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Dosimetric Comparison Between Geometric Centroid and Minimax Isocenter Placement in Multitarget HyperArc Fractionated Stereotactic Radiosurgery Plans

Introduction

Varian HyperArc conventionally utilizes the geometric centroid of all targets for isocenter placement. While this method is computationally efficient and produces high quality plans, its reliance on target clustering can result in significant distances to outlier lesions. Studies have shown that these distant outlier lesions are more susceptible to coverage loss due to rotational and setup errors.

One method to mitigate this sensitivity is to minimize the worst-case lesion to isocenter distance, or the “minimax” method. The minimax isocenter is the spatial coordinate that minimizes the maximum distance from the isocenter to any single target, theoretically improving plan robustness.

The purpose of this study is to compare HyperArc fSRS plan quality using the standard geometric centroid isocenter placement versus an optimized minimax isocenter location for patients with multiple brain metastases.

Methods

Two plans were generated for each of ten anonymized patients previously treated at Essentia Health in Duluth, MN: one plan using HyperArc’s default isocenter placement, and another using the minimax isocenter placement. The prescription dose for all lesions was 27 Gy.

For the minimax method, a Python script was written to determine the minimax isocenter location using the center of mass of each lesion as a 3D point in space, consistent with HyperArc’s geometric centroid isocenter calculation. The minimax isocenter was then set manually, and new collimator angles were optimized in the HyperArc workspace. All optimization objectives were consistent between the two techniques.

Quality Metrics

Various metrics were analyzed for each PTV to assess overall plan quality, including the Paddick Conformity Index (CI), gradient index (GI), V100%, D2%, D95%, D98%, minimum dose, and maximum dose.

In addition to PTV metrics, total V50%, whole brain V10Gy, V12Gy, and V20Gy were all assessed for changes. Dose to all organs at risk were analyzed as well.

Results

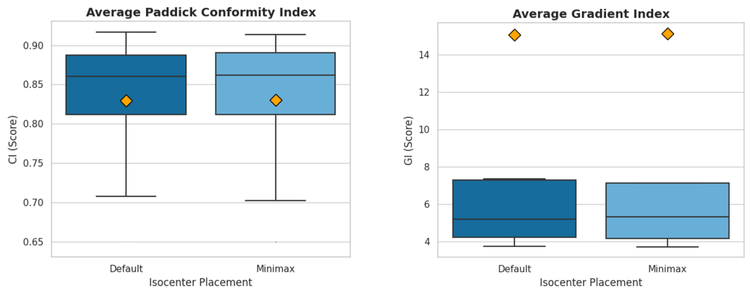

Fig 1 & 2. Paddick Conformity Index and gradient index for default isocenter and minimax isocenter placements, with the mean values included.

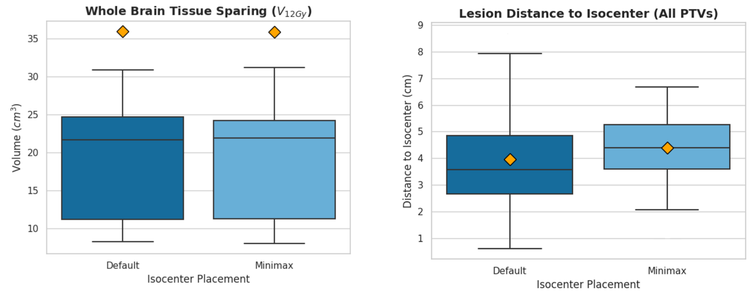

Fig 3 & 4. Brain V12Gy and isocenter-to-PTV distance for default isocenter and minimax isocenter placements, with the mean values included.

Metric	Default Isocenter	Minimax Isocenter	*p* value
Paddick CI	0.830	0.830	0.7076
GI	15.09	15.14	0.3262
PTV V100%	96.36%	96.38%	0.9379
D2%	37.25 Gy	37.51 Gy	0.1720
D98%	26.67 Gy	26.67 Gy	0.9320
Brain V10Gy	45.58 cm^3	45.46 cm^3	0.5884
Brain V12Gy	35.96 cm^3	35.90 cm^3	0.5935
Total V50%	35.01 cm^3	34.95 cm^3	0.3797
Total MU	3457	3449	0.8460

Table 1. Paired t-tests were performed, and no statistically significant changes were observed across all metrics. The average plan metrics are shown above.

Conclusion

Shifting from HyperArc’s default geometric centroid isocenter placement to the minimax isocenter location maintained plan quality across all primary indices for patients with 3-5 lesions . Although the average distance to isocenter increased, there was no compromise in prescription dose coverage, Paddick CI, GI, or whole brain V12Gy. These findings suggest that isocenter placement can be optimized for mechanical robustness without degrading plan quality or dosimetric outcomes.

Limitations

The patient population was limited to those previously treated on CyberKnife, and all patients in this study had 3-5 lesions. In addition, the largest lesion to isocenter distance for the minimax plans was 6.68 cm. The results may not necessarily apply for patients with lesions that exceed these marks, and further studies are warranted to determine if plan quality is impacted in these cases.

References

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