Bladder Filling Kinetics and Intrafraction Prostate Motion: Implications for MR-Guided Adaptive SBRT Scan Timing

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Introduction

Maintaining a full bladder during prostate radiotherapy helps reduce bladder toxicity, but the increased length of MR-linac adaptive treatments often makes it not feasible for patients to begin treatment with a full bladder and comfortably maintain it. Instead, patients are instructed to void their bladder and drink before treatment which leads to continuous bladder filling during adaptive planning, potentially displacing the prostate.

Purpose

To characterize bladder filling kinetics and associated intrafraction prostate motion to identify optimal MR-adaptive planning timing on the Unity MR-Linac.

Methods

Intrafraction variability was analyzed in six prostate SBRT patients. For each of their five fractions, two to four T2-weighted MRI scans were acquired. Pearson correlation analysis evaluated predictions in bladder filling over time and the relationships between bladder filling and prostate displacement in the superior-inferior, anterior-posterior, and left-right directions. Dosimetric impact was evaluated by recalculating the daily adaptive plan on each intrafraction scan in Monaco.

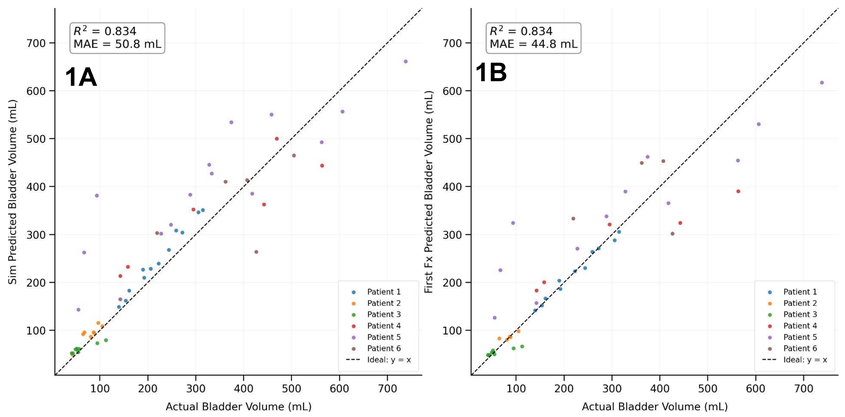

Figure 1. The patient-specific bladder filling kinetics throughout the adaptive treatment process. Bladder volume was predicted using the slope of bladder filling over time from MR simulation (Panel 1A) or the first fraction (Panel 1B) along with the daily starting bladder volume.

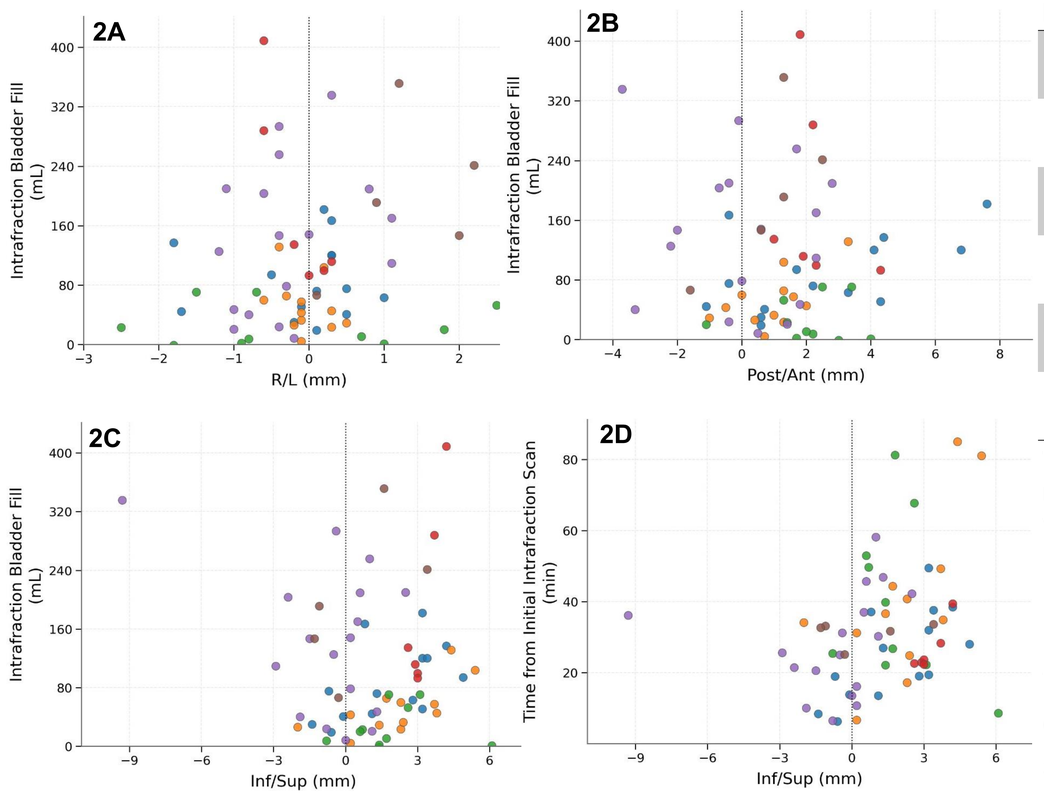

Figure 2. The intrafraction prostate shift with bladder filling in the right/left (Panel A), posterior/anterior (Panel B), and inferior/superior direction (Panel C) and the intrafraction prostate shift with time from the initial intrafraction scan (Panel D).

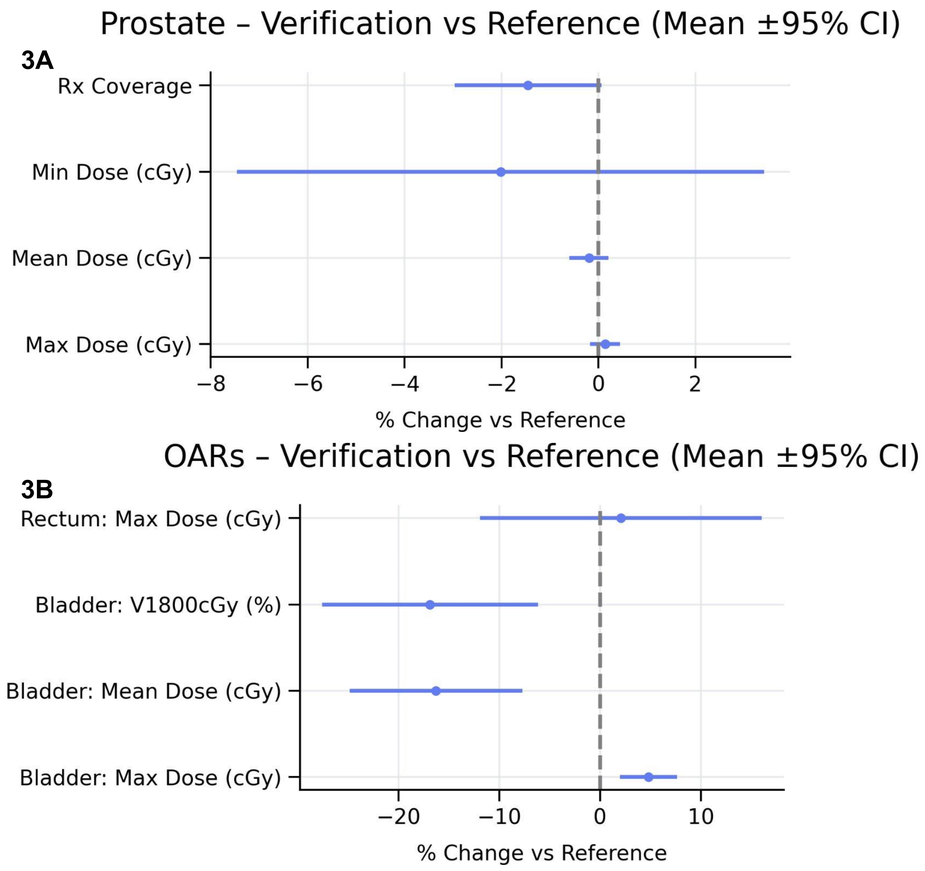

Figure 3. Forest plots with 95% confidence intervals of the % change in dosimetric values from the reference scan to verification scan for the prostate (Panel A) and OARs (Panel B).

Prostate Movement From Reference		Correlation
Right/Left	Δ Intrafraction Bladder Volume	-0.04
	Time from First Intrafraction Scan	-0.17
Inferior/Superior	Δ Intrafraction Bladder Volume	0.34
	Time from First Intrafraction Scan	0.52
Posterior/Anterior	Δ Intrafraction Bladder Volume	0.17
	Time from First Intrafraction Scan	0.39

Table 1. Correlation between prostate movement from the reference scan to the change in intrafraction bladder volume and time from the first intrafraction scan.

Results

Bladder filling increased linearly with time for individual patients, allowing prediction of intrafraction volume using the MR simulation or first fraction fill rate and starting daily bladder volume.

Increased bladder volume and time from initial intrafraction scan produced a systematic inferior prostate shift.

Recalculated plans using the verification scan compared to the initial intrafraction (reference) scan for each fraction had no meaningful degradation in prostate coverage. There was a decrease in the V1800 cGy to the bladder by -16.9% (-27.6%, -6.2%) and mean dose to the bladder of -16.3% (-24.8%, -7.7%). The maximum dose to the bladder increased by an average of 4.8% (2.0, 7.6%).

Conclusions

Bladder filling follows a predictable, patient-specific linear trajectory that is associated with an inferior prostate shift over time. These findings support the use of the void and drink protocol for the MR linac to allow for patient comfort, comparable prostate coverage, and limiting the mean dose to the bladder and % volume receiving 18 Gy.