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Permanent prostate brachytherapy postimplant MRI dosimetry using positive contrast MRI markers

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ABSTRACT

PURPOSE: Permanent prostate brachytherapy dosimetry using computed tomography-magnetic resonance imaging (CT-MRI) fusion combines the anatomic detail of MRI with seed localization on CT but requires multimodality imaging acquisition and fusion. The purpose of this study was to compare the utility of MRI only postimplant dosimetry to standard CT-MRI fusion-based dosimetry.

METHODS AND MATERIALS: Twenty-three patients undergoing permanent prostate brachytherapy with use of positive contrast MRI markers were included in this study. Dose calculation to the whole prostate, apex, mid-gland, and base was performed via standard CT-MRI fusion and MRI only dosimetry with prostate delineated on the same T2 MRI sequence. The 3-dimensional (3D) distances between seed positions of these two methods were also evaluated. Wilcoxon-matched-pair signed-rank test compared the D90 and V100 of the prostate and its sectors between methods.

RESULTS: The day 0 D90 and V100 for the prostate were 98% versus 94% and 88% versus 86% for CT-MRI fusion and MRI only dosimetry. There were no differences in the D90 or V100 of the whole prostate, mid-gland, or base between dosimetric methods ($p > 0.19$), but prostate apex D90 was high by 13% with MRI dosimetry ($p = 0.034$). The average distance between seeds on CT-MRI fusion and MRI alone was 5.5 mm. After additional automated rigid registration of 3D seed positions, the average distance between seeds was 0.3 mm, and the previously observed differences in apex dose between methods was eliminated ($p > 0.11$).

CONCLUSIONS: Permanent prostate brachytherapy dosimetry based only on MRI using positive contrast MRI markers is feasible, accurate, and reduces the uncertainties arising from CT-MRI fusion abating the need for postimplant multimodality imaging.

Keywords: Prostate; Brachytherapy; MRI; Dosimetry

Introduction

Permanent low-dose-rate prostate brachytherapy is one treatment option available to prostate cancer patients that can provide excellent disease control and an acceptable toxicity profile (1–3). Numerous studies have demonstrated that to achieve optimal disease outcomes with this technique, the prostate D90 or V100 should be greater than 90% (4–6). Traditionally, these postimplant dosimetric quality indicators have been determined by obtaining a computed tomography (CT) scan of the pelvis after the procedure to identify the location of the brachytherapy seeds and anatomic boundaries of the prostate, urethra, bladder, and rectum. There is, however, large interobserver variability in defining anatomic

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Conflicts of interest: SJF is founder and director of C4 imaging and also a consultant/advisor at Varian.

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structures on CT, leading to increased contour and dose variability (7). More recently, magnetic resonance imaging (MRI) has been introduced into the postimplant quality assessment process as it can provide improved soft tissue contrast and reduce observer variability in identifying several structures in the pelvis including the prostate, urethra, penile bulb, neurovascular bundles, and external urinary sphincter (8, 9). Although MRI provides significant advantages in anatomic delineation compared with CT, accurate identification of brachytherapy seed locations on MRI alone remains challenging because of local magnetic field distortions produced by the seeds, MRI image acquisition variability, and decreased seed-prostate contrast.

Instead, CT and MRI are often combined for postimplant dosimetric analysis CT-MRI fusion. This allows use of seed localization on CT combined with improved anatomic detail on MRI. CT-MRI fusion has been shown to be feasible and to provide small deviations in CT-MRI bony landmark alignment (10, 11). CT-MRI fusion is encouraged in the 2012 ABS prostate brachytherapy guidelines (12), yet uncertainties in CT-MRI fusion can be associated with significant variability in D90 of up to 16% (7). Studies investigating the use of various MRI sequences for identification of prostate brachytherapy seed positions without the use of CT are few and have been limited by heterogeneous MRI protocols, difficulty with detecting extraprostatic seeds (13), and the need for multiple MRI sequences with and without contrast for seed detection and organ contouring (7, 14, 15).

To address the problem of prostate brachytherapy seed identification on MRI, Frank et al. (16) have developed positive contrast prostate brachytherapy MRI markers. The marker uses the paramagnetic properties of 1% cobalt-dichloride-N-acetyl cysteine to produce a positive contrast on MRI. The markers are positioned between prostate brachytherapy seeds within a brachytherapy strand at the positions of traditional strand spacers, allowing potential seed identification on MRI. Preclinical studies have confirmed the ability of the markers to produce positive contrast in phantoms and have identified appropriate MRI sequences for identification of the markers (17). These markers demonstrate minimal biotoxicity (18), are FDA-approved, and have been implemented into our prostate brachytherapy program at our institution. The purpose of this study was therefore to report on the ability to perform MRI-only based dosimetry with the use of these markers and to compare the dosimetric outcomes with those of prostate brachytherapy seed identification on CT with subsequent CT-MRI fusion.

Methods

Patients

Consecutive men with prostate cancer undergoing permanent prostate brachytherapy at our institution were evaluated for the possibility of using the positive contrast MRI markers in their prostate brachytherapy implant. Patients were deemed candidates for prostate brachytherapy monotherapy if they were had low- or intermediate- risk prostate cancer (PSA <15, Gleason score <8, and $<$T3 disease), and prescription brachytherapy doses for monotherapy were 144 Gy, 125 Gy, and 115 Gy for iodine, palladium, and cesium implants, respectively. Patients could also be treated with a prostate brachytherapy boost using palladium (prescription dose 100 Gy) along with external beam radiation therapy for high-risk disease (PSA $\geq$ 15, Gleason score $\geq$ 8, or $\geq$ T3 disease). All patients had staging workup with biopsy of the prostate confirming the diagnosis of prostate cancer and diagnostic pelvic MRI. Additional workup was implemented as necessary per physician and patient preference. Eligibility for brachytherapy was determined for each patient before the procedure by obtaining preoperative CT scan and ultrasound volume studies to assess pubic arch interference as described elsewhere (19). After prostate brachytherapy implantation, patients underwent a pelvic CT scan and MRI on the day of the procedure (day 0) for treatment planning to determine dosimetric parameters such as prostate D90 and V100. The dosimetric parameters were determined from MRI-only or CT-MRI fusion as described below.

CT and MRI sequences

Day 0 axial pelvic CT scans were acquired with 2.5 mm-thick slices. MRI sequences included an axial 3-dimensional (3D) fast spin echo T2-weighted image and an additional image sequence to identify the positions of the positive contrast MRI marker. Throughout the course of this investigation, two different MRI sequences were used for MRI-specific brachytherapy strand marker identification depending on the type of MRI scanner used: either a 3D fast spoiled gradient echo (FSPGR) sequence (used with a 3T General Electric Signa HDxT scanner) and a 3D axial fast low angle shot (FLASH) sequence (used with a 1.5 T S MAGNETOM Aera scanner) (20, 21). The MRI parameters for the FSPGR sequence were repetition time = 6.18, echo time = ~3.3 ms, flip angle = 20, number of excitations = 8, field of view = 14 cm, imaging matrix = 256 x 256, and slice thickness = 2 mm, whereas MRI parameters for the FLASH sequence were repetition time = 6, echo time = 2.38, flip angle = 25, field of view = 15 cm, imaging matrix = 256 x 256, and slice thickness = 1−2 mm. The FSPGR sequences were obtained with an inflatable endorectal coil, whereas FLASH sequences were obtained with an Invivo (Invivocorp, Gainesville, FL) MRI rigid endorectal coil. Before the FSPGR or FLASH sequences, 1 mg of glucagon was injected intramuscularly to suppress rectal contractions.

Dosimetry

Anatomic delineation of the prostate gland and organs at risk was done by an experienced radiation oncologist (SJF)