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Dosimetric comparison of Gamma Knife ICON and LINAC VMAT SRS treatment plans for single brain metastasis

Bin Wang, PhD; Curtis Miyamoto, MD; Jeremy Price, MD, PhD; Shidong Li, PhD; Tawfik Giaddui, PhD; Nina Burbure, MD
Fox Chase Cancer Center at Temple University Hospital, Philadelphia, PA

ABSTRACT

Purpose: Our department has two modalities for stereotactic radiosurgery (SRS) for brain metastasis, namely Gamma Knife Icon (GK-ICON) and VMAT on Versa-HD LINACs. In this study, we aim to conduct a dosimetric comparison of the GK-ICON plans generated with inverse-plan-optimization (IPO) in GammaPlan V11 with the LINAC-based VMAT plans generated in Eclipse V16.

Methods: 10 cases that have been treated with GK-ICON were selected. The target volumes range from 0.41 cc to 16.76 cc (on average 7.79+/-2.1cc). The VMAT plans were generated using 6MV flattening-filter-free beams and were normalized so that the target coverages are the same as the corresponding GK plans. Target dose heterogeneity, Conformity index (CI), Paddick conformity index (PCI), gradient index (GI), and beam-on time (BOT) were compared for the GK-ICON and VMAT plans.

Results: The prescription doses are on average 53%+/-2% and 72%+/-2% of the maximum dose for the GK and VMAT plans, respectively. The VMAT plan CI (1.14+/-0.02) is slightly better than that of the GK plans (1.18+/-0.03). PCI is overall comparable between the VMAT (0.86+/-0.01) and GK plans (0.84+/-0.02). GI of the GK plans (2.64+/-0.04) is less sensitive to the tumor size and is significantly better than that of the VMAT plans (3.75+/-0.34). In general, VMAT plan GI deteriorates with decrease of tumor size. The GK plans, however, have significantly longer BOT (51.1+/-7.8 min) than the VMAT plans (4.7+/-0.3 min). No significant difference was found in the brain stem or the optical nerve/chiasm maximum dose for the cases in which they were close to the target.

Conclusion: The GK plans have “hotter” hotspots but longer treatment times than VMAT plans. For large brain metastasis, the plan quality is comparable between the inversely optimized GK and VMAT plans. For smaller lesions, the sharper dose falloff of the GK plans becomes more advantageous than the VMAT plans.

CONTACT

Bin Wang
Dept of Radiation Oncology, FCCC @ TUH
3401 N Broad St, Philadelphia, PA 19140
Bin.Wang@fccc.edu

INTRODUCTION

In our department, most SRS for brain metastasis are currently treated using Gamma Knife Icon, if the desired GK shots have no clearance issues. When the lesions are not accessible with GK shots, we treat them with 6 MV FFF VMAT on Versa-HD LINACs. In this study, we aim to conduct a dosimetric comparison of the GK-ICON plans generated with the inverse-plan-optimization (IPO) in Gamma Plan Version 11 with the LINAC-based VMAT plans generated in Eclipse Version 16.

METHODS AND MATERIALS

10 single brain metastasis cases that have been treated with GK-ICON were selected for this study. The target volumes range from 0.41 cc to 16.76 cc (on average 7.79+/-2.1cc).

For simplicity, the prescription dose was set to 20 Gy for all plans in this study. The structure sets were exported from Gamma Plan and then imported into the Eclipse planning system. The skull contours for the GK plans were used as body contours in Eclipse and were assigned a uniform density (HU=0, water equivalent) for Eclipse dose calculations. For each case, the same target volume was considered as PTV and was used for both Gamma Knife and VMAT plans.

For VMAT plan optimizations in this study, the same photon energy (6MV FFF) and beam arrangement, namely two full-arcs at couch 0° and one half-arc (gantry 0°-181°) at 90° couch-kick, were used. A 3 mm-ring around PTV was created to control the prescription isodose conformity and manual normal tissue objective (NTO) was applied to control the dose falloff.

There are only two parameters for GK inverse plan optimization, namely the relative importance for low dose (LD) and relative importance for beam-on time (BOT). Increasing the relative importance of LD for optimization would in general lead to a sharper dose falloff, but at the price of increasing treatment time. LD=0.5 was used for all the Gamma Knife plans in this study, but BOT setting ranges from 0.55 to 0.8 for various cases.

RESULTS

Figure 1 shows the axial views of the GK and VMAT plans for an example case. The tumor volume is 10.50 cc. The CI, PCI, and GI are comparable between the two plans. The brain stem D0.1cc is also comparable. The GK plan has a tighter 5 Gy isodose line than the VMAT plan for this case, but with a much longer BOT (70 min vs 5 min).

Figure 2 shows another example case with tumor volume of 0.54 cc. The CI and PCI of the VMAT plan are slightly better than the GK plan. The GI of the GK plan is significantly better than the VMAT plan, but again with longer BOT (19 min vs 4 min).

Table 1 lists the comparison of GK and VMAT plans for the 10 selected cases. The beam-on time (BOT) for all GK plans has been normalized to the same dose rate for 16 mm collimation (2.6 Gy/min). BOT for all VMAT plans were estimated by using the nominal 1400 MU/min dose rate for Elekta Versa HD 6 MV FFF beams. The prescription doses are on average 53%+/-2% and 72%+/-2% of the global maximum dose for the GK and VMAT plans, respectively. The VMAT plan CI (1.14+/-0.02) is slightly better than that of the GK plans (1.18+/-0.03). PCI is overall comparable between the VMAT (0.86+/-0.01) and GK plans (0.84+/-0.02). GI of the GK plans (2.64+/-0.04) is less sensitive to the tumor size and is significantly better than that of the VMAT plans (3.75+/-0.34). In general, VMAT plan GI deteriorates with decrease of tumor size. The GK plans, however, have significantly longer BOT (51.1+/-7.8 min) than the VMAT plans (4.7+/-0.3 min). No significant difference was found in the brain stem, optical nerves, and optical chiasm maximum dose for the cases where the organs are close to the target volumes.

Table 1. Comparison of GK and VAMT plans.

Tumor	Rx % of Dmax		CI		PCI		GI		BOT (min)	
volum (cc)	GK	VMAT	GK	VMAT	GK	VMAT	GK	VMAT	GK	VMAT
0.41	50%	81%	1.40	1.18	0.72	0.85	2.49	5.39	19.4	4.2
0.54	48%	79%	1.19	1.20	0.83	0.80	2.62	4.90	33.3	3.8
1.28	70%	81%	1.26	1.22	0.81	0.80	2.91	5.16	14.3	3.5
2.92	51%	78%	1.28	1.21	0.78	0.82	2.60	3.74	41.7	3.8
6.83	56%	67%	1.18	1.20	0.85	0.83	2.72	3.55	65.3	6.3
9.44	50%	67%	1.12	1.10	0.88	0.90	2.70	3.17	49.4	5.2
10.50	52%	70%	1.07	1.04	0.87	0.90	2.61	2.98	69.7	4.7
13.92	50%	63%	1.08	1.10	0.92	0.90	2.66	3.01	61.3	5.1
15.31	54%	63%	1.13	1.12	0.88	0.88	2.60	2.84	74.9	5.7
16.76	53%	72%	1.13	1.08	0.87	0.91	2.48	2.72	81.7	4.9

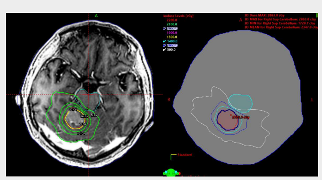

Figure 1. Axial views of GK (Left) and VMAT(Right) plan for a case with tumor volume of 10.50cc. 20 Gy, 14 Gy, 10 Gy, and 5 Gy isodose lines are displayed. The 0.1cc Dmax of brain stem is 7.7 and 7.3 Gy for the GK and VMAT plan, respectively..

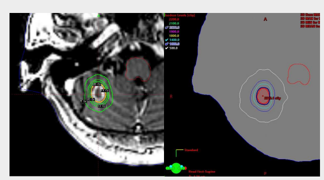

Figure 2. Axial views of GK (Left) and VMAT(Right) plan for a case with tumor volume of 0.54 cc. 20 Gy, 14 Gy, 10 Gy, and 5 Gy isodose lines are displayed. The 0.1cc Dmax of brain stem is 1.6 Gy and 3.3 Gy for the GK and VMAT plan, respectively..

DISCUSSION

In general, the GK plans have the advantage of higher target dose and sharper dose falloff (especially for smaller lesions) over the VMAT plans. However, As shown in Chart 1, for targets larger than 5 cc, the dose delivery efficiency for GK plans becomes increasingly worse than the VMAT plans, while they are also losing the edge in dose falloff.

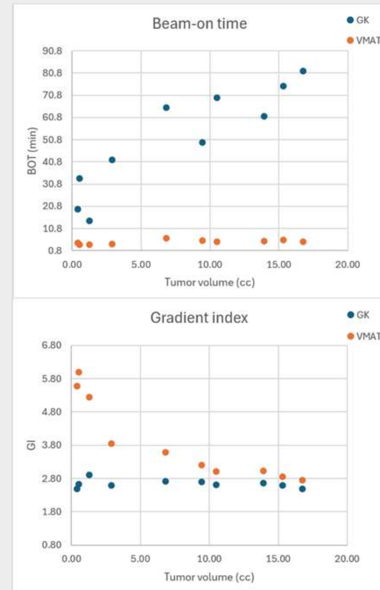

Chart 1. Beam-on time and gradient index versus target size for GK and VMAT plans.

CONCLUSIONS

With the same target coverage, the GK plans give hotter target doses, but with significantly longer treatment times than the VMAT plans. For relatively small lesions, the GK plans allow a sharper dose falloff than the VMAT plans. For relatively large brain metastasis (>5cc), the plan quality is comparable between the inversely optimized GK and VMAT plans. But as the tumor size increases, the GK plans suffer from aggressively prolonged treatment times. Such information could aid clinicians in choosing more appropriate modality for individual cases.

REFERENCES

1. Irina Vergalasova et. al, Multi-Institutional Dosimetric Evaluation of Modern Day Stereotactic Radiosurgery (SRS) Treatment Options for Multiple Brain Metastases. Front Oncol (2019), 9:483.