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The influence of a rectal ultrasound probe on the separation between prostate and rectum in high-dose-rate brachytherapy

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ABSTRACT

PURPOSE: The aim of this study was to compare the distance between prostate and rectum as well as rectal dose-volume histogram (DVH) parameters for high-dose-rate (HDR) prostate brachytherapy (BT) with and without a transrectal ultrasound (US) probe in place during delivery.

METHODS AND MATERIALS: The study included 20 patients with high-risk prostate cancer treated consecutively with combined external beam radiotherapy (EBRT) and MRI-based HDR-BT. The MRI-based HDR-BT dose plan and prostate gland contour were transferred to the US images after rigid MRI/US coregistration, followed by delineation of the rectum on US images acquired with a transrectal US probe. The prostate–rectum separation was estimated at the apex, reference, and base plane on the US (with rectal probe) and MR images (without rectal probe). Rectal DVH parameters for EBRT + HDR-BT given in equivalent 2 Gy fractionation doses were estimated and compared for US-based and MRI-based HDR-BT dose planning.

RESULTS: The median (and range) prostate–rectum separation increased on MR images (without rectal probe) as compared with on US images (with rectal probe) by 10 mm (−5, 18) at the base, 1 mm (−2, 3) at the reference and decreased at the apex by 2 mm (−5, 11). The rectal $D_{5.0cm3}$, $D_{2.0cm3}$, and $D_{0.1cm3}$ decreased by a median of 4 Gy (−1, 10), 4 Gy (−2, 13), and 7 Gy (−4, 26), respectively.

CONCLUSIONS: MRI-based HDR-BT without a rectal US probe in place as compared with US-based BT with the probe in place demonstrated a significant increase in the prostate–rectum separation, with a potential of reducing rectal dose.

Keywords: Transrectal ultrasound probe; High-dose-rate; Brachytherapy; Prostate; MRI-based

Introduction

High-dose-rate brachytherapy (HDR-BT) in combination with external beam radiotherapy (EBRT) has the potential to deliver high dose to the prostate target while minimizing dose to adjacent organs at risk (OAR) (1–3). Dose escalation to the prostate using EBRT alone or combined with HDR-BT (EBRT + HDR-BT) has resulted in both increased biochemical control rates and lower clinical failure rates (4–6). Even higher doses have been proposed, although this escalated dose has been discussed to focus mainly on the visible dominant intraprostatic lesion to limit rectal toxicity (7–10).

Most prostate cancers are situated in the peripheral zone of the prostate gland close to the rectum (11). Acute and late gastrointestinal (GI) toxicities have been reported in high-risk prostate cancer patients after EBRT + HDR-BT (12–14). One study reported acute Grade 2 and acute Grade 3 GI toxicity in 114 (26%) and 35 (8%) out of 438 patients, respectively, whereas late Grade 2 GI toxicity was reported in 39 (9%) patients (12).

Dose planning in prostate HDR-BT is predominately based on target and OAR volumes defined on ultrasound (US) images obtained with a transrectal US probe (15). The rectal probe is then typically positioned in the rectum

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during treatment delivery to obtain the same patient setup as on the planning images. Dose planning can also be performed on magnetic resonance (MR) images or with computed tomography (CT) without the use of a rectal probe (16–21). The supplementation of MR imaging (MRI) in interstitial HDR-BT facilitates more accurate prostate delineation and needle reconstruction. Furthermore, dose escalation to the dominant tumor foci (index lesion) is of upcoming interest based on recent standard use of multiparametric MRI sequences such as T2-weighted (T_2W), diffusion weighted, dynamic contrast–enhanced sequences or less frequently MR spectroscopy (22–26).

We hypothesize that the absence of a rectal probe in an MRI-based planning leads to a larger separation between the rectum and prostate and consequently to a lower rectal dose as compared with an US-based approach.

The aim of this study was to compare the prostate–rectum distance and rectal dose-volume histogram (DVH) parameters for HDR prostate BT with and without a rectal probe in place during delivery.

Materials and methods

The study included 20 patients with high-risk prostate cancer disease treated consecutively with two individual HDR-BT fractions of each 8.5 Gy after EBRT of 46 Gy in 23 fractions. A total of 39 HDR-BT fractions were analyzed, since one patient received only one fraction.

The HDR-BT planning involved transperineal insertion of temporary flexible plastic catheters (length = 200 mm and diameter = 2 mm) through an MRI-compatible needle template (TPV 061, GfM–Medizintechnik mbH, Darmstadt, Germany) under live transrectal US-guidance, with the patient being in dorsal lithotomy position and in general anesthesia. Before catheter insertion, an US-based preplan was performed to decide on the most optimal catheter positions. All patients were manually US-scanned (slice spacing = 1 mm) immediately after catheter insertion using the transrectal US probe. Thereafter, the rectal probe was removed, and the patients were placed in supine position with a pillow between the legs and the knees slightly bended to the sides. A strap (width = 15 cm) was placed around the legs for fixation. The patients were then moved to an MRI couch positioned on a trolley, which was docked to the MRI scanner (Ingenia 1.5 T, Philips Healthcare, The Netherlands). Each patient underwent two T_2W turbo-spin-echo MRI scans (slice thickness = 2/3 mm, TE = 80/80 ms, TR = 11,366/7104 ms, acquired resolution = 1.40 x 1.76/1.09 x 1.18 mm). The HDR-BT dose plans were primarily based on the T_2W-MR images with 3 mm slice thickness, whereas the images with slice thickness 2 mm were used for supporting the catheter reconstruction. After the MRI acquisition, the patients remained on the MRI couch until the end of the HDR-BT delivery, which was given in a separate shielded room.

Changes in the prostate and rectum separation (prostate–rectum distance) after removing the US probe were evaluated by comparing the distance between the anterior rectal wall and the dorsal prostate edge on the axial MR images (without rectal probe) and the axial US images (with rectal probe) at the base and apex plane as well as the midaxial plane (reference plane). The number of HDR-BT fractions was quantified in which a larger prostate–rectum separation was observed on the axial MR images as compared with US images at the base, reference, and apex plane.

The reproducibility of obtaining the same prostate–rectum separation on US and MR images in HDR-BT fraction 1 (HDR-BT1) and HDR-BT fraction 2 (HDR-BT2) was evaluated at the base, reference, and apex plane. Also, the spread or standard deviation (SD) of the difference in prostate–rectum distance observed in HDR-BT1 and HDR-BT2 was estimated.

The HDR-BT dose plans were based on MRI-reconstructed catheters and MRI-defined volumes of the prostate gland ($CTV_{Prostate}$) and OAR (urethra, rectum, and bladder). The dose planning aims and dose constraints used for optimization are presented in Table 1. The dose optimization was performed using the hybrid inverse planning optimization (HIPO) algorithm (OncentraProstate version 4.1.6, Nucletron, ELEKTA Brachytherapy, Veenendaal, The Netherlands) followed by manual corrections of the loading pattern.

The MRI-based dose plan was transferred to the US images after manual rigid MRI/US coregistration to evaluate the rectal dose for an US-based dose planning. With this methodology, it is assumed that an US-based dose plan would be identical to an MRI-based dose plan, although this is an approximation. Deformation of the prostate with/without US probe would lead to different dose plans in reality. The reasons for applying the MRI-based dose plan to the US images were: (*i*) the superior prostate visualization on MRI, leading to a more precise delineation of the prostate as compared with US-based delineation, and (*ii*) to avoid systematic variations in contouring, catheter reconstruction and dose planning. The MRI/US coregistration was based

Table 1
Planning aims and prescribed dose

Target and OAR	Planning aim[a]	Prescribed dose[b] EBRT + HDR-BT
$CTV_{Prostate+3mm}$[c]	$D_{90\%} > 95\%$	83.4 ± 4.0 Gy_{EQD_2}
	$V_{150\%} < 45\%$	
	$V_{200\%} < 20\%$	
$CTV_{Prostate}$	$D_{90\%} > 100\%$	89.4 ± 3.6 Gy_{EQD_2}
Rectum	$D_{2.0cm3} < 75\%$	64.4 ± 2.9 Gy_{EQD_2}
	$V_{100\%} = 0\ cm^3$	
Urethra	$D_{10\%} < 115\%$	95.1 ± 2.1 Gy_{EQD_2}
	$D_{30\%} < 110\%$	90.6 ± 2.0 Gy_{EQD_2}

OAR = organs at risk; EBRT = external beam radiotherapy; HDR-BT = high-dose-rate brachytherapy; EQD_2 = equivalent 2 Gy fractionation dose; CTV = clinical target volume.

[a] Dose normalized to 8.5 Gy (100%).

[b] Prescribed dose (mean ± standard deviation) is defined as the final dose distribution approved by the physician.

[c] $CTV_{Prostate}$ plus a 3-mm margin constrained to rectum and bladder.