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Development of a Single-Isocenter Planning Strategy for SRS Treatment of Multiple Brain Metastases Using RayStation Treatment Planning System

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ABSTRACT

Purpose: To develop and evaluate a clinically practical single-isocenter stereotactic radiosurgery (SRS) planning strategy for patients with multiple brain metastases in RayStation, with the goals of establishing institutional planning guidelines.

Methods: Nine patients with 3–9 brain metastases were selected. For each patient, three planning methods using single-isocenter, multitarget approach were generated and compared: (1) non-coplanar arcs with manual optimization of collimator angles to minimize island blocking effect; (2) non-coplanar multiple arcs per couch position targeting grouped lesions using RayStation "treat" feature; and (3) coplanar arcs treating one lesion at a time using the "treat" feature. All plans were normalized to achieve comparable target coverage and meeting organ-at-risk (OAR) dose limits. Plan comparisons were performed based on gradient index (GI), normal brain tissue dose, monitor units (MUs) and beam time.

Results: Our preliminary results show that coplanar arc plans achieved excellent conformity and dose fall-off, with CI and GI comparable to those reported for HyperArc-style non-coplanar techniques, and were less planning-intensive. However, these plans required substantially higher MU, resulting in longer treatment delivery time, particularly for patients with more lesions. The grouped-target non-coplanar approach demonstrated consistently favorable CI and GI values, reduced normal brain dose, and significantly lower MU compared to coplanar techniques. Overall, using the "treat" feature for grouping lesions along with a non-coplanar beam arrangement provided the best balance between dosimetric quality and clinical practicality.

Conclusion: Lesion grouping combined with a non-coplanar beam arrangement is an optimal planning strategy for single-isocenter, multi-target SRS VMAT in RayStation, improving dose gradients, enhancing normal brain sparing, and achieving efficient monitor unit (MU) utilization.

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INTRODUCTION

Single-isocenter, multiple-target (SIMT) stereotactic radiosurgery (SRS) using volumetric modulated arc therapy (VMAT) has become an efficient treatment approach for patients with multiple brain metastases by reducing treatment time, improving patient comfort, and enhancing clinical workflow while maintaining excellent plan quality. However, treatment planning is challenged by the **island-blocking effect**, where multiple lesions align along the multileaf collimator (MLC) motion, potentially increasing normal brain dose. Although collimator and couch angle optimization can mitigate this effect, identifying optimal beam arrangements becomes increasingly difficult as the number of lesions increases, making lesion grouping a practical solution.

This study developed a clinically practical planning strategy using the **treat** feature in RayStation to group lesions and assign dedicated non-coplanar VMAT arcs to each target group. Three planning strategies were compared to evaluate dosimetric quality, treatment efficiency, and clinical feasibility for SIMT SRS of multiple brain metastases.

METHODS AND MATERIALS

- **Number of patients:** 9 (3–9 metastases, Total: 48, median: 5)
- **Lesion volume:** 0.13 cm^3 – 4.3 cm^3 (Mean: 0.95 cm^3)
- **Distance to isocenter:** Min (1.3 cm), Max (8.47 cm), Median (4.5 cm)
- **PTV Margin:** 1 mm
- **Isocenter:** Geometric center of all PTVs
- **Dose Calculation algorithm:** Collapsed-Cone
- **Dose-grid** = 1 mm
- **Photon energy:** 6FFF
- **Prescription:** 20 Gy to 99% of the PTV
- **Evaluation Metrics**: Conformity index RTOG and Paddick (CI_{RTOG} & $CI_{Paddick}$), Gradient index ($GI_{Paddick}$), V_{12Gy}, V_{8Gy}, and V_{4Gy} of Normal Brain (Brain – GTV), MUs and estimated beam-on time
- **Statistical Analysis:** One-way ANOVA and Tukey's post-hoc Test

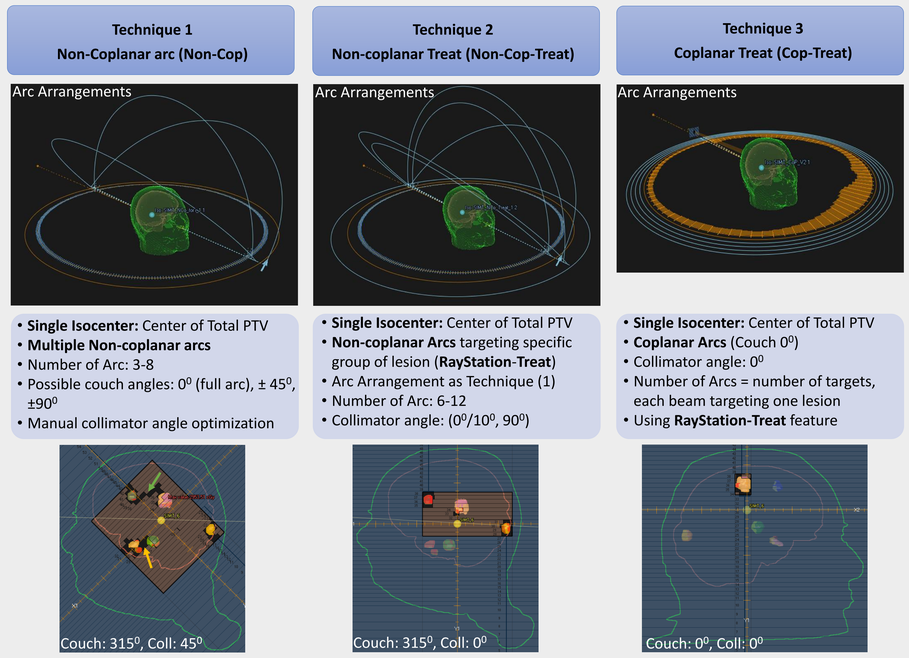

Figure 1 Schematic illustration of three planning strategies, showing the arc arrangement, planning methodology, and beam's-eye view (BEV) for selected arcs. In the BEV for Technique 1, the green arrow indicate multileaf collimator (MLC) repositioning, and yellow arrow highlights the island-blocking effect.

RESULTS

Plan quality and delivery metrics for the three planning strategies are summarized in Chart 1 (a–h).

- All techniques achieved clinically acceptable target conformity, CI_{RTOG} (Chart 1a) remained ≤1.5 for all lesions, while $CI_{Paddick}$ (Chart 1b) was comparable across techniques. One-way ANOVA demonstrated no significant differences in CI_{RTOG} (p=0.904) or $CI_{Paddick}$ (p=0.928).
- A significant difference was observed for $GI_{Paddick}$ (Chart 1c) (F=8.302, p=0.002). Tukey analysis showed significantly lower gradient indices for both Non-Cop-Treat (Technique 2) and Cop-Treat (Technique 3) compared with the manually optimized Non-Cop technique (p=0.003 and p=0.009, respectively), with no difference between the treat-based strategies (p=0.845), indicating improved dose fall-off.
- Normal brain dose metrics remained clinically acceptable, with V_{12Gy} <30 cm^3 for all plans. Normal brain dose metrics remained clinically acceptable, with V_{12Gy} <30 cm^3 for all plans. While differences in V_{12Gy}, V_{8Gy}, and V_{4Gy} were not statistically significant (all p>0.05), Non-Cop-Treat demonstrated lower brain doses in a majority of plans compared. Cop-Treat achieved comparable V_{12Gy}, V8Gy and V4Gy with Non-cop-treat.
- Delivery efficiency differed significantly among techniques. MU per lesion and estimated beam-on time increased progressively from Non-Cop to Non-Cop-Treat and Cop-Treat (both p<0.0001), with Tukey analysis confirming significant pairwise differences. These findings demonstrate that lesion grouping improves dose gradient while maintaining comparable target conformity, with a trade-off of increased monitor units and treatment delivery time.

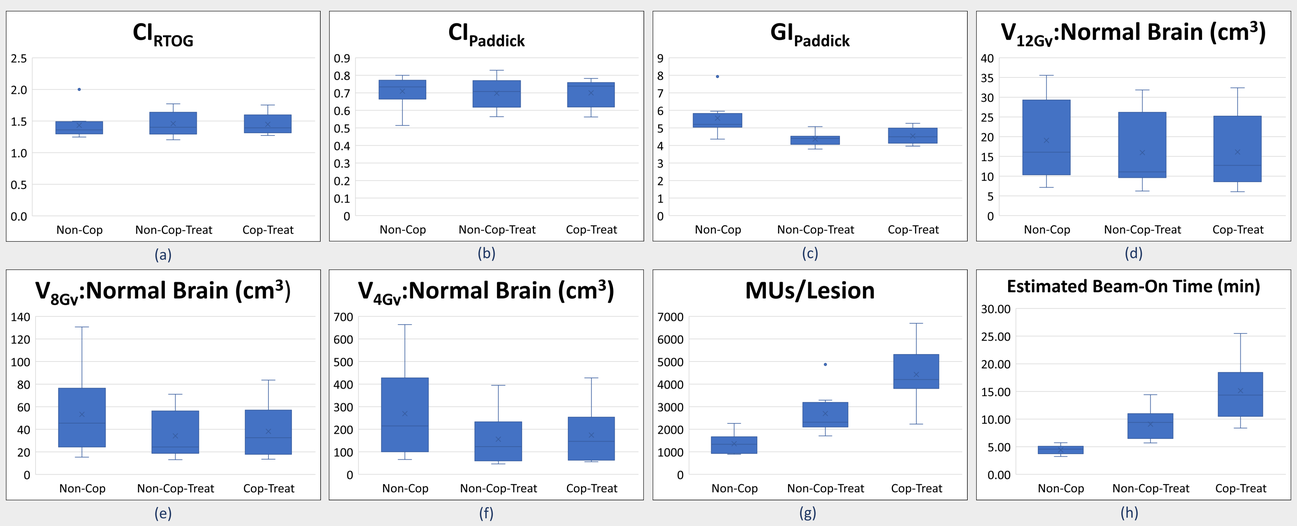

Chart 1. Box plot comparison of plan quality and delivery metrics for three single-isocenter VMAT SRS planning strategies. (a) RTOG conformity index (CI_{RTOG}), (b) Paddick conformity index ($CI_{Paddick}$), (c) gradient index ($GI_{Paddick}$), (d) V_{12Gy} of normal brain, (e) V_{8Gy} of normal brain, (f) V_{4Gy} of normal brain, (g) Monitor units per lesion (MUs/lesion), and (f) beam-on time estimated for 6FFF delivery at 1400 MU/min.

DISCUSSION

Overall, plan quality and normal brain dose were influenced by patient-specific factors (number of lesion, size, and spatial distribution). For patients with up to five lesions, all three planning strategies produced comparable dosimetric quality, and automated couch and collimator optimization will improve planning efficiency. As the number of lesions increases, however, manual optimization becomes increasingly challenging due to the island-blocking effect. In these cases, lesion grouping using the RayStation treat feature provides a practical and reproducible planning strategy while maintaining target conformity and improving dose gradient and normal brain sparing. The Cop-Treat technique also offers workflow advantages by simplifying planning and eliminating uncertainties associated with couch rotations. A limitation of this study is that target distance from the isocenter was not considered. Future work will evaluate that and compare the methods to conventional single-isocenter, single-target approach, and develop scripting-based automation of lesion grouping and arc assignment to further improve planning efficiency.

CONCLUSIONS

Single-isocenter SRS for multiple brain metastases is feasible using both coplanar and non-coplanar techniques in RayStation. The HyperArc-style non-coplanar grouped-lesion approach offers a robust and efficient solution, especially for cases with more than five lesions.

REFERENCES

1. Lai et al. Quant Imaging Med Surg. 2025;15(12):12413–12424
2. NRG-BN013 (NCT06500455). ClinicalTrials.