

Be free from repainting in proton PBS free-breathing treatment by planning

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Purpose

In proton therapy with pencil beam scanning (PBS), repainting mitigates respiratory motion effects but increases treatment time, burdening patients who must remain on the couch for extended periods. To address this challenge, we propose an advanced planning strategy that generates multiple plans with varying delivery efficiency and robustness under free-breathing conditions, then uses 4D Monte Carlo (4DMC) to identify an optimal plan that balances efficient delivery and robustness to respiratory motion.

Methods

Our approach employs a dose-influence matrix (D_{ij}) sampling method to generate plans with varying efficiency levels, followed by a time-prediction model to estimate delivery duration. 4DMC evaluates motion robustness, enabling selection of a plan that optimizes both speed and dose accuracy. We delivered the selected plan on a proton delivery system; the time log recorded during beam delivery was used to confirm feasibility and efficiency. Seven reference repainting plans were collected and re-planned for comparison; all computations were performed in our in-house treatment planning system (TPS).

Results

The percentage difference of 4DMC dose-volume histograms (DVHs) metrics between Raystation repainting plans and in-house non-repainting plans was summarized: At efficient-level 1, the differences were $2.33 \pm 3.32\%$ for the clinical target volume (CTV) and $-0.75 \pm 4.01\%$ for organs at risk (OARs); at efficient-level 2, the differences were $3.51 \pm 3.83\%$ for CTV and $0.03 \pm 4.67\%$ for OARs. In terms of delivery time, efficient-level 1 achieved a $69.9 \pm 2.7\%$ reduction, while efficient-level 2 achieved an $81.8 \pm 1.5\%$ reduction. All 15 tested beams passed the physical delivery test; the deviation of the time model prediction was -0.12 ± 0.89 seconds.

Conclusion

Using 4DMC dose calculations and actual beam-delivery tests, we demonstrated the feasibility, robustness, and delivery efficiency of our proposed in-house advanced planning method for proton therapy. This approach offers a practical and efficient alternative to conventional repainting strategies in PBS proton therapy.

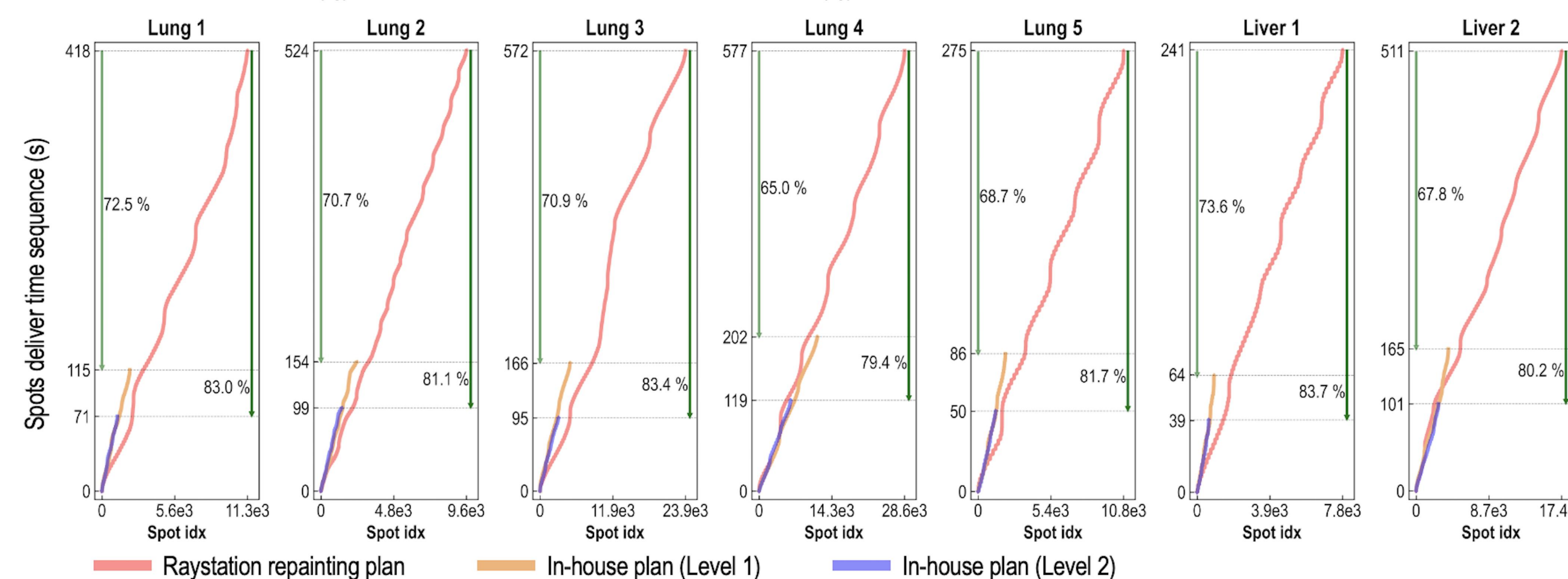


Figure 1. Spot delivery time sequences for the Raystation repainting and in-house plans at efficient levels 1 and 2.

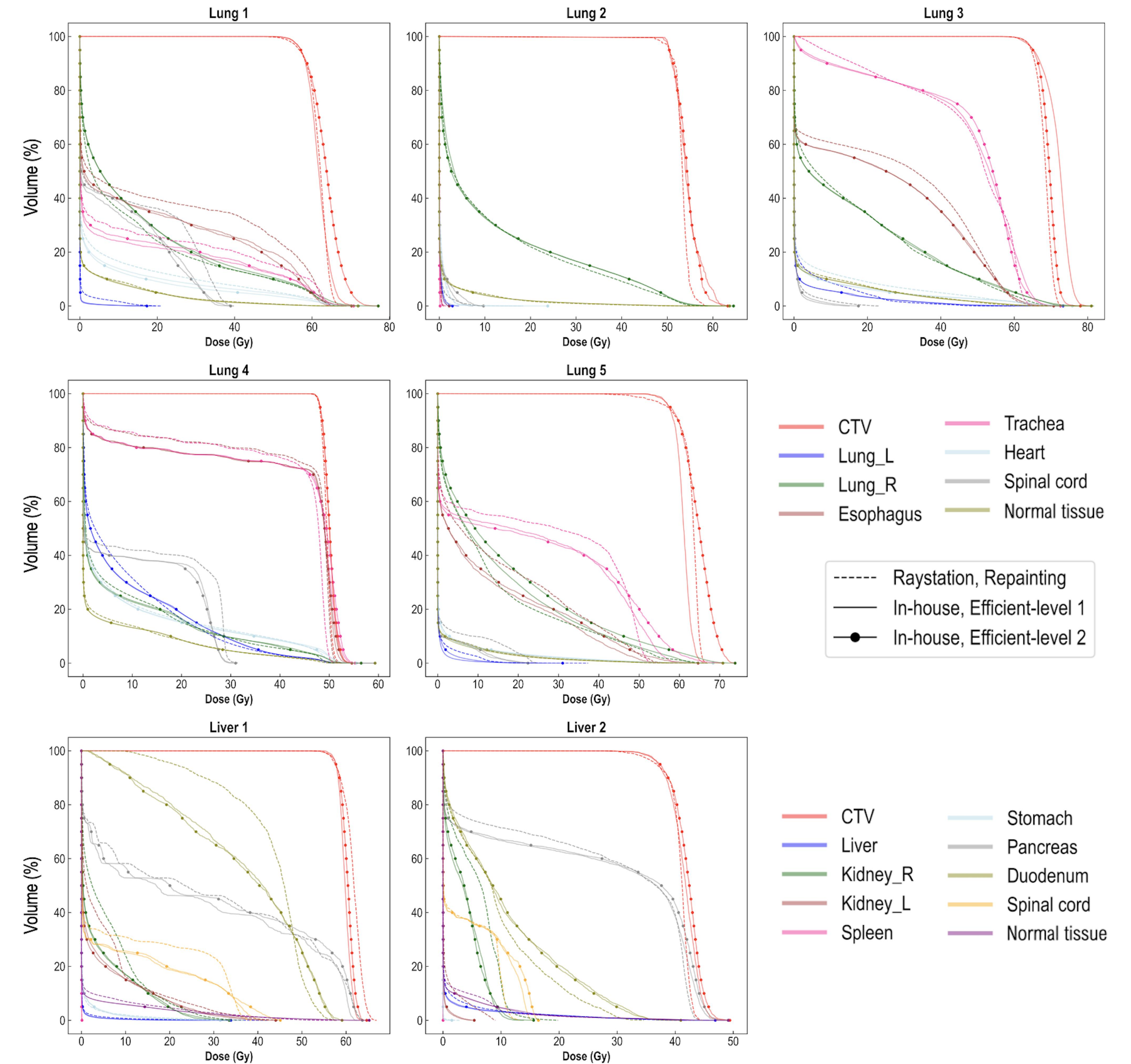


Figure 1. DVHs of 4DMC doses for the Raystation repainting and in-house plans at efficient levels 1 and 2.