Delivery validation of VMAT stereotactic ablative body radiotherapy at commissioning

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Abstract. Dosimetric validation of two volumetric modulated arc therapy (VMAT) stereotactic ablative radiotherapy (SABR) plans was completed as part of the commissioning process of this technique in our clinic. Static and dynamic ion chamber, EBT3 film and leuco crystal violet (LCV) micelle 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.

1. Introduction

Previous end-to-end delivery validation measurements of the non-coplanar 3D conformal lung SABR technique used at our centre have shown good agreement between Varian Eclipse plan dose and ion chamber, EBT3, EPID and Fricke-xylenol orange-gelatin (FXG) gel measurements [1]. This technique is employed as a treatment option for early stage (Stage I, T1/2, N0, < 5 cm), medically inoperable, non-small cell lung cancer. A process is now underway at our centre to transition to a VMAT SABR technique which offers the potential for reduced planning and delivery time. The purpose of this work is then to validate the VMAT SABR lung treatment delivery in a similar manner as before, using different dosimetric modalities. We have included a relatively new formulation of LCV gel dosimeter in this work which has an appropriate level of optical absorption-to-dose response for the high single fraction doses used in lung SABR, and minimal degradation of the optical response due to diffusion [2].

2. Materials and Methods

2.1. SABR Delivery Validation

The dosimetry tools used for SABR delivery validation in this study were: a) point single ion chamber (PR-05P 0.07 cc, Capintec, Ramsey, NJ), b) 2D Gafchromic EBT3 film (ISP, Wayne, NJ), c) 3D leuco crystal violet dye-micelle based gel dosimeter with optical CT readout [3] and d) 3D ArcCheck (Sun Nuclear, Melbourne, FL). Static and dynamic 4D computed tomography (4DCT) scans were acquired of a Quasar motion phantom (Modus Medical Devices Inc, London, ON, figure 1a) with a cedar insert containing a 3 cm diameter acrylic sphere ‘tumour’ and a hole for insertion of the ion chamber. A GE Lightspeed RT16 scanner (GE Healthcare, Maple Grove, MN) was used for CT data acquisition, with
the addition of a Varian RPM motion tracking system for the dynamic scan. A similar cedar insert was used for the EBT3 film (figure 1b). The scans were then repeated with a custom gel insert in the Quasar phantom (figure 1c). A sinusoidal breathing cycle of 15 breaths per minute (BPM) and 20 mm amplitude peak-to-peak was used for all 4DCT scans.

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 (figure 1d). The collimator angle on the two arcs was set to ±30 degrees to minimize discrepancies arising from the interplay effect. High monitor unit (MU) and low monitor unit RapidArc™ VMAT plans were optimized and calculated in Eclipse™ v.10 (Varian Medical Systems, Palo Alto, CA) on the 4DCT 1.25mm slice thickness average scan of the ion chamber-Quasar phantom geometry. These plans were then re-calculated (but not re-optimized) on the rest of the ion chamber, film and gel static and dynamic CT phantom datasets. The high MU dynamic plan was optimized without any constraints on the total number of plan MUs. As a result, the high MU dynamic (HMUD) and static (HMUS) plans have reasonably complex multi-leaf collimator (MLC) leaf motions/apertures in the delivery. The low MU dynamic plan had a limit placed on the total number of MUs in the optimization stage of treatment planning; hence it has more open MLC apertures throughout the arc. A corresponding 30% decrease in the number of MUs was achieved in the low MU dynamic (LMUD) and static (LMUS) plans. The ion chamber and gel plans were normalized to the clinical single fraction prescription dose of 12 Gy, while the film plans were re-normalized (i.e. monitor units scaled down) to a prescription dose of 2 Gy to accommodate the dose.

Figure 1. (a) Quasar motion phantom with ion chamber insert, (b) photo of cedar film insert with overlaid EBT3 film from dynamic delivery, (c) gel insert and dynamic delivery LCV gel, and (d) Eclipse screen capture of the high monitor unit dynamic ion chamber plan used in this study.
range (up to 10 Gy) of EBT3 film. A screen capture of the high MU dynamic delivery ion chamber plan is shown in figure 1d.

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) phantom 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 [5] (www.slicer.org).

3. Results

3.1. Dosimeter-Plan Dose Comparison

Dosimetric results for the dosimeters used in this work are summarized in Table 1. The near isocentre ion chamber point measurements are in good agreement with Eclipse. 2D Film and 3D gel results are consistent with this, although the point film measurements were lower than expected. Most of the dynamic film and gel disagreement (figures 2 and 3) is near the edges of the high dose region in the superior-inferior direction along the axis of phantom motion.

| Dosimeter | Plan   | Prescription (Gy) | Point Dose Difference (%) | % Gamma ≤1 (3%/3mm) |
|-----------|--------|-------------------|---------------------------|---------------------|
| Ion Chamber | HMUS   | 12                | -1.1                      |                     |
| Ion Chamber | HMUD   | 12                | -1.6                      |                     |
| Ion Chamber | LMUS   | 12                | -0.8                      |                     |
| Ion Chamber | LMUD   | 12                | -2.0                      |                     |
| EBT3 Film | HMUS   | 2                 | -3.7                      | 94.6                |
| EBT3 Film | HMUD   | 2                 | -4.1                      | 69.1                |
| LCV Gel   | HMUD   | 12                | -1.3                      | 86.1                |
| ArcCheck  | HMUS   | 12                | -                         | 100.0               |
| ArcCheck  | LMUS   | 12                | -                         | 99.4                |

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

4. Discussion & Conclusions

With reference to table 1, the slight increase in the point dose disagreement for the dynamic deliveries versus the static measurements is likely due to interplay effects [4, 6] which are not accounted for in Eclipse. The fact that all point dose measurements were less than that calculated by the TPS can be can also be partly attributed to planning system limitations in modelling dual electronic disequilibrium conditions (i.e. small field size and small target in inhomogeneous media). The disagreement near the edges of the high dose region in the dynamic delivery film and gel measurements is well-explained by
motion during delivery, which is not accounted for by the TPS. The disagreement in the centre of the film for both deliveries (figure 2) leading to larger than expected central point dose differences (table 1) and gamma values (figure 3a and b) is believed to be due to multiple reflections off the camera lens in the custom CCD-lightbox scanner. This is expected to be resolved through the addition of an anti-reflection filter in front of the CCD camera. The ArcCheck results validate the delivery of both static plans, providing additional support to the assertion that the increase in point dose discrepancy of the dynamic plans near isocentre is largely related to interplay effects. Finally, gel dosimetry uniquely provides a 3D validation of the dynamic delivery. Good agreement is observed between plan and measurement over the full range of solid acrylic tumour motion (i.e. internal target volume (ITV), see figure 3c), suggesting that the 0.5 cm planning target volume (PTV) margin is adequate for the delivery.

![Figure 3](image)

**Figure 3.** 3%, 3mm gamma comparison for the (left) static 2 Gy film delivery, (centre) dynamic 2 Gy film delivery, and (right) the central 9 cm high, 7 cm diameter cylindrical gel volume of the 12 Gy dynamic gel dose delivery, with ITV and PTV contours shown in red and blue respectively.

The 2 cm peak-to-peak motion chosen in this study represents an extreme clinical scenario. Tumour motion for most patients is typically less than 1 cm, and not entirely directed along the superior-inferior axis. With this in mind, it appears that both the LMUD and HMUD planning approaches are acceptable from the standpoint of delivery validation. Overall, good agreement is observed between the measured delivery and calculated Eclipse treatment planning system dose.

5. Acknowledgements
Research funding for this work has been provided by the Canadian Institutes of Health Research (CIHR) and the Cancer Centre of Southeastern Ontario.

6. References
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