Evaluation of the Biological Effectiveness of Mixed Sphere Size Spatially Fractionated Radiation Therapy Using Gamma-Knife vs. VMAT

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PURPOSE

Purpose: To evaluate the biological effect of Spatially Fractionated Radiation Therapy (SFRT) using Gamma Knife (GK) or volumetric-modulated arc therapy (VMAT) with multiple sphere sizes in a lattice arrangement.

Innovation/Impact: SFRT is reported to successfully treat extremely large tumors by delivering highly heterogeneous dose distributions, which is guided by a planning structure shaped with spheres in a lattice arrangement. Physical properties like sphere size and lattice separation can influence important dosimetric features like valley to peak dose ratio, average target dose, EUD, and therapeutic ratio. Past work has examined the difference between Gamma Knife and VMAT plans using a lattice of fixed target sphere sizes, while this study examines the difference with a lattice of mixed target sphere sizes. Since VMAT is widely available at most clinics and in general offers faster treatment delivery times, it is useful to examine SFRT plan quality as compared with Gamma Knife.

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INTRODUCTION

Spatially Fractionated Radiation Therapy (SFRT) is a specialized form of radiation therapy that delivers a highly inhomogeneous dose distribution inside a large tumor volume. Important dose metrics used for evaluation of an SFRT plan:

Therapeutic Ratio (TR):

$$TR = \frac{SF_n(D_{SFRT})}{SF_n(D_{EUD})}$$

where SF is the surviving fraction of the normal tissue for either the mean dose of the grid technique or the overall average dose if given uniformly, calculated from the linear quadratic model.

Valley to Peak Ratio (VPR):

$$VPR = \frac{D_H}{D_L}$$

where D_H is the mean dose at voxels in high dose regions (D90%) and D_L is the mean dose at voxels in low dose regions (D10%).

METHODS AND MATERIALS

CT images and tumor contours were obtained from the 20 patients with the largest brain metastases from a group previously enrolled in an IRB-approved study. Spherical contours were generated by in-house scripts and placed inside of the tumor, with a mix of 4 mm and 8 mm sizes. For VMAT plans, 3 full arcs were used to generate a dose of D50% ≥ 18 Gy. For GK plans, shots were manually placed to cover sphere targets with 18 Gy to the 70% isodose line. The sphere arrangement for both VMAT and GK was a face-centered-cubic. The VPR, average target dose, and EUD were compared. The TR was compared after renormalizing the mean target dose to 6 Gy for fair comparison. An axial and sagittal view of the target and shot contours for a sample patient in this retrospective study are shown in Figure 1, along with the dose distribution for the VMAT plan created for this patient. The smaller shots are the 4 mm spheres, and the larger shots are the 8 mm spheres, which are both present in this mixed sphere size face-centered-cubic (FCC) lattice.

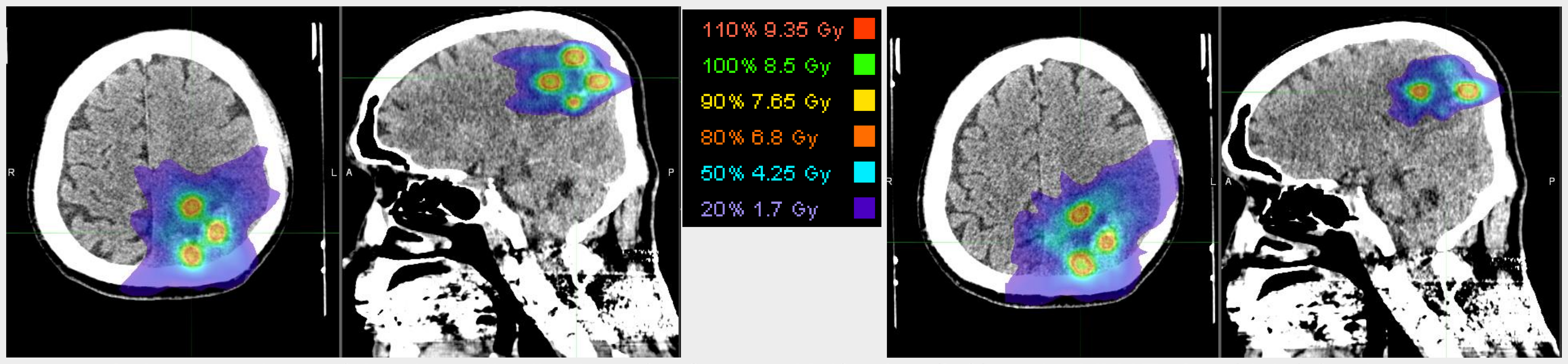

Figure 1. A comparison of the dose distribution of a Gamma Knife plan (left) and a VMAT plan (right) for the same patient, with the same lattice and sphere targets

RESULTS

On average, VPR and tumor mean dose was higher in VMAT plans than for GK plans with mixed shot sphere sizes. The sphere mean dose was slightly higher in GK plans than for VMAT. GK plans showed more consistency in EUD and TR as compared with VMAT. On average, EUD was 36% higher for the VMAT plans as compared with the GK plan, and VMAT TR was higher for semi-resistant (8%) and resistant tumors (14%), while GK TR was higher for sensitive tumors (10%).

Table 1. Comparison metrics between Gamma Knife (GK) and Volumetric Modulated Arc Therapy (VMAT) plans with a lattice of 8 mm and 4 mm sphere sizes.

Modality	Number of Spheres	VPR	Tumor Mean Dose (Gy)	Sphere Mean Dose (Gy)	Mean Tumor EUD (Gy)	Mean TR
Gamma Knife	8.15 ± 2.2	0.26 ± 0.03	6.18 ± 0.89	20.58 ± 0.31	4.14 ± 0.13	1.25 ± 0.03
VMAT	8.10 ± 2.0	0.34 ± 0.09	8.89 ± 1.22	18.11 ± 0.08	5.64 ± 0.31	1.34 ± 0.03

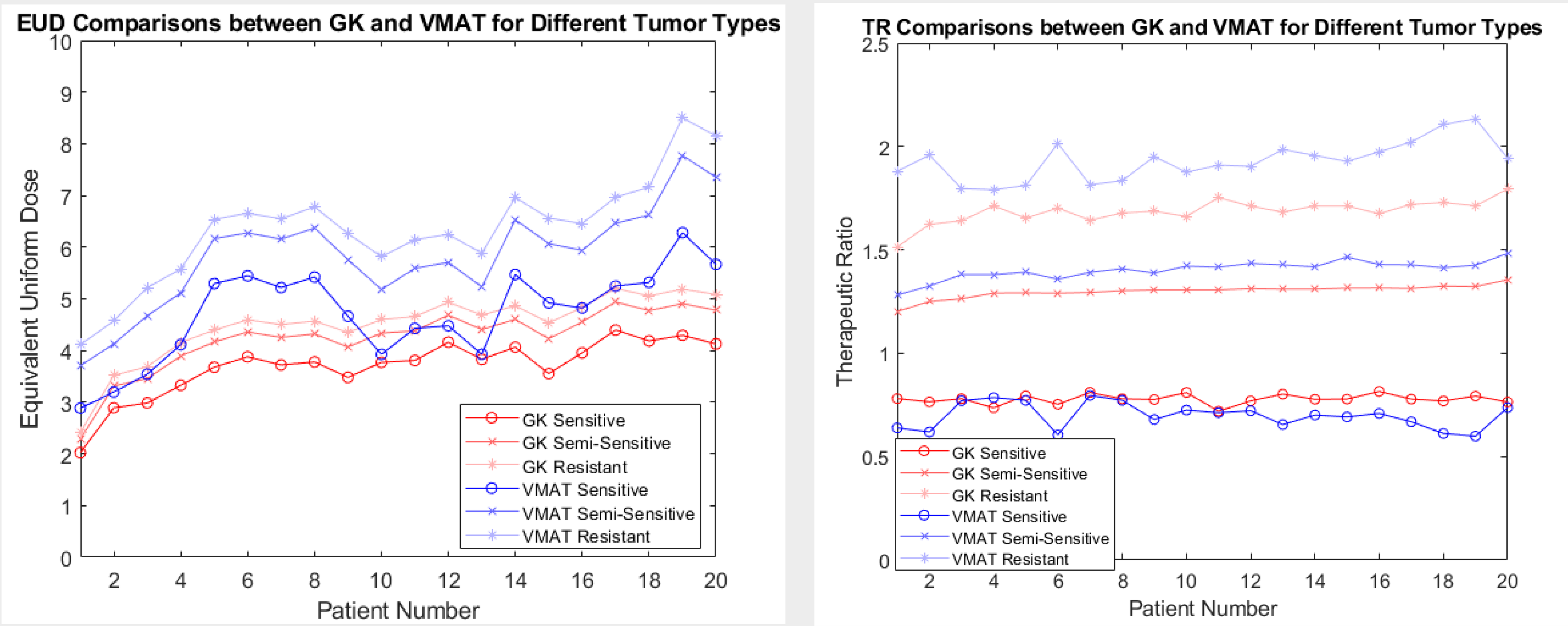

Figure 2. Comparison of equivalent uniform dose (EUD) and therapeutic ratio (TR) between GK and VMAT for different tumor types, ranging from radio-sensitive to radio-resistant. To calculate TR, the mean target dose was renormalized to 6 Gy for both GK and VMAT plans for a fair comparison. In general, the VMAT plans achieve higher EUD and TR than the GK counterparts for the same tumor type.

CONCLUSIONS

On average, VMAT plans had higher VPR, average target dose, EUD and TR as compared with GK. This could be because VMAT plans had higher tumor doses on average. GK plans had a higher TR for radio-sensitive tumors. Higher VPR, average target dose, EUD, and TR for VMAT plans indicates that VMAT does not achieve the same level of dose modulation as GK plans, but plan metrics were still acceptable and comparable with GK.

REFERENCES

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