In Vivo Diffusion Tensor Distribution MRI of the Human Brain Using 300 mT/m Gradients

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INTRODUCTION

- MRI voxel in the brain consists of processes orders of magnitude smaller than the actual voxel size (Figure 1).
- The goal of diffusion tensor distribution (DTD) MRI is to reveal these sub-voxel features [1]–[3].
- The DTD assumed to be a constrained normal tensor variate distribution (CNTVD) within the manifold of 3 x 3 symmetric positive definite matrices [4].
- We show *in vivo* results obtained on a human brain using this new framework on the MGH Connectome scanner using 300 mT/m gradients.

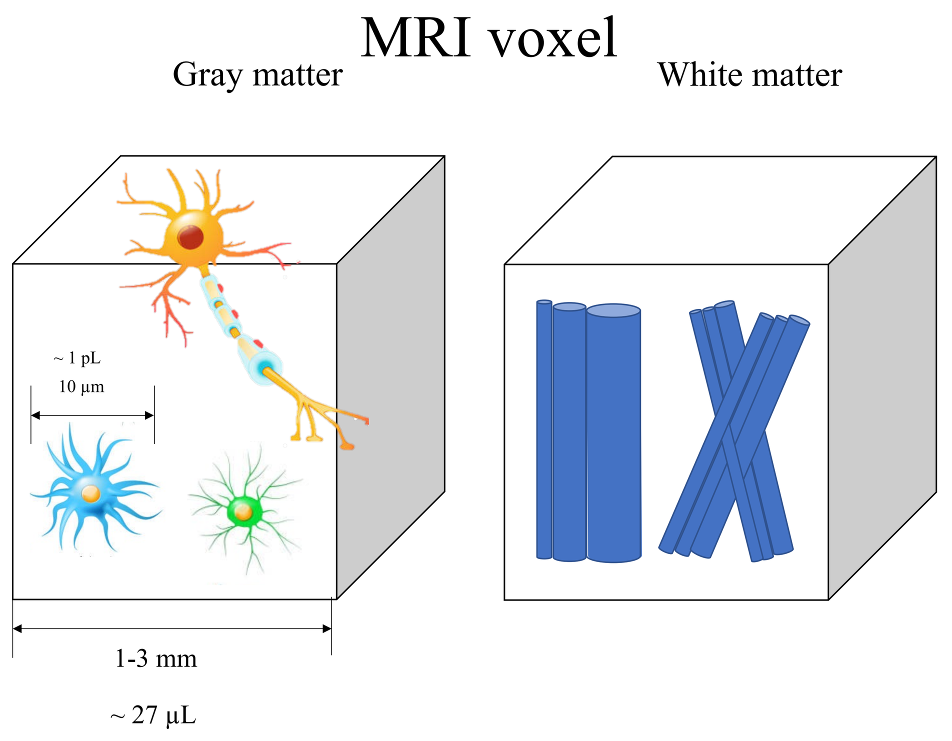

FIGURE 1: Contents of a typical gray and white matter voxel in the brain.

MODEL

- MRI voxel modeled to consist of a multitude of Gaussian diffusion compartments described by a probability density of diffusion tensors (i.e., DTD) [1] (Figure 2).
- MR signal approximated using Monte-Carlo (MC) method by drawing samples from a CNTVD with given second order mean and fourth-order covariance tensors which are estimated using parsimonious model selection [4].
- Given the estimated mean and covariance tensors, we provide a new definition for microscopic fractional anisotropy (μFA) based on the non-commutativity of the FA operator,

$$\mu\text{FA} = \overline{\text{FA}(\mathbf{D})} \neq \text{FA}(\overline{\mathbf{D}})$$

- We further identify the sources of μFA using size, shape and orientation heterogeneity metrics which increase with the amount of heterogeneity within the voxel [4].

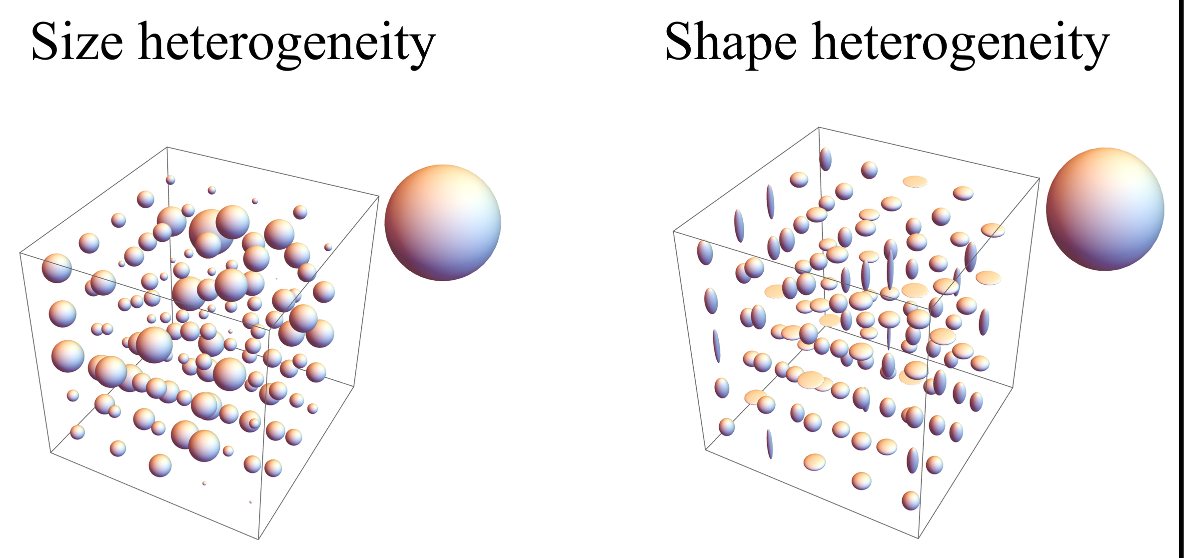

FIGURE 2: DTD model composed of microscopic Gaussian diffusion compartments within a voxel. Shown are two voxels with identical mean diffusion tensor with size and shape heterogeneous micro diffusion tensors

EXPERIMENTAL DESIGN

- Rank-1 and rank-2 b-matrices with uniform size, shape and orientation distributions were acquired using a standard double PFG pulse sequence with EPI readout (Figure 3).
- MRI data was acquired on a 3T system (MAGNETOM Connectom, Siemens Healthineers) capable of up to 300 mT/m gradient strength and 200 T/m/s slew rate. The DTD data was acquired in a healthy volunteer with FOV=200x200 mm, TR/TE=10,000/101 ms at 2 mm isotropic spatial resolution.

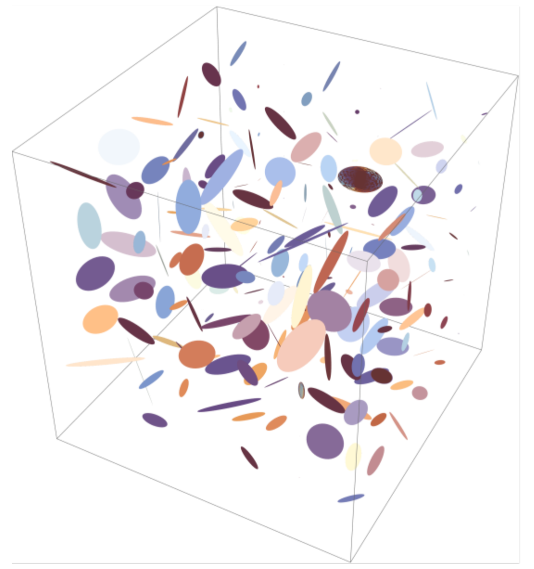

FIGURE 3: Sampled b-matrices (N = 216) shown as ellipsoids

RESULTS & DISCUSSION

- The mean tensor was similar to that of DTI in brain tissue.
- The μFA was elevated in the corona radiata due to increased shape heterogeneity in the region visible in shape heterogeneity map, likely due to splaying fibers.
- The size heterogeneity was elevated at the CSF-parenchyma boundary due to the presence of highly diffusive CSF and slowly diffusing water in brain parenchyma.

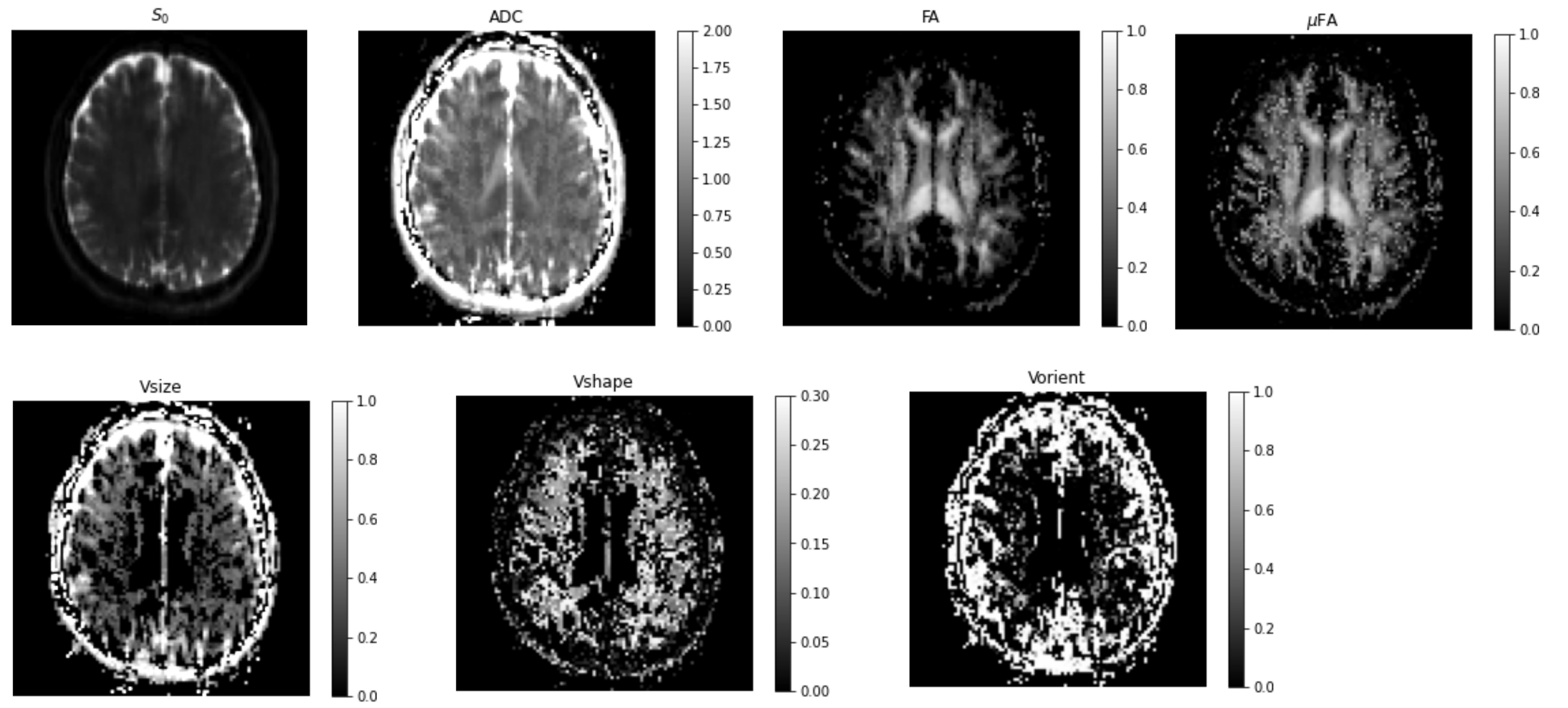

FIGURE 4: DTD results with the brain showing the estimated parametric maps. S_0, FA, µFA, ADC, and Vsize, Vshape, Vorient – Size, shape and orientation heterogeneity metrics. The units for ADC and Vsize are in µm²/ms.

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