Neurite Density and Diffusion Kurtosis Characterization of Brain Tumors with Accelerated DSI

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Target Audience: Neuroradiologists, oncologists and MR physicists.

Purpose: Compressed sensing (CS) can be applied to accelerate acquisition of diffusion spectrum imaging (DSI) in 15-minutes at 3T with standard receiver arrays [1], which may enable routine, multi-directional fiber-tracking in surgical planning for brain tumors. In addition, the intrinsic multi-b-value sampling of CS-DSI may provide further characterization of the microstructure of brain tumors [2]. In this work, we report on preliminary results applying both kurtosis [3,4] and neurite orientation dispersion and density imaging (NODDI) [5,6] for brain tumor characterization and visualization.

Methods: Fifteen patients with intracranial tumors (mean age 47.4, sd 21.9, 10M/5F) were recruited for imaging at 3T MRI (GE, MR750) using a standard 8-channel brain coil. A 15-minute CS-DSI acquisition was added to a brain tumor protocol, using a single-shot EPI acquisition (FOV=22-24 cm, 128×128 matrix, thickness=3 mm, TR=4-5 s, TE=107-116 ms). CS acceleration factors of R=4 (b=10,000 s/mm^2, 127 diffusion directions, 9 subjects) and R=5 (b=6,000 s/mm^2, 102 diffusion directions, 6 subjects) were applied, trading off q-space fidelity for slice coverage. The data were fitted for kurtosis [4] (limited to b<3000 s/mm^2) and NODDI [6] without CS reconstruction.

The maps selected for analysis included the T2 (b=0) image, standard metrics of ADC and FA, selected kurtosis metrics (maximum apparent kurtosis coefficient, orthogonal and parallel kurtosis), and NODDI metrics (ICVF, orientation dispersion index, and isotropic).Tumor regions were identified on ADC maps and semi-automatically segmented using the ICVF maps [7]. Edema was distinguished from tumor in 4 subjects. Contralateral white matter regions of comparable volume as the tumor were selected on the FA maps. Lateral CSF regions were identified on the ADC and NODDI-isotropic maps.

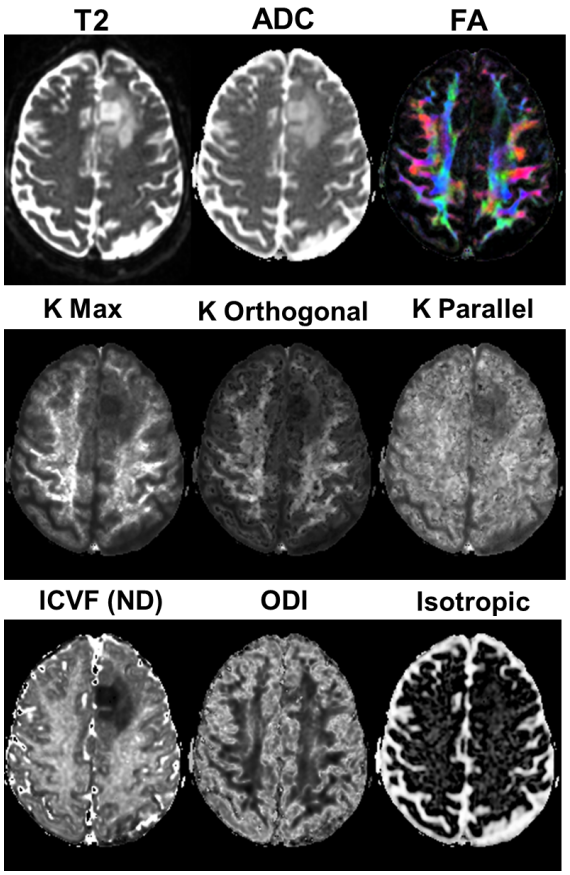

Fig.1. Standard diffusion outputs (T2, ADC, FA), selected kurtosis outputs, and NODDI outputs (intra-cellular volume fraction or neurite density, orientation dispersion index, and isotropic) from CS-DSI of a patient with low grade astrocytoma .

Results: In all subjects, the tumor regions were clearly visualized in the T2, ADC, K Max, K Orthogonal and ICVF maps. Fig. 1 shows the maps that were analyzed from one subject (#15). Quantitatively (Fig. 2), the ADC and the ISO maps were best at distinguishing tumor from CSF (P<0.0001), followed by the T2 maps (P=0.001). The percentage standard deviation (%sd) of ISO-CSF (4%) was three-fold smaller than that for ADC-CSF (13%). 3/4 of the edema labels appeared clustered, while 1/4 appeared to be CSF-like. The %sd of ISO-tumor (79%) was much larger than that of ADC-tumor (32%). FA, K Max and K Orthogonal distinguished tumor from normal tissue (P<0.0001). In both tumor and normal tissue, the %sd of K Max and K Orthogonal were smaller than that of the respective standard maps (T2, ADC, FA). Interestingly, the %sd of all NODDI-tumor maps and NODDI-ODI and ISO maps of normal tissue were all larger than that of the standard maps.

Discussion and Conclusion: The application of CS-accelerated DSI was extended to microstructure characterization using kurtosis and NODDI models. Kurtosis maps and NODDI-ISO may provide additional information to improve tumor segmentation from normal tissue and CSF. The larger spread of NODDI values in tumors may provide added information for tumor classification. This preliminary work motivates further analysis of tumor sub-classes, and machine-learning methods to improve tumor segmentation and classification.

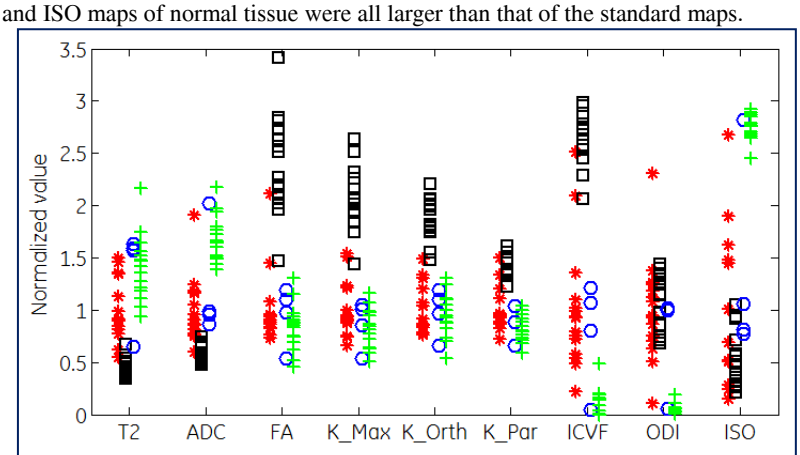

Fig.2. Diffusion values for tumor tissue (red *), normal contralateral tissue (black □), edema (blue °), and CSF (green +), normalized to the population mean for tumor tissue.

References: [1] Menzel MI, Magn. Reson. Med. 2011;66:1226-33. [2] Wen Q, Proc. ISMRM 2015; 4448. [3] Jensen JH, Magn. Reson. Med. 2005;53:1432-40. [4] Sperl JI, Proc. ISMRM 2011; 4011. [5] Zhang H, NeuroImage 2011;56:1301-15. [6] Zhang H, NeuroImage 2012;61:1000-16. [7] Yushkevich PA, Neuroimage 2006;31:1116-28.