Cardiac-Gated Hepatic MR Elastography with Intrinsic Transient Waveforms

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Introduction:

In conventional harmonic MR elastography (MRE), an external vibration source is used to generate propagating harmonic mechanical waves that are imaged with a modified phase contrast MRI technique in order to quantify the mechanical properties of soft tissue [1]. Harmonic MRE has been adopted as an alternative to biopsy for assessing liver fibrosis [2] and is being investigated for applications including breast, brain, and cardiac imaging. In this study, we developed and evaluated a dynamic MRE method for characterizing the liver that does not require an external vibration source. Instead, the technique uses naturally-occurring transient mechanical waveforms imparted on the liver by the beating heart. By synchronizing the motion-encoding gradients to the cardiac cycle, this technique visualizes propagating dynamic transient shear waves [3] to estimate the elasticity of the liver. In a recent abstract, investigators assessed the quasi-static deformation of the liver created by the beating heart and showed that the amount of deformation decreased with increasing hepatic stiffness [4]. However, in contrast to dynamic MRE, this quasi-static approach cannot provide a quantitative estimate of hepatic stiffness. This study evaluated the feasibility of using cardiac transient waves for dynamic MRE of the liver and compared estimates of hepatic stiffness obtained with this technique to those obtained with conventional harmonic MRE.

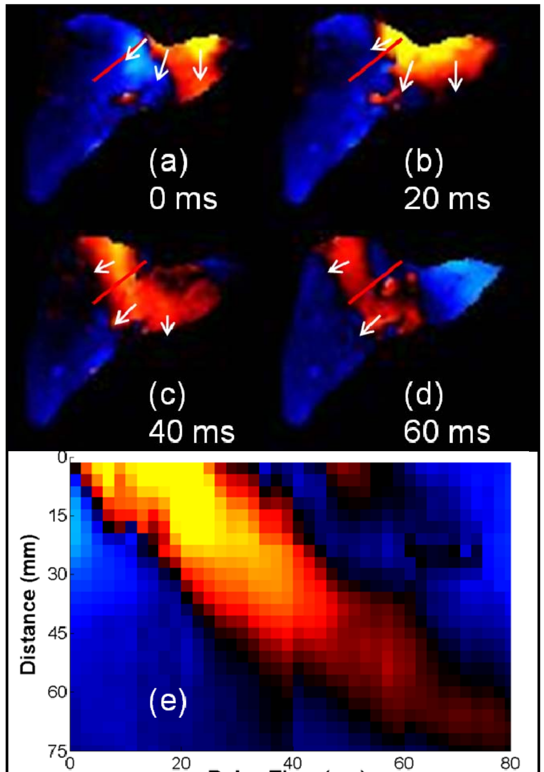

Fig. 1 *(a-d) Representative transient waveform at 4 temporal offsets. (e) Displacement-time profile for the highlighted 1-D profile.*

Materials and Methods:

Six healthy volunteers and 10 patients with potential liver disease were imaged after obtaining written informed consent in accordance with our institutional review board procedures. All data were collected in a 1.5T HDx GE scanner with an 8-channel torso coil. First, a harmonic MRE exam of the abdomen was performed as described in [2] using an FGRE MRE sequence, a 19-cm passive pneumatic driver, and 60-Hz continuous vibrations with the following imaging parameters: FOV = 28-44 cm; flip angle = 30°; 4 10-mm axial slices; TR/TE = 50/20 ms; matrix = 256x64; ASSET factor = 2; 1 16.7-ms flow-compensated trapezoidal motion-encoding gradient (MEG) in the SI direction, and 4 phase offsets. Acquisition time was 54 seconds (4, 14-s suspended respirations performed at end expiration). Next, the active driver was disabled and an SE-EPI MRE imaging sequence with cardiac ECG gating was used to measure the transient displacement of the liver produced by the heart with the following parameters: FOV = 28-44 cm; 1 10-mm coronal slice; TR = R-R interval, TE = 64 ms; matrix = 72x72; ASSET factor = 2; 1 20-ms flow-compensated trapezoidal MEG in the right-left direction. Every 2 R-R intervals yields one wave image or temporal offset (using positive and negative MEGs), with the delay between the ECG trigger and image acquisition incremented to capture 50 offsets at 2-ms intervals (performed in 5 ~20-s end-expiration suspended respirations) starting with a minimum delay of 20 ms. The harmonic MRE data were processed with a 2-D multiscale direct-inversion algorithm with the mean liver stiffness recorded. For the intrinsic motion datasets, 10 1-D profiles were selected by careful observation of the propagating wave direction (Fig. 1) and a time-of-arrival method was used to measure the shear wave speed (c) and thus the shear stiffness (μ) as $\mu = c^2\rho$, where the density (ρ) is assumed to be 1 g/cm^3 [3]. The mean and standard deviation of the 10 measurements were recorded for each subject. Two subjects were excluded due to irreproducible breath holds which resulted in discontinuous wave propagation in the measured data.

Results:

Figure 1 shows an example of several time frames from a typical transient MRE acquisition showing the propagation of the cardiac-induced wave and a displacement-time graph from the profile indicated in red showing the wave progression over time. Figure 2 shows the mean stiffness values for conventional harmonic and transient MRE for each of the subjects. No patients had significant fibrosis based on the harmonic MRE results.

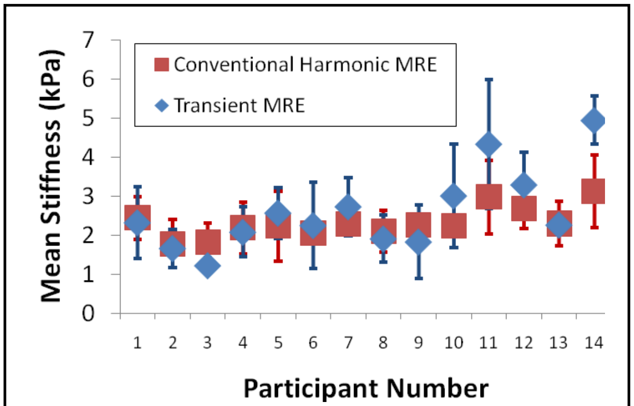

Fig 2. *Mean liver stiffness measured using harmonic MRE (red) and transient MRE (blue). Error bars represent one standard deviation from the mean for each measurement.*

Discussion:

This study demonstrates a novel method for quantifying liver stiffness that utilizes the intrinsic transient shear waves created by adjacent cardiac motion. This mechanism is reproducible between subjects and can give quantitative stiffness values that approximate those obtained with harmonic MRE. Limitations include problems created by complex multidirectional wave fronts produced by the cardiac motion, low signal-to-noise ratio depending on the image orientation and ASSET acceleration, and an assumption of uniform/repeatable cardiac impulses with each heart beat. However, intrinsic transient MR elastography may allow for the eventual screening and monitoring of patients with liver disease using standard MRI equipment.

References:

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