Original Article

Evaluation of the Lung Dose in Three-dimensional Conformal Radiation Therapy of Left-Sided Breast Cancer: A Phantom Study

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Abstract

Background: Three-dimensional 3D-CRT: conformal radiation therapy is a selective modality in many radiotherapy centers for the treatment of breast cancer. One of the most common side effects of this method is radiation lung injury. Considering such an injury, lung dose deserves to be studied in depth. **Methods:** Computed tomography scan of a node-positive left-sided breast cancer woman was used for generating a thorax phantom. Ten thermoluminescent dosimeters (TLDs) were distributed evenly in the left lung of the phantom, and the phantom was scanned. The optimal plan, including supraclavicular and tangential fields, was created by the treatment planning system (TPS). The results of TLD dose measurements at the selected points in the phantom were compared to TPS dose calculations. **Results:** Lung doses calculated by TPS are significantly different from those measured by the TLDs (P = 0.007). The minimum and maximum differences were −0.91% and 4.46%, respectively. TLDs that were on the inner margin of the lung and breast tissue showed higher dose differences than the TLDs in the lung. **Conclusion:** The results of this study showed that TPS generally overestimated doses compared to TLD measurements due to incorrect beam modeling caused by contaminated electrons in the lung.

Keywords: *Left-sided breast cancer, lung dose, phantom, three-dimensional conformal radiation therapy*

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Introduction

Breast cancer is one of the most common types of cancer in women worldwide.[1] It is often diagnosed at an early stage and treated with surgery, radiotherapy (RT), and systemic therapy.[2,3] Over the past decades, treatment modalities have evolved to deliver the highest dose to the tumor, while minimizing the radiation dose to normal tissues.[4] Recently, three-dimensional conformal radiotherapy (3D-CRT) and intensity-modulated RT (IMRT) have been adopted in RT centers for the treatment of breast cancer.[5]

In breast cancer RT, 3D-CRT is superior to IMRT because it uses less complicated techniques and minimizes the heart, lung, and contralateral breast dose.[6,7]

Lung dose assessment in breast cancer patients is challenging because of the deformities of the breast or chest wall[8] and the dose-dependent side-effects.[9,10] The importance of such an assessment increases in high-risk breast cancer women with lymph node involvement, where tangential and supraclavicular fields are merged and a large part of the lung is within the radiation volume.[11]

Thermoluminescent dosimetry (TLD) measurement is a reliable method for the verification of many dosimetric aspects of an external beam RT.[12] It is the gold standard dosimetry program recommended for quality assurance of machine calibration, planning dosimetry, and dose calculation.[13]

Several studies evaluated lung dose in cancer patients treated with RT. Butson *et al*.[14] calculated lung dose in an anthropomorphic phantom irradiated with the anterior–posterior field and compared treatment planning system (TPS) dose calculations with TLD dose measurements. Their results showed a 5% TPS dose-overestimation compared to TLD dose measurements. Similar results were found in a study by Davidson *et al*.[15] They

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compared lung dose in an IMRT plan with values measured by TLD chips placed in an anthropomorphic phantom. The results of their study showed that TPS overestimated dose levels 10%–15% compared to TLD dose measurements.

The aim of this study was to assess lung dose in left-sided breast cancer treated with 3D-CRT. The results of TLD dose measurements were compared at the same selected points in a thorax phantom with TPS dose calculations.

Methods

Study design

The 3D model of the phantom was generated using computed tomography (CT) images of a left-sided breast cancer patient with 3D-DOCTOR software [Figure 1]. According to ICRU Report Number 44,[16] polymethyl methacrylate with a mass density of 1.18 g/cm^3 has been used as normal tissue. The Cork, Plexi, and Teflon were used as lung, heart and spine simulating materials, respectively.

The phantom has several TLD-positioning holes at various locations [Figure 2]. The holes were numbered to enable dose assessment in the exact positions for each measurement. The dose was measured at different depths of the phantom, which would not be possible in *in vivo* dosimetry.

The phantom used in this study did not have any attachments as breasts because we only intended to compare two different measurement techniques.

TLD calibration

TLD chips used in this study were LiF (TLD-100, NE Technology) with a cross-section of 3 mm × 3 mm and a thickness of 0.9 mm. They are widely used because of their small size, their independent energy response in our study range (4 to10 MV), and their ability to provide high spatial resolution with acceptable precision.[17] They also determine actual doses administered at either skin or body cavities of patients undergoing RT.[18]

Initially, the TLDs were annealed in a TLD oven at 400°C for 1 h and then at 100°C for 2 h. For calibration, all TLDs were placed on a 1-mm Perspex slab and distributed within a 10 cm × 10 cm field at 100 cm source to surface distance (SSD), and a 5-cm slab was placed on top of the Perspex slab to create a build-up region. The 6-MV photon beam was delivered for TLD irradiation at a dose rate of 200 MU/min. The individual correction factor was then calculated by Eq. 1.

$$ICF = \frac{< TLD >}{TLD} \quad (1)$$

<TLD> and TLD are the average reading of the total TLDs and individual reading, respectively.

Afterward, the chips were divided into 5 groups. Four groups were exposed to 0.5, 1, 1.5, and 2 Gy, respectively, and the remaining group was used to measure the background dose. Batch calibration factor was then calculated by Eq. 2.

$$BCF = \frac{Dose}{CC_{dose} \times ICF} \quad (2)$$

BCF is the batch calibration factor (Gy/nC) and CC_{dose} (the correct count) is the TLD reading (nC). TLD dose (Gy) was calculated by Eq. 3 where BGD_{dose} (Gy) is the background dose.

$$Dose = \left[CC_{dose} \times BCF - BGD_{dose} \right] \times ICF \quad (3)$$

Finally, the chips were calibrated and read by an automatic double-channel reader (SOLARO 2A, NEC company) and annealed again for reuse.

Dose measurements

In the present study, ten TLD chips were evenly distributed throughout the left lung of the thorax phantom.

Accurate TLD placement is an important factor in determining the measured dose. A study by Herbert *et al.* showed that TLD positioning errors, caused by changes in the SSD, patient

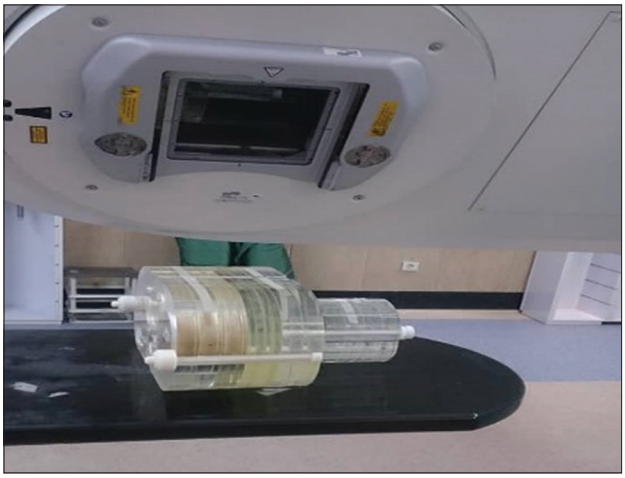

Figure 1: Phantom picture during breast radiotherapy

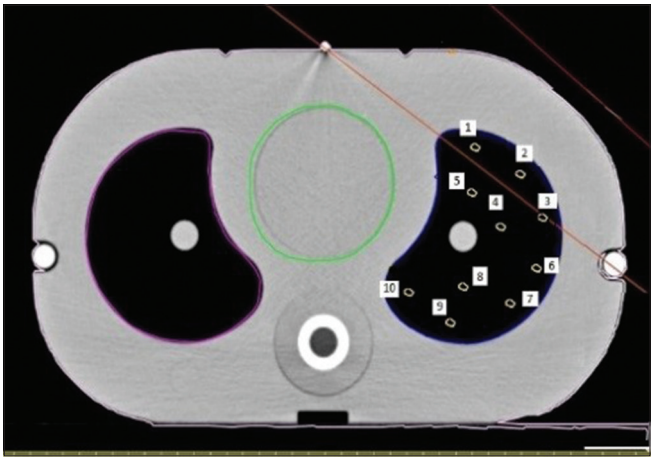

Figure 2: TLD positions on a computed tomography scan of a phantom

contour, and TLD response would lead to changes in the measured dose. To avoid TLD placement error, each set of TLD positions was repeated 3 times and the results were averaged.

The chips were placed in the phantom, and then, a CT scan was performed using an MDCT-64 (Siemens, SOMATOM Sensation). According to the RTOG breast contouring atlas,[19] the target and organs at risk including lung, heart, and spinal cord were contoured by the oncologist.

The images were transferred to TPS (TiGRT, LinaTech, China). The usual RT technique in breast cancer with lymph node involvement is two tangential opposing fields and two anterior–posterior supraclavicular fields. The phantom was irradiated by 6 MV photons with a total dose of 50 Gy, using the linear accelerator Siemens Primus. Finally, the TPS dose calculations, derived from the dose–volume histograms, were compared with TLD dose measurements.

Statistical analysis

Paired sample *t*-test was used to compare mean TLD and TPS dose. Statistical analysis was performed with SPSS 22.0 (SPSS, Chicago, IL, USA). *P* value of 0.05 was considered statistically significant.

Results

Mean TLD and TPS doses were 42.12 (SD = 13.22) and 43.26 (SD = 10.78), respectively. The TLD and TPS doses along with their mean differences, obtained by Eq. 4, are listed in Table 1 as separate columns.

$$\%\sigma = \frac{D_{calc} - D_{meas}}{D_{meas}} \times 100 \quad (4)$$

The results showed a significant difference between the mean doses (P = 0.007). The minimum and maximum difference were −0.91% and 4.46%, respectively. Higher dose differences were observed in the inner margin of the lung and breast tissue (TLD numbers 2, 3, 6, 7, and 8).

Discussion

Lung exposure is unavoidable in breast or chest wall irradiation, with or without regional lymph node involvement. This incidental exposure may increase the risk of subsequent lung damage, such as pneumonitis.

In breast cancer RT, 3D-CRT is superior to IMRT as it uses less complex techniques, reduces the lung dose,[6,7] and improves the conformity in the target volume.[20] Accurate

Table 1: Treatment planning system and thermoluminescent dosimeters dose in the lung

TLD number	TLD dose (Gy)	Mean TLD dose (Gy)	TPS dose (Gy)	Mean difference (%)
1	59.21	57.90	59.1	+2.07
	54.48			
	60.02			
2	61.18	60.57	63.2	+4.35
	60.67			
	59.85			
3	56.44	58.28	60.7	+4.15
	58.69			
	59.72			
4	49.32	52.28	51.8	−0.91
	58.14			
	49.37			
5	36.99	60.20	60.81	+1.02
	31.47			
	32.81			
6	58.31	33.76	34.9	+3.39
	62.15			
	60.13			
7	22.16	23.93	24.8	+3.65
	26.10			
	23.52			
8	34.25	32.07	33.5	+4.46
	31.54			
	30.42			
9	21.30	22.33	22.8	+2.09
	23.29			
	22.41			
10	19.06	19.84	20.4	+2.82
	18.86			
	21.60			

lung dose assessment is particularly challenging because of the breast or chest wall deformities[8] and dose-dependent side effects.[21] The purpose of this study was to evaluate the lung dose in left-sided breast cancer with 3D-CRT by comparing TLD dose measurements in a thorax phantom with TPS dose calculations.

Castro *et al*.,[22] according to the detailed analysis of the International Atomic Energy Agency,[23] assessed a 5.8% TLD uncertainty for the megavoltage photon beams. The final standard uncertainty of 5.8% is because of repetitive TLD measurement uncertainties, TLD and Linac calibration uncertainties, absorbed dose energy dependence, TLD positioning uncertainties, and energy-dependence corrections. In another study, Almond *et al*.[24] determined a 5% TLD readout uncertainty by considering repetitive TLD measurements of 2.2%, TLD calibration of 1.8%, TLD positioning uncertainty of 0.2%, and energy dependence correction of 0.8%.

McCullough and Krueger[25] and Van Dyk *et al*.[26] suggested that the acceptable difference between TPS dose calculations and TLD dose measurements for external photon beams is 5%.

The results of the current study showed a 5% TPS dose-overestimation compared to TLD dose measurements. The dose difference might be due to limitations of the TPS dose calculation algorithm in inhomogeneous regions like the lung,[18] inaccurate beam modeling caused by contaminated electrons in low-density regions like lung,[27] and inherent limitations of the TLD.[28] Another result showed that the TLDs that were on the inner margin of the lung and breast tissue (TLD numbers 2, 3, 6, 7, and 8) showed higher dose differences than the TLDs in the lung. Dose differences are due to large density differences caused by a greater range of electrons in the lung.[29]

Our results were consistent with those of other studies. Baird *et al*.[30] compared 3D-TPS dose calculations with TLD dose measurements in the lung and concluded that the measured and calculated dose differed because of the limitations of the TPS dose calculation algorithm in regions of inhomogeneities. In a study by Farhood *et al*.,[27] TPS dose calculations in the build-up region of the tangential field of the breast were compared with TLD measurements. The results of their study showed that TPS overestimated doses compared to TLD measurements. They reached a conclusion that the dose overestimation may be due to inaccurate modeling of the dose contributions from contaminated electrons and secondary scatter photons derived from the accelerator head.

In addition, Zhao *et al*.[31] showed a 3% TPS dose-overestimation compared to TLD dose measurements in a water phantom. Butson *et al*.[14] used a male anthropomorphic phantom and placed 1.5 mm solid water between each slab. The solid water increased the complexity of dose measurement and verification and produced a distortion in the results. They showed a 5% TPS dose-overestimation in 3D-CRT. Other studies showed greater dose-overestimations. Davidson *et al*.[15] used an anthropomorphic phantom with polyvinylchloride plates, a nylon heart, a polybutadiene spine, and a proprietary material representing lung tissue and indicated a 10% dose-overestimation in IMRT treatment. Aljarrah *et al*.[32] performed a study with a prefabricated lung phantom and reported a 20% dose-overestimation in the IMRT treatment. As was expected, the overestimation was larger for the IMRT treatment compared to the 3D-CRT because of the higher dose received by the lung.

In the future work, TPS dose calculations could be compared by another dose calculation algorithm such as Monte Carlo and dose calculations could be studied *in vivo* in patients.

Conclusions

The results of the current study showed up to 5% difference between dose measurements and calculations. TPS dose-overestimations were due to incorrect beam modeling caused by contaminated electrons in low-density regions like lung. Moreover, greater dose differences in the inner margin of the lung and breast tissue were as a result of large density variations.

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Conflicts of interest

There are no conflicts of interest.

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