MR Elastography Reveals the Local Properties of White Matter Structures

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INTRODUCTION: Magnetic resonance elastography (MRE) is a promising technique for *in vivo* mapping of the shear modulus of tissue. Current application of the technique to brain tissue is limited by low spatial resolution or low SNR, and a lack of studies on the reliability of spatial variations in property maps. The potential benefits of high-resolution MRE of the human brain have been underscored by recent applications of murine brain MRE involving localized effects in neurodegenerative diseases, such as multiple sclerosis [1,2]. A high-resolution MRE acquisition scheme has been introduced, and improvements in local property estimation afforded by MRE with high spatial resolution and SNR have been demonstrated [3]. Maps of *in vivo* shear modulus of the brain revealed variations in stiffness corresponding to structures in the white matter architecture, including the *corpus callosum* and *corona radiata*. In this work, we quantify the shear modulus of these individual white matter structures across multiple healthy volunteers using atlas-based segmentation [4], and demonstrate that these measures are repeatable through multiple examinations of a single subject.

METHODS: ***Acquisition and Inversion:*** A group of 7 healthy subjects (age range: 24-53 years; median age: 30 years; all male) volunteered for an MRE examination using a Siemens 3T Allegra head-only scanner. One subject volunteered for six separate visits to test the repeatability of elastography measures. Three-dimensional, full vector field MRE displacement data at 50 Hz was acquired using a multishot, variable-density spiral sequence [3]. Images had a 2x2x2 mm^3 isotropic spatial resolution, and the imaging volume comprised 20 axial slices covering the lateral ventricles, *corpus callosum*, and *corona radiata*. The data from one subject and from one visit of the repeated subject did not have an octahedral shear strain-based SNR of 3.0, the minimum needed for accurate inversion [5], and were discarded from the analysis. Mechanical properties were estimated from displacement data with nonlinear inversion with a Rayleigh damped material model [6,7]. Here, we present the viscoelastic equivalent real shear modulus (RSM) and imaginary shear modulus (ISM), which describe the elastic and viscous properties of the tissue, respectively.

Segmentation: All segmentation was performed in FSL. High-resolution T_1-weighted MPRAGE images were acquired in each imaging session and the FAST tool was used to segment white matter (WM). WM masks were created after registration to MRE data using FLIRT. The ICBM-DTI-81 white matter atlas [4] was registered to the data through the ICBM-152 template, and individual masks of both the *corpus callosum* (CC) and *corona radiata* (CR) were created for each dataset.

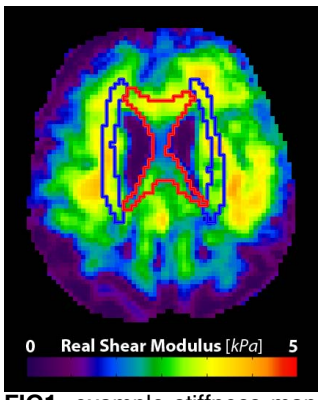

FIG1. example stiffness map with CC (red) and CR (blue) masks outlined

RESULTS and DISCUSSION: Figure 1 shows a single slice of the real shear modulus for one subject, with masks for both the CC and CR outlined in red and blue, respectively. Quantitative property values for these structures, as well as total WM, were calculated by averaging over the respective masks for each subject. Figure 2 presents the average RSM and ISM values for each region across all subjects. The RSM of total WM was found to be 2.34 kPa: stiffer than the segmented CC at 1.93 kPa, yet softer than the CR at 2.67 kPa. The ISM of the CR was 1.44 kPa, greater than both the CC and total WM (1.15 and 1.03 kPa, respectively). This finding is consistent with a previous *ex vivo* study that found the CC to be softer than the CR [8], though there is some ambiguity in those results [9]. Additionally, the previous studies may not have considered variation within the structure. Figure 3 shows two sagittal profiles of the average stiffness of the repeated subject, which exhibits a posterior-to-anterior gradient in both CC and CR stiffness. The genu is found to be the stiffest part of the CC and the splenium the softest. Separate *t*-tests comparing WM vs. CC, WM vs. CR, and CC vs. CR were performed with significance set at $p < 0.05$. Significant differences were found in each test for both RSM and ISM, except for the ISM of WM vs. CC. This demonstrates that the structure properties are distinct from each other and those of global white matter, and can be detected using a high-resolution MRE acquisition. All measures were found to be very repeatable, with the variations of each measure less than 0.19 kPa.

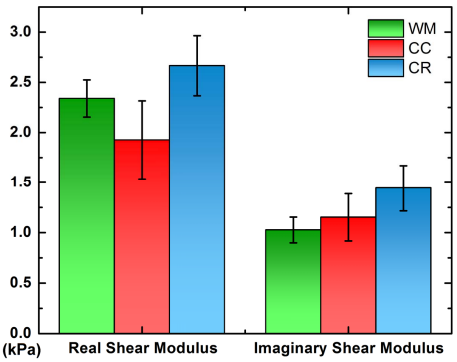

FIG2. average property values (RSM, ISM) for each region (WM, CC, CR)

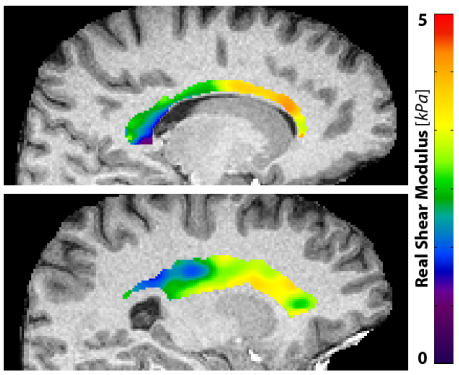

FIG3. profiles of CC (top) and CR (bottom) stiffness averaged for the repeated subject, overlaid on paramedial MPRAGE slices

CONCLUSION: The most common measures used in brain MRE involve global averages over large regions of the brain. Here we demonstrate that spatial variations in MRE property maps are reliable and we provide the first quantitative *in vivo* stiffness values for the *corpus callosum* and *corona radiata*. We show that properties of the two structures are significantly different, and are distinct from the global white matter average. Future MRE studies utilizing high-resolution acquisitions can take advantage of atlas-based segmentation to investigate the mechanical properties of specific structures in the brain, which will be useful in studying localized neurodegeneration.

REFERENCES: [1] K Schregel, *et al.*, *PNAS*, 2012,109:6650-6655; [2] K Riek, *et al.*, *NeuroImage: Clinical*, 2012,1:81-90; [3] CL Johnson, *et al.*, *MRM*, 2012, in press; [4] S Mori, *et al.*, *NeuroImage*, 2008,40:570-582; [5] MDJ McGarry, *et al.*, *Phys Med Biol*, 2011,56:N153-N164; [6] MDJ McGarry, *et al.*, *Med Phys*, 2012,39:6388-6396; [7] EEW Van Houten, *et al.*, *Med Phys,* 2011,38:1993-2004; [8] MT Prange and SS Margulies, *J Biomech Eng*, 2002,124:244-252; [9] S Chatelin, *et al.*, *Biorheology*, 2010,47:255-276.