

High resolution 3D multifrequency MR elastography at 7T

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Target audience: Radiologists and physicists interested and working in ultrahigh-field imaging and MR elastography (MRE).

Purpose: Magnetic resonance elastography (MRE) [1] is a unique modality for the measurement of the in vivo mechanical properties of the brain and has been proven to be sensitive to Multiple Sclerosis [2], hydrocephalus [3] and Alzheimer's disease [4]. MRE is an image-based modality; however, its capability to produce highly-resolved images of viscoelastic parameters is still limited. Hence, the objective of this study was to create highly resolved maps of viscoelastic parameters for brain tissue. For this purpose we combined the recently introduced concept of least-squares multifrequency inversion [5] with ultrahigh-field MRE of the brain at 7 T.

Methods: *Subjects:* Experiments were performed on five healthy male volunteers. All volunteers gave informed written consent prior to the study according to the declaration of Helsinki. *Experiment:* MRE was accomplished on a 7 T Magnetom (Siemens, Erlangen, Germany) using a single-shot spin-echo EPI sequence with sinusoidal motion-encoding gradients (70 mT/m @ 200 T/m/s) applied in 3 orthogonal directions. A custom-made bite bar with attached electromagnetic coils resulting in a tilted motion of the head was used to generate shear waves in the brain (fig. 1). Harmonic drive frequencies were 40, 50, and 60 Hz. Further imaging parameters: TR/TE = 5420/76 ms, 200 × 186 matrix size, 200 × 186 mm² FoV, 20 adjacent slices, 1.0 mm slice thickness, eight dynamic scans per vibration period. *Multifrequency dual parameter inversion:* Raw phase images were unwrapped and Fourier-transformed along time axis for extracting the vibration component at drive frequencies, and finally transferred to curl fields (fig. 2) [6]. To improve the resolution of MRE parameter maps, we used multifrequency dual elasto-visco (MDEV) inversion. Two MRE parameters $|G^*|$ and ϕ were obtained by independent inversions: $|G^*|$ is the least-squares solution of the magnitude-Helmholtz equation $|G^*| |\Delta c_m^*(\omega_n)| = \rho \omega_n^2 |c_m^*(\omega_n)|$, where c_m^* is the component of the curl wave field. The phase of complex modulus ϕ was reconstructed using eqs. (9), (10) from [5] and finally scaled by $2/\pi$ to α which is the powerlaw exponent of the springpot-model. *Registration and segmentation:* T2-weighted images (MRE magnitude images) were registered to standard brain space (MNI152_T1_1mm) using ANTS [7]. Subsequently, gray and white matter were segmented in the registered MRE images using SPM8 [8]. The according segmented tissues were then used as regions of interest.

Results: Figure 3 shows representative maps of the magnitude of the complex modulus $|G^*|$ and the springpot parameter α for a central transversal slice. Interfaces between tissues such as white matter, gray matter, thalamus, caudate nucleus and corpus callosum are well delineated. Group-mean viscoelastic parameters were calculated for white matter with $|G^*|$ (0.911 ± 0.133 kPa) and α (0.554 ± 0.021). Gray matter exhibited a $|G^*|$ of (0.794 ± 0.102 kPa) and α of (0.502 ± 0.013) and was significantly softer ($p \leq 0.05$ [$|G^*|$], $p \leq 0.02$ [α]) than white matter.

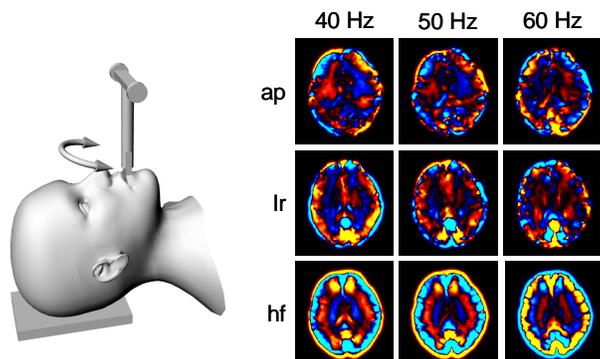


Fig. 1: Sketch of the bite bar actuator and the major motion direction (arrow). **Fig. 2:** Curl fields in head-feet (hf), left-right (lr), and anterior-posterior (ap) direction.

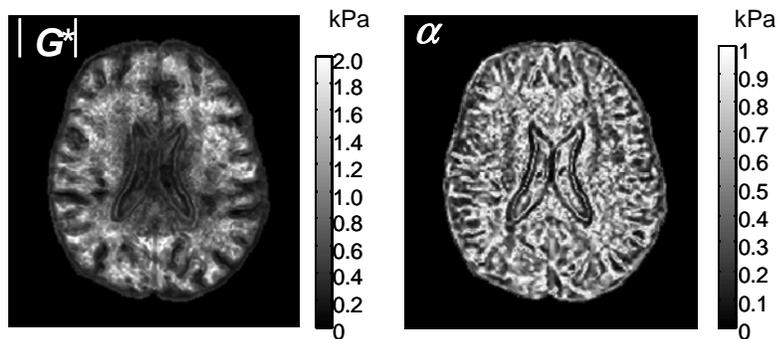


Fig. 3: Representative maps of the magnitude of the complex modulus $|G^*|$ and the springpot parameter α of one volunteer. Note that the parameter maps represent the direct result of MDEV-inversion without further processing and filtering.

Discussion: The high signal-to-noise ratio provided by 7T-MRI and 3D multifrequency MRE allowed us to resolve anatomical details in the individual $|G^*|$ - and α -maps (Fig.3) due to the highest spatial resolution achievable at present. Compared to previously published MRE studies at 7T [9] this method allows a more precise analysis of mechanical structures and may for this reason enhance the diagnostic power of cerebral MRE in clinical examinations. White matter fibers have a significantly higher stiffness (represented by $|G^*|$) and mechanical network density (given by α) than gray matter structures which is in good agreement with theoretical work [10] and results of other MRE studies of the human brain [11].

Conclusion: The signal gain by 7-T MRI, combined with multifrequency wave excitation, 3D-wave field acquisition of 1-mm³ voxel resolution and MDEV inversion allowed us to resolve anatomical details of brain mechanics in unprecedented details.

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