Quantitative MRI and DTI of human white matter tracts: Myelin density and diffusivity

Robert Dougherty[1], Nikola Stikov[2], John Pauly[2] and Brian Wandell[1,2]
[1]Psychology and [2]Electrical Engineering Departments, Stanford University

Inroduction

Diffusion tensor imaging (DTI) is used to identify and measure white matter fascicles of the brain in-vivo.

Quantitative measures of diffusivity provided by DTI (especially fractional anisotropy) are widely used to infer tissue microstructure.

However, these inferences are limited by the fact that multiple tissue structures can give rise to the same DTI measures.

We combine DTI with other quantitative magnetic resonance (qMR) techniques to disambiguate tissue microstructure inferences in the human brain.

Methods

General

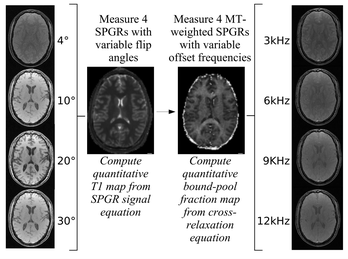
- Two human volunteers scanned on GE 1.5T Signa Lx
- Whole-brain, ~2mm isotropic voxels
- White matter mask based on diffusivity (fa>0.1, linearity>0.2, md 0.6-1.0 μm/msec^2) and T1 (0.6-1.4 sec). *Small changes to these parameters did not alter the results.*

Diffusion Imaging

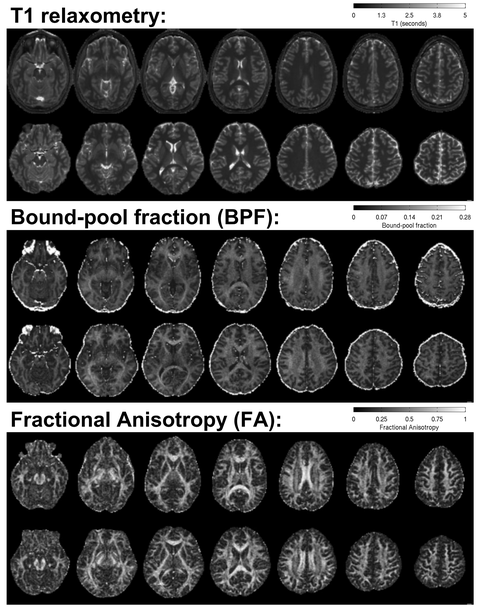
- 6 non-colinear directions (results confirmed on a 23 direction dataset)
- b-value of 0.8 msec/micrometer^2
- 16 repeats (~12 minute scan time)
- Eddy-current correction (Rohde 2004 MRM)
- Least-squares tensor fitting (Basser 1994 J Magn Reson B)
- Deterministic tractography (Mori 1999 Ann Neurol; Basser 2000 MRM)

Cross-Relaxation Imaging

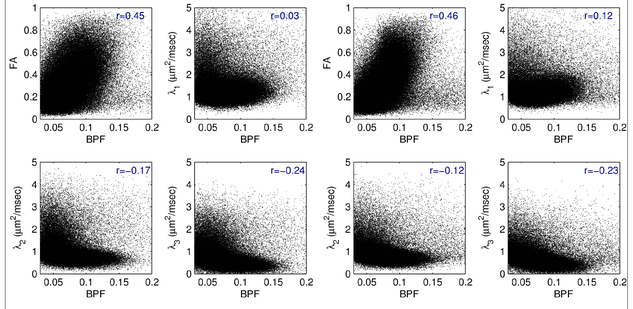
- Quantitative magnetization transfer (MT) method based on Yarnykh & Yuan (2004 Neuroimage)
- Estimate longitudinal relaxation time (T1) from multiple flip angles (Deoni 2005 MRM)
- Measure MT at several offset frequencies
- For each voxel, fit a non-linear model to T1 estimate and MT data to estimate the bound-pool fraction (BPF)
- BPF indicates the proportion of H atoms that are bound to macromolecules, such as myelin



T1, BPF, and FA maps for two subjects

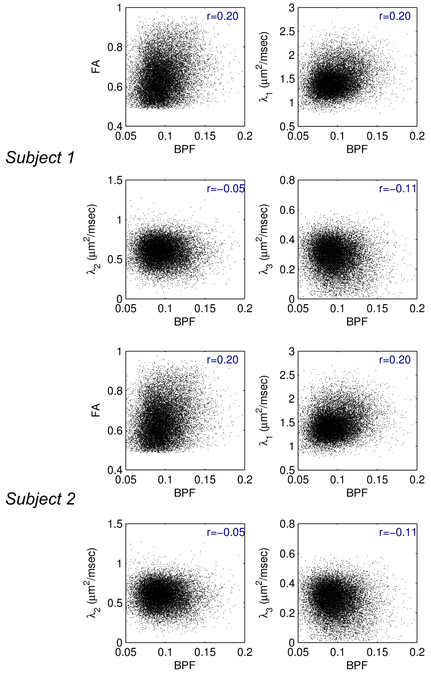


Result 1: For all brain tissue, bound-pool fraction is strongly correlated with diffusion anisotropy.

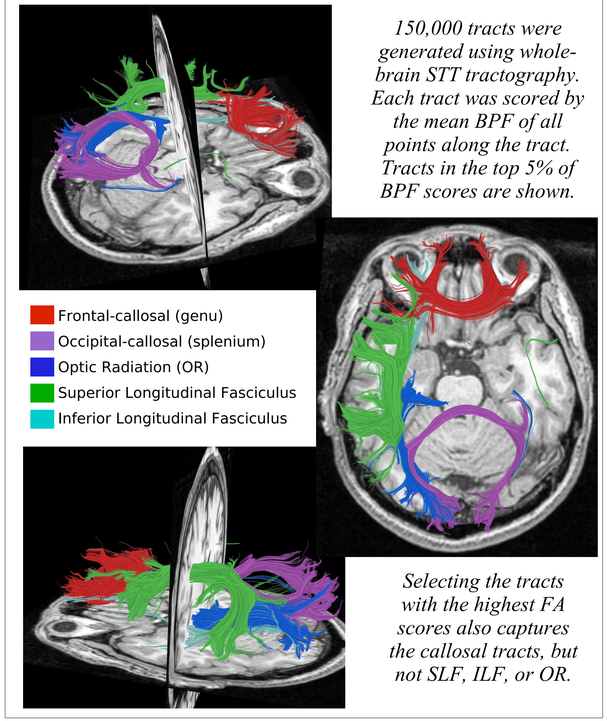


BPF vs. FA and all 3 diffusivities ($\lambda_{1,2,3}$) for S1 (left) and S2 (right).

Result 2: In white matter, bound-pool fraction is *weakly* correlated with diffusion anisotropy. The correlation in Result 1 is driven by gross tissue differences (gray, white CSF).



Result 3: Identifying tracts with high BPF.



150,000 tracts were generated using whole-brain STT tractography. Each tract was scored by the mean BPF of all points along the tract. Tracts in the top 5% of BPF scores are shown.

Selecting the tracts with the highest FA scores also captures the callosal tracts, but not SLF, ILF, or OR.

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Conclusions

- **Within the white matter, BPF and diffusivity are complementary measures**
  - BPF most likely reflects myelin density
  - Diffusion anisotropy is strongly affected by fiber direction coherence
  - Both are likely to be sensitive to fiber packing density
- **BPF + tractography identifies several heavily-myelinated white matter tracts:**
  - left SLF,occipital-callosal, frontal-callosal and optic radiation, left ILF