

Investigating the reproducibility of a complex multifocal radiosurgery treatment

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Abstract. Stereotactic radiosurgery has become a widely used technique to treat solid tumors and secondary metastases of the brain. Multiple targets can be simultaneously treated with a single isocenter in order to reduce the set-up time to improve patient comfort and workflow. In this study, a 5-arc multifocal RapidArc treatment was delivered to multiple PRESAGE[®] dosimeters in order to explore the repeatability of the treatment. The three delivery measurements agreed well with each other, with less than 3% standard deviation of dose in the target. The deliveries also agreed well with the treatment plan, with gamma passing rates greater than 90% (5% dose-difference, and 2 mm distance-to-agreement criteria). The optical-CT PRESAGE[®] system provided a reproducible measurement for treatment verification, provided measurements were made immediately following treatment.

1. Introduction

The use of high single dose fractions with steep gradients requires more stringent tolerances than standard hyperfractionated schemes, which in turn requires additional set up time. Recently stereotactic techniques have emerged which enable treatment of multiple intracranial targets with a single isocenter, thereby greatly reducing treatment time [1]. Verification of multifocal, RapidArc plans is a challenge due to the complexity of the dose distributions. Providing true 3D, fast, and high resolution 3D dosimetry could be an ideal solution for SRS treatment verification, and prior works reflect this interest [2-5]. In this work we deliver the same complex treatment plan to 3 identical PRESAGE[®] dosimeters in order to determine the repeatability of the complex treatment delivery.

2. Methods and Materials

A single isocenter, multifocal stereotactic radiosurgery plan was delivered to three PRESAGE[®] dosimeters. The dosimeters were from the same formulated batch and were irradiated and imaged in sequence. The treatment plan was a 5-arc RapidArc plan with a single isocenter, and 14 Gy prescribed to 99% of the volume of the central target. In addition to the central target, four peripheral targets were treated off isocenter with doses of roughly 20 Gy. The treatment was planned using iPlan (localization and isocenter placement) and Eclipse (arc optimization) and delivered on a Novalis Tx machine to three PRESAGE[®] dosimeters. The dose distributions were measured using an in-house optical-CT system, the Duke Large-Field Optical Scanner (DLOS) [6], both immediately after treatment and two weeks after treatment.



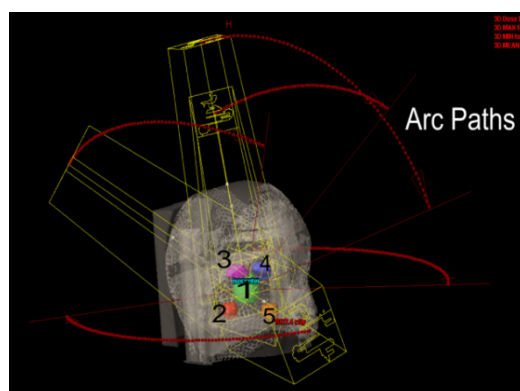


Figure 1: 5-arc RapidArc radiosurgery plan treating 5 targets displayed in Eclipse.

The batch of PRESAGE[®] used for this study was specially formulated to have a significantly lower sensitivity compared to normal batches in order to allow a higher prescription dose without overexposure. While the formulation had a lower sensitivity, other properties, such as effective Z value and tissue equivalency were intended to remain unchanged from previous batches [7]. The sensitivity was measured prior to setting an appropriate prescription dose for the plan by irradiating cuvettes containing the formulation with known doses.

The DLOS system uses a LED light source, a CCD camera, and two telecentric lenses which provide a central region of parallel light where the dosimeter can be imaged free of object magnification effects. The dosimeter is immersed in a fluid bath with a matched refractive index to minimize bending of the light at the dosimeter-fluid interface. The dosimeter is placed on a motorized rotating stage in the bath, allowing projection images to be captured from any angle [6]. The system has a spatial resolution of 175 μm (typically downsized to save disk space) and acquires 360 projections in 5-10 minutes.

The projections were reconstructed using a MATLAB-based GUI with 2 mm resolution and a 15x15 median filter to reduce noise. The reconstructed data cubes were exported to CERR (Computational Environment for Radiotherapy Research) along with the treatment plan from Eclipse [8]. Using CERR, the optical density distribution was registered to the planned dose distribution and scaled using an absolute dose point from an ion chamber measurement. After proper registration and scaling, the average and standard deviation of the three distributions was calculated to examine consistency. Each immediate measurement was tested against its two weak measurement counterpart using 3D gamma analysis (5% dose difference/2 mm distance-to-agreement) to examine stability of the measurement over time. Gamma analysis with the same criteria was also used to compare the Eclipse planned dose to the measured distributions.

3. Results and Discussion

3.1 Cuvette Sensitivity

The sensitivity of the PRESAGE[®] formulation used in this experiment was found to be 0.0029 $\Delta\text{OD}/(\text{Gy}\cdot\text{cm})$. The linear relationship between OD change and dose allows scaling of the entire OD change distribution to a single absolute dose point to determine the dose distribution.

3.2 Consistency Between Dosimeters

Target dose distributions varied between each of the three deliveries very little, with less than 3% standard deviation in voxels located in the high dose regions. Figure 2 shows the range of isodose contour deviations between the three deliveries, with tight agreement in high dose regions. Figure 1 also shows excellent agreement between the planned dose distribution and the average measured distribution of the three dosimeters.

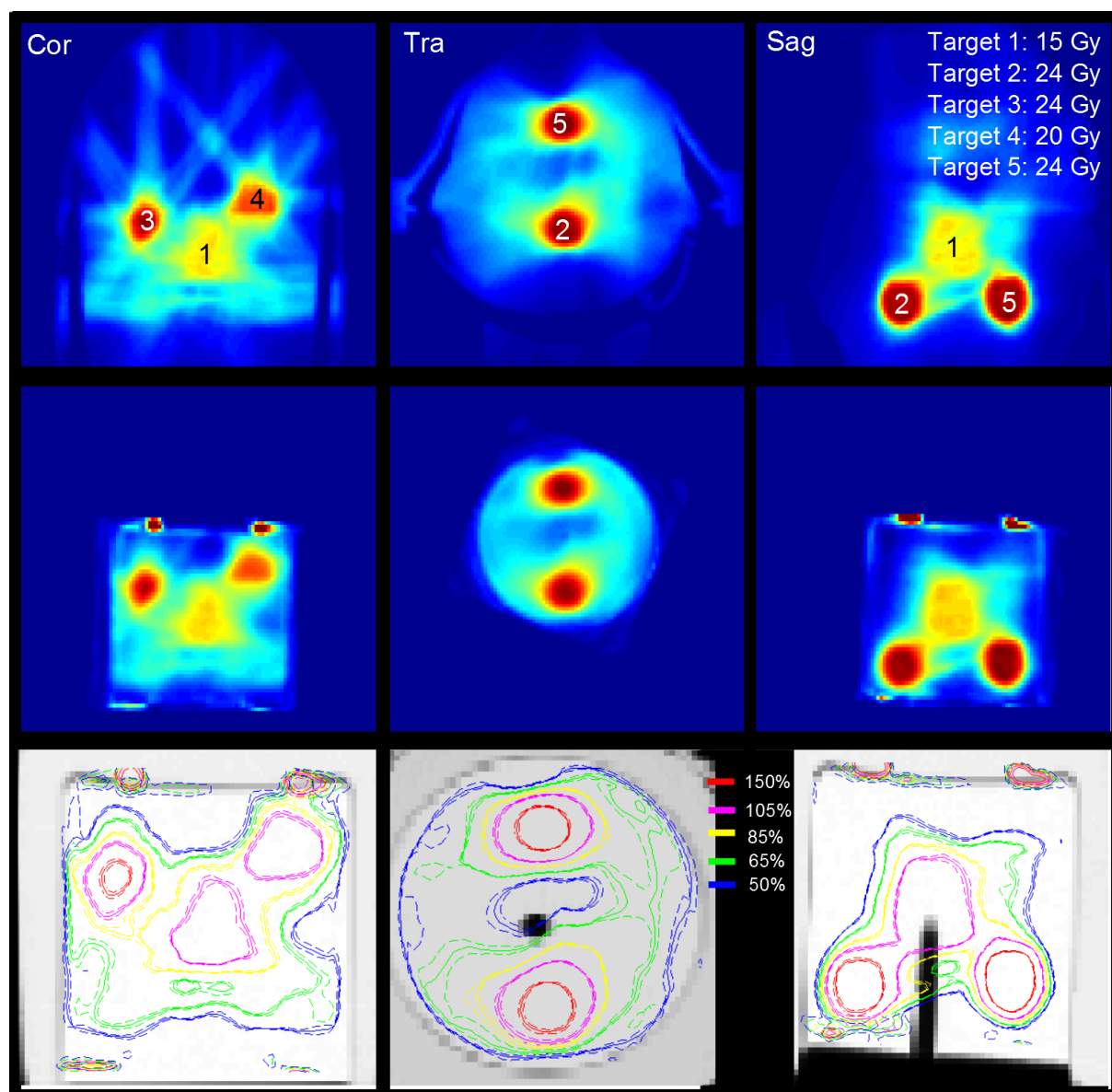


Figure 2: Top row: planned dose distributions from Eclipse to the five targets; Middle row: average of the three measured dose distributions; Bottom row: isodose lines for the average measured distribution (solid) as well as ± 1 standard deviation (dashed lines).

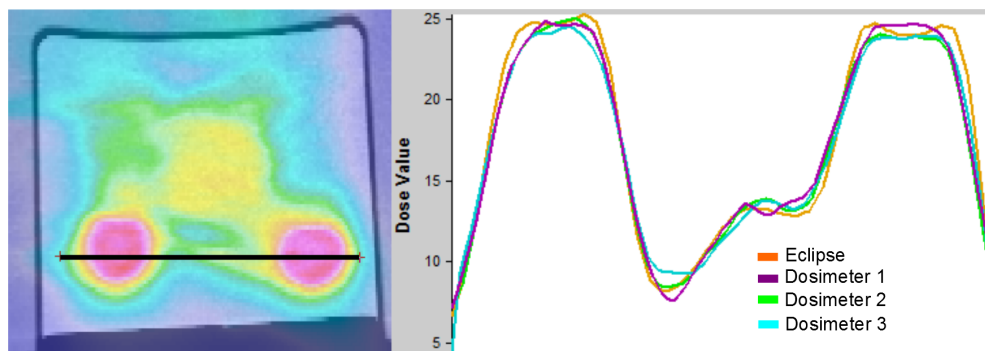


Figure 3: Line profile over two targets illustrates consistent delivery and low noise.

3.3 Consistency Over Time

The three initial measurements agreed well with the Eclipse planned dose with gamma passing rates of 92.4%, 93.0%, and 91.7% with 5% DD/2 mm DTA criteria. Closer inspection revealed the dosimeters were not stable with time. Dose measurement values in the peripheral targets changed by as much as 12% over the two week period. Gamma analysis (5%/2mm) comparing the initial measurements to measurements two weeks later yielded passing rates of 46.4%, 62.9%, and 55.7% for the three dosimeters.

4. Conclusions

The three deliveries of the radiosurgery treatment were found to be very consistent (less than 3% dose deviation in targets) with each other, demonstrating the accuracy of the treatment machine and the reproducibility of the measurement technique of PRESAGE[®] with optical-CT. While the three treatment deliveries agreed well with each other, as well as with the treatment plan, significant discrepancies (less than 63% gamma pass rate) were found when measuring each dosimeter at different times, limiting the window after treatment to acquire accurate measurements. Reducing the sensitivity of these dosimeters appears to have also reduced post-irradiation stability. Finding a PRESAGE[®] formulation with a stable optical density or at least a dose-independent change over time would solve this issue.

5. Acknowledgements

This study was supported by the NIH R01CA100835 grant.

6. References

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