Application of compressed-sensing-accelerated diffusion spectrum imaging in patients with brain tumors

Ek T Tan[1], Robert J Young[2], Kyung K Peck[2,3], Xiaofeng Liu[1], Jonathan I Sperl[4], Mehrnaz Jenabi[2], and Luca Marinelli[1]

[1]GE Global Research, Niskayuna, NY, United States, [2]Radiology, Memorial Sloan Kettering Cancer Center, New York, NY, United States, [3]Medical Physics, Memorial Sloan Kettering Cancer Center, New York, NY, United States, [4]GE Global Research, Garching, Munich, Germany

Target Audience: Neuroradiologists, neurosurgeons and MR physicists.

Purpose: In regions where white matter (WM) tracts cross, merge or diverge, deterministic tractography employing conventional diffusion tensor imaging (DTI) acquisition[1] often fails to reconstruct individual WM bundles and instead reconstruct erroneous or truncated pathways. Tractography in patients with brain tumors are susceptible to further compromise by mass effect from the tumor or peritumoral vasogenic edema, tract infiltration, and/or destruction. This study compares compressed-sensing-accelerated diffusion spectrum imaging[2] (CS-DSI) vs. DTI in such patients. We hypothesize DSI[3-4] will provide superior visualization of WM tracts in regions of crossing-fibers and low diffusion anisotropy.

Methods: Ten patients with intracranial tumors (5M/5F, mean age 49.7 S.D. 23.5) were recruited for imaging at 3T MRI (GE, MR750). The imaging protocol included a 5-minute conventional DTI (25 directions, b=1,000 sec/mm^2, FOV=26 cm, 128×128 matrix, thickness=3 mm, TR/TE=11000/64 msec, ASSET R=2), and CS-DSI accelerated at factors of R = 4 (7 subjects) and R = 5 (subjects #7, 8, 10) to achieve scan times under 14 minutes (11-cube q-space, b = 10,000 sec/mm^2, TR/TE = 5000/116.2 msec). As compared to the R = 4 CS-DSI (127 directions, 27-34 slices), the R = 5 acquisition traded-off q-space fidelity for slices (102 directions, 42-50 slices). DSI images were CS-reconstructed offline on parallelized code[2] written in Matlab (Mathworks, MA, USA). Tract visualization was performed using Trackvis (Wang, MA, USA). The angle thresholds were set to 60° (DTI) and 38° (DSI).

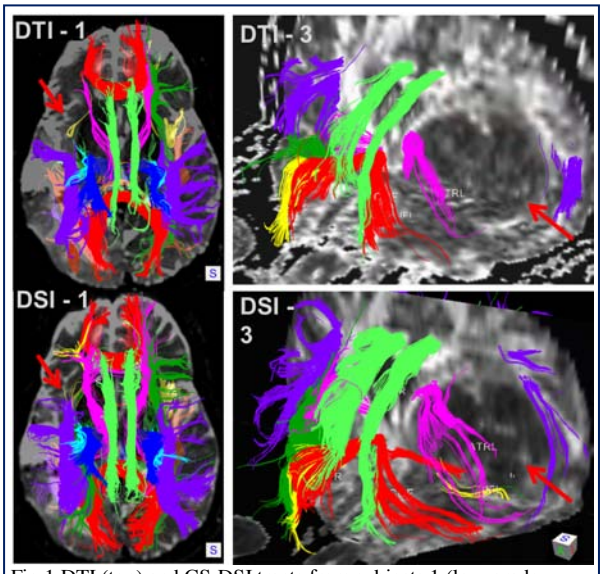

Fig.1.DTI (top) and CS-DSI tracts from subjects 1 (low-grade oligoastrocytoma, axial T2 overlay) and 3 (anaplastic astrocytoma, oblique FA overlay), showing increased tract density with DSI in peritumoral regions (arrows). SLF: purple.

In addition to qualitative visual assessment, we analyzed the superior longitudinal fasciculi (SLF), which are associated with both language and crossing-fiber regions. The ratios of dependent measures between the left and right SLFs were hypothesized to deviate from unity due to pathology; i.e., a track count ratio TC<0.9 or a fractional anisotropy ratio A<0.9 were observations consistent with mass/edema effect affecting only the left SLF, but were inconsistent if only the right SLF was affected. The conditions for the opposite side were TC>1.2 and A>1.1. Six of the subjects were deemed to have pathology that affected only either SLF (4 left, 2 right). The tracts (22 sets) were semi-automatically segmented using only two spherical ROI seeds per tract without exclusion criteria.

Table 1. Track count (TC) and anisotropy (A) ratios between left and right SLFs in ten subjects. Green/yellow indicate observation consistent/inconsistent with pathology (SLF affected in 6/10 subjects). Inconsistency (*) was due to inadequate slice-coverage of the SLF.

#	Cons-istent	Incon-sistent	DTI		CS-DSI	
			TC	A	TC	A
1	Left	Right	0.90	0.43	1.18	0.50
2	Right	Left	0.89	1.09	1.59	1.03
3	Left	Right	1.00	0.84	0.84	0.87
4	None	R,L	0.50	0.80	0.81*	0.97
5	None	R,L	0.54	1.03	1.04	1.00
6	None	R,L	0.57	1.08	0.91	1.04
7	None	R,L	1.10	0.97	1.09	1.04
8	Right	Left	0.66	1.01	2.21	1.00
9	Left	Right	1.04	0.89	0.62	0.98
10	Left	Right	0.66	0.84	0.95	0.87

Results: In all subjects, DSI provided superior tract visualization to DTI. Increased tract density and anatomical accuracy were observed with DSI in peritumoral regions (Fig. 1). Table 1 shows that the dependent measures made with DSI were consistent with pathology affecting the SLF (6/6 subjects); inconsistent observations with DTI was seen in 4 subjects, compared to just one in DSI that was due to inadequate slice-coverage of the SLF. Visually, the SLF tracts from DSI had fewer stray tracts branching into fiber crossings, primarily the corona radiata (Fig. 2). Each SLF bundle was also more consistent in its fiber directionality.

Discussion and Conclusion: CS-accelerated DSI was completed in clinically feasible times in patients with brain tumors without motion artifact. CS-DSI outperformed DTI in visualizing abnormal WM tracts in all patients. These preliminary results suggest that CS-DSI is useful for preoperative planning purposes, particularly for patients with large tumors and/or peritumoral abnormalities that may adversely limit tract reconstruction in DTI. Since track counts have been correlated with hypoxia and cellular proliferation in glioblastoma[5], futher work will also investigate the potential role of CS-DSI to improve glioma grading and margin delineation.

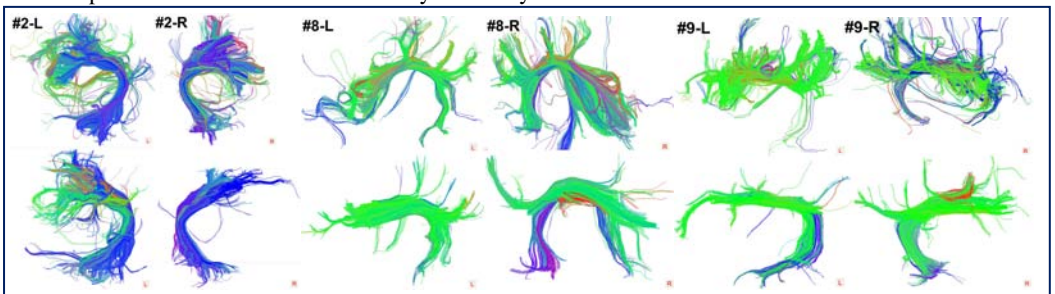

Fig.2. SLF tracts obtained from DTI (top) and CS-DSI (bottom) in 3 subjects (#2, 9 with CS R=4, #8 with CS R=5, #2: right frontal glioblastoma, #8: right frontal oligodendroglioma, #9: left frontal astrocytoma), showing markedly reduced stray tracts and directional consistency. The color indicates the direction of the middle segment of each track.

References: [1] Mori S, Annal. Neurol 1999;45:265–9. [2] Menzel MI, Magn. Reson. Med. 2011;66:1226-33. [3] Wedeen VJ, Magn. Reson. Med. 2005;54:1377–86. [4] Verstynen T, J. Neurophysiol 2011;105:336-46. [5] Barajas RF Jr, AJNR Am J Neuroradiol. 2013;34:1319-25.