Analysis of Neuronal Fiber Orientation distribution in Gray Matter and at Gray-White Matter Borders using Spherical Deconvolution of high-resolution (1.4 mm) ^{3} 7T DWI Data

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Introduction:

Although Diffusion-Weighted Imaging (DWI) has become indispensable for non-invasive determination of white matter fiber tracts the fiber orientation in gray matter and across gray-white matter borders is much more difficult to analyze due to the often insufficient resolution and the resulting partial volume effects. As recently shown (1), ultra-high field MRI with its superior signal-to-noise ratio is a promising approach to increase the resolution of DWI and resolve diffusion behavior in gray matter. But the analysis and visualization of neuronal structures when fibers cross or touch is still discussed. Therefore, we applied spherical de-convolution that has the potential to resolve several fiber orientations within one voxel to high resolution DWI at 7T (2, 3). We acquired DWI with 1.4 mm isotropic resolution which is optimal when no data are averaged. (4)

Methods:

The protocol included a high-resolution anatomical scan (MPRAGE, 0.8 mm^3 isotropic, whole head), DWI (12 healthy volunteers, 7 T whole-body MR scanner [Siemens Healthcare, Germany] equipped with a 70 mT/m gradient coil, slew rate of 200 T/m/s). A 32-channel phased-array head coil (Nova Medical, USA) and an optimized Stejskal Tanner sequence with monopolar plus gradient scheme served for DWI. (5). 137 data sets were acquired per subject, 128 diffusion-weighted, b-values 0, 1000 s/mm², and 9 un-weighted images (to realign each of the 17 weighted data sets. The Post-processing was performed with FSL and the EPI distortions were corrected acquiring an additional field map (6). Other image parameters were: GRAPPA (factor of 3, 36 reference lines, 6/8 partial Fourier mode), bandwidth of 1526 Hz/Pixel (echo spacing of 0.76 ms), TE = 54.8 ms, monopolar diffusion gradient scheme, base resolution 156*156, 98 slices, field of view 220 mm. The whole brain including the cerebellum was covered. Tensors, Fractional Anisotropy, Eigenvalues and spherical de-convolution maps resulting in maps of fiber orientation distribution (FOD) were calculated using MRTrix 0.2 (7). Registered DW images were finally registered on anatomic images. The transformation matrix was additionally used to correct the DWI-vector scheme.

Results:

Gray and white matter could be clearly differentiated in the FOD maps of all volunteers. This was confirmed when overlaying FOD maps on anatomic maps (fig. 1). Multiple fiber orientations can be seen more unambiguously in gray matter and at gray-white matter borders (fig.1) as compared to standard direction encoded color maps (DEC) where only the direction of the largest Eigenvector is depicted (7). The orientation in gray matter varies strongly depending on the local complex folded structure (fig. 1 b, d, e) (1, 8).

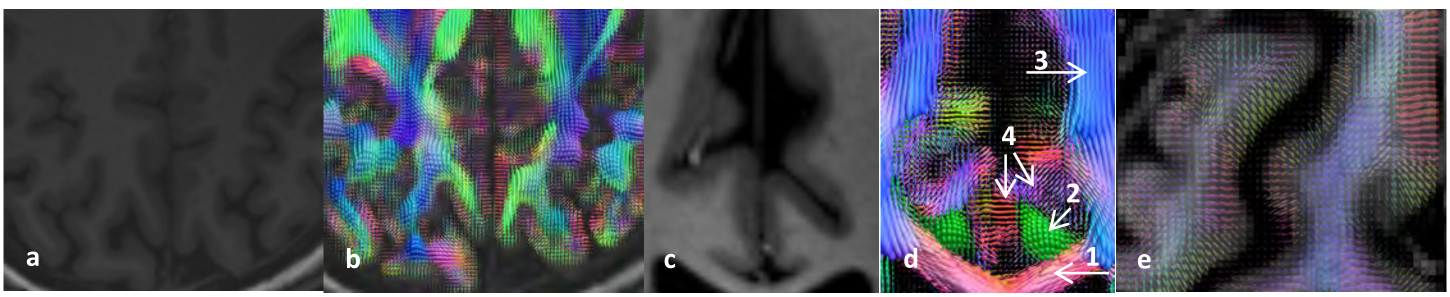

Fig. 1: Axial slice of a high resolution (0.8 mm isotropic) anatomic MPRAGE (a), overlaid with voxel-wise fiber orientation distribution (FOD; red: left-right, green: head-feet, blue: up-down) resulting from spherical de-convolution (b). Close up (coronal orientation) showing large white matter tracts (corpus callosum [red, 1], cingulum [green,2] and superior corona radiata [blue, 3]) surrounded by folded cortical gray matter [4]. Fiber orientation in white matter, at gray-white matter boundary, and within gray matter (e). The fiber orientation density within gray matter and from gray into white matter is clearly visible, sharp bending's are seen especially at the rims (e).

Discussion:

To fully profit from high resolution data, anatomic and DTI images have to be registered due to their different geometric distortions and the DWI vector scheme has to be corrected accordingly. 1.4 mm isotropic resolution depicted to enough gray matter voxels to reduce partial volume effects and to resolve more reliably the fiber orientation in gray matter. Gray matter fibers are oriented mainly perpendicular to the outer surface of the complex folded cortex (best seen in fig. 1d in the cingulate gyrus surrounding the cingulum). Using FOD maps may be therefore a promising approach to gain more insight into neuronal structures when entering or leaving gray matter or building smaller connections between different brain areas.

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