Ashford, Kent: Nuclear Technology Publishing, 1995.

[11] B. Rudén. *"Evaluation of the clinical use of TLD."* Acta Raiol. Ther. Phys. Biol., v. 15, p. 447-467, 1976.

[12] Nunes, M.G.; Campos, L.L. *"Study of $CaSO_4$:Dy and LiF:Mg,Ti detectors TL response to electron radiation using a SW SolidWater phantom".* Rad. Measurements. v. 49, p. 459-462, 2008.

[13] S. Chatterjee.; A.K. Bakshi; R.A. Kinhikar; G. Chourasiya,; R.K. Kher. Response of $CaSO_4$:Dy phosphor based TLD badge system to high energy electron beams from medical linear accelerator and estimation of whole body dose and skin dose. Rad. Measurements., v.44, p.257-262, 2009.

[14] A. Bravim; R.K. Sakuraba; J.C. Cruz; L.L.Campos. *"Study of LiF:Mg,Ti and CaSO4:Dy dosimeters TL response to electron beams of 6 MeV applied to radiotherapy using PMMA and solid water phantoms."* Radiation Measurements. 2011. doi:10.1016/j.radmeas.2011.05.033

[15] L.C. Matsushima. *"Avaliação da resposta de detectores termoluminescentes na dosimetria de feixes clínicos utilizando diferentes simuladores."* Dissertação (Mestrado) – Instituto de Pesquisas Energéticas e Nucleares, São Paulo. 2010.

[16] M.G. Nunes; L.L. Campos. "*Study of $CaSO_4$:Dy and LiF:Mg,Ti detectors TL response to electron radiation using a SW SolidWater phantom."* Rad. Measurements. v. 49, p. 459-462. 2008.

[17] International Atomic Energy Agency. "*Absorbed dose determination in external beam radiotherapy."* An International Code of Practice for Dosimetry based on standards of absorbed dose to water. Vienna, Abr. 2000 (TRS-398).