A novel single-sided imaging device for MR elastography

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Introduction:

While conventional MRI scanners rely on large magnets, extremely homogeneous and increasingly strong polarizing fields, recent years have also seen the development of small, single-sided NMR systems suitable for a variety of applications in the realm of biomedicine, such as tendon and skin [1]. These novel imaging systems are typified by their small size, single-sided nature and nonuniform polarizing fields. Although they face many technical challenges, these systems benefit from their low cost and imaging versatility, exhibiting the potential for high through-plane resolution, flexible detector orientation, and relative immunity to certain imaging artifacts, like chemical shift and susceptibility artifacts. Another emerging field of research is non-invasive imaging of material properties of tissues and biomaterials using techniques like MR elastography, a highly-sensitive phase-contrast based technique for imaging cyclical motion on a microscopic scale [2]. Most notably, MRE has been used to accurately grade different stages of liver fibrosis non-invasively, obviating the need for biopsy, but the technique has been applied to numerous other tissues and organs [3,4]. The goal of this work was to develop a low cost single sided NMR device, capable of MR elastography, which would be potentially useful for applications such as evaluation of normal and pathological skin, benchtop pathology, and evaluating engineered tissue constructs.

Materials & Methods:

System Design: The magnet designed for this work consists of a permanent, longitudinally-magnetized cylinder of NdFeB (10 cm diameter, 15 cm length). Field-shaping elements consisting of a NdFeB ring and a low-carbon steel disc were positioned on the end of the cylinder. These elements were optimized to produce a suitable region of interest (ROI) at the end of the magnet assembly that is approximately 1 cm^3 in volume with an average field strength of 0.28 T, a static, linear gradient of 1 T/m in the z-direction, and relative homogeneity in the radial direction. The static gradient in the z-direction allows for slice-selection and readout. Imaging coils for the device were fabricated separately on two-sided PCB substrate and positioned inside the magnetic ring. The RF coil, an eight-turn open-Helmoholtz design, is mounted flush with the top of the magnet, and produces B1 field that is orthogonal to the longitudinal polarizing field. The x and y-gradient coils are similar in design, and the z-gradient is a simple spiral. Coil cabling is passed through gaps beneath the magnetic ring. The entire magnet assembly weighs approximately 12 kg (Figure 1). A custom built, PC-based spectrometer was used to generate waveforms, control data acquisition and reconstruct image data.

Experimental Methods: A conventional spin-echo-based MRE sequence was used to image the cyclic motion in a cylindrical silicon-based phantom (1 cm diameter and length) using the single-sided device. Slice selection and readout were both performed in the z-direction, resulting in a 1D radial projection that was spatially resolved along the length of the phantom. Details of the pulse sequence are as follows: SE, 11.8 MHz center frequency, 100 kHz pulse bandwidth (2.2 mm slice), TR/TE 500/3.5 ms, 512 NEX, 16 Nz (140 μm resolution). A piezoelectric bending element was used to apply one period of cyclic motion to the phantom at 600 Hz, which was sensitized in the x-direction by a single motion-encoding gradient, and imaged over 4 equal phase offsets.

Results & Discussion:

The 1D magnitude profile is shown in Figure 2, illustrating the excitation slice. The 1st harmonic of the four phase offsets are shown in Figure 3, and a temporal profile a single pixel is shown in Figure 4 to demonstrate the periodic nature of the encoded motion.

Conclusions:

In conclusion, these results demonstrate that it is possible to perform motion-encoding in a grossly inhomogeneous polarizing field, suggesting that MRE is feasible with a single-sided NMR device. Future work will consist of maximizing the FOV (slice bandwidth) and the development of a higher-frequency driver to increase the number of waves per FOV to a usable number. Selective excitation and the addition of phase encoding gradients will allow 2D and 3D imaging to be performed. Suitable reconstruction algorithms will likely be needed to account for mechanical waveguide effects existing at the surfaces of the objects under investigation.

References:
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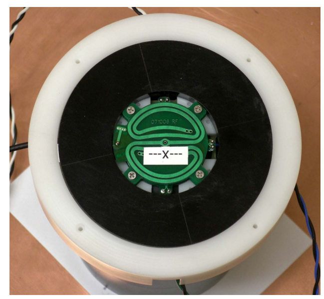
2. Muthupillai R, Science 1995; 269:1854-1857.
3. Yin M et al. Clin Gastroenterol Hepatol. 2007; 5(10):1207-1213.e2.
4. Manduca A et al. Med Imag Anal 2001; 5(4):267-54.

Figure 1



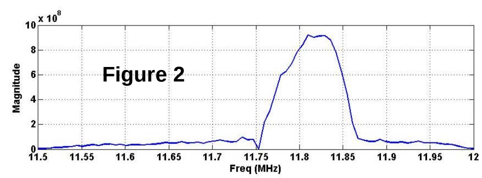


Figure 2

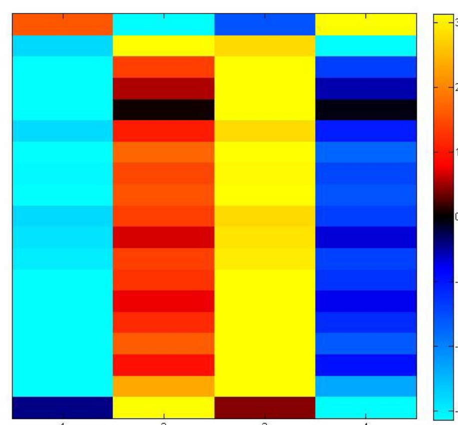


Figure 3

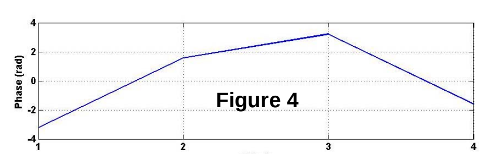


Figure 4