Single-isocenter SBRT for Five or More Liver Metastases: Impact of Rotational Setup Uncertainty on Target Coverage

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ABSTRACT

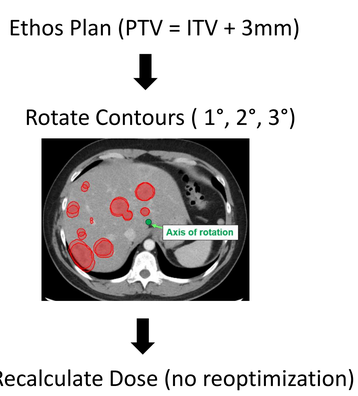
Single-isocenter stereotactic body radiotherapy (SBRT) enables efficient treatment of patients with multiple liver metastases but increases sensitivity to rotational setup uncertainty because translational corrections cannot compensate for rotational displacement of individual targets. This study evaluated the dosimetric impact of rotational error in three single-isocenter liver SBRT plans comprising 36 metastatic targets (mean: 12 targets per plan). Plans were generated in Ethos 2.0 and optimized to the planning target volume (PTV = ITV + 3 mm) such that all targets achieved the clinical coverage goal (V5000cGy ≥ 95%) in the simulation geometry. Target contours were then rigidly rotated by 1°, 2°, and 3° about the superior–inferior axis while treatment plans remained unchanged (i.e. not reoptimized), and target coverage was recalculated in Eclipse for PTV, ITV + 2 mm, and ITV + 1 mm target expansions. Coverage decreased with increasing rotational error, with 5, 23, and 29 targets failing the clinical PTV coverage criterion at 1°, 2°, and 3°, respectively. Although smaller targets located farther from isocenter were generally more susceptible to coverage loss, rotational sensitivity varied substantially across targets. Several distant lesions maintained adequate coverage despite large rotational offsets, suggesting that plan-specific dose distributions, including overlap with neighboring treated targets, can mitigate rotational effects. These findings demonstrate that rotational uncertainty can meaningfully affect target coverage in single-isocenter liver SBRT and should be considered during treatment planning and delivery, particularly for patients with numerous metastases.

INTRODUCTION

The use of stereotactic body radiotherapy (SBRT) for patients with multiple liver metastases has increased as advances in treatment planning and delivery have enabled efficient treatment of numerous lesions in a limited number of fractions. Compared with multiple-isocenter approaches, single-isocenter techniques substantially reduce treatment time and improve workflow, with only a modest increase in mean liver dose. (Tang 2023) Single-isocenter treatments are inherently more sensitive to rotational setup uncertainty because all lesions share a common isocenter. Although translational image guidance can partially compensate for rotational errors, these corrections cannot simultaneously optimize alignment for multiple spatially separated targets. This challenge may be further compounded by automated planning systems, such as Ethos 2.0, where manual optimization of isocenter placement may be limited. While geometric models predict increasing displacement with distance from isocenter, the dosimetric consequences in patients with five or more liver metastases remain poorly characterized. This study quantified the impact of rotational setup uncertainty on target coverage in single-isocenter liver SBRT and evaluated factors associated with coverage degradation.

METHODS

Three single-isocenter liver SBRT plans comprising 36 metastatic targets (mean 12 targets/plan) were generated in Ethos 2.0 and optimized to the planning target volume (PTV = ITV + 3 mm), with all targets meeting the clinical coverage goal (V5000cGy ≥ 95%). Rotational setup uncertainty was simulated by rigidly rotating target contours by 1°, 2°, and 3° about the superior–inferior axis while treatment plans remained unchanged. Dose was recalculated in Eclipse without plan reoptimization, and coverage was evaluated for the PTV and nested ITV+2 mm and ITV+1 mm structures to estimate the extent to which rotational uncertainty consumed the available setup margin.



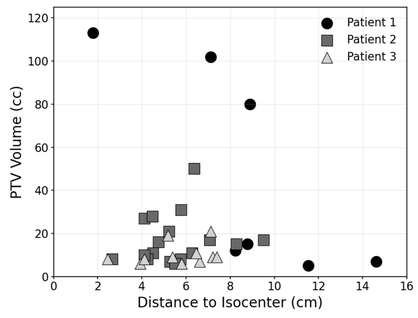


Fig. 1 Scatter plot illustrating the range of target volumes and distances to isocenter.

RESULTS

- **Target coverage progressively decreased with increasing rotational setup error across the analyzed targets.**
- **PTV coverage failures increased from 5 targets at 1° to 23 targets at 2° and 29 targets at 3°. ITV-based evaluations demonstrated greater robustness, with only 5 (ITV+2 mm) and 2 (ITV+1 mm) targets failing at 2°, increasing to 21 and 9 targets, respectively, at 3°.**
- **Smaller targets and lesions farther from isocenter were generally more susceptible to coverage loss; however, variability between targets highlights the influence of local dose distribution and target geometry on rotational robustness.**

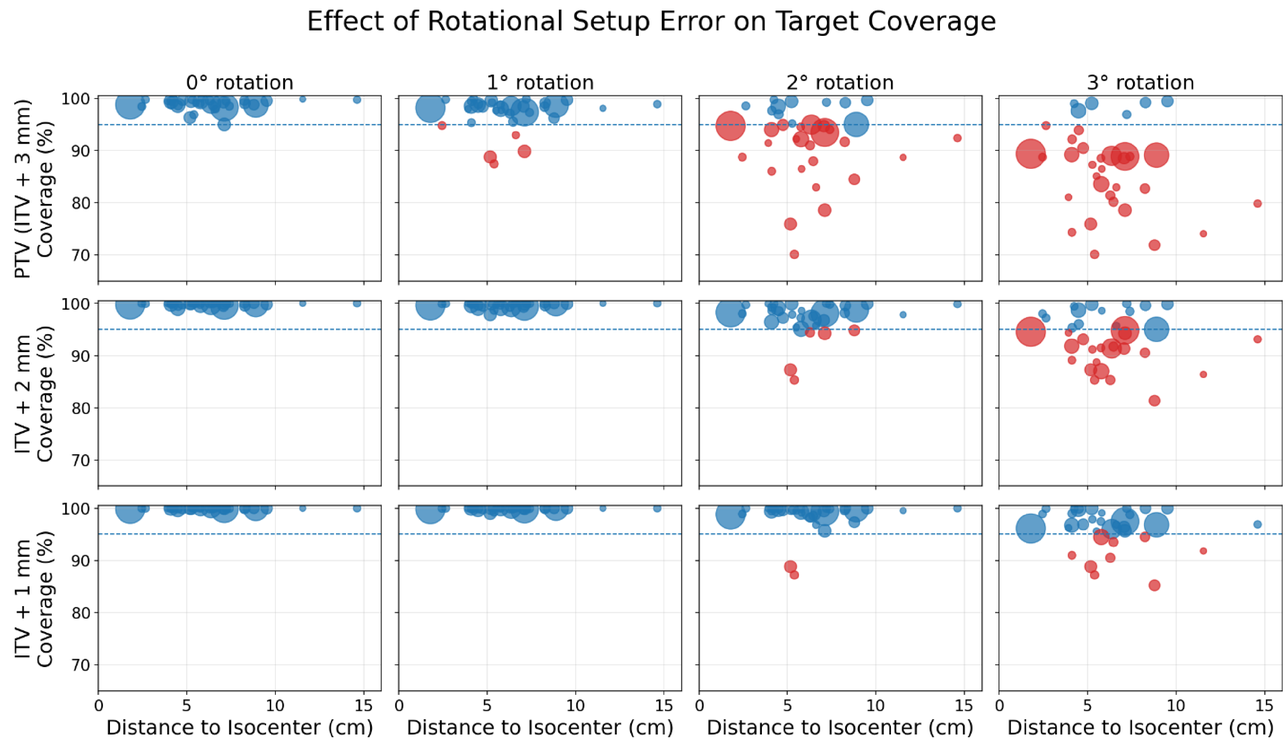


Fig. 2 Target coverage (V5000cGy) as a function of distance from isocenter for rotational offsets of 1°, 2°, and 3°. Each marker represents an individual target, with marker size proportional to target volume. Blue/red markers indicate targets meeting/failing the clinical coverage criterion (V5000cGy ≥ 95%). The dashed line denotes the clinical coverage goal.

CONCLUSIONS

- **Rotational setup errors progressively reduce target coverage in single-isocenter liver SBRT.**
- **Target size and isocenter distance provide limited prediction of robustness, with local dose distribution playing a key role.**
- **Accounting for rotational uncertainty may improve planning and selection of patients undergoing multi-target liver SBRT.**

FUTURE WORK

Future work will include plan reoptimizatioin using multiple PTV margins to quantify the balance between normal tissue sparing and rotational robustness in single-isocenter SBRT for multiple liver metastases.

CONTACT INFORMATION

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