High-Resolution MR Elastography of the Brain in a Clinical Setting

Our group seeks to exploit the inherent mechanical contrast in diseased tissue for diagnosing neurological conditions. This is achieved using an imaging method called magnetic resonance elastography (MRE), which allows for noninvasive characterization of brain tissue mechanics. However, obtaining accurate measures of tissue properties requires advanced imaging procedures and inversion algorithms and thus correspondingly significant computational power. We use the Blue Waters system to process the MRE images and generate viscoelastic property maps for applications in neurology, neurosurgery, and neuroscience in partnership with the Carle Foundation Hospital and the Biomedical Imaging Center at the University of Illinois’ Beckman Institute. Here, we highlight clinical research results obtained using Blue Waters that significantly reduced computational time. In particular, we discuss the use of MRE in the pre-surgical evaluation of intracranial tumors and the hippocampus in temporal lobe epilepsy.

Methods & Results

All scans used a 3D multistab, multishot MRE sequence [3] for whole-brain harmonic shear wave imaging on a Siemens 3T Trio scanner. This data is the input to a finite element-based shear wave inversion algorithm to estimate viscoelastic mechanical properties, which is termed nonlinear inversion (NLI) [4]. The NLI algorithm divides the object of interest into overlapping subzones and performs an interleaved series of local subzone property updates executed in parallel and global rezone operations in order to achieve convergence on the solution. This code is executed on Blue Waters, taking advantage of the massive parallelization available for updating all subzones simultaneously. A typical problem uses 300 subzones, each assigned to its own processor, and the memory-intensive finite-element operations require 1 GB of memory per core. Depending on the exact imaging and inversion parameters, complete computations for each dataset require between 20 and 100 node hours.

Our initial results on clinical populations have been very promising. We have investigated patients with different types of intracranial tumors in order to characterize the mechanical properties of the lesions prior to surgery. Knowing the stiffness of tumors allows surgeons to appropriately plan their surgery based on how difficult they expect the resection to be, ultimately making the procedures safer for patients. Figure 1 shows the stiffness map of a patient with a meningioma on the falx (the fold of dura mater that descends in the fissure between the brain’s two hemispheres). This tumor has a maximum stiffness of approximately 8.3 kPa—nearly three times that of normal brain tissue—and would require an extensive surgical resection procedure that could be appropriately and safely planned.

We have also explored using MRE to identify the presence of a specific form of temporal lobe epilepsy termed mesial temporal sclerosis (MTS). This condition is marked by degeneration of the hippocampus, which serves as the epileptogenic source, and we hypothesize that this results in a detectable change in the mechanical properties of the tissue. The most effective treatment for MTS is resection of the hippocampus, which can eliminate or reduce seizure activity and significantly improve length and quality of life for treated patients. However, this surgery is often not performed or is severely delayed due to the difficulty in confirming MTS diagnosis with standard imaging techniques. Our initial results suggest that the mechanical contrast observed with MRE may be a more sensitive marker for the presence and lateralization of MTS than other imaging techniques (Figure 2).

The development of reliable methods for the pre-surgical evaluation of brain tissue through mechanics represents a potentially significant advance for clinical practice. As evidenced by the results presented here, allowing neurologists and neurosurgeons access to viscoelastic property maps in an acceptable timeframe. As MRE becomes more widely accepted by physicians looking to use the inherently sensitive mechanical contrast in pathological tissue, Blue Waters will allow for images to be generated for radiological interpretation in minutes rather than days. Ultimately, we aim to develop a pipeline through a direct connection between the MRI scanner and Blue Waters to seamlessly integrate MRE with NLI in the clinical imaging workflow.

Executive Summary

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