Dosimetric Evaluation and Verification of External Beam 3-D Treatment Plans in Humanoid Phantom Using Thermoluminescent Dosimeters (TLDs)

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Abstract: Dosimetric Evaluation & Verification Of External Beam 3-D Treatment Plans In Humanoid Phantom have been carried out. In this study male anthromorphic phantom, model no.702 D, manufactured by Atom Ltd has been used. The plan was delivered to phantom and TLD- 100 was placed in cavities to evaluate and verify the dose delivered by implementing 3D treatment plans. TLD 100 was calibrated using SIEMENS PRIMUS PLUS Linear Accelerator with calibrated 6 MV X ray beam. We chose phantom skull, abdomen and pelvis region for making treatment plans and then doses by treatment plans have been verified by TLDs. 4%, 3.5% and 3% variation in the results was found for skull, pelvis and abdomen region respectively which is within the safe limit of accuracy i-e from 3% to 5 %. Before working with TLDs, it has also been found that thermoluminescent dosimeters were showing the linear response and results are reproducible for the dose range from 50 cGy to 200 cGy. This study has been performed at Karachi Institute of Radiotherapy and Nuclear Medicine (KIRAN) during the year 2010-2011.

Keywords: Thermoluminescent (Tlds) Dosimeters, anthromorphic phantom, vitro Dosimetry, vivo Dosimetry, Linear accelerator.

INTRODUCTION

The process of radiation therapy applied on patient includes many steps. Uncertainties in any step can have a dramatic effect on outcome related with the control of disease or the complications as a result of inappropriate treatment so quality assurance is major part of any clinical procedure. Accurate prediction of dose distribution is important for 3D conformal radiotherapy. According to International Commission for Radiation Units and Measurements (ICRU) accuracy of 3% to 5% within dose delivered is necessary for successful radiotherapy procedure.

In this study we verified the dose by implementing external beam 3D Treatment Plan in human phantom using TLDs. TLDs are calibrated in 6MV calibrated X Ray beam of linear accelerator. Treatment planning is the process of determining the most appropriate way to irradiate the patient providing less harm to normal tissues. 3D treatment planning system refers to the use of software & hardware tools to design and implement more accurate and conformal radiation therapy. Different 3D RTP system use different software tools for accelerating and simplifying the task of manually drawing contours [1].

In our study we used RT suite version 2.0 treatment planning system as a tool to implement a protocol based treatment plan and to quality assure the process from receiving patients' image data to sending approved treatment planning data to radiation delivery system [2,3]. International commission on radiation units and measurements (ICRU) report # 50 is used as a protocol to follow for treatment planning. A comprehensive document on treatment planning quality assurance is developed by Task group 53 of American Association of physicists in medicine. (AAPM) [4].

To verify the accuracy of delivery of treatment plan, the plan is delivered to a suitable phantom because it is seldom possible to measure dose distribution directly on patients treated with radiation; data on dose distribution is entirely derived from measurements on phantoms [5].

METHOS AND MATERIALS

According to International commission on radiation units and measurements (ICRU), "Tissue substitute" can be defined as any material that simulates a body of tissue in its interaction with ionizing radiation and a "phantom" as any structure that contains one or more tissue substitutes and is used to simulate radiation interaction in the human body [6-7]. The phantom is shaped into a human torso and sectioned transversely for dosimetric applications. A detailed tabulation of

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tissue substitutes & their properties for all the body tissues is included in ICRU report no.44. Phantom Material specification of our used phantom is mentioned in the literature provided by the manufacturer [8, 9].

TLDs were used for verification of dose because of their small size and extensive use. Tl Dosimetry is based on the ability of certain imperfect crystals to store and absorb the energy of ionizing radiation, that upon heating is reemitted in the form of light and light is detected by Photo multiplier tube (PMT), and the light output is correlated to absorbed dose previously received by them. TL dosimeters can be reused once they have been subjected to a process of annealing to eliminate any residual thermoluminesecent signal. The most important thing is to calibrate the TLDs [10, 11]. The explanation of the observed thermo-luminescence properties can be obtained from energy band theory of solids. This simple model has been proposed by A.J.J Bos to explain the TLD phenomenon qualitatively [12].

There are a number of different crystalline materials that exhibit thermoluminescent properties. The most commonly used within radiotherapy are those based on lithium fluoride (LiF) because LiF is approximately tissue equivalent (effective atomic number of 8.2 compared with 7.4 for tissue) and almost energy independent in the range 100 keV – 1.3 MeV gamma radiation [13, 14].

A plot of light emitted as a function of temperature or time is known as glow curve [15, 16]. A typical glow curve has one or more peaks as electrons trapped at various energy levels are released. Figure **1** shows a typical glow curve for TLD-100. The different peaks correspond to different trapped energy levels. There are several peaks for TLD-100 at room temperatures [17, 18]. Low temperature peaks are sensitive to fading and undesirable in dosimetry. Fading is the loss of trapped charges before readout. Factors which affect the shape of glow curve are annealing, heating rate and its uniformity, size and history of sample, the reading instrument.

The standard pre-irradiation annealing procedure for TLD MTS-100(lithium fluoride magnesium titanium sintered) is 4000 ^{o}C for 1 hour followed by 1000 ^{o}C for two hours or 24 hours at 800 ^{o}C. The slow heating namely 24 hours at 800 ^{o}C, removes peak 1 and 2 of the glow curve by decreasing the trapping efficiency. Peaks 1 and 2 can also be eliminated by post irradiation annealing for 10 minutes at 100 ^{o}C. The need for eliminating peak 1 and 2 arises from the fact that magnitude of these peaks decreases rapidly with time after irradiation, by removing these peaks the glow curve becomes more stable and therefore predictable [19].

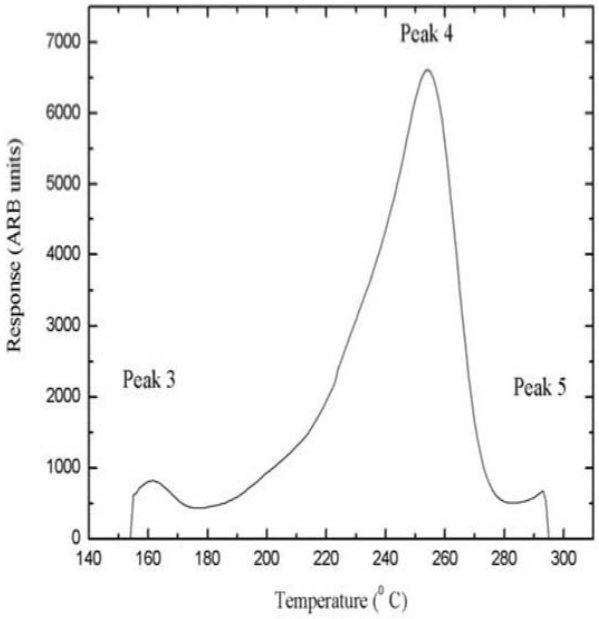

Figure 1: Typical glow curve for TLD MTS-100 from TLD Poland after about 10 hours of the irradiation [17].

In this study we used treatment planning system RT-suite version 2.0 by Multi-data company [20], anthromorphic phantom (Model no .702-D manufactured by ATOM Ltd.), [17] TLD-100, TLD reader marketed by HARSHAW, HARSHAW OS 3500 (Manual reader) and for External beam therapy, Linear Accelerators are available at KIRAN (Karachi institute of Radiotherapy and Nuclear Medicine), we did work with PRIMUS PLUS Linear Accelerator and TLD-100 was calibrated on another SIEMENS PRIMUS PLUS linear accelerator with calibrated 6MV X-rays beam and TLDs are placed in cavities of phantom to verify the absorbed dose by implementing 3D treatment plan on it. Verification is necessary to check either the dose delivered to target is within the range of predetermined accuracy i.e. 3 % to 5% recommended by ICRU [21].

RESULTS AND DISCUSSIONS

The first step involved in the use of thermoluminescence dosimeters is grouping and sorting. In the sets of 20 and 40 TLDs are randomly selected first and then element correction coefficient of each single TLD was calculated manually. Readings were taken in Harshaw 3500 single chip TLD reader to determine the individual chip sensitivity. As a rough

guess only some TLDs whose ECC factor approaches to unity or equal to one had been selected for the purpose of dose verification.

After grouping of TLDs the next step involved is the calibration of TLDs. Initially and after each use TLDS are annealed in an Thermolyne 47900 furnace at 400 ^{o}C for one hour followed by 100 ^{o}C for two hours. TLDs were kept at room temperature for 48 hours then zero readings (nC), without any exposure were taken. Time from anneal to exposure and exposure to read were kept constant i.e. 48 hours to avoid fading effects. Background or zero read were being rechecked after annealing, along with test light reading.

A set of annealed TLD -100 square shaped chips were irradiated in a solid water phantom at depth of 5cm to a dose of 200 cGy with a 6 MV photon beam, source to surface distance, SSD of 100 cm and 10 x 10 cm^2 field size. A calibration factor (nC/Gy) was assigned to each one. This process of calibration was repeated for second time with different doses of 50 cGy, 100 cGy, 150 cGy and 200 cGy to check the linearity and reproducibility of TLD response.

Linearity and reproducibility in TLD response has been checked from 50 cGy to 200 cGy. Graphs have been plotted between dose (cGy) and TLD response (μC), It has been found that TLDs are showing almost linear relationship from the range 50 cGy to 200 cGy.

Treatment Planning

3D treatment plans were made for skull abdomen and pelvis region and then dose implemented by

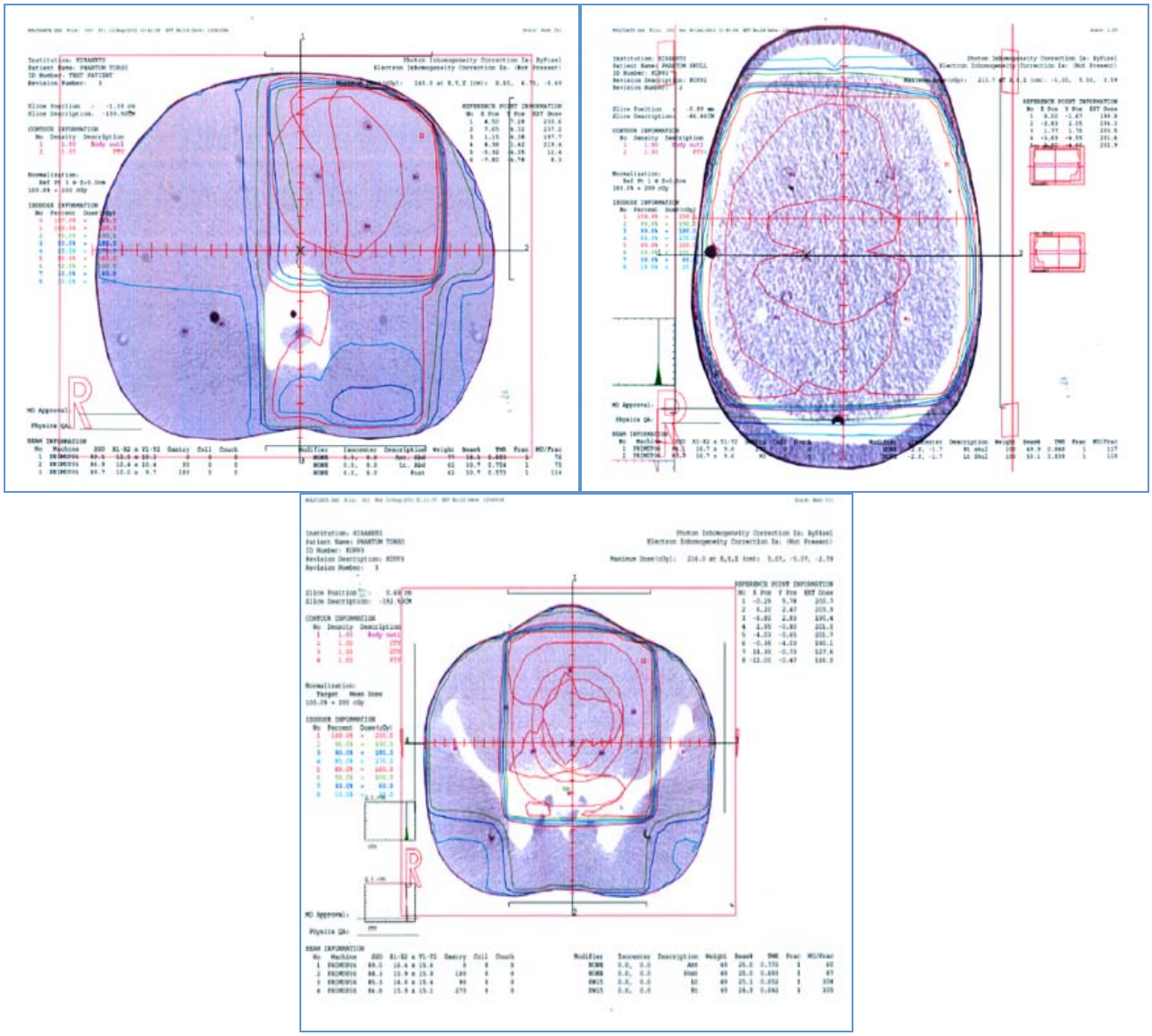

Figure 2: Iso-dosed curves of representatives for skull, abdomen and pelvis.

Table 1: Treatment Plan for Skull

TLD Chip Reading (cGy)	Treatment Plan Reading (cGy)	Average (cGy)	Standard Deviation (cGy)	Coefficient of Variation
225	206.1	215.55	13.364	6.2
222	207.1	214.55	10.536	4.911
193.07	199.5	196.285	5.812	2.316
208.22	200	204.11	4.547	2.848
188.64	204.3	196.47	11.095	5.647
191.868	203.5	197.684	8.225	4.161
193.07	201.6	197.335	6.032	3.057
192.85	202.9	197.875	7.106	3.591

treatment plans has been verified by placing TLDs in phantom. TLD Response (cGy) and Treatment plan doses (cGy) on different points in phantom slices of skull, abdomen and pelvis region were recorded and compared. Tables **1**, **2** and **3** show TLD Response (cGy) and Treatment plan doses (cGy) for Skull, Abdomen, and Pelvis, respectively. Figures. **3**, **4**, and 5 show comparison of TLD readings and treatment plan readings.

DOSE COMPARISON BETWEEN TLD DOSES AND DOSES BY TPS

To verify the dose first we did calibration of TLDs with Siemens Primus plus Linear Accelerator at KIRAN with calibrated 6MV photon beam at 200 cGy. Calibration of TLDs was performed in plastic phantom at 5 cm depth for 200 cGy. Background reading was calculated and this factor was multiplied with the TLD responses to get the corrected TLD response.

Table 2: Treatment Plan for Abdomen

TLD Chip Reading (cGy)	Treatment Plan Reading (cGy)	Average (cGy)	Standard Deviation (cGy)	Coefficient of Variation
220.72	230.6	225.66	6.986	3.096
231.23	237.2	234.215	4.221	1.802
194.275	197.7	195.9875	2.422	1.236
217.71	219.4	218.555	1.195	0.547
9.9828	11.4	10.6914	1.002	9.373
7.6464	8.3	7.9732	0.462	5.796

Table 3: Treatment Plan for Pelvis

TLD Chip Reading (cGy)	Treatment Plan Reading (cGy)	Average (cGy)	Standard Deviation (cGy)	Coefficient of Variation
198.71	200.7	199.71	1.407	0.705
213.03	203.9	208.47	6.456	3.097
203.55	190.4	196.98	9.298	4.721
192.36	201	196.68	6.109	3.106
187.76	201.7	194.73	9.857	5.062
183.01	190.1	186.56	5.013	2.687
120.99	127.6	124.3	4.674	3.76
116.96	126	121.48	6.392	5.262

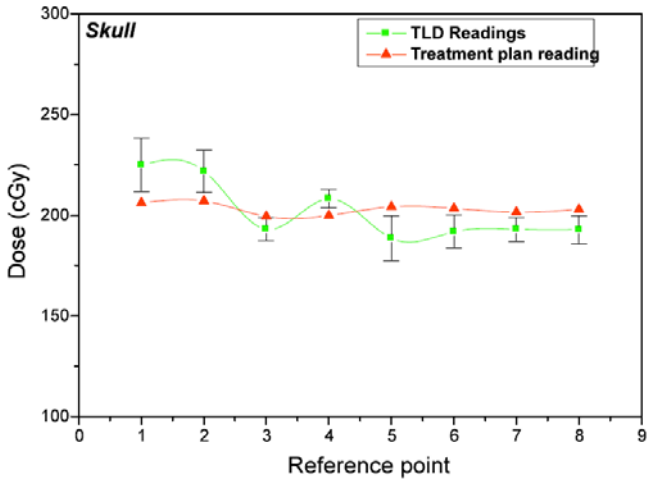

Figure 3: Dose verification of 3D treatment Plan by TLD chips for skull.

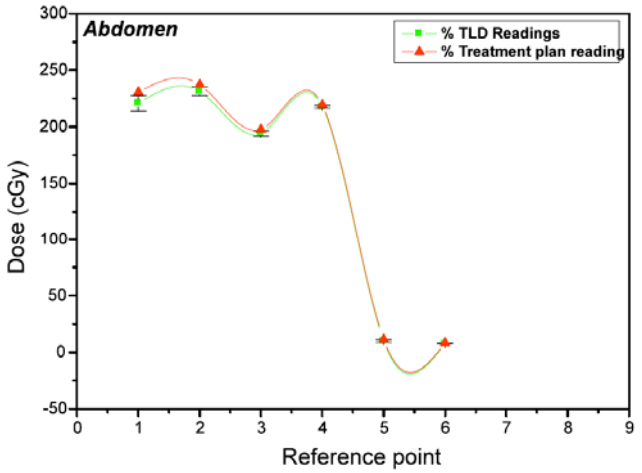

Figure 4: Dose verification of 3D treatment plan by TLD chips for abdomen.

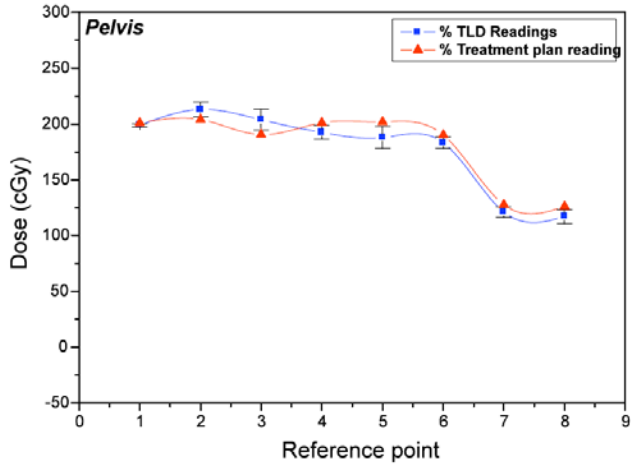

Figure 5: Dose verification of 3D treatment plan by TLD chips for pelvis.

It has been observed that TLDs are showing almost linear relationship at different doses from 50 cGy to 200 cGy. Therefore there was no need to put supralinearity correction factor in the output of Doses by TLDs. It has also been verified that there is a linear relationship between dose and the TLD Response for different doses used in radiotherapy for (MTS-100 TLD Poland) as claimed by the manufacturer that linearity range is from 5×10^{-5} to 5 Gy.

For the Dose Verification purpose, three different treatment plans were made with different beam combination at 200 cGy. It has been concluded that doses were in a safe limit of 3% to 5% accuracy in delivered dose prescribed by International bodies like IAEA, AAPM and ESTRO. For skull case there is a variation of 4% in results. 3.5% variation was observed for the pelvis case and 3% variation in abdomen region case. Out of the field dose was also calculated for abdomen case and very low values of doses were also observed there because of scattering. The large variation at some points was mainly because of the manual errors in any step from treatment plan to dose reading but the main factor which affects the most on the TLD responses is improper placement of TLDs because small change in the position of TLD group can affect the dose significantly due to inverse square dose variation.

CONCLUSION

The main aim of this study was to perform patient dose verification, case dose calculations were performed on Phantom. TLDs are used to find out the doses and then compared with the doses implemented by 3D treatment plan. The linearity in TLD response was checked first to use them in the desired range of doses. It has been found that results show good agreement with the values of doses given by Treatment Planning System.

To verify the accuracy of delivery, the plan be delivered to a suitable phantom. It is useful to perform measurements using special purpose or anthromorphic phantoms or to perform measurements on or in the patients.

ABBREVIATIONS

TLD = Thermoluminesecent Dosimeter

cGy = centigray

ICRU = International Commission for Radiation Units and Measurements

RTP = Radiation Therapy Protocol

RT = Radiation Therapy

AAPM = American Association of physicists in medicine

PMT = Photo multiplier tube

IAEA = International atomic energy Agency

ESTRO = Europeans Society for Radiotherapy & Oncology

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