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INTERCOMPARISON PROGRAMME OF ABSORBED DOSE FOR MEGAVOLTAGE X-RAY TELETHERAPY UNITS IN MALAYSIA

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ABSTRACT

The objective of this study is to perform a thermoluminescent dosimetry (TLD) postal dose quality audit for megavoltage X-ray teletherapy units in Malaysia. This audit is essential to be carried out to ensure adequate precision in the dosimetry of clinical beams before being delivered to the patients. Through this work, participating centres were requested to irradiate three capsules of TLD-100 powder with an absorbed dose to water of 2 Gy for 6 MV and 10 MV photon beams. The International Atomic Energy Agency (IAEA)'s Technical Report Series No. 398 is used as a reference standard for TLD irradiation. A total of 22 photon beams from ten radiotherapy centres comprising one government hospital and nine private medical centres were evaluated. The percentage deviation of user's measured absorbed dose relative to Secondary Standard Dosimetry Laboratory (SSDL) mean absorbed dose was calculated. The results showed that all photon beams are within the IAEA's acceptance limit of ± 5% except six photon beams. These centres were followed up with a second round of TLD irradiation which resulted in a better compliance. As a conclusion, regular audits should be performed to ensure consistency of radiotherapy treatment unit performances thus maintaining the accuracy of dose delivered to patients in all radiotherapy centres in Malaysia.

Keywords: Absorbed dose, irradiate, quality audit, radiotherapy, thermoluminescent dosimetry,

INTRODUCTION

Accurate, reliable and reproducible of absorbed dose delivered to patients in radiotherapy treatment is essential in order to ensure the effectiveness of the cancer treatment and for the purpose of dose optimisation to the patients. For this reason, since 1969, the International Atomic Energy Agency (IAEA) in collaboration with the World Health Organisation (WHO) has organised a project on dose intercomparison for radiotherapy centres worldwide (Izewska et al., 2002, Izewska et al., 2003, Izewska et al., 2004, Izewska et al., 2006, Izewska and Meghzifene, 2011). Being a member state of the IAEA/WHO Network of SSDL, Malaysia has participated in the IAEA/WHO Thermoluminescence Dosimeter (TLD) Postal Audit Programme for SSDLs and Radiotherapy centres since 1985 and 2011, respectively. However, only less than eight radiotherapy centres in Malaysia were involved in the programme annually. Currently, the number of participating centre was reduced by the IAEA due to limited laboratory resources. Therefore, the Secondary Standard Dosimetry Laboratory (SSDL) Malaysia initiates to establish the National TLD postal dose quality audit in Malaysia. The objective of this programme is to provide a quality audit on the dose delivered by megavoltage X-ray teletherapy units throughout Malaysia using TLD-100 powder as a radiation detector and IAEA's TRS No. 398 as a standard dosimetry protocol (IAEA, 2000).

Currently, in Malaysia there are 27 radiotherapy centres comprising 6 government hospitals and 21 private medical centres, which are using medical linear accelerator (linac), Tomotherapy and Cyberknife. In addition to calibration of absorbed dose to water that was performed by medical physicists, it is our interest to carry out this independent dosimetry check at regular intervals. This is to investigate the compliance of radiotherapy machines resulting in consistency and reliability of radiation beams used to treat cancer patients in Malaysia.

MATERIALS AND METHODS

Preparation of TLD-100 Powder

The thermoluminescence dosimeter (TLD) used in this study was TLD-100 powder consists of Lithium Fluoride doped with Magnesium and Titanium (LiF:Mg,Ti) manufactured by Thermoelectron Inc., USA. The virgin TLD-100 powders were initially pre-annealed at maximum temperature of 400^oC for 1 hour and followed then at 100^oC for 2 hour before the first irradiation to increase their sensitivities (Driscoll et al., 1986). Konn TLD annealing system, type A134307 was used for annealing process. After annealing, the TLD-100 powders were loaded into small black plastic capsules using a stainless steel spatula. The capsule is made of opaque polyethylene capsules (IAEA type) of 3 mm diameter, 15 mm length and with 1 mm thick walls. Each capsule contains about 100 mg of TLD-100 powder.

TLD Calibration Procedures

The TLD calibration curves for 6 MV and 10 MV photon beams which being the most typical photon beam energies used in radiotherapy were established using Varian Trilogy Linear Accelerator, type IX Series (Varian Medical System Inc., Palo Alto, California). Absorbed dose determination was performed according to the IAEA's TRS No. 398 code of practice with a calibrated 0.6 cm^3 Farmer ionization chamber, type NE 2571 (PTW-Freiburg, Freiburg, Germany) connected to a PTW Unidos electrometer, type 10005 and having a calibration in term of absorbed dose to water for Co-60 traceable to the IAEA's Dosimetry Laboratory. The measurement set-up was at 10 cm depth in water at the beam central axis with 10 cm x 10 cm field size at surface and source-surface distance (SSD) of 100 cm (Figure 1(a)). Using the same geometrical set-up, five capsules of TLD-100 powder were irradiated with absorbed dose to water of 150 cGy, 180 cGy, 200 cGy, 220 cGy and 250 cGy each. One capsule was kept as a control for background radiation measurement. The range of 150 – 250 cGy absorbed dose to water is adequate for evaluating the accuracy of user's delivery dose under reference condition. The irradiated TLDs were analysed using Harshaw TLD reader, type 3500 manufactured by Thermoelectron Corporation, USA. Calibration curves of TL signal (μC) against absorbed dose to water (in cGy) for 6 MV and 10 MV photon beams were plotted (Figure 2). Linear equations and determination coefficients (R^2) for both energies were determined.

TLDs Irradiation by the Participating Centres

Every centre was provided with instruction sheets, data sheets, a few sets of TLD (four capsules of TLD-100 powder in one set where three capsules to be irradiated and one capsule to act as control) and a standard TLD jig for used during irradiation. The participant were asked to irradiate the TLDs under reference condition; absorbed dose to water of 200 cGy at 10 cm depth in water at central axis with 10 cm x 10 cm field size (FS) at 100 cm source-surface distance (SSD) or source-axis distance (SAD) as shown in Figure 1. The participant was requested to return the irradiated TLDs with the completed data sheets to the SSDL within a week after irradiation.

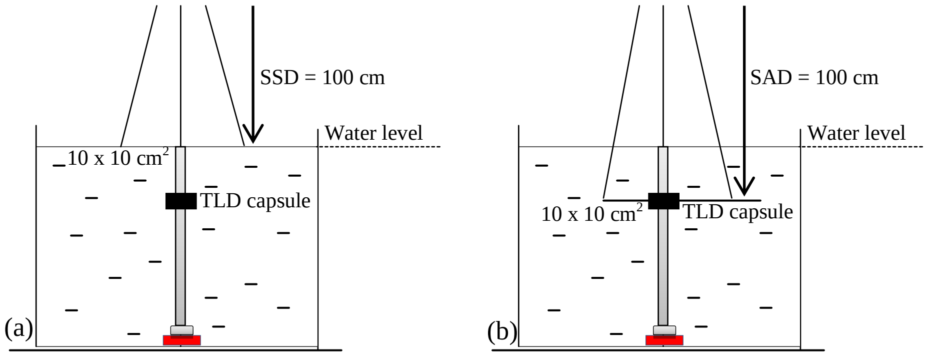

Figure 1: Two alternative geometry set-ups for irradiating the capsules of TLD-100 powder. (a) The capsule of TLD-100 powder is placed at 10 cm depth, field size of 10 cm x 10 cm at surface and 100 cm Source-Surface Distance (SSD). (b) The capsule of TLD-100 powder is placed at 10 cm depth, field size of 10 cm x 10 cm at axis and 100 cm Source-Axis Distance (SAD)

Measurement and Dose Evaluation

The irradiated capsules of TLD-100 powder were analysed within a month after returned in order to reduce uncertainty due to fading effect. To ensure good reproducibility of the TLD reader system, periodic quality control checks including checks of the photomultiplier tube (PMT) noise and reference light were carried out prior to starting the TLD analysis. The checks were repeated for every 10 readings. Consistency and reliability of the TLD reader then was confirmed by reading a capsule of TLD-100 powder that was irradiated at 200 cGy absorbed dose to water. On average, ten TL signals of 10 mg TLD per sample were obtained for each capsule. A special TLD dispenser was used to ensure the correct mass of TLD-100 powder was transferred onto the planchet. The TL signal was obtained by heating TLD-100 powders at the maximum temperature of 300^{o}C with a heating rate of 10^{o}C/s within 13 seconds. An average TL signal from three capsules of irradiated TLDs minus the background radiation was calculated to obtain net TL signal. The standard uncertainty was calculated from standard deviation of the TL signals. Result of TLD audit was described in the form of the percentage relative deviation between the user stated dose and the measured absorbed dose where the IAEA's acceptance limit of ± 5% should be complied (Izewska and Andreo/ 2000).

RESULTS AND DISCUSSION

Establishment of TLD Calibration Curve

The TLD calibration curve for 6 MV and 10 MV photon beams within the range of 150 to 250 cGy was established as shown in Figure 2. From the graph, the TL signal is linearly proportional to absorbed dose to water with gradient of 0.1143 µC/cGy and 0.1119 µC/cGy for 6 MV and 10 MV photon beams, respectively. Strong correlation between TL signal and absorbed dose to water with determination coefficient, R^2 of 0.993 is given by 6 MV photon beam and 0.997 by 10 MV photon beam. The linear equations obtained from the graph will be used in determining the absorbed dose to water in calculating the accuracy of user's dose.

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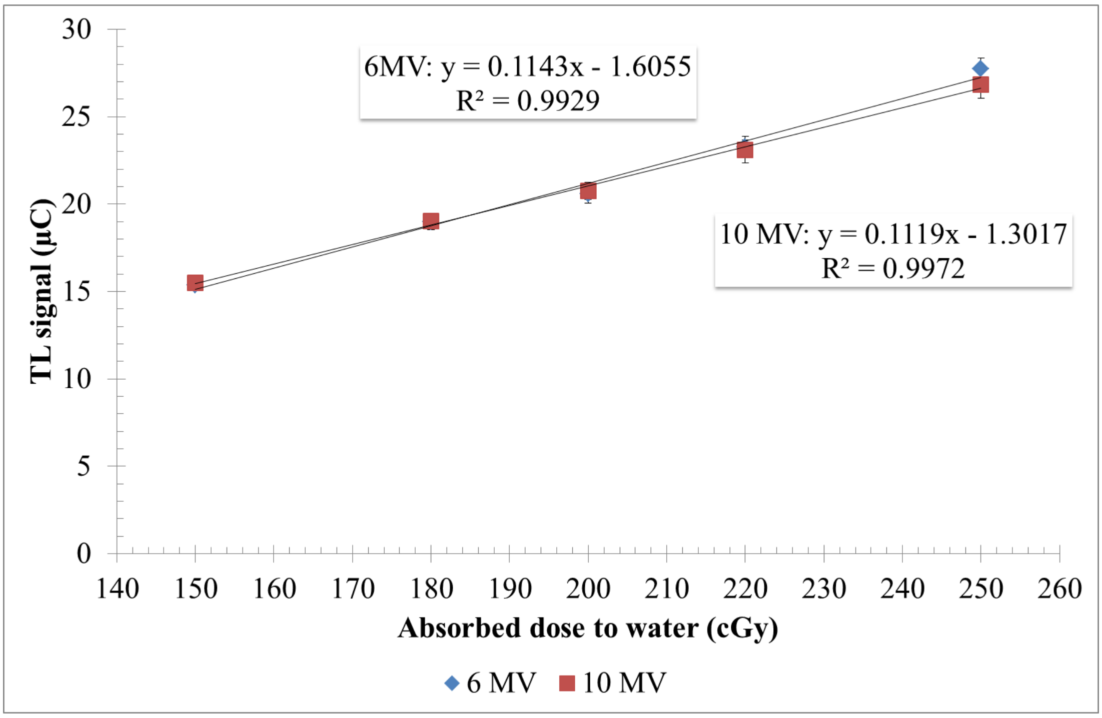

Figure 2: A graph of TL signal against absorbed dose to water for 6 MV and 10 MV photon beams. Error bars represent the standard uncertainty of 10 TL signals

The relative expanded uncertainty of determination of absorbed dose to water from TLD measurement for megavoltage X-ray teletherapy units in Malaysia is estimated to be 4.1% (Table 1). This value is given to a level of confidence of approximately 95% using a coverage factor, *k* of two. The uncertainty is raised from two components: (i) the uncertainty of determination of the absorbed dose to water from standard ionization chamber using IAEA's TRS No. 398; and (ii) the uncertainty of TLD procedure. The relative standard uncertainty from the TLD procedure is estimated to be 1.7%.

Verification of TLD Calibration Curves

The calibration curves produced in Figure 2 were verified using the irradiated capsules of TLD-100 powder that were exposed with absorbed dose to water of 200 cGy at 6 MV and 10 MV photon beams in one of the radiotherapy centres in Malaysia. These absorbed doses were measured by the SSDL using a standard ionization chamber inside a water phantom. Results for the TLD dose verification are shown in Table 2. The percentage deviation between user stated dose and SSDL measured dose result within ± 5% is considered satisfactory based on the IAEA/WHO TLD audits for radiotherapy centres (Izewska, Bera et al. 2002). This value follows the tolerance limit given the ICRU Report 24 (ICRU 1976). A relative deviation with negative sign indicates that the user estimates lower dose than what is measured. Result of 6 MV photon beam was exceeded the acceptance limits of ± 5%. Therefore, a review of dosimetry procedure and data analysis of the TLD irradiation should be done to identify the origin of the discrepancy. A second round TLD irradiation also should be performed with the shortest possible delay.

Table 1: Uncertainty evaluation of absorbed dose to water determination at the SSDL

Source of Uncertainty	**Relative Standard Uncertainty (%)**	
	Type A	**Type B**
Standard Ionization Chamber		
$N_{D,W}$ calibration at IAEA		0.548
Charge measurement	0.036	
Accuracy of charge measurement		0.289
Long term stability of electrometer		0.058
Pressure		0.029
Temperature		0.021
Chamber positioning		0.058
Correction of beam quality, K_Q		1.0
TLD Procedure		
TL signal measurement	1.667	
Quadratic sum	**1.667**	**1.180**
Combined uncertainty	**2.042**	
Expanded uncertainty (k = 2)	**4.085**	

Table 2: Results of verification of TLD calibration curve

Beam	**TL Signal (μC)**	**User Stated Dose (Gy)**	**SSDL Mean Dose (Gy)**	**% Deviation Relative to SSDL Mean Dose**
6 MV	22.87 ± 0.96	2.00	2.14	-6.54
10MV	21.30 ± 1.05	2.00	2.02	-1.04

Intercomparison Programme of Absorbed Dose for Megavoltage X-ray Teletherapy Units in Malaysia

Table 3 lists the participating centres in the absorbed dose intercomparison programme for megavoltage X-ray teletherapy unit in Malaysia. Amongst the 27 radiotherapy centres in Malaysia, only 10 centres comprising 1 government hospital and 9 private medical centres volunteered to join in the programme. Some centres were not interested because they already joined the IAEA/WHO TLD postal dose quality audit in previous year. Total numbers of photon beams involved in this programme are 22 which consist of thirteen 6 MV and nine 10 MV photon beams. Seven centres participated for two photon beams and the other three centres participated for four, three and one photon beams, respectively. Table 3 also notes the most common dosimetry protocol for determining the absorbed dose used by the radiotherapy centres in Malaysia is the IAEA's TRS 398 and one centre only still using the IAEA's TRS 277 protocol. In the TRS 277, the absorbed dose to water under reference condition was determined from the readings of ionization chamber calibrated in terms of air kerma (IAEA, 1987). Introduction of TRS 398 in 2000 has implemented the determination of absorbed dose in water using a calibrated ionization chamber in terms of absorbed dose to water.

Table 3: Lists of participating centres in the absorbed dose intercomparison programme for megavoltage X-ray teletherapy unit in Malaysia

Centre	**Protocol**	**Photon Beam**		**No. of Photon Beam**
		6MV	**10MV**	
1	TRS 398	√	√	2
2	TRS 398	√	√	2
3	TRS 398	√ √	√	3
4	TRS 398	√ √	-	2
5	TRS 277	√ √	√ √	4
6	TRS 398	√	√	2
7	TRS 398	√	√	2
8	TRS 398	√	√	2
9	TRS 398	√	√	2
10	TRS 398	√	-	1
Total Photon Beam		**13**	**9**	**22**

Results of TLD irradiation for 6 MV and 10 photon beams are shown in Figure 3. The results are expressed as percentage relative deviation between user stated dose and SSDL mean dose. Each value in the graph represents the mean of percentage deviation from three capsules of TLD-100 powder. The mean of the distribution for 6 MV photon beam is -0.04% and the standard deviation is 5.70%. The deviations vary between a minimum percentage relative deviation of -8.11% and a maximum of 15.03%. The mean of the distribution for 10 MV photon beam is 1.90% and the standard deviation is 4.18%. The deviations vary between a minimum percentage relative deviation of -5.86% and a maximum of 6.92%. Out of 22 beams, ten 6 MV beams and six 10 MV beams fall within the acceptance limit of ± 5%.

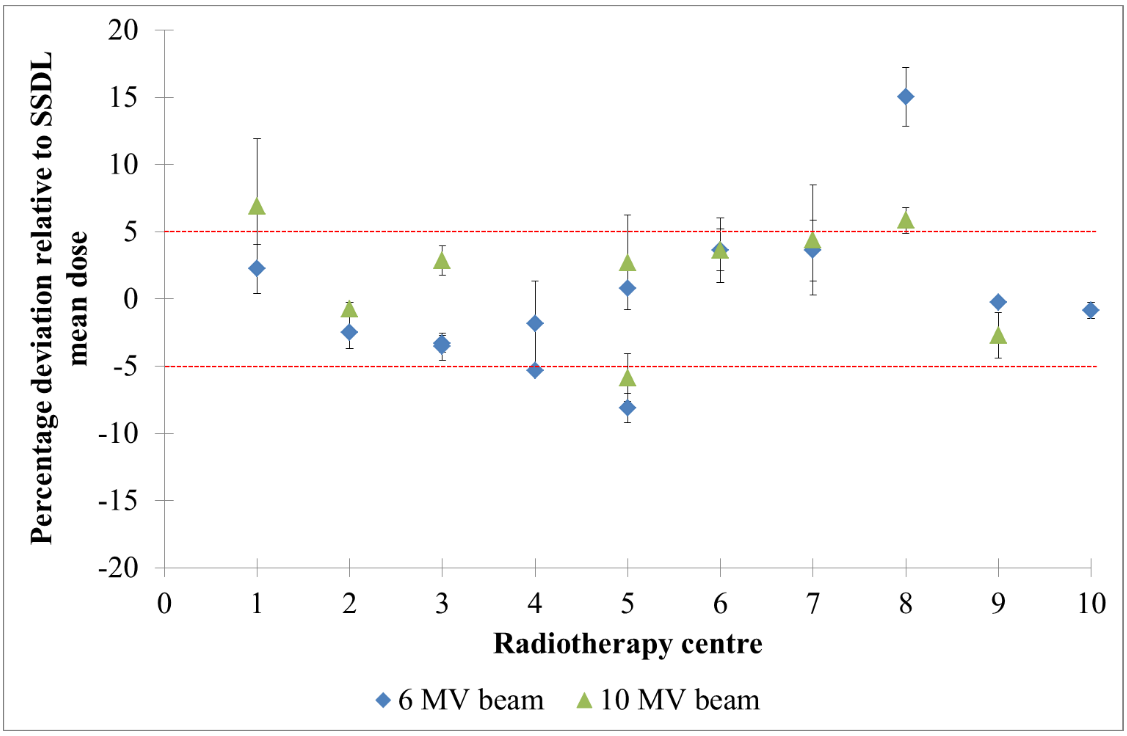

Figure 3: Results of TLD irradiation for 6 MV and 10 MV photon beam.

A total of 22 beams from 10 radiotherapy centres have been evaluated consist of thirteen 6 MV beam and nine 10 MV beam. Each data represents the mean of percentage deviation from three capsules of TLD-100 powder. Error bars represent the standard deviation of the mean of three TLD measurements.

Follow up TLD Irradiation

Participating centres with the results outside the acceptance limits were asked to perform a second round of TLD irradiation. This includes three 6 MV beams and three 10 MV beams at four radiotherapy centres. The participants were requested to investigate the reasons for the poor results in the first irradiation. Feedback from the medical physicists, the discrepancies in the results were identified due to: (i) incorrect positioning of TLD capsule during irradiation i.e absorbed dose was calculated at 100 cm SSD but capsules of TLD-100 powder were irradiated at 90 cm SSD; (ii) mistake in recording the absorbed dose in data sheets i.e TLDs were exposed at 240 cGy but they stated 200 cGy in the forms; and (iii) mistake in absorbed dose calculation using treatment planning system i.e person in charge was not familiar with the system since she is a new staff. Some of the participants commented that they have a difficulty in inserting the TLD capsule into the TLD capsule holder because the TLD capsule hole is slightly smaller than the TLD capsule. Based on their comments, the hole on the TLD capsule holders was made larger to enable easy insertion of the TLD capsule.

Comparison of percentage deviation between the first and follow up TLD irradiations is shown in Table 4. Four beams show improved results within ± 5% in the follow up irradiation. However, two beams still give percentage deviation of more than ± 5%. The reasons for these conditions were unclear. Therefore, further investigation will be made by the SSDL including an on-site visit to the centre. The on-site visit includes verification of the beam calibrations with an ionisation chamber, a review of the dosimetry data and techniques, corrective measurements and ad-hoc training.

Table 4: Results of follow up TLDs irradiation

Centre	Photon Beam	Percentage Deviation Relative to SSDL Mean Dose	
		1st Irradiation	2nd Irradiation
1	10MV	6.92 ± 5.01%	3.72 ± 0.93%
4	6 MV	-5.33 ± 1.65%	9.79 ± 1.32%
5	6 MV	-8.11 ± 1.08%	4.75 ± 1.52%
5	10MV	-5.86 ± 1.78%	3.24 ± 0.06%
8	6 MV	15.03 ± 2.21%	-7.47 ± 0.65%
8	10MV	5.84 ± 0.96%	-4.03 ± 1.13%

CONCLUSIONS

The pilot study to verify the accuracy of photon beam for megavoltage X-ray teletherapy unit using powder form of thermoluminescence dosimeter has been carried in Malaysia. The results demonstrated that ten 6 MV photon beam and six 10 MV photon beam comply with the tolerance limits of ± 5%. From this study, the X-ray outputs from six photon beams were identified to exceed this tolerance limit due to human-related errors. These centres were followed up with a second round of TLD irradiation which resulted in a better compliance and identification of causes of errors. The result can be used as a base line data for future intercomparison that will be organized by the SSDL every two years. This information may be useful for the Ministry of Health (MOH) so that the recommendation for all centres to participate in the future dose intercomparison thus ensuring compliances of megavoltage X-ray teletherapy units in Malaysia.

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