In this presentation, we will focus mostly on focal liver lesion detection and we will review:
1. How to optimize diffusion acquisition parameters in the abdomen.
2. The added value of DWI for detection and characterization of liver lesions.
3. Few examples in renal and pancreatic lesions will be given.

Liver lesion detection

- **Comparison with T2WI**

  Diffusion-weighted imaging (DWI) has been shown to be equal or superior to T2-weighted imaging (T2WI) for liver lesion detection (1-9). Several studies have compared DWI and T2WI in terms of lesion detection, generally showing improved detection with DWI (1, 5, 8, 9); or in terms of image quality, showing comparable image quality with DWI using low b values (10, 11). The improved lesion detection with DWI compared to T2WI relate to improved image contrast using low b values and lack of blurring with SS EPI, compared to T2 FSE or single shot FSE sequences (10). Black-blood DWI has also been recently proposed as an alternative to T2WI at 3T, giving comparable image quality, improved suppression of fat and blood signals, high contrast-to-noise ratio and SNR (11). Our experience (in 53 patients with 211 lesions) is similar, also showing that DWI performs better than standard breath-hold T2WI for lesion detection using b value of 50 s/mm², with sensitivity of detection of 87.7% vs. 70.1% for all lesions, and 86.4% vs. 62.9% for malignant lesions (p < 0.001), respectively for DWI and T2WI (7). In addition, DWI significantly improved detection of small malignant lesions (< 2 cm) when compared to breath-hold T2WI (78.5% vs. 45.8%, p < 0.001).

- **Comparison with extracellular gadolinium agents**

  A retrospective comparison between DWI and dynamic 3D contrast-enhanced T1WI before and after gadopentetate dimeglumine administration on a population of 51 patients with liver metastases was performed by Hardie et al (12). Both per-patient and per-lesion analysis did not reveal any significant differences in detection rate, sensitivity and specificity between the two image sets for observer 1 and for pooled data (between 2 observers); however a lower sensitivity was observed with DWI for observer 2 (more experienced than observer 1), with no difference in specificity. In addition, results from the study of Another recent study retrospectively compared a free-breathing DWI sequence (using b 0, 600 and 1000 s/mm²) to fat suppressed T2WI and dynamic T1WI (using gadopentetate dimeglumine) separately and in combination for the detection of 64 pathologically proven hepatic metastases (13). In their study, the sensitivity of DWI (84.4%) resulted to be 7.8-26.9% greater than that of T2WI (68.8%) and higher than that of CE T1WI (79.7%) for the detection of metastases. As confirmation of the advantage of combined approach DWI with contrast-enhanced T1WI, results of a study of Kenis et al. (14) revealed a non-significant (p = 0.09) difference in diagnostic accuracy between contrast-enhanced T1WI (AUC = 0.89) and DWI (AUC = 0.85), with an substantial improvement by using a combined approach (AUC = 0.93). There is limited data on the use of DWI for detection of HCC (15-21). Recently, the study by Piana et al (20) which assessed the role of DWI vs. CE T1WI for the detection of HCC (> 10 mm) in a large number of patients (91 patients and 109 HCCs) reported higher sensitivity for DWI compared to CE T1WI for HCC detection. The sensitivity of conventional MR imaging criteria (wash-in/wash-out) for the diagnosis of HCC was 59.6% for both radiologists, compared to 81.7%-72.5% for DWI alone.

- **Comparison with liver specific agents**

Only a limited number of published studies compared DWI with liver-specific contrast agents for the detection and characterization of liver lesions, using mangafodipir trisodium or MnDPDP and gadoxetic acid (Gd-EOB-DTPA) (6, 22, 23). At this point, there are only two published studies directly comparing the accuracy of Gd-EOB-DTPA-enhanced MRI to DWI for the detection of metastatic liver lesions (22, 23). In the study by Shimada et al (22), who used a 3T system, the ROC analysis showed a better diagnostic performance using Gd-EOB-DTPA compared to DWI (AUC: 0.958-0.966 and 0.881-0.906 respectively; p=0.04 for observer 1 and no significant difference for observer 2) for the detection of small metastatic lesions (≤ 2 cm), without significant differences in sensitivity and positive predictive values. In the study by Lowenthal et al (23), performed at 1.5T, breath-hold DWI was compared to Gd-EOB-DTPA-enhanced T1WI. The authors demonstrated superiority of Gd-EOB-DTPA enhanced MRI (detection rate respectively: 94.4% and 100%, 2 observers) compared to DWI (detection rate: 78.3% and 97.5%) and contrast-enhanced T1WI at the dynamic phase (detection rate: 81.5% and 89.9%). On the hepatocyte phase images after administration of Gd-EOB-DTPA, there were no apparent signal differences between vessels and focal lesions, and small hepatic lesions may be missed, and DWI can easily differentiate these small metastases from vessels. On the other hand, artifacts caused by cardiac motion and by magnetic susceptibility artifacts due to the proximity of the lungs, can limit the sensitivity of DWI for the detection of small hepatic lesions at the upper regions of the liver and the left lateral hepatic lobe; while these lesions can be clearly detected on Gd-EOB-DTPA-enhanced images.

Liver lesion characterization

- **Role of visual assessment**

Visual assessment of DWI images which include higher b values (≥ 500 s/mm²) can help distinguish between solid and cystic lesions. Whilst simple cysts typically show suppression of high signal intensity at higher b values, T2 shine-through may occasionally be encountered. As a general observation, both benign and malignant solid lesions may demonstrate residual high signal on higher b value images, and would be difficult to characterize by visual assessment of the DWI images alone. Thus, once a cellular hepatic lesion is identified visually, further characterization usually relies on conventional morphologic (with or without contrast enhancement) imaging, supplemented with ADC measurements. Specifically, in malignant lesions, DWI is useful in distinguishing the different components of tumors (cystic/necrotic vs. solid components). On visual inspection of diffusion images alone, false positive identification of malignant disease may result from T2-shine through, partial volume effects from adjacent structures, and cellular benign lesions (e.g. FNH, adenoma and abscess). False negatives may result from metastases arising from mucinous tumors, which can mimic the appearance of a cyst, well-differentiated tumors (e.g. well-differentiated HCC), necrotic lesions (either primarily necrotic or secondary to treatment) and image artifacts which could obscure lesion visualization. In our experience, lesion characterization as benign or malignant was correct in 89% of lesions using DWI with visual assessment (7).

- **Role of ADC quantification**

ADC quantification requires minimum acceptable SNR at higher b values (24), as well as minimal lesion size of 1.5 to twice the in-plane resolution so to avoid partial volume effect. As a general rule, statistically higher ADC values have been demonstrated for benign lesions compared to malignant lesions, with variable overlap (7, 25-34). The more common benign hepatic lesions, cysts and hemangiomas have significantly higher ADC values compared to normal liver parenchyma or other lesions, including metastatic lesions. Hemangiomas, in particular, have mean ADC values lower than that of cysts, but generally higher than solid focal lesions. In clinical practice, the additional value of DWI in distinguishing cysts and hemangiomas from other lesions is small, as T2WI and CE T1WI sequences easily and reliably are able to diagnose them. However, in cases of contraindication to administration of contrast media, measurements of ADC values can be useful to differentiate between cysts, hemangiomas and solid hepatic lesions. Although cysts and solid lesions are easily distinguishable on ADC map, sometimes metastases and hemangiomas can have similar DWI features. Cystic, mucinous or necrotic metastases may show relatively high ADC values, while occasionally hemangiomas display portions with low ADC values (25, 28, 35). Conversely, liver metastases originated by neuroendocrine tumors, histopathologically constituted by highly concentrated small round cells, are usually...
characterized by low ADC values (34). Among cystic lesions, since diffusion signal depends principally on the degree of viscosity of the fluid, liver abscesses are characterized by hyperintensity on DW images and low ADC, which distinguishes them from cystic or necrotic tumors (36, 37). For solid benign liver lesions (FNH, adenoma), intermediate ADC values have been reported, with no statistical difference observed with malignant lesions, likely secondary to the high cellularity of these (29, 32, 38). HCC usually display low ADC values, except when treated and/or necrotic (39). A large variability in ADC values have been described in the literature for similar type of lesions, due to the lack of standardization of sequence parameters, particularly, in the choice of b values (40, 41). Therefore, the reported ADC thresholds for lesion characterization can be considered reliable only when applied on imaging studies obtained with similar techniques and b values. It is generally suggested to use at least two b-values (with either a low and a high b value), in order to reliably discriminate malignant and benign focal liver lesions, also allowing reasonable acquisition time of diffusion sequence (29, 33, 42). In a recent systematic meta-analysis (43) compiling 14 diagnostic studies matching inclusion criteria, eight studies reported a cutoff ADC in the distinction between malignant and benign FLLs, ranging from $1.47-5.5 \times 10^{-3}$ mm$^2$/sec (in 6/8 studies the threshold was $1.47-1.6 \times 10^{-3}$ mm$^2$/sec). Diagnostic performance, expressed by the area under the curve of the summary receiver operator characteristic (SROC) in this meta-analysis was $0.96$ (95% CI 0.94–0.98) (43). The sensitivity ranged from 0.74–1.0 (mean 0.91), while the specificity ranged from 0.77–1.00 (mean 0.93) indicating that DWI could be used as a helpful diagnostic test for diagnosis of malignant hepatic lesions. However, when cysts and hemangiomas are excluded, the specificity decreased substantially suggesting that the ADC cut-off is not as effective in distinguishing malignant lesions from adenomas, FNHs, or abscesses (7, 26, 29, 44).

**Role of DWI for renal mass characterization**

DWI can help characterize tumors based on their cellularity. There is limited data on the use of DWI for renal lesion characterization (45-49). Prior studies have demonstrated lower ADC of RCCs and solid renal lesions compared to that of simple renal cysts. For example, a prior study (50) based on a total of 109 renal lesions (mean size $4.2 \pm 2.5$ cm) in 64 patients showed good to excellent performance of DWI in differentiating benign from malignant renal lesions. Mean and SD of ADC ($10^{-3}$ mm$^2$/sec) of RCCs were significantly lower than those of benign lesions: $1.41 \pm 0.61$ vs. $2.23 \pm 0.87$ ($p<0.0001$). AUC, sensitivity and specificity of DWI for diagnosis of RCC were $0.865$, $85.7\%$ and $84.6\%$ (when excluding AMLs and oncocytomas), using cutoff ADC $\leq 1.80$ or $1.92 \times 10^{-3}$ mm$^2$/sec.

**Conclusion**

There is compelling data showing better performance of DWI compared to T2WI for liver lesion detection. In addition, even if more data demonstrating the added value of DWI over contrast-enhanced imaging is needed, the combination of DWI with conventional sequences (including T2WI and contrast enhanced sequences) may potentially improve the diagnostic accuracy of conventional imaging alone for liver lesion detection and characterization. As such, we believe that DWI should be fully integrated in routine liver MR protocols.

**References**


