MR Elastography for Studying the Biomechanics of Traumatic Brain Injury

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Synopsis: The mechanisms by which head trauma causes hemorrhage, cerebral contusions and diffuse axonal injury are theorized as resulting from angular acceleration and its resulting shear motion. To develop a technique for studying the underlying biomechanics of brain trauma, we implemented a method for phase contrast MR imaging of small amplitude transient shear displacements as they traverse through the brain, in vivo. This technique was successfully implemented and preliminary results suggest that it has promise as a tool for detailed analysis of injury mechanism models.

Introduction

More than 1.5 million people sustain a traumatic brain injury each year in the United States at a treatment cost of over $4 billion dollars. There has been much research into the mechanisms by which head trauma causes lesions, hemorrhage, cerebral contusions and diffuse axonal injury. This has ranged from experimental, animal and cadaver models to many advanced mathematical models and finite-element simulations. Beginning with Holbourn, there has been continual discussion concerning the effects of angular acceleration and the resulting propagating shear waves as the predominant method for injury.

Magnetic Resonance Elastography (MRE) is a recently described technique that non-invasively images propagating shear waves in vivo using specific motion sensitive gradients. To better understand the underlying biomechanics of brain trauma, we have imaged a small amplitude transient shear displacement within healthy volunteers.

Methods

We applied low amplitude mechanical shear transients of a 12.5 msec duration to heads of volunteers by means of an electromechanical driver coupled to a bite bar. This generated shear transients in the brain with a maximum displacement of 34 microns. We performed phase contrast imaging using a gradient echo sequence with a 1.5T GE Signa whole-body imager with additional motion encoding gradients to detect and measure the shear wave propagation. Up to sixteen images of the wave displacement were captured as it traversed the brain in several imaging planes. Fourier direction filtering was used to help visualize the focusing effects of the skull which indicated a motion similar to the coup/contrecoup mechanisms. As shown in Figure 1, peak displacement was tracked from the skull/brain interface to past the midline of the head using algorithms developed in MATLAB.

Results

Shear displacements resulting from a transient impulse to the head of a volunteer are measured in the axial and coronal planes. Though the maximum shear displacement at the periphery of the brain was 33.6µm, the wave pattern was clearly tracked from the coup site towards the contrecoup site in the third example. The concentric pattern of the shear motion in each case appears to move through the center of the brain, possibly indicating mechanisms for deep lesions.

Discussion

Though still under investigation, the ability of MRE to image shear displacements resulting from an impulse may be a useful tool in understanding the mechanisms of brain trauma. It will be necessary to study several rotational motions and varying impulse periods to mimic injuries often seen in automobile accidents and falls. Though the amplitude of shear displacement is much smaller than injury causing impulses, we feel that the ability to image this motion will be a useful verification tool for injury mechanism models.

References