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PFG Filter for Oscillating Gradient Diffusion Measurements

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TARGET AUDIENCE: Researchers interested in tissue microstructures and their contribution to MRI signal.

INTRODUCTION: Oscillating gradients diffusion weighted (OG-DW) measurement in brain white matter can reveal frequency dependent diffusion coefficient. However, it is unable to separate contributions from intra and extra axonal water. Recently it has also been reported that frequency dependent diffusion could be dominated by the extra axonal water fraction [1]. Since the compartments have similar T1, T2 and MTR properties, these methods cannot be used to discriminate between diffusion compartments [2].

A discriminating feature between hindered extra-axonal water and restricted intra-axonal water is their diffusional behavior at long times. In this limit whereas the diffusion coefficient in the hindered pool approaches a tortuosity dependent non-zero asymptotic limit, for the restricted pool it is inversely proportional to the diffusion time. Thus, a PFG at low q and long Δ 'kills' signal from the hindered pool so that the remaining signal is solely due to the restricted pool. We propose to use this property, the 'PFG-filter' as a preparation step for OG-DW measurements. Since both the PFG-filter and oscillating gradients are sensitive to diffusion, the sequence design should ascertain that there are no cross term between the two. In this study we have tested it in celery stalk.

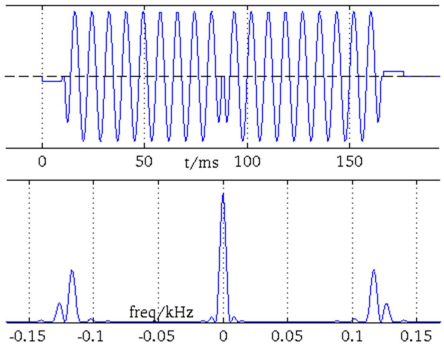

Figure 1: Schematic of the effective gradients (top) and the power spectrum of the gradient integral (bottom). Switch in gradient polarity due to refocusing pulse (not shown) has been considered.

METHODS: Measurements were performed in a 9.4 T BioSpec small animal MR-scanner (Bruker BioSpin MRI, Germany; max gradient strength 676 mT/m; 2-channel mouse quadrature volume coil). A 35 direction DTI acquisition (δ=2.5 ms, Δ= 6.25 ms, TE= 32 ms) confirmed that the celery fibers were aligned along the main magnetic field (z-direction). PFG-Filtered OG-DW-EPI was implemented as shown in Fig. 1. PFG-filter gradients were always played in the x-direction with 10 ms duration and 54 mT/m amplitude. Two sets of measurements were performed: one with and other without PFG-filter. Measurements parameters were: FOV = 2.56 cm, matrix = 96×96, slice = 2 mm, TE = 172.5 ms, and maximum b-value = 0.5 ms/μm^2. Eight cosine waveforms were measured in x, y and z axes for frequencies between 250 and 29 Hz.

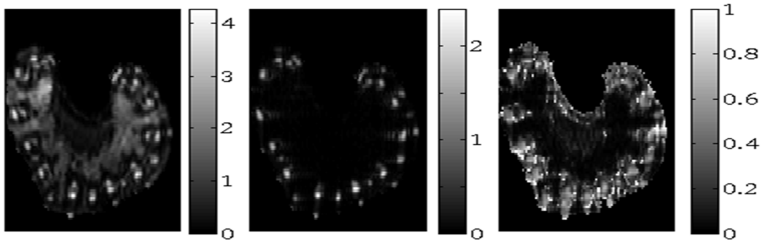

Figure 2: Effect of the PFG-filter. Image without PFG-filter (left), after applying the filter (middle), ratio between images with and without filter (right).

RESULTS: Fig. 2 shows images obtained with (middle) and without (left) PFG-filter and the ratio between the two images (right). While almost all the signal is lost at the parenchyma, the fibers on average retain around 58% of the signal. Fig. 3 shows frequency-dependent diffusion. In voxels containing just fibers (ratio>0.5, Fig. 3 left), there is virtually no difference between frequency dependent diffusion with and without the filter. However, for voxels in heterogeneous regions (0.3< ratio <0.4; Fig. 3 right) measurements without the filter is affected by partial volume and results in a more isotropic, less frequency dependent diffusion. The PFG filter resolves partial volume and reproduces results similar to that obtained for homogeneous fiber regions.

DISCUSSION: After applying the PFG-filter, similarity between the diffusion coefficients between x and y direction confirms that the PFG-filter was properly applied and that cross terms between the gradient used for the filter and the oscillating waveform were nulled. Furthermore, switching the polarity of the OG gradients (x vs. –x) also does not affect our results. Furthermore, we also observe that although the fibers bundles are around 30 μm in diameter, the ADC drop in the perpendicular direction seems to be associated with much small microstructures present inside the fibers.

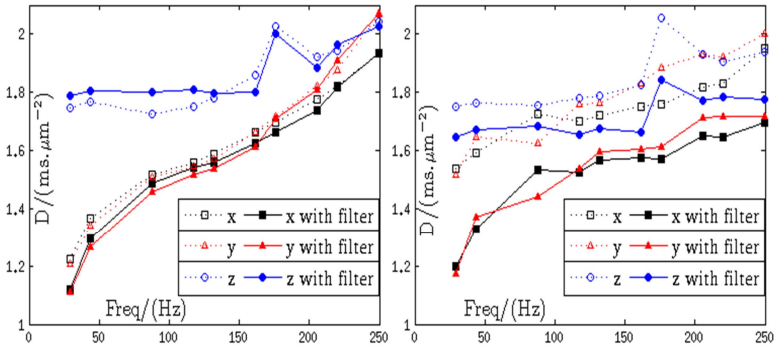

Figure 3: Frequency dependent diffusion with (solid symbols, line) and without (empty symbols, dots) PFG- filter. Axes: Z (blue, circles), Y(red triangles), X(black squares)

REFERENCES: [1] Novikov et al. arXiv:1210.3014 (2012) [2] Mulkern et. al., MRI 2009:27(8) 1151-1162