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Electromagnetic Tracking of Intrafraction Prostate Motion During Dose-Escalated Linac-Based Stereotactic Body Radiation Therapy for Unfavorable Prostate Tumors

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Abstract
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Abstract

Objective: Extreme hypofractionation requires tight CTV to PTV margins, high dose gradients, and strict adherence to planning criteria in terms of patient positioning and organ motion mitigation. An electromagnetic (EM) transmitter-based tracking device for prostate and urethra monitoring during linac-based SBRT was implemented. The aim of this study was to evaluate the intra-fraction prostate motion in its pioneering clinical use.

Methods: Thirteen patients with organ-confined prostate cancer underwent dose-escalated SBRT in 4 or 5 fractions (BED1.5= 279 Gy and 253 Gy, respectively), using Volumetric Modulated Arc Therapy (VMAT) techniques with flattening filter free (FFF) beams on Linac platform. The EM tracking device consisted of an integrated Foley catheter with a transmitter in a dedicated lumen. Signals sent by the transmitter were detected by antennas in a specific receiver placed on the Linac couch. The system was calibrated to the treatment room isocenter and allowed treatment localization in addition to motion tracking. Starting from the daily cone-beam computed tomography (CBCT) and during the delivery, the prostate motion was tracked with the EM system and SBRT was interrupted when a 2-mm threshold was trespassed and corrected by a new CBCT unless the offset was transient. Real-time assessment of the duration and magnitude of prostate displacement along the three directional axes was recorded for each fraction.

Results: Overall, 56 treatment fractions were delivered. In 31 sessions (55%), no intervention was required to correct the target position as a result of an excessive displacement. In 45% of the monitored fractions, a new CBCT was mandated. The CBCT was repeated during the initial setup phase in 15 out of 56 fractions, while the beam delivery was interrupted in 10. Total treatment time lasted on average 10.2 minutes [range 5.5-22.7], 6.7 minutes [range 2.7-17.8] for setup and 3.5 minutes [range 2.5-7.3] for beam delivery. Overall, the mean value of the target average deviation was -0.18 mm, -0.01 mm, and -0.26 mm in vertical, lateral, and longitudinal directions, respectively. Prostate displacement did not occur in a distinct direction. The prostate was found inside the 2 mm threshold from its initial position in 96% of the treatment time, i.e. in 94% of the time during the setup phase and in 98% during the delivery phase (beam on + interruptions). Without any management of intrafraction motion, total session time would have lasted on average 7.6 minutes [5-12], 4.4 minutes [3-8] for setup, and 3.2 minutes [2-4] for beam delivery, and the prostate would have been found outside tolerance in 7% of the session total time, i.e. in 4% of the time during the setup phase and in 12% during the beam-on phase.

Conclusion: Our findings show that EM tracking is a reliable technique for real-time non-ionizing prostate monitoring during dose-escalated SBRT, allowing to keep the target motion within 2 mm, by interrupting the beam delivery when the prostate was in an unsafe position. Without any management of intrafraction motion, both the setup and the treatment phases would have been shorter, but significant displacements would have occurred leading to potential target missing and overdose to organs at risk.