Interleaved Spiral Sequence for MR Elastography of the Brain

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Introduction

Magnetic Resonance Elastography (MRE) is a promising technique to noninvasively probe the mechanical properties of tissue [1]. MRE has been applied successfully to a number of different tissues [2], and has recently been used to investigate the stiffness of human brain tissue *in vivo* [3,4,5]. One of the major considerations in brain MRE is subject comfort, as shaking of the head for long scan times can become intolerant to the subject. As elasticity inversion techniques become more sophisticated, and more motion encoding is necessary [6,7], the required scan time may become prohibitively long. In this work, we propose an MRE sequence with interleaved spiral readout gradients for brain experiments. This sequence allows for easy tradeoff of spatial resolution, scan time, and sensitivity to field inhomogeneity and T2*-induced blurring. With this sequence, significantly shorter scan times can be achieved relative to typical MRE sequences while maintaining the high-resolution not possible with other fast sequences, such as EPI.

Methods

Sequence: MRE was performed using a novel spin-echo sequence with spiral readout gradients. The sequence utilized twenty-four interleaves to cover *k*-space, resulting in a FOV of 240 mm with a 128x128 matrix size. MRE encoding gradients were inserted with opposite polarity on either side of the refocusing pulse with a spacing equal to one period of mechanical excitation, as can be seen in Figure 1. The external mechanical actuation is triggered before each phase offset and the repetition time of the sequence is set to a multiple of the excitation period [6].

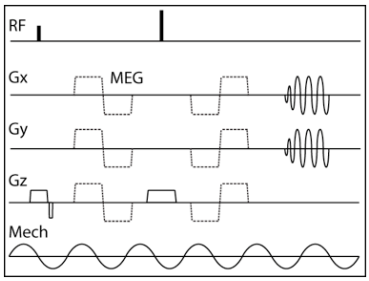

Figure 1. Schematic of implemented MRE sequence

Experiments: The new MRE sequence was used on a cylindrical gel phantom with a 2 cm-diameter stiffer center core, as well as on the brain of a subject. The phantom and brain were actuated via an electromagnetic shaker attached to a cradle by a long rod, and resulted in axial and rocking motions, respectively. A driving frequency of 50 Hz was used for the brain (100 Hz for the phantom), with TR/TE = 1000/65 ms (500/35 ms for the phantom). Eight phase offsets were acquired with a single direction of sensitization, resulting in a total acquisition time of 6:24 for the brain. This should be compared to an equivalent spin-echo with a cartesian read-out, which would result in a total time of 34:08, representing an overall 5.33 times increase in speed. All MRE data was subtracted, unwrapped, bandpass filtered, directionally filtered [7] and processed using an LFE algorithm.

Results & Discussion

The reconstructed stiffness from the phantom experiment can be seen in Figure 2. The stiff gel center can be distinguished from the surrounding softer material. While the interleaved spiral readout sequence results in decreased SNR compared to cartesian high-resolution acquisitions (owing to shorter total acquisition time), it has been demonstrated to accurately detect and quantify small, stiffer structures. An example wave image from the brain measurement is shown in Figure 3, and the corresponding stiffness map is presented in Figure 4. The grey and white matter at the periphery of the brain is stiffer than the tissue in the center, which can be seen when the stiffness is overlaid on a T2-weighted image of the brain in Figure 5. Stiffness values for grey and white matter were found to be 2.2 ± 0.7 kPa and 1.8 ± 0.7 kPa, respectively. These values are comparable to previously published *in vivo* brain MRE studies [4,5], and demonstrate the ability of the spiral MRE acquisition to give reliable estimates of the stiffness of brain tissue.

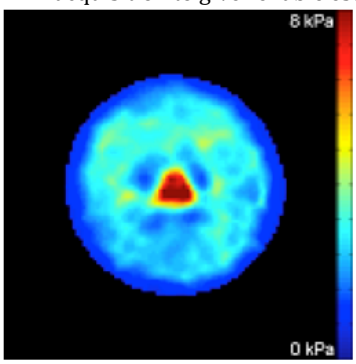

Figure 2. Stiffness map from phantom experiment

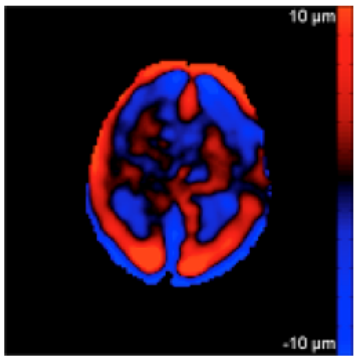

Figure 3. Example MRE wave image from brain experiment

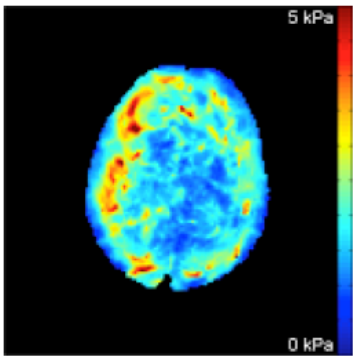

Figure 4. Corresponding stiffness map of the brain

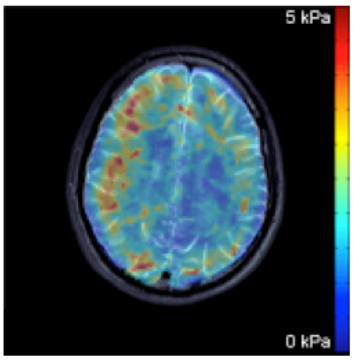

Figure 5. Stiffness map overlaid on anatomical T2 image

Conclusions

In order to increase the comfort for the patient during brain MRE studies, scanning time must be kept short, especially in the face of more complicated and intensive motion encoding schemes. In this work, and for the first time to our knowledge, a novel MRE sequence has been implemented that utilizes spiral readout gradients to reduce scan time while maintaining high-resolution. Experiments on both a phantom and brain demonstrated the ability of the sequence to obtain accurate results with a time reduction factor of 5 versus spin echo.

References: [1] Muthupillai, R., et al., *Science*, 1995. 269(5232): p. 1854-1857; **[2]** Mariappan, Y.K., et al., *Clin Anat*, 2010. 23(5): p. 497-511; **[3]** Kruse, S.A., et al., *NeuroImage*, 2008. 39(1): p. 231-237; **[4]** Sack, I., et al., *NMR Biomed*, 2008. 21(3): p. 265-271; **[5]** Green, M.A., et al., *NMR Biomed*, 2008. 21(7): p. 755-764; **[6]** Sinkus, R., et al., *Phys Med Biol*, 2000. 45(6): p. 1649-1664; **[7]** Weaver, J.B., et al., *Med Phys*, 2001. 28(8): p. 1620-1628; **[8]** Manduca, A., et al., *Med Image Anal*, 2003. 7(4): p. 465-473.