RADIOBIOLOGICAL AND DOSIMETRIC EVALUATION OF DAILY MR-GUIDED ADAPTIVE REPLANNING IN PROSTATE STEREOTACTICBODY RADIATION THERAPY

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Introduction

Prostate stereotactic body radiation therapy (SBRT) delivers large doses in only five fractions, making treatment highly sensitive to daily anatomical variation. Changes in bladder filling, rectal distension, and prostate position may reduce target coverage or increase dose to organs at risk (OARs). MR-guided radiotherapy enables daily adaptive replanning using the patient's anatomy at treatment. While previous studies have demonstrated dosimetric improvements, fewer have evaluated adaptive planning using both clinical dose constraints and radiobiological outcome metrics.

Methods

This retrospective study included 20 patients with localized prostate cancer treated on an Elekta Unity MR-Linac using MR-guided stereotactic body radiotherapy (SBRT) (36.25 Gy in 5 fractions). For each treatment fraction, the clinically delivered adaptive plan was compared with the original reference plan recalculated on the same daily MR anatomy, allowing paired comparisons while controlling for anatomical variation.

Plan quality was evaluated using a scorecard of clinically relevant planning objectives for the planning target volume (PTV) and organs at risk (OARs), including the bladder, rectum, sigmoid colon, urethra, penile bulb, and femoral heads. Each objective was classified as pass or fail.

Radiobiological performance was assessed using the P+ metric (complication-free tumor control probability), which combines tumor control probability (TCP) and normal tissue complication probability (NTCP). McNemar's exact test was used to compare paired scorecard outcomes, while paired P+ values were analyzed using the Wilcoxon signed-rank test. Statistical significance was defined as $p < 0.05$.

Results

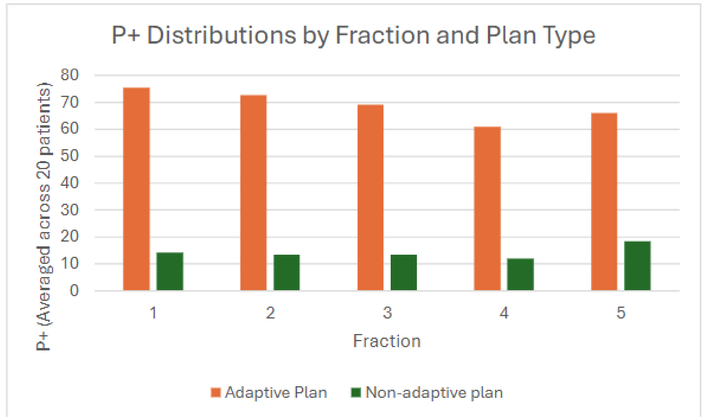

Figure 1. Mean P+ values by treatment fraction. Adaptive plans achieved consistently higher complication-free tumor control probability (P+) than non-adaptive plans across all five treatment fractions.

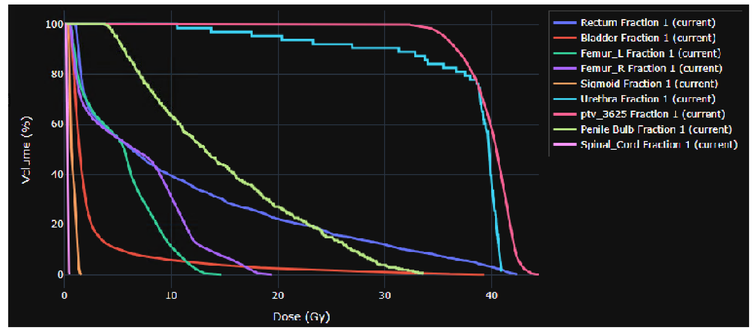

Figure 2. Representative dose-volume histogram (DVH) for an adaptive treatment plan. The adaptive plan achieved adequate target coverage while maintaining clinically acceptable dose to surrounding organs at risk.

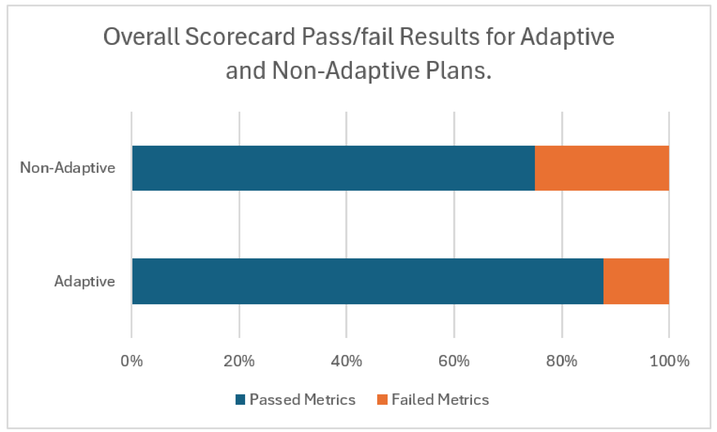

Figure 3. Overall scorecard pass rate for adaptive and non-adaptive plans. Adaptive plans satisfied 87.7% of clinical planning objectives compared with 74.9% for non-adaptive plans, demonstrating significantly improved overall plan quality ($p < 0.001$).

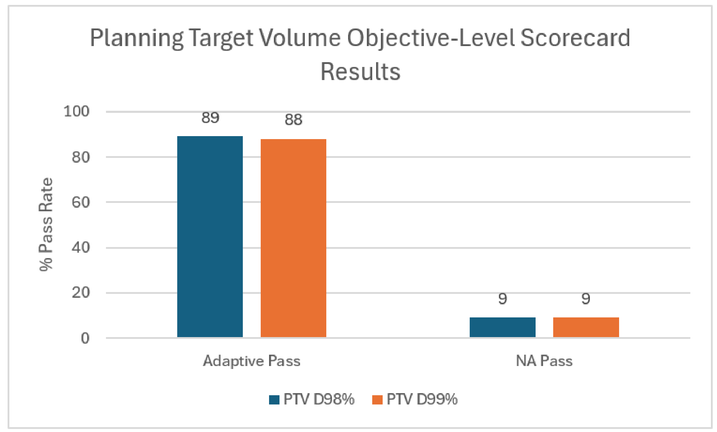

Figure 4. PTV coverage pass rates. Daily adaptive replanning substantially improved target coverage, increasing PTV pass rates from 9.0% for non-adaptive plans to 88.5% for adaptive plans.

Conclusion

Daily MR-guided adaptive replanning significantly improves prostate SBRT treatment quality. Adaptive plans demonstrated superior target coverage, higher overall clinical constraint satisfaction, and significantly improved complication-free tumor control (P+) compared with non-adaptive plans evaluated on identical daily anatomy. These findings support routine adaptive replanning for MR-guided prostate SBRT.

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