Diffusion-Weighted Genitourinary Imaging

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KEYWORDS

• Diffusion-weighted imaging • Genitourinary imaging • Magnetic resonance imaging
• Prostate cancer • Bladder cancer • Renal cell carcinoma

KEY POINTS

- Diffusion-weighted MR imaging (DW-MR imaging) allows the detection of early microstructural and functional changes in the genitourinary tract with a high sensitivity and specificity.
- In the kidneys, DW-MR imaging permits further differentiation between benign and malignant lesions compared with conventional cross-sectional imaging.
- DW-MR imaging improves the preoperative workup of bladder cancer in distinguishing between superficial and muscle-invasive urothelial cancers.
- In the pelvis, DW-MR imaging allows detection of lymph nodes metastases even in normal-sized lymph nodes.
- In addition to conventional T2-weighted imaging, DW-MR imaging improves tumor detection in the prostate (mainly the peripheral zone [PZ]) and recurrent tumor in patients after radiation therapy.

INTRODUCTION

In the urogenital tract, cross-sectional imaging methods like computed tomography (CT) and MR imaging are established techniques that allow a comprehensive morphologic overview of all parts of the genitourinary tract to detect and stage different malignant lesions (eg, renal cell carcinoma (RCC), prostate and bladder cancers, pelvic lymph node staging). However, conventional cross-sectional imaging methods have limitations concerning a proper differentiation between benign and malignant lesions and may have a reduced value in patients with an impaired renal function when contrast media cannot be applied.

Diffusion-weighted MR imaging (DW-MR imaging) measures the microscopic mobility of water molecules in biologic tissues, which highly depends on the cellularity within the different tissues and thus allows the detection of biologic abnormalities without the use of contrast media.[1] At first, the clinical use of DW-MR imaging was within the brain to detect microstructural changes in brain tissue after a stroke before morphologic changes can be detected with conventional cross-sectional imaging techniques.[2,3] Although DW-MR imaging has become the gold standard in the early diagnosis of stroke, extracranial applications have been limited initially owing to artifacts caused by physiologic movement of the lung, heart, and bowels.[4] Nevertheless, extensive developments in the technique of DW-MR imaging now allow application in various parts of the abdomen and pelvis, with the potential for the detection, characterization, and treatment monitoring of different malignant lesions.[5–8] This review provides an overview of the possible applications of DW-MR imaging in the urogenital tract with focus on the kidneys, bladder, and prostate, as well in the characterization of pelvic lymph nodes.

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IMAGING TECHNIQUE OF DIFFUSION-WEIGHTED MR IMAGING

Because DW-MR imaging visualizes the Brownian motion of water molecules in different human tissues, the degree of such a motion of molecules is known as diffusion.[9] DW-MR imaging measures the path length traveled by water molecules within a certain time period. The imaging procedure is based on an application of 2 diffusion-sensitizing gradients, which have an opposed polarity.[10] The usual effect on water molecules that do not move is a complete rephrasing. However, in substances with moving water molecules, the random displacement of molecules between the gradient pulses with opposed polarity leads to a signal loss that correlates with the degree of water mobility. The image in DW-MR imaging is based both on the amplitude of random movement of water molecules and on the duration and strength of the paired gradients, which determine the *b*-value. In practice, the *b*-value usually is varied by a variation of the gradient strength. An acquisition of at least 2 *b*-values (usually between 0 and 1000 s/mm^2) allows the calculation of apparent diffusion coefficient (ADC) maps. ADC maps are generated from ADC values voxel by voxel based on the equation ADC = log $[(S_0/S_1)/(b_1/b_0)]$. Here, S_0 is the signal intensity on the unweighted b_0 image (without a diffusion sensitizing gradient) and S_1 is the signal intensity on the DW-MR image with a higher *b*-value. The *b*-value is the gradient factor of the diffusion-sensitizing gradient measured in seconds per square millimeter (s/mm^2). In tissues with tightly packed cells like malignancies, Brownian motion is less than in an environment with a lesser degree of compartmentalization and, therefore, diffusion is impeded, appearing bright on DW-MR images and darker in the ADC map.[11] The extend of diffusion impediment can be measured objectively on the ADC map.

DW-MR imaging can be performed on nearly all currently available clinical MR scanners and is usually integrated in a conventional cross-sectional imaging protocol. Under free breathing, the extra time that is needed for the acquisition of axial DW-MR imaging sequences is approximately 4 minutes.

In this discussion, the use of DW-MR imaging in genitourinary imaging is described with a focus on its application in the kidneys, prostate, bladder, and pelvic lymph nodes. Imaging protocols for DW-MR imaging used in our institution are listed in **Table 1**.

IMAGE INTERPRETATION

DW-MR imaging sequences can be analyzed both qualitatively and quantitatively. Usually, the first step in image analysis is a visual qualitative assessment. In relation to their cellularity, different tissues show a different appearance using various *b*-values. Tumors with tightly packed cells show a lesser signal attenuation of the signal (ie, they seem to be hyperintense) when using higher *b*-values (eg, $\geq$800 s/mm^2) than normal parenchymal tissue or free fluid. However, a typical pitfall in the qualitative interpretation is the so-called T2 shine-through effect of some normal tissues like the PZ of the prostate, which shows a high signal intensity also in higher *b*-values, because the signal intensity does not only depend on the diffusion on water molecules within a tissue, but also on the intrinsic T2 relaxation time of the specific tissue (**Fig. 1**).[12,13]

A possible misinterpretation of the imaging material owing to the T2 shine-through effect can be avoided by comparing areas with a high intensity in images with high *b*-values with the corresponding ADC map. In the ADC map, a high signal in corresponding areas of high signal intensity in the *b*-value DW-MR imaging image indicate a T2 shine-through effect. In contrast, a signal attenuation in corresponding areas in the ADC maps indicates a high cellularity of a tissue like in solid tumors (eg, renal cell carcinoma (RCC), **Fig. 2**) or pus-filled structures like the renal pelvis (**Fig. 3**).

A quantitative analysis of DW-MR images can be performed by a calculation of the ADC value within specific regions of a tissue. Therefore, a region of interest (ROI) is drawn manually within a tissue region that is to be evaluated in a *b*-value image and is then copied to the corresponding region in the ADC map, because tumor margins may be difficult to identify within the ADC map. For a quantification, summary statistics like the mean value with in the ROI can be used. Furthermore, ROIs can be analyzed on a voxel-by-voxel basis and their distribution within the ROI can be displayed by histograms that visualize the heterogeneity within different tissues like tumor tissue.

APPLICATIONS OF DIFFUSION-WEIGHTED MR IMAGING IN THE GENITOURINARY TRACT

Kidney

Cross-sectional imaging (CT and MR imaging) combined with intravenous contrast medium administration allows a reliable detection and characterization of most focal renal masses. However, the differentiation between cystic lesions like complicated cysts and cystic RCC, solid lesions like oncocytomas and RCCs, as well as between different subtypes of RCCs remains challenging. In various cases, DW-MR imaging can be helpful for further differentiation, because ADC values in