Transient MR Elastography: Modeling Traumatic Brain Injury

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Abstract. Current theory holds that the mechanisms by which head trauma causes hemorrhage, cerebral contusions and diffuse axonal injury result from angular acceleration and its resulting shear motion. We have developed 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 studying the underlying biomechanics of brain trauma and for detailed analysis of injury mechanism models.

1 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 [1]. Since 1943, it has been theorized that angular acceleration, rotational forces, and the resulting propagating shear waves are the predominant mechanism causing diffuse axonal injury [2]. However, there are no existing methods to non-destructively test this theory on an *in vivo* human brain. The existing research has ranged from destructive experimental animal and cadaver models, to advanced mathematical models and finite-element simulations [3]. There still exists little data about how the human brain actually reacts during impact.

Magnetic Resonance Elastography is a technique that non-invasively measures displacements from propagating shear waves [5]. This technique typically uses applied harmonic motion and has been used to study breast, prostate and skeletal muscle *in vivo*. More recently, the idea of using a mechanical transient impulse as the excitation for MR elastography was introduced [6]. Using transient elastography, the goals of this work were to measure *in vivo* brain displacements resulting from a small amplitude impact, determine the displacement pattern or path of the particles during and immediately after impact, and calculate the resulting shear strains within the brain.

2 Methods and Results

All experiments were run on a 1.5 T GE Signa MRI scanner (GE Medical Systems, Milwaukee, WI). We applied a low amplitude rotational mechanical shear transient of 5 msec duration to the heads of volunteers by means of an electromechanical driver coupled to a bite bar. This generated shear transients in the brain with a maximum

C. Barillot, D.R. Haynor, and P. Hellier (Eds.): MICCAI 2004, LNCS 3217, pp. 1081–1082, 2004.

displacement of approximately 40 microns. We performed phase contrast imaging using a gradient echo sequence with additional motion encoding gradients to detect and measure the shear wave propagation. The experiment measured displacements every 4 msec for a 60 msec time period at MR pixel resolution (~1 mm). Measurements of 1-2 micron displacements are readily achievable, and the technique can in principle measure all three components of displacement in 3D space over time. From the measured displacements, the strain tensor can be calculated, and from it the principal strains and the maximum shear strain and maximum shear angle at each point in space and time can be derived. The maximum shear strain is a quantity of interest in the literature that is hypothesized to indicate possible regions of injury.

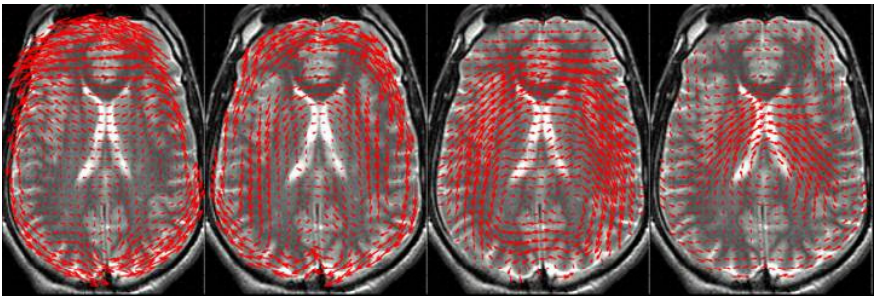

Fig. 1. Measured 2D displacement field at 4 points in time after initial counter-clockwise rotation (left) and clockwise restoring rotation (second image) mapped onto an anatomical image. The largest arrows represent approximately 40 micron displacements.

Future work includes (1) the validation of transient MR measurements of displacement in phantoms in which the displacement can be simultaneously measured with other techniques such as laser vibrometry, (2) the use of such transient data to refine and test existing finite element and biomechanical models of the brain, and (3) the exploration of what quantities are most predictive of actual location and severity of brain injury. The results suggest that it may be possible to use transient wave imaging to directly study the biomechanics of head trauma using *in vivo* models.

References

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