Low dynamic mechanical tissue stimulation for high resolution magnetic resonance elastography: An in vivo feasibility study in the liver and the brain

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Target audience: Physicists and physicians interested in magnetic resonance elastography (MRE).

Background and Purpose of the Study: MRE is an MRI modality which typically employs shear vibrations of frequencies between 40 and 70 Hz to quantify viscoelastic tissue properties (1). Here we propose the application of shear vibrations at much lower frequencies between 10 and 20 Hz for the following reasons: 1) Shear waves of low frequencies propagate nearly unattenuated through the body and therewith provide a homogeneous shear strain stimulus for elastography. 2) Low dynamic tissue stimulation has a potentially higher sensitivity to poroelastic tissue properties which may be exploited as new diagnostic markers. 3) External vibrations between 10 and 20 Hz used for MRE are of low amplitude thus well tolerated by patients. 4) Novel high resolution reconstruction algorithms based on multiple shear wave fields as described in (2) may provide high-resolution elastograms also in the proposed low frequency range. The latter will be demonstrated by comparing three different ranges of frequencies from the low-dynamic range to the range of normal MRE in human liver and brain.

Methods: An MRE sequence was developed based on single shot spin-echo EPI in which the acquired images are synchronized to continuous harmonic vibrations (3). In principle, this method is capable of measuring wave fields at arbitrarily low vibration frequencies without transient effects. The liver and the brain of 5 healthy volunteers were investigated at 9 frequencies (low range: 10/15/20Hz; medium: 25/30/35Hz; high: 40/45/50Hz). Imaging parameters for brain [liver]: 3T[1.5T] MRI, 17[11] transverse slices, 2×2×2 [2.7×2.7×5]mm^3 voxel size, 8[16] wave dynamics, TR = 2.4[1.6]s TE = 70[55]ms, FoV = 200×168[350 × 284]mm^2, matrix size: 100×84 [128×104]; encoding gradient 35[32]mT/m in all Cartesian axes, scan time per freq.: 1:00[1:20]min. During the liver exams the volunteers were allowed to breathe freely. Postprocessing: multifrequency dual elasto visco (MDEV) inversion (2) was applied to all 3 grouped frequency ranges yielding 3D maps of magnitude |G*| and phase angle φ of the complex shear modulus. As a reference, oscillatory shear rheometry and MRE were performed on a phantom made of ultrasound (US)-gel.

Results: Fig. 1 shows one slice of the in-plane curl component ($\partial u_2/\partial x_1 - \partial u_1/\partial x_2$) for 10 to 20 Hz in the brain and liver of a volunteer. The corresponding |G*|- and φ-maps were based on 10, 15 and 20 Hz including all field components. The wave images show high amplitudes throughout the FoV and the |G*|- and φ-maps demonstrate high quality and good agreement to anatomical features. Fig. 2 shows group mean (± STD) of |G*| in three frequency ranges for the liver, brain and the gel phantom. Excellent agreement of |G*| measured by MRE and rheometry is observed.

Discussion & Conclusion: Using low drive frequencies lead to improved patient comfort and to homogenous shear wave amplitudes in the tissue. Despite long wave lengths, high resolution elasticity maps are obtained showing anatomical details of viscoelasticity in the human liver and brain. Averaged values of |G*| and φ illustrate the strong dispersion of shear viscoelasticity in these organs. In conclusion, in vivo low dynamic MRE is feasible for investigations of the liver and the brain. The method is less prone to damping artefacts and may therewith improve the consistency and diagnostic precision of MRE. The method is sensitive to a new dynamic range of viscoelastic tissue parameters whereby its diagnostic sensitivity remains to be investigated.

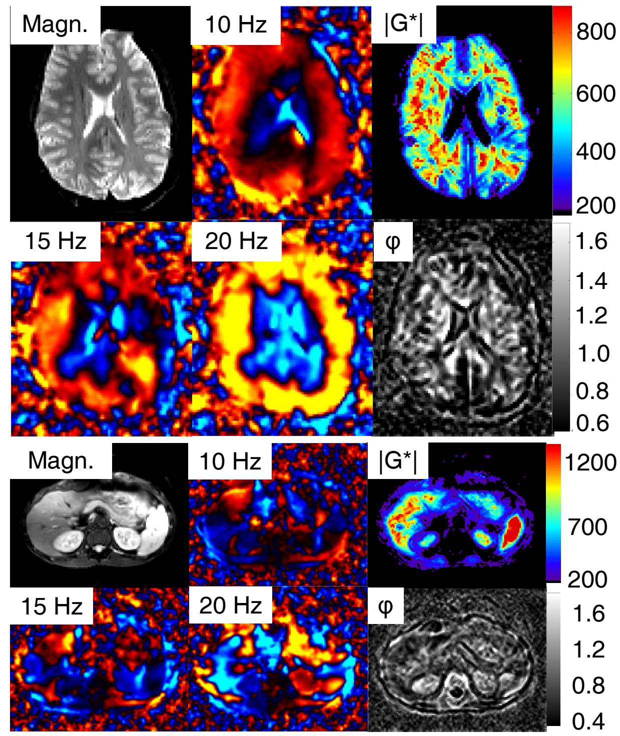

Fig.1: Demonstration of low frequency MRE in the brain and liver: MRE magnitude signal (Magn.), 3rd curl component of the wave field (10-20Hz), and high resolution MRE maps (|G*| in [Pa] and φ in [rad]).

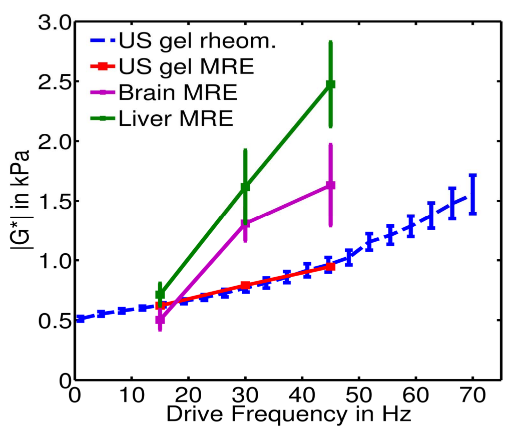

Fig.2: Frequency dispersion curve for |G*| in liver, brain, and US-gel phantom based on MRE and oscillatory shear rheometry measurements. Error bars for MRE indicate the standard deviation (STD) across the individuals, for rheometry the STD across measurement repetitions.

References: (1) Muthupillai R, Ehman RL. *Nature Med* 1996;2:601-603. (2) Guo J, Hirsch S, Fehlner A, et al. *PloS one* 2013;8:e71807 (3) Dittmann F, Hirsch S, Guo J, et al. *Proc ISMRM* 2014;22:1684.