High resolution whole brain diffusion imagining at 7T for the Human Connectome Project

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Target Audience: Clinicians and researchers interested in diffusion imaging at 7T.
Purpose: To optimize high resolution whole brain diffusion imaging at 7T.
Introduction: Mapping the structural connectivity in healthy adults for the Human Connectome Project (HCP) benefits from high quality, high resolution, multiband (MB)-accelerated whole brain diffusion MRI (dMRI) [1,2]. Higher fields provide higher SNR and the opportunity to acquire at higher resolution [3], however, this comes at the cost of increased B_1^+ inhomogeneity (resulting in signal loss in cerebellar and temporal lobe regions) and SAR (limiting our ability reduce TR or accelerate). This abstract describes the steps we have taken to facilitate high resolution, whole brain dMRI at 7T.
Methods: High resolution dMRI was acquired using the following spin-echo EPI parameters: TR=7000ms, TE=65.6ms, 1.05mm isotropic voxels, FOV = 210x210 mm^2, echo spacing = 0.82ms, IPAT=3, MB=2, PE_{shift}=2, PF=6/8, b=1200, # of dirs = 143, and scan duration of ~18 minutes per PE direction. To ensure whole brain coverage, 132 slices were acquired, which required custom modification to both pulse sequence and reconstruction code to overcome the vendor specific 128 slice limit. Low SAR fat suppression was achieved using 5ms excitation and 10ms refocusing RF pulses [4]. Peak power and online (vendor specific) SAR measurement overestimations were reduced using ~2ms time shifted MB RF pulses [5]. To enhance the B_1^+ in the cerebellum and temporal lobes, high permittivity pads, consisting of a suspension of calcium titanate powder ($\varepsilon_r \approx 110$) were placed under the neck and on both sides of the head [6]. A 32 channel receive and quadrature transmit coil (Nova Medical, Wilmington, MA) was used on a Siemens Magnetom 7T body gradient system (70mT/m, 200mT/m/s). Images were acquired from four subjects. One subject was scanned with and without pads and three were scanned on both the 7T and the custom HCP 3T Skyra for comparison.
Results and Discussion: Low SAR fat saturation and time shifting enabled an MB acceleration factor of 2 and a TR of 7000ms without compromising the slice bandwidth or profile. Without these, TR and acquisition time would have increased by at least 70% (~32 mins) to stay within SAR limits. Figure 1 shows the effect of the dielectric pads on B_1^+ (AFI [7]; top row) and image quality (bottom row). Without the pads, flip angles in the cerebellum are ~1/4th of the nominal flip angle resulting in low signal/tissue contrast in the cerebellum. With the pads, flip angles in cerebellar regions increase on average by a factor of 2 corresponding to a 4-fold increase in image SNR relative to without the pads. Figure 2 compares factional anisotropy (FA) weighted DTI maps from the HCP 3T (1.25mm, top) and 7T (1.05mm, bottom). The 7T data provides excellent detail including layer specific regions of low FA along the gray-white matter boarders previously only shown in high-resolution human data ex-vivo [8,9]. Figure 3 compares a zoomed in coronal view of the principle diffusion from both the HCP 3T (left) and 7T (right). The improvement in spatial resolution at 7T enables visualization of the white matter tracts making sharp turns into cortex, which are much harder to see in the 3T data.

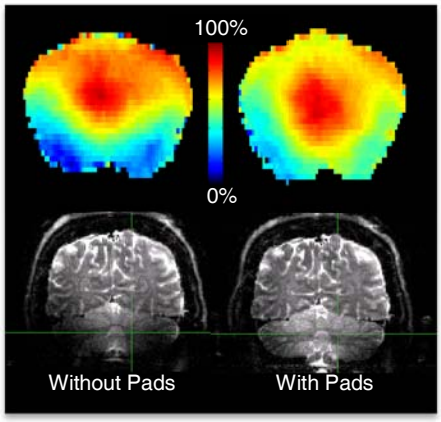

Figure 1: Effects of dielectric pads
AFI flip angle maps (top) and 7T b=0 in-vivo images (bottom)

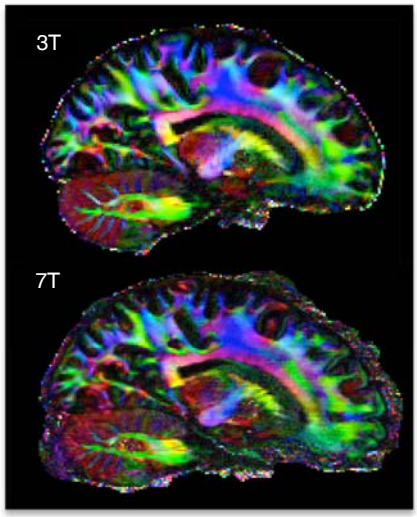

Figure 2: 3T vs 7T whole brain MRI (Pricipal direction of diffusion).
3T 1.25mm (top) 7T 1.05 mm (bottom) from the same subject. The 7T data provides exquisite detail despite the stronger gradients on the HCP 3T Skyra (100 vs 70 mT/m).

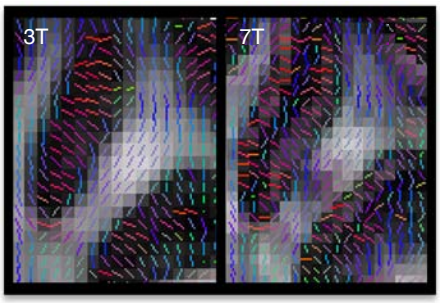

Figure 3: Enhanced layer specific cortical diffusion information at 7T in-vivo.
3T (left) 7T (right) Dark bands of low FA at the gray-white matter boundaries accompanied by fibers turning sharply into cortex become visible at 7T (coronal slice).

Conclusion: With careful optimization of SAR and B_1^+ at 7T, high resolution, high quality, whole brain diffusion weighted imaging is achieved in less than 20 minutes. The higher spatial resolution enables visualization of cortical layer specific anisotropy and FA previously only seen in ex-vivo human studies. It should be noted that while high quality high SNR diffusion data can be generated at 7T, the HCP 3T acquisitions benefit from higher gradient strengths and relaxed SAR limits, putting the 7T acquisitions at a significant disadvantage. Improvements in gradient performance at 7T, along with parallel transmit technology to reduce SAR at 7T [10], will only improve the 7T data further. For the HCP, we will evaluate whether there is benefit of combining information from 3T and 7T diffusion data.

References: [1] Van Essen et al. NeuroImage 2013; [2] Sotiropoulos et al. NeuroImage 2013; Yacoub et al. MRM 2001; [4] Ivanov et al. MRM 2010; [5] Auerbach et al. MRM 2013; [6] Teewisse et al. MRM 2012, [7] Yarnykh MRM 2007; [8] Miller et al. NeuroImage 2011; [9] Leuze et al. CerebCortex MRM 2012 [10] Wu et al. MRM 2013

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