Stereotactic body radiation therapy delivery validation

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Abstract. This work describes the use of a motion phantom and 1D, 2D, and 3D ion chamber, EBT3 film, electronic portal imaging device (EPID) and FXG gel measurements for dosimetric validation of a stereotactic ablative radiation therapy (SBRT) technique in our clinic. Results show good agreement between the measurements and calculated treatment plan dose.

1. Introduction
Stereotactic body radiation therapy (SBRT) is a high precision image-guided radiation therapy (IGRT) technique in which hypo-fractionated ablative doses of radiation are delivered to small, accurately delineated tumors [1]. Dose distributions for SBRT are designed such that the ablative dose is confined to the tumor and immediate vicinity, with the tumor motion characterized and compensated for. SBRT is typically offered as a treatment option for early stage (Stage I, T1/2, N 0, < 5 cm), medically inoperable, non small cell lung cancer. Typical multi-fraction dose regimes include 48-60 Gy in 3-5 fractions. With such a high dose being delivered in only a few fractions, it is imperative that high geometric and dosimetric precision is maintained at each step of the treatment process. End to end validation of dose delivery during the commissioning process is, therefore, vital to a successful SBRT program. The purpose of this work is to validate a newly implemented SBRT lung treatment delivery using different dosimetric modalities. We included gel dosimetry in this work, encouraged by the success of previous gated radiation delivery validations using 3D dosimeters [2, 3].

2. Materials and Methods

2.1. SBRT Delivery Validation

The dosimetry tools used for SBRT delivery validation in this study were: a) point single ion chamber (Capintec PR-05P 0.07 cc/Capintec electrometer), b) 2D Gafchromic EBT3 film (ISP, Wayne, NJ), c) 3D EPID based fluence measurement and dose prediction algorithm [4], and d) 3.5D Fricke-xylenol orange-gelatin (FXG) based gel dosimeter with optical CT readout [5]. 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 left). The rubber ball “tumour” in the gel was used to establish a target for contouring in the CT data sets, the
inside of the jar was turned to unit electron density in the CT scan for dose calculation and the gel insert was replaced with a FXG gel during the SBRT deliveries (Fig.1c centre and right). Figure 1d left shows the breathing cycle used for the ion/chamber and film 4DCT scans and SBRT deliveries (15 breaths per minute (BPM), 20 mm amplitude peak-to-peak). The sinusoidal respiratory cycle used for the gel measurements (figure 1d right) had the same rate of 15 BPM, but with reduced 10 mm amplitude due to the limitations of motion imposed by the acrylic gel holder insert. A screen capture of the 9 field ion chamber plan (with 2 non-coplanar fields) calculated in Eclipse™ (Varian Medical Systems, Palo Alto, CA) is shown in figure 1e.

Figure 1: (a) Quasar motion phantom with ion chamber insert, (b) CT cross section and photo of cedar film insert, (c) CT gel insert and FXG gel dosimeter setup, (d) Breathing patterns for the dynamic 4DCT scans and SBRT deliveries (e) Eclipse screen capture of ion chamber plan.

gel was used to establish a target for contouring in the CT data sets, the inside of the jar was turned to unit electron density in the CT scan for dose calculation and the gel insert was replaced with a FXG gel during the SBRT deliveries (figure 1c centre and right). Figure 1d left shows the breathing cycle used for the ion/chamber and film 4DCT scans and SBRT deliveries (15 breaths per minute (BPM), 20 mm amplitude peak-to-peak). The sinusoidal respiratory cycle used for the gel measurements (Fig.1d right) had the same rate of 15 BPM, but with reduced 10 mm amplitude due to the limitations of motion imposed by the acrylic gel holder insert. A screen capture of the 9 field ion chamber plan (with 2 non-coplanar fields) calculated in Eclipse™ (Varian Medical Systems, Palo Alto, CA) is shown in figure 1e.

All treatment plans were calculated in Eclipse and delivered on a Varian Trilogy 2100iX linear accelerator (Varian Medical Systems), 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 commercial software designed for that QA tool. EBT3 film measurements were analyzed using Welhoffer QA software (OmniPro v 1.6.0002-2008-03-12). EPIDOSE 3D dose was compared with Eclipse using MATLAB (Mathworks, Newark, NJ) based software provided by Ansbacher. The reconstructed, calibrated gel dose data from the Vista™ optical CT scanner (Modus Medical Devices Inc., London, ON) was converted to Dicom format, and compared to Eclipse in the CERR environment (Computational Environment for Radiotherapy Research, Washington State University, St. Louis, MO).

3. Results

3.1. Dosimeter-Plan Dose Comparison

Dosimetric results for the different dosimeters used in this work are summarized in table 1. The dynamic film delivery indicated the greatest disagreement between the calculated Eclipse plan and measured 2D dose distribution, as shown in figure 2. Most of the disagreement is near the edges of the high dose region in the superior-inferior direction, which is the axis of phantom motion. All dosimeters are consistent in reporting a lower point dose than the TPS at or near the plan isocentre.

Figure 3 shows axial and coronal views in CERR of the Eclipse plan and measured gel dose distributions for the 2 Gy, 9 field non-coplanar dynamic delivery. While the 3%, 3mm gamma comparison indicates full agreement between the plan and measured dose, lower doses are observed in the posterior region of the dosimeter near the edge of the high dose region.

![Figure 2](image-url) 3%, 3 mm gamma maps and y-axis dose profiles between the plan (red) and measurement (green) for the static and dynamic film deliveries.

![Table 1](image-url) Summary: measured vs. Eclipse doses. Note that the delivered dose was modified to account for the dynamic nature of the delivery and the calibration range of the dosimeter.

| Chamber | Film | EPID | Gel |
|---------|------|------|-----|
| Plan    | Static | Dynamic | Static | Dynamic | Static | Dynamic |
| Dose (Gy) | 12 | 12 | 2 | 2 | 12 | 2 |
| Fields | 2POP* | 9NCP* | 9NCP | 9NCP | 9CP* | 9NCP | 9NCP |
| Dose Rate (Mu/min) | 600 | 600 | 100 | 100 | 600 | 100 | 100 |
| 1D Point Dose Difference (%, measured vs. Eclipse) | -1.3 | -2.3 | -1.0 | -1.5 | -0.5 | -0.8 | -0.5 |
| % Gamma ≤1 (3%/3mm) | - | - | 100 | 82.4 | - | 98.5 | 99.9 |
| % Chi ≤1 (2%/2mm) | - | - | - | - | 98.5 | - | - |

* POP = parallel opposed pair in the anterior-posterior direction, * NCP = non-coplanar, * CP = coplanar.
4. Discussion and Conclusions

With reference to Table 1, the fact that the static point dose measurements were less than that calculated by the TPS can be attributed to a few possible factors: 1) attenuation of the photon beam through the carbon fibre couch top is not accounted for in current Eclipse dose calculations (which also could explain the decreased dose in the posterior region of the gel dosimeter); 2) TPS limitations related to dose calculations in dual electronic disequilibrium conditions (i.e. small field size + small target surrounded by inhomogeneous media; and 3) the difference in scatter conditions in Eclipse versus the measurement due to blurring of moving GTV (i.e. ITV) on 4DCT images.

Delivery of a full 12 Gy treatment fraction to both the EBT3 film and FXG gel was initially contemplated, but after an initial trial run on the EBT3 film, it was decided that the film calibration in that range was not sensitive enough to faithfully record the dose range. It was therefore decided to deliver a lower dose (2 Gy) over the same treatment time by lowering the dose rate from 600 MU/min to 100 MU/min to preserve the number of breathing cycles during the treatment. It was verified that EBT3 film and FXG gel are insensitive to dose rate in this range; these results are not presented here. The significant disagreement near the edges of the high dose region in the dynamic delivery film measurement are well-explained by the ‘smearing out’ of measured dose in the gradient regions due to motion during delivery. This effect is not as strongly observed in the gel dynamic delivery due to the smaller motion amplitude and the more forgiving 3D (versus film 2D) gel gamma comparison analysis.

![Figure 3: 3%, 3mm 3D gamma comparison (right) of the agreement between calculated plan dose (left) and measured FXG gel dose (centre) for the 2 Gy SBRT dynamic delivery.](a)

One of the practical challenges in this work was registration of the dose data: the gel holder design had to accommodate placement of registration fiducials on the gel jar, and the film registration had to be similarly thought through. This is an important process step that is perhaps not emphasized enough in the reporting of 2D/3D dose comparisons.

There were initial problems encountered with gel when the smaller jar size for the SBRT dosimeter needed to fit in the Quasar phantom cavity, was calibrated against doses from a calibration electron beam given to a larger sized jar. This was overcome by using a smaller field size calibration electron beam delivered to the same sized smaller jar as that used for the SBRT delivery. This result highlights a known limitation of optical CT based FXG gel dosimetry: the confounding effect on the measurement if the calibration and measurement jars are not the same size.

Overall, this work indicates good consistency between the data obtained from the various dosimetric methods (1D, 2D and 3D settings) used to validate the SBRT-lung dose delivery.
5. Acknowledgements
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6. References
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