Single-Voxel Diffusion-Weighted MR Spectroscopy for Fat-Corrected ADC Measurement

Valentina Taviani[1], Diego Hernando[1], and Scott B. Reeder[1,2]

[1]*Radiology, University of Wisconsin, Madison, WI, United States,* [2]*Medical Physics, University of Wisconsin, Madison, WI, United States*

Target audience: Scientists and clinicians interested in accurate quantification of apparent diffusion coefficients (ADCs) in fat-containing tissues.

Purpose: Accurate measurement of ADC is important to characterize pathology and monitor treatment. A recent retrospective analysis of liver ADC values showed a systematic decrease of ADC with increasing fat content[1]. The same study also demonstrated that correcting for the confounding effect of fat could mitigate this dependence[1]. This suggests that conventional fat suppression methods used in diffusion-weighted (DW) pulse sequences (e.g. spectral-spatial pulses) could result in biased ADC values when used to image organs containing fat (e.g. bone marrow, breast, fatty liver) due to incomplete suppression of minor fat resonance peaks near the water resonance. The purpose of this work was to develop a fat-corrected diffusion-weighted spectroscopic method to quantify ADC. In this work we demonstrate the feasibility of single-voxel DW MR spectroscopy (MRS) to measure ADC in the spine, breast and liver and compare to conventional DW-EPI.

Methods: Our Diffusion-Weighted MR Spectroscopy (DW-MRS) technique is a PRESS (point-resolved spectroscopy)-based pulse sequence with flow-compensated diffusion-encoding gradients stepped through a series of different amplitudes to produce a series of spectra with increasing diffusion weighting (b values) (Fig 1). Intravoxel dephasing induced by residual cardiac pulsation was minimized using peripheral gating and end-diastolic acquisition. Multiple signal averages (512 samples; 2.5kHz spectral width), corrected for relative shifts in frequency before summation over multiple averages, were acquired for each b value. An in-house, constrained, nonlinear, least-squares fitting algorithm, accounting for the spectral complexity of fat, was used to jointly fit all averaged spectra. ADC values corrected for perfusion effects were estimated by mono-exponential fitting of the water peaks at different b values.

Phantom experiments: DW-MRS and DW-EPI ADC values were measured in a water-fat-agar phantom with different fat fractions (FF) built according to Hines[2] (b = 0, 100, 250, 500, 750, 1000, 1500 s/mm^2; 8 averages; TE = 111ms (DW-MRS)/90ms (DW-EPI); TR = 3.5s).

Spinal bone marrow: ADC values of the L4 vertebral body were obtained with DW-MRS in 6 healthy volunteers (b = 0, 100, 250, 500, 750, 1000, 1500 s/mm^2; 8 averages; TE = 111ms; TR = 2 R-R).

Breast: Localised ADC measurements using DW-MRS were performed in the breast of a healthy volunteer (b = 0, 100, 250, 500, 750, 1000, 1500, 2000 s/mm^2; 8 averages; voxel size = 20×20×20mm^3; TE = 118ms; TR = 2 R-R) and compared to corresponding ADC values obtained from DW-EPI (b = 0, 1000 s/mm^2).

Liver: Single breath-hold DW-MRS was performed in 7 healthy volunteers and 19 patients referred for clinical MRI exams (b = 0, 100, 250, 500, 750 s/mm^2; 4 averages; voxel size = 20×20×20mm^3; TE = 95ms; TR = 1 R-R). Respiratory-triggered DW-EPI (b = 0, 500 s/mm^2) and an investigational version of IDEAL-IQ[3] were also performed. All MRI/MRS measurements were performed at 1.5T (SignaHDx and MR450w, GE Healthcare, Waukesha, WI). All subjects who participated in the study gave written informed consent.

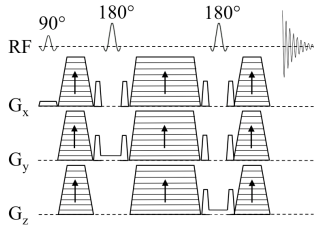

Figure 1: DW-MRS pulse sequence. Note the orthogonal slice-select gradients for single-voxel localization.

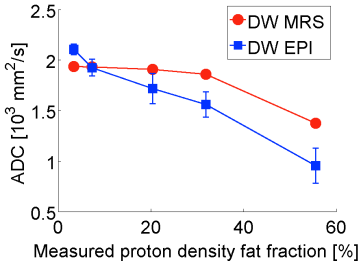

Figure 2: Phantom experiments. The decrease of ADC with FF is reduced when DW-MRS is used instead of DW-EPI.

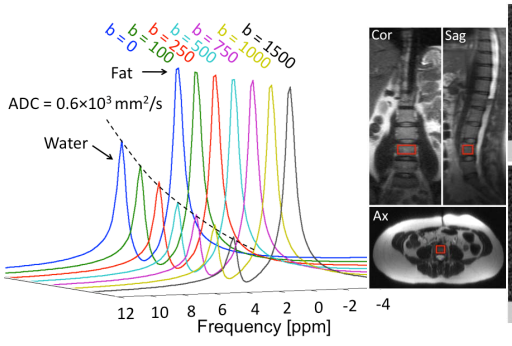

Figure 3: Diffusion weighted spectra acquired in the L4 verterbral body of a healthy volunteer and corresponding voxel position.

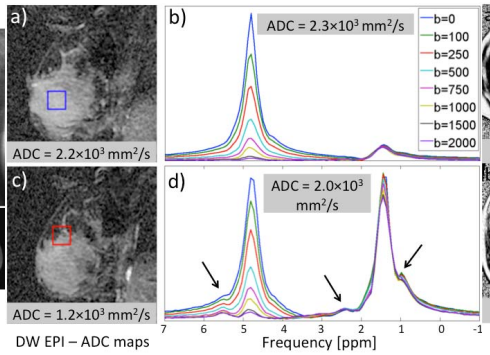

Figure 4: ADC maps (a, c) and DW-MRS spectra (c, d) acquired at 2 locations in the breast of a healthy volunteer.

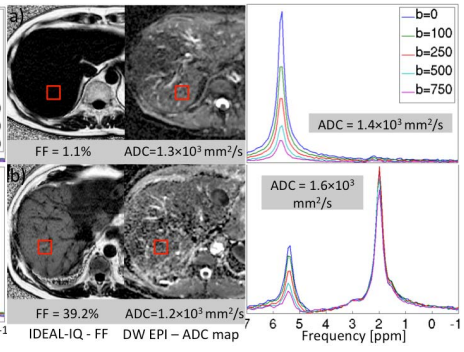

Figure 5: FF, DW-EPI ADC and DW-MRS ADC in a healthy volunteer (a) and a patient with fatty liver (b).

Results and discussion: Most of the ADC variation with FF that was observed in phantoms was removed when the spectral complexity of fat was accounted for with DW-MRS (Fig. 2). An example of spectra acquired in the L4 lumbar vertebral body is shown in Fig. 3 together with scout images showing the position of the voxel. Fig. 4 shows ADC maps acquired at two different locations in the breast of a healthy volunteer with DW-EPI (a and c) and the corresponding DW-MRS spectra (b and d). When the voxel/ROI contained a significant amount of fat (c), DW-EPI underestimated ADC by 40% due to incomplete fat suppression. A similar example is shown in Fig. 5. DW-MRS and DW-EPI gave similar results when the FF was low (FF~1%) but DW-EPI resulted in a 25% lower ADC than DW-MRS in the presence of liver fat (FF = 39%).

Conclusions: We have shown that DW-MRS can be used to estimate fat-corrected ADC in phantoms, as well as the spine, breast and liver of healthy volunteers and patients (liver). This approach has potentially important implications for cancer staging and treatment monitoring, as well as evaluation of diffuse liver disease and osteoarthritis.

References: [1] Hansmann J. et al. MRM 2012, *in press*; [2] Hines C.D. et al. MRM 2009; 30: 1215; [3] Yu H. et al. MRM 2008; 60:1122.