Coherent motion preparation of the magnitude signal in MR elastography

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Introduction: Shear stiffness sensitively indicates various pathologic changes of living soft tissue. In MR elastography (MRE) [1] bulk shear waves are used for testing elastic parameters of human organs.
Problem: Phase-contrast MRE often suffers from phase aliasing in vicinity to wave sources or at elastic heterogeneities. To avoid phase wrapping the amplitudes of wave deflection have to be decreased which also decreases the depths of wave penetration. To a certain degree, intra voxel phase dispersion [2] bounds the magnitude signal in MRE to the shear strain. However, this mechanism requires large strain gradients relative to the spatial resolution which are hard to achieve in vivo.
Objective: An experiment is introduced for sensitizing the longitudinal magnetization to moving spins. The vibration response in the magnitude image can be coherently cycled for generating an image contrast that is scaled by the mechanical resistance of the tissue to shear vibrations (shear wave impedance). The new method may be of value as a qualitative means for detecting and discriminating pathologically altered tissues based on their mechanical properties. The method is demonstrated on a heterogeneous gel phantom and the brain of one healthy volunteer.

Methods:
Coherent motion preparation (CMP) based on an echo planar imaging (EPI) sequence was implemented on a Siemens Sonata 1.5 T scanner. The motion preparation sequence incorporates a single bipolar motion encoding gradient (MEG) encompassed by two 90°-RF pulses (see fig.1). The MEG was applied in slice selection with a length of 2 ms in phantom studies (wirogel [Bego Inc., Bremen, Germany]; wirogel matrix: 5%w; one stiff wirogel inclusion [Ø1.5 cm]: 10%w; one oft aquagel inclusion [Ø1.5 cm]) and 20 ms in human brain experiments (one healthy male volunteer, 26 years). The phase ϕ of the CMP-pulses was switched in consecutive experiments with 0°, 90°, 180° and 270° relative to the *x*-axis of the rotating frame. Vibrations were induced using a loudspeaker coupled by a carbon fiber rod to a phantom actuator or a head rocker device. Vibration frequency was 25 Hz. The vibration phase (θ) was varied in twenty steps from 0.1π to 2π.
Results and Discussion:
Fig.2 demonstrates CMP-EPI on a phantom. While in standard MRE (fig.2a) only minor signal variations appear due to intra voxel phase dispersion [2], CMP (fig.2b) imposes strong signal deteriorations in areas of large mechanical deflection amplitudes. Cycling θ and averaging twenty CMP-images yields fig.2c with gray-scale contrast that depends on both T2* and shear wave impedance. Fig.2d shows the relative impedance weight in the phantom after subtracting the reference T2*-intensity. Fig.3 demonstrates in vivo CMP-EPI on the human brain. Here the effect of harmonic wave excitation on the signal magnitude is shown for several RF-pulse phases ϕ. Motion tags reflect isolines of equal strain magnitudes in the vibrating brain which is equivalent to position tags produced by SPAMM-MRI [3]. Thereby, the position of the tags depends on the spin precession imposed by the MEG. Figs.4a and 4b represent the mean CMP-EPI contrast averaged over all experiments of the static and vibrating brain, respectively. In 4c, the mechanical impedance contrast corrected for T2* is shown. The dark sulci indicate a very low shear wave impedance of liquor resulting high strain amplitudes as reported by [4]. The shading in the frontal area of the brain is an effect of increased wave amplitudes in this region which are caused by a nodding head motion.
Conclusion:
CMP sensitizes magnitude images to tissue strain. The obtained motion patterns show contours of mechanical deflections. Their positions can be shifted corresponding to the vibration phase θ and the RF-phase ϕ. The averaged image contrast is inversely scaled by the strain magnitudes and proportional to the shear wave impedance of the tissue. Incomplete wave penetration has to be avoided. The proposed technique might aid the diagnosis of pathologic brain tissues.

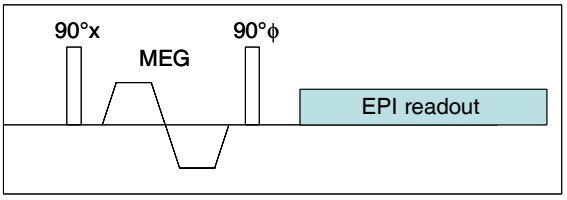

Fig.1: CMP-EPI sequence for preparing the longitudinal magnetization to be sensitive to vibrating spins.

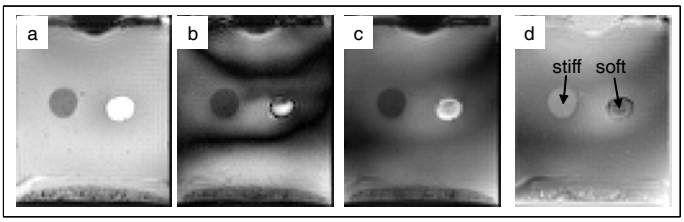

Fig. 2: Phantom studies: Magnitude image (a), CMP-contrast (b), Mean CMP-amplitudes averaged over one cycle of θ (c) and mean CMP-image corrected for T2* (fig2c minus fig2a) (d).

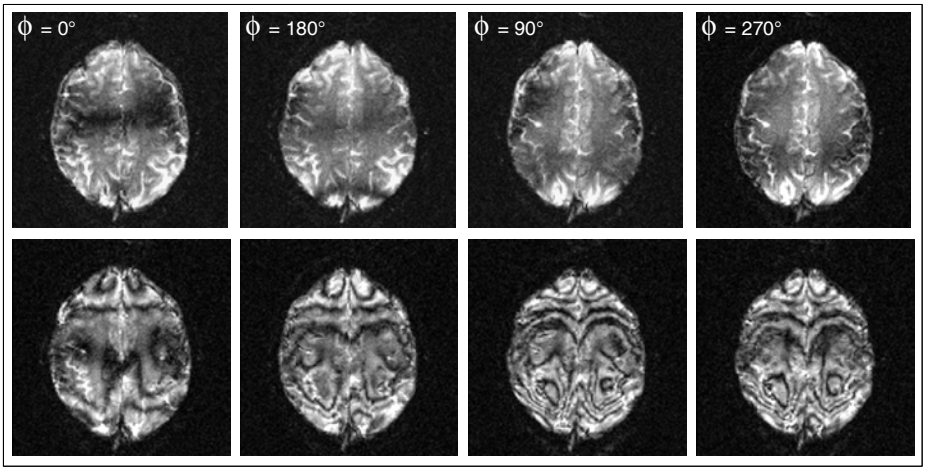

Fig.3: Brain CMP-EPI experiments. First row: no motion, second row with 25 Hz vibration of the head (deflection on the head surface is approximately 0.5 mm).

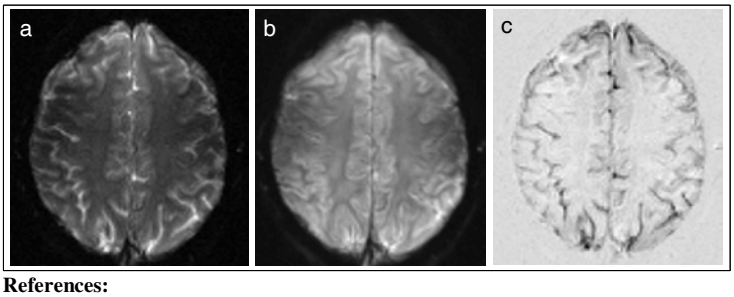

Fig.4: Mean signal intensities of non-vibration (a) and vibration (b) experiments on the human brain. c: CMP-intensity corrected for T2* (fig4.b minus fig4.a)

References:
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