Hippocampal Sparing HyperArc VMAT Radiosurgery for Multiple Brain Metastases Patients in 15 Minute Treatment Slot

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INTRODUCTION

- Gamma Knife radiosurgery is the current gold standard for SRS for multiple brain metastases.[1]
- However, Gamma Knife is not readily available to all patients, has extremely long treatment times, and requires an intolerable headframe.
- Single-isocenter VMAT SRS, or HyperArc, has potential to improve tolerability and efficiency. [1]
- However, isocentre misalignments could produce clinically unacceptable target coverage, degrade plan quality and increase dose to normal tissues [2,3]
- HyperArc is not an accurate treatment modality without the use of correction strategies for isocentre misalignment

AIM

- To quantify the potential loss of target coverage in HyperArc VMAT SRS treatment and the affect on plan quality.
- To investigate the correlation between loss of target coverage as a function of tumor size.
- To investigate correction strategies to compensate for loss of coverage when treating with single-isocenter HyperArc VMAT

METHOD

- Nine patients (2-16 tumor/patient, total 61 tumors) who underwent gamma-knife radiosurgery were replanned in Eclipse using 10MV-FFF beam (2400 MU/min) and a single-isocenter (placed at geometric center of all tumors) VMAT plan mimicking HA-style treatment geometry.
- 20 Gy to each tumor was prescribed. Average GTV and PTV were 1.1 cc (range: 0.02-11.5 cc) and 1.9 cc (range: 0.11-18.8 cc).
- Isocenter to tumor distance was 5.50 cc, on average (range: 1.6-10.1 cc).
- Six-degrees-of-freedom patient setup uncertainty was simulated [±2mm and ±2°] using an in-house script, including randomly generated setup errors and systematic setup errors.
- Loss of target coverage, collateral damages to OAR and treatment delivery efficiency were evaluated.
- Two clinically promising correction strategies: 1) risk-adopted prescriptions and 2) dual-isocenter HA treatment were introduced.

RESULTS

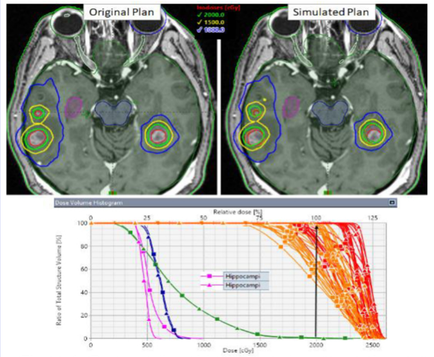

Figure 1: Demonstration of loss of target coverage of an example case (with 16 tumor patient) of a single-isocenter VMAT plan with induced random setup uncertainty. Top left original plan and top right simulated plan, randomly generated set up uncertainties within [-2, +2] mm and [-2, +2]. See vertical black line in DVH, the triangles DVHs (Orange-PTVs and Red-GTVs) for all 16 tumors received at least 95% of the prescribed dose (20 Gy). However, due to clinically realistic set up uncertainties, unacceptable loss of target coverage was observed (square DVHs) and higher OAR doses including hippocampi.

Target (s)	Parameter	Original VMAT plans	Simulated VMAT plans	*p*-value
GTVs	Max dose (Gy)	25.4 ± 0.5 (24.5–26.1)	25.3 ± 0.51 (24.3–26.1)	p = 0.385
	Min dose (Gy)	21.9 ± 0.65 (20.8–23.3)	18.3 ± 2.2 (14.3–21.3)	***p* < 0.001**
	Mean dose (Gy)	24.0 ± 0.47 (23.2–24.8)	22.6 ± 1.4 (19.8–24.6)	***p* < 0.001**
PTVs	% Volume covered by Rx dose (%)	98.7 ± 1.4 (95.0–100.0)	77.2 ± 13.7 (5.0 –99.7)	***p* < 0.001**
	CN	0.70 ± 0.11 (0.35–0.91)	0.43 ± 0.18 (0.04–0.89)	***p* < 0.001**
	UR	0.95 ± 0.15 (0.13–0.913)	0.75 ± 0.16 (0.13–1.0)	***p* < 0.001**
	HI	1.3 ± 0.03 (1.1–1.3)	1.2 ± 0.04 (1.0–1.3)	***p* = 0.04**

Table 1: Analysis of the loss of target coverage for the original VMAT plans. Mean ± STD (range) and p-values were reported for the original VMAT and simulated VMAT plans. Significant values are in bold. STD = standard deviation. CN = Paddick conformation number. UR = Under-treatment ratio. HI = Heterogeneity index. Decrease in plan quality was evident in the simulated VMAT plan with decrease in minimum dose, coverage, heterogeneity index and conformity number

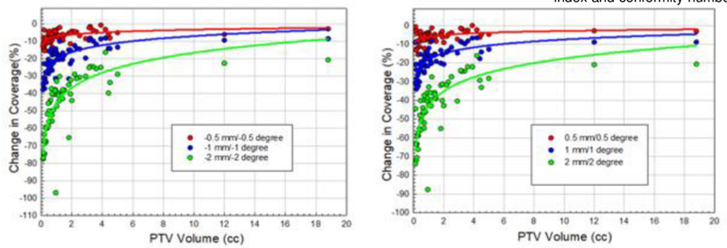

Figure 2: Scatter plots of relative loss of target coverage as a function of PTV volume is shown for all 9 patients (61 targets). All systematically induced errors were within [±2 mm, ±2°] in all 6DoF. As expected, there was a greater loss of target coverage for smaller tumors with the larger residual set up errors (green).

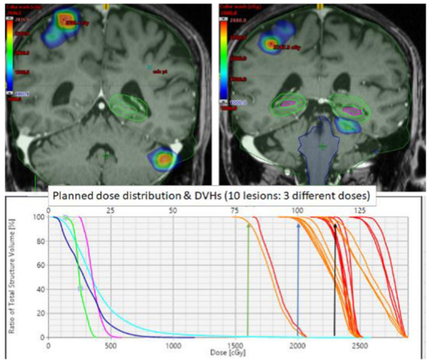

Figure 3 (Correction Strategy #1): Isodose distribution (top) for 16-lesions patients planned with 3 dose levels. 3 small lesions with 24 Gy each, 12 lesions with conventional 20 Gy each and 1 lesion (near left hippocampus) for 16 Gy. Compared to original plan (with 20 Gy dose to all 16 lesions), risk-adopted strategies provided higher dose to small lesions far away from isocenter and critical structures, conventional dose to other lesions and also sparing hippocampus by de-escalating dose to the tumor adjacent to sensitive critical structures (see DVH).

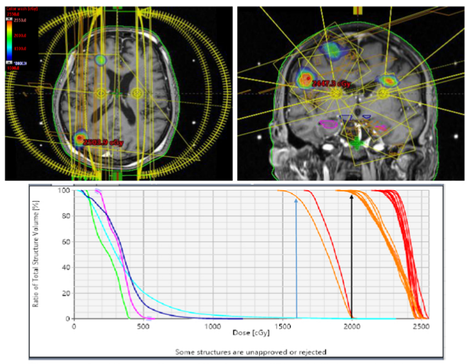

Figure 4 (Correction Strategy #2): Utilizing dual-isocenter technique (see left axial and coronal views), shorten tumors to isocenter distance, potentially improving the treatment delivery accuracy – compared to original single-isocenter plan (see top right). Additionally, with partial-arc approach, dose to OAR were reduced including hippocampi as well as preserving the risk-adopted prescriptions approach (see vertical lines in DVH) for the safe delivery of HR-SRS treatment.

Table 2: Example patient of OAR doses for the original VMAT plans. for the original VMAT and simulated VMAT plans. Results from figure 1 show OAR doses fluctuated depending on the random uncertainty induced to the simulated VMAT plans, and in some cases resulted in a substantial increase to OAR doses. This table is an example of how correction strategies help mitigate increases to OAR doses. Hippocampi, brainstem, optic apparatus, mean brain dose, V12, and V16 brain dose decreased with both correction strategies. Dose limit to the hippocampus is < 6.5 Gy per RTOG protocols

Organs	Original Plan	Risk Adopted Plan	Dual-Iso plan
Hippocampi (Gy)	6.6	5.9	5.8
Brainstem (Gy)	13.1	11.7	12.1
Optic apparatus (Gy)	5.2	3.9	4.1
Mean brain (Gy)	4.1	3.9	3.7
Brain, V12 (cc) & V16 (cc)	37, 14	30, 11.7	30, 11

CONCLUSIONS / FUTURE RESEARCH

- Treating multiple brain lesions using a single-isocenter HyperArc style VMAT is fast treatment technique (< 6 min, beam on time)
- However, small residual setup errors resulted in large deviations from the planned target coverage, specifically for the smaller targets.
- This loss of target coverage due to small isocenter misalignment cannot be ignored for HyperArc style VMAT plan, if uncorrected.
- In some cases, large increases of normal brain dose V12 and V16 and maximal dose to OAR including hippocampi could be harmful to the multiple brain metastatic patients.
- Utilizing either of these corrections strategies, HR-SRS can become an efficient and more accurate treatment option for multiple brain metastases patients–improving patient compliance and treatment accuracy. Further clinical validation of these correction strategies is underway.
- Future investigation includes investigating techniques for minimizing the dose bridging problem between adjacent lesions

SUMMARY

- A single-isocenter HyperArc style VMAT treatment to multiple brain metastases can reduce treatment time significantly, improving treatment tolerability and clinic workflow.
- However, due to small but clinically observable residual set up errors an unacceptable loss of target coverage was observed. This could increase dose to OAR including normal brain as well.
- It is therefore very important for any HyperArc style VMAT users to quantify these dosimetric discrepancies and come up with corrections strategies to minimize the dosimetric effects.

REFERENCES

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3. Roper, J., et al., *Single-Isocenter Multiple-Target Stereotactic Radiosurgery: Risk of Compromised Coverage.* International Journal of Radiation Oncology*Biology*Physics, 2015. **93**(3): p. 540-546.

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