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Defining a magnetic resonance scan sequence for permanent seed prostate brachytherapy postimplant assessment

David Bowes[1], Juanita M. Crook[1,*], Rasika Rajapakshe[2], Cynthia Araujo[2], Brent Parker[2]

[1]*Department of Radiation Oncology, British Columbia Cancer Agency, Centre for the Southern Interior, University of British Columbia, Kelowna, British Columbia, Canada*

[2]*Department of Medical Physics, British Columbia Cancer Agency, Centre for the Southern Interior, University of British Columbia, Kelowna, British Columbia, Canada*

ABSTRACT

PURPOSE: We describe a magnetic resonance (MR) scan sequence for prostate brachytherapy postimplant assessment.

METHODS AND MATERIALS: One brachytherapy team at the British Columbia Cancer Agency has incorporated MR–CT fusion into their permanent seed prostate brachytherapy quality assurance procedure. Several attempts were required to ensure that the diagnostic MR scanner at the adjoining general hospital performed the desired sequence, providing many examples of suboptimal scans and underlining the pitfalls for a center trying to incorporate the use of MR scanning into their brachytherapy program.

RESULTS: The recommended sequence (Fast Spin Echo T2-weighted, repetition time [TR]/echo time [TE] 4500/90, echo train length [ETL] 10, 20 × 20 field of view [FOV], 80 bandwidth [BW]) is associated with superior edge detection when compared with those images in which a typical diagnostic sequence was used. The use of a low bandwidth sequence does not compromise edge detection or seed identification when compared with a higher bandwidth.

CONCLUSIONS: We have defined a magnetic resonance imaging sequence, which appears to optimize both prostate delineation and identification of seeds, lending itself to straightforward fusion with CT images and allowing for less uncertainty in permanent seed prostate brachytherapy quality assurance.

Keywords: Prostate neoplasms; Brachytherapy; Magnetic resonance imaging; Quality assurance

Introduction

Implant quality is an important determinant of outcome in patients with prostate cancer treated with permanent seed brachytherapy. Accurate dosimetry provides feedback to the brachytherapy team, fosters technical changes to improve quality, and identifies suboptimal implants that may require corrective measures. Programs with meticulous quality assurance (QA) report higher biochemical control rates than those where poor-quality implants predominate. Recent articles from Zelefsky *et al.* (1) and Henry *et al.* (2) report a large variation in implant quality with inferior biochemical control rates in patients with low postimplant *D*90's (minimum dose received by 90% of the prostate).

Postimplant dosimetry is very dependent on the quality of prostate imaging. Computed tomography (CT) imaging is the accepted standard for evaluation of implant quality, although the implanted seeds produce artifacts and obscure the outline of the prostate gland. Prostate volume determination by CT tends to overestimate the prostate volume (3, 4) when compared with either ultrasound or magnetic resonance imaging (MRI). Contrary to the situation with CT imaging, the presence of brachytherapy seeds does not affect the quality of prostate imaging using MRI, and consequently edge detection is superior to that achievable with CT. The use of MRI has been shown to reduce

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* Corresponding author. Department of Radiation Oncology, British Columbia Cancer Agency, Center for the Southern Interior, University of British Columbia, 399 Royal Avenue, Kelowna, BC V1Y 5L3, Canada. Tel.: +1-250-712-3979; fax: +1-250-712-3911.

E-mail address: jcrook@bccancer.bc.ca (J.M. Crook).

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interobserver variation in prostate delineation for the purpose of external beam planning and in the postimplant setting (5–7).

When MRI is used for the purpose of quality assessment after brachytherapy, it is important that the optimal scan sequence be selected. The use of a nonoptimal scan sequence leads to disappointing imaging results that diminish the value of the scan. In the post brachytherapy setting, the chosen imaging modality should sharply define the edges of the prostate while allowing visualization of the implanted seeds. The use of the typical diagnostic magnetic resonance (MR) sequence does not meet these requirements and can lead to uncertainty in both contouring and seed identification. The purpose of this article is to demonstrate with case reviews what we have found to be an ideal MR scan sequence for postimplant assessment after permanent seed brachytherapy. We will also demonstrate the potential pitfalls that can be encountered with suboptimal imaging.

Methods and materials

The British Columbia Cancer Agency Center for the Southern Interior is one of four regional sites of the British Columbia Cancer Agency where prostate brachytherapy seed implants are performed. Four radiation oncologists at our center perform permanent ^{125}I seed implants, using either stranded or loose seeds. MRI and CT imaging are systematically performed at 30 days postimplant, and are manually fused using the seeds as fiducial markers. MR images are used to delineate the prostate gland and relevant normal structures, and CT is used to determine the location of the seeds. Both loose and stranded seeds are used, and patients receiving implants with loose seeds also undergo plain film imaging of the chest and pelvis. Our brachytherapy team meets regularly to review the postimplant dosimetry.

Imaging

Axial MR images of the prostate and lower pelvis are taken using a 1.5 Tesla Signa GE scanner with the patient supine. A Fast Spin Echo T2-weighted MR sequence is used with the following technical parameters: repetition time (TR) = 4500 msec, echo time (TE) = 90 msec, echo train length (ETL) = 10, pixel bandwidth (BW) = 80 Hz/pixel, field of view = 20 × 20 cm, 3-mm slice thickness, 0-mm gap, acquired matrix sixe = 320 × 224 with phase encoding direction along rows, flip angle = 90°.

CT images are likewise obtained in the supine position, imaging the prostate and all seeds visible on the scout image in 2-mm slices. Catheterization is performed for urethral localization when required by the oncologist. No specific bowel preparation is used before either scan but they are performed sequentially, with the CT following the MRI generally within half an hour.

Results

Figure 1 shows MR images on a patient in whom our standard sequence is used. Using this sequence, both the prostate edge and seed locations are easily detectable. Caudal to the prostate, the plane of fat separating the urethra and levator ani muscle displays high signal (white) on T2-weighted images. The prostate apex can be identified as the most caudal slice, where this ‘‘white’’ plane is lost and there is low-signal density apparent in this space. Superiorly, bladder neck has different signal intensity than prostatic tissue, allowing identification of the prostate base. Intraprostatic anatomy is not clearly identified with this sequence. For instance, the urethra is not as clearly visible as on a diagnostic scan and the distinction between the transition and peripheral zones is diminished. However, these features are not important for the purposes of implant evaluation. If urethral localization is desired, catheterization can be performed at the time of either the MR or the CT.

We have previously acquired MR images using this sequence with a longer bandwidth of 120 Hz/pixel. With a lower bandwidth of 80 Hz/pixel, there is a savings of about 2 min in image acquisition per patient. As our MR scans are performed at the adjoining general hospital where MR time is at a premium, this time saving was significant in obtaining the required number of MR bookings per week. Reducing the bandwidth reduces the noise and increases the chemical shift artifact that is expected to improve the visibility of implanted seeds. Our experience indicates that the increased static magnetic field (B0) distortions because of the lower bandwidth do not cause CT–MRI fusion issues for MR images acquired with the scan sequence identified in this study. The images obtained are indistinguishable for both the prostate edge detection and seed identification. Shorter imaging time also reduces motion artifact, and improves patient convenience. The images below (Fig. 2) demonstrate the lack of effect of this modification on image quality.

A diagnostic sequence is not optimal for the purposes of evaluating a brachytherapy implant, as demonstrated in Fig. 3. In a typical diagnostic sequence, the peripheral zone is relatively isointense with the periprostatic fat, diminishing prostate edge detection. Thus, the readily visible interface between the peripheral and transition zones (‘‘surgical capsule’’) can be mistaken for the prostate capsule. Even when one is aware of this issue, the outline of the prostate can be indistinct, particularly at the apex as shown in Fig. 3. Although intraprostatic pathology is more readily visible, this information is not essential to postimplant evaluation.

The prostate brachytherapy program at the British Columbia Cancer Agency previously explored the use of MRI in postimplant QA but did not appreciate the

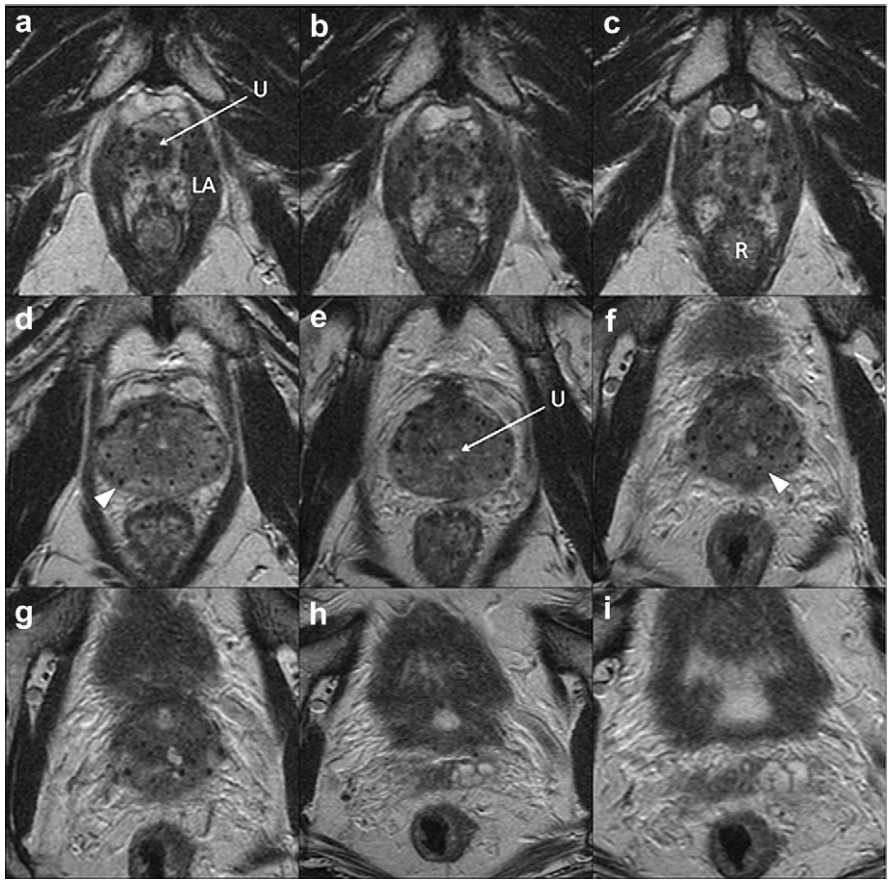

Fig. 1. Magnetic resonance image series of the prostate (repetition time [TR] = 4500 msec, echo time [TE] = 90 msec, echo train length [ETL] = 10, bandwidth [BW] = 80 Hz/pixel). Image (b) represents the most inferior slice, where prostate is visible. Images (d–f) are taken through the midgland. Image (h) represents the most superior slice, where prostate is visible. Example seed voids are demonstrated with the white arrowheads. LA = levator ani muscle; U = urethra; R = rectum.

importance of specifying the MR sequence. Figure 4 is an example of an MR series using a suboptimal sequence, demonstrating the importance of using a sequence that is specific to the postimplant setting. Figure 5 shows a patient in whom motion artifact has impaired seed and prostate identification, despite the use of the proper sequence.

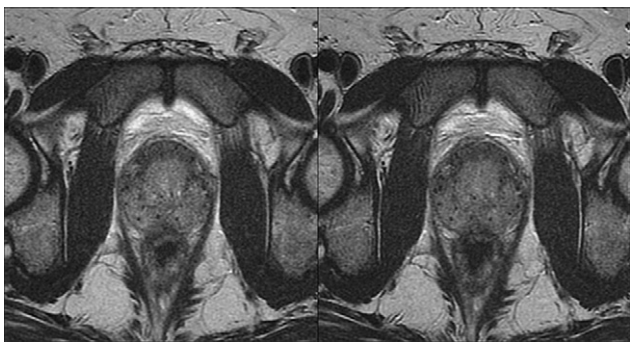

Fig. 2. Magnetic resonance images through the midprostate. A bandwidth of 120 Hz/pixel was used in the image on the left, and the image on the right was taken using a bandwidth of 80 Hz/pixel. These images were taken from the same patient.

Discussion

Evaluation of dosimetry after permanent seed brachytherapy provides invaluable feedback to the brachytherapy team, and is essential to individual patient care. Interobserver variation in prostate contouring using CT alone in the postimplant setting leads to substantial variation in dosimetric interpretation (8), and may fail to identify substandard implants when compared with MR–CT fusion (9). The MR sequence described in this article optimizes edge detection needed for prostate delineation and allows adequate identification of seeds and spacers.

High-quality MRI is paramount to meet the dual purposes of defining the outline of the prostate and clearly visualizing the seed voids (10, 11). The literature describing the use of MRI for the purposes of QA after permanent seed prostate brachytherapy commonly reports difficulty with fusion and simultaneous identification of the prostate and seeds. Amdur *et al.* (12) have described a method of fusing CT and MR images using a Foley catheter balloon and urethral position as landmarks. However, such an approach is confounded by prostate deformation by the catheter and proximal movement of the catheter

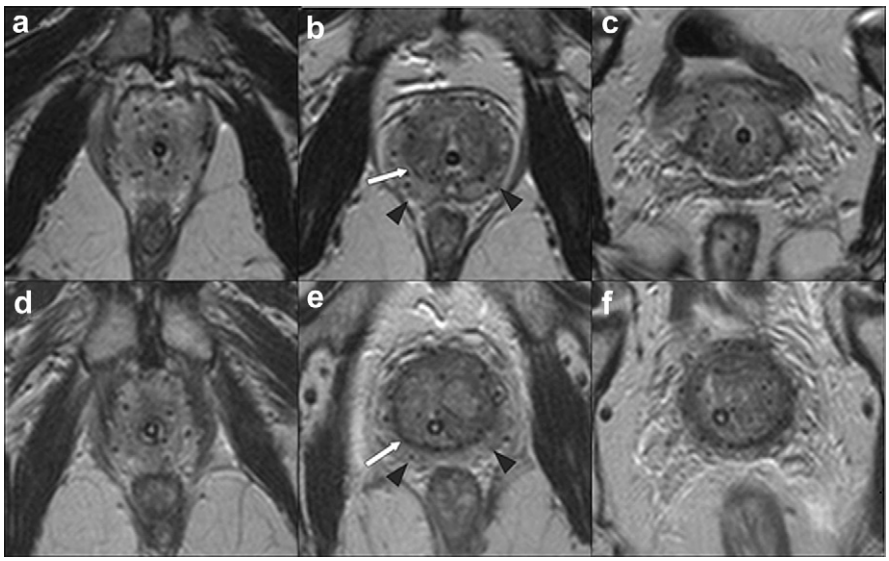

Fig. 3. Diagnostic magnetic resonance sequences for 2 patients (a–c and d–f). Technical parameters for these sequences are as follows: repetition time (TR) = 4080 msec, echo time (TE) = 85 msec, echo train length (ETL) = 13, bandwidth (BW) = 130 Hz/pixel, field of view [FOV] = 34 × 34 cm, 3-mm slices, 0-mm gap, 256 × 256 matrix with phase-encoding direction along rows, flip angle = 90°. Images (a) and (d) demonstrate the prostate apex. Images (b) and (e) are taken from the midgland. Images (c) and (f) show the prostate base. The white arrows demonstrate the interface between the transition zone and peripheral zone. The black arrows outline the prostate capsule. Note that a Foley catheter is in place in both the patients.

balloon. Tanaka *et al.* (13) evaluated the utility of various MR sequences vs. the use of MR–CT fusion. The sequences used in this article were still confounded by the lack of ability to clearly identify extraprostatic seeds, and the use of MRI alone appeared to overestimate dosimetric parameters vs. MR–CT fusion; however, the accuracy appeared to be superior to that associated with CT alone. Katayama *et al.* (14) have made further advancements in this area by fusing T2* (which allows improved seed detection) and T2 MR sequences to one another, observing dosimetry that was at least comparable and possibly superior to that obtained using T2 MR alone. For some patients in this series, there were large differences noted with T2*T2 fusion vs. CT–MR fusion, likely resulting from seed identification. Although CT imaging is still necessary for seed identification, the results reported by these studies suggest that the use of MRI alone may be possible in the future. With the single MRI sequence described in our article when compared with two sequences used by Katayama *et al.*, (14) the seed positions on CT and signal voids on a single MR sequence can be fused to within 1–1.5 mm accuracy (9), and thus may be a useful starting point for centers wishing to incorporate MRI into postbrachytherapy QA.

The goals of MRI after permanent seed brachytherapy are distinct from those of diagnostic prostate MRI, and as discussed above, a diagnostic sequence is not ideal for the purposes of post brachytherapy QA. The details of diagnostic prostate MRI are relevant to both brachytherapy and external beam radiotherapy and are reviewed elsewhere (15, 16). Whereas postimplant imaging requires clear prostate edge detection and visualization of seed voids, diagnostic imaging strives to enhance intraprostatic detail. One approach to improve the resolution of MRI in the diagnostic realm is to use an endorectal coil. However, if used in the postimplant setting, this would deform the prostate

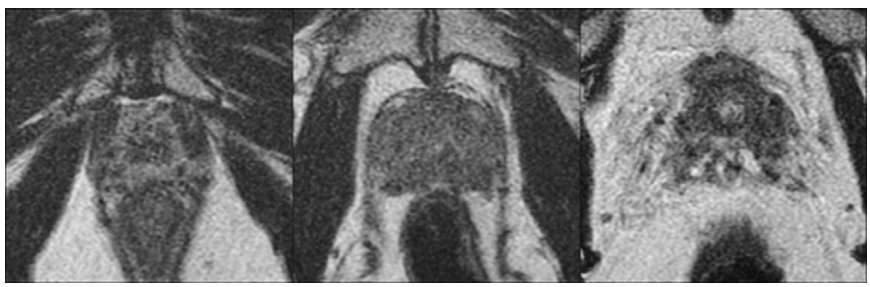

Fig. 4. For unknown reasons, the magnetic resonance (MR) sequence parameters were adjusted for a series of patients such that the repetition time was shorter (3650 sec). Neither the prostate edge nor seed voids are well defined in the images displayed above. It was not understood why the imaging was so poor until these parameters were reviewed and corrected. Communication with the radiology department is critical to ensure a common understanding of the goals of MR imaging in the postimplant setting.

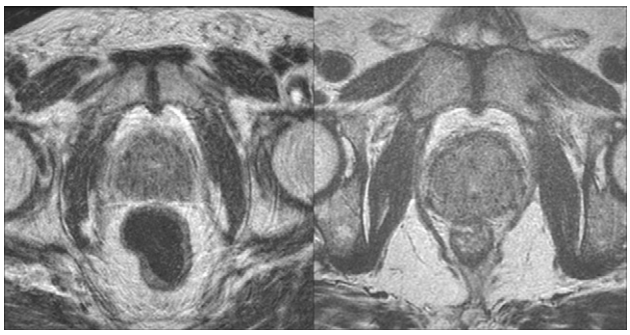

Fig. 5. Example of a poor image quality resulting from motion artifact, despite the use of the appropriate sequence.

shape making subsequent fusion with CT more difficult. Also, because the deformed shape does not represent the natural state of the prostate, the dose calculations will not correspond to what is actually delivered to the unperturbed prostate.

McLaughlin *et al.* (17) found that CT imaging, and T1-weighted and T1-weighted fat saturation MR, consistently overestimated the prostate volume when compared with T2-weighted MR and suggested that overestimation at the prostate base may be a factor in the misperception of underdosing at the anterior prostate base. T2-weighted MR also resulted in the best prostatic definition at the pelvic diaphragm, distinguishing the apex from soft tissue, and at the base distinguishing prostate from bladder and seminal vesicle. However, T2-weighted MR was inferior to both CT and T1-MR sequences in terms of seed definition, image acquisition time, and cost. The T2-weighted sequence we have described allows for both adequate seed definition to allow fusion with CT, and the low bandwidth reduces acquisition time without compromising edge detection.

Several barriers exist, which have limited the use of MRI in the postimplant setting. MRI is costly and access to machine time may be limited. If one succeeds in obtaining MRI, the process of fusion of MR and CT requires some training and adds to the time required for implant evaluation. In our practice, an experienced dosimetrist, physicist, or physician can complete most of the fusions in only 5–15 min per case. MR as a single-imaging modality, avoiding the use of CT imaging postimplant, is being investigated but is not feasible at present as seeds and spacers leave similar voids and extraprostatic seeds are not well visualized on MRI.

Conclusion

We have defined an MRI sequence, which provides satisfactory prostate delineation and identification of seeds, lending itself to straightforward fusion with CT images and allowing for greater certainty in permanent seed prostate brachytherapy QA. The choice of the correct MR sequence is essential in making the additional time and expense of MRI worthwhile.

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