Preliminary Results on Measuring Intravoxel Incoherent Motion Using Oscillating Diffusion Gradients

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Target Audience: Researchers in the field of diffusion MRI aiming to quantify phenomena related to tissue perfusion such as intravoxel incoherent motion.

Purpose: Preliminary experiments using oscillating gradients are performed to evaluate whether the timescale of intravoxel incoherent motion (IVIM) could be accessed by temporal diffusion spectroscopy.

Methods: Oscillating diffusion gradient profiles were implemented into a single-shot EPI sequence (Fig. 1). Imaging gradients were flow compensated along all gradient axes. The sequence was used to obtain abdominal diffusion weighted MR images from six healthy volunteers (age 20-32) at 1.5 T (Magnetom Avanto, Siemens Healthcare, Erlangen). During each expirational breath hold three orthogonal diffusion directions at four different b-values were acquired as well as three unweighted images (TR=2.1 s, TE=140 ms, BW=1923 Hz/px, matrix 100x78, in-plane resolution 4.0 mm, slice thickness 5.0 mm). The total duration of the diffusion profile was set to T=120 ms, where the number of oscillations N was varied between 4 and 16 and b-values chosen in range 5-100 s/mm². Data was evaluated in a region of interest (ROI) in the pancreas, an organ for which it is known, that a substantial fraction of the signal can be attributed to the blood signal[1].

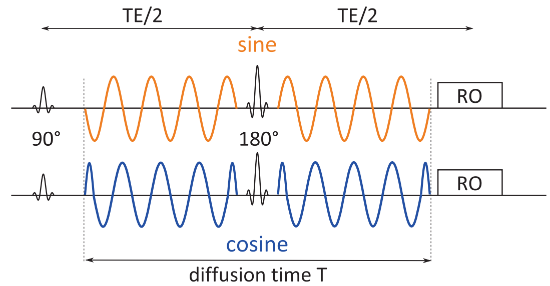

Fig. 1 Diffusion weighted sequence with symmetric sine and cosine profiles (8 oscillations).

Results: Images acquired from a healthy female volunteer are shown in Fig. 2. The evaluated region of interest is marked in the unweighted image (Fig. 2a). In strongly perfused organs, such as liver and pancreas, the stronger signal attenuation caused by sine gradients (Fig. 2b) can be visually perceived when compared to cosine gradients (Fig. 2c). This is also apparent when the signal attenuation averaged over volunteers is compared for different profiles (Fig. 3). While no clear dependence on the oscillation number is found for sine gradients, larger oscillation numbers lead to a less attenuated signal for cosine gradients.

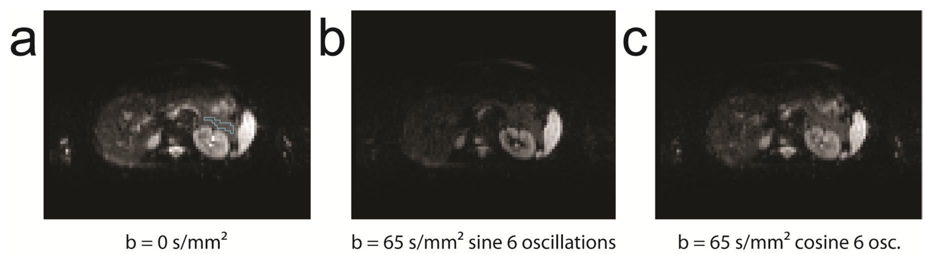

Fig. 2 a: Unweighted image with ROI in pancreas, b+c: Diffusion weighted images. Sine gradients (b) cause a larger signal attenuation than cosine gradients (c).

Discussion: The larger signal attenuation observed for sine gradients can be understood in the picture of temporal diffusion spectroscopy[2] as the power spectrum $F(\omega)$ of a cosine profile does not probe the spectrum of the diffusion tensor $\mathbf{D}(\omega)$ at $\omega=0$ (which corresponds to a component of constant flow). An oscillating gradient diffusion experiment could be considered to be a repetition of several shorter experiments of effective diffusion time $T_{\text{eff}} = T/N$. Regarding the characteristic timescale τ of the incoherent motion, increasing N thus pushes the experimental settings further away from the pseudo-diffusion limit[3] ($T \gg \tau$) such that the difference between flow compensated (cosine) and not flow compensated (sine) gradients is maximized.

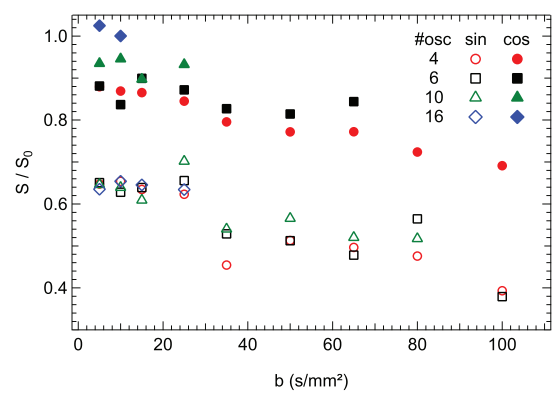

Fig. 3 Signal attenuation measured in pancreas averaged for six volunteers. Sine gradients cause a larger signal attenuation than cosine gradients. For cosine gradients signal attenuation decreases with the number of oscillations.

Conclusion: Diffusion experiments using oscillating gradients might prove valuable for characterization of the incoherent blood motion, in particular in organs where the characteristic timescale τ of the blood motion is shorter than the diffusion time T. In this regard IVIM measurements using oscillating gradients are complementing the proposed method of using flow compensated gradients[4], which in turn might be more suited for probing the regime $\tau > T$.

References: [1]A. Lemke *et al.*, *Magn Reson Med* **64**, p. 1580 (2010); [2]J. C. Gore *et al.*, *NMR in Biomedicine* **23**, p. 745 (2010); [3]D. Le Bihan *et al.*, *Radiology* **168**, p.497 (1988); [4]A. Wetscherek *et al.*, *Proc ISMRM 20th Annual Meeting*, p.2012 (2012)