3-D dosimetric evaluation on isocenter positioning error in the dynamic arc stereotactic radiosurgery based on optical CT based polymer gel dosimetry

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1. Introduction
Accurate isocenter positioning on the target through the treatment process is crucial for high precision stereotactic radiosurgery. There are two main reasons that can cause isocenter deviation from the planned isocenter: 1) The shift of isocenter at various couch and gantry angles and 2) patient and/or target movement during the treatment. For dynamic arc stereotactic radiosurgery, the isocenter positioning error can be minimized through the use of patient positioning devices, patient immobilization devices, and image-guided target localization devices, such as Novalis Body systems (BrainLAB, Inc) [1]. It has been reported that the average isocenter deviation from the planned isocenter, using the Novalis radiosurgery system, can be limited to within 2 mm [2]. This leads to an important question: What is the impact of isocenter positioning error on the dose distribution for both target and critical organs. To assess this impact, a polymer gel dosimeter and an optical CT scanner have been employed to implement 3-D dose distribution measurements. A plastic cylinder of 12 cm diameter and 17 cm height, filled with BANG®3 polymer gels (MGS Research, Inc., Madison, CT) and modified to optimal dose-response characteristics, was used for dose measurement. In this study, we report a dosimetric evaluation on the isocenter positioning error in the dynamic arc stereotactic radiosurgery using the Novalis shaped beam radiosurgery unit.

2. Materials and Methods
The Novalis radiosurgery unit has a 6 MV beam with dose rate up to 800 MU/min. The machine was modified by BrainLAB based on Varian Clinic machine. The radiosurgery system consists of a micro-multileaf collimator (mMLC) installed under the primary collimators, patient immobilization devices, an automated patient-positioning device, and an image-guided system including the infrared and video detectors, as well as the dual diagnostic x-ray tubes with an amorphous silicon flat panel detector. The system also provides manual adjustment along the three vertical axes for isocentric inaccuracy caused by the patient support system and gantry/couch rotation. In this study, to assess the impact of isocenter positioning error on the dose distribution, we selected a specific radiosurgery treatment with an isocentric uncertainty of 1.5 mm-diameter caused by the gantry and couch rotation. Two plastic cylinders of 12 cm diameter and 17 cm height, filled with polymer gel, were used to evaluate the dosimetric impact of isocenter positioning error in this case. One gel was irradiated with an adjustment on each isocenter shift due to couch rotation between two treatment couch positions. One gel was irradiated without any correction for the isocenter shift.
A slice thickness of 3 mm without spacing was used for simulation CT on both the patient and the gel cylinder. The DICOM CT images were then sent to the BrainLAB treatment planning system through the network. The planning system was used to design the stereotactic radiosurgery plan for a patient with a small brain tumor, using a 6 MV photon beam and mMLC to deliver radiation through dynamic shape conformal arcs. The leave sequence files and monitor units for the patient plan were then transferred to the gel phantom to generate a hybrid phantom plan. The gel irradiation was performed under the same set-up geometry as used in the hybrid phantom plan. The set-up geometry of the gel measurement was verified with source-to-surface distance from irradiation gantry angles.

In order to estimate the optical density response of the gel versus dose, the optical density dose response of the gel was determined by irradiating the same type of cylinder containing the same batch of gel to various known doses at the same dose rate used in the patient treatment. The gel sample was scanned with 1 mm pixel resolution using a commercial optical CT scanner, OCTOPUS™ (MGS Research Inc., Madison, CT). Details of the operating principles and instrument architecture of the optical scanner were described previously [3,4].

3. Results and Discussion

The gel samples for the radiosurgery irradiation and the gel sample for the calibration of optical density dose response were from the same batch. The optical density versus dose was found to be linear in the dose range of 2-20 Gy. Figure 1a shows the superimposed dose distributions at 18 Gy, 15cGy, 10cGy and 5cGy Isodose lines from gel measurement with correction for isocenter shift (black), gel measurement without correction for isocenter shift (green), and treatment planning calculation (red), at the axial plane passing through the isocenter. All three isodose distributions are in good agreement. The agreement of these dose distributions at the central slice suggests that the measured isodose distributions were comparable to the planned isodose distributions; and that the dose distribution at the central slice does not shift significantly with the isocenter shift.

Figure 1b shows similar dose distribution comparison as described for Figure 1a, except that the axial plane is 8 mm superior to the central slice. The measured dose distribution without correction for isocenter shift displays an overall displacement in the dose distribution. The difference in the displacement of isodose distribution between these two axial planes can be partially attributed to the fact that the isocenter shift in this case is more toward the superior direction. In addition, the dose
gradient along the central slice is in general smaller than those along other slices. Therefore the
displacement in the isodose distribution is not significant.

Table 1 presents the effect of isocenter shift on the dose-volume-histogram. The DVH obtained
from the gel measurement without any correction for isocenter shift shows a smaller volume at the
high dose region (100% isodose and above) and a larger volume at the high dose gradient region (80-
100%). The volumes in the low dose region (0-80%) are similar for both irradiations with and without
correction for isocenter shift. The reduction in the V100 (volume covered by 100% isodose or more)
from the irradiation without correction for isocenter shift, in this case, is as much as 18.5%. The
clinical impact can be significant.

Based on this study, optical CT based polymer gel dosimetry can provide a method of acquiring 3-
D dose distribution, with high resolution and precision, for a complex treatment modality.

Table 1. Effect of isocenter shift on the dose-volume-histogram.

| Percent dose (%) | 0 to 20 | 80 to 100 | Above 100 |
|------------------|--------|----------|-----------|
| With correction (cc) | 627.1  | 20.8     | 22.2      |
| Without correction (cc) | 629.7  | 22.3     | 18.1      |

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BANG®3 polymer gels and scanning of the gels.

5. References
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