Continuous vibration single shot magnetic resonance elastography for fast wave image acquisition

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

Background: MRE is capable of generating image contrast based on the viscoelastic properties of tissue by inducing and detecting time harmonic shear waves in the body (1). The spatial resolution of so called elastograms depends on the resolution of wave images and the stability of the solution of the time harmonic inverse problem (2). Both can be improved by repetitive scans, e.g. by accounting for signal accumulation in order to increase SNR or by applying different drive frequencies for avoiding wave amplitude nulls. Therefore, MRE measurement time is critical in particular when high resolution elastograms are needed. A limiting factor for fast single shot MRE has been the need for wave synchronization after each image acquisition block by introducing a waiting time in order to avoid transient vibrations (3).

Purpose: To develop fast single shot MRE synchronized to continuous vibrations and to demonstrate the new method by generating high resolution elastograms of the human brain.

Methods: In order to synchronize the motion encoding gradients (MEG) of a single-shot EPI sequence with the continuous mechanical vibration, two delays were introduced before ($\Delta_{pre,i}$) and after ($\Delta_{post,i}$) the image acquisition block (Fig.1). Both delays fulfill the condition $\Delta_{pre,i} + \Delta_{post,i} = 1/min(f_{mech})$, where $min(f_{mech})$ denotes the minimum vibration frequency used for multifrequency MRE. For each image slice, the fill times are individually computed for adjusting the desired phase of the vibration. As a result no transient vibrations for the re-synchronization of image acquisition and wave cycle are necessary which reduces measure time by avoiding trigger forerun times. Furthermore this sequence ensures time harmonic steady-state oscillations which are a required model assumption in many reconstruction algorithms. The new MRE sequence was tested for high resolution multifrequency MRE of the brain in five healthy volunteers. Therefore, full wave field data at 15 harmonic drive frequencies of 25, 27.5, to 60 Hz were acquired and analyzed by multifrequency dual elasto visco (MDEV) inversion (3) yielding two parameter maps for each image slice corresponding to the magnitude |G*| and the phase angle φ of the complex shear modulus. Sequence parameters: 7 transverse slices of 2 mm isotropic resolution, 8 wave dynamics, 3 wave field components, TR = 1560 ms, TE = 115 ms, FoV = 256 × 256 mm^2, matrix size 128×128; MEG frequency = f_{mech}, MEG amplitude = 26 mT/m, Total measurement time: 9:40 min

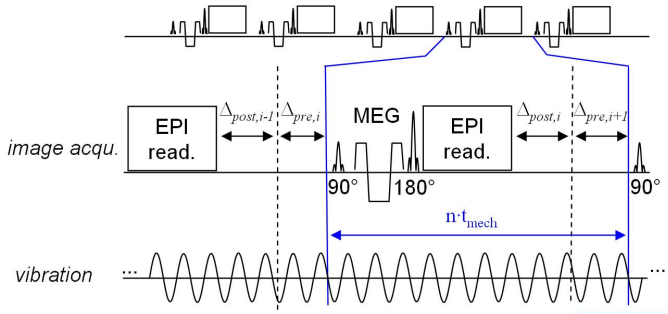

Fig.1: Sequence timing diagram illustrating the delay of single shot image acquisition relative to continuously applied harmonic vibrations in order to achieve the dynamic capture of wave propagation.

Results: Fig. 2 shows wave images in a central image slice through the brain of a volunteer for all applied 15 drive frequencies with corresponding magnitude image as well as |G*|- and φ-maps. The viscoelastic parameter maps demonstrate the high image quality due to the involvement of a high number of drive frequencies in our multifrequency reconstruction.

Discussion: The proposed MRE sequence needed 9:40 min scan time for a total 2520 images. The idle times during the single-shot EPI acquisition of one slice can be approximated by TR per slice minus the time needed from the 90° pulse until the end of the readout ($t_{idle} \approx TR/n_{slices} - 1.5 \cdot TE$). In our setup, this results in $t_{idle} = 50$ ms per image – compared to $t_{idle} = 92$ ms and total measurement time of 11:20 min for the sequence proposed in (3) corresponding to a ~15% reduction of total measurement time by our sequence. For higher mechanical frequencies the idle time of our sequence is further reduced, e.g. $t_{idle} = 20$ ms for f = 100 Hz, resulting in faster scans. Furthermore, we consider continuous vibrations without transient re-synchronization delays a better conditioning of time-harmonic oscillations for an improved solution of the inverse problem in elastography.

Conclusion: Using continuous vibration and adaptive measurement block shifting, MRE acquisition can be significantly accelerated without loss of SNR. The saved time can be used to measure more frequencies for further improvement of the quality of |G*|- and φ-maps.

References: (1) Muthupillai R, Ehman RL. *Nature Med* 1996;2:601-603. (2) Manduca A, Oliphant TE, Dresner MA, et al. *Med Image Anal* 2001;5:237-254. (3) Guo J, Hirsch S, Fehlner A, et al. *PloS one* 2013;8:e71807

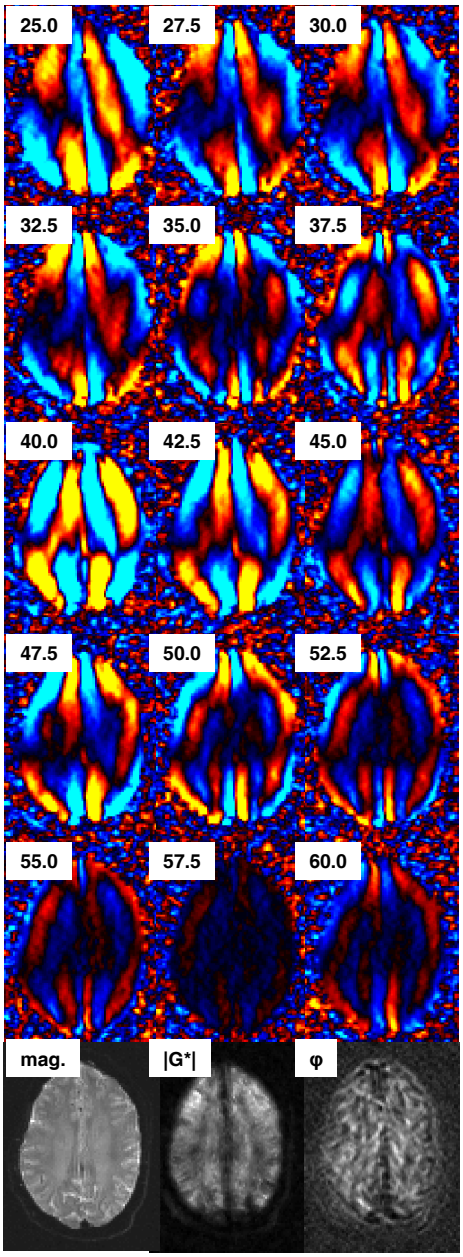

Fig.2: Demonstration of cvMRE in the brain: Full wave fields at 15 frequencies (numbers on wave images in Hz) were consecutively acquired for multifrequency parameter reconstruction in high resolution (|G*| and φ).