Clinically Feasible NODDI Characterization of Brain Tumor in 5.5 minutes Using Multiband EPI at 7T

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Purpose: Diffusion tensor imaging is a sensitive yet non-specific technique for characterization of brain tumors where tissue is highly heterogeneous. Intact neuron and tumor invading neuron near lesion sites are often masked by vasogenic edema and are not distinguishable by ADC or FA. Recently Neurite Orientation Dispersion and Density Imaging (NODDI) model has been shown to differentiate tissue compartment from CSF and provide realistic neurite density and orientation dispersion estimates,[1] demonstrating a great potential for revealing underlying tissue structure in brain tumor. However, with a two-shell 90 directions protocol its acquisition can take up to 25min. Multiband EPI employs a multiband excitation pulse that simultaneously excites multiple slices. Its utility has been demonstrated in improving temporal resolution in fMRI and for reducing scan time for diffusion spectrum imaging.[2] The goal of this study was to demonstrate the feasibility of acquiring 7T data suitable for NODDI in under 6 minutes with a tailored multiband technique for routine clinical application.

Methods: *Multiband EPI* was conducted on a GE Signa MR950 7T system with 2-channel transmit and 32-channel receive head coil (Nova Medical, Wilmington, MA). Three slices (40 mm apart) were simultaneously excited with a three-band RF excitation and axial SE-EPI readout with phase-encoding in the AP direction, resulting in 60 slices for whole brain coverage with isotropic voxels of $2\times2\times2mm^3$ over a field of view of 256×256 mm^2, an in-plane acceleration factor of 3, ¾ partial Fourier k-space sampling, and TE/TR=71/3000ms. *A two-shell NODDI protocol* included 7 b=0 images, 30 directions at b=1000 s/mm^2, and 60 directions at b=2000 s/mm^2 within a total acquisition time of 5.5 min. Two methodological improvements were implemented to account for the B1 and B0 inhomogeneity at high field: 1) the transmitter gain was automatically adjusted based on the median B1 of the image volume,[3] and 2) susceptibility artifacts were corrected with TOPUP (FSL, FMRIB, Oxford, UK)[4] by adding an extra b=0 image with reversed phase encoding. 3D ARC,[5] an auto-calibrating parallel imaging reconstruction, was implemented to unfold both the in-plane and multiband acceleration. *Subjects:* Two volunteers and one patient with a low-grade glioma (58yo) were scanned with the multiband NODDI sequence described above. Anatomical images (T1 post-contrast, FLAIR, FSE) of the patient were acquired at 3T on the same day and aligned to the 7T images with linear registration.

Results: The TOPUP method adequately corrected susceptibility distortion artifacts at 7T in all volunteers and the patient, facilitating the alignment of diffusion to anatomic images. Figure 1 displays the parameters generated by NODDI: orientation dispersion (OD), intra-neurite volume fraction/neurite density (V_{ic}), and CSF volume fraction (V_{iso}), as well as ADC, FA, and 3T anatomical images for the patient. Within the T2 lesion, FA was low and ADC was high, suggesting the presence of edema. With NODDI, varying intensity in V_{iso} was observed, indicating a spatially varying volume of vasogenic edema within the extracellular space. V_{ic} quantifies the intra-neurite fraction within tissue, in which the hypointense region demonstrates low intra-neurite volume and high extra-neurite volume (including glial cells, dendrites, and somas). The enhancing nodule appears dark in both V_{ic} and V_{iso}, compatible with a large extra-neurite volume.

Discussion: NODDI calculates CSF volume fraction, which in principle separates vasogenic edema from tissue in the peritumoral region. It aims to detangle two key factors, neurite dispersion and neurite density, that contribute to FA. In a brain tumor patient NODDI provided unique contrast within the T2 lesion. Although NODDI does not directly model tumor characteristics, it demonstrates great potential in revealing underlying tissue components that are complimentary to FA and ADC. With the multiband EPI technique, we reduced the acquisition time of this two-shell diffusion sequence to 5.5 minutes, making it clinically feasible. In addition to NODDI, both diffusion tensor and tractography data can also be generated from this protocol. Future work will continue the collection of NODDI data from patients with brain tumors to generate a more detailed quantitative analysis that will provide an insightful interpretation of NODDI images of brain tumor lesions.

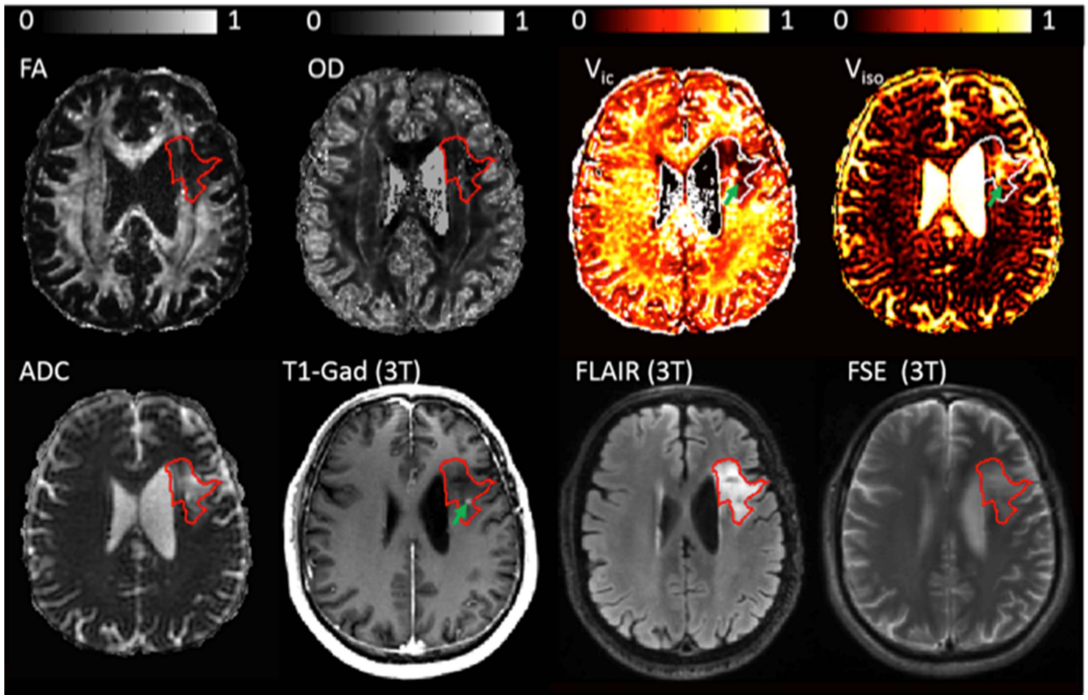

Figure 1. 7T NODDI/DTI and 3T anatomical images of a patient with a low-grade glioma. FA and ADC were fitted with tensor model. OD, V_{ic}, and V_{iso} were fitted with NODDI. T2 lesion is contoured in red. Arrows are explained in the results section.

Reference: [1] Zhang H, et al. NeuroImage 61 (2012) 1000–1016 [2] Uğurbil K, et al. NeuroImage 80 (2013) 80-104 [3] Kelley D, ISMRM 2013 #6456. [4] Andersson J, et al. NeuroImage 2003. [5] Beatty JP, ISMRM 2007 #1749

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