Magnetic Resonance Rheology of the human brain

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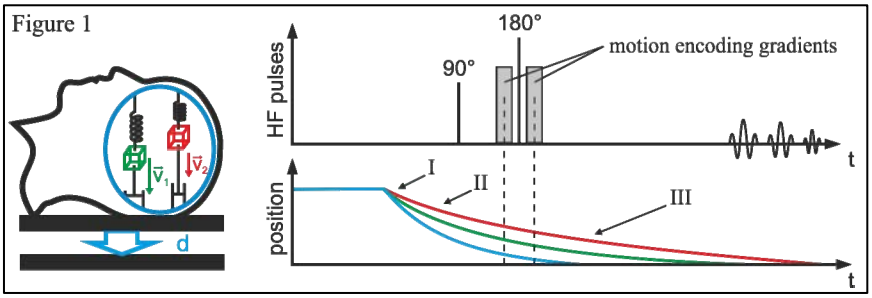
Introduction

The knowledge of viscoelastic properties of human brain tissue may be useful for the diagnostic of various diseases like multiple sclerosis, Alzheimer's disease and brain cancer.[1,2] While this is under investigation for the shear modulus or the equivalent Young's modulus, also the time dependence of creeping tissue may provide useful information. Magnetic Resonance Rheology (MR-R) is a novel method to image the viscoelastic properties of brain tissue *in vivo* using MRI phase images. By depicting the motion out of a steady state and the relaxation back into it, it is possible to gain information about both the elastic and viscous properties of the tissue.

Method and Materials

Using a simple rheological model (Kelvin material), the human brain inside the hard cranial bone can be described by assigning elastic springs and dashpots to every part of the tissue, thus characterizing the elastic and the viscose part of the behavior (Young's modulus **E** and viscosity **η**, respectively). To measure these properties, we disturb the system by a free fall of the head. Due to inertia the brain tissue performs a delayed motion compared to the cranial bone. The velocity of this motion depends amongst others on the spring and damping constants. Differences in the local viscoelastic properties therefore lead to different velocities during the free fall. The head is lifted a small distance *d* inside the MRI scanner using a custom-made pneumatic lifting device and is then dropped synchronously to the imaging sequence. We use a single shot EPI sequence equipped with two additional monopolar gradients positioned symmetrically around the 180°-pulse. Motion between these two gradients is encoded in the phase image[3] (see figure 1). The different velocities of different parts of brain tissue therefore create a contrast in this image (see figures 2.I-III). By varying the time at which the head is dropped relatively to the imaging sequence, the complete trajectory can be investigated.

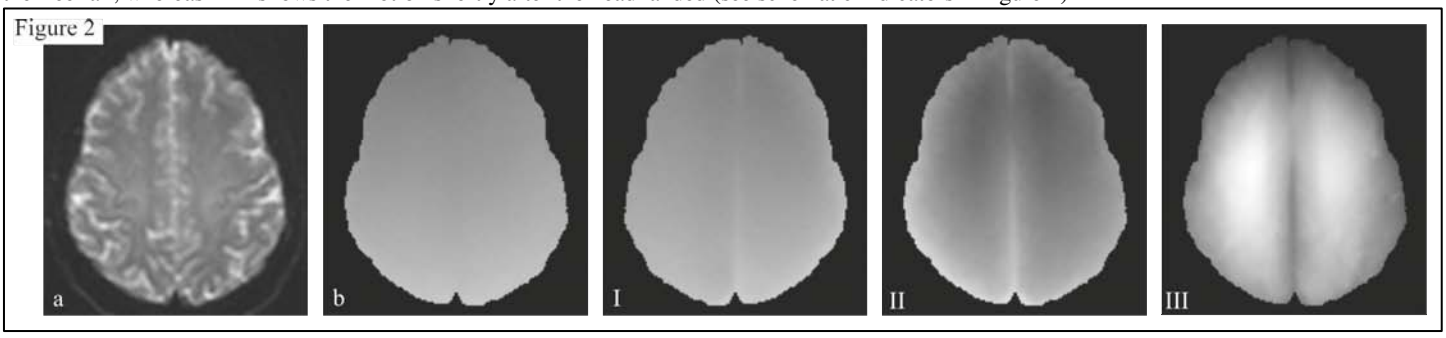
Figure 1



Measurements and Results

The measurements were performed using a 1.5 T Magnetom Avanto Scanner (Siemens Healthcare) with a Head Matrix Tim Coil (sequence parameters: TR: 2500 ms, TE 150 ms, fat saturation, G: 25.4 mT/m, δ: 5 ms, Δ: 45 ms, voxel size: 2 mm × 2 mm × 5 mm, lifting height d: 1 mm corresponding to a free-fall-time of approx. 14 ms). Figure 2 shows exemplary measurements of the same transversal slice of a female volunteer: 2.a is a magnitude image, whereas 2.b and 2.I-III are phase images. All images shown are an average of five measurements. Where necessary, phase data was unwrapped. Figure 2.b shows a measurement without prior lifting and dropping of the head. The phase inside the brain is homogenous. Figures 2.I-III show phase images obtained with a synchronized free fall for different points in time. 2.I and 2.II depict the motion during the early stages of the free fall, whereas 2.III shows the motion shortly after the head landed (see schematic indicators in figure 1).

Figure 2



Discussion and Outlook

The presented results show the feasibility of the application of this novel method on the human brain. The locally different viscoelastic coupling of the tissue creates a contrast in the phase images. By comparing the images of different points in time, the time dependence of the relaxation movements may be obtained. Additional measurements on healthy volunteers as well as probands with known diseases will be necessary to evaluate whether an improvement in diagnostics is possible using this method. Since the measurements with it are nonhazardous and provide a good spatial resolution we are confident that this method holds great potential for future medical applications.

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3. Stejskal, E. O. *et al.*, J. Chem. Phys. **42**:288-292 (1965)