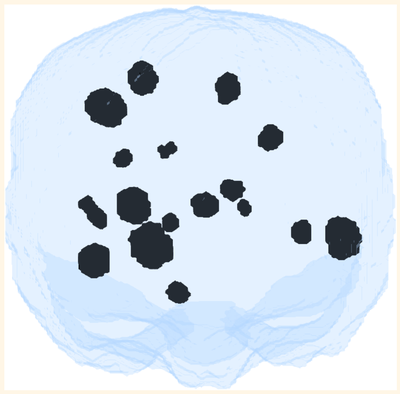
A Rapid Target-Clustering Metric for Multi-Target Radiotherapy

Vinayak Mull [1], R. Lee MacDonald [1,2,3], Christopher G. Thomas [1,2,3,4], Alasdair Syme [1,2,3]

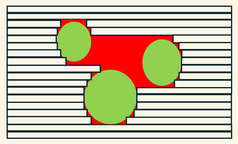
1 Department of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, Canada
2 Department of Medical Physics, Nova Scotia Health, Queen Elizabeth II Health Sciences Centre, Halifax, Nova Scotia, Canada
3 Department of Radiation Oncology, Dalhousie University, Halifax, Nova Scotia, Canada
4 Department of Radiology, Dalhousie University, Halifax, Nova Scotia, Canada

Introduction

- In multi-target SRS, targets treated from a common isocenter are constrained by rotational setup uncertainty, which increases with distance from the isocenter. [1] As target number increases, manually selecting which targets should be treated together becomes difficult, time-consuming, and planner dependent.



- The quality of a target cluster depends on both inter-target distance and relative 3D geometry. Poor clustering can lead to inefficient collimation, increased aperture island-blocking, and higher normal brain dose, including V12Gy, a toxicity surrogate associated with radiation necrosis.[2]



- Existing automated approaches often estimate island blocking from target projections across candidate beam angles. These methods can become computationally infeasible for large target numbers, require prior choices about cluster count and arc geometry, and may under-represent 3D depth relationships and inter-cluster crossfire. [3]

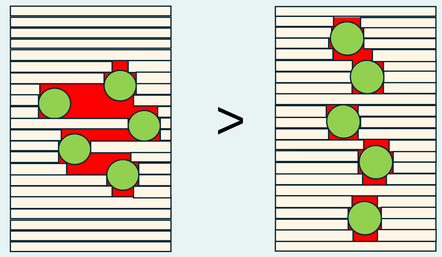
Methods

We have developed a fast, geometry-driven and fully automated clustering workflow that selects cluster combinations directly from the 3D target distribution and then optimizes arc geometry for the final dose optimization.

1. **Generate valid clusters** – Generate clusters such that all targets in a cluster must lie within **6 cm** of the volume-weighted cluster isocentre.

2. **Score each cluster** - Cluster score increases with target-envelope size and non-linearity.

Geometry score ≈ cluster size × non-linearity



3. **Score cluster combinations –** Each cluster combination is scored by balancing the total cluster score with the worst individual cluster score.

4. **Optimize delivery geometry –**
   - The lowest-scoring cluster combination is selected.
   - The algorithm selects couch-shifted four-arc templates that reduce overlap between clusters in beam's-eye view while maintaining adequate angular coverage of each target.
   - Collimator angles and jaw positions are optimized to reduce intra-cluster island blocking.

5. **Export to Eclipse -** Plans are exported to Eclipse for dose optimization.

Results

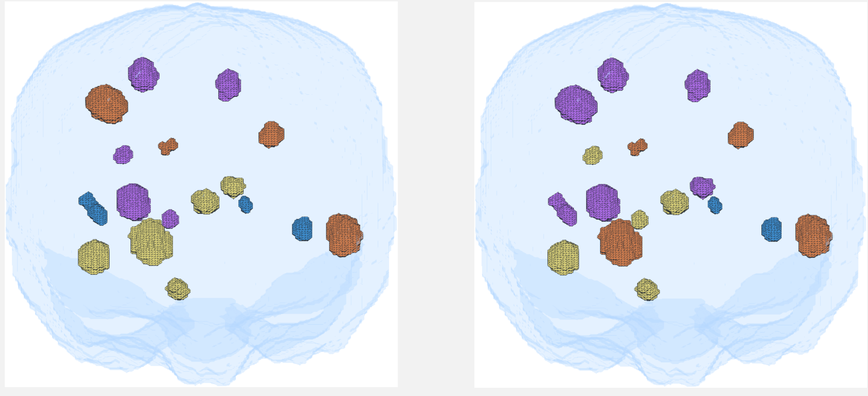
- Three simulated high-target-count SRS cases were evaluated:
  - 15, 17, and 20 metastases
  - Patient-derived brain/OAR anatomy
  - Randomly selected real metastasis contours resized to 5-15 mm and randomly placed within the brain

- For each case:
  - Best- and worst-scoring cluster combinations were planned in Varian Eclipse
  - Same planning workflow was used for both combinations
  - All targets met coverage criteria, with ≥99% of each target volume receiving prescription dose

- **Best-scoring cluster combinations had lower normal brain V12Gy than worst-scoring combinations in all three cases with no meaningful differences in OAR maximum doses.**

Mets	Worst V12Gy (cc)	Best V12Gy (cc)	V12Gy reduction (cc)
15	105.93	51.40	54.53 (51.47%)
17	147.48	103.61	43.87 (29.75%)
20	213.60	128.80	84.8 (39.70%)

Best (score=0.28) **Worst (score=0.71)**



Representative 17-metastasis case: best- and worst-scoring cluster combinations

Conclusion

Our automated clustering algorithm identified cluster combinations with **29.8-51.5%** lower normal brain V12Gy than the worst-scoring combinations across the three tested cases.

Future

- Fine-tune the geometry-risk metric to improve agreement with final dose outcomes.
- Evaluate intermediate-scoring cluster combinations as well and compare with an external baseline.
- Test on a larger simulated and clinical cohort.
- Perform statistical analysis of V12Gy reduction, OAR doses, and planning efficiency.

References

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Contact

Vinayak.mull@nshealth.ca
Vinayak.mull@dal.ca

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