Diffusion-Weighted MR Imaging for Diagnosis of Liver Metastases

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Liver metastases are the most frequently encountered malignant lesions, most frequently related to colorectal, lung and breast carcinomas. Diagnosis of liver metastases can be obtained with ultrasound (which suffers from limited sensitivity), CT and MR imaging before and after intravenous contrast injection. In some instances, 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 necessary to avoid unnecessary treatments and anxiety for patients. In addition, in patients with known liver metastases undergoing surgical resection, an accurate detection of metastases is necessary for the surgical planning.

Diffusion is the thermally induced motion of water molecules in biological tissues, called Brownian motion. With the addition of motion probing gradient (MPG) pulses, magnetic resonance imaging (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) is possible by using diffusion gradients on each side of the 180° pulse when using single-shot Spin Echo echoplanar imaging (EPI) sequences, using various b-values. The b-value represents the diffusion factor (measured in s/mm²) and

represents 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 300-1000 s/mm² for liver imaging. Pure diffusion images are obtained when using b-values > 1000 s/mm², however images will be limited by signal loss.

The ADC (measured in mm²/s) represents the slope of the curve of signal intensity vs. b-value, and is calculated using the following formula: ADC = (-1/b) Log S1/S0; where b = diffusion factor, S_0 = signal intensity (SI) for b= 0 (before application of diffusion gradient), S_1 = SI after application of diffusion gradient.

The primary application of diffusion-weighted imaging has been in brain imaging. With the advent of EPI technique, DWI of the abdomen has become possible with fast imaging times minimizing the effect of gross physiologic motion from respiration and cardiac movement. DWI can be used to detect and characterize liver lesions (including malignant lesions), and also for treatment follow-up.

Protocol used in our institution

At NYU medical center, for DWI of the liver, we use breath-hold single shot EPI sequences on 1.5T (MAGNETOM Sonata and MAGNETOM Avanto), using CP array surface coils, a pulse trigger to minimize artifacts from heart beating [1]. We use a short TR (1300 ms) to decrease the acquisition time, and the shortest possible TE (approximately 50-70 ms. depending on the b-value) close to the T2 of the liver (which is approximately 50 ms at 1.5T). We use parallel imaging (GRAPPA 2) in order to decrease distortion artifacts, acquisition time as well as to get the shortest possible

TE [2]. The matrix size is 128 x 128, with a large FoV in order to decrease ghosting artifacts, and a slice thickness of 7-8 mm. We use typically b-values of 0-50-500-1000 s/mm².

Role of DWI for detection of liver lesions

There is limited data on the use of DWI for lesion detection. For example, a recent study from the Netherlands [3] showed that DWI with small b-values < 50 s/mm² giving black-blood images can potentially replace the routine Turbo Spin Echo T2 for lesion detection. Fig. 1 shows images in a normal volunteer using small diffusion gradients.

DWI for characterization of liver lesions and diagnosis of liver metastases

DWI represents a potential new tool for the characterization of liver metastases, and differentiation of benign from malignant liver lesions. DWI is non invasive, requires no contrast injection, and can be performed within a breath-hold.

Most of previous 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 [4-8]. This is likely related to free water motion in benign lesions, and restricted water motion in the presence of tumor. However, ADC values are often variable from a 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 plays only a minor role in that case, and ADC values are contaminated by microperfusion. When higher b-values
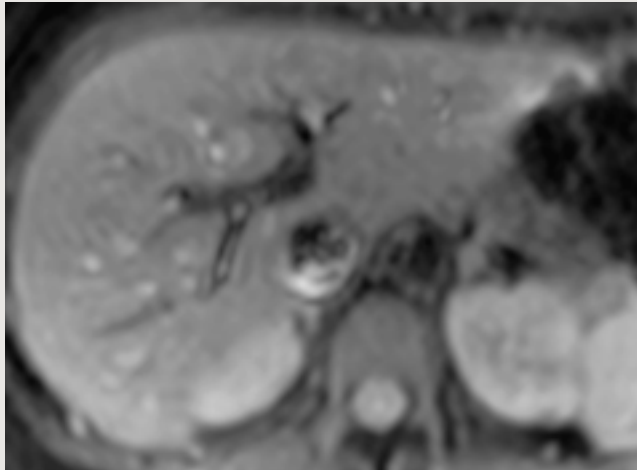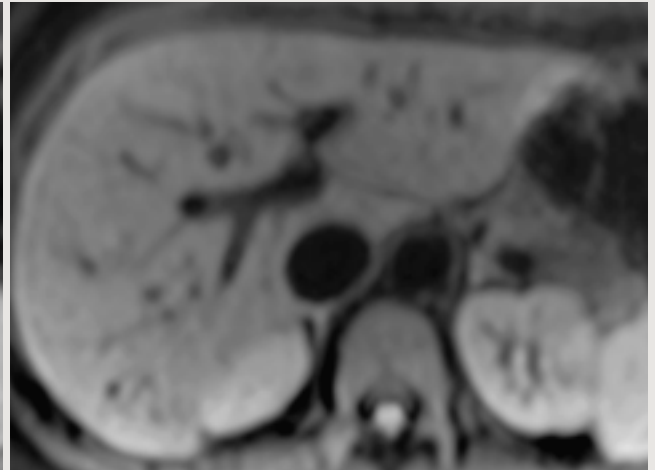
Figure 1a

Figure 1b

Figure 1 (a, b)   *Diffusion-weighted images in a 31-year-old normal volunteer. Single-shot EPI images without application of a diffusion gradient (b = 0 s/mm²) and after application of a small diffusion gradient of b = 50 s/mm² (b, black-blood image). Note complete vessel darkening on b. This allows easier detection of liver lesions which will not attenuate at this small b-value.*
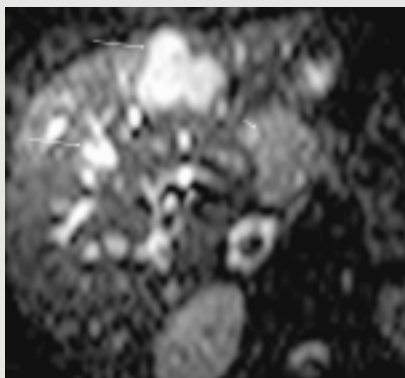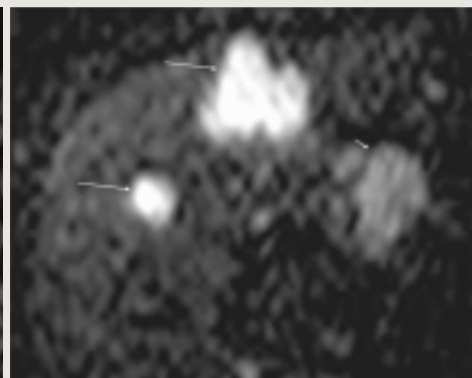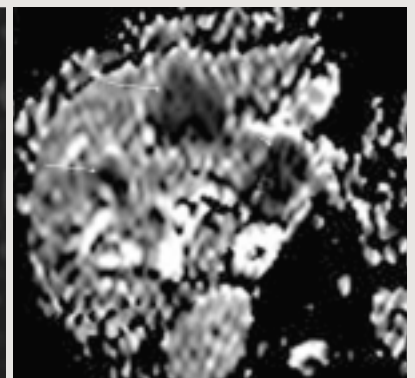

Figure 2a

Figure 2b

Figure 2c

Figure 2 (a-c)   *33-year-old man with liver metastases from pancreatic islet cell tumor. Diffusion-weighted images obtained using single-shot EPI for b = 0 s/mm² (a) and b = 500 s/mm² (b), without parallel imaging, show metastases of the right and the left liver lobes (long arrows) in high signal, with no attenuation at b = 500 s/mm². The primary tumor is located in the pancreatic head (short arrow). These lesions can be easily confused for hemangiomas. ADC measured on the mapping image (c) was very low (0.5 x 10⁻³ mm²/s).*

are used, ADCs tend to decrease, in relation with less perfusion contamination. We showed in a previous study [8] a significant difference between ADCs of benign and malignant lesions ($2.45 \pm 0.96 \times 10^{-3}$ and $1.08 \pm 0.50 \times 10^{-3}$ mm^2/s for b = 0 and 500 s/mm^2; respectively, $p < 0.001$). The mean $\pm$ SD ADCs ($\times 10^{-3}$ mm^2/s) of the different groups of lesions were: metastases 0.94 ± 0.60, hepatocellular carcinomas 1.33 ± 0.13, FNH / adenomas 1.75 ± 0.46, hemangiomas 2.95 ± 0.67 and cysts 3.63 ± 0.56 [8]. Using a threshold ADC value of 1.5×10^{-3} mm^2/s, we were able to differentiate benign from malignant lesions with 84% sensitivity and 89% specificity. Potential limitations will include necrotic and cystic metastases, where ADC might be elevated, and the diagnosis will then rely on post-contrast images. Fig. 2 and 3 show examples of patients with liver metastases.

DWI for follow-up of treated liver metastases

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 prediction of hepatocellular carcinoma necrosis in cirrhotic patients [9]. An animal study has also shown a good correlation between response to therapy and ADC changes [10, 11].
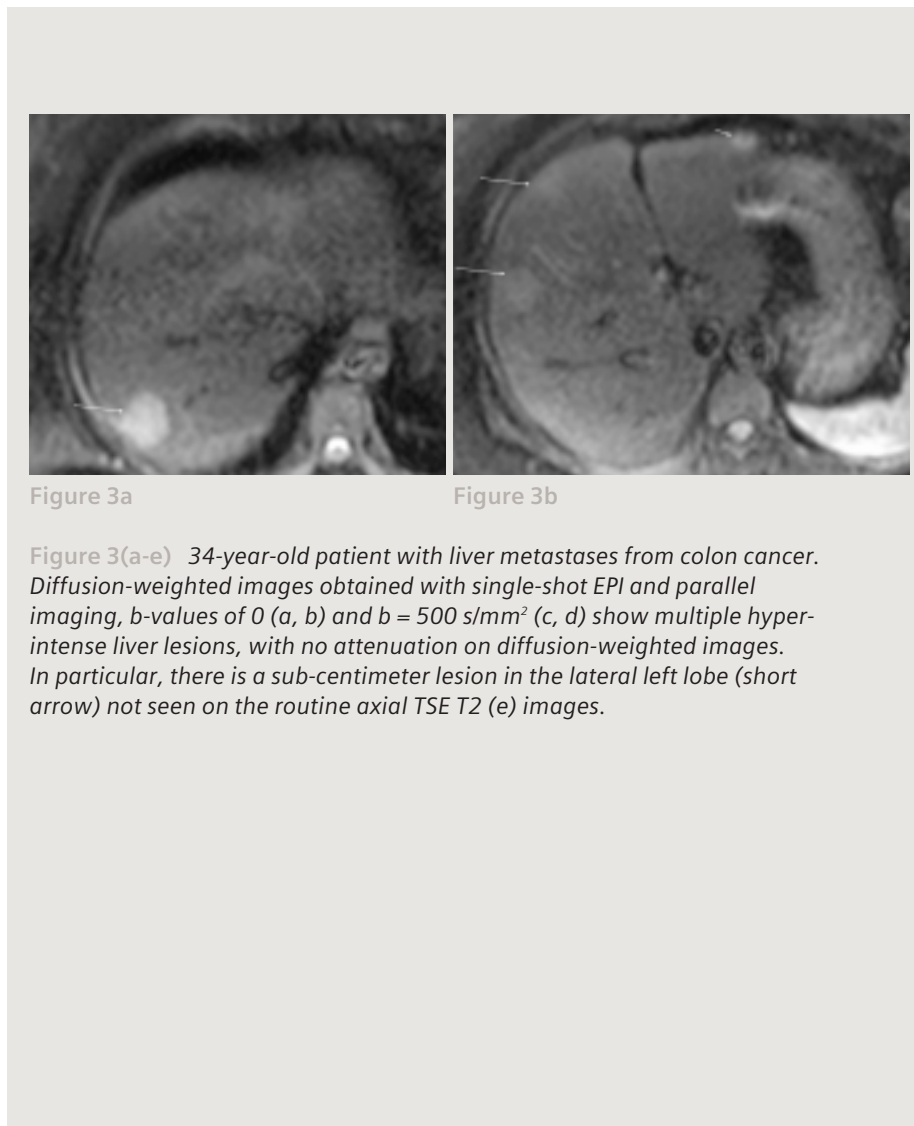

Figure 3a   Figure 3b

Figure 3(a-e)   *34-year-old patient with liver metastases from colon cancer. Diffusion-weighted images obtained with single-shot EPI and parallel imaging, b-values of 0 (a, b) and b = 500 s/mm^2 (c, d) show multiple hyperintense liver lesions, with no attenuation on diffusion-weighted images. In particular, there is a sub-centimeter lesion in the lateral left lobe (short arrow) not seen on the routine axial TSE T2 (e) images.*

Future improvements in image quality

3T technology will be potentially able to provide better image quality in relation with improved signal. However, susceptibility and distortion artifacts with EPI sequences may also be increased [12].

Conclusion

DWI allows functional imaging of liver lesions and liver disease. The acceptance of DWI into routine practice will be parallel to the new developments in sequences and also to the improved experience of the radiologists in this area.
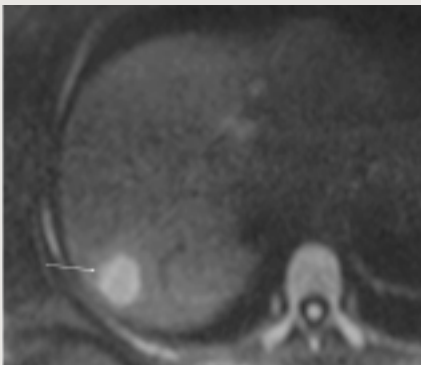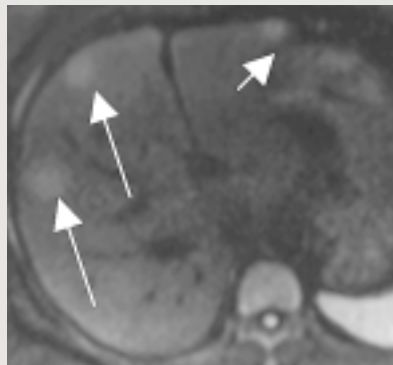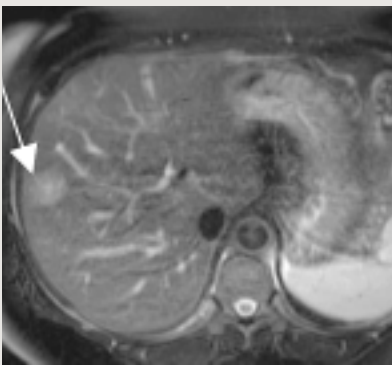
Figure 3c

Figure 3d

Figure 3e

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