Monte-Carlo simulation of susceptibility effects on the PGSE signal and diffusion measures

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Target audience MR physicists, Technician, Clinical Researchers

Purpose The susceptibility in the white matter fiber is orientation-dependent and, thus, affects the gradient-echo signal [1]. Rotating a fibrous phantom in the magnetic field [2], we also observed signal changes in diffusion-weighted spin-echo (SE) experiments (see fig 1). Consequently, calculated diffusion parameters, such as FA and ADC, can be distorted by these orientation-dependent effects. In the study, Monte-Carlo (MC) simulations were performed to investigate the effect of susceptibility changes in a PGSE experiment, to better understand the complex interaction of local field changes and diffusion gradients and its effect on diffusion measures.

Methods MC setup: an impenetrable cylinder with radius 2.5µm was placed in the center of the volume, perpendicular to B_0. A volume fraction of 0.02 was used to calculate the simulation volume. Spins were allowed to diffuse freely. Phase accumulates as a result of the local field induced by the cylinder and due to the diffusion gradient experienced by the spin. Phases were inverted at TE/2 for spin-echo signal simulation. Anisotropy was created by restricting spin displacement perpendicular to the cylinder. The signal was simulated for b=0 and 6 gradient directions at b=1000s/mm^2, TE=80ms, and a range of susceptibilities representing a frequency change of 0-250 Hz on the cylinder surface. From the simulated data, FA and ADC were estimated.

Results Fig 2 shows the effect of susceptibility on diffusion measures as a function of susceptibility, expressed as frequency change on the cylinder surface. An increase of FA/FA0 with increasing frequency is observed. ADC is lower than ADC0 at increased frequency change and b0 signal decreases with increased frequency.

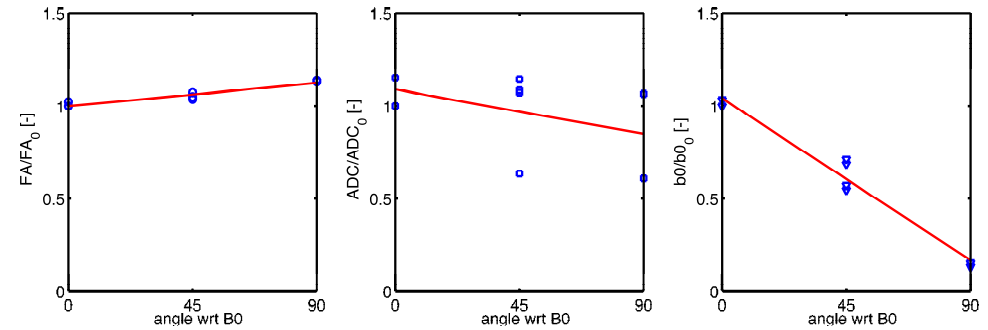

Fig 1 Phantom measurements FA, ADC and b0 signal obtained by rotating a fibrous phantom in the magnetic field. At each orientation a DW-MRI scan was made. There is a variation in all measures according to the orientation of the phantom with respect to B0. Measures are expressed as fraction of the signal with the phantom oriented parallel to B0.

Fig 2 Monte-Carlo simulations Effect of susceptibility-induced frequency change on FA, ADC and b0 signal. Measures are expressed as fraction of the measure at no frequency change.

Discussion The MC simulations confirm our hypothesis that diffusion measures are affected by local susceptibility changes. These susceptibility changes can be induced in experiments by rotation of a fibrous structure (i.e. white matter) in the magnetic field. The simulated data follows a similar trend as the measured data: FA increases, ADC decreases and b0 signal decreases with increased susceptibility. In brain white matter regions, susceptibilities in the range of 0.1-0.2 ppm have been reported [3], which corresponds to a frequency shift of up to 80Hz at 9.4T and is in the range of frequencies used in our simulations. Because the head cannot be rotated at the large angles used in the phantom measurements (and EPI distortions will play a role), the effects described here are difficult to replicate in human subjects. Although the MC model is a simplification, the observed effect may be of importance when analyzing diffusion-weighted data and related measures in humans at high or ultra-high fields.

References: 1. Lee J. et al (2010), PNAS 107:5130-5135 2. Removed for referee. 3. Wharton et al, NeuroImage 53 (2010) 515–525.