Characterization of Genitourinary Lesions Using Diffusion-Weighted Imaging at 3T MRI

Farhood Saremi, M.D.; Helmuth Schultz-Haakh, Ph.D.*

1Professor of Radiology and Medicine, University of California, Irvine (UCI), USA
2Siemens Medical Solutions USA, Cypress, CA, USA

There is growing interest in the application of diffusion-weighted imaging (DWI) for the evaluation of lesions in the abdomen and pelvis [1–3]. DWI yields both qualitative and quantitative information that can be helpful in differentiating benign from malignant processes. The application of DWI is useful for tumor detection, tumor characterization, and in the evaluation of tumor recurrence or response to treatment [4–7]. DWI has been widely used in neuroimaging [8–11]. However, its application to body imaging was initially limited by the inherent motion sensitivity of the technique coupled with the presence of bulk physiologic motion in the abdomen. Routine extracranial application of DWI has become feasible following a series of technological advancements in MR imaging. These developments include faster imaging techniques with echo-planar imaging (EPI) and parallel imaging, high performance gradients, phased array multi-channel surface coils, and clinical use of higher magnetic field strengths [12–17]. Using new techniques, breathhold DWI sequences can be appended to existing imaging protocols without a significant increase in the total examination time. In this review, we describe our experience in using DWI for the characterization of genitourinary tract lesions as done on our MAGNETOM Trio, A Tim System with the Body Matrix coils.

Basic understanding of DWI technique

DWI sequences are designed to detect alterations in thermally-induced random (Brownian) motion of water molecules within tissues also known as diffusion [8, 9]. Diffusion effects are very small to the apparent diffusion coefficient (ADC). The optimal b-values for abdominal DWI have not yet been determined. DWI is typically performed using at least two b-values (within a range of 0 to 1000 s/mm²) to allow the calculation of the apparent diffusion coefficient (ADC).

As the b-value is increased, sensitivity to the effects of diffusion increases at the expense of longer TE and worsened signal-to-noise ratio (SNR) and image distortion.

Imaging protocol at our institution

Most of the images shown herein were obtained using a 3 tesla (T) magnet (MAGNETOM Trio, Siemens Healthcare, Erlangen, Germany). We used a breathhold single-shot spin echo EPI combined with parallel imaging and spectral fat suppression [11–14]. Our DWI protocol is shown in Table 1. In breathhold techniques, although the signal-to-noise ratio (SNR) is inferior compared with multiple averaging methods, the use of higher magnetic field strengths (e.g., 3 Tesla) and surface coils with more receiver channels (> 8) can compensate for poor SNR [17, 18]. We found spectral fat saturation technique more practical than STIR (short TI inversion recovery) for breathhold studies, since with STIR the acquisition time is longer and lesion visibility may be inferior compared with spectral fat saturation, especially in the center of the abdomen [19]. Parallel imaging is also essential for breathhold DW imaging. With parallel imaging, a shorter TE is possible which in fact increases the SNR and reduces susceptibility-induced image distortions [20–22] (Fig. 1). In our experience, syngo GRAPPA is more advantageous to mSENSE given the degree of off resonance and motion ghost artifacts associated with mSENSE [23]. It is reported that the DW image quality is superior at 3T compared to 1.5 T and that small lesions are better visualized [17]. 3T is particularly useful at higher b-values. However, with 3T we should expect larger susceptibility-induced image distortions and signal loss, and more motion-related artifacts [18]. Traditionally, most DWI studies have reported b-values of below 1000 s/mm². However, the use of even greater b-values may be beneficial. For example, high grade tumors may retain their bright signal with b-values above 1000 s/mm², whereas low grade tumors will lose their signal [23]. High b-values have also been used effectively to assess early recurrences of a tumor [24].

Signal of normal tissues in DWI

Abdominal DWI – Normal Appearance. ADC of the kidney is the highest among all abdominal organs, followed by the liver, pancreas, and spleen. As the b-value increases, the signal of normal kidney drops. The spleen remains bright and liver signal decreases mildly. Note that the signal of the left liver lobe is generally lower than the right lobe (which may be caused by transmitted cardiac pulsations). The center of the abdomen generally has no signal mostly due to susceptibility effect of gastrointestinal air. The bright signal in the ADC-map is stomach content, not a solid organ.

**Table 1**

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<th>Procedure</th>
<th>B-value (s/mm²)</th>
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related to susceptibility effects caused by the renal cortex is generally higher than the medulla [27]. At high b-values, the signals from normal tissue such as blood vessels, muscle, and bowel will be suppressed. The kidneys, adrenal gland, and gallbladder lose their signal gradually and lose nearly all signal at b = 1000 s/mm² and above. In contrast, some signals from normal tissue such as blood vessels, muscle, and bowel will be suppressed. The kidneys, adrenal gland, and gallbladder lose their signal gradually and lose nearly all signal at b = 1000 s/mm² and above. In contrast, some normal structures such as the spleen, prostate, testes, ovaries, endometrium, and spinal cord retain their bright signal at the higher b-values.

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Signal depletion in the center of the abdomen (pancreas) is common and likely related to susceptibility effects caused by gastrointestinal air. In the pelvis, the endometrium and endocervix show the highest signal values and appear bright on all DWI series. Junctional zone (inner layer of myometrium) and cervical body demonstrate the lowest ADC values. In other words, both appear low in signal on b = 50 s/mm² and bright on b = 1000 to b = 1500 s/mm². Normal myometrium is intermediate signal on all b-values.

Assessment of cystic lesions

The signal intensity of most simple cysts drops significantly on b = 500 s/mm² images and is lost completely on b = 1000-1500 s/mm² images. The presence of blood products and high proteinaceous material within a cyst may result in loss of signal on T2-weighted (T2w) and low b-value DWI images (compared with simple cysts) due to magnetic susceptibility effects of their contents. A similar effect can be seen with infected cysts and abscesses. ADC values of simple and complicated cysts are usually higher than solid lesions [28]. However, it should be noted that some overlap between the gross morphologic characteristics and ADC values of a complicated cyst and cystic renal cell carcinoma is not unusual. While needle biopsy is considered a relatively safe procedure, the incidence of complications is not negligible. In our experience with biopsy of cystic neoplasms, attention to findings provided by DWI can be very helpful in selecting biopsy sites to maximize the likelihood of positive results and may prevent an unnecessary repeat biopsy or surgery (Fig. 3).

Characterization of primary and metastatic tumors

DWI technique has been used successfully for the diagnosis and characterization of genitourinary lesions, including benign and malignant processes arising from the kidneys [29, 30], uterus [31], ovaries [32], and prostate [33], as well as for the detection of metastatic lesions in the liver, lymph nodes, and skeletal system [34–36]. Although ADC values have been demonstrated to differ significantly between benign and malignant lesions, it is not yet possible to confidently distinguish benign from malignant renal neoplasms on the basis of qualitative assessment of ADC measurements alone [37–40]. The degree of restriction to water diffusion in biologic tissue is inversely related to the tissuecellularity and the integrity of cell membranes [37–40]. As a consequence, diffusion is mostly restricted in highly cellular parts of a tumor because of a reduced extracellular space (Fig. 4). In contrast, diffusion is less restricted in hypervascular tumors and in tumors with glandular, necrotic, hemorrhagic, or cystic components (Fig. 3).

In most benign processes such as cysts or benign masses of low cellularity (e.g., typical cavernous hemangioma), the signal intensity on DWI decays with increasing b-values may indicate malignancy or viable hypercellular tissue (Fig. 4).

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Pelvic masses

DWI performed with parallel imaging techniques has demonstrated potential as a method for differentiating benign from malignant pelvic lesions. Both endometrial cancer and normal endometrium appear hypointense on DW images [42]. However, the ADC values of high grade endometrial cancers are lower than those of normal endometrium and low grade cancers. “Cellular” leiomyomas, composed of compact smooth muscle cells with little or no collagen, tend to be brighter on T2-weighted and DW images.

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It has been suggested in numerous reports that DWI together with T2w imaging can significantly improve differentiation of prostate cancers [33].

Conclusions

DW imaging in combination with 3T equipment is a robust method to facilitate the diagnosis of genitourinary lesions with equivocal signal characteristics on routine MRI. It is not only helpful in differentiating benign from malignant processes, but can also be used as a tool for assessing possible tumor recurrence and to evaluate response to radiation treatment or chemotherapy on follow up scans.

References

1. Namimoto T, Yamashita Y, Sumi S, Tang Y, Benign cellular sub-endometrial fibrosis in a 45-year-old patient (arrows). The mass demonstrated homogenous signal on DWI images with areas of mild, non-calcified diffusion on ADC map consistent with the diagnosis of cervical fibroma. The tumor appears enhancing on post contrast T1w image. Note: high signal intensity of normal endometrium on all b = 50 and b = 1500 s/mm2 values of the hyperintensity.

2. Le Bhain D, Breton E, Lallemant D, Grenier P, Cabanes L, Javelet IM. MR imaging of intra- 
   vesical incipient movements: application to diffusion and perfusion in neurologic disorders. 

3. Le Bhain D, Breton E, Lallemant D, Aubin M, 
   Vignaud J, Javelet IM. Separation of diffusion 
   and perfusion in intravesical incipient motion 

   Diffusion-weighted MR imaging of acute stroke 
   combination with T2-weighted and magnetic su-
   ceptibility-enhanced MRI imaging in cats. AJNR 

5. Rothen-Hayl GR, Grant PR, Roberts TP. Diffusion 
   imaging: theory and applications. Neuroimag-

6. Müller ML, Prasad P, Sower B, Nissenbaum MA, 
   Rapaport VS, Miralbell R. Abdominal diffu-
   sion mapping with echo planar system of a 
   whole-body echo planar system. Radiology 

7. Cho EK, Gavrilovic JJ, Grenier P, Sommer FG. 
   Single breath-hold diffusion-weighted imaging 
   17: 387–392.

   MR imaging of the abdomen: echo-planar and 
   diffusion-weighted imaging. J Magn Reson Imaging 

   T2-weighted MR imaging of hepatic tumors: value 
   of echo-planar imaging with diffusion sensitizing 
   gradient. Comput Assist Tomogr 1998; 

    ADC measurement of abdominal organs and le-
    sions using parallel imaging technique. AJR Am

    parison of 3.0 and 1.5 T diffusion imaging of the 

12. Münz P, Sailer S, Trabert, F, van den Brink JS, 
   Gavrielovic J, Schill H-H. Abdomen: diffusion-
   weighted MR imaging with pulse triggered 
   single-shot sequences. Radiology 2002; 224: 
   236–244.

13. Herneth AM, Guccione S, Bedwardi M. Apparent 
    diffusion coefficient: a quantitative parameter 
    for in vivo tumor characterization. Eur J Radiol 

14. Charles-Edwards EM, deSouza NM. Diffusion-
    weighted magnetic resonance imaging and its 
    application to cancer. Cancer Imaging. 

15. Thoen HC, DeKayser J, Futter N. Extracranial applica-
    tions of diffusion-weighted magnetic resonance 

16. Namimoto T, Awa K, Nakada T, Yanagita Y, Hira- 
   i T, Yamashita Y. Role of diffusion-weighted 
   imaging in the diagnosis of gynecological 

   G. Predicting the histopathological grade of 
   cervical glomus using high value MR DWI 

18. Ishikawa T, Harada H, Hachisuy J, Naito T, 
   Araki T. Diffusion-weighted MR imaging with 
   single-shot echo-planar imaging in the upper 
   abdomen: preliminary clinical experience in 61 

19. Klicicke D, Yirik Y, Bayangolu S, Cimiki T, 
   Aydin S. Non-breath-hold high b value di-
   ffusion-weighted MR with parallel imaging tech-
   nique: apparent diffusion coefficient in normal 
   abdominal organs. Diagn Interv Radiol 2008; 14 

    detection of response to radiation therapy in 
    patients with breast malignancies using T2w 
    and high b-value diffusion-weighted MRI. 

    LH, Hricak H. Renal masses: characterization 
    with diffusion-weighted MR imaging—prelimi-
    464.

    weighted MRI in the evaluation of renal neoplasms. 
    Pern 2004; 47(2): 851– 

23. Thoen HC, De Kayser J, Oyen RJ, Peeters RR. 
    Diffusion-weighted MR imaging of kidneys in 
    healthy volunteers and patients with parenchy-
    mal diseases: initial experience. Radiology 2000; 
    219: 329–337.

    Hypointense uterine leiomyoma at T2-weight-
    ed MR imaging: differentiation with dynamic 
    magnetic resonance imaging and tissue perfu-
    sion imaging. Radiology 1999; 217(2): 

25. Barata AA, Megadath AD, Denewer AI, Moradiat A, 
    Tahavi A, Nala R. Role of diffusion-weighted 
    magnetic resonance imaging in differentiation 
    between (diffusion-weighted MRI) and tissue 
    370.

26. Tamai K, Koyama T, Saya E, et al. Diffusion-
    weighted MR imaging of uterine endometrial 
    688.

    uterine leiomyoma at T2-weighted 
    MR imaging: differentiation with dynamic magnetic 
    resonance imaging and tissue perfusion 

Contact
Farhood Sarem, M.D.
Professor of Radiology and Medicine 
Chief, Cardiothoracic Division 
Dept. of Radiological Sciences 
University of California (UCI) 
Medical Center 
101 City Drive South 
Irvine, CA 92698 
USA
fsarem@uci.edu

Table 1: Diffusion-Weighted Imaging protocol on MAGNETOM Trio with software version syngo B15.

| 2D single shot spin echo EPI (EPI factor = 84) | b-values: 50, 400, 1000, and 1500 s/mm² | Body Matrix coils: 8-channel, BW: 2056 Hertzpixel |
| Fat suppression: normal Fat Sat | TR/TE: 2500–3000 s/mm² | / 72 b-values for 50 and 2800, 3000-3000 s/mm² |
| 78 b-values for b-values 400 and 1500 s/mm² | Total Imaging Time: 21–24 sec for each set | Matrix size: 84 x 128 |
| Slice Thickness/Gap: 5/1.5 mm, 20 slices | Noise level: 0 | Parallel imaging: syngo GRAPPA, acceleration factor = 2 |
| Direction of diffusion gradients: 3-gradient factor = 2 | Typical resolution, pixel size | Typical FOV with rectangular FOV |

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