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Dosimetric impact of a change in breathing period on VMAT stereotactic ablative body radiotherapy

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Abstract. The dosimetric impact of a change in breathing period during treatment was assessed for a volumetric modulated arc therapy (VMAT) stereotactic ablative radiotherapy (SABR) lung plan optimized according to our centre's planning protocol. Plan delivery was evaluated at three breathing rates ranging from 7 to 23 breaths-per-minute (BPM) against the planning anatomy (15 BPM) calculated dose. Dynamic ion chamber, EBT3 film and Fricke-xylenol orange-gelatin (FXG) gel measurements were acquired using a motion phantom with appropriate inserts for each dosimeter. The results show good agreement between measured and calculated plan dose within the internal gross tumour volume (IGTV) target.

1. Introduction

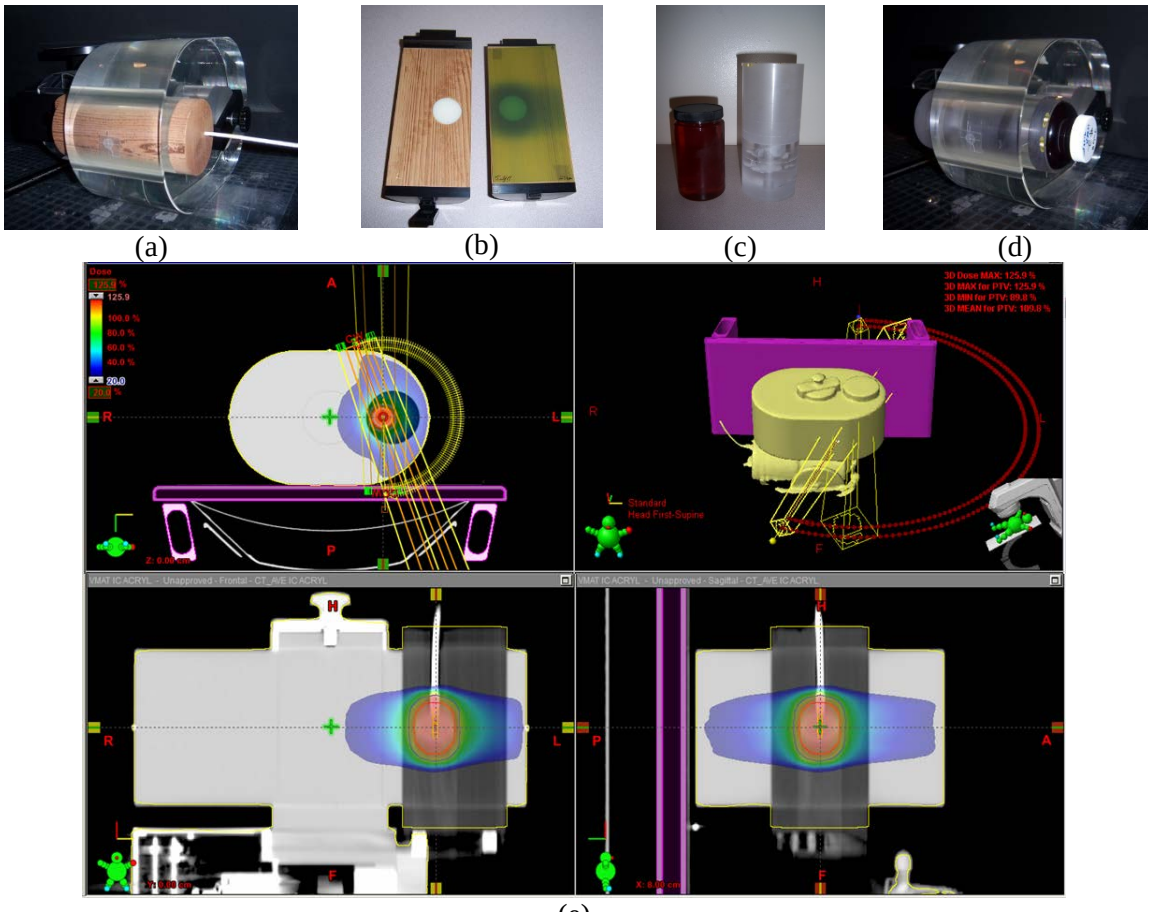
There has been a steady increase in the number of patients treated at our centre using the lung VMAT SABR technique since its adoption. Poor pulmonary function is a major reason for choosing radiation treatment over surgery in treating early stage (Stage I, T1/2, N0, <5 cm), non-small cell lung cancer. One of the associated challenges is that these patients often have a hard time maintaining regular breathing both at the time of 4DCT imaging and on treatment. The change in breathing amplitude can be monitored to some degree by assessment of the internal gross tumour volume (IGTV) via CBCT imaging at the time of treatment as compared to the planning CT IGTV [1]. However, breathing rate is not actively monitored during treatment for the motion-encompassing treatment technique used at our centre. Variations ranging from 7 up to 40 breaths-per-minute (BPM) have been observed at the time of planning CT, though most patients are reasonably consistent in breathing in the 10-20 BPM range.

Previous studies have looked at the dosimetric effects that accompany a change in breathing pattern, including ion chamber [2] and 2D film measurements for 3D conformal deliveries and ion chamber measurements for VMAT deliveries [3, 4]. Our centre's VMAT SABR planning approach aims to minimize the motion of the multi-leaf collimator (MLC), keeping an open beam aperture around the planning target volume (PTV) during delivery in order to produce the desired dose distribution and reduce the effects of interplay [5] in the delivery. However, limited MLC motion is allowed within the PTV volume (beam's eye view) for plan optimization, which raises a greater possibility of dosimetric variations with change in breathing rate compared to open aperture 3D conformal deliveries. The purpose of this work is to evaluate the impact of a change in breathing rate (period) on our centre's VMAT SABR technique using different dosimetric modalities in a similar manner as before [6], including 0D ion chamber, 2D EBT3 Gafchromic film, and 3D FXG gel dosimetry.

2. Materials and Methods

2.1. Delivery Validation

The dosimetry tools used for delivery validation in this investigation were: a) point single ion chamber (PR-05P 0.07 cc, Capintec, Ramsey, NJ), b) 2D Gafchromic EBT3 film (ISP, Wayne, NJ), and c) 3D FXG gel dosimeter with optical CT readout [6]. Dynamic 4D computed tomography (4DCT) scans were acquired of a Quasar motion phantom (Modus Medical Devices Inc, London, ON, Fig. 1a) with a cedar insert containing a 3 cm diameter acrylic sphere 'tumour' and a hole for insertion of the ion chamber. A Philips Brilliance Big Bore CT scanner (Philips Medical Systems, Cleveland, OH) was used for CT data acquisition, with the addition of a bellows motion tracking system for 4DCT phase binning. A similar cedar insert was used for the EBT3 film (Fig. 1b). The scans were then repeated with a custom gel insert (Fig. 1c) in the Quasar phantom (Fig. 1d). A 10 mm peak-to-peak amplitude 15 BPM sinusoidal breathing cycle was used for all 4DCT scans. This 10 mm amplitude was chosen as it is the limit for inclusion in the associated SABR clinical trial that our centre participates in.



(a) (b) (c) (d)

(e)

Figure 1. (a) Quasar motion phantom with ion chamber insert, (b) photo of cedar film insert with overlaid EBT3 film from dynamic delivery, (c-d) gel insert and FXG gel in Quasar phantom, and (e) Eclipse screen capture of the high monitor unit dynamic ion chamber plan used in this study.

For VMAT SABR planning, dual coplanar clockwise/counterclockwise 6MV partial arcs were employed, extending from just outside the approximated edge of the contralateral lung anteriorly to 180 degrees posteriorly (Fig. 1e). The collimator angle on the two arcs was set to ±30 degrees to minimize discrepancies arising from the interplay effect [5]. A RapidArc™ VMAT plan was optimized and calculated in Eclipse™ v.10 (Varian Medical Systems, Palo Alto, CA) on the 2 mm slice thickness

4DCT-derived average scan of the film-Quasar phantom. The plan had a target objective placed on the total number of monitor units (MU) in the optimization stage of treatment planning to limit MLC motion and realize open MLC apertures throughout the arc. This plan was then re-calculated (but not re-optimized) on the ion chamber and gel 4DCT-derived average phantom datasets. The film and ion chamber plans were normalized to a prescription dose of 2 Gy (100% prescription dose covers 95% of PTV target volume), while the gel plans were re-normalized (i.e. monitor units scaled down) to a prescription of 1.8 Gy to accommodate the optimal range for FXG gel dose readout accuracy. A screen capture of the ion chamber plan is shown in Figure 1e.

All treatment plans were delivered on a Varian Trilogy 2100iX linear accelerator (Varian Medical Systems, Palo Alto, CA), with Advanced OBI™ imaging cone beam CT (CBCT) setup verification. Each dose measurement was compared against calculated Eclipse treatment planning system (TPS) dose using software appropriate for that QA tool. EBT3 film measurements were acquired using an in-house built CCD-lightbox film scanner and analyzed in MATLAB (Mathworks, Newark, NJ). The reconstructed, calibrated gel dose data from the Vista™ optical CT scanner (Modus Medical Devices Inc., London, ON) was compared to Eclipse dose in 3D Slicer [7] (www.slicer.org).

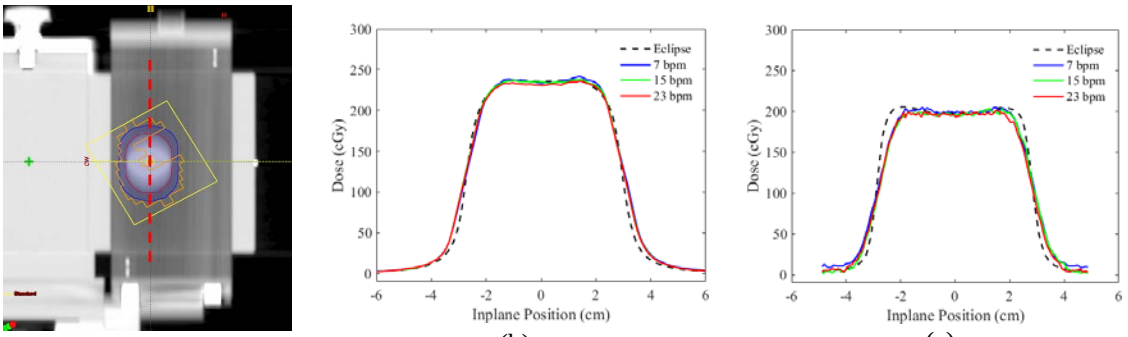
3. Results

3.1. Dosimeter-Plan Dose Comparison

Results for the dosimeters used in this work are summarized in Table 1. The reported ion chamber values are the average of 5 readings. Point measurements are in similar agreement with Eclipse as previous work [6]. 2D Film and 3D gel results in Table 1 are reported for gamma comparison within the IGTV volume. These results are consistent with the point ion chamber readings, although the gel measurements were lower than expected along the motion direction near the edges of the IGTV.

Table 1. Summary: measured vs. Eclipse doses.

Dosimeter	Breathing Rate (BPM)	Prescription (Gy)	Point Dose Difference (%)			% Gamma ≤1 (3%/3mm)
			CW Arc	CCW Arc	Total	
Ion Chamber	7	2	99.4 ± 0.9	98.7 ± 0.1	99.2 ± 0.6	-
Ion Chamber	15	2	99.2 ± 0.3	98.9 ± 0.1	99.0 ± 0.2	-
Ion Chamber	23	2	99.3 ± 0.4	98.8 ± 0.1	99.1 ± 0.2	-
EBT3 Film	7	2	-			94.7
EBT3 Film	15	2	-			99.5
EBT3 Film	23	2	-			94.5
FXG Gel	7	1.8	-			95.9
FXG Gel	15	1.8	-			95.1
FXG Gel	23	1.8	-			85.3



(a) (b) (c)

Figure 2. (a) Eclipse screen capture of the film plan with red dashed line along axis of motion showing location of profile measurements for the (b) EBT3 film and (c) FXG gel deliveries.

4. Discussion & Conclusions

With reference to the results summarized in Table 1, a negligible variation was observed in mean value of the ion chamber measurements from the different breathing rate deliveries. However, the standard deviation in ion chamber readings was noticeably higher for the 7 BPM delivery, and in particular, the clockwise arc. This is related to the fact that there is more MLC motion within the PTV for this arc (orange outline in Fig. 2a shows the MLC aperture with the great incursion into the PTV outline on beams-eye view). For the slower BPM tumour motions, there is greater potential for the ion chamber to spend an increased fraction of the delivery time either directly behind the MLC leaves or not blocked by the MLC leaves, depending on the starting point of the motion. This leads to greater variability in ion chamber readings. The standard deviation on the point dose was observed to be on the order of 1% at the lower BPM, so the result is not clinically significant. However, it does show that limiting the MLC motion during plan optimization reduces day-to-day variability in the dose delivery. The 2D film results show good agreement with Eclipse. The 7 bpm film dose profile in Figure 2b shows some evidence of the variability introduced by tumour motion at slower breathing rates, with the dose being greater than the Eclipse dose on the right side of the central axis profile and less than the Eclipse dose on the left side of the profile. The gel results (Table 1, Fig. 2c) show evidence of the effects of diffusion, with the gradients at the edges of the dose distribution being less than expected. This leads to a reported larger dose difference between Eclipse and gel in these regions and lower IGTV volume gamma agreement. Even with this effect being present, the relative comparison of 3D gel results to each other at the different breathing rates still supports the conclusion that the variability in delivery at different breathing rates is clinically insignificant. Again, the 7 bpm results show the greatest difference between the left and right side of the profile along the central axis.

Our Eclipse VMAT SABR planning strategy limits MLC incursion into the PTV volume by a combination of a high priority on reducing the dose in the ring region outside the target volume and an objective setting an appropriate upper limit on the number of monitor units (MU) delivered by the plan, which correspondingly opens up the MLC aperture and heats up the plan. From the results reported in this work, it can be concluded that the dose delivery from this planning approach is not greatly affected by variations in patient breathing rate at the time of treatment, with the caveat that the amplitude of the motion is properly monitored at CBCT setup verification and is subsequently stable throughout the radiation treatment.

5. Acknowledgements

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