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Use of MRI in low-dose-rate and high-dose-rate prostate brachytherapy from diagnosis to treatment assessment: Defining the knowledge gaps, technical challenges, and barriers to implementation

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ABSTRACT MRI is rapidly evolving as an imaging tool in both low-dose-rate and high-dose-rate brachytherapy for prostate cancer. The ability of MRI to identify intraprostatic tumors and reduce uncertainties in the workflow process should enable a more accurate and precise radiation delivery approach while simultaneously improving the quality assurance process. The ability to identify functional anatomic structures adjacent to the prostate cancer could reduce or eliminate some of the more common side effects of the treatment. However, MRI is complex, and collaborative efforts and future research are required to address the current knowledge gaps, technical challenges, and barriers to widespread the implementation of MRI-assisted and MRI-guided prostate brachytherapy.

Keywords: Prostate cancer; Magnetic resonance imaging; Prostate brachytherapy; LDR; HDR; MRI-assisted radiosurgery; MRI physics; Pulse sequences

Introduction

The use of MRI in prostate cancer diagnosis, staging, and treatment has become a standard of care (1). For diagnostic radiologists, radiation oncologists, urologists, and multidisciplinary prostate cancer teams, MRI provides information important for staging disease and predicting prognosis and has emerged as an essential tool in the assessment, treatment, and management of the disease (2).

Prostate brachytherapy is one standard-of-care approach component of the management of localized prostate cancer in patients who receive definitive radiation therapy (3−5). With high-quality brachytherapy, patient-reported outcomes have been excellent after brachytherapy with respect to sexual function, bowel function, urinary continence, and overall patient satisfaction (6, 7). However, treatment-related toxicity after poor-quality brachytherapy can be severe owing to the proximity of the tumor to the bladder, rectum, urethra, and neurovascular bundles (8), and patient-reported outcomes have included increased urinary irritability and bother and also erectile dysfunction that can persist for years after treatment (9, 10). Traditionally, MRI has been used with brachytherapy for quality assurance after the implantation (3).

Over the past 4 decades, ultrasonography and CT have been the standard "workhorse" imaging tools used from diagnosis to treatment assessment in the management of localized prostate cancer. In 2016, the National Comprehensive Cancer Network incorporated the use of MRI into its standard guidelines for the workup and management of the disease because of MRI's superior soft-tissue contrast and dynamic imaging capabilities (1). Advances in MRI technology have allowed MRI to be incorporated into each step of the workflow of prostate brachytherapy, to improve quality

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assurance by further reducing uncertainties in both treatment planning and treatment delivery, and to ensure greater accuracy and precision of radiation delivery to the tumor while limiting the dose to the pelvic organs at risk, thereby improving clinical outcomes (11). For example, the external urinary sphincter contains both the intraprostatic sphincter surrounding the urethra from the verumontanum to the prostate apex and the membranous urethral sphincter that surrounds the urethra from the prostate apex to the penile bulb. Heterogeneities in radiation dose to these structures can result

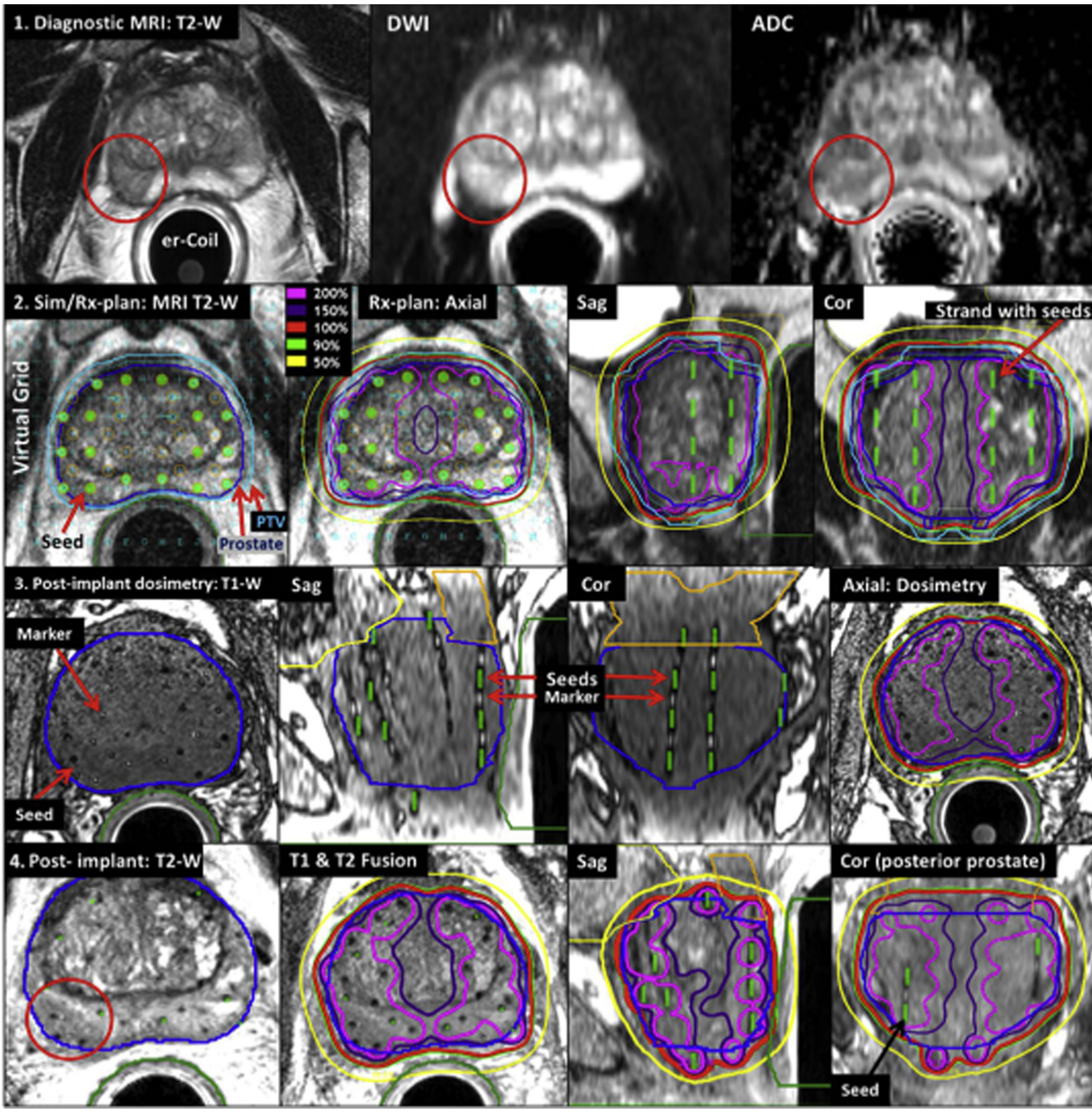

Fig. 1. MRI-assisted brachytherapy workflow at MD Anderson Cancer Center for LDR prostate brachytherapy, from diagnosis (row 1) to simulation and treatment planning (row 2) to postimplant assessment (rows 3 and 4). Row 1: Diagnostic MR axial images show a prostate tumor in the right peripheral zone (red circles). Row 2: Simulation MRI T2-weighted image with virtual grid in place. Prostate and PTV have been contoured. Pretreatment plan dosimetry is shown in axial, sagittal, and coronal views. Row 3: Postimplant assessment. T1-weighted image showing seeds (hypointense) and markers (hyperintense) within the prostate (outlined in blue). Strands with seeds (green) and markers (white) are seen on sagittal and coronal views. Row 4: Postimplant T2-weighted image highlights prostate anatomy. Postimplant fused T1 and T2 images provide optimal anatomic information and precise dosimetry. ADC = apparent diffusion coefficient; Cor = coronal; DWI = diffusion-weighted imaging; er = endorectal; LDR = low-dose-rate; PTV = planning target volume; Sim = simulation; Sag = sagittal. Reprinted with permission of Springer Science & Business Media, from Image-Guided Brachytherapy, 2017; permission conveyed through Copyright Clearance Center.