Dosimetric impact of interplay effect in lung IMRT and VMAT treatment using in-house dynamic thorax phantom

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Abstract. Tumor motion due to patient's respiratory is a significant problem in radiotherapy treatment of lung cancer. The purpose of this project is to study the interplay effect through dosimetry verification between the calculated and delivered dose, as well as the dosimetric impact of leaf interplay with breathing-induced tumor motion in IMRT and VMAT treatment. In this study, a dynamic thorax phantom was designed and constructed for dosimetry measurement. The phantom had a linear sinusoidal tumor motion toward superior-inferior direction with variation of amplitudes and periods. TLD-100 LiF:Mg,Ti and Gafchromic EBT2 film were used to measure dose in the midpoint target and the spinal cord. The IMRT and VMAT treatment had prescription dose of 200 cGy per fraction. The dosimetric impact due to interplay effect during IMRT and VMAT treatment were resulted in the range of 0.5% to -6.6% and 0.9% to -5.3% of target dose reduction, respectively. Meanwhile, mean dose deviation of spinal cord in IMRT and VMAT treatment were around 1.0% to -6.9% and 0.9% to -6.3%, respectively. The results showed that if respiratory management technique were not implemented, the presence of lung tumor motion during dose delivery in IMRT and VMAT treatment causes dose discrepancies inside tumor volume.

1. Introduction

The utilization of radiotherapy modality in IMRT treatment and the newest modality such as VMAT treatment are widely applied in radiation oncology. Modern linear accelerator is able to modulate radiation beam dynamically and create dose distribution by steep dose gradient that is enable to increase sparing dose on the organ at risk and escalate dose in tumor target [1]. Nowadays, IMRT and VMAT treatment have been widely used in Non-Small Cell Lung Cancer (NSCLC) treatment [2, 3].

Radiotherapy complexity of IMRT and VMAT treatment correlates with several uncertainties [4]. Those can lead to inaccuracy of given dose and has implication in tumor control, morbidity and toxicity treatment [5]. Quality assurance in radiotherapy treatment planning process is very important to ensure the dose calculation is carried out precisely and accurately, as well as minimize the possibility of radiation accident occurrence [6, 7].

The presence of tumor motion driven by patient breathing [8], further limits the maximum dose deliverable to the tumor volume, as an additional margin is generally assigned around the tumor volume to encompass the entire range of tumor motion. This significantly increases the total irradiated volume of normal lung tissues. In addition, the presence of tumor motion during dose delivery can generate unwanted dose discrepancies inside the tumor volume [9].

The aim of this study was to evaluate the dosimetric accuracy between planning dose and measured dose for lung treatment, as well as the possible interplay between MLC motion and tumor motion in IMRT and VMAT treatment using an in-house dynamic thorax phantom.

2. Materials and methods

The experiment was performed using a specially designed dynamic thorax phantom, calibrated TLD-100 LiF:Mg,Ti and Gafchromic EBT2 detectors, calibrated RapidArc Clinac® iX Linac, and Eclipse treatment planning system ver. 11.0. In this study, the following constraints were the tumor target could be moved only in superior-inferior direction and the experiment was performed for point dose measurement at midpoint the tumor target.

2.1. Development of in-house dynamic thorax phantom

A dynamic thorax phantom was constructed to simulate lung tumor motion. Phantom material made from local materials consisting of acrylic (ρ = 1.10 g/cm^3), cork (ρ = 0.22 g/cm^3), teflon (ρ = 1.88 g/cm^3), and polyethylene (ρ = 0.98 g/cm^3) to simulate soft tissue, lung, bone, and baseplate respectively. Phantom was dedicated the human ordinary thorax in term of structure, proportion and composition with oval shaped the phantom size of 19.5 × 30.9 × 20.1 cm^3. A rod equivalent to lung tissue with a diameter of 5.4 cm contains a spherical shaped target with a volume 19.7 cc (diameter of 3.35 cm) is represented tumor target.

Tumor motion was simulated along superior-inferior direction to simulate the respiratory-induced tumor motion. TLDs and EBT2 films can be placed inside the spherical target. The amplitude and period of motion were designed to be adjusted in static mode, 9.3 mm and 2.3s, 20 mm and 3.44s, and 30 mm and 4.22s, which was driven by a DC motor. Using these parameters, the experiment was able to mimic various clinical situations like amplitude and frequency (period) of the tumor motion. The literature stated that the average breathing cycle of lung tumor motion is of amplitude ±2 cm and a frequency of 12-17 cycles/minute (period of 3.5s to 5s). The speed control circuit in the phantom was tuned so that the abovementioned criteria were met.

2.2. IMRT and VMAT dose planning

CT images of the phantom were acquired with a target in static position using Philips Brilliance CT Simulator with a slice thickness of 3 mm. The image series were transferred from the CT control station to the treatment planning system server through the DICOM radiotherapy planning network for planning. After CT data series of the phantom was received by TPS, tumor target, and critical organs were contoured on the acquired CT images.

The CTV was defined to be the GTV plus a 0.5 cm margin as appropriate to account for microscopic tumor extension and then the ITV plus 0.5 cm was added to the ITV to form the CTV. A margin of 0.5 cm was given to simulated IM in the inferior-superior direction and an additional set-up margin of 0.5 cm. Thus, the total PTV includes the CTV plus a total margin of at least 1.5 cm to the superior-inferior dimensions and at least 1.0 cm in the axial plane [10].

IMRT and VMAT plans were created with the Eclipse treatment planning system version 11.0. The plans were generated and delivered based on x-ray photon beam 6 MV from a Varian RapidArc Clinac® iX Linac with a Millennium MLC (spatial resolution of 10 mm at isocenter). All dose calculations with a grid resolution of 2.5 mm using the Eclipse AAA were performed, taking into account heterogeneity correction. TPS dose planning applied dose prescription (95%) for a total dose of 6000 cGy and 30 fractions (200 cGy per fraction). For optimization, seven irradiation fields for IMRT treatment with gantry rotation for 15o each was used, whereas VMAT treatment utilized RapidArc double partial arc with gantry arc from 181o CW 20o and 20o CCW 181o are shown in figure 1. The approved plan was then transferred to the RapidArc treatment linear accelerator unit.

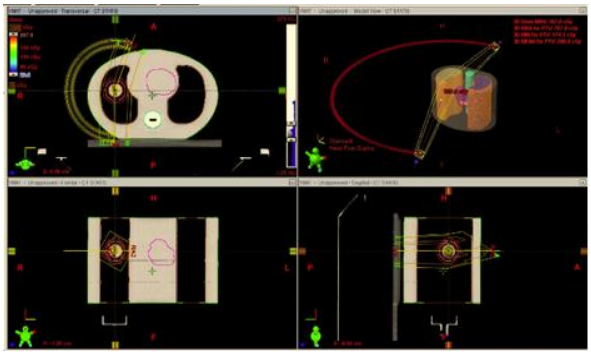

Figure 1. Planning of the dynamic phantom which shows the cross-sectional images of the phantom and field setup.

Figure 2. Irradiation technique of the dynamic thorax phantom for both IMRT and VMAT technique.

2.3. Dose measurements

The phantom assembly was positioned on the Varian RapidArc Clinac® iX Linac as if it was positioned during CT image acquisition. TLDs and gafchromic EBT2 films were inserted in tumor target and spinal cord of the thorax phantom. The phantom was irradiated by x-ray photon beam 6 MV using IMRT and VMAT techniques. The dosimetry measurement methods are presented in figure 2.

Gafchromic EBT2 films were scanned at least 48 hours after the irradiation using an Epson V700 flatbed scanner (Seiko Epson Corp., Suwa, Japan) with a resolution 72 DPI and it was stored in TIFF format. Furthermore, the pixel values were measured using FilmQA Pro and ImageJ software in the red channel, whereas TLDs were measured at least 48 hours after the irradiation using Harshaw M3500 TLD reader which integrate with WinREMS software. The dose difference (Δ%) of measured dose (Dmeas) and planned dose (Dplan) was calculated as

$$\left(\left(\boldsymbol{D}_{meas}-\boldsymbol{D}_{plan}\right)/\boldsymbol{D}_{plan}\right)*100$$

3. Results and discussion

Based on TPS dose calculation with prescribed dose of 200 cGy, PTV dose of IMRT treatment were resulted in the range of 161.4 cGy to 210.2 cGy (mean dose of 200 cGy), while PTV dose of VMAT treatment were in the range of 174.3 cGy to 207.9 cGy (mean dose of 200 cGy). Furthermore, the spinal cord of IMRT treatment were in the range of 0.3 cGy to 51 cGy (mean dose of 8.8 cGy), whereas for VMAT treatment were 0.3 cGy to 49.9 cGy (mean dose of 10.3 cGy).

The point dose measurement in lung tumor target at static and dynamic condition of IMRT and VMAT treatment using TLDs and gafchromic EBT2 film are presented in figure 3, which indicated that mean dose of tumor target decreases with increasing of tumor target amplitude. A decrease dose of tumor volume is possibly caused by interplay effect, where only a fraction of the PTV is irradiated at any given time [11]. According to McCarter and Beckham, the interplay effect is caused by the combination of the intra-fraction target motion and the beam motion which generates variations of the dose in each voxel [12]. On the other hand, the mean dose of the spinal cord is below the dose calculated TPS for both IMRT and VMAT treatment as illustrated in figure 4.

Mean dose deviation of tumor target between TPS calculation and measurement in IMRT treatment by tumor target moves at condition of static, 9.3 mm, 20 mm and 30 mm were 0.3% to 0.5%, -2.7% to -3.0%, -3.7% to -4.6%, and -6.0% to -6.6% respectively while dose deviation in VMAT treatment were 0.2% to 0.9%, -1.6% to -1.9%, -2.9% to -3.1%, and -5.0% to -5.3% respectively. On the other hand, mean dose deviation of the spinal cord in IMRT treatment were -5.6% to -1.0%, -6.8% to -6.9%, -3.7% to -5.9%, and 0.7% to 1.0% respectively and in VMAT treatment were -1.4% to -3.1%, -3.0% to -6.3%, -1.6% to -4.2%, and 0.1% to 0.9% respectively.

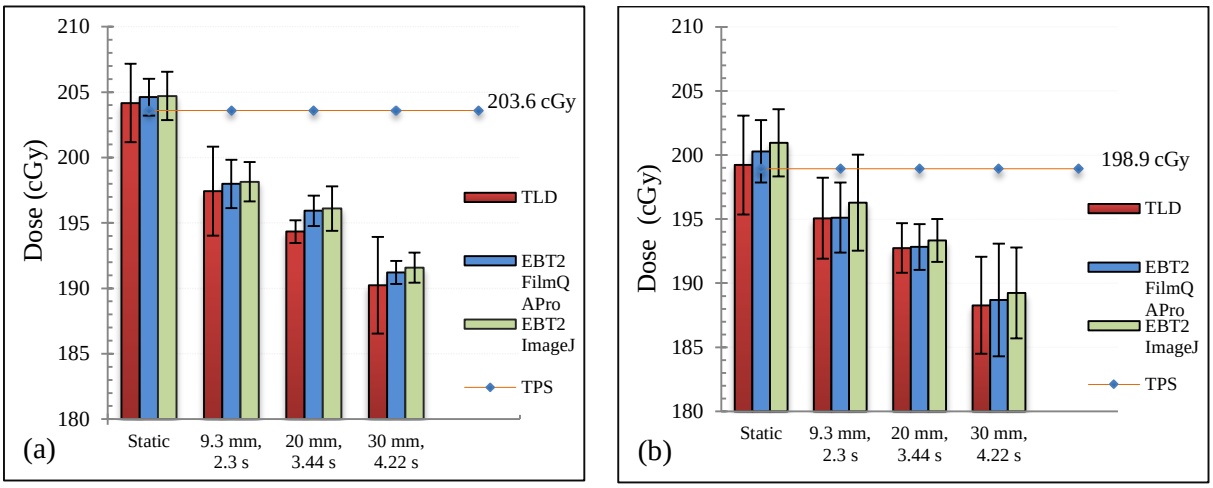

Figure 3. Ratio of mean dose in tumor target (a) IMRT treatment; (b) VMAT treatment.

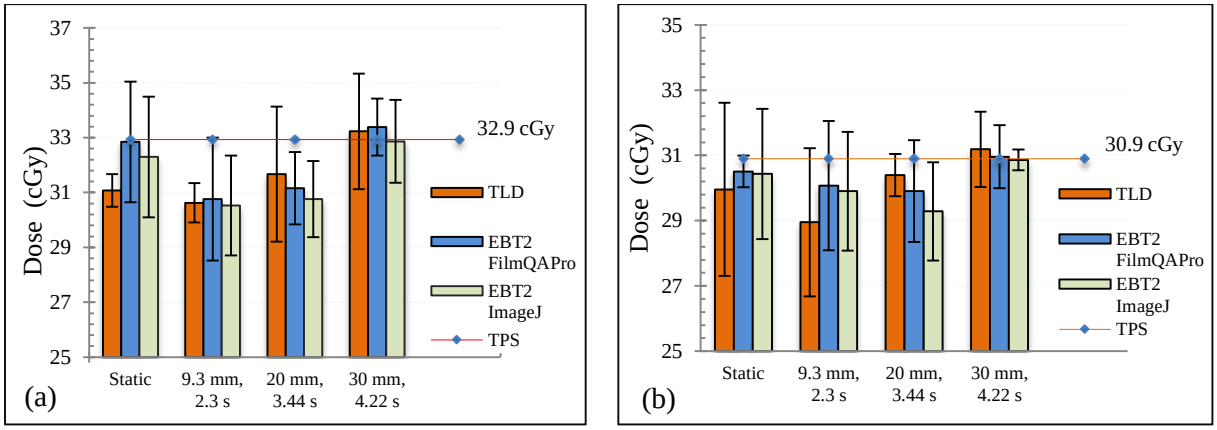

Figure 4. Ratio of mean dose in spinal cord (a) IMRT treatment; (b) VMAT treatment.

According to this experiment result, the interplay effect causes dose discrepancies inside the target, both in IMRT and VMAT treatment. This result is in accordance with previous experimental research by Jiang *et al*., Berbeco *et al*., Boopathy *et al*., Ong *et al*., and Ceberg C *et al*., which stated that interplay effect will cause unwanted dosimetry effect [13-17].

The mean dose deviation are relatively higher than previous research of Jiang *et al*., Berbeco *et al*., Ong *et al*., and Ceberg C *et al*., this might be contributed from material deviation of the phantom, for instance density value and CT number (HU), Linac photon output deviation and the phantom mechanical are required for further development in term of its motion accuracy. Contrary, mean dose deviation percentages are relatively lower than previous research by Boopathy *et al*., in which its deviation was in the range of 5 to 10%.

Patient respiratory cycle demonstrated the complex pattern, in which amplitude and period tumor motion are altering continuously during irradiation. The motion of tumor position is induced by lung tidal volume alteration as time function [18, 19]. Mathematically, human respiratory is non-stationary circumstance and difficult to be modeled [18].

This investigation can be considered as preliminary research to evaluate lung tumor target motion effect at dose received by tumor target using dynamic thorax phantom by modeling lung tumor motion due to respiratory, as tumor target merely moves along superior-inferior and dose measurement was only performed in the midpoint target. Therefore, a further experiment is required for measurement in the peripheral target.

4. Conclusions

The results indicated that the presence of tumor motion during dose delivery can generate unwanted dose discrepancies inside the tumor volume. The percentage of dose discrepancy for tumor target of tumor motion static, 9.3 mm and 20 mm are closed to tolerance level, while the tumor motion of 30 mm could not meet tolerance level criteria of ICRU (+7% to -5%) and AAPM (±5%) recommendation.

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