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Dosimetric impact of intrafraction changes in MR-guided high-dose-rate (HDR) brachytherapy for prostate cancer

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ABSTRACT

PURPOSE: To assess changes in implant and treatment volumes through the course of a prostate high-dose-rate brachytherapy procedure and their impact on plan quality metrics.

METHODS AND MATERIALS: Sixteen MRI-guided high-dose-rate procedures included a post-treatment MR (ptMR) immediately after treatment delivery (135 min between MR scans). Target and organs at risk (OARs) were contoured, and catheters were reconstructed. The delivered treatment plan was applied to the ptMR image set. Volumes and dosimetric parameters in the ptMR were evaluated and compared with the delivered plan using a paired two-tailed *t*-test with $p < 0.05$ considered statistically significant.

RESULTS: An average increase of 8.9% in prostate volume was observed for whole-gland treatments, resulting in reduction in coverage for both prostate and planning target volume, reflected in decreased V_{100} (mean 3.3% and 4.6%, respectively, $p < 0.05$), and D_{90} (mean 7.1% and 7.6%, respectively, of prescription dose, $p < 0.05$). There was no significant change in doses to OARs. For partial-gland treatments, there was an increase in planning target volume (9.1%), resulting in reduced coverage and D_{90} (mean 3.6% and 12.4%, respectively, $p < 0.05$). A decrease in $D_{0.5cc}$ for bladder (3%, $p < 0.05$) was observed, with no significant changes in dose to other OARs.

CONCLUSIONS: Volumetric changes were observed during the time between planning MR and ptMR. Nonetheless, treatment plans for both whole- and partial-gland therapies remained clinically acceptable. These results apply to clinical settings in which patients remain in the same position and under anesthesia during the entire treatment process.

Keywords: MR-guided HDR; Prostate; Intrafraction dosimetry; Treatment verification; Edema

Introduction

Brachytherapy (BT) is a highly effective treatment modality and an integral component of prostate cancer management across the different clinical scenarios of the disease spectrum. In the last decade, there has been a continuous migration toward high-dose-rate (HDR) BT used as monotherapy (1) or boost to external beam radiotherapy (2). In parallel, the increasing use of magnetic resonance (MR) has translated into a growing interest in integrated boost to MR-identified gross tumor in the

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context of whole-gland (WG) therapy (3) and for focal HDR treatments (4). However, these approaches demand higher degrees of precision, and therefore a pressing need for evaluating the robustness of current workflows and need for quality assurance processes.

Considering HDR steep dose gradients, move toward hypofractionation, and a growing interest in partial-gland (PG) approaches, incongruences between planned- and delivered-treatment may have a critical impact on treatment outcomes. Previous studies have shown clinically significant (e.g., affecting dose distribution if not accounted for) changes in prostate volumes and/or implant geometry after catheter insertion, occurring in a time dependent manner over the course of 1 up to 36 h (5–9). Nonetheless, the quantification of these changes in the increasingly common scenario in which implant, planning, and delivery of HDR for prostate cancer is performed during a single procedure under anesthetic without patient's displacement remains understudied.

Herein, we test the assumption that, without patient movement, the planning image set is representative of the reality at the time of treatment delivery. In the context of our MR-only workflow, we prospectively acquired an MR image immediately after treatment completion. We aimed to quantify the implant and prostate volume changes occurring between HDR planning and delivery, and their potential impact on plan quality metrics in prostate cancer cases treated with either WG or PG HDR treatment.

Methods and materials

Study cohort

All patients were treated as part of ongoing Research Ethics Board–approved MR-guided HDR BT for prostate cancer studies (NCT00913939, NCT01802242). In total, 16 patients were reimaged (same protocol as planning MR) (10) at the end of their treatment and are included in this report. Eight patients were treated with WG HDR BT boost (single fraction), 2 patients with salvage BT (only first of two implants included in the analysis), and 6 patients with focal boost (single fraction). The patient and implant characteristics are listed in Table 1.

Workflow

All prostate patients underwent implant, planning imaging, and treatment in the MR-guided radiotherapy facility (11). The patients remained on the same bed under general anesthesia for the entire duration of the procedure, whereas the MR on-rails scanner (1.5 T Magnetom Espree; Siemens, Munich, Germany), the C-arm (Philips Veradius Neo, Amsterdam, Netherlands), and the remote afterloader, RAL, (Elekta microSelectron v3, Stockholm, Sweden) were brought into the treatment room when required. A detailed schematic of the workflow is shown in Fig. 1.

The HDR BT procedure for prostate cancer was previously described elsewhere (10). In short, with the MR in the treatment room and RAL, C-arm, and other MR unsafe equipment stowed away in the equipment room, the patient was positioned on the MR diagnostic bed with a custom leg riser. Anesthesia was induced with intravenous propofol, a laryngeal mask inserted and general anesthesia maintained with sevoflurane. A Foley catheter was inserted, the endorectal coil and template (Hologic, Marlborough, MA; Invivo) were positioned, and patient was draped and immobilized using custom-made leg straps. T2-weighted (field-of-view [FOV] 200 mm; repetition time [TR], 5200 ms; echo time [TE], 105 ms; matrix 320 × 320, 2.0 mm thickness reconstructions, 0 mm gap) and diffusion-weighted images (FOV 180 mm, TR 4000 ms, TE 90 ms, matrix 128 × 128, voxel resolution 1.4 × 1.4 × 3.0 mm, b = 0, 100, 600, 1000 s/mm^2) were obtained for disease characterization and registration of the navigation software (Hologic, Inc.). Needle insertion (2–4 at a time), followed by a proton density–weighted needle verification scan was done iteratively until completion of implant, followed by high-resolution T2-weighted axial images (FOV 180 mm, TR 5600 ms, TE 108 ms, matrix 320 × 320, 2.0 mm thickness reconstructions, three averaging, 0 mm gap) which are the clinical data sets used for treatment planning. Once the image was complete, the MR bed was undocked and the MR scanner was moved out of the suite. The MR doors were closed and equipment room doors were opened to allow the movement of the RAL and C-arm into the treatment room. Contouring, catheter reconstruction, and inverse optimization were done in Oncentra Brachy (v4.3.1 or v4.5.2, Elekta, Stockholm, Sweden). The gross tumor volume

Table 1
Study cohort characteristics

Cohort detail	Whole-gland boost	Focal boost	Salvage
Number of patients	8	6	2
Total number of PTVs	8	10	2
NCCN risk group	IR/HR	IR	IR/HR
Prior EBRT	No	No	Yes
Use of ADT	Yes (7/8)	No	No
Number of catheters per target	17 ± 2 (range 14–20)	4 ± 2 (range 2–7)	7 ± 1 (range 6–8)
Number of catheters per implant	17 ± 2 (range 14–20)	7 ± 1 (range 5–9)	7 ± 1 (range 6–8)
Prescribed dose (Gy)	15	10	13

PTV = planning target volume; IR = intermediate risk; HR = high risk; EBRT = external beam radiotherapy; ADT = androgen deprivation therapy; NCCN = National Comprehensive Cancer Network.