

## Rayleigh Damped based Brain Magnetic Resonance Elastography

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### Introduction:

Magnetic Resonance Elastography (MRE) has demonstrated its ability to quantify soft tissue elasticity deduced from displacement measurements within the tissue obtained by phase contrast Magnetic Resonance Imaging (MRI) techniques [1]. It is believed to have potential in the detection of wide variety of pathologies, diseases and cancer formations, especially tumors. Recently, Rayleigh, or *proportional*, damping (RD) moduli for soft tissue attenuation has been introduced to the non-linear, optimization based, subzone reconstruction method [2] to provide a more accurate model for the elastic energy attenuation occurring in the brain tissue under time-harmonic actuation. The motivation that supports this research project arises from an interest in the development of MRE methodologies for quantification of not only stiffness estimates, but also dispersion properties of the *in vivo* brain.

### Materials and Methods:

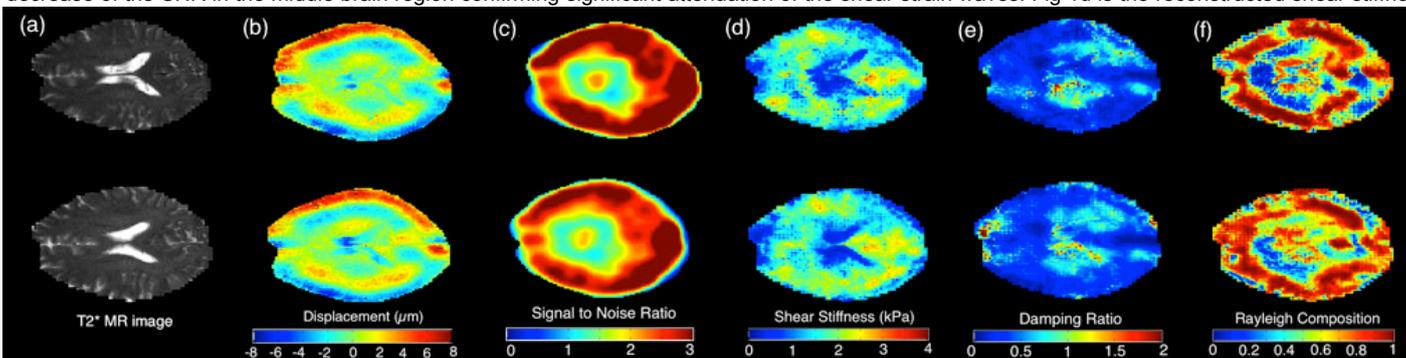
The *in vivo* brain experiments were performed on 3T TIM Trio Siemens MRI scanner using a standard single channel transmit / receive head coil. Acoustic actuation was utilized to introduce shear waves into the head at a mechanical frequency of 50 Hz. Two active subwoofers, modified with the airtight acrylic lids, were used to generate acoustic waves delivered through long tubing to Pressure Actuated Drivers (PADs), located in the MR head coil and placed under the subject head [3].

The 3D steady state displacement fields were acquired by a single shot, spin-echo EPI using: TR/TE=3000/120ms; FOV=220 × 220 mm; resolution of 128 × 128 pixels; and 10 slices of 3 mm thickness. The isochromatic displacements were encoded with 1 cycle of sinusoidal-shaped motion encoding gradient (MEG) of 32 mT/m magnitude in 8 equally spaced time increments [3].

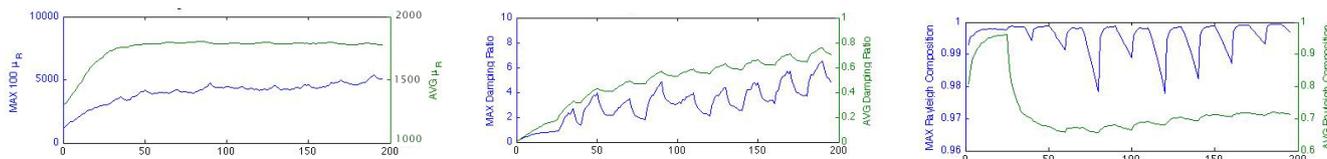
The octahedral shear strain (OSS) SNR calculation was performed on the brain data set [4]. A 3D subzone based reconstruction algorithm using RD material model [2] was applied to reconstruct mechanical properties, damping behavior and elastic energy attenuation mechanism of the *in vivo* healthy brain.

### Results & Discussion:

High resolution brain images were obtained in the axial plane including the ventricles as shown in the T2\* image in Fig. 1a. Fig 1b shows the displacement image indicating significant motion attenuation in the interior region of the brain. Fig 1c illustrates the OSS based SNR image depicting decrease of the SNR in the middle brain region confirming significant attenuation of the shear strain waves. Fig 1d is the reconstructed shear stiffness



**Fig.1** (a) T2\*-weighted image (b) The displacement image (c) The OSS SNR image (d) The estimated shear stiffness image (e) The reconstructed DR image (f) The reconstructed RC image



**Fig. 2.** Convergence plots for (left to right): 1. Shear stiffness 2. Damping ratio 3. Rayleigh composition

image clearly depicting the anatomical structure of ventricles with very low shear modulus, which is correct given that they contain cerebro-spinal fluid (CSF). The ventricles and intracranial matter were segmented to calculate statistic distribution of the property values. The latter revealed that central region of the brain about the ventricles exhibits much lower elasticity (**0.7 kPa**) that the surrounding white and grey regions (**2 kPa**). Fig 1e shows reconstructed damping ratio (DR) image, indicating measure of the attenuation in the brain tissue. The ventricles are clearly visible here as well, indicating high loss of mechanical energy within the CSF fluid. Fig 1f illustrates the reconstructed Rayleigh composition (RC) image, representing a relative measure of the damping mechanism. Previous studies of RD elastography [2] suggested that values close to 0 indicate fluid saturated cellular materials, while values close to 1 indicate viscoelastic materials. The connection between the RC and anatomical structure is less obvious, but some correlation is evident. For example, the region in the vicinity of the ventricle structures is indicated as fluid in nature.

Figure 2 shows convergence plots for the nonlinear optimization fitting of the reconstruction results depicted on Fig.1 d, e, and f. The graph reveals that convergence was achieved after 50th iteration of the reconstruction process for shear modulus and RC. DR estimate has not been fully stabilized, however a trend to a convergence is evident.

### Conclusion:

The first results achieved by the RD brain MRE show promise for potential *in vivo* determination of different brain tissue types, and the possibility of providing additional diagnostic tools. Moreover, the values obtained for brain viscoelastic properties agree well with *in vitro* and *in vivo* brain data published elsewhere. Further RD brain elastography experiments as well as studies of a variety brain simulating damping phantoms are needed to investigate attenuation mechanisms across different intracranial tissue types, including tissue in diseased states such as multiple sclerosis, Alzheimer's, hydrocephalus and cancer.

### References:

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