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Review Article

Magnetic resonance imaging basics for the prostate brachytherapist

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ABSTRACT Magnetic resonance imaging (MRI) is increasingly being used in radiation therapy, and integration of MRI into brachytherapy in particular is becoming more common. We present here a systematic review of the basic physics and technical aspects of incorporating MRI into prostate brachytherapy. Terminology and MRI system components are reviewed along with typical work flows in prostate high-dose-rate and low-dose-rate brachytherapy. In general, the brachytherapy workflow consists of five key components: diagnosis, implantation, treatment planning (scan + plan), implant verification, and delivery. MRI integration is discussed for diagnosis; treatment planning; and MRI-guided brachytherapy implants, in which MRI is used to guide the physical insertion of the brachytherapy applicator or needles. Considerations and challenges for establishing an MRI brachytherapy program are also discussed.

Keywords: Prostate; Brachytherapy; HDR; LDR; MRI; Quality assurance

Introduction

Prostate radiotherapy is currently in a period of rapid development, with an ongoing move toward use of hypofractionation for tightly conformal dose escalation in both brachytherapy and external beam radiotherapy. Level I evidence exists indicating that increasing the dose administered through low-dose-rate (LDR) brachytherapy improves biochemical control (1), and a dose-effect relationship has been identified for high-dose-rate (HDR) brachytherapy in intermediate- and high-risk prostate cancer (2). Interest is also increasing in the use of focal treatment and focal boost doses to intraprostatic lesions (3−6). Given the importance of both dose and location in brachytherapy, magnetic resonance imaging (MRI)−guided brachytherapy is becoming increasingly relevant to improve the identification of targets and organs at risk (OARs). MRI may also improve accuracy in dose prescription and reporting for the prostate gland, for gross target volumes within the prostate, and for the OARs (6−9).

In brachytherapy, high-quality MRI is important to ensure that adequate radiation dose covers the prostate target while maintaining the dose to the surrounding critical structures such as rectum and bladder below predefined levels. Any images used for treatment planning and postimplant quality assessment must provide adequate spatial accuracy for target delineation, localization of the seed and needle dwell positions, and visualizing the anatomy of surrounding critical structures.

For LDR prostate brachytherapy, the current standard for preimplant dosimetry is transrectal ultrasonography (TRUS) and that for postimplant dosimetry is computed tomography (CT). On postimplant CT, seed positions can be reconstructed and the resulting dose distribution confirmed to be within acceptable limits (10, 11). However, the anatomic boundaries of the prostate and some of the

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surrounding structures are difficult to visualize on CT, which can cause uncertainties and variations in target and OAR delineation leading to inaccuracies in dosimetry (12). Furthermore, the numerous metallic seeds implanted in the prostate introduce severe streak artifacts that can make visualizing anatomic structures challenging, although these artifacts can be reduced with improved CT reconstruction algorithms. On the other hand, although MRI provides better visualization and hence delineation of prostate and surrounding soft tissues, seed localization is difficult because the seeds, markers, and needle tracks all show up as signal void or negative contrast on the MR images (Fig. 1). Some institutions use CT-MRI fusion, in which seeds are identified on CT and anatomy is delineated on MRI. The American Brachytherapy Society has recommended the use of CT-MRI fusion for postimplant dosimetry (13, 14). Given its superiority for tissue visualization, MRI may have important roles in dosimetric assessments of brachytherapy, both during treatment planning and after seed implantation (15−17).

For HDR prostate brachytherapy, TRUS is also recognized as the gold standard for guiding the implantation of needles. Recent advances have allowed treatment planning to be done directly with TRUS, and, if a shielded operating room is available, radiation can be delivered according to the TRUS plan while the patient is still in the lithotomy position (i.e., lying supine with the knees bent and positioned above the hips). A challenge when using an US-based workflow is delineation of the prostate after needle insertion, because the needles cast shadows that lead to significant deterioration of image quality. Needle shadowing may also cause difficulties in reconstructing the position of the needles. Another common workflow involves TRUS-guided needle implantation in the operating room, with the patient in the lithotomy position, followed by postimplantation CT-based dose planning and subsequent dose delivery outside the operating room, with the patient's legs down. The drawbacks of this approach are the limited visualization of the prostate on CT, which can lead to the prostate contours being larger on CT than on MRI or US (18) and, to some extent, the differences in leg position for US and CT. New approaches have incorporated MRI into the HDR brachytherapy procedure to improve visualization of target and OARs (7). The most advanced approach is needle insertion under real-time MRI guidance (19, 20), and another strategy is TRUS-based needle insertion combined with postimplantation MRI and MRI-based treatment planning (21). These alternatives are discussed in the section, Workflows for using MRI in brachytherapy below.

Current trends in prostate brachytherapy suggest that the use of MRI for planning, for guidance, and for postimplant evaluations is growing. Although a firm framework has been established for the preparation, execution, and documentation of MRI for cervical cancer brachytherapy (22−24), such consensus does not yet exist for prostate brachytherapy. This systematic review of the basic MRI concepts is aimed toward brachytherapists who are considering integrating MRI in their workflow for prostate cancer brachytherapy. This review will start with a general description of the main components of MRI (section A), followed by the MRI safety in brachytherapy (section B). Then the general workflow of MRI in brachytherapy (section C), treatment planning with MRI (section D), and some miscellaneous issues such as image fusion and MRI image artifacts are discussed (section E).

General description of MRI main components

MRI scanner system

MRI-based prostate brachytherapy can be done with diagnostic MRI scanners or with MRI simulators dedicated for radiation oncology purposes. When MRI is used for treatment planning, use of MR-compatible leg rests, rolls, straps, or mats to stabilize the patient's legs and hips can help to ensure reproducibility of patient position and geometry between planning and treatment. There are three major

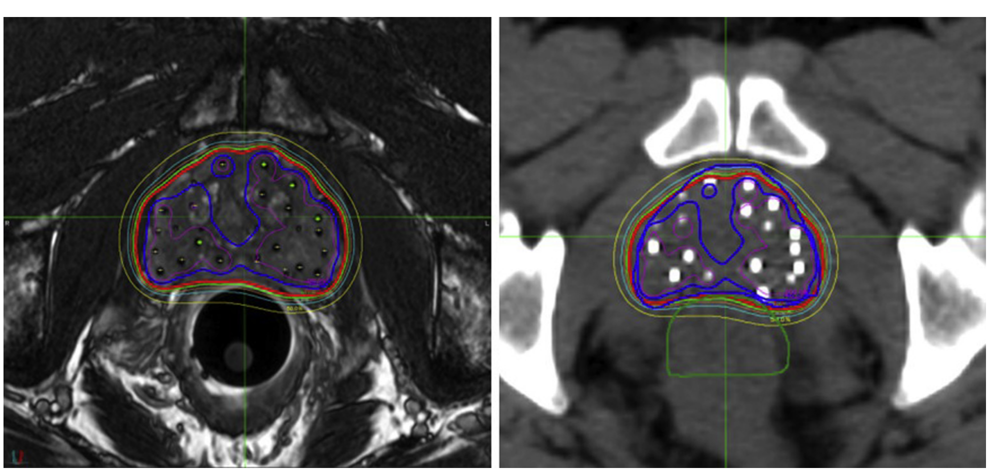

Fig. 1. CT and MR images for dosimetric assessment after implantation of seeds. The anatomic boundaries are notably clearer on the MR images (left) compared with CT images (right).