Radiation Dosimetry By Tlds Inside Human Body Phantom While Using ^{192}Ir HDR In Breast Brachytherapy

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Abstract: Radiation dose delivery to infected or healthy organs inside human body takes high efforts in recent studies and researches by scientists. Dosimeters took a part of their concerning to do an acceptable results due to accurate readings. TLDs is one of the most accurate and suitable dosimeters to be used in human body phantom or in mathematical computer simulation phantom used by Monte Carlo simulation program. Sensitivity, linearity, ability to reuse, fading, accuracy, dimensions, use, dose range stability, application, independency, and other properties can affect choosing suitable dosimeter in a certain application of radiation treatment.

Index Terms: Radiation, Dosimetry, TLD 100, TLD 100H, Brachytherapy.

1 Introduction

Radiation describes electromagnetic waves, electrons, natural radioactivity, and x-rays. It refers to the atomic and subatomic particles and the whole of electromagnetic spectrum. There are two types of radiation; ionizing radiation can ionize a material it passes through and non ionizing radiation has a wavelength of 1 nm or longer, like radiowaves, visible light, microwaves, and ultraviolet light; the rest is ionizing radiations. Radiation emission is a release of any amount of energy by a system, the maximum energies calculated for alpha, beta, gamma, neutron, and heavy ions are 20, 10, 20, 15, and 100 MeV respectively, all radiation emissions obey quantum mechanics roles [1]. The first use of absorbed dose as the energy deposited per mass was 1950 by ICRU to provide appropriate metric to the biological effect of ionizing radiation in many applications; later, ICRU took into account the stochastic quantities to describe the energy depositions like lineal energy and energy imparted. Different types of radiations have different biological effects; radiation quality referred to the relative biological effectiveness (RBE) was used to describe the absorbed dose of gamma radiation or X rays as references to that of the used radiation at the same biological outcomes. ICRU introduced the quality factor which is a function of linear energy transfer (LET) of certain type of radiation, the choice of its values was depending on the RBE experimental ranges of biological objects and their endpoints [2].

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Dosimetry is the practical part of measuring or calculating of the absorbed dose in medium. In brachytherapy, it is used to determine the distribution of used sources (Ir^{192}) in certain volumes to develop acceptable dose distributions, calculate patient doses, and to provide a prescription dose system [3]. Near the brachytherapy sources, the dose gradients are large so the need for an efficient and accurate detector which can record doses simultaneously with low atomic number [4], and small active volume [5]. The comparison between different types of detectors were made of using Ir^{192} HDR brachytherapy source, the diamond detector was the most accurate one with large physical size, MOSFET (metal-oxide-semiconductor field effect transistor) within a range between 2 to 5 cm was accurate within 5% in water has a small size and easy to use [5,6].

2 THERMOLUMENSCES DOSIMETERS

The need for a wide range of dose with stability, high sensitivity, and excellent reproducibility pushed scientists from 1950s to do their search for a perfect TLD, Farrington Daniels and his cooperators were the first group who suggested the use of TL as a radiation dosimeter. LiF:Mg was studied in 1960s and became the most important on TLD materials, which used in many different applications like medical dosimetry, spacecraft, mineral prospecting, environmental dosimetry, monitoring of radiation exposure, and in geological dating [7]. The first TL material used as a dosimeter is TLD-100 [8]; it has a large variety of applications in radiotherapy especially in vivo dosimetry and phantom measurements because it is a free standing detector and has a wide dose range so it is used widely in radiotherapy [9].

2.1 TLD Components and Principle

Thermoluminescent means the emission of light after heating, when ionizing radiation hits TLD material, electron will escape from one atom to another part of material, leaves a hole of positive charge behind it, then after heating the TLD, the recombination of electron and hole will occur to release energy as a light, the light intensity is related to the amount of energy absorbed through exposure to radiation. TLD is not a radioactive material even after exposure [10], The TL process happened by the ionizing radiation which elevates an electron into a conduction band to electron trap, and leaves a hole that is called hole trap; these traps must be deep to prevent recombination in room temperatures [37]. Photons produce secondary electrons by interacting with TLD; these secondary electrons deposit their energy to produce the TLD signal [11]. TLD contains a sensitive volume of 1 to 100 mg of crystalline dielectric mass with suitable activators which provide two types of centers that are traps and luminescence centers, the traps are for electrons and holes for long period of time, and the luminescence centers which are located at hole traps and electron traps, and emit light in the recombination process between holes and electrons [37]. The TLD100 contains magnesium and titanium, the magnesium increases the number of traps which increases the number of glow peaks exponentially to form the glow curves, while titanium increases the number of luminescence centers within TLD100. It has five main peaks at room temperature, only peaks 4 and 5 are more appropriate for dosimetric purposes due their long half life comparing with the rest [12].

2.2 Factors Affecting TLD Readings

Many factors affect its readings like the stability of produced signal, the availability, fading rate which should be lower than 5% per month, glow curves must be simple and a plain anneal heating cycle. Some activators (impurities) can be added to increase its sensitivity of tissue equivalent material to increase the number of traps which emit more light during TL process then increase its efficiency. The need of background signal variation is to help measuring the low dose threshold (< 0.1mGy) with high accuracy. Ideal dosimeter has a linear response for doses which is not affected from any dose rate but using different angles can affect its response [13]. The interest is increased in the improvement of the accuracy of dosimetry in brachytherapy purposes by the use of remote afterloading, CT scan data, MRI for volume definition, dose calculation by Monte Carlo methods, the use of low energy gamma radiation sources, and the possibility of real time biological and dosimetric optimization. All of these led improved the accuracy of dose distributions and dose calculations in tissue equivalent materials to modify the algorithms [14]. The sensitivity of TLD varies with photon energy; it is the response per unit dose. TLD sensitivities varies with depth, it have the values 1.08, 1.06, 1.05, 1.02, and 1.00 for depth of 10, 7, 5, 3, and 1 cm respectively [15].

2.3 TLD Advantages

Many advantages like its small size, usage in medical applications because of it is close to tissue equivalent in some materials (LiF) and high sensitivity for all dose values, no need for cable connections, and the independence of environment conditions like temperature, made TLD suitable for in vivo dosimetry, but it should handled carefully because of its small size, waiting a period of time for readings, using of an expensive device (TLD readers), and it cannot keep permanent record of dose [14,16]. TLD dose range is up to 1000 rad, its lowest limit of detection is less than 0.001 rad, and it has a high sensitivity for most radiation types [16]. Monte Carlo simulations are agreed with TLDs readings in solid water within a distance range 5 -100 mm [5,17].The TLD 100 has sensitivity per unit mass equals 1, it's dose threshold is 50 μGy, Fading factor is about 5 per year (if 5 loss at 20°C), and the energy response ratio equals 1.3 [18]. TLD-100 (LiF:Mg.Ti) is a suitable detector for energies within 10 MV in the treatment field, because of neutron production at higher energies, but it will be used if TLD (contains ^{6}Li (7.5%) and ^{7}Li (92.5%)) encased in cadmium foil to block thermal neutrons , so it can respond for photons, electron and thermal neutrons [35], it is dosimetry professional in radiology, radiation therapy and other applications, but variations in annealing procedure (duration and temperature) will affect response variations to exposure [36]. A lot of advantages and disadvantages for TLDs as a general had been listed; there advantages like TLD has a small size, can be found in many forms, has large dose range, independent on the dose rate, can be reused after annealing, low cost, quick read-out, many of them can be exposed together and by the use of calibration, 1-2% reproducibility can be achieved, but on the other side it has many disadvantages like it loses reading easily, only one time signal readout because it is erased during readout, it has different sensitivities, annealing cycle is needed, sensitive to light and large dose affect its sensitivity [19].

3 TLD 100H (LiF:Mg,Cu,P)

The use of TLD 100H in a wide dosimetry program has a special interest because of its extreme sensitivity to maximum readout temperature and the assortment of different dosimetry part and the consideration of implementation in routine dosimetry [20]. The TL material has a tissue equivalent property, and the (LiF:Mg,Cu,P) material has a high sensitivity and near flat photon energy response and without the need to use correction factor [21], it is an advanced TLD, it has a new dosimetric material, and has insignificant fade along simple glow curve structure up to one year and reduced the high temperature peaks, it is a premier choice for dosimetry [22]. The main peak at its glow curve is peak 4 at ~ 210 °C which called the dosimetric peak that is used in dosimetric applications, other peaks 1,2, and 3 are in the range between 70 and 160°C, but peak 5 appears at ~300°C , so peaks 4 and 5 are overlapping peak. Its absorption in the range of 300 to 400 nm is defects for TL emission at peak 4 at ~200°C [23].

3.1 Advantages of TLD-100H over TLD-100

The main difference due to components is that TLD 100H has ten times magnesium than TLD 100 also other components like titanium, copper, and oxygen impurities have different concentrations [24]. The type of dosimetry material TLD 100H is chosen many different studies, it has a high sensitivity and linearity to doses, low rate of fading, with good stability through a numbers of readout cycles, and tissue equivalent effective atomic number (Z) to represent the contribution of photons energy. Its sensitivity is 30-40 times higher than other TLDs, the readout protocol has a maximum temperature of 300°C, but some additional traps do not appear at this temperature. During radiation; the radiation induced population of the traps above Fermi level which refers to radiation defect causes electronic excitation and displacement damage [25]. TLD 100H sensitivity for gamma radiation is 30 times higher than of TLD 100 beside the high internal background for TLD 100. The detection threshold of TLD 100H is below 1 μGy but it is in the range of 20 to 50 μGy for TLD 100 [26].

4 TLD Reader

The TLD reader available is Harshaw® in different types like 3500, 4500, 5500 and 6600; its chamber has a metal tray used to put the dosimeter on, the heating coil heats the dosimeter then the temperature of the heating cycle inside the chamber will be measured by a thermocouple. The use of Nitrogen gas is to reduce signals from impurities in the air. After heating the dosimeter, TLD emits light which passes through optical filter to enter the PMT (photomultiplier tube) through the light guide, it consists of photocathode that has the ability to convert the incident light into amplified current to give measured output which is proportional to the number of generated photons and as a result proportional to the absorbed dose, the output is a pulse counting process, the peak sensitivity of most photocathodes is about 400 nm wavelength in the blue region of EM spectrum, so the emitted light can deal with PMT response, by the large light transmission[27], to avoid false signals read from TLD Reader, three readings without dosimeter should be taken, the output response in the unit of electric charge (nC) represents the sum of all luminescence signals while the glow curve can select the region of dosimetric measurements [28].

5 The Use of TLDs in Measuring Doses

TLDs output read by Harshaw TLD reader is the charges produced by electrons due to the annealing process. To convert the output readings of TLDs from charge (nC) to dose (Gy); the following equations should be followed:

$$\text{absorbed dose} = \frac{\text{equivalent dose}}{\text{quality factor}} \qquad (1)$$

The time between irradiation and readout must be the same to keep same fading from one calibration to another for all dosimeters. The calibration factor ($f_{calibration}$) can be calculated as in the following equation:

$$f_{calibration} = \frac{D_{ionizing\ champer\ (mGy)}}{TLD_{reading\ (nC)}} \qquad (2)$$

While the TLD reading should be without background counts as the following equation:

$$R_{TLD} = R_{ave} - BG \qquad (3)$$

Then the dose at each TLD dosimeter is calculated due to the following equation:

$$D_{TLD}\,(mGy) = f_{cal}\left(\frac{mGy}{nC}\right) \times TLD_{reading}\,(nC) \qquad (4)$$

6 TLDs Annealing Procedures and Sorting

Before TLDs irradiation, the annealing is a compulsory step, it consists of two main steps; the first is prior irradiation consists of high temperature and low temperature annealing and the second is after irradiation and prereadout annealing at low temperature. The procedure of annealing is done by the use of Nabertherm Furnace; its maximum heating rate is 15°C/min. The high temperature annealing is by using a furnace preheated to 400 °C for 1 hour, the heating rate must be cared to reach this temperature from the normal furnace temperature (~30°C) within at least 25 minutes. Then after the high temperature annealing procedure; TLDs must be immediately removed and transferred into another furnace with low temperature (105°C) for two hours, and then to be cooled down to the room temperature. The use of Furnace centre is to keep TLDs out of unnecessary gradients of heat which affect its response. After irradiation and prior the use of Harshaw to get the readout, a Furnace with 105°C is used to anneal the TLDs. This is a standard annealing procedure [29]. The faster cooling the higher sensitivity for TLD [30]. Another annealing procedure was introduced by the use of low temperature annealing to be 80 °C for 24 h to eliminate the unneeded first two peaks and minimize the third peak effect and with the keeping of the preirradiation annealing procedure as 400°C for 1 h [31]. The third annealing protocol also kept the preirradiation annealing procedure but stated a 100 °C for 10–15 min after irradiation and before readout [32]. As Olko (2006); TLD 100 (LiF:Mg,Ti) must be annealed at 400 °C for one hour and 100 °C for 15 minutes after each use and initially, after calibration with scintillation detector using calibration conditions for the field (10cm x10 cm,) and calibration SSD/SAD, it can be exposed to radiation then by the use of Harshaw 3500 TLD reader, and after 24 to 48 hours the charge can be measured, data from calibration process can give dose readings. The response of TLD depends on the type of detector, dose level, radiation LET, annealing, activator content, and other factors. Its efficiency refers to the TL light conversion factor with respect to ^{137}Cs gamma rays [11]. TLD will keep this energy state after irradiation, and after a period of time it can be readout. The reuse of TLD is after annealing by a furnace to allow the mobilization of holes and electrons in traps to the equilibrium positions, and then TLD will give its glow curve by the use of HARSHAW 3500® in the lap. The sorting procedure for used TLDs after the readout is by keeping it all in a container of lead by which each individual TLD has its special number and location. TLD electron be released from its traps thermally as well as optically; it can absorbs light photons and be lifted to the conduction band with no need for thermal excitation [33].

7 TLDs Sensitivity Test

TLD sensitivity is defined as the amount of light can be released by the phosphor (P) per unit of the radiation exposure. The sensitivity of TL is the integrated signal from the photomultiplier tube (PMT: which detects the light emitted from TLD due to annealing inside TLD reader) per unit of radiation exposure. The sensitivity of TL depends on the characteristic of TLD and the reader system. TLD sensitivity was independent of the various time delays between irradiation, prereadout anneal, and readout but was affected by the duration of annealing. TLDs contains magnesium and titanium impurities for the purpose of improve the radiation induction, the purest form of TLD exhibits little TL (photon emission following TLD heating). The energy stored in the TLD crystal lattice due to the absorbed energy after irradiation is recovered by putting it on the planchet heater as a visible light. The relation between TL response and readout temperature refers to the glow curve depends on the TL nonlinearity dose response and annealing procedures that the longer half life peak is most stable and suitable for dosimetry. To check the sensitivity of TLD, the following process of TLDs annealing was followed; 400°C for 1 hour, immediately by 105°C for 2 h, and after exposure to 1 Gy (4 MV x rays) and before read out, TLDs were annealed at 105 °C for 15 min and without using nitrogen gas in planchet heater at TLDs reader. For a dose range from 0.5 cGy to 10 Gy; the result was as followings: flat response per unit dose over the range 0.5 cGy – 100 cGy and increased by 15% over the range 100 cGy – 1000 cGy [29]. Before using the TLDs to read doses from the source, its sensitivity should be evaluated by irradiation to a certain amount of dose, and then the average reading of all TLDs is calculated. A diagram can be drawn for all TLDs readings between TLD signal and TLD number. Diagram between TLD signal and dose in Gy can explain the TLD linearity. Also by using the mean value and SD; TLDs readings can be trusted by comparing its values to manufactures' [34]. The structure of glow-curve for both TLD 100 and TLD 100H is quite similar but for TLD 100; the main dosimetric peak is peak 5 while for TLD 100H is peak 4, both peaks occur at a temperature of ~220°C by similar activation energy (E >2 eV) and same frequency factor (s $>10^{20}$ s^{-1}) which means a similarity of thermoluminsce process in each for the main glow [24].

8 Conclusion

The use of an accurate dosimeter in radiation therapy has its role to deliver accurate amount of dose to target volume and protect organs at risk to achieve harmful. TLD 100H appears a high response, sensitivity, and linearity to doses under 10 Gy more than TLD 100.

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