Using Diffusion Tensor Imaging to Predict Transport Patterns in Brain

Malisa Sarntinoranont*, Thomas Mareci

University of Florida, Gainesville, FL, USA
*msarnt@ufl.edu

Vital nutrients, accumulated wastes and therapeutic agents are all transported by diffusion in their journey through brain tissues. 3D computational models of the brain that predict species transport have proven helpful in regional analysis of disease and drug delivery. In our group, we have developed computational models using magnetic resonance diffusion tensor imaging (DTI) data sets that account for heterogeneity and anisotropy of transport. To date, we have used these models to predict spatial depositions following brain infusions.

DTI provides measures of the effective diffusion tensor of water at each imaged voxel in the brain. We take advantage of structural information within these tensor measures in order to develop our model. Mainly, water diffusion is hindered in certain directions by aligned fiber structures (axons) within white mater regions. First, this allows us to use fractional anisotropy measures to distinguish between white matter and gray matter regions which are known to be more isotropic. Such segmentation allowed us to account for heterogenous transport properties.

Second, the axonal fiber bundle direction within white matter aligns with the eigenvector that points in the direction of maximum diffusivity. Also, the bundle structure of axons allows us to assume transversely isotropic transport properties. So long as we know transport properties in directions parallel and perpendicular to aligned fiber directions, we can build spatially varying transport tensors that account for anisotropy due to fiber alignment. For example, diffusion of a tracer agent can be constructed.

$$\mathbf{D_t} = \mathbf{V}\begin{bmatrix} D_\perp & 0 & 0 \\ 0 & D_\perp & 0 \\ 0 & 0 & D_{||} \end{bmatrix}\mathbf{V^T} \qquad (1)$$

where $D_\perp$ and $D_{||}$ are tracer diffusion eigenvalues in perpendicular and parallel directions, respectively. $\mathbf{V} = [v_1, v_2, v_3]$ are the DTI measured eigenvectors at each location where $\mathbf{v_3}$ corresponds to the maximum diffusion direction. We used these methods to predict transport of large macromolecular tracers following infusions into the hippocampus of the rat brain. We also compared predictions to MR measurements, Fig. 1.

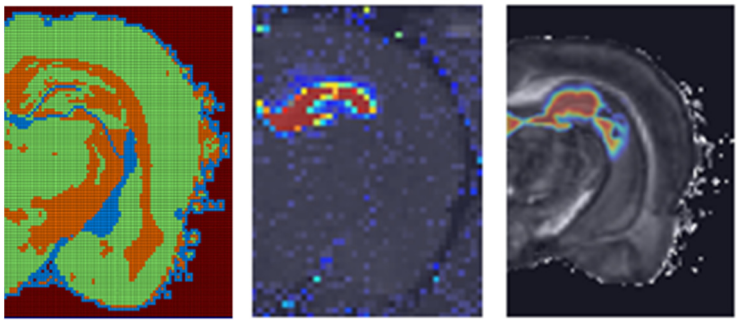

Figure 1: Brain transport model of the rat brain. (Left) Segmented region of the rat brain that based on fractional anisotropy showing white matter, gray matter, and cerebrospinal fluid regions. (Middle) MRI measures of tracer distribution and (Right) model predictions following infusion into the hippocampus.

References

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