Initial commissioning measurements of respiratory gated liver VMAT stereotactic ablative body radiotherapy

KM Alexander¹, A Kerr¹,² and T Olding¹,²
¹Department of Physics, Queen’s University, Kingston, Ontario, Canada, K7L3N6
²Cancer Centre of South Eastern Ontario at Kingston Health Sciences Centre, 76 Stuart Street, Kingston, ON, Canada K7L 2V7

E-Mail: kevin.alexander@kingstonhsc.ca

Abstract. A dosimetric evaluation of a respiratory gated VMAT SABR technique was performed at two different beam energies. Dynamic ion chamber, EBT3 film and Fricke-xylenol orange-gelatin (FXG) gel measurements were acquired using a motion phantom with custom inserts for each dosimeter. Ion chamber and gel dosimeter measurements show good agreement between the measured and calculated plan dose within the planning target volume (PTV). Lower agreement than expected was observed between calculated plan dose and measured film dose, particularly for the 10 MV flattening filter free beam plan, a result that warrants further investigation.

1. Introduction
Patients with liver metastases may be treated with ablative radiation therapies as an alternative to surgical resection. There are a number of different options available for motion management within the broad categories of motion-encompassing, respiratory gated, breath-hold, forced shallow breathing, and real-time tumour tracking methods [1]. Our centre employs a motion-encompassing volumetric modulated arc therapy (VMAT) technique in lung stereotactic ablative body radiotherapy (SABR), a breath hold technique for left-sided breast radiotherapy, and is now investigating the use of a respiratory-gated technique for liver SABR treatments. The intention is to use a high dose rate 10 MV flattening filter-free (10FFF) beam (on a Varian TrueBeam linear accelerator, Varian Medical Systems, Palo Alto, CA) to decrease total time of delivery, as is done at other centres, but also to evaluate the 6 MV (6X) beam for possible future use.

The purpose of this work is to perform a dosimetric validation of a gated VMAT SABR technique on a well-characterized motion phantom using different dosimeters that each uniquely contribute to the strength of the validation process. These dosimeters include a 0D ion chamber, 2D EBT3 Gafchromic film, and 3D Fricke-xylenol orange-gelatin (FXG) gel dosimeter, following a similar test methodology as before [2]. Different approaches have been employed for dose verification of respiratory-gated Truebeam VMAT deliveries e.g. [3,4] and the study of respiratory gated deliveries with gel dosimetry is not new e.g. [5,6]. The results reported in this work are intended to add to this previous experience, using high resolution dose data from both film and gel dosimetry in combination with well-established point ion chamber measurements to evaluate this complex delivery process in our specific clinical environment prior to technique rollout, and establish an acceptable clinical protocol for use. This report also is part of our ongoing efforts to show the application of 3D gel dosimetry to selected clinical problems and highlight the practical challenges associated with its use.
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. Dynamic 4D computed tomography (4DCT) scans were acquired of a Quasar motion phantom (Modus Medical Devices Inc, London, ON, Figure 1a) with custom inserts for each of the dosimeters. A GE Lightspeed scanner (GE Healthcare, Maple Grove, MN) was used for CT data acquisition, along with a Varian real-time position management (RPM) motion management system (Varian Medical Systems, Palo Alto, CA) for phase binning of the CT images. A similar cedar insert was used for the EBT3 film (Figure 1b). The scans were then repeated with a custom gel insert (Fig. 1c). A 20 mm peak-to-peak amplitude 5 breath-per-minute (BPM) sinusoidal breathing cycle was used for all 4DCT scans. This amplitude was chosen as a representative clinical tumour motion. While a 5BPM sinusoidal waveform is not a true representation of a patient’s normal breathing pattern, it is adequate to test the gating system for use in the clinic.

For VMAT SABR planning, two coplanar clockwise/counterclockwise 6X partial arcs were employed, ranging from just outside the approximated edge of the contralateral lung anteriorly to 180 degrees posteriorly (figure 1c upper right). The collimator angle on the arcs was set to ±30 degrees. A RapidArc™ VMAT plan was optimized and calculated in Eclipse™ v.13.6 (Varian Medical Systems, Palo Alto, CA) on the 2.5 mm slice thickness 4DCT-derived average (of phases 60 to 40) scan of the Quasar phantom with each respective insert. The plan had a target objective placed on the overall monitor units (MU) allowed in the optimization stage of treatment planning, to limit multi-leaf collimator (MLC) motion and force the MLC aperture open throughout the arc. A 10FFF plan was also optimized and calculated on the same anatomy. A similar process was followed to produce optimized 6X and 10FFF plans on the ion chamber and gel 4DCT-derived average (again, phases 60 to 40) phantom datasets. Film and ion chamber plans were normalized to a prescription dose of 2 Gy (100% prescription dose covers 95% of PTV target volume) unless otherwise specified, while gel plans were normalized to a prescription dose of 1.8 Gy for optimal optical CT FXG gel dose readout. A screen capture of the 6X ion chamber plan is shown in figure 1c.

All treatment plans were delivered on a Varian TrueBeam linear accelerator (Varian Medical Systems, Palo Alto, CA), with cone beam CT (CBCT) setup verification. Plans were delivered within the 60 to 40 phase thresholds used to generate the average planning CT scan, or with a slightly larger phase threshold up to 70 to 30. EBT3 film measurements were acquired using an Epson 10000XL flatbed scanner (Epson Canada, Markham, ON). A calibration set of 6MV 10x10 cm2 films were delivered under machine reference conditions to doses spanning the range of 0-4.5 Gy. Gel dosimeters were calibrated using a single field electron beam under machine reference conditions [7], and imaged using a Vista™ optical CT scanner (Modus Medical Devices Inc., London, ON). Measured film and gel dose were compared against calculated Eclipse treatment planning system (TPS) dose using 3D Slicer (www.slicer.org) [8].
3. Results

3.1. Dosimeter-Plan Dose Comparison

Results for the dosimeters used in this work are summarized in table 1. All ion chamber measurements were in good agreement with TPS calculated dose. Film and gel gamma comparison results are also reported in table 1, with selected profiles and 2D gamma comparison slices shown in figures 2 and 3.
Table 1. Summary: measured vs. Eclipse doses.

| Dosimeter  | Plan               | Prescription (Gy) | Ratio of measured to calculated doses (%) | % Gamma ≤1 (3%/3mm) |
|------------|--------------------|-------------------|------------------------------------------|---------------------|
| Ion Chamber | 6X (60-40 gated)  | 2                 | 99.1 ± 0.5                                | -                   |
| Ion Chamber | 6X (70-30 gated)  | 2                 | 98.8 ± 0.5                                | -                   |
| Ion Chamber | 10FFF (60-40 gated) | 2             | 99.9 ± 0.5                                | -                   |
| Ion Chamber | 10FFF (60-40 gated) | 12            | 101.3 ± 0.5                               | -                   |
| EBT3 Film  | 6X (60-40 gated)  | 2                 | -                                         | 90.1                |
| EBT3 Film  | 6X (65-35 gated)  | 2                 | -                                         | 85.0                |
| EBT3 Film  | 10FFF (60-40 gated) | 2             | -                                         | 64.6                |
| FXG Gel    | 6X (60-40 gated)  | 1.8               | -                                         | 96.6                |
| FXG Gel    | 6X (65-35 gated)  | 1.8               | -                                         | 95.0                |
| FXG Gel    | 10FFF (60-40 gated) | 1.8            | -                                         | 97.9                |

Figure 2. (a) Eclipse screen capture of the 10FFF film plan with red dashed line along axis of motion showing location of profile measurements for the (b) 10FFF and (c) 6X plan deliveries.
4. Discussion & Conclusions
With reference to the results summarized in table 1, increasing the phase limits on the delivery beyond the average scan-planned 60 to 40 phase window to a slightly larger 70 to 30 phase window had only a slight effect in lowering the recorded ion chamber reading. This was expected, as this corresponded to approximately ± 5 mm range of motion whereby the ion chamber was still located within the mostly open MLC-defined field aperture. The gamma comparison results from the EBT3 film analysis were lower than expected, particularly for the 10FFF beam (see table 1). Gel dosimeter measured dose showed good gamma agreement with Eclipse-calculated dose for both delivery energies. The gel dosimeter phantom anatomy does not have significant inhomogeneities near to or within the target volume, so it is not surprising that better agreement is observed from the gel gamma comparison. In the clinic, the inhomogeneous film anatomy would be a better representation of the situation where a target volume in the liver is near the diaphragm, with lung tissue in proximity. This underscores the importance of using the most realistic phantom anatomy combined with multiple dosimeters to assess new techniques prior to clinical implementation. A closer look at the 10FFF profile measurements for both film and gel (see figures 2b and 3b) show larger “horns” than calculated by the planning system on both anatomies near the field edge in the direction of motion (i.e. with and without inhomogeneities). This issue could be related to the 10FFF beam model in Eclipse, which has not yet been released for clinical use. Further evaluation is warranted, with repeat measurements and comparison to beam commissioning water tank data. Overall, the initial measurements are promising, but more work is required to fully establish a clinical protocol for respiratory gated liver VMAT SABR at our centre, including a better understanding of the source of delivery disagreement in the inhomogeneous film insert CT anatomy.
5. Acknowledgements

This work was funded by the Canadian CIHR funding agency, project MOP-115101.

6. References

[1] Keall P et al 2006 Med. Phys. 33 3874
[2] Olding T and Alexander KM 2017 J. Phys.: Conf. Ser. 847 012032
[3] Qian J et al 2011 Phys. Med. Biol. 56 4827
[4] King R B et al 2016 Phys. Med. Biol. 61 5529
[5] Ceberg S et al 2008 Phys. Med. Biol. 53 N387
[6] Jong W L et al 2016 J. Phys.: Conf. Ser. 694 012015
[7] Olding T, Darko J and Schreiner LJ J. Phys.: Conf. Ser. 250 012028
[8] Alexander K M et al 2017 J. Phys.: Conf. Ser. 847 012061