Abstract #02337 ISMRM ABSTRACT

# [USGOV] Intrinsic Waveguide MR Elastography of the Human Brain

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## Impact

We have developed a MRE method to measure the anisotropic mechanical properties in white matter without using a tamper. The method has the potential to detect subtle changes in the brain structure that may occur in disease.

## Synopsis

**Motivation:** Characterization of mechanical anisotropy of brain tissue via MRE has been mainly limited to transverse isotropy and requires a tamper.
**Goals:** To estimate the orthotropic elasticity tensor using the deformation caused by intrinsic brain pulsations.
**Approach:** We simultaneously measure both the displacement and diffusion tensor fields by cardiac gated displacement-encoded acquisitions, which were used to estimate the orthotropic tensor in each voxel using a waveguide approach.
**Results:** We compared results from isotropic, transverse isotropic, and orthotropic model inversions. White matter was stiffer than gray matter in all models but contrast across various white matter tracts differ between models.

## Introduction

MR elastography (MRE) [1] has been successfully used to characterize mechanical properties of isotropic tissues such as the liver. MRE of the brain is more challenging because of tissue anisotropy, which requires a $4^{th}$-order elasticity tensor, and mechanical shielding by the skull, which can limit certain patient cohorts. The anisotropy is typically characterized by the transverse isotropic tensor with fiber direction obtained from diffusion tensor imaging (DTI) [2]. This approach has been demonstrated with and without tamper [3, 4], however a more promising method is the waveguide MRE which assumes an orthotropic material model with fewer symmetries [5].

The goal of this work is to perform intrinsic waveguide MRE by simultaneously estimating both the displacement and diffusion tensor field from motion encoded MRI brain scans. Deformations caused by internal pressure pulse waves from the heart obviate the use of an external tamper. While intrinsic brain MRE has been attempted in several previous studies [4, 6, 7], they have not been used to measure the orthotropic elasticity tensor. In this study, we use standard Stejskal-Tanner DWI sequence to encode the diffusive and advective motions and reconstruct isotropic, transverse isotropic, and orthotropic elasticity tensors in a live human brain without a tamper.

## Methods

MRI data was acquired in six healthy young adults on a 3T scanner (Prisma, Siemens Healthineers) with 80 mT/m peak gradient strength and a 200 T/m/s slew rate using a 20-channel coil. Whole-brain displacement-encoded MRI data were acquired along the six directions of the icosahedron at b = 350 s/mm$^2$ and $v_{enc}$= 0.6 mm/s along with b = 0 s/mm$^2$ scan using the following parameters:  = 7\48 ms, FOV=210 x 210 x 120 mm, GRAPPA factor = 2, TR\TE = 5,600\71 ms, NEX = 144, and a 2 mm isotropic spatial resolution. The pulse-oximeter signal and MRI triggers were simultaneously recorded using a Biopac System (Biopac, Goleta, CA, USA) for retrospective gating.

Linear phase errors arising from eddy currents, rigid body motion, etc., were removed using linear regression. The $\Delta B_0$-induced geometric distortion is corrected using FSL's *topup* software [8]. The displacement-encoded images were then segmented into eleven different bins each 100 ms long covering the entire cardiac cycle. Multiple repetitions of the data acquired in each bin for a given direction were utilized to reject inconsistent phase measurements in each voxel. The 3D displacement vector and the diffusion tensor fields were concurrently estimated from the phase and magnitude signals, respectively, using linear regression. The displacement vector field is Fourier transformed in time to estimate its amplitude at the cardiac frequency (i.e., ~1 Hz) which was subject to a Helmholtz decomposition to estimate the voxel wise isotropic [9], transverse isotropic [4], and orthotropic elasticity tensors [5]. The orientation averaged shear modulus is obtained from the estimated tensor [10] and mapped onto fiber tracts obtained from DTI.

## Results and Discussion

The DTI and displacement vector field maps at various cardiac phases are shown in Figure 1. The funnel shaped motion of the brain along its superior-inferior axis, well documented in the literature [11, 12], is captured in these plots. The diffusion tensor maps show changes in mean diffusivity (MD) and fractional anisotropy (FA) in ventricles due to changes in voxel composition across cardiac phases. The dilatation and shear strains in the brain at the cardiac frequency are shown in Figure 2. We observe that the divergence and curl are both very small (< 0.5%) and heterogeneous in the brain parenchyma. The estimated orientation averaged shear modulus in the brain from the three models overlaid on FA map are shown in Figure 3 for all three orthogonal planes. The orientation averaged shear modulus is heterogeneous with white matter being stiffer than gray matter as shown in high-frequency MRE studies [13]. The transverse isotropic model predicted the highest heterogeneity within white matter regions compared to other models tested. The brain appears ultrasoft at the

cardiac frequency given the very long waves (~15-20 cm) observed. The shear modulus mapped onto fiber tracts are shown in Figure 4 which shows differences in stiffness among various white matter pathways with crossing fiber regions exhibiting higher stiffness.

## Conclusion

We have demonstrated a method to map the orthotropic elasticity tensor without a tamper by simultaneously performing both waveguide MRE and DTI in live human brain using heart induced brain pulsations. The difference in contrast across models maybe from the quality of data fit.


## Acknowledgements

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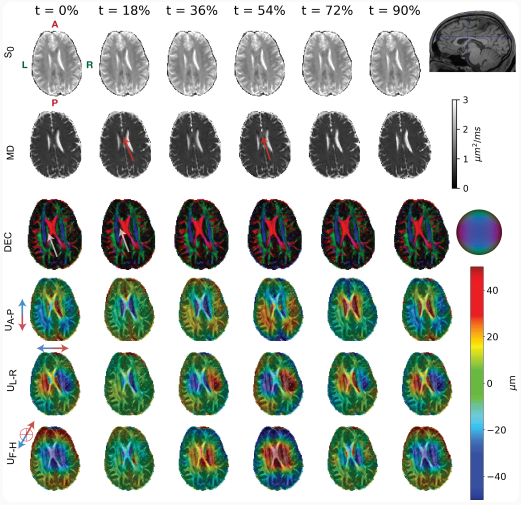


***Figure 1:*** *Diffusion tensor and displacement vector fields across cardiac phases for an axial slice from a volunteer. DTI-derived maps including $S_0$, mean diffusivity (MD), and direction-encoded color (DEC) are displayed as a function of the cardiac phase (given as percent R-R interval). The three components of the displacement vector field in the patient coordinate system are overlaid with a map of fractional anisotropy (FA) for anatomical context. Changes in DTI due to pulsations are shown using arrows.*

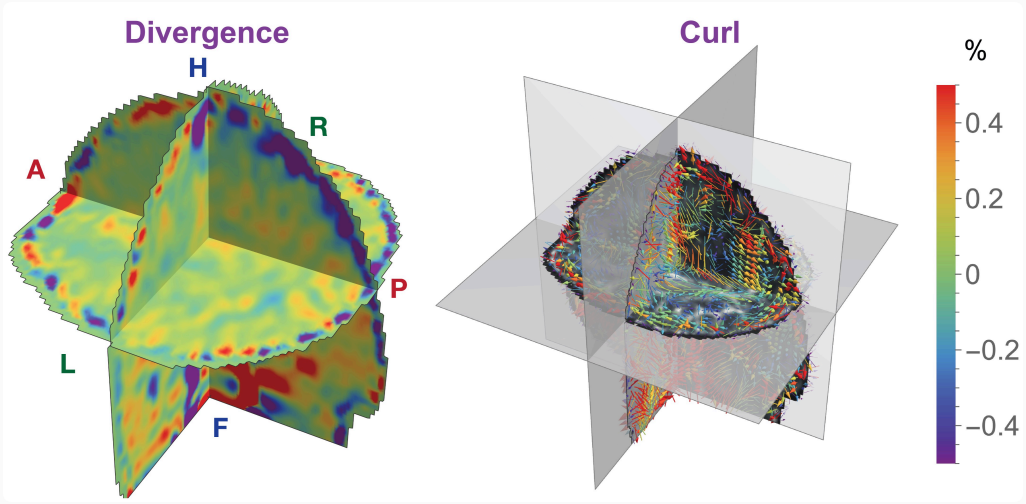


***Figure 2:*** *The intrinsic dilatation and shear motions in the brain shown in a "3-D slicer" format using the real part of the divergence and curl of the harmonic displacement field, respectively, for a representative healthy volunteer. The results are overlaid on the fractional anisotropy (FA) map to provide anatomical context. The divergence in the brain tissue was minimal but above noise with curl having an overall higher magnitude.*

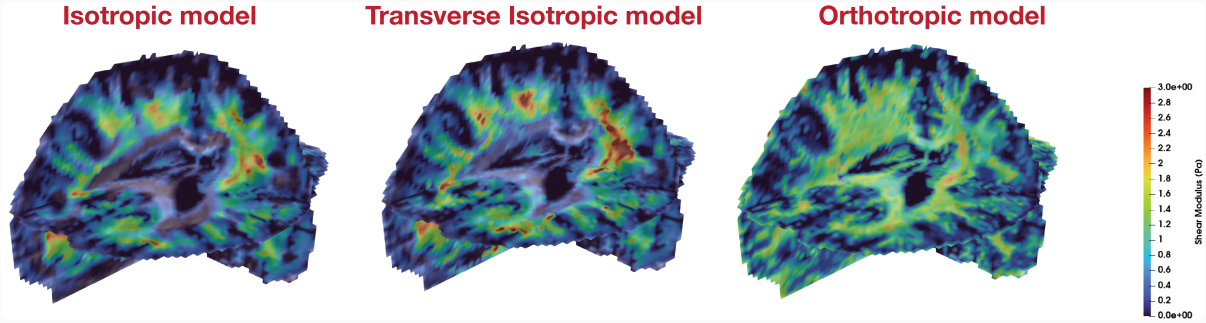


***Figure 3:*** *Orientation averaged shear modulus obtained on the same MRE and DTI data using the isotropic, transverse isotropic and orthotropic model (i.e., waveguide MRE) in three orthogonal slices overlaid on FA map. The white matter is stiffer than gray matter in all the models but the variability in the heterogeneity of various white matter regions across models is noted.*

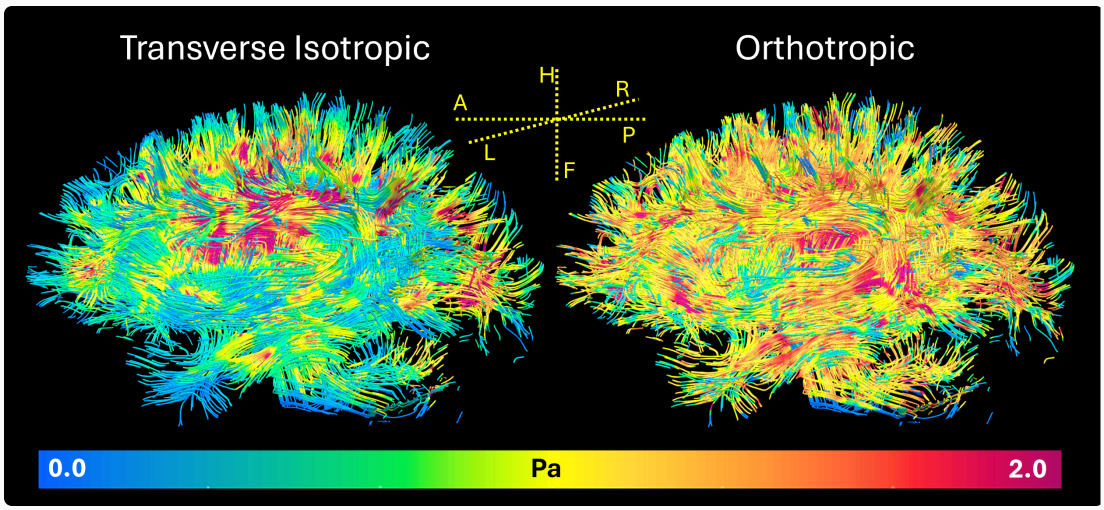


***Figure 4:*** *Orientation averaged shear modulus obtained from transverse isotropic and waveguide MRE mapped onto fiber tracts obtained from DTI. The mechanical properties of fiber tracts are heterogeneous and seems higher at fiber crossing regions in both the models.*