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Validation study of ultrasound-based high-dose-rate prostate brachytherapy planning compared with CT-based planning

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ABSTRACT

PURPOSE: The use of transrectal ultrasound (TRUS) to both guide and plan high-dose-rate (HDR) brachytherapy (BT) for prostate is increasing. Studies using prostate phantoms have demonstrated the accuracy of ultrasound (US) needle tip reconstruction compared with CT imaging standard. We have assessed the *in vivo* accuracy of needle tip localization by TRUS using cone-beam CT (CBCT) as our reference standard.

METHODS AND MATERIALS: Needle positions from 37 implants have been analyzed. A median of 16 needles (range, 16−18) per implant were inserted, advanced to the prostate base, and their tips identified using live TRUS images and real-time planning BT software. Needle protrusion length from the template was recorded to allow for reverification before capturing images for planning. The needles remained locked in the template, which was fixed to the stepper, while a set of three-dimensional TRUS images was acquired for needle path reconstruction and HDR-BT treatment planning. Following treatment, CBCT images were acquired for subsequent needle reconstruction using a BT Treatment Planning System. The coordinates of each needle tip were recorded from the Treatment Planning System for CT and US and compared.

RESULTS: A total of 574 needle tip positions have been compared between TRUS and CBCT. Of these, 59% agreed within 1 mm, 27% within 1−2 mm, and 11% agreed within 2−3 mm. The discrepancy between tip positions in the two modalities was greater than 3 mm for only 20 needles (3%).

CONCLUSIONS: The US needle tip identification *in vivo* is at least as accurate as CT identification, while providing all the advantages of a one-step procedure.

Keywords: Prostatic neoplasms; High-dose-rate brachytherapy; Ultrasound-based planning; Varian Vitesse

Introduction

High-dose-rate brachytherapy (HDR-BT) has the potential to be the most precise and conformal form of dose escalation in radiotherapy for prostate cancer. It does not have the problems inherent in external beam radiotherapy (EBRT) of dealing with variability in daily prostate position or reproducibility of setup over a protracted 7−8-week course of treatment (1−3). It also avoids many technical difficulties that can plague permanent seed implants owing to seed loss and migration as well as the inaccuracies of seed deposition intraoperatively (4−7). HDR prostate brachytherapy permits dose optimization that both reduces operator dependence by compensating for suboptimal needle placement and increases therapeutic ratio by shaping the isodoses around the organs at risk. The potential benefits of HDR BT, however, depend on accurate identification of the HDR needles, and in particular their tips, in the planning images.

The objective of this study is to determine the accuracy of transrectal ultrasound (TRUS)−based needle tip reconstruction *in vivo* using cone-beam CT (CBCT) as the reference standard.

Methods and materials

Patients

A total of 20 consecutive patients were included in this study. Eligible patients had newly diagnosed, histologically proven intermediate- or high-risk adenocarcinoma of the

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prostate with negative-staging abdominal/pelvic CT scan and bone scan. The study was approved by the university institutional review board, and informed consent was obtained from all patients. There was no randomization as each patient served as his own internal control in comparing the two methods of HDR needle tip identification.

Treatment

The treatment protocol consisted of EBRT given as 46 Gy/23 fractions over 5 weeks, with two fractions of 10-Gy HDR-BT, one fraction per implant, in the first and third weeks of the treatment course. The EBRT treatment was three-dimensional (3D) conformal, based on CT simulation. The clinical target volume (CTV) was the prostate and seminal vesicles for intermediate-risk disease but included pelvic lymph nodes for higher risk disease. The planning target volume (PTV) was the CTV plus a 10-mm margin in all directions. At the first HDR-BT fraction, three gold fiducials were implanted for subsequent EBRT image guidance. The planning CT was repeated and the PTV margin reduced to 7 mm posteriorly.

On the same day as the CT simulation, an ultrasound (US) simulation was performed to determine optimal positioning for the procedure and to assess potential pubic arch interference. On days 5 and 15 of the EBRT treatment course, HDR-BT treatment replaced the fraction of EBRT. Under general anesthesia, the patients were positioned in dorsal lithotomy with leg and probe angles as determined at simulation. A continuous set of transverse US images were acquired at 1-mm intervals for 3D reconstruction of the prostate to guide the HDR needle positioning as required by the Vitesse (Varian medical Systems, Inc., Palo Alto, CA) software.

A median of 16 needles (range, 16–18) were positioned to the midgland according to the predetermined pattern. Starting with the anterior-most needles and working posteriorly, each needle was then advanced to the base of the prostate, the tip was identified using live TRUS images and Vitesse (Varian) software, and then locked in place (Fig. 1). The needle protrusion length from the template was recorded. When all needles were positioned, the protrusion lengths were checked and any discrepancy of 2 mm or more between the measurement and the record was corrected by physically moving the needle back into position. Two experienced physicists confirmed each needle tip placement.

Following needle tip identification, the urethra was opacified with aerated gel for ease of US visualization. A second set of continuously acquired transverse TRUS images was then obtained. The prostate, rectum, and urethra were contoured on this set of images and the needle paths were identified, with the HDR CTV defined as the entire prostate. For the initial patients, 2-mm diameter plastic needles were used with steel stylets for insertion. The stylets were removed before acquiring the second 3D data set. The remaining implants were performed using steel needles without stylets, the change being made for ease of insertion. There were no detectable differences in the visualization of either needle type by either TRUS or CT.

Treatment planning was performed using BrachyVision (Varian). The homogeneity parameters used for optimization aimed for a prostate V_{100} of 98% or greater, a V_{125} of 55–65%, and a V_{150} of 25–35% (V_{100}, V_{125}, and V_{150} are the percentage of the prostate volume covered by the prescription, 125%, and 150% isodoses, respectively.) The urethral maximum dose was limited to 115% of the prescribed dose or less (2–3% at 110%) and the dose to 1 cc of rectal wall was restricted to 7 Gy or less. For accuracy of rectal dose calculations, treatment was delivered with the TRUS probe in place. All patients remained anesthetized and paralyzed until treatment was completed.

Cone-beam CT verification

At the completion of treatment, the patient's legs were lowered from 90° to approximately 40° to permit acquisition of CBCT images (Arcadis; Siemens AG, Munich, Germany). In anticipation of this repositioning, when the template was locked to the stepper at the start of the procedure, it was not positioned flush with the perineum but a 1.5-cm gap was left so that this degree of hip extension would not cause the template and attached needles to be pulled distally. While carefully lowering the knees and maintaining hip abduction, the needles were continuously monitored on live sagittal US. As for the second set of TRUS images, the recorded needle protrusion lengths were used to ensure the fidelity of needle positions in the CBCT images. X-ray contrast was used to replace the aerated gel in the urethral catheter to improve visualization on CBCT. The CBCT images were then transferred to BrachyVision (Varian) for needle tip identification.

Monitoring

At the completion of the first HDR fraction, three gold fiducial seeds were inserted under TRUS visualization for image guidance of the remaining EBRT treatments. Patients participating in this study were followed in the usual fashion and did not require any additional tests beyond those of standard practice.

Analysis

The needle tip positions identified using US during HDR-BT planning were compared postoperatively with those identified using CBCT. Needle tips were reconstructed in the CBCT images using the BrachyVision Treatment Planning System (Varian; Fig. 2). The coordinates of each needle tip in either CT or US were recorded from the Treatment Planning System. Each pair of TRUS–CBCT image sets for each implant had its own unique coordinate