Gradient Echo Signal Recovery at Late TE due to Partial Volume Effects

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Introduction

The underlying principles of all BOLD techniques, such as fMRI [1] or susceptibility weighted imaging (SWI) [2] are spin dephasing caused by local field inhomogeneities and signal cancellation due to frequency shifts between venous vessels and parenchyma. In a two-compartment model (i.e. one straight vessel within a voxel occupying a volume fraction λ) this frequency shift leads to a beat in the MR signal as a function of TE [3,4]. We employed multi-echo T2*-weighted gradient-echo imaging to verify the beats in a capillary phantom with different orientations with respect to B_0 and for small, partially volumed venous vessels in the human brain.

Methods

T2*-weighted, multi-echo images of a phantom and healthy subjects were acquired on a 1.5 T MR-system with a 3D, velocity compensated gradient echo sequence and using a receive-only bird cage head coil. The sequence parameters were TR = 57 ms, TE = 5 –100 ms, ΔTE = 5 ms, α= 20°, three averages, FoV = 25.6 x 19.2 x 9.6 cm³, matrix of 256 x 192 x 48 *in vivo* measurements. Phantom measurements were carried out with a matrix of 128 x 64 x 16 and an adjusted FoV to obtain volume fractions of λ = 0.1, 0.2 and 0.3. The phantom consists of a pivotable capillary of 1 mm diameter filled with an aqueous Gd-DTPA solution which is immersed in a slightly doped tap water bath (Gd-DTPA) to reduce T_1. The magnetic susceptibility difference between the internal and external compartment was adjusted by different Gd-DTPA concentrations. The orientation of the capillary could be continuously adjusted from parallel (θ = 0°) to orthogonal (θ = 90°) with respect to B_0.

Results

With the capillary oriented parallel to B_0 (θ = 0°) the signal showed the expected beat (Fig.1). The beat frequency depends on the magnetic susceptibility difference and the amplitude of the beat depends on the volume fraction. For $\theta \neq 0°$ extravascular field inhomogeneities exist and the overall observed signal loss is stronger with less pronounced beats. As expected for the magic angle (θ = 54.7°) the signal decay is nearly monotonic showing a very weak signal recovery at later TE. A signal beat could also be verified *in vivo* for a vein oriented parallel to B0 (blue curve in Fig. 2a and blue arrow in Fig. 2b). A minimum occurred at TE ≈ 70ms. For a vessel oriented perpendicular to B0, more or less exponential decay without a minimum was observed (red curve in Fig. 2a and red arrow in Fig. 2b).

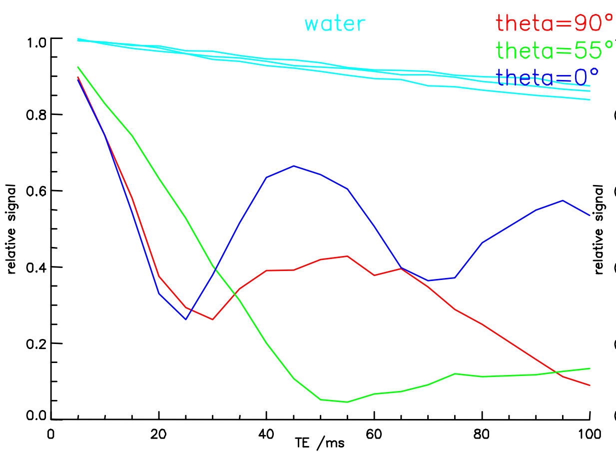

Fig. 1 Measured signal as a function of TE for a capillary with different orientations to B_0.

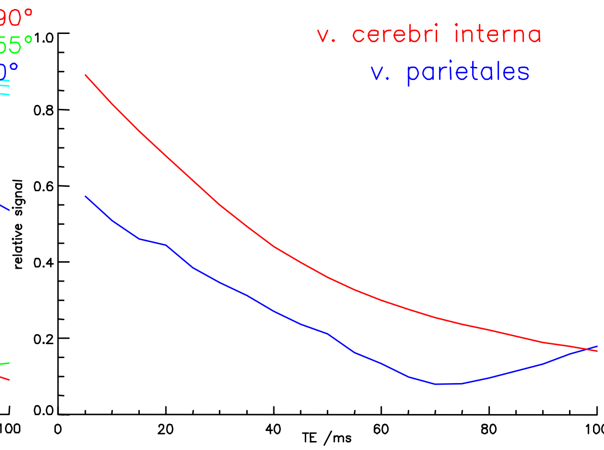

Fig. 2a: Signal of voxels containing a vein (see arrows in Fig. 2b) plotted as a function of TE.

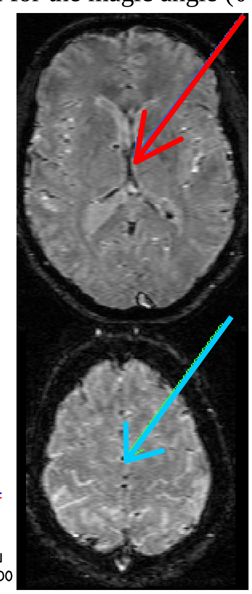

Fig. 2b: Transverse brain images with marked veins.

Discussion

Using susceptibility-weighted multi-echo imaging we could demonstrate that the signal behavior of voxels containing venous vessels or capillaries with different orientations to B_0 is determined by destructive and constructive superposition of intra- and extravascular spins at different echo times. Measuring these characteristic beats *in vivo* is, however, limited due to the long echo times needed to observe the corresponding minima and maxima. However, for veins parallel to B_0 the first minimum was found in a vessel at TE of about 70 ms. The verification of the signal beat *in vivo* may have implications for functional studies where partial volume effects can lead to negative BOLD responses.

References

[1] Ogawa S *et al*. Magn Reson Med 1990. [2] Reichenbach JR *et al*. MAGMA 1998 6: 62-9. [3] Yablonskiy D *et al*. MRM 1994 32: 749-63. [4] Springer CS *et al*. NMR in Physiology and Biomedicine, Academic, New York, 1994, 75-99