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

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Objectives

Extreme hypofractionation requires tight 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 first clinical use worldwide.

Methods

Thirteen patients with organ-confined prostate cancer underwent dose-escalated linac-based SBRT in 4 or 5 fractions ($BED_{1.5}$ = 279 Gy and 253 Gy, respectively), using Volumetric Modulated Arc Therapy (VMAT) techniques with flattening filter free (FFF) beams. The EM tracking device consisted of an integrated Foley catheter with a transmitter in a dedicated lumen [RayPilot HypoCath]. 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 the table couch position corrected by a new CBCT unless the offset was transient. Assessments of the duration and magnitude of prostate displacement along the three directional axes with and without organ motion management were recorded and analyzed for each fraction [1].

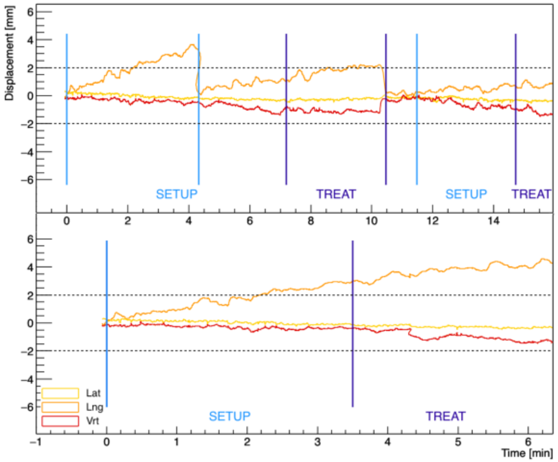

Figure 1 - Trajectories by spatial directions of the prostate displacements during the same treatment session with the real-time organ motion management and in the case no interruptions and patient position corrections would have been applied. [1]

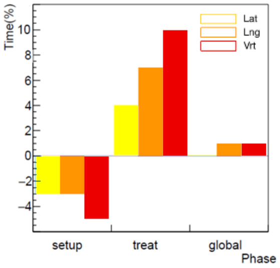

Figure 2 - Graphical representation by spatial directions of the differences in percentage of time for the setup, delivery, and global treatment session, spent by prostate outside the 2 mm threshold without the intrafractional organ motion management and with the real-time management. [2]

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 the remaining 25 (45%) monitored fractions, at least another CBCT was mandated. In 15 out of 56 fractions the CBCT was repeated only during the initial setup phase, while 10 fractions required a beam delivery interruption and a new CBCT acquisition to correct patient position.

Total treatment time lasted on average 10.2 minutes [5.5-22.7], 6.7 minutes [2.7-17.8] for setup and 3.5 minutes [2.5-7.3] for beam delivery. The mean value of the target average deviation was -0.18 mm, -0.01 mm, and -0.26 mm in lateral, longitudinal, and vertical direction, respectively. Prostate motion occurred randomly in all directions.

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 intrafraction motion management, the overall mean treatment time and the mean delivery time would have been 6.9 minutes [5.5-9.9] and 3.2 minutes [2.5-4.2], respectively. The prostate would have been found outside the tolerance in 8% of the session total time, i.e. in 4% of the time during the setup phase and in 14% during the delivery [2].

Conclusions

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.