Automatic Selection of Isocenter(s) and Minimization of Normal Tissue Dose for Multi-Target Oligometastatic Extracranial SABR

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Introduction

- The Stereotactic Ablative Radiotherapy for the Comprehensive Treatment of Oligometastases (SABR-COMET) trials have shown that ablating all sites in extracranial polymetastatic disease provides demonstrable clinical benefit, at the cost of extended treatment times.
- Targets may be clustered together and treated with shared isocenters for more efficient delivery
- Increased distance between targets and its isocenters results in greater rotational uncertainties and potential loss of target coverage or increased dose to organs at risk (OARs).
- A method by Chang et al. was used to determine PTV margin required to achieve a set probability of target coverage given the distance between target and isocenter and an assumed translational and rotational error (Figure 1) [1].

Purpose

To develop and evaluate an automated method for target grouping and isocenter selection that minimizes normal tissue dose while maintaining target coverage for multi-target extracranial SABR.

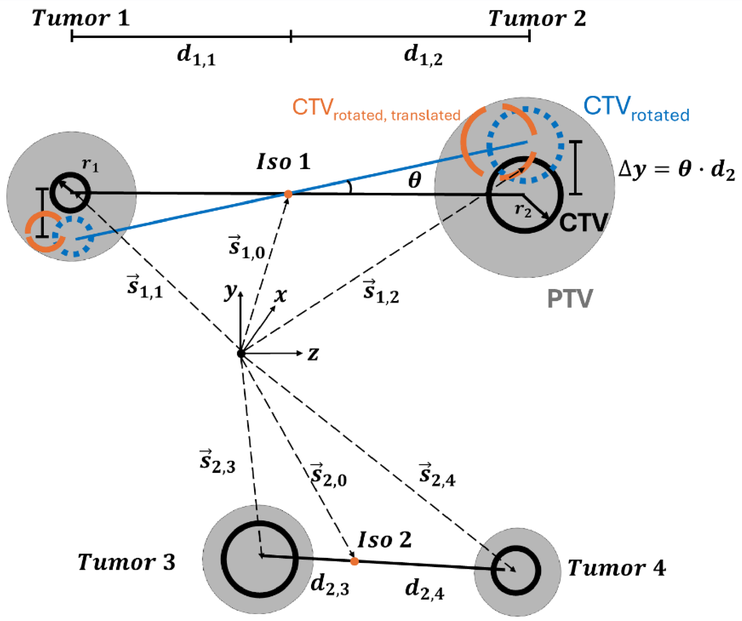

Figure 1. In addition to rigid translational errors, rotational uncertainties θ introduce additional errors Δ that increase with distance from isocenter d.

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Methods and Materials

- Agglomerative hierarchical clustering using Ward's minimum variance method (HC) was used to automate target grouping and isocenter assignment in RayStation 2024A on a proof-of-concept 12 lung target case.
- Clustering was performed iteratively such that for N=1 isocenters, all targets were in a single isocenter group; for N=2, all targets were divided into two groups, etc.
- For each cluster set, margins were calculated such that 95% of the GTV received the prescription dose when accounting for a 2° rotational error and 5 mm translational error
- For each set of N=1 to 12 isocenters, the point of maximum curvature was used to find the final number of isocenters [2].
- Treatment plans were generated with margin expansions of (i) 5 mm uniform margins (ii) 10 mm uniform margins, (iii) Dynamic margins (DM) based on Chang's method

Results

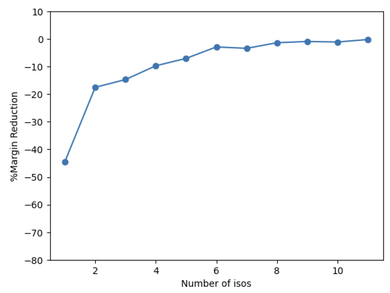

Figure 2. Percent margin reduction from N to N-1 isocenters. As more isocenters are added, the reduction in total margin volume becomes asymptotic.

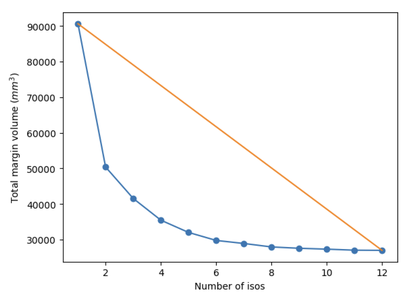

Figure 3. To determine the final number of isocenters and their positions, the total margin volume V_N for a given isocenter arrangement was plotted against the number of isocenters N. The maximum distance to the line drawn between the points at $[1,V_1]$ and $[M,V_M]$ was used to determine the point of maximum curvature and chosen as the isocenter arrangement to use.

Lung-GTV Metric	5 mm Margin	Dynamic Margin	10 mm Margin
D_{mean} [Gy]	6.8	7.2	10.9
$V_{13.5\,Gy}$ [cc]	326.1	392.1	894.9
$V_{20\,Gy}$ [%]	3.9	4.8	11.8

Table 1. DVH metrics for the Lung-GTV subvolume for plans generated using 5 mm, 10 mm, and dynamic margin expansions. Mean DM expansion was 5.75 [5.21-6.63] mm

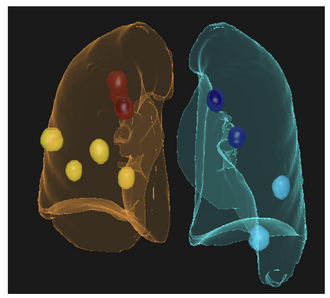

Figure 4. HC resulted in 4 separate clusters, color coded as yellow, red, blue, and teal.

Results

- Target coverage for the DM plan was similar to the 5 mm uniform expansion (Figure 5)
  - Lung-GTV dose metrics were similar for the DM and 5 mm margin plan (Table 1)
  - Lung-GTV dose metrics were superior for the DM plan compared to the 10 mm margin plan (Table 1)
- For a set of 6 test cases, automated clustering using HC resulted in an average total margin reduction of 4.5% compared to clinically used clusters manually determined by dosimetrists (Figure 6)

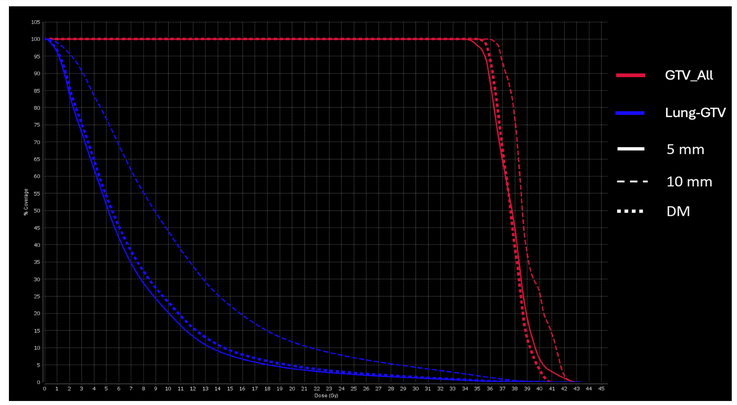

Figure 5. DVH for plans generated using the HC determined isocenter arrangement. Plots are shown for the union of all 12 GTVs (GTV_All, red) as well as the normal lung volume (Lung-GTV, blue). Plans were generated using PTV margins of 5 mm, 10 mm, and dynamic margins.

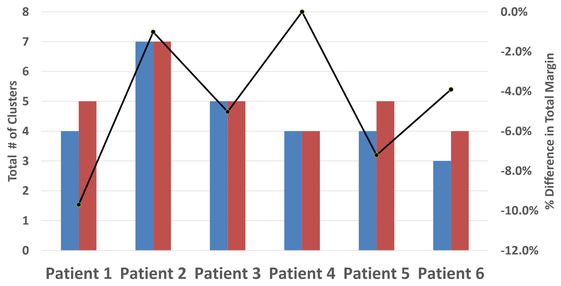

Figure 6. Comparison of manually determined clinically used clusters and automated clusters and the % difference in total margin volume between the two when DM using HC was used. For Patient 4, the clinically used and HC determined clusters were identical, resulting in the same total margin volume.

Conclusions

- Dosimetric results were limited to a single patient as proof of concept
- DM using HC can achieve superior lung dose versus 10 mm uniform margin expansion and similar lung dose and GTV coverage as less conservative 5 mm margins
- HC can efficiently determine isocenter assignment with only minimal increases in target margin and Lung-GTV dose.

References

1. J. Chang, "A statistical model for analyzing the rotational error of single isocenter for multiple targets technique," Medical Physics, no. 44, pp. 2115-2123, 2017.
2. V. Satopaa, et al., "Finding a "Kneedle" in a Haystack: Detecting Knee Points in System Behavior," in 2011