Phase preparation in balanced steady state MR elastography

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Introduction: MR Elastography (MRE) allows the quantification of the viscoelasticity of soft tissue deep within the body [1]. Thereby, the mechanical response of externally induced shear vibrations is measured by phase contrast (PC) MRI techniques. As has been shown by several groups, the use of balanced steady state free precession sequences (bSSFP) in PC- MRI results in a nonlinear relationship between offset phase and phase response [2,3]. Here, an experiment is introduced that exploits the nonlinear phase response in bSSFP-MRE using phase preparation gradients (PPG), which counteract to shim gradients as they strongly inhomogenize the magnetic field. As a result, alternating regions of enhanced and attenuated phase-to-noise-ratio appear, yielding an overall increase of wave signal in bSSFP-MRE. The new technique is demonstrated on in vivo human liver and heart.

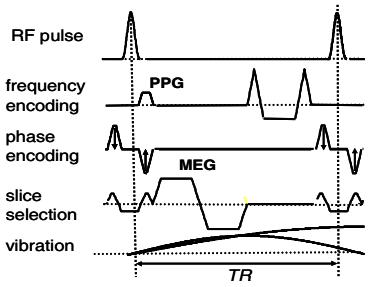

Fig. 1: bSSFP-MRE with additional PPG, here in frequency encoding direction. The vibration is tuned by either two (liver) or four (heart) TR's.

Methods: Experiments were run on a 1.5 T Siemens scanner (Siemens Magnetom Sonata, Erlangen, Germany). Both balanced (bSSFP) and spoiled (FLASH) gradient echo sequences were sensitized to motion using a single-cycle through-plane motion encoding gradient (MEG) with durations of 5 ms for the liver and 2 ms for the heart. A phase preparation gradient (PPG) of 520 µs duration was introduced parallel to the phase encoding gradient in read-out direction (fig.1). Shear vibrations of 61.8 Hz A 2×*TR* (liver) and 47.5 Hz A 4×*TR* (heart) were induced by a remote vibration generator.

Liver experiments were performed using a transversal image slice at the center of the liver. The transducer was attached onto the body surface in the vicinity of the lower tip of the liver. The total acquisition was within one breath-hold of 24 sec (128×64 matrix size). Experiments were evaluated using a complex-modulus inversion based on Voigt's model after applying a spatial band-pass filter [4].

Heart ECG-gated bSSFP- and FLASH-MRE experiments were applied to in vivo human myocardium. The image plane was aligned with the interventricular septum and the transducer was placed onto the thorax. Total image acquisition time: four breath-holds of 32 heart cycles resulting in 16 complex, time-resolved phase-difference wave images (128×64 matrix size). The experiments were applied to a healthy male volunteer (age 36 years).

Results: *Liver* Applying a strong PPG imposes black signal bands in the magnitude image perpendicular to the PPG-direction (fig.2, first row). Correspondingly, the phase signal is locally enhanced and attenuated. Bands of signal enhancement in the phase image are located between bands of signal deterioration in the magnitude image. The net gain of phase signal enhancement using the PPG is demonstrated in fig.2, second row. Moreover, in case of strong phase preparation spatial filtering results in a homogeneous phase contrast, i.e. spatial variations of nonlinear phase response are eliminated. The elastograms (fig.2d, fourth row) further indicate the effect of increased phase homogeneity on the wave reconstruction.

Heart Opposed to liver experiments, phase signal enhancement occurs twice between the black magnitude signal deteriorations shown in fig.3a. This is due to the changed synchronization of one vibration cycle to 4xTR, which inherently affects the nonlinear phase response in bSSFP-MRE. In regions of phase signal enhancement (fig.3b), a tenfold increase of vibration signal was found compared to FLASH-MRE (fig.3c).

Conclusion Combining the advantages of fast bSSFP phase mapping and MRE wave reconstruction one has to consider effects of an inhomogeneous phase distribution. Such effects as described in [3] can be compensated using the proposed phase preparation gradients. As a result, TR can be prolonged, shimming is less important and the reproducibility of bSSFP-MRE results is improved. Furthermore, the spin phase response to external vibrations can regionally be increased about a factor of ten.

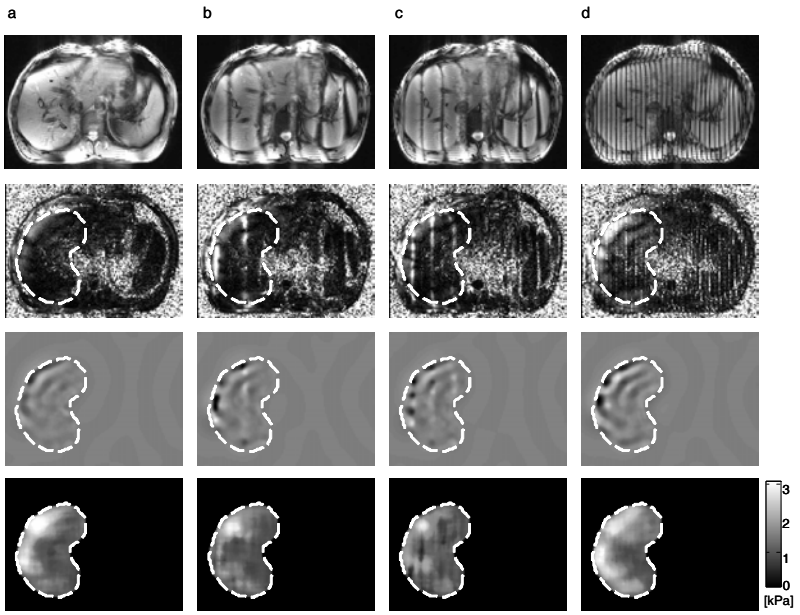

Fig. 2 First row: magnitude bSSFP images of the human abdomen. The amplitude of the PPG (in left-right direction) is incremented from 0 mT/m, to 0.96, 1.44 and 5.77 mT/m (**a-d**). **Second row:** magnitudes of the complex phase difference wave images. The contour of the *ROI* in the liver is demarcated as a dotted line. **Third row:** real part of spatial filtered phase difference images. **Fourth row:** shear modulus elastograms reconstructed by wave inversion.

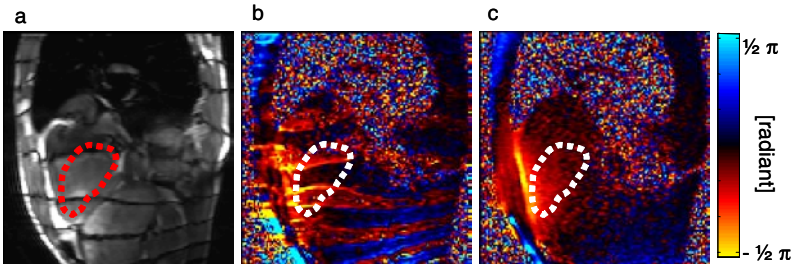

Fig. 3a: Phase prepared bSSFP magnitude image of the human heart. The PPG was along the up-down direction. The dashed lines demarcate the interventricular septum. **3b:** Corresponding phase image showing the phase response to 47.5 Hz external vibrations. **3c:** For comparison, the linear phase response is shown observed by FLASH-MRE. Here, same sequence timing, MEG amplitude and vibration frequency as in b) was used.

References:

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