Transient-Based MR Elastography of the Brain

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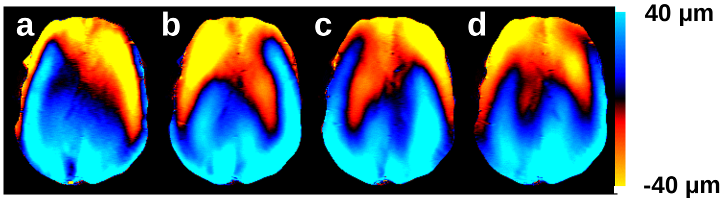
Introduction

Magnetic Resonance Elastography (MRE) is a recently described technique that quantifies material properties by measuring cyclic displacements of propagating shear waves. To date, most work in dynamic MRE has focused on the use of continuous harmonic mechanical excitation. However, mechanical transients may offer certain advantages in dynamic MRE, such as potentially simplifying the inversion process. Mechanical transients have been used to model traumatic brain injury, but there is still debate about the underlying material properties of the *in-vivo* human brain, which are often used in mathematical simulations of traumatic brain injury.[1] We introduce the idea of using a transient impulse for mechanical excitation to interrogate stiffness in the brain.

Methods

We used transient mechanical shear waves of various periods to examine the brains of healthy volunteers (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. Sixteen images of the shear wave were taken as it propagated through the head, using multiple gradients to effectively double the coverage of the mechanical impulse. The oscillating gradient pairs were synchronized to and encoded the wave motion. Several transient wave images have been displayed in Figure 1 for time intervals of 5 msec.



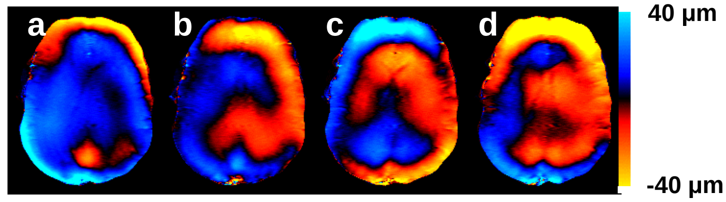


Figure 1 (left). **a.** Anterior/posterior dual sensitized wave image of transient impulse shown at 5 msec, **b.** 10 msec, **c.** 15 msec, and **d.** 20 msec.
Figure 2 (right). **a.** Right/left dual sensitized wave image of transient impulse shown at 5 msec, **b.** 10 msec, **c.** 15 msec, and **d.** 20 msec.

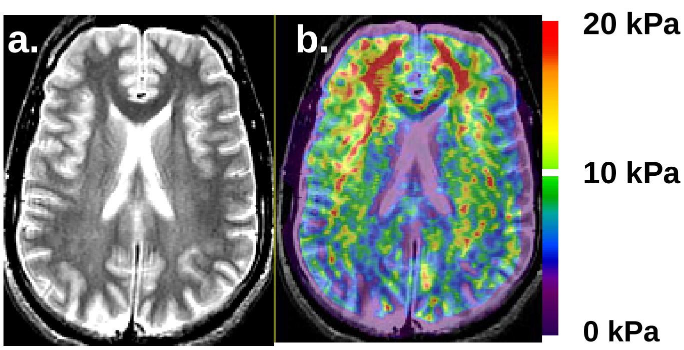
Stiffness reconstruction from continuous wave data is performed on using a Local Frequency Estimation (LFE) technique, which is based on the spatial frequency content of the wave image, or by direct inversion of the Helmholtz equation from filtered data and its spatial Laplacian.[2] However, stiffness reconstruction methods previously described from continuous wave data assume a complete wave field and are inappropriate for transient wave data, in which the wave is only present in a portion of the image. We instead model our system as a linearly elastic material with assumptions of isotropy, local homogeneity, and incompressibility, reducing to the wave equation. 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 utilizing a weighted least squares method. Shear modulus values are then calculated.[3]

Results

Figure 3 show the fast spin echo image of the brain of a volunteer (a) and the transient elastogram overlaid onto the anatomical image (b). The shear stiffness values are scaled from 0 to 20 kPa. There is a trend for the stiffer regions to follow the fiber tracts as in the anterior portion of the brain including the corpus collosum. Many of the sulci are clearly shown as well as the ventricles, which is to be expected, due to the sharp drop shear propagation.



Discussion

Using a transient mechanical excitation, the material properties of the *in-vivo* human brain may be measured. Further study in this area may prove helpful in traumatic brain injury modeling, diffuse disease analysis, and possibly complement fiber tract studies.

Figure 3. **a.** Fast spin echo image of volunteer. **b.** Elasticty map derived from inversion of transient wave data overlayed onto anatomical image (0 to 20 kPa).

References

1. McCracken PJ, et al., *MR Elastography for Studying the Biomechanics of Traumatic Brain Injury*. in *International Society for Magnetic Resonance in Medicine*. 2003. Toronto, Canada.
2. Manduca A, et al., "Magnetic Resonance Elastography: Non-Invasive Mapping of Tissue Elasticity", *Medical Image Analysis*, **5** 237-254.,2001
3. McCracken PJ, et al., *Mechanical Transient-Based MR Elastography*. in *International Society for Magnetic Resonance in Medicine*. 2002. Honolulu, Hawaii.