Original Article

Peripheral dose measurements with diode and thermoluminescence dosimeters for intensity modulated radiotherapy delivered with conventional and un-conventional linear accelerator

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ABSTRACT

The objective of this paper was to measure the peripheral dose (PD) with diode and thermoluminescence dosimeter (TLD) for intensity modulated radiotherapy (IMRT) with linear accelerator (conventional LINAC), and tomotherapy (novel LINAC). Ten patients each were selected from Trilogy dual-energy and from Hi-Art II tomotherapy. Two diodes were kept at 20 and 25 cm from treatment field edge. TLDs (LiF:MgTi) were also kept at same distance. TLDs were also kept at 5, 10, and 15 cm from field edge. The TLDs were read with REXON reader. The readings at the respective distance were recorded for both diode and TLD. The PD was estimated by taking the ratio of measured dose at the particular distance to the prescription dose. PD was then compared with diode and TLD for LINAC and tomotherapy. Mean PD for LINAC with TLD and diode was 2.52 cGy (SD 0.69), 2.07 cGy (SD 0.88) at 20 cm, respectively, while at 25 cm, it was 1.94 cGy (SD 0.58) and 1.5 cGy (SD 0.75), respectively. Mean PD for tomotherapy with TLD and diode was 1.681 cGy SD 0.53) and 1.58 (SD 0.44) at 20 cm, respectively. The PD was 1.24 cGy (SD 0.42) and 1.088 cGy (SD 0.35) at 25 cm, respectively, for tomotherapy. Overall, PD from tomotherapy was found lower than LINAC by the factor of 1.2-1.5. PD measurement is essential to find out the potential of secondary cancer. PD for both (conventional LINAC) and novel LINACs (tomotherapy) were measured and compared with each other. The comparison of the values for PD presented in this work and those published in the literature is difficult because of the different experimental conditions. The diode and TLD readings were reproducible and both the detector readings were comparable.

Key words: Diode, TLD-100, intensity modulated radiotherapy, linear accelerator, peripheral dose, tomotherapy

Introduction

Rapid developments in medical technologies have extended the life expectancy of cancer patients. However, the life expectancy following malignant tumors posed a growing concern on the long-term effects of radiation-induced cancers.[1-4] These technologies mainly include intensity modulated radiotherapy (IMRT) delivered with conventional linear accelerator (LINAC) and novel LINAC (tomotherapy). Large number of monitor units (MUs) in the range of few thousands (1000-15000) are delivered to planning target volume (PTV) to deliver the desired prescription dose with the goal to minimize the dose to the surrounding healthy tissues and to avoid the side effects as well.

As the side effects are strongly dependent on the dose deposited outside the PTV, investigations in the delivery techniques, and treatment planning systems (TPSs) have to accomplish the optimal degree of beam modulation to spare the healthy tissue during the irradiation. During radiotherapy treatment with high-energy photon beams, a small fraction of delivered dose contributes a few centimeters away from the irradiated field due to leakage radiation (more than

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20 cm) from the gantry head and scattered radiation (less than 20 cm). This is known as peripheral dose (PD). This PD increases with the intensity-modulated radiation therapy (IMRT) treatments due to the increased beam-on time to deliver modulated fields.

The patient-specific dosimetric verification of these IMRT techniques primarily depicts the information of variation in planned and measured dose in the PTV and not outside the PTV. There is no objective to measure the radiation reaching out of the field. The dose distributions are verified inside the PTV only. Considering the long-term sequelae of IMRT such as induction of secondary malignancy, the estimation of PD has been vital. The primary contributor to the PD is leakage, which contributes to the doses at distances greater than 20 cm, and the secondary contributor is scattered radiation, which is dominant at distances less than 20 cm.[5] The structural, shielding design, and mechanism of treatment delivery system are the key factors for PD.

Various detectors have been reported to measure the radiation outside the PTV. Diamond detectors and thermoluminescence dosimeters (TLD-700) were used to measure PD from photons and protons.[6] Ion chamber, diamond detector, and TLD (600 and 700) were used to measure out-of-field dose in a water phantom using photons, protons, and carbon ions.[7] PD were measured with LINAC and tomotherapy using TLD-100 placed on an anthropomorphic phantom.[8] TLDs were used to quantify the PDs from noncoplanar IMRT fields.[9] PD was compared between segmented multileaf modulation (sMLM)-based IMRT and helical tomotherapy.[10] A 0.6 cc ionization chamber was used in plastic water phantom to measure PD from uniform dynamic multileaf collimation fields.[11]

Another study measured PD with three modalities: Conventional LINAC, conventional LINAC IMRT, and LINAC-based tomotherapy.[12] The study reported PD from LINAC-based tomotherapy (Peacoco/MiMic, NOMOS, Inc., Sewickley, PA) measured with TLD in a water equivalent plastic phantom.[13] The study reported PD from helical tomotherapy.[14] Measurements were made by cylindrical ion chamber at distances 10-30 cm from the field edges. Out-of-field contributions for IMRT and volumetric modulated arc therapy was measured using gafchromic films and compared with calculations using a superposition/convolution-based TPS.[15] A study compared second cancer risk due to out-of-field doses from 6-MV IMRT and proton therapy based on six pediatric patient treatment plans.[16]

The purpose of this study was to measure and quantify PD from two IMRT modalities: Conventional approach (LINAC) and novel approach (Hi-Art II helical tomotherapy). This study comprises *in vivo* dosimetric measurements both with diode and TLD-100.

Materials and Methods

Ten IMRT patients each were randomly selected from treatments using trilogy dual-energy linear accelerator (Varian Medical System, Palo Alto, USA) and Hi-Art II tomotherapy (Tomotherapy Inc Corp, WI, USA). Patients with head and neck cancer were selected for this study. All the patients were planned for IMRT with 6 MV X-rays. Two DPD-12 diodes (IBA Dosimetry, Sweden) were kept longitudinally in central axis on patient's skin at 20 and 25cm from treatment field edge.

Twelve diodes can be connected simultaneously to the electrometer for measurements. These diodes are precalibrated and characterized by the manufacturer for the measurements between 1 and 100 cGy. We had only two diodes and hence only two diodes were used in this study for measurement of PD. TLD-100 (LiF: MgTi) powder packets were also kept along with diodes in a similar manner at various distances (5, 10, 15, 20, and 25 cm) from the treatment field edge.

TLD packets were used in this study. The handling, packing, and necessary precautions for TLD powder has been described in details.[17] Figure 1 shows diodes placed on the patient's skin at 20 and 25 cm from the field edge. Figure 2 shows TLDs placed on the patient's skin from 5 to 25 cm at 5 cm interval from the field edge. TLDs were calibrated at our center by the physicists against Co-60 telecobalt source (1.25 MeV average energy) for 10×10 cm field size at the isocentre (80 cm) with depth of 5 cm.

Diodes were irradiated for 10 consecutive fractions to check the reproducibility. TLDs were irradiated for 10 consecutive fractions to get significant thermoluminescent (TL) signal. TLDs were read 24 hours postirradiation with REXON (UL-320) reader (USA). The readings at the respective distance were recorded for both diodes and TLDs. The PD was estimated by taking the ratio of measured dose at the particular distance to the prescription dose. The prescription dose to PTV was in the range of 2-2.5 Gy. PD was then compared with diode and TLD for LINAC and tomotherapy. All PD values were normalized to the median dose of PTV.

Results

Table 1 shows PD for LINAC with TLD and diode for 10 patients. Mean PD for LINAC with TLD and diode was 2.52 cGy (SD 0.69), 2.07 cGy (SD 0.88) at 20 cm, respectively, while at 25 cm, it was 1.94 cGy (SD 0.58) and 1.5 cGy (SD 0.75), respectively.

Table 2 shows PD for tomotherapy with TLD and diode for 10 patients. Mean PD for tomotherapy with TLD and diode was 1.681 cGy SD 0.53) and 1.58 (SD 0.44) at 20 cm, respectively. The PD was 1.24 cGy (SD 0.42) and 1.088 cGy (SD 0.35) at 25 cm, respectively, for tomotherapy.

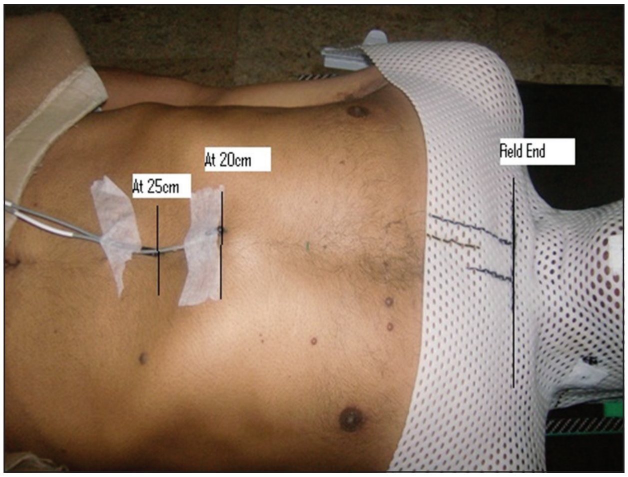

Figure 1: DPD-12 diodes placed on the patient's skin at 20 and 25 cm from the field edge

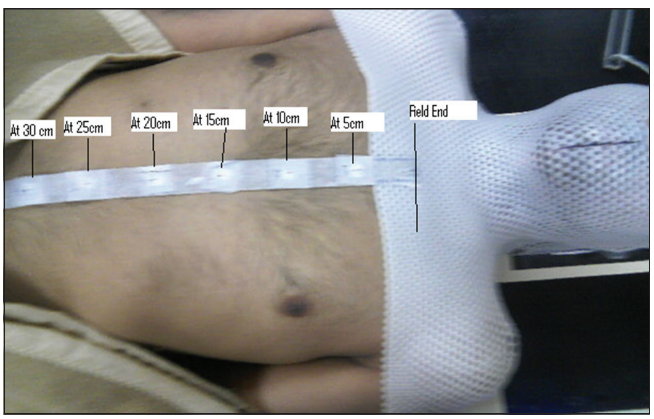

Figure 2: TLDs placed on the patient's skin from 5 to 30 cm at 5 cm interval from the field edge

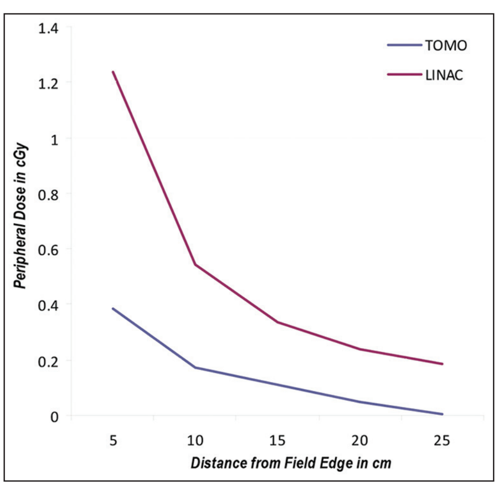

Figure 3: Peripheral dose with thermoluminescence dosimeter and diode for 10 patients undergoing linear Accelerator therapy [or tomotherapy] for 10 patients for various distances (5-25 cm) from the field edge

Figure 3 shows PD with TLD for LINAC and tomotherapy for 10 patients for various distances (5-25 cm) from the field edge. PD decreases with the distance from the field edge. The decrease in PD is larger at lesser distances (less than 15 cm) while it is smaller for the distances more than 15 cm. Overall, PD from tomotherapy was found less than LINAC. As can be seen in Figure 3, the PD from tomotherapy was a factor of 1.2-1.5 lower than that from the LINAC.

From the results, it has been observed that the tomotherapy PD approaches zero at 25 cm outside of the field. As the expectation would be an exponential fall off for scatter plus a constant leakage contribution. There could be many reasons for this and few perhaps may lead to conclude following statements: Considering all the factors for detectors and the machines.

- The tomotherapy machine has only three field sizes (1 × 40 cm, 2.5 × 40 cm, and 5 × 40 cm).

Table 1: Peripheral dose with thermoluminescence dosimeter and diode for 10 patients for linear accelerator at 20 and 25 cm

Patient #	*PD from TLD (cGy)*		*PD from diode (cGy)*	
	20 cm	*25 cm*	*20 cm*	*25 cm*
1	1.69	1.53	2.0	1.6
2	2.88	2.23	1.2	0.8
3	2.80	1.91	1.2	0.9
4	2.87	2.82	2.7	2.4
5	1.05	0.71	0.7	0.2
6	2.26	1.66	1.4	1.3
7	3.00	2.24	3.0	2.3
8	2.61	2.29	2.8	1.4
9	2.69	1.67	2.7	1.6
10	3.39	2.29	3	2.5
Mean	2.524	1.935	2.07	1.5
SD	0.69	0.58	0.88	0.75

Table 2: Peripheral dose with thermoluminescence dosimeter and diode for 10 patients for tomotherapy at 20 and 25 cm

Patient #	*PD from TLD (cGy)*		*PD from diode (cGy)*	
	20 cm	*25 cm*	*20 cm*	*25 cm*
1	1.72	1.40	2.0	1.6
2	0.9	0.7	1.2	0.8
3	2.11	2.05	1.8	1.7
4	1.78	1.28	1.5	1
5	1.75	1.17	1.5	0.9
6	1.23	0.78	1.4	1
7	2.69	1.67	2.4	1.2
8	1.00	0.82	0.8	0.5
9	1.83	1.23	1.5	1.08
10	1.8	1.34	1.7	1.09
Mean	1.68	1.24	1.58	1.088
SD	0.53	0.42	0.44	0.35

A 2.5 × 40 cm field size is quite often used for the patients. Further modulation in the beam is done by using high modulation factors from the multileaf collimator (MLC), which are 10 cm thick. The transmission through which is 0.3%, whereas in LINAC, it is usually in the order of 2-4%. Due to narrow beam geometry, fan beam modality and low MLC leakage, the PD was seen approaching zero rather.
- The detectors used in this study (both TLD and diode has limited sensitivity). Hence the readings at larger distances from the field edge might not have been truly grabbed by the detector. For this a high sensitivity detectors are required and another study is being carried out to rectify this issue and record actual and precise PD.

Discussion

The aim of this study was to measure PD for conventional (LINAC) radiation therapy (RT) technology and novel (tomotherapy) RT technology. In all experiments, the PD was measured on the patient's skin directly during the IMRT treatment with 6 MV X-rays. The data were always collected under similar experimental conditions to allow a systematic comparison of both the radiation type and delivery modalities. PD was measured with TLD and diode only in the longitudinal axis of the patient and not in the transverse axis.

A higher amount of MUs is necessary to deposit a homogeneous dose in a realistic tumor volume. Furthermore, both IMRT and tomotherapy require many more MU (up to a factor 3) than conventional therapy to deliver the same amount of prescribed dose to the tumor. This trend results in a higher exposure of the patient to leakage radiation. Three main sources can be identified as contributors to the PD in photon therapy: leakage in the beam head, scattering in the beam head, and scattering in the target. While the latter is unavoidable, the others can be minimized through optimization of the accelerator design.

Our study confirmed results from the Kaderka *et al.* study. Followill *et al.* measured PD with three modalities: conventional LINAC, Conventional LINAC IMRT, and LINAC-based tomotherapy. The authors reported higher PD for LINAC-based tomotherapy. Mutic and Low reported higher PD from LINAC-based tomotherapy (Peacoco/ MiMic, NOMOS, Inc., Sewickley, PA). PD was measured with TLDs in a water equivalent plastic phantom. Yet another study by Wiezorek *et al.*, reported the influence of different IMRT techniques on PD. They carried out the measurements with IMRT delivered with LINAC and tomotherapy. The authors also reported higher PD for tomotherapy compared with LINAC.

In contrast, the study by Ramsey *et al.* reported PD from helical tomotherapy to be lower than LINAC suggesting that even though the beam-on times are long, the helical tomotherapy unit produced less leakage. The authors measured the PD in a water-equivalent phantom resembling a human. Measurements were made by cylindrical ion chamber at distances 10-30 cm from the field edges.

In our study, PD for tomotherapy was lower than LINAC and one of the reasons could be the MLC transmission (0.3% for tomotherapy and 1.8% for LINAC) and hence less scatter in case of tomotherapy. Second reason could be the delivery method in tomotherapy and the finite field size. Thus, PD depends on technical equipment, on the technology, on inverse planning, and on the optimization modules to restrict the MUs.

Conclusion

PD measurement is crucial in the evaluation of potential of secondary cancer. PD for both conventional (LINAC) and novel LINACs (tomotherapy) were measured and compared with each other. The comparison of the values for PD presented in this work and those published in the literature is difficult because of the different experimental conditions. The diode and TLD readings were reproducible and both the detector readings were comparable. The agreement between the two detectors was within the standard deviations.

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