Prostate Intrafractional Motion In SBRT and PTV Margin Determination

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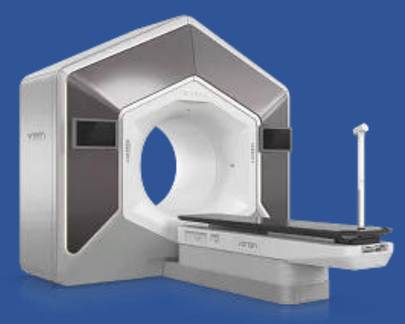
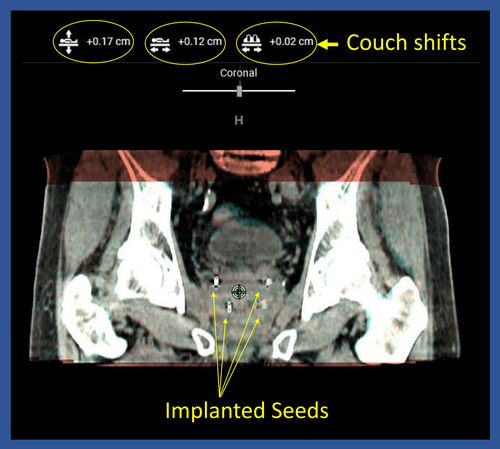
Purpose

Adaptive radiotherapy (ART) enables daily plan adjustment to account for anatomical changes. Given the high doses and tight margins in prostate SBRT, this study quantifies intrafractional prostate motion and its implications in the PTV margins.



Varian Ethos ART system



Fusion of initial CBCT with the second CBCT for one patient

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INTRODUCTION

The use of SBRT for prostate cancer relies on steep dose gradients and small PTV margins to maximize target coverage while sparing surrounding organs at risk. Although online adaptive radiotherapy (ART) addresses interfractional anatomical changes, prostate motion occurring during the adaptive process may compromise target coverage. As adaptive workflows continue to evolve, determining whether PTV margins can be reduced below 3 mm remains an important clinical question. In this study, we characterized intrafractional prostate motion during Ethos-based adaptive prostate SBRT and assessed whether the observed motion supports the use of margins smaller than 3 mm.

METHODS AND MATERIALS

Prostate SBRT treatments were delivered on a Varian Ethos ART platform. A total of 250 fractions from an institutional cohort were analyzed. For each fraction, an initial cone-beam CT (CBCT) was acquired for online adaptive planning. Following plan selection and approval, a second CBCT was obtained immediately prior to beam delivery to verify patient's positioning. All patients had implanted intraprostatic fiducial markers that facilitated the positioning process (illustrated in the prostate image on the left). Translational prostate shifts were recorded, and three-dimensional displacement was calculated. The interval between the two CBCT acquisitions was recorded to evaluate any correlation between elapsed time and intrafractional motion. Shift distributions were assessed across all fractions.

RESULTS

Directional Prostate Motion (Figure 1)
Histograms demonstrated greater posterior than anterior motion and greater inferior than superior motion.

Relationship Between Treatment Time and Prostate Motion (Figure 2) No clear correlation between elapsed time and shift magnitude was observed (P = 0.399).

Distribution of Intrafractional Motion (Figure 3)
Intrafractional prostate shifts were predominantly small: 22% of fractions showed 0–1 mm shifts and 37% showed 1–2mm shifts. Shifts ≤3mm occurred in 77% of fractions, and ≤5 mm in 87%. Larger excursions were uncommon, with 12% exceeding 5mm and 2% exceeding 14 mm.

Bladder Volume and Prostate Motion (Figures 4) no apparent relationship between bladder volume variation and prostate displacement.

Clinical Implications for PTV Margins
The interval between the two CBCT scans ranged from 6.3 to 39 minutes across all fractions. For fractions with ~8-minute intervals, comparable to typical beam delivery time, the maximum observed shift was 3mm. Due to the dose gradient, ~3mm falloff exists between 100% and 90% isodose lines. Combined with the 3-mm PTV margin, prostate shifts up to ~6 mm would still maintain a minimal dose ≥90% of prescription dose, a condition met in 94% of fractions.

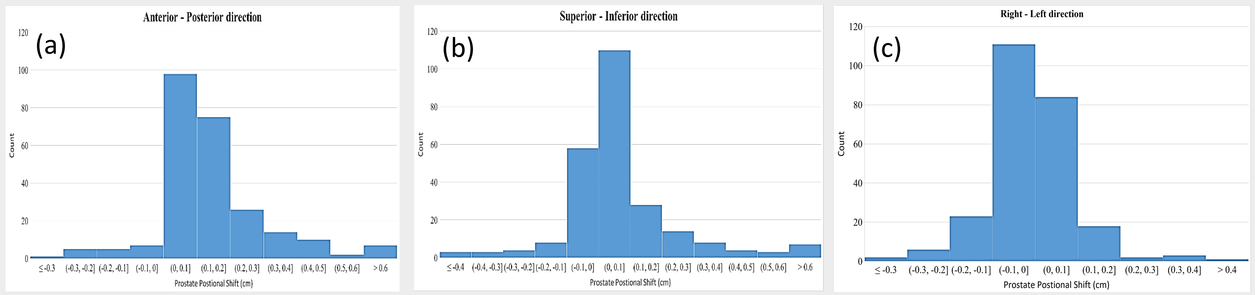

Figure 1 shows histograms of prostate displacement in the anterior–posterior (a), superior–inferior (b), and (c) right-left directions.

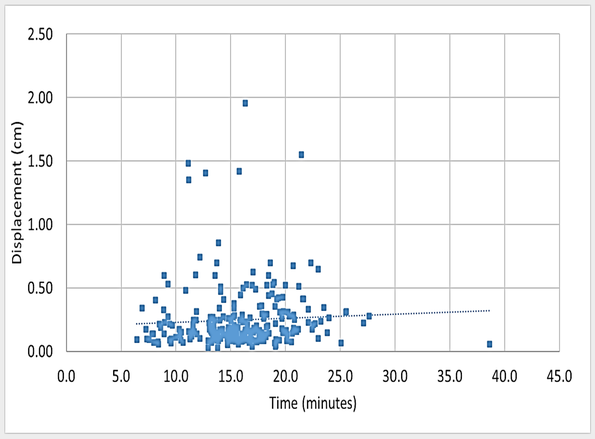

Figure 2 3D prostate displacement versus time, with no significant correlation observed

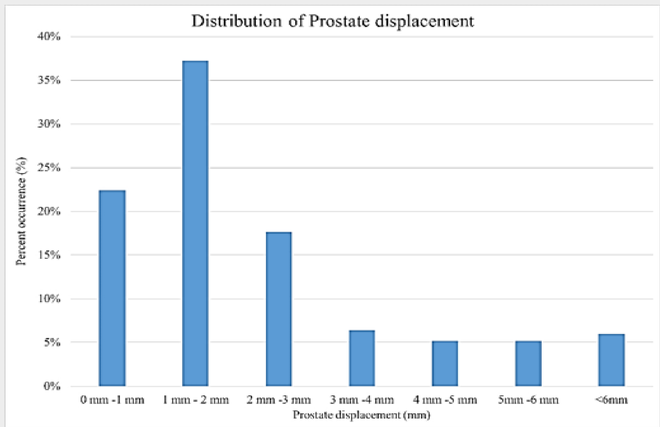

Figure 3 illustrates the distribution of 3D prostate displacement

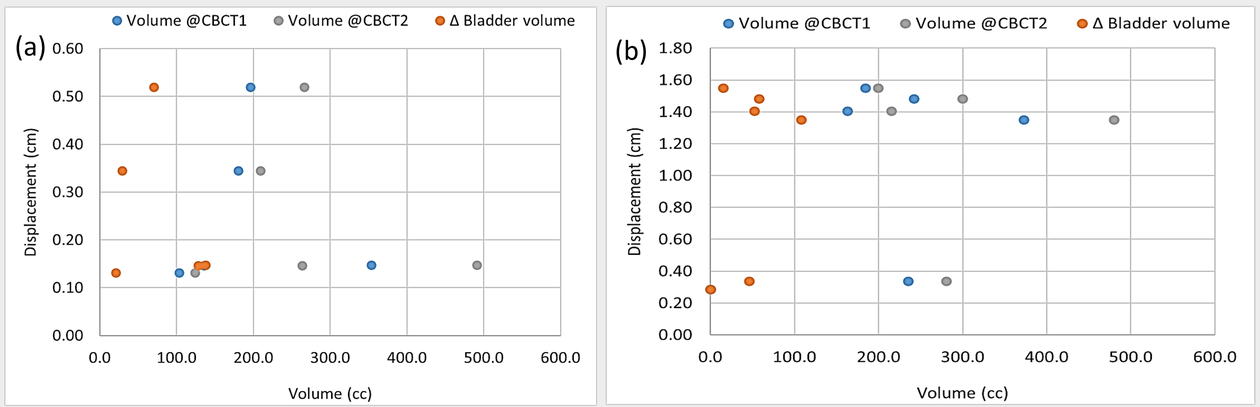

Figure 4. Representative examples of patient-specific bladder volume versus prostate displacement during prostate SBRT: (a) Example 1 and (b) Example 2.

CONCLUSIONS

Intrafractional prostate motion during adaptive SBRT was generally small, with most shifts within 3mm. Occasional larger excursions were observed, indicating smaller PTV margins below 3mm are not supported by these data.

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