High Speed MR Elastography Using SEA Imaging

J. C. Bosshard[1], N. Yallapragada[1], M. P. McDougall[2], and S. M. Wright[1,2]

[1]Electrical and Computer Engineering, Texas A&M University, College Station, TX, United States, [2]Biomedical Engineering, Texas A&M University, College Station, TX, United States

Introduction:

Magnetic resonance elastography (MRE) offers the ability to obtain stiffness information about tissues in a non-invasive manner, providing information comparable to what a physician learns from palpation [1,2]. While this can be accomplished at high frame rates using ultrasound, both the ability of MRI to access areas with no acoustic window and its spatial resolution are superior [3]. Elastograms are obtained either by applying a mechanical transient or by introducing more periods of harmonic vibration into tissue [3]. For harmonic and steady state MRE, a single image with phase encoding stepped in synchronization with the applied harmonic vibration enables the propagating or standing acoustic wave to be visualized. However, there is increasing interest in visualizing transient effects. When applying a mechanical transient, many temporal offsets are required to capture the propagation of vibration in the tissue, resulting in long acquisition times as each "frame" in the elastogram movie requires the acquisition of a complete image. This abstract shows that by eliminating phase encoding, single echo acquisition (SEA) imaging [4] can greatly facilitate MRE in certain cases where the imaging region is parallel to the array. Using this technique, we demonstrate movies of transient and harmonic motion in gel phantoms containing two different concentrations of agarose gel and estimate the shear modulus of the gel in each region.

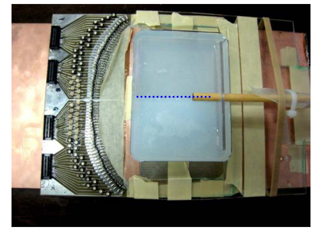

Figure 1. Phantom and 64 channel array.

Methods:

A phantom measuring 10.3 by 7.5 cm was constructed with two gels side by side, one with twice as much agarose as the other (Figure 1). The gels were in direct contact, providing a continuous phantom with two different levels of stiffness. Vibrations were created in the phantom using a solenoid placed in the B_0 field with its axis in the x-direction. When supplied with an alternating current, the solenoid vibrates, creating x-directed shear waves into the gel via a wooden rod and vibrating plate. A single period of a 200 Hz sine wave was supplied to the solenoid by a National Instruments PCI-6713 analog output card and standard audio amplifier. The output card was controlled by a MATLAB script and triggered by an output from the MRI console which activates the vibrator after a programmed delay. The delay was initially 100 ms and was decreased by 138.8 µs after acquisition of each SEA image, corresponding to 10 degrees of the 200 Hz vibration. This allowed the vibration to be imaged as it propagated through the gel. A standard spin echo sequence was modified to include an x-directed 200 Hz bipolar sinusoidal motion sensitization gradient and the phase encoding gradient was made static to provide phase compensation, necessary for SEA imaging. Each echo is received by a 64 channel array and receiver system, designed in-house [4]. As the imaging slice is parallel to the array and the coil patterns are highly localized, the 1D FFT of each channel represents the profile of the gel above each coil. These profiles are combined to form an entire image per echo. The corresponding phase image was subtracted from a reference phase image, showing the phase encoded by the applied vibration. A non-vibrating piece of gel was placed beside the phantom for purposes of normalization of any gross phase variations due to the system and the overall vibration of the phantom. Shear stiffness values were calculated using $\mu = c^2\rho$, where µ is the shear stiffness, c is the velocity of propagation, and ρ is the density [3].

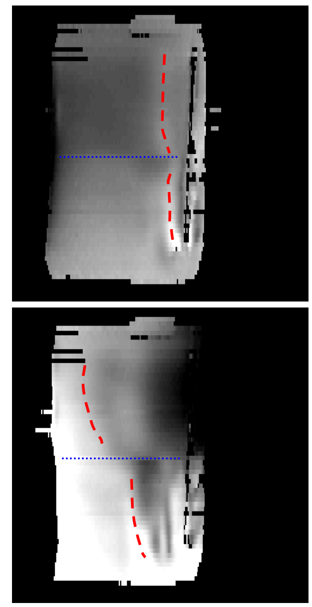

Figure 2. Two SEA elastography phase subtraction images from a set of 720, the top obtained 8.3 ms after the vibration pulse was applied at the right, the bottom obtained 9.7 ms later. The gel in the upper half of the phantom contains twice the agarose as the gel in the lower half. Results are in agreement with fully encoded volume coil images.

Results and Discussion:

Two sets of 720 images were obtained using SEA to capture the emergence and propagation of both mechanical transient and harmonic transverse shear waves in the agarose gel phantom. The movie clearly depicts the vibration of the excitation device and the gross motion of the phantom in addition to the shear wave of interest. Also, because the applied vibration was not purely in the x-direction, longitudinal waves are also seen. Two frames of transient elastography are shown in Figure 2. As expected, the shear wave propagates faster in the stiffer gel in the upper half of the phantom than in the softer gel in the lower half of the phantom. In the stiffer gel, the wave moves 3.7 cm in 9.7 ms, giving a velocity of 3.8 m/s. In the softer gel, the velocity is 2.4 m/s. This corresponds to wavelengths of 1.9 and 1.2 cm in the stiffer and softer gels, respectively. These wavelength values are in agreement with those measured in the harmonic frame shown in Figure 3. Taking the density of the gel equal to water, the calculated shear stiffness of the stiff and soft gels are 14.4 and 5.8 kPa, respectively, in the range of results reported by others [3].

We have demonstrated that SEA imaging can be used to construct elastography animations at a rate of a single frame per echo, enabling the rapid acquisition of transient events. Though the transient still requires repetition, it reduces the number of excitations dramatically. This could be important in cases where material fatigue or other mechanisms make repetition difficult.

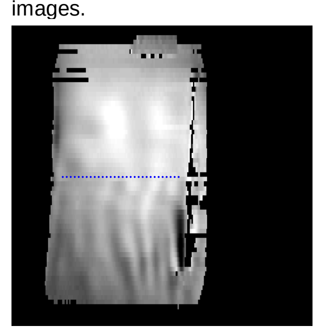

Figure 3. SEA image of a harmonic wave after 34 ms of applied vibration.

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