Mechanical Transient-Based MR Elastography

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Abstract: Magnetic Resonance Elastography (MRE) is a recently described technique that quantifies material properties by measuring cyclic displacements of propagating shear waves. We introduce the idea of using a transient impulse for mechanical excitation to avoid reflections, interference and standing waves sometimes seen in continuous wave MRE. We interrogated several phantoms using mechanical transients and developed a novel processing method to calculate shear stiffness from this data. Evaluated against continuous wave MRE techniques, the mechanical transient-based method yields comparable and promising results. Complicated geometries such as those within the head may benefit from transient based analysis.

Introduction

Magnetic Resonance Elastography (MRE) is a recently described technique that quantifies material properties by measuring cyclic displacements of propagating shear waves. We introduce the idea of using a transient impulse for mechanical excitation to avoid reflections, interference and standing waves sometimes seen in continuous wave MRE.

Methods

We used transient mechanical shear waves of various periods to interrogate agar contrast phantoms that contained both stiff and soft inclusions (Figure 1a). We performed standard gradient echo imaging on a 1.5T GE Signa whole-body imager with additional motion encoding gradients used to detect and measure the shear wave propagation. Up to 100 images of the shear wave were taken as it propagated through each of the phantoms. A single oscillating gradient pair was synchronized to and encoded the wave motion. Several transient wave images have been displayed in Figure 1 for time intervals of 3.6 msec. Standard continuous wave data sets were collected for comparison to each of the transient wave data sets.

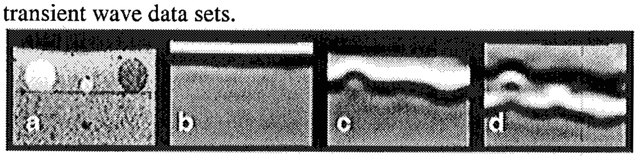


Figure 1. **a.** Gradient echo image of agar phantom with a soft inclusion (right) and two stiff inclusions (left). **b.** Wave image of transient impulse shown at 3.6 msec, **c.** 7.2 msec, and **c.** 10.8 msec.

Inversion of the continuous wave data is commonly performed using the spatial frequency information contained within the wave images. As one can see from the transient wave image, this approach is no longer applicable. We instead model our system as a linearly elastic material with assumptions of isotropy, local homogeneity, and incompressibility, reducing to the wave equation[1]. We then solve for shear stiffness in each pixel by direct local inversion of the wave equation:

$$\mu = \frac{\partial^2\Psi / \partial t^2}{\nabla^2\Psi}\rho$$

where μ is shear modulus, ρ is density (assumed 1), and Ψ is displacement.

The spatial Laplacian and 2nd temporal derivatives are discretely calculated, weighted through time by the amplitude of the displacement, and then combined. Shear modulus values are then calculated.

Results

Figure 2 shows elastograms calculated by inverting continuous wave data (a) and transient wave data (b). The shear stiffness values are scaled from 0 to 75 kPa. The continuous wave data was inverted using a Local Frequency Estimation algorithm[2].

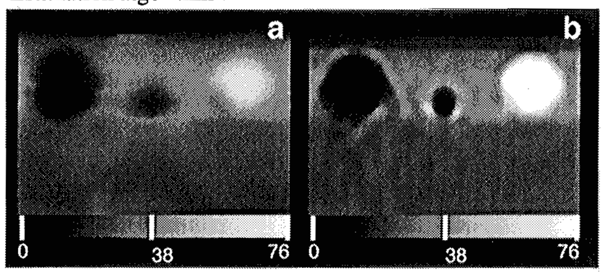
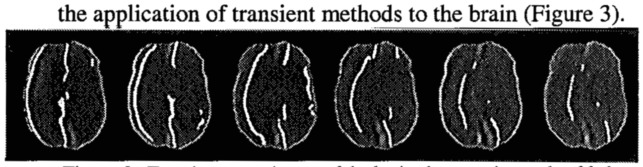


Figure 2. **a.** Inversion of continuous wave data with existing Local Frequency Estimation algorithm (0 to 76 kPa). **b.** Inversion of transient wave data with investigated method (0 to 76 kPa).

Note that both the continuous wave elastogram and the transient wave elastogram show all of the inclusions with shear stiffness values at close to known values. The transient wave results more clearly indicate the shape and size of the inclusions and more accurately calculate the shear stiffness of the stiff inclusions. In addition, the homogenous region located in the bottom half of the phantom shows very little fluctuation in stiffness for the transient case.

Discussion

Using a transient mechanical excitation, a simple inversion of the wave equation can calculate shear stiffness values comparable to continuous MRE methods. Complicated geometries such as those within the head may benefit from this type of processing to avoid difficulties caused by reflections and standing waves. We are studying the application of transient methods to the brain (Figure 3).



₃**Figure 3.** Transient wave image of the brain shown at intervals of 3.6 msec. The white lines indicate tracking of the maximum wave amplitude.

References

1. Manduca A, et al., "Magnetic Resonance Elastography: Non-Invasive Mapping of Tissue Elasticity", *Medical Image Analysis*, **5** 237-254.,2001

2. Manduca A, et al., *In: Proc. SPIE Int. Symposium Med. Imaging* **2710** 616-623, 1996.