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Dosimetric impact of intrafraction prostate motion and interfraction anatomical changes in dose-escalated linac-based SBRT

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Abstract

Purpose: The aim of this study was to investigate the impact of intrafraction prostate motion and interfraction anatomical changes on dose metrics and the effect of beam gating and motion correction in dose-escalated linac-based SBRT.

Materials and Methods: Thirteen patients (56 fractions) with organ-confined prostate cancer underwent dose-escalated SBRT using FFF–VMAT technique. Accurate patient setup was ensured by CBCT acquired before each fraction. Real-time 3D prostate motion data were obtained using a novel electromagnetic tracking device. Treatment was interrupted when the signals exceeded a 2 mm threshold in any of the three spatial directions and couch position was corrected unless the offset was transient. Prostate trajectories with and without beam gating and motion correction events were reconstructed and analyzed. Rectum and bladder volumes contoured on each daily CBCT were recorded and compared with volumes at simulation. The prostate motion observed for each fraction was incorporated into the patient original treatment plan with an isocenter shift method. Actually delivered treatments were then simulated by recalculating this reconstructed motion-encoded plan on deformed CTs reflecting the patient CBCT-anatomy of the day. Non-gated treatments were also recomputed using the prostate motion data assuming that no interventions have occurred. Target and organs at risk (OARs) parameters were extracted from individual fraction and individual cumulative patient dose-volume histograms and used for dosimetric comparisons. Correlations between both prostate motion and OARs volume variations with the relative dose differences were also investigated.

Results: Treatment interruptions because of target motion trespassing the predefined threshold in the setup or delivery phase occurred in 25 fractions (45%). Rectum and bladder volume changes were considerable in most patients and especially the bladder filling appeared very little repeatable. Considering both intrafraction motion and anatomical changes as a source of errors, the mean relative dose differences between actually delivered and planned treatments were -3.0% [-18.5 – 2.8] for CTV D99% and -2.6% [-17.8 – 1.0] for PTV D95% over all 56 analyzed fractions. However, the median cumulative CTV coverage with 93% of the prescribed dose has been satisfactory. Urethra planning organ at risk volume sparing was slightly degraded, with the maximum dose increased by only 1.0% on average. A mean favourable underexposition of rectum and bladder was seen in all but two dose metrics: the maximum dose to rectum mucosa and the bladder D40%. Nevertheless, only 2 major clinically irrelevant deviations in rectum mucosa D0.035cc were observed at the end of the treatment. The greatest contribution to target missing and OARs doses came from the anatomical variations during treatment with respect to the simulation, while intrafraction prostate motion marginally contributed in gated treatments. In non-gated treatments, an additional 2.4 – 2.8% to target dose deficit would have occurred on average and the bladder would have further deteriorated by 3.1 – 11.6%. This simulated scenario would have led the protocol dose constraint violation rate to increase for rectum wall D0.035cc by 8%.

Conclusions: The implemented prostate motion management strategy and the strict patient preparation regimen, along with the current PTV margins, the robustness of original treatment plans, and the fast FFF beam delivery, were effective at ensuring no significant degradations of dose metrics for target and OARs due to intrafraction motion and interfraction anatomical changes. Non-gated

treatments would have resulted in larger target dose deficits and bladder overdoses in some fractions. Thus, continuous monitoring, beam gating and motion correction are recommended to safely deliver dose-escalated prostate SBRT treatments.