Neural Tissue as Porous Media

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MR measurements of molecular displacements and porous media models provide useful information not only about transport properties and microstructure of inanimate porous materials, but also about living tissue, particularly neural tissue.

Hansen's early *ex vivo* measurements of ADCs in nerves were followed by *in vivo* diffusion MRI studies demonstrating diffusion anisotropy in cat and in human white matter (WM). Diffusion tensor NMR and MRI (DTI), based on a Gaussian displacement *PDF*, characterized anisotropic water diffusion in brain WM using maps of material parameters derived from the apparent (or effective) diffusion tensor (ADT). Tuch used cross-property relations to derive an electrical conductivity tensor from this ADT.

Model independent approaches are also useful in characterizing neural tissue structure and organization. Callaghan and Xia's "k- and q-space imaging" method was adapted to clinical scanners by Wedeen (DSI) to estimate a 3-D average propagator in each voxel, providing information about restriction, distinct compartments, etc. The burden of sampling $E(q)$ uniformly throughout 3-D q-space led Tuch to consider functions of the average propagator, e.g., its orientation distribution function (ODF), obtained by collecting $E(q)$ data only over a spherical shell in q-space. Alternatively, Pikalov et al. estimated the 3-D average propagator with less $E(q)$ data by using CT reconstruction methods and *a priori* information.

Several model-based displacement MR approaches have also been used to estimate distinct features of neural tissue. One method treats the extra-axonal space in WM as hindered, described by a DTI model, and the intra-axonal space as restricted. This composite hindered and restricted model of diffusion (CHARMED) MRI framework has been extended to measure the diameter distribution in a pack of axons (AxCaliber), extending and adapting the approach Packer et al. used to estimate the diameter distribution in droplets.

Various porous media approaches have been developed to study gray matter (GM) microstructure. Treating GM as hierarchically organized, exhibiting fractal diffusion, Özarslan et al. proposed scaling relationships for time-dependent displacement distributions; this approach provides a means to estimate several parameters characterizing anomalous diffusion. Viewing dendrites in GM as a network of restricted tubes, Komlosh et al. have applied multiple PFG-MR sequences to measure and characterize *microscopic* diffusion anisotropy in GM, which appears using DTI to be macroscopically isotropic.

Useful analytical and simulation environments have been developed to aid in understanding water transport in neural tissue and its effect on the MR signal. Szafer and Stanisz used Monte Carlo methods in idealized WM to model MR signal attenuation. Wehrli's group used digitized histological WM cross-sections to build more realistic micromodels to simulate diffusive transport and the MR signal attenuation. Frank has developed a computational environment to simulate diffusion in complex media that can treat microstructural heterogeneity over a large range of length scales. Sen et al. developed a model of diffusion within a pack of cylindrical tubes to assess how different microstructural parameters affect the ADCs parallel and perpendicular to the WM fiber axis.

In summary, the use of porous media concepts in conjunction with MR displacement measurements has resulted in the development of novel models and experimental methods to characterize biologically relevant transport properties in neural tissue, and measure microstructural features that otherwise could only be obtained by invasive and tedious histological analysis.