MICRO-MAGNETIC RESONANCE ELASTOGRAPHY (µMRE)

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INTRODUCTION:

MR-Elastography (MRE) is a phase contrast technique that allows the visualization of the spatial and temporal pattern of strains associated with the propagation of shear and compression waves within viscoelastic objects [1]. Scaling MRE to µMRE must overcome all the obstacles associated with scaling MRI to MR-Microscopy [2] (e.g., reduced SNR, increased susceptibility artifacts) as well as issues associated with the miniaturization of the mechanical actuator, integrating it with the RF coil, and efficiently transmitting the mechanical waves to the sample in a confined space with minimal mechanical loss and electromagnetic coupling artifacts. Reduced signal strength associated with smaller sample size is overcome by the use of a stronger magnet. However a larger static magnetic field also increases the problem of susceptibility artifacts since they are linearly dependent on the strength of the magnetic field. Improved spatial resolution is obtained by the use of stronger magnetic field gradients. In addition, in order to visualize the shear wave in the available FOV, higher frequency of mechanical excitation is required. The disadvantages of using a higher mechanical frequency include higher signal attenuation, gradient switching limitations, and the difficulty of generating high amplitude mechanical waves. In this paper, a miniature mechanical actuator with localized excitation is integrated with the RF coil to visualize shear waves in 3D gel phantom in order to validate our method.

METHOD

Localized shear waves were introduced into agar gel phantoms of different concentrations (0.5%-2%) by a piezo electric actuator (Piezo system, MA) driven at its structural resonance frequency. The actuator was placed inside a 1 cm test tube and mechanically coupled to the gel via a thin needle (0.5 mm) to reduce susceptibility artifact. Laser Doppler Vibrometry was used to measure the frequency response of the mechanical actuator, and its structural frequency was found to be 570 Hz. All experiments were conducted at 500 MHz in a 56-mm vertical bore 11.74 T magnet (Oxford Instruments, Oxford, UK) using a Bruker DRX 500 MHz Avance spectrometer (Bruker Instruments, Billerica, MA). The samples and the imaging coils (1 cm saddle coil and 2 mm solenoid coil) were inserted in the Bruker Micro5 microimaging probe with a triple axes gradients (200 Gauss/cm maximum). The raw data were acquired using ParaVision imaging software (PV2.1), reconstructed and analyzed using MATLAB. A modified gradient echo pulse sequence with variable number of bipolar gradients was implemented [1]. Fresh frog oocyte and bovine articular cartilage fixed in agar gel were also tested to validate our method.

RESULTS

Figure 1 shows shear wave images of a gel phantom with 8 and 16 bipolar gradients. The shear modulus can be extracted by fitting a line profile to a damped sinusoidal function [1], Figure 1c.

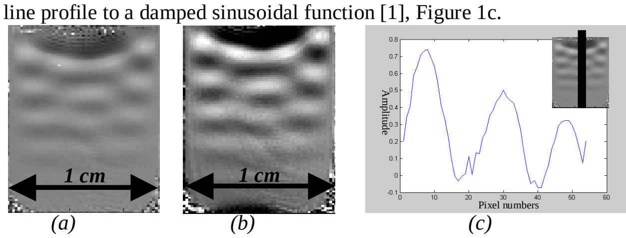

Figure 1: Shear waves of gel phantom (0.5%) using: (a) 8 bipolar (b) 16 bipolar (c) a line profile along the phantom showing a damped sinusoid. TR = 200 ms, slice thickness = 2 mm, in-plane resolution 140 x 140 µm.

Figure 2 shows shear waves at different locations leading to the construction of the 3D image. As can be seen from the figure, more phase is accumulated as moving towards the mechanical excitation source leading to phase wrapping. Currently we are investigating small biological tissues including articular cartilage and frog oocyte using µMRE. Articular cartilage is a heterogeneous tissue and controversial to image [3]. Figure 3 shows shear wave propagating through an articular cartilage. Phase wrapping can be seen before the waves penetrate the cartilage, and weaker waves can be seen after penetrating the cartilage to the gel again.

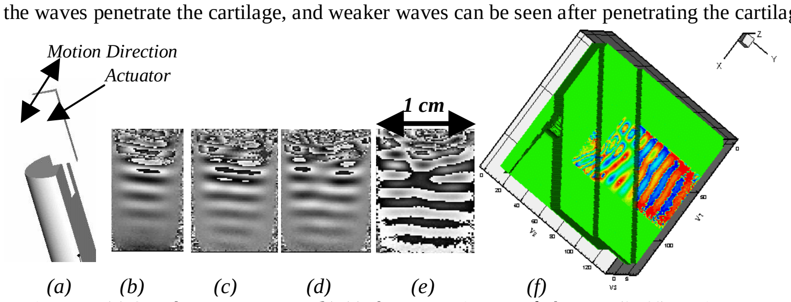

Figure 2: (a) Sample-actuator setup, (b)-(e) shear wave images of phantom (0.5%) moving from the edge of the coil all the way near the actuator tip, (f) reconstructed 3D image. TR = 200 ms, slice thickness = 0.5 mm, slice thickness = 0.5 mm, in-plane resolution 125 x 125 µm.

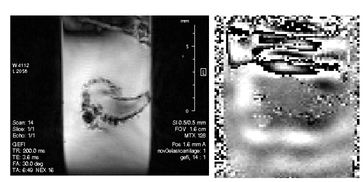

Figure 3: Magnitude and shear wave images of articular cartilage slice thickness = 0.5 mm, in-plane resolution 125 x 125 µm.

CONCLUSION AND FUTURE WORK

The experiments demonstrated that it is feasible to extend MRE to microimaging resolution. µMRE has the potential of visualizing biomechanical properties of small biological samples like muscle fiber, articular cartilage, and oocyte all the way to cellular level.

REFERENCES

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