Diffusion-Weighted Magnetic Resonance Imaging

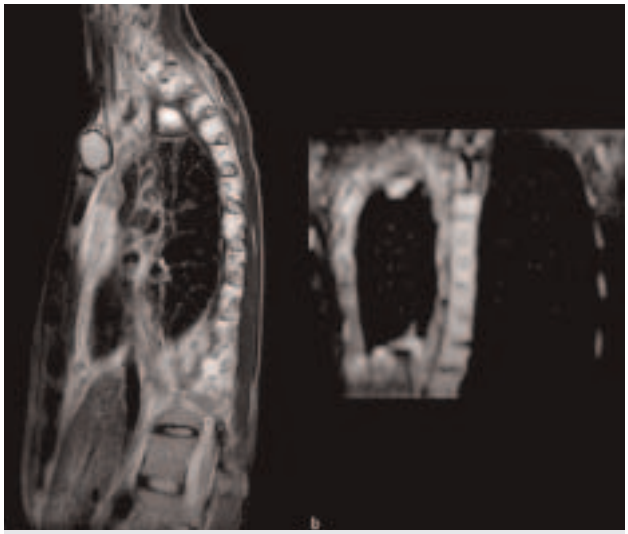
The Jikei University Hospital Tokyo, Japan, is conducting clinical research of diffusion-weighted MRI and its potential in terms of imaging the abdomen, pelvis, and organs other than the brain. On another continent, NYU Medical Center New York is also using this method to obtain information about liver metastases.
This article presents a compendium of the work done in two world-renowned institutions.

By Bachir Taouli, M.D., Department of Radiology, NYU Medical Center, New York, NY,
and Noriatsu Ichiba, M.D., Kunihiko Fukuda, M.D., Department of Radiology, Jikei University Hospital, Tokyo, Japan

Up to now, diffusion magnetic resonance imaging (MRI) was mostly applied in the head. By detecting water motion over small distances, it is now routinely performed and also enables the diagnosis of acute strokes. Recently, there have been several publications showing that diffusion MRI in the body can indicate the malignancy of lesions, thereby prompting interest for diffusion imaging in liver metastases.
Liver metastases are the most frequently encountered malignant lesions, usually related to colorectal, lung, and breast carcinomas. Diagnosis of liver metastases can be achieved with ultrasound, CT, and MRI – either before or after intravenous contrast injection. In some cases, metastases can be difficult to differentiate from benign lesions such as hemangiomas or focal nodular hyperplasias (FNH), and therefore an accurate method of characterization is needed to avoid unnecessary treatments and anxiety for the patients. In addition, for patients with known liver metastases undergoing surgical resection, an accurate detection of metastases is required for successful surgical planning.

The Technical Principle

Diffusion is the thermally induced motion of water molecules in biological tissues called Brownian motion. With the addition of motion-probing gradient (MPG) pulses, MRI – by means of the apparent diffusion coefficient (ADC) measurement – is currently the best imaging technique for in vivo quantification of the combined effects of capillary perfusion and diffusion. Diffusion-weighted imaging (DWI) can be performed by using diffusion gradients on each side of the 180° pulse when using very fast, single-shot spin-echo echo-planar



LUNG CARCINOMA. Diffusion imaging using parallel imaging.
(Images courtesy of Dr. Ichiba, Jikei University Hospital, Japan)

imaging (EPI) sequences with various b-values. The b-value represents the diffusion factor (measured in s/mm²) and the strength of the diffusion gradients. The ideal b-value for lesion characterization is a trade-off between signal attenuation and perfusion contamination. This is generally possible using b-values between 300 and 1 000 s/mm² for liver imaging. "Pure" diffusion contrast is obtained when using b-values above 1 000 s/mm². However, image quality can be limited by signal loss that occurs at such b-values and higher.

Diagnosis of Liver Metastases – Technical Considerations

The primary application of DWI is brain imaging. With the advent of the EPI technique, DWI of the abdomen has been made possible with fast imaging times minimizing the effect of gross physiologic motion from respiration and cardiac movement. In addition, the use of iPAT (integrated Parallel Acquisition Techniques – mSENSE and GRAPPA) has made it possible to improve image quality in EPI DWI, by reducing susceptibility artifacts. Today, DWI can be used to detect and characterize liver lesions (including malignant lesions) and treatment follow-up.

DWI represents a potential new tool for the characterization of liver metastases, and differentiation of benign from malignant liver lesions. DWI is noninvasive, requires no contrast injection, and is very fast. Recent studies have used DWI to characterize liver lesions and have shown that benign lesions, such as liver cysts and hemangiomas, show higher ADCs than malignant lesions, such as hepatocellular carcinomas and metastases [1–5]. This is likely related to free water motion in benign lesions, and restricted water motion in the presence of a tumor. However, ADC values often vary from one study to another, partially related to different equipment and different b-values. ADCs tend to be larger when using small b-values because the signal attenuation due to diffusion only plays a minor role in that case, and ADC values are contaminated by microperfusion. When higher b-values are used, ADCs tend to decrease, in relation to lower perfusion contamination. Fat suppression is also an important issue in

Case 1: 35-year-old male with renal cell carcinoma

Figures 1–3 show a round mass with a capsule in the lower pole of the left kidney, which showed mild enhancement after administration of contrast medium. The lesion showed very high signal on DWI (b = 1000) and proved to be renal cell carcinoma (Figure 4). There was no evidence of metastasis. Experience has shown that DWI eliminates the need for contrast medium in evaluation of primary and metastatic tumors in such patients.

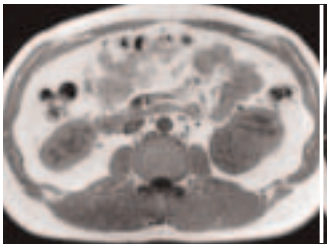


FIGURE 1: T1-weighted image.

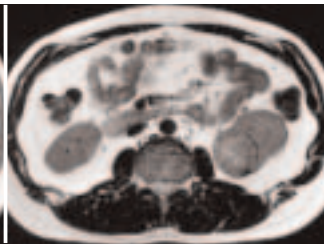


FIGURE 2: T2-weighted image.

FIGURE 3: Post enhanced 3D VIBE (Volume Interpolated Breathhold Examination) with fat saturation.

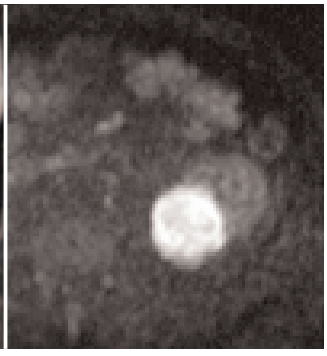


FIGURE 4: Diffusion-weighted – DWI (b = 1000).

(Images courtesy of Dr. Ichiba, Jikei University Hospital, Japan)

Case 2: 36-year-old female whose PAP smear result was Class V

There were no remarkable malignant tumors in the uterus, but a huge intramural myoma was seen on sagittal images (Figures 1–4). Careful observation of the DWI (b = 1 000) showing a bright region in the uterine cervix (Figure 5) revealed that a cervical cancer in the portio vaginalis had been missed on the sagittal FS TrueFISP image.

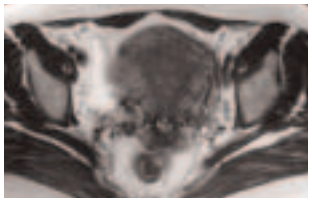
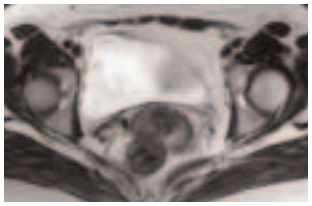
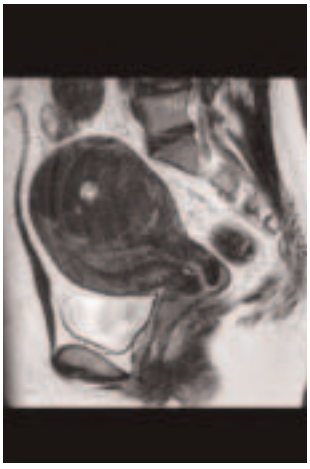


FIGURE 1: T1-weighted image.





FIGURES 2 AND 3: T2-weighted images.

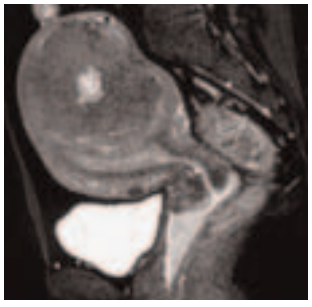


FIGURE 4: TrueFISP (Fast Imaging with Steady Precession) with fat saturation.

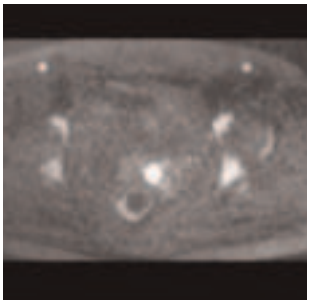


FIGURE 5: Diffusion-weighted image – DWI (b = 1 000).

(Images courtesy of Dr. Ichiba, Jikei University Hospital, Japan)

achieving best results. Dr. Ichiba and colleagues have been using CHESS pulses.

Clinical Considerations

DWI allows functional imaging of liver lesions and liver disease. The acceptance of DWI in the clinical routine will be accompanied by new developments in sequences and also by improved experiences of radiologists in this area.

DWI can potentially be used to follow treated metastases, whether using systemic or local chemotherapy (transarterial catheter chemoembolization), or local treatment (such as radiofrequency or cryoablation).

A recent study has shown the usefulness of DWI over routine contrast-enhanced MRI for the prediction of hepatocellular carcinoma necrosis in cirrhotic patients. An animal study has also shown a good correlation between response to therapy and ADC changes [6, 7]. Further work should confirm the potential of DWI MR technique so that it may be included in clinical protocols addressing such clinical questions.

Conclusion

The single-shot EPI with iPAT and CHESS fat suppression on the MAGNETOM Avanto MRI system has produced very satisfactory body diffusion results. Therefore, Dr. Ichiba and his team currently perform a body diffusion scan during all body MR examinations – more than 600 patients as of today. This adds only 3.5 minutes to the entire examination and has proven very useful for the detection of primary as well as metastatic malignant tumors, differentiation between benign and malignant tumors, and differentiation between postoperative inflammatory changes and recurrences. DWI in the body, pelvis, liver, significantly reduces the need for intravenous administration of contrast medium in evaluation of malignancies.

ADCs of benign and malignant lesions

In a previous study [5], Bachir Taouli, M.D., showed a significant difference between ADCs of benign and malignant lesions. Using a threshold ADC value of 1.5×10^{-3} mm^2/s, he was able to differentiate benign from malignant lesions with 84 percent sensitivity and 89 percent specificity. Potential limitations will include necrotic and cystic metastases, where ADC might be elevated, and the diagnosis will then rely on post-contrast images.

Case 3: 39-year-old female with rectal cancer accompanied by liver metastasis

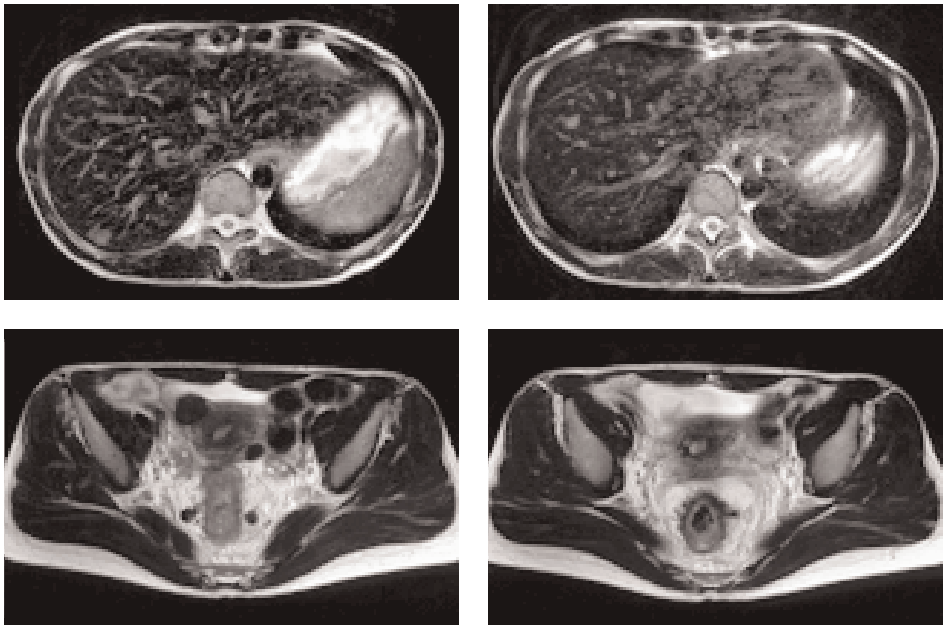


FIGURE 1-4: SPIO T2-weighted image.

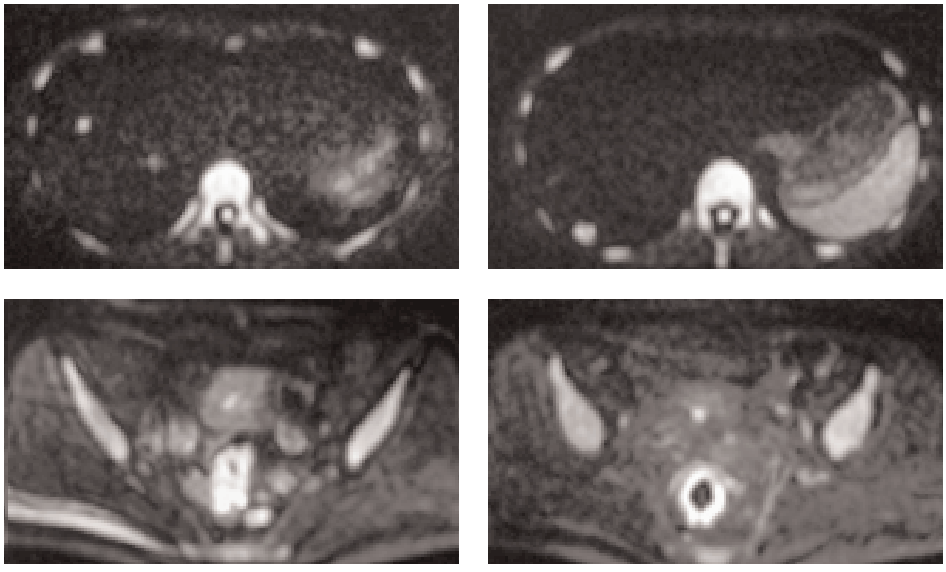


FIGURE 5-8: SPIO diffusion-weighted images – DWI (b = 1 000)

(Images courtesy of Dr. Ichiba, Jikei University Hospital, Japan)

Rectal wall thickening and multiple liver nodules were seen on SPIO (Small Particle Iron Oxyd)-T2-weighted (Figures 1–4), but it was unclear whether the lesions were malignant. SPIO-DWIs (b = 1 000) showed high signal in the corresponding lesions, revealing that they were malignant tumors (Figures 5–8). Regional lymph-adenopathy around the rectum can also be seen on DWI.

Case 4: 70-year-old male with recurrence of rectal cancer

PET image showed mild uptake behind the urinary bladder (Figure 1). There was an enhancing mass adjacent to the rectum (Figures 2, 3), which showed high signal on DWI (b = 1 000), turning out to be local recurrence (Figure 4). Fusion image of contrast enhanced 3D VIBE and DWI (b = 1 000) (Figure 5) was useful in identifying the lesion.

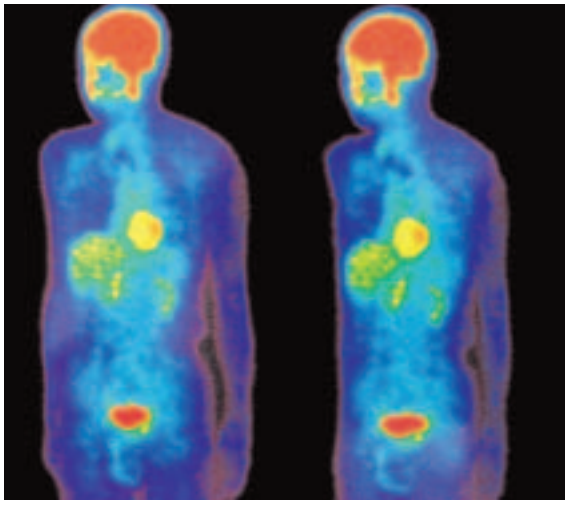


FIGURE 1: PET image (Positron Emission Tomography).

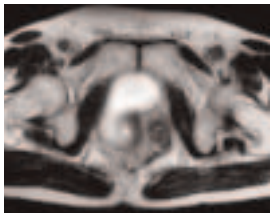


FIGURE 2: T2-weighted image.

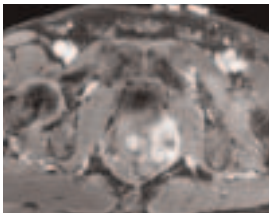


FIGURE 3: Post-enhanced 3D VIBE (Volume Interpolated Breathhold Examination) with fat saturation.

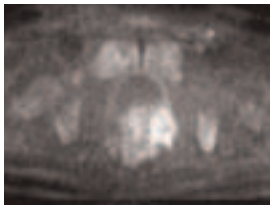


FIGURE 4: Diffusion-weighted image – DWI (b = 1 000).

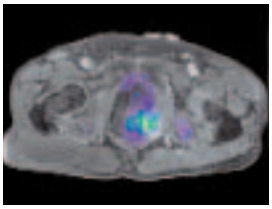


FIGURE 5: Fusion image.

(Images courtesy of Dr. Ichiba, Jikei University Hospital, Japan)

Respiratory-triggered body diffusion imaging

The Department of Radiology at the Jikei University Hospital in Tokyo, Japan, works with a MAGNETOM Avanto and performs respiratory-triggered body diffusion imaging using a single-shot EPI sequence with a PAT factor of 2. The parameters of the triggered scan are as follows: respiration cuff placed on the abdominal wall, TR of 1 500 ms, TE of 65 ms, slice thickness of 5 mm, 128 x 64 matrix with zero-fill interpolation, 12 slices, and scan time of 3 to 4 minutes depending on the patient's breathing. Low (50) and high (1 000) diffusion b-values are typically investigated. The total time for an examination of a specific anatomical segment is 15 to 20 minutes. A whole abdominal examination consists of T1-weighted, T2-weighted and diffusion-weighted images and can be done in the same period of time. Slice thickness of DWI is usually 6 mm.

References

[1] Muller MF, Prasad P, Siewert B, Nissenbaum MA, Raptopoulos V, Edelman RR. Abdominal diffusion mapping with use of a whole-body echo-planar system. Radiology. 1994. 190:475-478.
[2] Namimoto T, Yamashita Y, Sumi S, Tang Y, Takahashi M. Focal liver masses: characterization with diffusion-weighted echo-planar MR imaging. Radiology. 1997. 204:739-744.
[3] Kim T, Murakami T, Takahashi S, Hori M, Tsuda K, Nakamura H. Diffusion-weighted single-shot echo-planar MR imaging for liver disease. AJR Am J Roentgenol. 1999. 173:393-398.
[4] Ichikawa T, Haradome H, Hachiya J, Nitatori T, Araki T. Diffusion-weighted MR imaging with single-shot echo-planar imaging in the upper abdomen: preliminary clinical experience in 61 patients. Abdom Imaging. 1999. 24:456-461.
[5] Taouli B, Vilgrain V, Dumont E, Daire JL, Fan B, Menu Y. Evaluation of liver diffusion isotropy and characterization of focal hepatic lesions with two single-shot echo-planar MR imaging sequences: prospective study in 66 patients. Radiology. 2003. 226:71-78. AJR Am J Roentgenol. 2003. 181:708-710.
[6] Roth Y, Tichler T, Kostenich G, et al. High-b-value diffusion-weighted MR imaging for pretreatment prediction and early monitoring of tumor response to therapy in mice. Radiology. 2004. 232:685-692.
[7] Herneth AM, Guccione S, Bednarski M. Apparent diffusion coefficient: a quantitative parameter for in vivo tumor characterization. Eur J Radiol. 2003. 45:208-213.