Diffusion-Weighted Imaging of the Male Pelvis

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KEYWORDS

• Diffusion-weighted imaging • Male pelvis • Magnetic resonance imaging • Cancer

KEY POINTS

- Diffusion-weighted (DW) imaging is playing an increasingly important role in disease detection, prognostication, and monitoring of treatment response. Particularly in the realm of oncology, the potential applications for DW imaging continue to expand.
- As magnetic resonance (MR) imaging plays a role in the diagnosis, characterization, and staging of most of these diseases, and DW imaging is a noninvasive, robust tool, its added value is only beginning to be realized.
- DW imaging holds promise for providing earlier cancer detection and evaluation of the treatment response. DW imaging enjoys several advantages over other advanced MR imaging tools, including the lack of reliance on intravenous contrast and relative rapidity of image acquisition.

INTRODUCTION

Diffusion-weighted (DW) imaging is playing an increasingly important role in disease detection, prognostication, and monitoring of treatment response. Particularly in the realm of oncology, the potential applications for DW imaging continue to expand. This technique has been applied toward the detection and characterization of a wide range of primary malignancies. It has also shown particular utility in the noninvasive staging of cancers. In addition, DW imaging holds promise for providing earlier cancer detection and evaluation of treatment response. DW imaging enjoys several advantages over other advanced magnetic resonance (MR) imaging tools, including lack of reliance on intravenous contrast and relative rapidity of image acquisition. As a quantitative imaging tool, DW imaging may also provide important information regarding tumor aggressiveness and histologic grading in a noninvasive manner.

In this article, the authors detail the role of DW imaging for pathologic processes involving the male pelvis. The authors describe the current data, new insights, and ongoing controversies regarding DW imaging of the male pelvis with a particular emphasis on oncologic applications. The authors also discuss imaging techniques and common pitfalls for DW imaging in this anatomic region.

TECHNIQUE

Principles of DW Imaging

Signal intensity in DW imaging is predicated on the relative freedom by which water molecules are able to move within tissue. In an unrestricted system, water molecules move randomly, a property initially observed in the 1800s and later mathematically characterized by Albert Einstein in 1905. Water within tissue, on the other hand, cannot move in an entirely random manner. Intracellular water is

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obstructed by organelles within the cell and the plasma membrane constraining the cellular contents; likewise, the motion of extracellular water is limited by extracellular matrix and cell membranes. Tissues with high cellularity, therefore, restrict the motion of water to a greater degree than tissues with low cellularity or tissues consisting of cells with defective plasma membranes.[1]

DW imaging as an MR imaging technique has its roots in 1965, when it was conceived as a variation of a T2-weighted pulse sequence.[2] The value of this imaging technique to identify areas of acute infarction in the brain led to its widespread use in neuroimaging. However, more recently, its relevance toward pelvic imaging has begun to be appreciated. This new appreciation is possible in part because of technological advances in the 1990s, including the development of stronger diffusion gradients and faster imaging sequences.[1,3]

Technical Aspects of DW Imaging

Imaging of the pelvis with MR imaging can be challenging because of the susceptibility artifact created at multiple air-tissue interfaces. Moreover, bowel motion can degrade image quality. Some institutions routinely administer spasmolytic drugs to inhibit peristalsis. Also, though not commonly performed, a homogenous material, such as ultrasound gel, can be used to fill the rectum to reduce the susceptibility signal caused by air in the rectum. DW imaging is typically performed in the axial plane, as the magnetic field homogeneity is best at the isocenter of the bore in addition to reducing eddy currents. However, for certain applications, such as rectal imaging, acquiring images in an oblique plane orthogonal to the long axis of the organ under investigation may facilitate evaluation of the extent of disease spread. Respiratory motion is not a common problem in pelvic imaging, though in some patients respiratory-triggered imaging may improve image resolution.[4]

DW imaging can be performed at either 1.5T or 3.0T, with the higher magnetic field strength offering higher signal to noise, though at the expense of worse susceptibility artifacts. In DW imaging, 2 symmetric gradients are applied on either side temporally of the 180° refocusing radiofrequency pulse of a conventional spin-echo T2-weighted sequence. The effects of the first gradient, known as the *dephasing gradient*, are nullified by the second gradient, known as the *rephasing gradient*, in tissues with protons whose free movement is restricted. The net effect on the transverse magnetization is, therefore, minimal, and there is no signal loss. On the other hand, protons that are freely moving within the tissue will experience different strengths of the 2 gradients, and so the net effect will not be zero; these protons will not be fully rephased, resulting in signal loss. The 2 diffusion gradients are characterized by a constant b, which encapsulates the strength, duration, and time interval between the 2 gradients and is measured in units of seconds per square millimeter. At b = 0, a DW imaging pulse sequence is simply a T2-weighted imaging sequence. As the b value increases, the relative contribution of tissue diffusivity to signal intensity increases. Areas of restricted diffusion will appear bright on high b-value images, whereas areas of free-flowing fluid, such as within cysts or within the bladder, will appear dark.

Diffusivity of tissue can be quantified using DW imaging by calculating a value known as the *apparent diffusion coefficient* (ADC). The ADC is calculated as the slope of the line on a log linear plot connecting the signal intensity of a pixel measured at different b values; therefore, measurements of signal intensity from at least 2 b values are required, and the accuracy of the ADC value improves when more data points (ie, b values) are acquired. The choice of b value, however, to determine the ADC is a point of controversy, with low b values (10–150) being heavily weighted to perfusion effects (so-called intravoxel incoherent motion), and higher b values demonstrating improved diffusion weighting. As a result of the perfusion weighting, there is alteration of the expected mono-exponential behavior of signal loss with b-value increase, potentially altering calculated ADC values. There is growing consensus about avoiding low b values (<150) when using mono-exponential fitting as a result of this added perfusion weighting, in addition to clearly visible nonlinear behavior on log-linear plots. The low b-value imaging, however, has excellent value in lesion detection secondary to its high signal-to-noise ratio. Until these data are better understood, it is recommended to use at least 3 to 4 b values less than 1000 in order to calculate ADC. Regardless, the ADC value is independent of magnetic field strength.

Interpretation of DW Imaging

The diffusivity of water is inversely proportional to the organization and compactness of a tissue's microenvironment. Three discrete tissue characterization patterns can be described in DW imaging. Malignant lesions, because of their dense cellularity and disordered interstitium, demonstrate restricted diffusion. Fluid or necrotic tissue in which the integrity of plasma membranes has been compromised, allow for the free diffusion of