Diffusion Imaging of Mouse Kidney with Oscillating Gradients: Feasibility Study

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Target audience: Researchers interested in renal applications of diffusion-weighted imaging.

Purpose: Diffusion MRI imaging has previously been used to evaluate both structural and functional changes in various renal diseases using measurements of apparent diffusion coefficient (ADC) or diffusion fractional anisotropy (FA). However, diffusion-weighted abdominal imaging using conventional pulsed gradient spin echo (PGSE) methods are highly sensitive to motion and flow artifacts especially for multi-shot acquisitions, which makes it challenging to achieve reliable diffusion measurements with high spatial resolution in vivo[1]. Moreover, ADCs can be significantly contaminated by intravoxel incoherent motion (IVIM) effects in organs that have large blood/fluid volume fractions, such as kidney. By contrast, oscillating gradient spin echo (OGSE) diffusion methods may provide several advantages over PGSE methods for imaging kidney microstructure. First, due to the short diffusion times achieved, OGSE measurements should be less affected by bulk motion that occurs during diffusion labeling. Second, the intrinsic first-order flow compensation[3] of OGSE waveforms may reduce the IVIM effect. In addition, the short diffusion times achieved using OGSE methods may provide new insights into kidney microstructure at shorter length scales compared with those obtained using PGSE methods. The goal of this study was to assess the feasibility of reliable in vivo diffusion measurements in kidneys with OGSE sequences.

Methods: Female Athymic nude mice were imaged on a Varian 4.7T scanner with both PGSE and OGSE sequences. For the PGSE measurements, the diffusion gradient duration/separation = 5/20 ms. The OGSE measurements were performed with both sine (OG-SIN) and apodized cosine (OG-COS) gradient waveforms with gradient duration = 10 ms, and oscillating frequency = 100 Hz. All the other parameters were the same for PGSE and OGSE: TR = 5 sec, respiratory triggered, fast spin echo readout with ETL = 4, effective TE = 30 ms, echo spacing = 8 ms, matrix size = 96 × 64, FOV = 24 × 16 mm, thickness = 2 mm, NEX = 4, diffusion gradients on three axes with five b-values ranging evenly from 0 to 0.4 ms/μm^2. ADC was measured based on fitting with the last four b-values.

Results and discussions: Figure 1 shows the non-diffusion weighted (b_0) image (Fig. 1a) and ADC maps measured with PGSE (Fig. 1b), OG-SIN (Fig. 1c), and OG-COS (Fig. 1d) methods. The signal-to-noise ratio (SNR) was ~ 100 for the region of interest (ROI) in the b_0 image. The ADC(PGSE) map showed strong artifacts in the left kidney, presumably due to motion effects. By contrast, both OG-SIN and OG-COS provided better image quality for ADC measurements. Consistent with theoretical predictions[2], ADC(OG-COS) was larger than ADC(OG-SIN) due to a relatively shorter effective diffusion time. Figure 2 shows the signal decays and mono-exponential fitting results for signals from the ROI shown on Fig. 1.a. Note that the ADCs were fit without b_0 to avoid any IVIM effects. Contrary to the significant signal drop (> 10%) caused by IVIM effects in PGSE, OG-SIN and OG-COS data were well described with a mono-exponential fitting, suggesting these measurements were not affected by IVIM effects.

Conclusion: Compared with conventional PGSE measurements, the OGSE methods show great potential for diffusion measurements in kidney with reduced motion artifacts and minimized IVIM effects. Moreover, OGSE data acquired with different frequencies may allow derivation of additional structural parameters. The sensitivity and specificity for assessing mouse kidney diseases will be further reported.

References: (1) Cheung JS, Fan SJ, Chow AM, Zhang J, Man K, Wu EX. Magn. Reson. Med. 2010; 23:496-502. (2) Does MD, Parsons EC, Gore JC. Magn. Reson. Med. 2003; 49:206-215. (3) Maki JH, MacFall JR, Johnson GA. Magn. Reson. Med. 1991; 17:95-107.

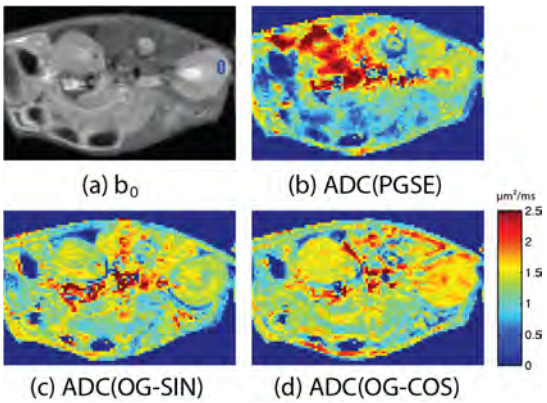

Figure 1. Non-diffusion weighted image (a) and ADC maps acquired with PGSE (b), OS-SIN (c), and OS-COS (d) sequences. The blue ROI in (a) was drawn manually on kidney.

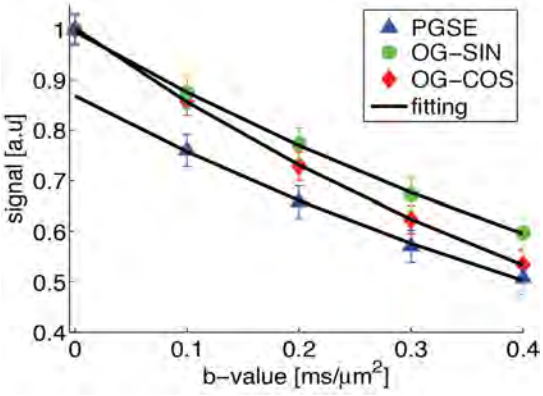

Figure 2. Signal vs b-value for the ROI in Figure 1a. Error-bars represent the standard deviations of signals in ROI. The solid curves represent the mono-exponential fitting results without b_0. Note the strong IVIM effect with b < 0.1 ms/μm^2 in PGSE, but not in OGSE measurements.