HOW TO PERFORM AND INTERPRET PROSTATE MRI

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INTRODUCTION

Initially, the role of MRI for assessment of prostate cancer was limited to staging patients with biopsy proven disease. However, along with the expansion of treatment options for prostate cancer and advances in MR technology (software, hardware, and 3T), clinical applications of prostate MRI now include detection, localization, active surveillance, and image guidance for biopsy and surgery. Traditional prostate MRI, which was based exclusively on morphologic imaging with standard T1-weighted and T2-weighted sequences, had limited capability to delineate prostate cancer foci and to distinguish between malignant and benign tissues. More recently, multiparametric MR imaging, which incorporates functional and physiologic MR imaging techniques such as diffusion-weighted imaging (DWI), dynamic contrast-enhanced (DCE) imaging, and MR spectroscopic imaging (MRSI), has been shown to improve accuracy.

NORMAL MR ANATOMY OF THE PROSTATE

The prostate is divided from superior to inferior into the base (just below the urinary bladder), the midgland, and the apex. In the axial plane, the prostate is divided into four zones: (a) the anterior fibromuscular stroma, which contains no glandular tissue; (b) the transition zone surrounding the urethra, which contains 5% of the glandular tissue; (c) the central zone, which contains 20% of the glandular tissue; and (d) the outer peripheral zone, which contains 70%-80% of the glandular tissue. On MR images, the transition zone can sometimes be separated from the central zone based signal intensity and location. However, more often, especially in older men, they cannot be distinguished and these two zones together are often
referred to as the central gland. The volume of the peripheral zone increases from the base to the apex of the gland. Approximately 70% of prostate cancers originate in the peripheral zone, 25% in the transition zone, and 5% in the central zone.

The prostate does not have a true capsule, only an outer band of concentric fibromuscular tissue that is an inseparable component of the prostatic stroma. It is seen as a thin layer that is dark on T2-weighted images. The capsule is an important landmark for assessment of extraprostatic tumor extension, since irregularities, focal bulges, and disruptions of the capsule are signs of tumor invasion or spread outside the confines of the prostate.

The neurovascular bundles, which play a role in sexual function, course posterolateral to the prostate bilaterally at the 5-o'clock and 7-o'clock positions in reference to the prostate. At the apex and base, the nerve bundles send penetrating branches through the capsule, which provide a route for extraprostatic tumor extension.

**IMAGING FEATURES OF PROSTATE CANCER**

A. Peripheral Zone
   1. Discrete, homogenous low SI focus/mass
   2. Linear, wedge shaped, poorly demarcated, or geographic non-focal low SI areas are less likely to be malignant

B. Transition Zone (Central Gland)
   1. Ill-defined homogenous low SI (“erased charcoal sign”)
   2. Cancer more likely if it originates anteriorly
   3. Often lenticular or teardrop shape
   4. Cancer less likely if it is round and discrete, especially with dark rim or high SI
ADVANCED MR TECHNIQUES

Diffusion-weighted Imaging (DWI) and ADC Mapping

Diffusion refers to the microscopic motion of water molecules. Diffusion-weighted imaging (DWI) interrogates the tissue microstructure. Changes in diffusion tissue signal may be due to an alteration in cellularity, cell membrane integrity, tortuosity of extracellular space, or fluid viscosity indicative of disease. Therefore, DWI provides an important quantitative biophysical parameter that can assist in differentiating benign from malignant prostate tissue.

Diffusion in tissues is determined by the diffusion coefficient $D$. The MR measurable spatially averaged biomarker of diffusion is the apparent diffusion coefficient (ADC). A decreased ADC is interpreted as reduced motion of water molecules or diffusion.

The ADC has been related to the state of tissue during the growth of tumors or progression of cancer. With proliferating cells, there is an increase in cellular density and a decrease in the amount of intracellular space or extracellular space available, leading to a reduction in the ADC. Malignant lesions have lower ADC values (about 20%–40%) than benign or normal prostatic tissue, but there are zonal variations in the normal tissue values for different zones of the prostate. Although in theory the ADC represents tissue properties only, in practice ADC measurements depend on the details of imaging unit hardware and imaging protocols. Therefore, comparison necessitates knowledge of the normal ranges for a specific system.

Diffusion-weighted images with different $b$ values can be generated, and ADC values can be derived and mapped on a pixel by pixel basis and then correlated with T2-weighted images, improving the sensitivity (54%–98%) and specificity (58%–100%) of MR imaging in
detection of prostate cancer. Higher Gleason score tumors have been associated with lower ADC values, likely due to the dedifferentiated infiltrative growth of these tumors, as opposed to the glandular organization of more well-differentiated prostate cancer, which more closely resembles normal prostatic tissue. Thus, DWI may also help to predict tumor aggressiveness.

The $b$ value summarizes the influence of the gradients on the diffusion weighted images. The higher the $b$ value, the stronger the diffusion weighting. At high $b$ value, diffusion-weighted imaging represents the molecular diffusion of water almost exclusively. However, as the $b$ value increases, the gradient radiofrequency pulse is prolonged, thus increasing the echo time and reducing the quality and SNR of the diffusion-weighted images.

The smaller the $b$ value, the higher the quality and SNR of the diffusion-weighted images; however, at the same time the T2 shine-through effect and tissue perfusion effects increase their influence on diffusion-weighted imaging. With lower $b$ values, the ADC value also reflects the perfusion of the microcirculation. To generate ADC maps of the prostate, it is best to omit lowest $b$ values (0-100).

Conspicuity of tumor foci can be limited by “T2 shine through” due to the fact that the Benign prostate tissue may have a prolonged T2 relaxation time and maintain high signal intensity on DWI at a $b$-values up to around 1000sec/mm$^2$, thus obscure the high intensity tumor signal. Choosing a short TE (≤90msec) decreases the T2-weighting and can thus reduce the T2 effect. Another means to increase the conspicuity of malignant foci is to use $b$-value ≥1400sec/mm$^2$. However, prostate at very high b values requires a strong signal to noise ratio, only available on most 1.5Tscanners by
using an endorectal coil. To circumvent this limitation, a $b_{1400}$ value, extrapolated from a multi $b$-value sequence, can be used.

**Dynamic Contrast-Enhanced (DCE)**

Dynamic contrast material–enhanced (DCE) MR imaging dynamically captures the distribution of intravenously administered gadolinium-based contrast agents between tissue and the blood pool, allowing characterization of alterations in the microvascular environment resulting from tumor angiogenesis. In prostate cancer, increased tumor vascularity leads to early focal hyperenhancement (higher and earlier peak enhancement than in normal tissue), and vascular permeability is associated with rapid washout of contrast material from the malignant tumors in comparison with normal prostate tissue.

DCE requires high temporal resolution (images obtained every 2-10 seconds for at least 5 minutes), so that spatial resolution is often compromised. DCE MR imaging parameters can be converted into color-coded parametric maps and overlaid on the anatomic T1- and T2-weighted images for interpretation.

**INTERPRETATION**

Recognizing that there has been too much variability in the performance, interpretation, and reporting of prostate MRI exams, and that a greater level of standardization and consistency was needed, the European Society of Uroradiology (ESUR) developed guidelines for prostate MRI. These guidelines, published in 2012, formed the foundation for the American College of Radiology (ACR) Prostate Imaging and Reporting Data System (ACR PI-RADS).

ACR PI-RADS is a quality assurance tool designed to standardize acquisition, interpretation, and reporting of prostate MRI examinations.
and minimize observer variability. The objective of ACR PI-RADS is to improve the diagnosis and management of prostate cancer and to facilitate research. It is based on evidence and consensus expert opinion.

TECHNIQUE

Magnetic Field Strength
Prostate MR imaging at both 1.5 T and 3T has been well established. The value of prostate imaging at lower magnetic field strengths has not been satisfactorily validated and it is not recommended. The fundamental advantage of 3T compared with 1.5T lies is an increased SNR, which increases linearly with the static magnetic field B0. This may be exploited to increase spatial, temporal, and/or spectral resolution. However, if the same pulse sequences are used, the power deposition increases fourfold at 3T compared with 1.5T, and shorter T2 and longer T1 relaxation, increased susceptibility, and signal heterogeneity also occur at 3T. Although, there are a number of techniques for addressing these issues, they often result in compensatory increases in imaging time and/or decreases in SNR so that the advantage of imaging at 3T is usually somewhat less than anticipated.

Endorectal Coils (ERCs)
When integrated with external phased array coils, endorectal coils (ERCs) increase SNR in the prostate at any magnetic field strength. This may be particularly valuable for high spatial resolution imaging required for staging and for inherently lower SNR sequences, such as DWI and high temporal resolution DCE. ERCs are also advantageous for larger patients where the SNR in the prostate may be significantly compromised using only external RF coils.
However, use of an ERC increases the cost and time of the exam, is uncomfortable for the patient, distorts the gland, and may introduce artifacts. It may also increase a patient’s reluctance to undergo the exam. Taking these factors into consideration as well as the variability of MRI equipment available in clinical use, the ACR PI-RADS Steering Committee recommends that supervising physicians strive to optimize imaging protocols in order to obtain the best and most consistent image quality possible with the MRI scanner used. However, cost and other considerations cannot be ignored, and adequate image quality may be obtained with or without an endorectal coil, depending on the situation.

With some contemporary 1.5T MR imaging systems, use of an endorectal coil is considered indispensable for achieving the type of diagnostic quality high resolution imaging needed for staging prostate cancer. However, some 1.5T scanners that employ a relatively high number of external phased array coil elements and RF channels (eg 16 or more) are able to achieve adequate SNR in many patients without an endorectal coil. At 3 T, image quality comparable with that at 1.5 T with an ERC can be achieved without use of an ERC. However, if ERCs are used, improvements in localization and staging of prostate cancer at 3T have been reported in comparison with use of phased-array surface coils only.

ERCs may introduce strong susceptibility gradients, especially if air is used to inflate the coil balloon. Although common practice at 1.5 T, use of air inflation at 3 T often causes prohibitive artifacts. This may also occur at 1.5T for DW-MRI pulse sequences. Therefore, balloon distention should be achieved using substances that are more similar to the tissue susceptibility (eg, liquid perfluorocarbon or barium). Rigid ERCs that avoid the need for inflatable balloons have been developed for use at 1.5 T.
ENDORECTAL COIL PROTOCOL

Foot first supine.

Coil coverage from perineum to aortic bifurcation.

Use torso phased array anteriorly and spine coil posteriorly.

Place the endorectal coil.

- **Scout**
- **Scout redo**
  - Redo the scout in ISO mode such that the prostate is isocenter in the magnet
- **Optional HASTE 3 plane scouts of the prostate**
  - Useful to quickly get the correct axial, sagittal, and coronal planes in a short amount of time.
- **Axial 2D T2 (high res)**
  - Free breathing
  - Phase must be L/R
  - Angle to the prostate on the sagittal images
- **Cor 2D T2 (high res)**
  - Free breathing
  - Phase must be L/R
  - Angle to the prostate on the sagittal images
- **Axial 3D T2**
- **Axial 2D T1 (high res)**
  - Free breathing
  - Phase must be L/R
  - Copy center of acquisition from Axial T2 above
- **Small FOV DWI**
  - Free breathing
  - Phase must be A/P
  - Copy center of acquisition from Axial T2 above
- **High Temporal Res Perfusion**
  - Free breathing
  - Phase must be L/R
- No fat suppression
- Copy center of acquisition from Axial T2 above
- Run 1 phase using flip angle of 5 to ensure coverage is adequate and that the hips do not wrap into the prostate
- Run 5 minutes worth of phases with a flip angle of 15
- Inject 0.1 mmol / kg at 2-3cc/sec. Wait for 4 phases to run and then give the contrast

**Large FOV VIBE Post-C from the bifurcation down**

Longitudinal orientation of the smooth muscle fibers of the outer myometrium) result in a decrease the signal of the junctional zone on T2-weighted imaging. A thickness of up to 8 mm is considered normal.
RECOMMENDED READING

   Prostate Cancer: Sextant Localization at MR Imaging and MR Spectroscopic Imaging before Prostatectomy—Results of ACRIN Prospective Multi-institutional Clinicopathologic Study Radiology April 2009 251:122-133

   Staging prostate cancer with dynamic contrast-enhanced endorectal MR imaging prior to radical prostatectomy: experienced versus less experienced readers.
   Radiology 2005; 237(2): 541–549

   Imaging Prostate Cancer: A Multidisciplinary Perspective
   Radiology April 2007 243:28-53

   Combined T2-Weighted and Diffusion-Weighted MRI for Localization of Prostate Cancer.
   AJR 2007;189: 323-328

   Peripheral Zone Prostate Cancer: Accuracy of Different Interpretative Approaches with MR and MR Spectroscopic Imaging
   Radiology January 2008 246:177-184

   Continuing Medical Education: Prostate Cancer: Multiparametric MR Imaging for Detection, Localization, and Staging
   Radiology October 2011 261:46-66
Continuing Medical Education: Advancements in MR Imaging of the Prostate: From Diagnosis to Interventions
Radiographics May-June 2011 31:677-703

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MR Imaging of Treated Prostate Cancer.
Radiology 2012;262:26-42

Endorectal MRI of Prostate Cancer: Incremental Prognostic Importance of Gross Locally Advanced Disease.
AJR 2011;197:1369-1374

Validation of European Society of Urogenital Radiology Scoring System for Prostate Cancer Diagnosis on Multiparametric Magnetic Resonance Imaging in a Cohort of Repeat Biopsy Patients.
European Urology 2012 (62);986-996

Scoring systems Used for the Interpretation and Reporting of Multiparametric MRI for Prostate Cancer Detection, Localization, and Characterization: Could Standardization Lead to Improved Utilization of Imaging within the Diagnostic Pathway.