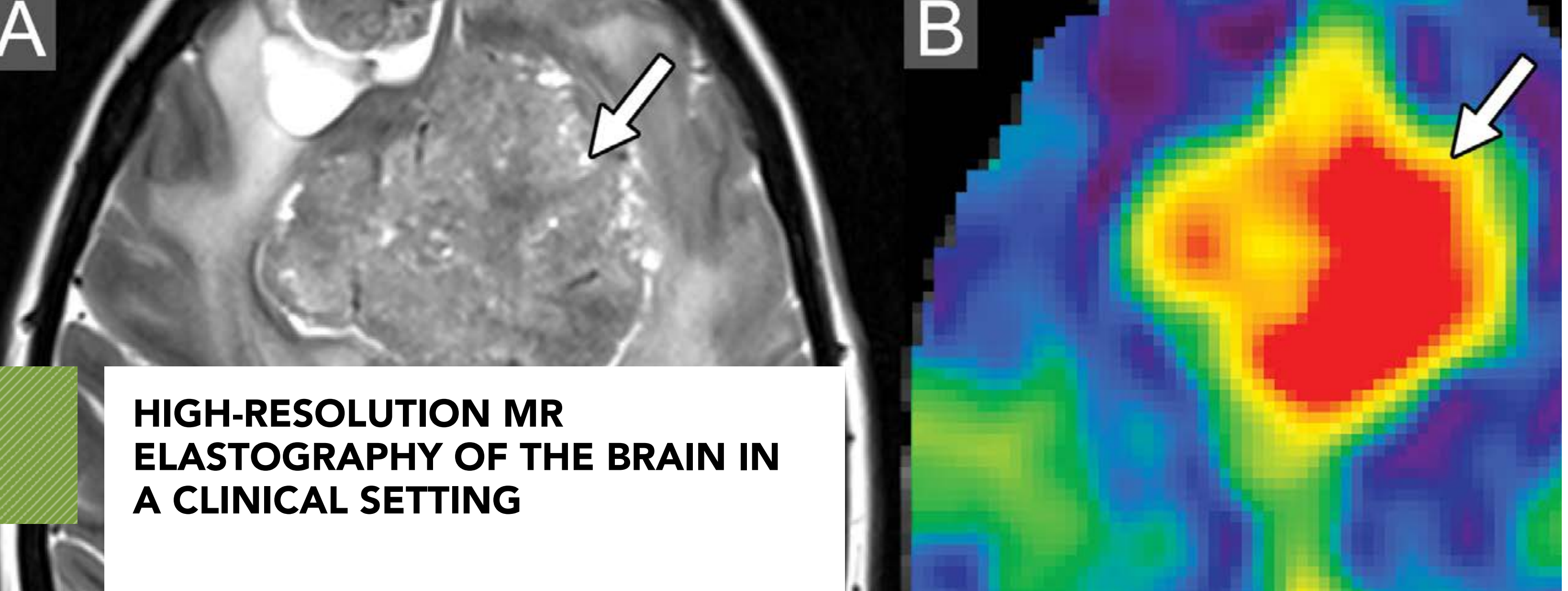

HIGH-RESOLUTION MR ELASTOGRAPHY OF THE BRAIN IN A CLINICAL SETTING

Allocation: Illinois/20 Knh
PI: Curtis L. Johnson[1]
Collaborators: Graham R. Huesmann[1,2], William C. Olivero[1,2], Bradley P. Sutton[1], Hillary Schwarb[1], Matthew DJ McGarry[3], Aaron T. Anderson[1]

[1]University of Illinois at Urbana-Champaign
[2]Carle Foundation Hospital
[3]Dartmouth College

FIGURE 1 (BACKGROUND): Imaging of a meningioma located on the falx in a 43-year-old patient. (A) T_2-weighted structural MRI with arrow highlighting location of the tumor, and (B) viscoelastic shear stiffness map obtained using high-resolution MRE demonstrating the very high stiffness of the tumor.

EXECUTIVE SUMMARY:

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 in using brain tissue mechanics for the pre-surgical evaluation of intracranial tumors and the hippocampus in temporal lobe epilepsy.

INTRODUCTION

Medical diagnostics have a long history of using the mechanical properties of tissues to identify the presence of pathology through manual palpation. Pathology can result in tissue stiffness and viscosity changes up to an order of magnitude relative to healthy tissue, thus making tissue mechanical properties potentially very sensitive markers of tissue health if they can be noninvasively measured. Magnetic resonance elastography (MRE; [1]) is a technique capable of probing tissue viscoelasticity through the imaging of nondestructive shear waves and the solution of an inverse problem to determine the underlying material properties from these waves. We have developed MRE methodology that allows for brain tissue mechanics to be investigated at a high resolution—revealing neuroanatomical features previously unseen [2]—and that can potentially result in powerful clinical techniques.

The challenge in performing high-resolution MRE scans in a clinical setting is the significant computational power needed to generate the viscoelastic property maps. In order to fit such a technique in the radiological workflow, results need to be generated in minutes rather than days. Here we present clinical research results obtained using Blue Waters that significantly reduced computation 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 multislab, 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 rezoning 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 requires 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 can greatly improve surgical treatment plans for a host of neurological conditions. The continued development of methodology to both improve the mechanical property measures and remove barriers impeding its adoption in clinical practice, such as oppressive computation time, could ultimately allow for the translation of the MRE technique into a standard patient care procedure.

WHY BLUE WATERS

Blue Waters is an integral part of the MRE efforts both at Carle and at Beckman as it provides the computational power necessary to achieve high-resolution 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.

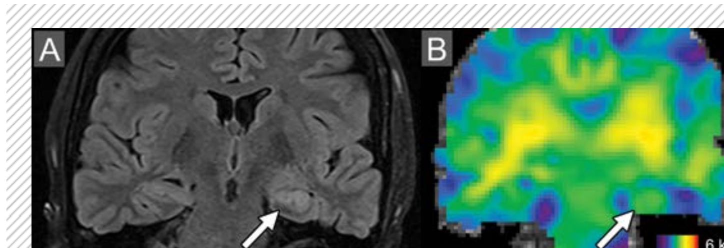

FIGURE 2: Imaging of the hippocampus in a 29-year-old patient with mesial temporal sclerosis epilepsy. (A) Coronal T_2-FLAIR MRI with arrow highlighting signal hyperintensity in left hippocampus, which is a signature of tissue pathology and the epileptogenic source. (B) Viscoelastic shear stiffness map with the epileptogenic hippocampus highlighted as a clearly stiff region.