Mechanical Properties of the Frontal Lobe Gray and White Matter Measured using MR Elastography with Soft Prior Regularization

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INTRODUCTION Magnetic Resonance Elastography (MRE) estimates the mechanical properties of tissue; it has been applied to the brain to investigate hydrocephalus, multiple sclerosis, tumors, and Alzheimer's disease. Properties are estimated using measurements of tissue motion taken with motion sensitive MRI sequences. Because the measurements are taken in an MRI scanner, there is a wide range of established sequences and contrast mechanisms which can be used to segment anatomical structures. Despite this readily available spatial information, the majority of MRE property reconstruction algorithms do not utilize it to guide the reconstruction. Most MRE results have been presented as averages taken over large regions; the additional constraints from incorporating spatial information in the reconstruction process may allow more accurate estimation of regional brain properties. This work will provide a framework for incorporating *a priori* spatial information into the estimation of mechanical properties in MRE.

DATA AND METHODS A subzone based nonlinear inversion algorithm [1] was modified to favor homogeneous properties within predefined regions by adding a soft prior regularization (SPR) penalty term [2] to the objective function. The algorithm was validated using a silicone phantom with a single stiff inclusion that was manually segmented into two regions based on a T2-weighted image. In vivo brain MRE data was collected on a healthy volunteer on six separate occasions using a high-resolution multishot spiral imaging sequence [3]. Motion was measured in all three directions using 2mm isotropic voxels during actuation at 50Hz. The frontal lobe usually has a reasonably homogenous structure in MRE images, therefore, frontal lobe gray and white matter were assigned to two separate regions for this SPR study. The white and gray matter were segmented from a T1-weighted MPRAGE anatomical scan using FSL, and the frontal lobe was selected using the MNI structural atlas. All other tissues remain fully distributed (no soft prior regularization applied).

RESULTS Figure 1 shows the estimated storage modulus distribution of a silicon phantom with and without application of SPR. Figure 2 is a representative slice of the storage and loss modulus of the brain. The recovered properties of the frontal lobe gray and white matter over the six scans revealed a statistically significant difference between the two tissue types, in both the storage modulus ($p=4.4e-9$) and loss modulus ($p=1.3e-8$). Figure 3 plots the values of each region over the six scans.

CONCLUSIONS This work demonstrates supplying spatial information to a nonlinear inversion elastographic algorithm. SPR leads to smooth regional properties in phantom experiments, and allows for more accurate estimation of the viscoelastic mechanical properties of frontal lobe gray and white matter.

REFERENCES [1] EEW Van Houten et. al. *Magn. Res. Med.* 2001; [2] AH Golnabi et. al. *J. Med. Phys.* 2011; [3] CL Johnson et. al. *Magn. Res. Med* 2012.

SPR Property Reconstruction Algorithm: Minimize

$$\Phi(\theta) = \sum_{i=1}^{N_m} \left(u^m{}_{(i)} - u^c{}_{(i)}(\theta) \right)^2 + \lambda_{sp} \theta^T L^T L \, \theta$$

by iteratively updating a discretized estimate of the mechanical properties, θ . Here, $u^m{}_{(i)}$ is the i'th of N_m displacement measurements, $u^c{}_{(i)}(\theta)$ is the analogous displacement predicted by a viscoelastic finite element model using the current θ. The second RHS term penalizes variation within predefined regions (generated using anatomical MRI). If a region R_i contains $N(R_i)$ mechanical property points, L is a $N_{prop} \times N_{prop}$ matrix defined by

$$L(i,j) = 0 \qquad if \quad R_i = 0 \;\; or \;\; R_i \neq R_j \;\; or \;\; N(R_i) < 2$$
$$L(i,j) = 1 \qquad if \quad i = j$$
$$L(i,j) = \frac{-1}{N(R_i) - 1} \;\; if \quad R_i = R_j$$

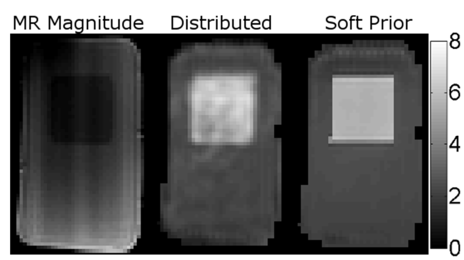

Figure 1: Soft prior regularization storage modulus (kPa) of a silicone phantom (right) compared to a fully distributed reconstruction (no SPR; middle), along with T2-weighted image used for segmentation (left)

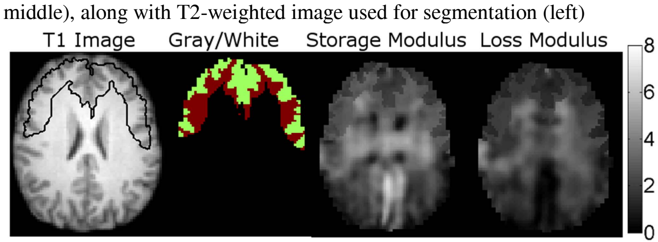

Figure 2: Representative slice of mechanical property images calculated using soft prior regularization where the frontal lobe gray and white matter were assigned to two regions with the remainder of the brain remaining fully distributed. Colormap is in kPa.

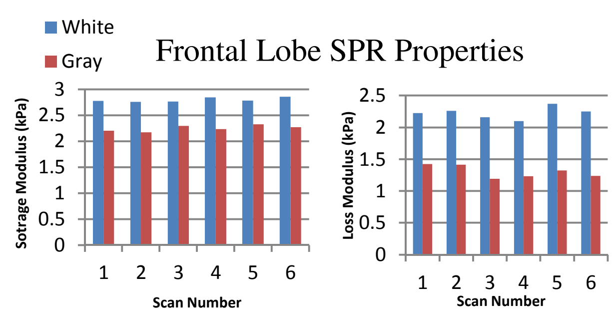

Figure 3: Values of frontal lobe gray and white matter calculated using soft