In vivo MR elastography of liver and brain using multi frequent shear wave excitation

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Introduction: MR Elastography (MRE) is able to measure viscoelastic properties of living soft tissue. The technique is based on the excitation of the investigated tissue by shear vibrations and their observation using phase contrast MRI [1].

Problem: Until now, in vivo tissue stiffness has been determined using a mono-frequent shear wave excitation in MRE [2-4]. The study of tissue rheology, however, requires the knowledge about wave propagation at multiple frequencies. To acquire this important information consecutive MRE experiments with changing driving frequencies had been performed [5].

Objective: In this study, a superposition of multiple harmonic driving frequencies is used for in vivo MRE on the human brain and liver. All harmonic vibrations were simultaneously detected exploiting the broad-band nature of the motion encoding gradient (MEG).The viscoelasticity of brain (5 volunteers) and liver (4 volunteers) was determined according to the Zener model [6].

Methods: MRE experiments were run on a 1.5T scanner (Siemens Sonata, Germany). Images of central transversal slices were acquired using a motion sensitized spin-echo EPI-sequence (fig. 1.a) (brain: MEG frequency f_G = 60Hz, number of MEG cycles N = 4, TR = 3s; liver: f_G = 50Hz, N = 1, TR = 0.5s). A loudspeaker in a distance of ≈2.5m to the scanner was used as wave source. The membrane vibrations of the loudspeaker were transferred by a carbon fiber rod to a head rocker (brain) or directly onto the surface of the volunteer underneath the right costal arch (liver). The waveform fed into the audio amplifier was a superposition of the frequencies 25Hz, 37.5Hz, 50Hz and 62.5Hz (fig. 1.a). The encoding efficiency of the vibrations is displayed in fig. 1.b. The trigger was shifted in 40 equal time steps over a 80 ms interval to capture wave propagation over one temporal cycle of the 12.5 Hz vibration. Total measurement time was 4 min (brain) or 40 s (liver, split into 2 breath-holds). The frequency content of the wave images was decomposed by a Fourier transformation. For each frequency component the complex shear modulus G(ω) was determined by a 2D-inversion of the wave equation and then averaged spatially over the segmented organ. Finally, the viscoelastic parameters were fitted using the Zener model [6].

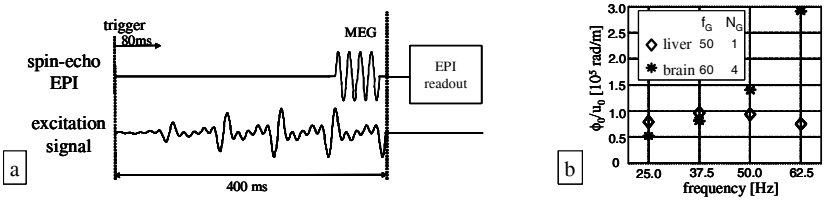

Fig. 1: a) Multi-frequent MRE experiment: Motion sensitization was achieved by combining a spin-echo EPI-sequence with motion encoding in slice-select direction. To avoid mechanical transients the amplitude of the multi-frequent signal of the wave generator increased linearly in time approaching its maximum at 200 ms. b) Conversion factors from deflection amplitudes u_0 to phase amplitudes ϕ_0 which represent the encoding efficiency in the current MRE experiments.

Results: Fig.2 shows for the brain the effect of frequency decomposition of experimental multi-frequent wave data. It is visible that the wave-lengths decrease with higher driving frequencies. The determined viscoelastic parameters according to the rheological Zener model are displayed in tab. 1. Both shear moduli and the shear viscosity were found to be significantly different in brain and liver. The corresponding dispersion relations and the mean experimental values over all volunteers are shown in fig. 3. The theoretical dispersion functions agree well to the experimental data.

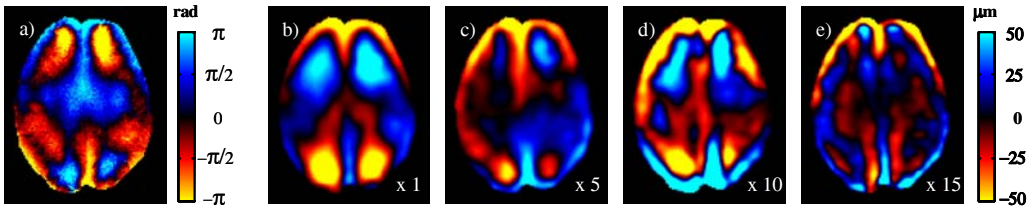

Fig. 2: a) Phase image of multi-frequent wave propagation in human brain. b-e) The decomposed fourier components correspond to vibration frequencies 25Hz, 37.5Hz, 50Hz and 62.5Hz, respectively and are displayed in deflections after dividing the phase values over the conversion factors (fig. 1.b). The colorbar values have to be devided by the factors displayed in the lower right corner of each wave image in order to represent metric deflections.

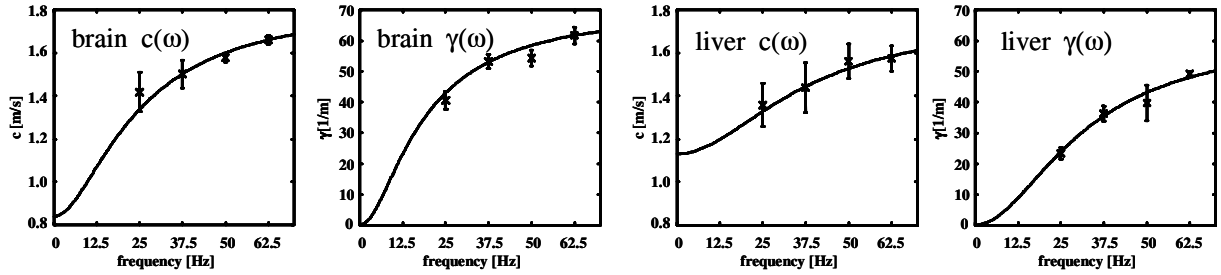

Fig. 3: Mean wave speed (c) and wave attenuation (γ) values averaged over all examined subjects. The determined viscoelastic parameters are summarized in tab. 1.

Discussion and Conclusion: Using multi-frequent MRE mean viscoelastic parameters according to the Zener model were determined for in vivo human brain and in vivo human liver. Although the experimental phase velocities were similar in brain and liver (±0.1 m/s), their viscoelastic Zener parameters are different due to the higher wave damping in brain compared to liver. This finding underscores the importance of choosing an appropriate viscoelastic model for interpreting MRE results. In summary, the shown technique allows the examination of tissue rheology in one time resolved MRE examination. The gain in rheological information potentially increases the accuracy and the diagnostic value of MRE results.

Subject	brain	liver
volunteer #	5	4
λ [kPa]	0.74±0.08	1.34±0.17
µ [kPa]	2.70±0.23	1.90±0.25
η [Pa s]	8.4±0.7	5.2±0.7

Tab.1: Viscoelastic parameters λ, µ, η according to the rheological Zener model for in vivo human liver and brain.

References: [1] Muthupillai et al., Science 269, 1854(1995); [2] Rouviere et al., Radiology 240, 440 (2006); [3] Huwart et al., NMR Biomed. 19, 173 (2006); [4] Klatt et al., Invest. Radiol. 41, 841 (2006); [5] Kruse et al., Phys. Med. Biol. 45, 1579 (2000), [6] Pritz et al., J. Sound & Vibr. 228, 1145 (1999).