

Dose profile measurements during respiratory-gated lung stereotactic radiotherapy: A phantom study

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Abstract. During stereotactic body radiotherapy, high radiation dose (~60 Gy) is delivered to the tumour in small fractionation regime. In this study, the dosimetric characteristics were studied using radiochromic film during respiratory-gated and non-gated lung stereotactic body radiotherapy (SBRT). Specifically, the effect of respiratory cycle and amplitude, as well as gating window on the dosimetry were studied. In this study, the dose profiles along the irradiated area were measured. The dose profiles for respiratory-gated radiation delivery with different respiratory or tumour motion amplitudes, gating windows and respiratory time per cycle were in agreement with static radiation delivery. The respiratory gating system was able to deliver the radiation dose accurately (± 1.05 mm) in the longitudinal direction. Although the treatment time for respiratory-gated SBRT was prolonged, this approach can potentially reduce the margin for internal tumour volume without compromising the tumour coverage. In addition, the normal tissue sparing effect can be improved.

1. Introduction

Stereotactic body radiotherapy (SBRT) refers to hypofraction radiotherapy where high radiation dose (~60Gy) was delivered in small fractionation regime [1]. Treating a lung tumour is a challenging task because of the moving tumour due to the respiratory motion. Erridge *et al.* has reported a mean range of lung tumour motion of 12.5 mm in superior-inferior (S-I) direction [2]. Another study also found that tumour motion of 5.8 mm in S-I direction [3]. According to AAPM Task Group 76, it was recommended that tumour with motion more than 5 mm should be treated with gating or tracking method [4]. This is so that the involvement of normal tissue with high dose can be reduced without compromising the coverage of the moving tumour [5].

In this work, we studied the dose profiles during respiratory-gated SBRT on a gating phantom. Specifically, the effect of respiratory or tumour motion amplitudes, respiratory cycle times and gating window on the dosimetry was studied. In addition, the tracking accuracy of the gating system was assessed.



2. Materials and methods

A linear accelerator (Novalis Tx, Varian Medical System, Palo Alto, CA) equipped with BrainLAB Exactrac gating system and BrainLAB ET Gating Phantom (BrainLAB AG, Heimstetten, Germany) were used in this study. A detailed description of the BrainLAB Exactrac gating system can be found in Tenn *et al.* [6].

A $15 \times 15 \times 15$ cm³ Perspex phantom embedded with a 7.5 mm diameter spherical fiducial marker at the centre was mounted on the gating phantom [figure 1(a)]. The fiducial marker represented the position of the target tumour during irradiation. The phantom was set to move and mimic normal respiratory pattern. The horizontal motion mimicked the lung tumour motion in the S-I direction. The vertical motion mimicked the chest wall motion due to respiration.

Five infrared (IR) markers were used as surrogates on the phantom to track the respiratory motion for the gated-radiation delivery. In this study, a sine function was used to simulate the respiratory pattern [figure 1(b)], and no offset was set between the vertical and horizontal motion of the phantom [figure 1(a)]. The radiation was delivered only at the exhalation phase within the gating window.

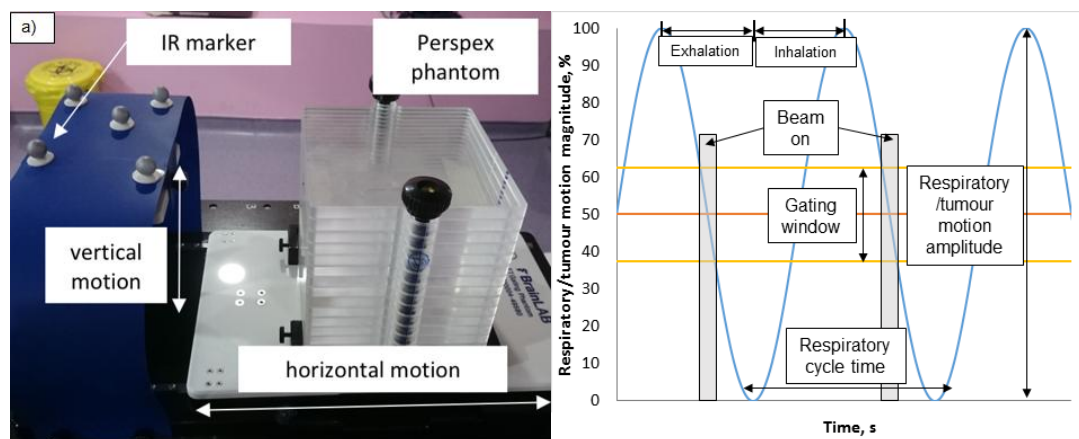


Figure 1. (a) The BrainLAB ET gating phantom and (b) respiratory and tumour motion as a sine function. The dashed line shows the level of the gating and the solid line shows the upper and lower levels (20% gating window) of the gating window (beam on area). The shaded bars show the beam on time during a gated radiation delivery.

2.1. Calibration

Gafchromic EBT2 film (International Specialty Products, Wayne, NJ) was calibrated under a reference condition (1.5 cm depth, 100 cm source-to-surface distance and 10×10 cm² field size) with 6 MV photon beam and dose rate of 1000 MU min⁻¹.

Gafchromic EBT2 film was cut into strips with dimensions of 10×2 cm². The films were scanned with Epson 10000XL scanner (Epson America, Inc. Long Beach, CA) 24 hours post-irradiation. Details of the scanning parameters were described by Jong *et al.* [7]. The image were analysed using ImageJ 1.49v software (National Institute of Health, Bethesda, MD).

2.2. Dose profile measurement

A piece of Gafchromic EBT2 film was placed at depth of 8 cm (below the fiducial marker) in the Perspex phantom. The films were irradiated with 300 MU under 6 MV photon beam with a radiation field size of 5×5 cm² and 1000 MU min⁻¹ at the end of exhalation as in figure 1(b).

The dose profiles for different (i) respiratory amplitudes (0%, 25%, 50%, 75% and 100%, where 100% is the total movement of 25 mm), (ii) respiratory times for a full respiration (3 and 5 seconds) and (iii) gating windows (10% and 20%) were measured. All dose profiles were compared with non-gated delivery (static and moving target).

2.3. Tracking accuracy

The accuracy of gated radiation deliveries was studied by assessing the displacement of the projection of the fiducial marker on the film (shown as a 'dip' in the dose profiles). The position of the lower dose of the fiducial marker's projection was considered as the centre of the target. The position of gated radiation deliveries was compared with the static delivery.

3. Results and discussions

The Gafchromic EBT2 film was calibrated from the dose range of 0 cGy to 300 cGy. The centre of the Perspex phantom was marked on the Gafchromic EBT2 films before irradiation to allow better accuracy in comparison. All measurements with Gafchromic EBT2 film were normalised at the maximum dose. All measurements during gated radiation deliveries were benchmarked against static radiation delivery.

3.1. Dose profiles of gated-lung SBRT

The dose profiles in the longitudinal direction (moving direction) were measured with Gafchromic EBT2 films. The lung tumour motion has been found to be quite substantial along this direction [3]. The 'dips' near the middle of the radiation beam profiles in figure 2(a)-(d) were due to the presence of the spherical fiducial marker. The 'dip' was also used to indicate the position of the tumour.

Figure 2(a) shows the EBT2 measured dose profiles with different respiratory amplitudes. The respiratory-gated dose profiles for different amplitudes of tumour motion were in good agreement with the static radiation delivery. The mean difference for gated dose profile with 0% tumour motion amplitude was 0.02% (range from -10.0% to 9.33%) while for 100% tumour motion amplitude was 1.16% (range from -8.22% to 11.31%).

Figure 2(b) shows the dose profiles with different gating windows and figure 2(c) showed the dose profiles with different respiratory times per cycle. A previous study reported that the dosimetric error increases with increasing gating window size during respiratory-gated radiotherapy [8]. However, no significant difference was observed with different gating windows in this study. This is due to the small area of radiation delivery [figure 1(b)].

The respiratory time per cycle simulated different respiratory or tumour speed [figure 2(c)]. There were no significant difference in gated radiation delivery for different respiratory times per cycle. The gating window was set based on the respiratory or tumour motion amplitude. This result is consistent with the result obtained by Shiinoki *et al.* [9].

Figure 2(d) shows non-gated radiation dose deliveries while the tumour is moving, simulating free-breathing SBRT without gating. When the tumour motion amplitude increased, the dose profile was degraded [left area of the dose profiles in figure 2(d)] and blurring effect was observed on the dose profile due to respiratory motion [right area of the dose profiles in figure 2(d)]. This indicates that tumour coverage may be compromised whilst more healthy tissues were irradiated unnecessarily. Conventional method of dealing with the inadequacy of tumour coverage involves a larger tumour margin to ensure better tumour coverage but on the expense of higher normal tissue complications. With gating, tumour margin can be reduced for tumour motion [5].

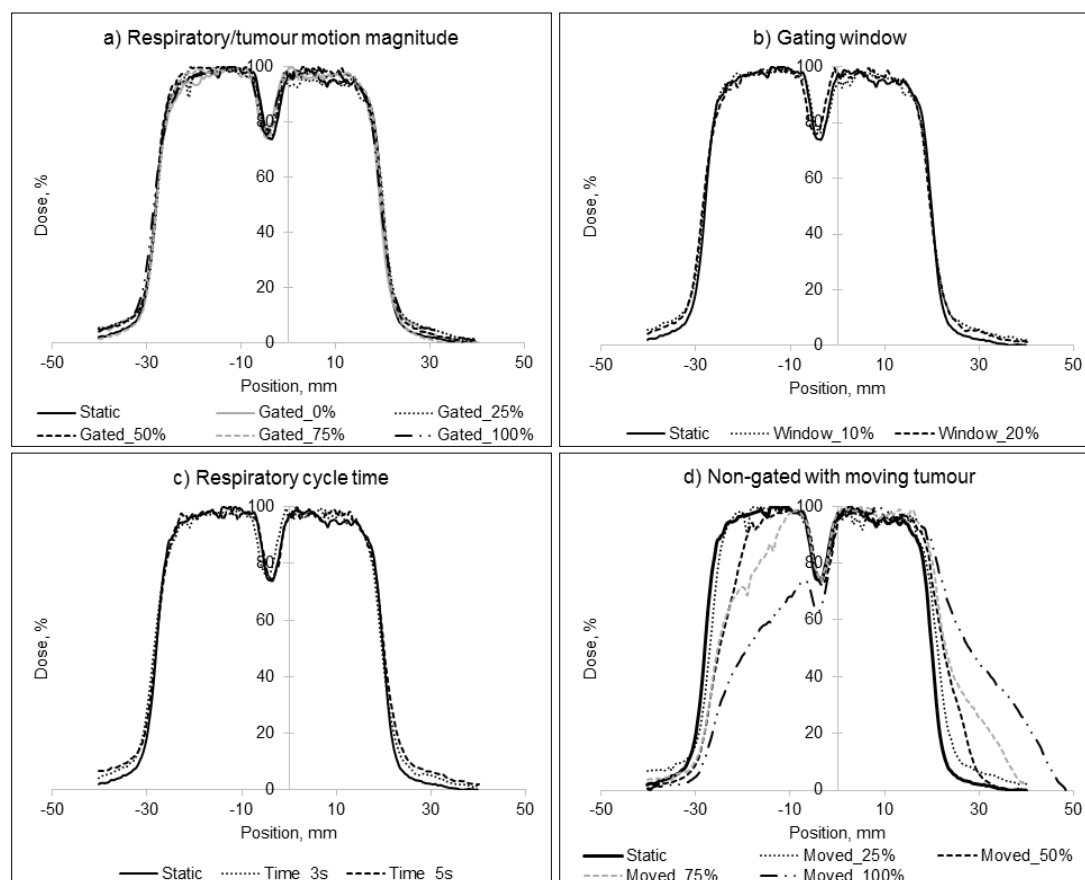


Figure 2. The dose profiles during gated radiation delivery with different (a) respiratory/ target motion amplitude, (b) gating windows, (c) respiratory cycle time, and (d) non-gated radiation delivery with moving target. All measurements were compared with static radiation delivery. The ‘dip’ in the middle of the dose profiles were caused by the shadowing effect of the fiducial marker.

3.2. Tracking accuracy

Table 1 shows the measured displacement of the fiducial marker between gated and static deliveries. Tenn *et al.* has reported a difference of approximately 1.0 mm in position between gated and non-gated radiation delivery at 10% gating level [6]. Willoughby *et al.* has reported the accuracy of 1.7 mm of the Exactrac system on phantom studies [10]. In this study, the maximum displacement of target was -1.05 mm and is in agreement with the previous studies. The result showed that the system is able to deliver the radiation with an accuracy of within -1.05 mm.

Table 1. Measured displacements of fiducial marker during respiratory-gated radiation delivery to the static radiation delivery.

Displacement (mm)		Displacement (mm)	
Amplitude		Time	
0%	-1.05	3 sec	-0.78
25%	0.01	5 sec	0.01
50%	-0.25	Gating windows	
75%	-0.78		
100%	-0.78		
		10%	0.37
		20%	-0.78

4. Conclusion

The respiratory gating system was able to track the respiratory and tumour motion with different amplitudes and speed and was able to deliver the radiation dose accurately (± 1.05 mm) in the longitudinal direction. Although the treatment time for respiratory-gated SBRT was prolonged, this approach can potentially reduce the margin for internal tumour volume without compromising the tumour coverage. In addition, the normal tissue sparing effect can be improved.

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Acknowledgments

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