Impact of Energy Layer Spacing on Treatment Delivery Time and Plan Quality in Intensity-Modulated Proton Therapy for Breath-Hold Cancer Patients

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BACKGROUND:

Reducing treatment delivery time in intensity-modulated proton therapy (IMPT) is essential for improving treatment efficiency and minimizing positional deviations, especially in breath-hold (BH) treatments. Shorter delivery times are crucial for simplifying treatment and increasing patient eligibility for BH-based therapies.

AIM:

This study evaluates the impact of energy-layer spacing (ELS) on treatment plan quality and delivery time in BH cancer patients.

MATERIALS/METHODS:

- Under IRB approval, 20 BH cases previously treated with IMPT were selected for this study. The cases included 7 liver, 5 thoracic, 4 abdominal, 3 pancreatic, and 1 esophageal tumor.
- All clinical treatment plans were generated using the RaySation 11B treatment planning system with an energy layer spacing scale factor (ELS-SF) of 1.0. Target volume sizes ranged from 8.7 to 756.3 cc.

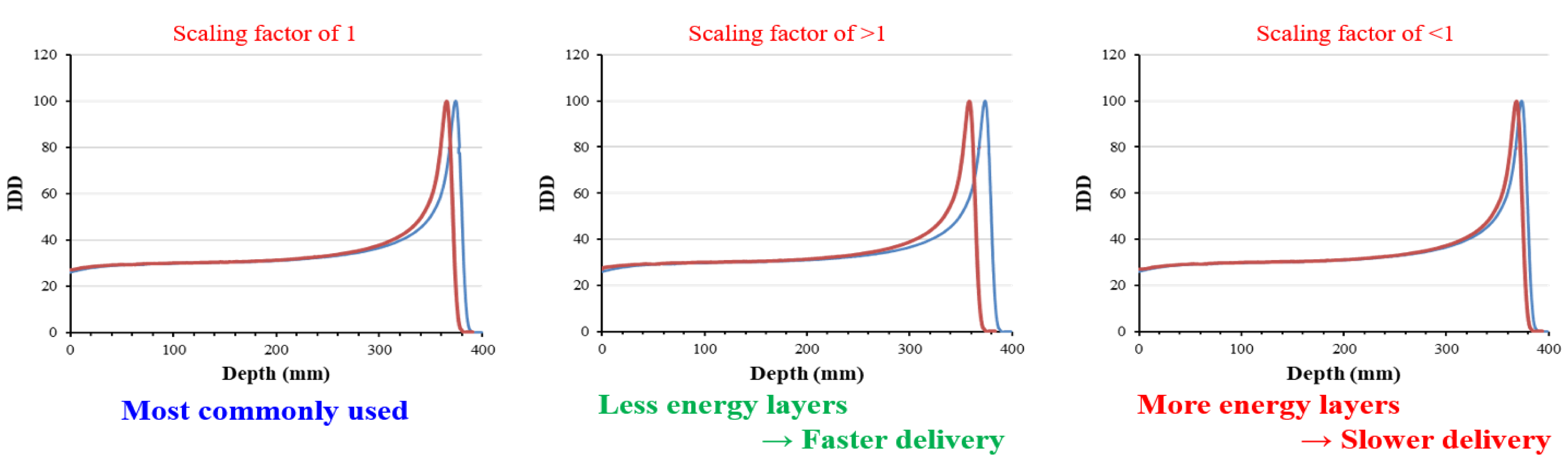


Figure 1: *Impact of Energy Layer Spacing Scale Factor (ELS-SF) on IDD curves in proton therapy. Left: ELS-SF = 1.0 (standard layer spacing). Middle: ELS-SF > 1 reduces energy layers for faster delivery. Right: ELS-SF < 1 increases layers for finer control but slower delivery. Red and blue curves show IDD variations across settings.*

- For each case, ten additional plans were created with varying ELS values (1.1 to 2.0, in 0.1 increments), while maintaining the same optimization parameters.
- The quality of each plan was evaluated by comparing target coverage, organ-at-risk (OAR) doses, and high-dose volumes to the original plan.
- Treatment delivery time reductions were estimated using an in-house program that incorporated machine delivery parameters.

RESULTS:

- Plans with higher energy ELS-SF up to 1.6 maintained similar plan quality, with no significant changes in target coverage or OAR doses. However, at an ELS-SF of 1.7, one patient plan exhibited unacceptable high-dose volumes (>20cc).

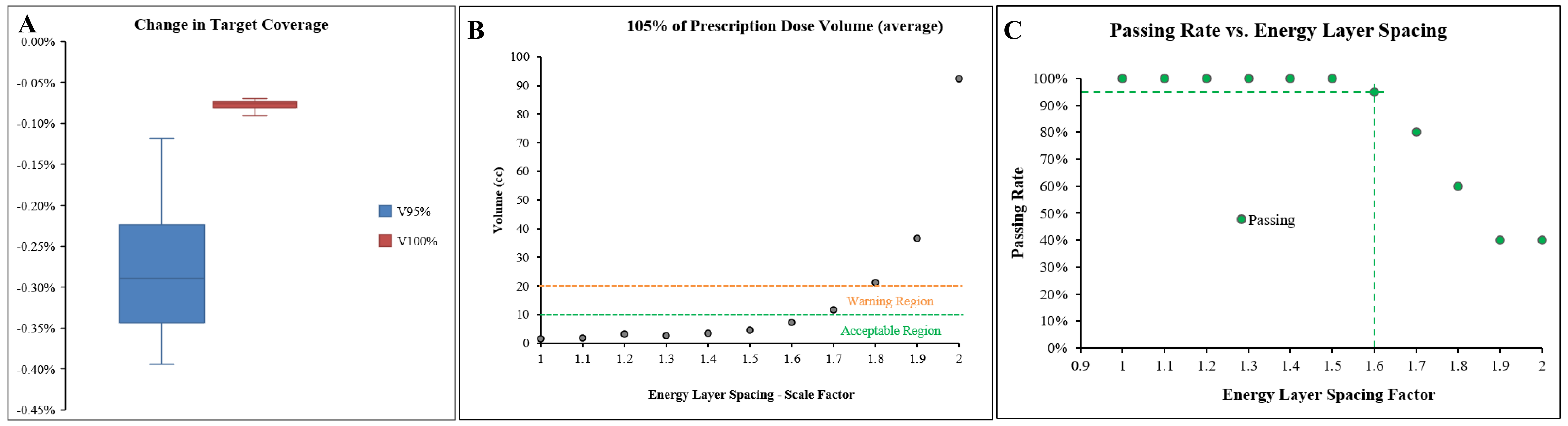
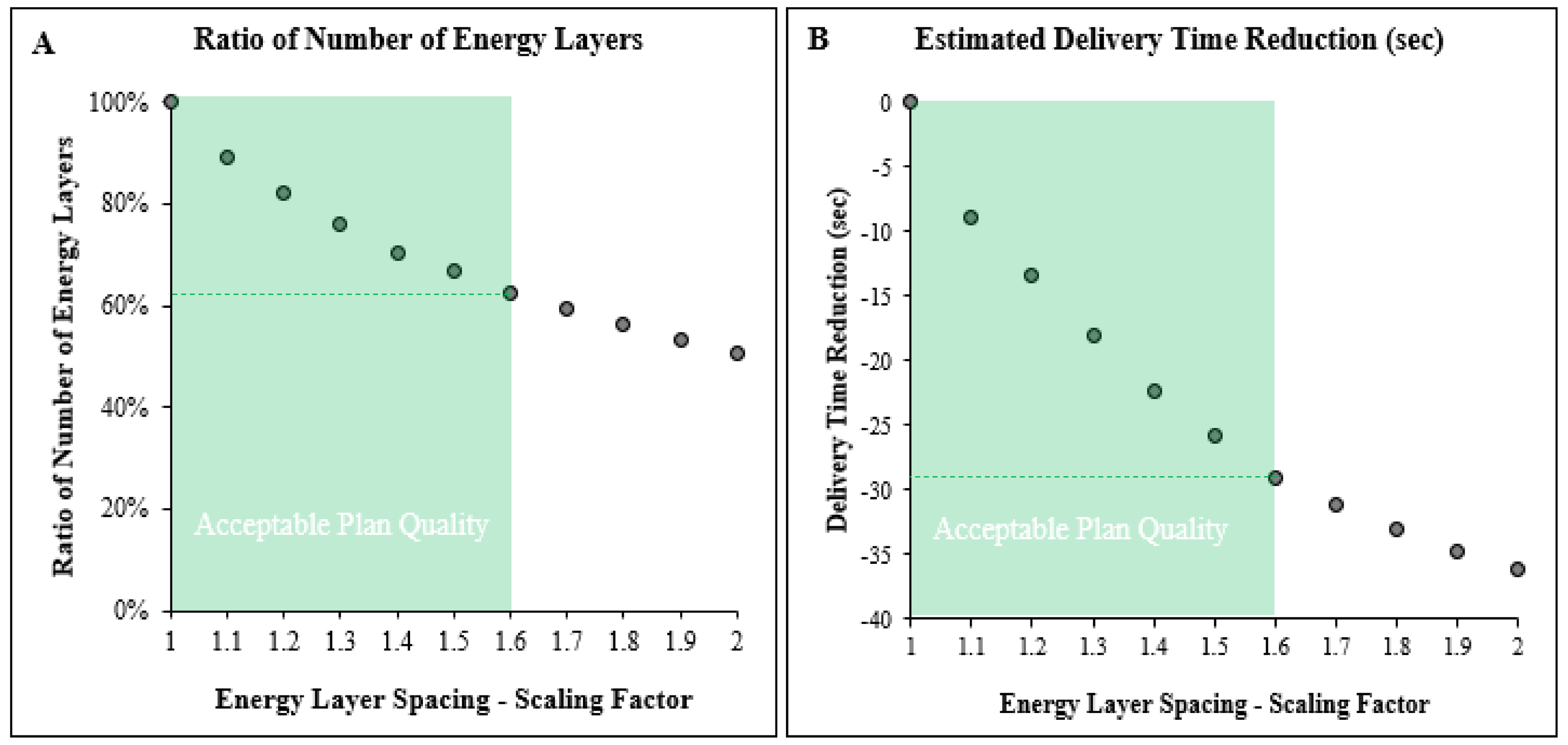


Figure 2: *A) No clinically significant difference observed in target coverage, B) Volume of 105% of prescription is acceptable (<10cc) using higher energy layer spacing scale factor (ELS-SF) up to 1.6, C) Passing rate of plan quality is shown as a function of spot spacing.*

- When compared to the original plan, the number of energy layers decreased by 36.43±5.45% in plans with an ELS-SF of 1.6. This reduction in energy layers resulted in an average treatment delivery time reduction of 25.06±12.02 seconds (28.72±6.81%).

Figure 3: *A) Ratio of number of energy layers 1.1 to 2.0 energy layer spacing scale factor (ELS-SF) relative to the clinical plan using 1.0 ELS-SF. B) Estimated delivery time reduction using higher ELS-SF relative to the one used in the clinical plans (1.0). Using 1.6 ELS-SF (acceptable plan quality) decreased the number of energy layers to ~64% and reduces the treatment delivery time by ~25 seconds.*



CONCLUSION:

Our study demonstrates that increasing the ELS-SF from 1.0 to 1.6 maintains comparable plan quality while reducing the number of energy layers by approximately 36%. As a result, average treatment delivery time is reduced by about 25 seconds. This approach significantly shortens beam delivery time in IMPT for BH treatments without compromising treatment plan quality.

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