A preliminary MR elastography database of in vivo human brain viscoelasticity

B. Beierbach[1], J. Würfel[2], J. Rump[1], S. Papazoglou[1], D. Klatt[1], U. Hamhaber[3], J. Braun[3], and I. Sack[1]

[1]Department of Radiology, Charité - Universitätsmedizin Berlin, Berlin, Germany, [2]Institute of Neuroimmunology, Charité - Universitätsmedizin Berlin, Berlin, Germany, [3]Institute of Medical Informatics, Charité - Universitätsmedizin Berlin, Berlin, Germany

Introduction: Since centuries manual palpation is used by physicians to detect pathologic alterations of tissue near the body surface. These experiences have stimulated the development of techniques called elastography which are able to quantify elastic parameters of soft tissue independent of its shielding by bones or other tissue layers. In particular brain elastography is a subject of high interest since the brain is not palpable and many neurodegenerative diseases are difficult to diagnose at an early state. Recent pilot studies in MR elastography (MRE) have demonstrated the feasibility of a technical palpation of living human brain.

Problem: Brain MRE has not yet been assessed for its reproducibility and its potential to provide consistent results within one experimental study design. Furthermore the published data show a large variety of shear modulus data [1-3].

Objective: A brain MRE protocol was developed that is suitable for the clinical use. The applicability of the technique on patients was achieved by short examination times and a very moderate head actuation from the back of the head using low frequency vibrations. The protocol was repetitively tested on ten healthy volunteers, six multiple sclerosis patients and one Alzheimer patient.

Methods:

Examinations were performed on a 1.5 T scanner (Magnetom Sonata, Siemens, Germany). A single-shot spin-echo EPI sequence was sensitized to motion by sinusoidal gradients [4]. Axial images were oriented within a slab of 2 cm thickness (lower boundary along the lower edge of the corpus callosum). Motion encoding was orthogonal to the image plane and synchronized to intracranial tissue vibrations at frequencies of 25 and 50 Hz induced by a head-rocker actuator.

Ten time-resolved phase-difference wave images were recorded within 60 seconds. The first harmonic vibration component was derived by *t*-FFT and subjected to a spatial Butterworth bandpass filter with lower and upper thresholds of 1.4 and 31.6 cm (f = 25 Hz) and 1.2 and 11.6 cm (f = 50 Hz). Complex wave image inversion was applied yielding a complex modulus [5], which was assigned by its real part to the shear modulus (μ) and its imaginary part to the shear viscosity (η) based on Voigt's model of viscoelasticity. μ and η were averaged over a region of interest determined by manually segmentation.

Institutional review board approval was obtained for each subject. 10 healthy volunteers (V1-V10, 8 men, age: 25–65, mean age 42.3 years; 2 women, age: 24–27, mean age 25.5 years), 6 multiple sclerosis patients (M1-M6, age: 25–45, mean age 35.5 years), and 1 Alzheimer patient (A, 60 years) underwent up to 20 follow-up MRE studies over a period of six months.

Results and Discussion:

Figure 1 shows example wave images acquired from a volunteer during several examinations with 25-Hz and 50-Hz vibration frequency performed by different operators at different days. The variation of wave patterns is presumably the result of different head positions relative to the head rocker and effects of different muscle tension of the neck.

Figures 2 and 3 represent experimental data of shear moduli and shear viscosities of the brain. Volunteers and patients are arranged with increasing age from left to right. An average of $\mu = 1.02 \pm 0.11$ kPa (mean ± SD) at $f = 25$ Hz and $\mu = 1.59 \pm 0.12$ kPa at $f = 50$ Hz was found for healthy volunteers. Corresponding values for multiple sclerosis patients were $\mu = 0.98 \pm 0.12$ kPa (mean ± SD) and $\mu = 1.53 \pm 0.15$ kPa (for all patients: 1.00 ± 0.12 kPa and 1.54 ± 0.14 kPa). Mean values found for the shear viscosity were $\eta = 7.16 \pm 1.29$ Pas and $\eta = 3.37 \pm 0.34$ Pas at $f = 25$ and 50 Hz for healthy volunteers and $\eta = 6.76 \pm 0.92$ Pas and $\eta = 3.10 \pm 0.37$ Pas for multiple sclerosis patients (for all patients: 6.69 ± 0.86 Pas and 3.22 ± 0.45 Pas). The frequency dispersion of μ and η indicates a limited applicability of Voigt's model to explain viscoelastic behavior of brain parenchyma within the applied frequency range.

Different types of brain tissue were not distinguishable in our experiments. The narrow data distributions within small confidence intervals demonstrate the excellent reproducibility of the experimental protocol. Small individual variations are seen which however, might result from systematic errors due to wave inversion close to boundaries, different boundary geometries, the 2D-analysis of the wave vector field etc. Such biases of elastic parameters deduced from shear waves are prevalent in elastography. It is therefore a promising result that viscoelastic data of the brain are well reproducible using a single MRE protocol.

Conclusion:

The proposed setup allows a fast and compliant determination of viscoelastic constants of brain parenchyma of healthy volunteers and patients. The acquired viscoelastic data are intended as preliminary database of healthy and symptomatic human brain viscoelastic constants, which is to be continued in ongoing projects.

References:

[1] McCracken PJ et al., *Magn Reson Med* 2005; 53: 628-639.
[2] Uffmann K et al., *Proc Intl Soc Mag Reson Med* 2004: 1768.
[3] Green M et al., *Proc Intl Soc Mag Reson Med* 2005: 2176.
[4] Hamhaber U et al., *Acta Biomaterialia* 2006; DOI: 10.1016/j.actbio.2006.08.007.
[5] Klatt D et al., *Invest Radiol* 2006; 41: 841-848.

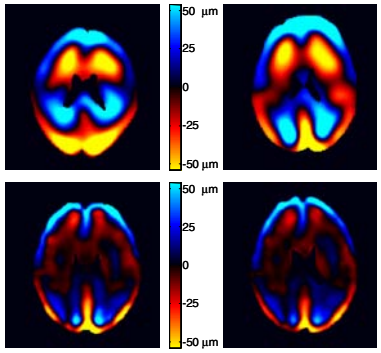

Fig.1: wave images of a healthy volunteer (upper row: 25 Hz, lower row 50 Hz). Lowest deflection amplitudes were found in the vicinity of the center of the brain in left–right direction. This is due to the pre-dominant nodding motion, with highest deflections at the forehead and at the back of the head.

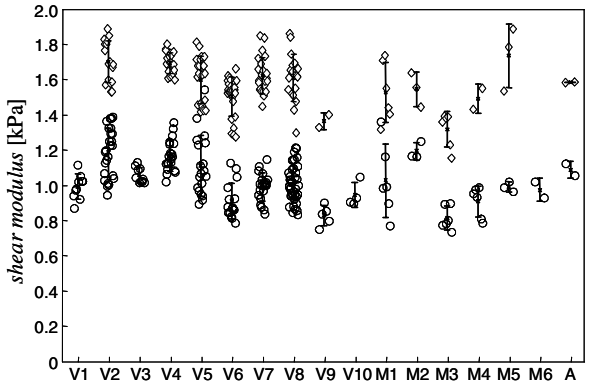

Fig.2: Shear moduli of human brain found in volunteers and patients at 25 Hz (circles) and 50 Hz (diamonds) mechanical excitation (error bars corresponding to the STD).

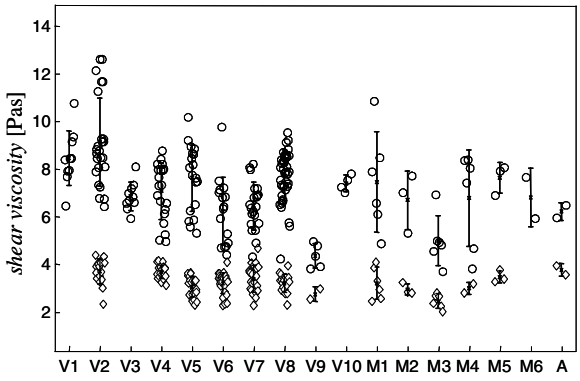

Fig.3: Shear viscosities of human brain found in volunteers and patients at 25 Hz (circles) and 50 Hz (diamonds) mechanical excitation (error bars corresponding to the STD).