Localized High Resolution DTI of the Human Brain Using Parallel Imaging and Outer-Volume Suppression at 7T

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Introduction

Diffusion Tensor Imaging (DTI) uses diffusion weighting gradients to identify variations in tissue diffusivity and white matter fiber orientations in the brain. Such information can provide insight into connectivity between brain regions that are functionally integrated, as well as identify changes in white matter structure that result from disease or injury. The challenge with DTI is first, the large data sets required to obtain diffusion information along several orientations for unambiguous mapping of brain white matter organization, necessitating rapid imaging techniques such as single shot EPI to keep scan times within reasonable durations. EPI, however, is sensitive to susceptibility variations that result in potentially significant geometric distortions, signal blurring, and dropout that worsen at higher field strengths such as 7T. Physiological and patient motion are also a constraint due to the long scan duration despite EPI acceleration, and sensitivity of the diffusion weighting gradients to phase variations. Use of parallel imaging has provided improvements in overall DTI image quality by further accelerating acquisitions, enabling improvements in DTI resolution [1,2]. Reduced-FOV methods have the potential to further diminish data set sizes by constraining the imaging to localized regions [3]. In this study, we explore the combination of outer-volume suppression (OVS) with parallel imaging at 7T to explore localized DTI in the human brain. The combination provides a potential approach to achieve high quality, high-resolution DTI images using single shot EPI.

Methods

OVS Design – Reduced-FOV using Outer Volume Suppression (OVS) was achieved using two repetitions of RF pulses that excite slabs right and left of the target FOV, with subsequent gradient spoiling after each pulse pair set to 40 mT/m and 16 ms duration. A frequency modulated RF pulse was applied for each repetition with linear phase distribution and 90 and 160 degree pulse angles to achieve a 100 mm slab thickness.

DTI Scans – DTI combined with OVS was performed on a 7T Philips System using a 32 channel receive array with volume coil transmission on two human subjects. All scans applied a b-value of 1000 s/mm^2, six diffusion directions along (0, 1, ±1), (±1, 0, 1), and (±1, 1, 0) using a single shot EPI sequence with resolutions of 2x2x2 mm^3 and 1x1x2 mm^3 targeted separately. Imaging was localized to the basal ganglia, lentiform, sagittal and coronal midbrain with a TR of 3000 ms, TE of 64 ms, SENSE factor of 2, NSA of 20 and 40 with 7m6s, and 14m3s for the respective resolutions. FOV sizes were further diminished to 60x60 to 90x90 mm^2 using OVS. Mean diffusivity, ADC and color-coded FA maps were generated, with mean FA and ADC values calculated in various regions.

Results

DTI-OVS using single shot EPI produced images with no visible fold-over artifacts and largely no EPI distortions or blurring with the exception of slight warping of the pons (figures 1 and 2). Resolution improvements corresponded to a four-fold reduction in voxel size for a visible increase in feature definition, isolating striations in the internal capsule, pons, and corpus collosum, and identification of the optic chiasm. Parallel imaging and OVS provided a 4.6 to 7.0 fold acceleration in data acquisition. Mean FA were, on average, 6.7% higher and mean ADC values 5.5% lower at 1x1 mm^2 in-plane versus 2x2mm^2 resolutions, with as high as a 70% difference in FA values in the narrowly visible optic chiasm. Values in a variety of structures were assessed, including the corpus collosum, internal capsule, substantia nigra, pons, crus cerebri, and hippocampus.

Conclusions

The combination of DTI, OVS, and SENSE produced high quality images using single shot EPI enabling resolution to be increased for discernable improvement in feature definition, and improved ADC and FA measurement. Artifacts in the form of distortion, signal loss, and blurring were minimal or not observed, with no change in artifact quality between resolutions. DTI-OVS offers a potential method for highly localizing diffusion measurements in the human brain at high resolution using 7T.

References [1] Jaermann T, MRM 51 (2004), 230-236. [2] Truong TK, Neuroimage 40 (2008), 53-58. [3] Wilm BJ, MRM 57 (2007), 625-630.

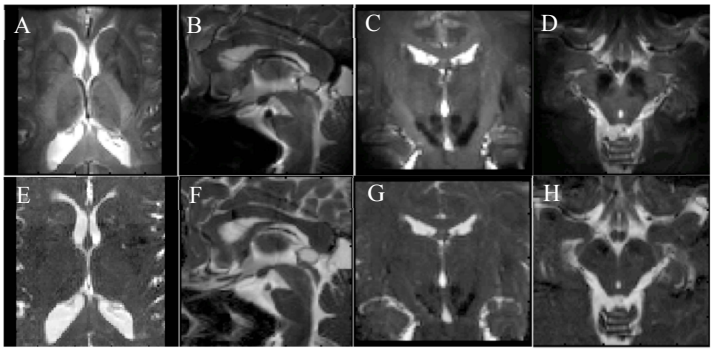

Figure 1 – Non-diffusion weighted DTI-OVS images at 1x1x2 mm^3 in lentiform (A), sagittal midbrain (B), coronal midbrain (C), and basal ganglia (D). (E-H) Corresponding ADC maps at same resolution.

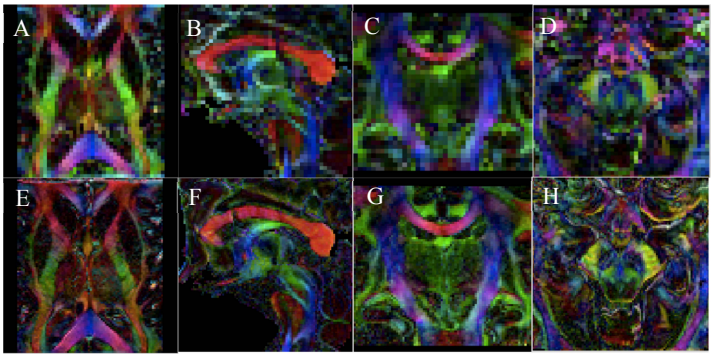

Figure 2 – Color-coded FA maps using principal eigenvectors at 2 mm^3 in lentiform (A), sagittal midbrain (B), coronal midbrain (C), and basal ganglia (D). (E-H) FA maps in same regions at 1x1x2 mm^3 resolution.

Location	FA (2x2 mm^2)	FA (1x1 mm^2)	ADC(mm^2/s) (2x2 mm^2)	ADC(mm^2/s) (1x1 mm^2)
Corpus Collosum	0.697	0.729	9.7×10^{-4}	9.6×10^{-4}
Pons	0.551	0.580	0.0013	0.0012
Optic Chiasm	0.387	0.660	0.0032	0.0016
Crus Cerebri	0.767	0.764	0.0016	0.0014
Substantia Nigra	0.773	0.545	8.9×10^{-4}	0.0015
Internal Capsule	0.792	0.834	0.0015	0.0014
Hippocampus	0.565	0.705	0.0020	0.0015

Table 1 – Mean FA and ADC values at 2x2x2 mm^3 and 1x1x2 mm^3 resolutions in a variety of targeted brain regions using DTI-OVS.