MRI Detection of Shear Wave Propagation: Remote Palpation with Focused Ultrasound

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INTRODUCTION

The ability to detect small motions with phase sensitive MRI has led to the development of elasticity imaging (1, 2). Current methods produce motions in tissue by external application of periodic or static displacements or rely on motions within the body. Data generated by these techniques are sensitive not only to the intrinsic tissue elasticity but also to geometric constraints.

Another approach to extract the elastic properties of tissue is to remotely apply a focused ultrasound pulse to create an internal displacement of tissue and follow the propagation of the shear wave. Since the shear wave velocity is directly proportional to the shear modulus, evaluation of elastic properties is greatly simplified. The tissue mechanical properties can be reconstructed assuming simplified boundary conditions in an infinite medium model. We present here a series of experiments which demonstrate MRI detection of remote displacement by focused ultrasound.

METHODS

An ultrasound transducer with 10 cm aperture and focal length was mounted to a rubber phantom which was either homogeneous or contained two cylindrical inclusions. Remote displacement of 20 microns was achieved by a single 555 kHz ultrasound pulse with a duration of 1.5 ms. The displacement was measured by phase sensitive MRI using a pair of opposite polarity gradient pulses with a magnitude of 6 G/cm and duration of 4 ms applied along the z direction. The gradient pulses, with a fixed separation of 18ms, were placed in the first half of a conventional spin-echo sequence with a 50 ms TE. The ultrasound pulse was initially applied just prior to the second gradient and then marched backward in the pulse sequence in 2 ms increments to measure propagation of the shear wave in the two phantoms.

To calculate phase, a reference dataset is collected and the phase difference calculated between the reference data and the data with shear wave propagation.

RESULTS

Figure 1 shows the time evolution of the shear wave induced by the focused ultrasound pulse. The left set of images are from the homogeneous phantom and the right set from the phantom with the two hardened inclusions. Propagation of the shear wave in the homogeneous phantom is cylindrically symmetric, radiating outward from the initial displacement. Propagation in the phantom with the two inclusion starts the same as the in the homogeneous phantom, but when the shear wave reaches the phantom the inclusions, it passes through much faster due to the difference in elastic modulus in the two media.

The phase change in a pixel measured by MRI is the overlap integral of the gradient waveform with the trajectory,

$$\phi = 2\pi\gamma \int \nabla_z(t) z(t) dt .$$

If we assume that the gradient waveform is square, the average z displacement is calculated as,

$$z = \frac{\phi}{2\pi\gamma\nabla_z t}$$

where the gradient waveform is replaced by the amplitude of the square gradient.

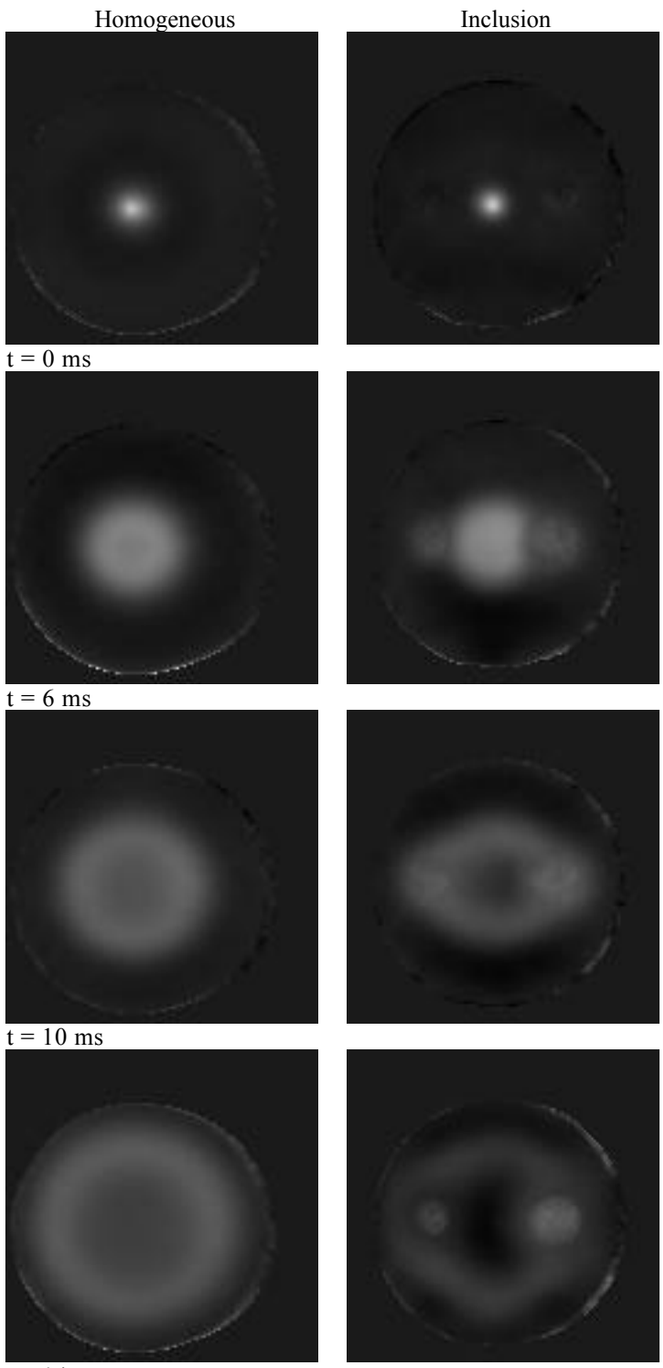


Fig. 1. Propagation of shear waves induced by remote focused ultrasound. The image is in the x-y plane and motion encoded along the z axis.

CONCLUSION

We have demonstrated focused ultrasound can generate localized, remote displacements of 20 microns and that the propagation of the shear wave can be followed phase sensitive MRI with a resolution of about 200 nm.

REFERENCES

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2. D.B. Plewes, et al. *J. Magn. Reson. Imag.* **5,** 733-738 (1995).