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A phantom study to assess accuracy of needle identification in real-time planning of ultrasound-guided high-dose-rate prostate implants

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ABSTRACT

PURPOSE: High-dose-rate brachytherapy of the prostate is commonly performed using transrectal ultrasound (US) guidance, with CT imaging used for needle reconstruction and treatment planning. Transrectal ultrasound images can, however, be used for the entire process, allowing treatment without changes in the patient position. This study assesses needle reconstruction accuracy using US images.

METHODS AND MATERIALS: Prostate phantoms were implanted with 10–18 needles. Three-dimensional US images were acquired, and needles were reconstructed using specialized software. A CT scan was also obtained. The image sets were registered and needle reconstruction errors were assessed. A dose plan was obtained using the US images and the dwell times were transferred to the CT reconstruction to obtain the true ''delivered dose,'' which was evaluated using standard dosimetric parameters.

RESULTS: Two sources of error were identified. First, reconstruction based on the bright echoes in the US images introduces a systematic error because these echoes correspond to the proximal wall of the needle, and not the center of the needle channel. If left uncorrected, this shift can lead to an underestimate of urethral doses. Second, incorrect needle tip identification can occur in the cranial–caudal direction. Errors up to 5.8 mm were observed. A measurement of needle lengths protruding beyond the template can be used to compensate for this.

CONCLUSIONS: Factors limiting the accuracy of US-based needle reconstruction have been identified. Once recognized, these errors can be corrected for, resulting in accurate implant geometry. This facilitates a treatment technique combining excellent anatomic definition, minimal prostate motion, and accurate dose planning and delivery.

Keywords: Prostate cancer; Prostate brachytherapy; HDR; US-based planning

Introduction

High-dose-rate brachytherapy (HDR-BT) of the prostate involves the placement of a number of hollow needles into the prostate through which an HDR radioactive source can be introduced using an afterloading device. Before delivery of the treatment, needle placement with respect to the prostate and organs at risk (OARs) must be determined and, based on this, a suitable dose plan must be generated.

Typically, prostate HDR-BT begins with the insertion of needles into the prostate under transrectal ultrasound (TRUS) guidance with the patient in the dorsal lithotomy position. There are advantages to using TRUS for this, most notably that the prostate and urethra are well visualized in ultrasound (US) images making development of appropriate implant geometry relatively straightforward. Additionally, needle placement can be followed in real time during insertion, which allows for adjustment of subsequent

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needle positions to compensate for any nonideal needle placement.

Following needle implantation, the most common practice is to send the patient for a CT scan. Typically, this requires lowering the patient's legs and transferring the patient onto and off of both a stretcher and a CT scanner table. After acquisition of the CT images, the target and OAR are contoured, the implant geometry is reconstructed, and a dose plan based on the CT images is produced. When the reconstruction and planning are complete, the treatment may be delivered.

CT is known to be geometrically accurate and is an excellent imaging modality for identifying the needle locations. However, the change in position of the patient's legs, the movement of the patient, and the delay between imaging and treatment are all known to produce changes to the needle positions and/or implant geometry (1–8). This is problematic because any such changes will result in differences between the planned dose and the dose that is actually delivered to the prostate and to the adjacent organs. When multiple fractions are delivered based on a single plan, which is often the case with CT-based planning but is not done with the one-step US-based procedure investigated here, the problem of needle migration is of even greater concern.

An alternate approach to prostate HDR-BT is to use TRUS imaging both to guide the implantation of needles and for treatment planning. In this process, implantation of the needles, three-dimensional (3D) imaging, dose planning, and treatment are integrated into a single process that does not require any change in patient position or movement of the patient. This approach solves many problems related to patient and needle motion, but does present other challenges. Although the prostate is generally much better delineated on TRUS compared with CT, TRUS images are not as geometrically accurate, and ultrasonic shadows produced by posterior needles often obscure the exact needle placement of more anterior needles. To realize the potential gains of this approach, the effects of these limitations on needle reconstruction must be understood. Highly accurate treatment plans can only be achieved through accurate reconstruction of the implant geometry.

The purpose of this study is to evaluate the accuracy of the implant reconstructions based on TRUS images using Vitesse software (Varian Medical Systems, Palo Alto, CA).

Methods and materials

Specialized prostate US phantoms (model 053MM; Computerized Imaging Reference Systems Inc., Norfolk, VA) were used for this study. These phantoms incorporate internal structures (prostate, urethra, seminal vesicles, and two nodules) that are clearly visible in both US and CT images. A transverse TRUS image of one of the phantoms and its corresponding CT image are shown in Figs. 1a and 1b, respectively. The central structure is the urethra. The structure on the left side of the images is a simulated nodule. These nodules proved useful in registering the images, but are otherwise not relevant to this study.

Six phantoms were implanted under US guidance using a standard technique for TRUS-based implants. The number of needles implanted in each phantom varied from 10 to 18. In each phantom, the prostate was visualized on TRUS (Flex Focus; B&K Medical Systems, Peabody, MA) at a midgland position, and the needles were implanted using a standard implant template. The needles were first advanced to the midgland position under TRUS guidance in the transverse mode. After all needles had been advanced to this position, the longitudinal transducer was selected and the needles were advanced one at a time to the base of the prostate. The positions of the needle tips in the cranial–caudal direction were tracked in the live image during this process, and their final positions were determined during this step. This last step is always carried out from anterior to posterior so that the needles do not fall into the shadow of more posterior needles as they are advanced. The needles used in this study (Varian Medical Systems) were plastic with a diameter of 2 mm.

After the completion of the implant, 3D US images of the phantoms were acquired using the Vitesse (Varian) software program. This software makes two modes available for 3D reconstruction. In Twister (Varian Medical Systems) mode, the probe is rotated about its long axis as images are acquired using the longitudinal transducer. The rotational

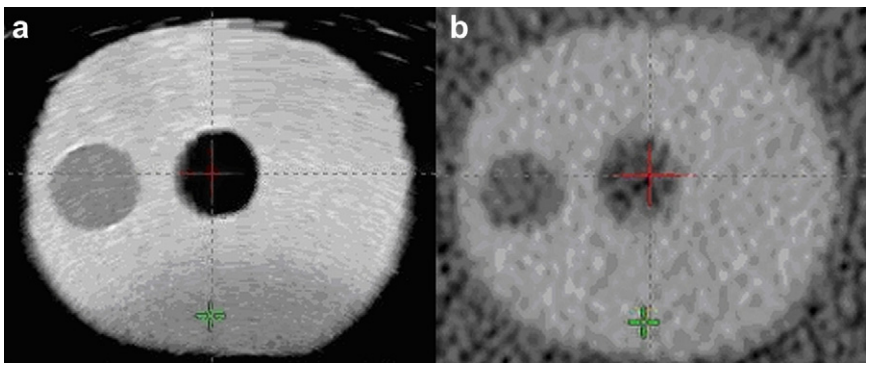

Fig. 1. (a) Midprostate transverse view of the phantom obtained using ultrasound and (b) the corresponding view obtained using CT.