Progress in Continuous Harmonic Excitation MR Elastography of the Brain

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Introduction

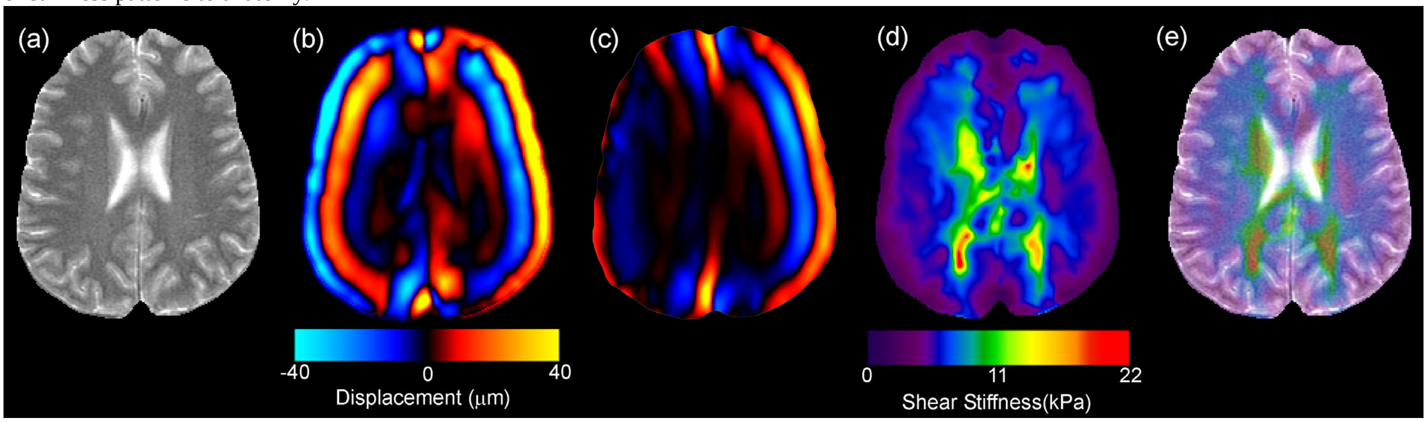
While there is no clinical precedent for "brain palpation", measurements of brain elastic properties have multiple useful applications for characterizing brain disease. Measurements of normal brain shear modulus values are necessary prerequisites for finite element analyses of brain trauma and for accurate surgical simulation. In the last four years we have made improvements to the three main components of an MR Elastography (MRE) experiment. They are: (1) a device to deliver mechanical waves to the tissue of interest, (2) a phase contrast acquisition to encode the motion, and (3) an algorithm to invert the wave motion and calculate the shear stiffness. First we developed an apparatus to better couple the wave motion to the skull. Second, a continuous drive technique was developed that greatly decreases the exam time. Third, spatio-temporal filters were applied to the data to improve shear stiffness reconstruction [1].

Methods

A thermoplastic "bite block" is custom fitted to each volunteer. The "bite block" is attached to an electromechanical driver that vibrates the head in the right-left direction. The applied global head vibration generates low amplitude shear waves that originate at meningeal surfaces. This is thought to be due to an inertial effect, with coupling between the skull and brain (across the arachnoid space) by the trabeculae of the pia mater [2]. The typical MRE pulse repetition time (TR) is 100-200 msec, and the echo time (TE) is 40-50 msec, resulting in an acquisition time of 18 seconds per offset. In each volunteer study, this sequence was repeated 8 times, resulting in a total acquisition time of 2 minutes 24 seconds. A continuous drive acquisition, where the vibration is on for the whole TR, was developed that uses a TR of 37.5 msec and a TE of 15 msec. The time for a single offset was 5.6 seconds and the time for 8 offsets was 45 seconds. Each set of wave images was processed using a set of spatio-temporal filters to decompose the complex wave fields into components propagating in orthogonal directions. Next, a spatial filtering algorithm was applied to extract the local wavelength. From there quantitative shear modulus maps were computed [3]. The maps from individual propagation directions were recombined using weighting based on the amplitude of the wave motion.

Results

The figure below shows (a) A T2-weighted FSE image for anatomical reference. (b) Image indicating shear waves propagating in the brain. Shear waves propagate from the perimeter of the brain inward and from the falx outward. (c) Wave image demonstrating right-to-left propagation, after application of a spatio-temporal filter. (d) A shear modulus map computed from 4 orthogonal spatio-temporal filters. The 'hot spots' deep inside the brain are artifacts that correspond to areas of very low signal. (e) Shear modulus map overlaid on anatomical reference to illustrate correlation of stiffness patterns to anatomy.



Discussion

The "bite block" apparatus provides an increase in wave amplitude as well as an increase in wave penetration over previously described techniques [4]. It also improved volunteer comfort. It has been shown that 2D MRE is a good approximation of the 3D wave propagation in the brain [5]. However, given the time improvement of continuous drive, 3D imaging may become more common. Spatio-temporal filters allow for use of low frequency vibrations, which provide better deep brain illumination, since the individual components are not subject to wave interference. The spatial resolution of the local frequency estimate is maintained even at low frequencies [6]. Several important, common, and interesting clinical states lend themselves to immediate investigation. Diffuse disease of the brain in its early stages is poorly imaged by conventional techniques. Because it is likely that the mechanical properties of the brain change before other changes are evident by conventional imaging, development of such a technique could be clinically beneficial. Processes such as Alzheimer's disease slowly replace brain tissue with neurofibrillary tangles, which would presumably stiffen the brain and therefore increase its elastic modulus. It has also been hypothesized that certain diseases such as hydrocephalus may be *caused* by changes in the mechanical properties of the brain.

References

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