Highly Accelerated MR Elastography

John C. Bosshard[1] and Steven M. Wright[1]
[1]*Electrical & Computer Engineering, Texas A&M University, College Station, TX, United States*

Introduction:

Highly parallel planar receive arrays allow both accelerated wide field of view magnetic resonance microscopy [1] and single echo acquisition (SEA) [2] imaging in regions close to the array surface. The field of view is extended by employing a biplanar or "sandwich" array configuration with an additional non-linear gradient coil to simultaneously provide opposite compensation for RF coil phase at the bottom and top regions of a sample, necessary for SEA imaging. By changing the imaging parameters and by selectively employing the non-linear gradient coil, a single imaging probe is capable of operating over a range of spatio-temporal regimes. This paper shows initial results and discusses potential uses of this probe in magnetic resonance elastography (MRE) [3], which can require either high resolution or high speed imaging depending on the application. Microscopic MRE (μMRE) [4] may benefit from high resolution at the extended field of view at offered by this system. Possible applications for SEA MRE include tissue samples under variable load conditions [5] and imaging during thermal ablation [6].

Methods:

An MR elastography driving unit consisting of a triggered function generator, an audio amplifier, a speaker, and a plastic tube provided 40 cycles of a 400 Hz longitudinal mechanical vibration to a 6.4 x 6.4 x 1 cm agarose gel phantom. A soft gel occlusion consisting of half agarose concentration was embedded in the phantom to provide some variation in wave field. A single period 400 Hz sinusoidal motion sensitizing gradient pulse was added to a spin echo sequence with the delay between the gradient and the applied vibration stepped in 0.125 ms increments. Two hundred forty frames depicting the emerging mechanical vibration were captured using a 64 channel receive array in a "sandwich" configuration as shown in Figure 1. The 90º pulse simultaneously excited slices near the bottom and top array planes. To demonstrate high resolution MRE, wide field of view microscopy was performed using 512 points and 64 phase encodes for a 156 x 125 μm resolution over each array element. The phase images of the elements minus a reference phase image obtained without motion were computed, after which rectangular windows centered on the position of each element within the full field of view were applied and the individual coil phase images summed to obtain a 410 x 410 image over the 6.4 x 6.4 cm field of view of the array, shown in Figure 2. The distance of this phantom from the top array was too great to yield sufficient SNR at this resolution. When displayed as an animation, wave motion in both the occlusion and the background gel is apparent. A TR of 1.5 s was employed to allow the mechanical vibrations to cease and to give the acquisition system time to demodulate and store the data, resulting in a total acquisition time of 6.4 hours. A comparable set of images acquired at two slices using only the volume coil would require 128 hours, plus additional time for averaging.

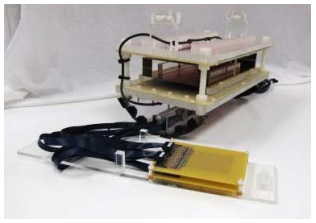

Figure 1. Insertable 64 element planar pair receive array in a "sandwich" configuration shown with non-linear gradient coil and integrated RF volume excitation coil.

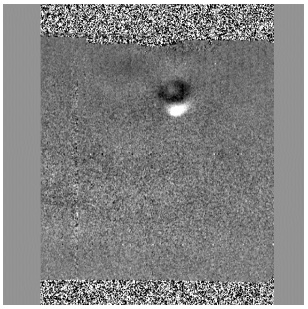

Figure 2. μMRE wave image from a set of 240 acquired from the bottom slice of an agarose gel phantom at 156 x 125 μm resolution over a 6.4 x 6.4 cm FOV. Animations show complex wave behavior at the soft gel occlusion.

To demonstrate ultra-fast MRE, SEA imaging was also performed, allowing capture of each temporal offset of the emerging vibration at the top and bottom of the sample in a single echo, shown in Figure 3. This required use of a non-linear gradient coil, shown in Figure 1, to simultaneously provide opposite compensation for RF coil phase at the top and bottom arrays. Two hundred fifty-six frequency encode points were acquired along the long axis of each array element, with spatial localization in the other direction provided by the array only. After correction by reference phase images acquired with motion disabled, SEA MRE wave images were constructed by stacking the images from each array element. As greater SNR is available at this resolution, the selected slices were further from the array surfaces where vibration amplitudes were greater. A TR of 1 s was employed, allowing capture of 240 frames in 4 minutes. The gel in the agarose phantom receded somewhat in the top plane, causing a signal void in the area near the soft gel occlusion. While this acquisition required repetition of the applied vibration at each temporal offset, another protocol was tested in which four gradient recalled echoes were acquired at 6 ms intervals following a single RF excitation and applied mechanical vibration with each echo yielding a SEA image. A motion sensitizing gradient pulse was inserted prior to each readout pulse to sensitize each image to the single mechanical wave at four time points as it propagated across the phantom. While this method will require further refinement and the images (not shown) will require additional processing, an elastic wave was seen advancing across the phantom.

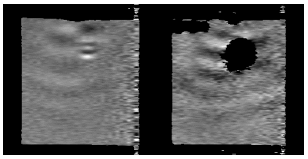

Figure 3. SEA MRE wave images from a set of 240, each echo simultaneously acquiring images at the bottom (left) and top (right) slices of the phantom, with the entire set acquired in 4 minutes. The non-linear gradient was employed for RF phase compensation.

Results and Discussion:

The described imaging method capable of both high spatial and high temporal resolution regimes may have utility in MR elastography, in which high resolution is demanded by μMRE and in which other applications such as non-repeatable or destructive testing may benefit from elimination of phase encoding. Also important to extending the field of view of μMRE are methods of improving the penetration of the rapidly attenuating high frequency shear waves needed for reconstruction of high resolution elastograms.

[1] M. P. McDougall and S. M. Wright, *Magn. Reson. Med.*, vol. 68, pp. 850-856, 2012.
[2] S. M. Wright and M. P. McDougall, *NMR Biomed.*, vol. 22, pp. 982-993, 2009.
[3] R. Muthupillai, *et al.*, *Science*, vol. 269, pp. 1854-1857, 1995.
[4] S. F. Othman, *et al.*, *Magn. Reson. Med.*, vol. 54, pp. 605-615, 2005.
[5] M. A. Dresner, *et al.*, *J. Magn. Reson. Imaging*, vol. 13, pp. 269-276, 2001.
[6] T. Wu, *et al.*, *Magn. Reson. Med.*, vol. 45, pp. 80-87, 2001.

The authors gratefully acknowledge the support from the National Institutes of Health (1R21EB007649).