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Dosimetric impact of inter-observer catheter reconstruction variability in ultrasound-based high-dose-rate prostate brachytherapy

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ABSTRACT

PURPOSE: To investigate the dosimetric impact of interobserver catheter reconstruction variability in transrectal ultrasound−guided prostate high-dose-rate (HDR) brachytherapy.
METHODS AND MATERIALS: Twenty consecutive patients with intermediate- or high-risk prostate cancer were treated with a single, 15-Gy HDR brachytherapy boost as part of this study. The treated plan was used as the study reference plan (P_R). Three expert treatment planners (observers) manually reconstructed the catheter paths on the static three-dimensional transrectal ultrasound images, and new plans were generated from the updated positions (P_{OBS}); subsequently, the dwell time and positions from the P_{OBS} plans were superimposed on the P_R catheter paths to evaluate the dosimetric effect of the interobserver variations (P_{EVAL}). Plans from each group were stratified by observer and by number of catheters (12 or 16) and then compared using a one-way Kruskal−Wallis *H* test with post hoc Mann−Whitney *U* tests reserved for significant variations ($\alpha = 0.05$).
RESULTS: Greater than 98.9% of catheter reconstruction variations were <3 mm. When stratified by observer, there was a significant decrease ($p << 0.05$) in planning target volume (PTV) $V_{100\%}$ and increases in the urethral D_{max} between the P_{OBS} plans propagated to the P_R catheter paths and dosimetry evaluated and P_R plans only. Stratification of plans by catheter number showed nonclinically significant decreases in PTV $V_{100\%}$, and $D_{90\%}$ and increases in urethral D_{max} for the 12-catheter plans.
CONCLUSIONS: Limiting interobserver variability, and its effects on prostate HDR brachytherapy plan quality, is critical to achieving good dosimetric outcomes; small variations in catheter reconstruction may translate to inadequate PTV coverage, excessive urethral dose, or both.

Keywords: High-dose-rate; Brachytherapy; Catheters; Dosimetry; Interobserver; Variability

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Introduction

Radiobiological studies increasingly report that prostate cancer has a very low alpha-beta ratio making it highly sensitive to large fractional doses of radiation (1−3). There is also compelling evidence to suggest that local dose escalation using high-dose-rate (HDR) brachytherapy—delivered in conjunction with external beam radiation therapy—offers one of the best means of achieving long-term, biochemical disease-free survival in patients with prostate cancer (4).

Although highly effective in delivering conformal, dose-escalated radiation, the efficacy of HDR brachytherapy is highly dependent on the expertise of the brachytherapy team and available image guidance. Traditional guidance approaches involved CT-based anatomical and catheter reconstruction, where patients were transferred to a CT-suite; significant displacement of catheters can occur during this process (5−8). More recently, workflows using transrectal ultrasound (TRUS) offer reduced cost and complexity compared to CT and allow delivery of intraoperative, real-time treatment in a single session.

TRUS workflows have since become the standard for intraoperative treatment, but the modality is not without limitations and suffers from significant image artifact and subjectivity in interpretation. Although target and organ at risk (OAR) delineations are comparable to that of CT- and MRI-based delineation (9, 10), identification and reconstruction of the implanted catheters remains a significant challenge (11−13). Discrepancies in catheter tip reconstruction or even misidentification of catheters can lead to significant errors in dose delivery, as identified by the 2014 Brachytherapy Physics Quality Assurance System report (14).

The ability to deliver highly conformal brachytherapy at increasingly larger doses per fraction requires an accurate understanding of the positions of implanted catheters relative to patient anatomy. An in-depth literature review found that publications to date have studied the effects of catheter reconstruction variability typically using rigid, stainless steel catheters (13), were limited to phantom studies that examined catheter tip error alone (11), or primarily used CT image-guidance (15) or some combination. Schmid *et al.* (11) also examined the dosimetric impact of catheter reconstruction variability using a TRUS-guided workflow; however, this was again limited to phantom studies. Examination of the dosimetric impact of catheter reconstruction variability on clinical patient data was limited to a single abstract (16), which also only looked at variations at the catheter tip. Batchelar *et al.* (13) examined TRUS-guided catheter variations using actual patient data from 37 implants but did not evaluate the dosimetric impact of these variations and also only evaluated needle tip discrepancies. This study sought to evaluate the dosimetric impact of interobserver catheter reconstruction variations on patients treated with a single 15-Gy HDR brachytherapy boost. Unique to this study was the implantation of more flexible, plastic catheters along with evaluation of variability for the entire catheter path, not just catheter tip error. In addition, to build on the earlier work of Charra-Brunaud *et al.* (17), the dosimetric impact of catheter number was also evaluated as part of this study.

Methods and materials

Patient population

Twenty patients with intermediate- (T1−T2, Gleason score 6−7, and prostate-specific antigen 10−20 ng/mL) or high-risk (T3−T4, Gleason Score 8−10, and prostate-specific antigen > 20 ng/mL) prostate cancer treated at the Sunnybrook Odette Cancer Centre (Toronto, ON, Canada) were enrolled in this retrospective, ethics-approved study.

Patients were treated with 37.5 Gy in 15 fractions with external beam radiation therapy and a single 15-Gy HDR brachytherapy boost. Analysis focused exclusively on the brachytherapy boost treatment. A 1:1 ratio of 12- to 16-catheter plans was present in the data set.

Prostate HDR brachytherapy workflow

Patients were positioned in dorsal lithotomy after administration of general anesthesia. Live TRUS-guidance was used to implant up to 16, flexible ProGuide catheters (Elekta BV, Stockholm, Sweden) into the prostate gland in a predefined geometric pattern. The radiation oncologist then contoured the prostate, planning target volume (PTV) and OARs—including the rectal wall and urethra—on the Oncentra Prostate planning system (Elekta BV, Stockholm, Sweden). Consecutive TRUS axial images were used to reconstruct a static, three-dimensional (3D) volume of the patient anatomy and implanted catheters. Manual catheter reconstruction was performed intraoperatively using the static, 3D TRUS volume by a radiation therapist (RT); the use of a static volume was to limit the impact of catheter misidentification. Catheter tip verification was obtained by measuring the free catheter length protruding from the end of the template grid. Inverse plan optimization was then used to determine the dwell positions and times of a single, stepping Iridium-192 source within the reconstructed catheter channels before treatment delivery. Table 1 shows the planning objectives used for dose optimization. Planning information consisting of the catheter paths, anatomical contours, 3D TRUS volume, and dwell times and positions was exported to create the reference treatment plans (P_R). The delivered treated plans were selected as the reference to evaluate the impact of catheter reconstruction variability.

Catheter variability and dosimetry study

Three RT observers experienced in TRUS-guided HDR planning were asked to independently reconstruct catheter paths on the Oncentra Prostate system. Treatment plans for a 15 Gy × 1 fraction brachytherapy boost were