

Quantifying White Matter: Integrating Diffusion Tensor Imaging and Bound Pool Fractions

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Introduction: We explore combining two quantitative MR contrast mechanisms in order to better understand the structure of white matter in the brain. Diffusion tensor imaging (DTI) can identify white matter fascicles and measure their diffusivity [1]. The bound pool fraction (BPF) estimates the proportion of protons bound to macromolecules, such as myelin [2,3,4]. We combine these two in order to obtain concurrent information about the direction, diffusivity, and myelin content of white matter tracts.

Methods: We obtained full-brain BPF and DTI maps of one healthy volunteer using a GE Signa 1.5 T Excite system and an 8-channel head coil. We used cross-relaxation imaging to map the BPF in vivo [4]. First, T_1 mapping was performed using four variable flip-angle SPGR scans, followed by four magnetization transfer SPGR scans with variable offset frequencies. These MT scans, combined with the T_1 maps, give the desired BPF maps. DTI measurements were performed using an optimized DTI sequence with isotropic 2mm^3 resolution. The total scan time for performing all measurements was just under 1 hour. Diffusion tensor tractography was used to segment the corpus callosum (CC) [5] and the optic radiation (OR) pathways [6] into 10 regions of interest. Figure 1 shows the superposition of one DTI fiber tract over the BPF map. We computed the mean BPF along 10 fiber tracts, and looked at the relationship between BPF and the quantitative DTI measures of diffusivity: fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD) and radial diffusivity (RD).

Results: The correlation between BPF and the other DTI parameters is small. White matter voxels with higher BPF tend to have higher FA ($r=.16$, as seen in figure 2), higher MD ($r=.10$), higher AD ($r=.18$) and lower RD ($r=-.09$). All correlations were significant at $p < 1e-8$. From the ROI analysis of FA vs. BPF three patterns can be identified (Figure 3).

Discussion: Combining DTI and BPF provides a quantitative method for differentiating white matter structures that cannot be distinguished by using only one of these techniques. For example, OR and the CC body have similar FA, but different BPF. Similarly, all the fibers in the CC have similar FA, but the genu and splenium have higher BPF than the body. The differences in BPF values in the CC are consistent with previous work suggesting that fibers in the genu and splenium are more tightly packed compared to the CC body [7]. We propose that BPF reflects the bulk myelin density within a voxel – a function of both the amount of myelin surrounding each axon and the fascicle packing density. Diffusivity measures are more sensitive to fascicle packing density and fascicle direction coherence within a voxel. Thus, BPF and DT are complementary measures that combine to provide a more complete insight into tissue microstructure.

Acknowledgements: This work was supported by NIH Grant EY015000. We thank Roland Bammer for the DTI sequence.

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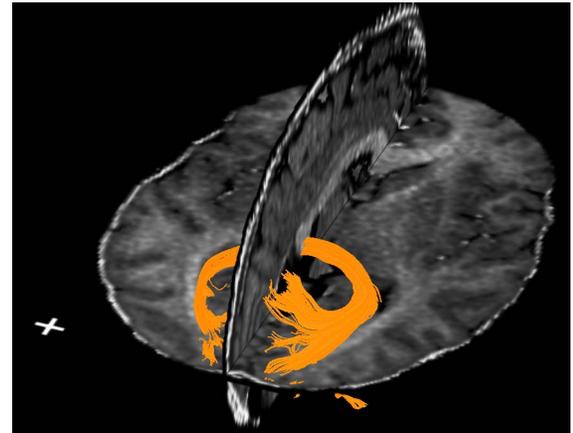


Figure 1 (color): The occipital fiber tract (orange) passing through the CC superimposed on a BPF map

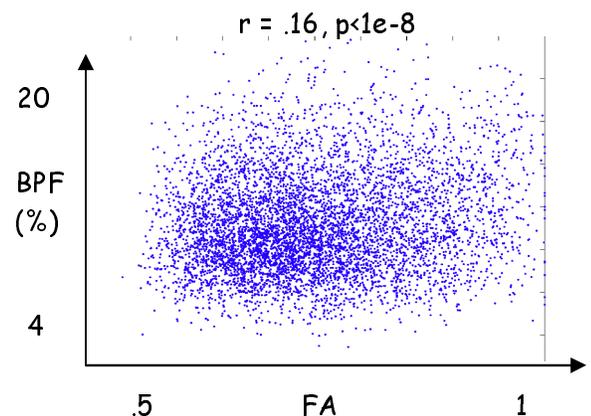


Figure 2: Scatter plot showing the correlation of fractional anisotropy and bound pool fractions. The small correlation coefficient ($r=.16$) means that FA and BPF are complementary quantities

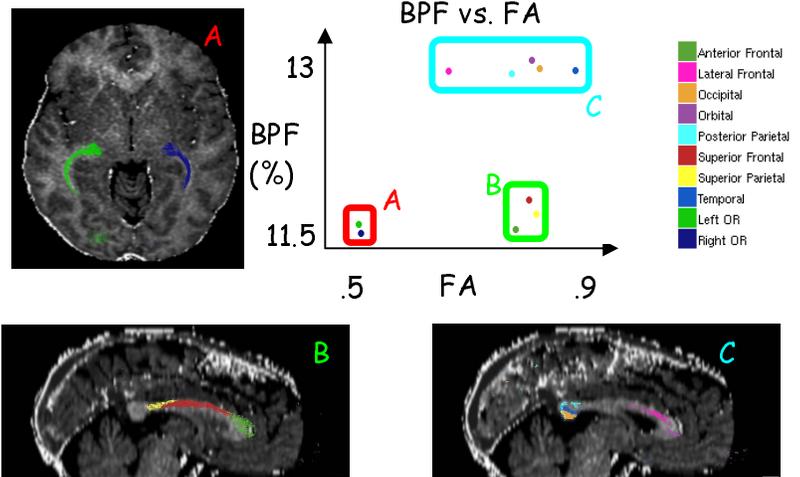


Figure 3 (color): ROI analysis of FA vs. BPF. Three patterns can be identified: (A) The Optic Radiation has low BPF (.113) and low FA (.52) (B) The body of the corpus callosum has low BPF (.115) and high FA (.75), and (C) The genu and splenium of the corpus callosum have high BPF (.13) and FA (.75).