Robust Automated Tractography of the Brain using Diffusion Spectrum Imaging

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Target Audience: Radiologists, neurologists, psychiatrists, psychologists, MR physicists.

Purpose: Diffusion tractography[1-3] of the brain provides exquisite information regarding white matter structures non-invasively. Tractography processing remains a manually-intensive and operator-dependent process, however, requiring detailed knowledge regarding brain anatomy for placement of ROI seeds and editing of false positive tracts. In addition, conventional diffusion tensor imaging (DTI) is poor at resolving crossing-fiber regions, which increases task complexity of manual tractography. Therefore, a robust, automated seeding method that also resolves crossing-fibers will improve workflow and increase reproducibility of brain tractography. In addition, the seed placement should be easily manipulated on a manual basis.

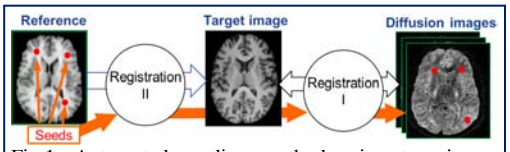

Fig.1. Automated seeding method using two image registration steps to generate tractography automatically.

Methods: A robust auto-tractography method is proposed (Fig. 1), whereby seeds are manually placed on a reference brain image by a user familiar with brain tractography. The reference is registered to an undistorted target image, which is in turn registered to the diffusion images. The seeds are transformed to the coordinate system of the target image. For simplicity, each seeding ROI is a sphere characterized by its position and its radius relative to the imaging FOV. Fig. 2 shows (a) whole-brain tractography and (b) the auto-seeding ROIs created. A tract template defines segmented tracts as logical functions (such as AND and NOT) of the ROIs to generate (c) the automated tractography. Finally, the spherical ROIs are (d) manually-adjusted to optimize for tract visualization.

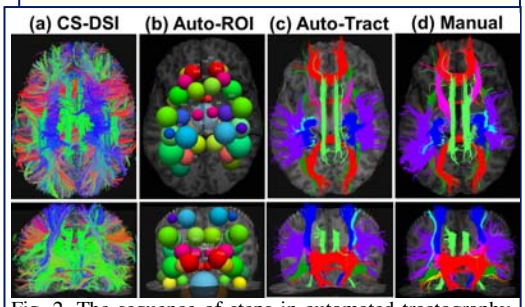

Fig. 2. The sequence of steps in automated tractography, showing (a) whole-brain CS-DSI tractography in a normal subject, (b) positions of automated seed ROIs, (c) the resulting tracts generated, and (d) the same tracts after manual adjustments. Top row: axial, bottom row: coronal.

An R=4, compressed-sensing-accelerated diffusion spectrum imaging (CS-DSI) acquisition[4] was performed, which can resolve crossing-fibers. Six healthy subjects (mean age = 20.8, SD = 2.9; 4M/2F), and seven patients with schizophrenia (mean age = 22.1, SD = 3.7; 4M/3F) were imaged at 3T MRI (GE, HDx) with a 3D T1 acquisition (FOV = 24 cm, TR/TE = 7.8/3.0 msec, TI = 650 msec) and a 26-minute CS-DSI (127 directions, b = 6,000 sec/mm^2, FOV = 24 cm, 128x128 matrix, thickness = 3 mm, TR/TE = 12 sec/125-134 msec, 27-31 slices). The DSI data provided direction count (C) and multi-directional anisotropy[5] (A) as dependent measures. Tractography was visualized using Trackvis (Wang, MA, USA).

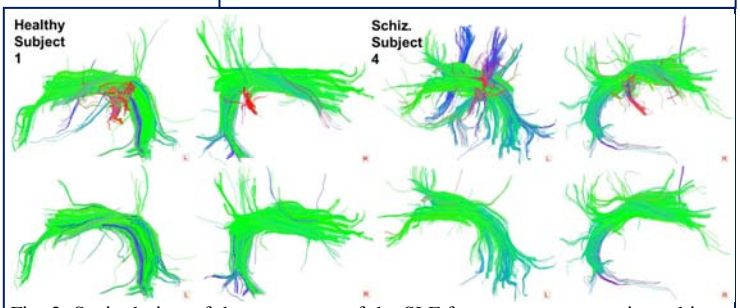

Fig. 3. Sagittal view of the auto-tracts of the SLF from two representative subjects before (top row) and after (bottom row) manual adjustment of the seeded ROIs. Tract color indicates the direction of the middle segment.

While the tract template had 47 spherical ROIs and 22 tracts (superior longitudinal fasciulus or SLF, cingulum, inferior longitudinal fasciculus, inferior-frontal-occipital fasciculus, uncinate fasciculus, commissural fibers, motor hands, feet, anterior thalamic radiation), quantitative analysis was performed only on the SLF that traverses several crossing-fiber regions. The SLF was defined with 3 ROIs per hemisphere. The ROI radius was kept constant, and ROIs were neither added nor removed. The tract length (L), A, and C were recorded.

Results: Fig. 3 shows auto-tracts and the effects of reduced false positives after manual adjustment. Across all 13 subjects, the mean distance moved for each ROI was 8.2 mm (SD = 1.0mm). Table 1 summarizes the dependent measures, showing a significant increase in track length after manual adjustment. Manual adjustment also increased anisotropy and decreased fiber direction count, which reflect a reduction in false positives. Compared to healthy subjects, patients had significantly shorter left SLF tract length and an absence of normal asymmetry in SLF fiber direction count.

Discussion and Conclusion: The proposed, automated tractography scheme demonstrated robustness on CS-accelerated DSI datasets in healthy and patient subjects. This simplifies tractography processing, provides tract-dependent diffusion measures that resolve fiber-crossings, and may improve reproducibility. Moreover, these findings, while preliminary, suggest involvement of the SLF in patients with schizophrenia early in the course of illness as assessed using DSI.

Table 1. Summary of SLF mean length (L), anisotropy (A) and direction count (C). Shaded entries indicate paired (gray) or two-group (cyan) t-tests, with * indicating statistical-significance (P < 0.05).

	Healthy (N=6)			Schizophrenia (N=7)			Schiz. vs. Healthy		
Measure:	L (mm)	A	C	L (mm)	A	C	L (mm)	A	C
Mean (Auto)	44.7	0.48	1.76	38.6	0.47	1.74	-6.2	0.00	-0.01
Mean (Manual)	60.9	0.49	1.73	53.9	0.49	1.72	-7.0	0.00	-0.02
Mean (Manual - Auto)	16.2*	0.02	-0.02	15.3*	0.02	-0.03	-0.9	0.00	-0.01
Mean (Left)	64.3	0.50	1.68	54.6	0.49	1.73	-9.6*	-0.01	0.05
Mean (Right)	57.6	0.48	1.79	53.1	0.49	1.70	-4.5	0.01	-0.09
Mean (Left - Right)	6.7	0.02	-0.11*	1.5	0.00	0.03	-5.2	-0.02	0.14*

References: [1] Mori S, Annal. Neurol 1999;45:265–269. [2] Jones DK, Magn. Reson. Med 1999;42:37–41. [3] Basser PJ, Magn. Reson. Med 2000;44:625–632. [4] Menzel MI, Magn. Reson. Med. 2011;66(5):1226-1233. [5] Tan ET, ISMRM 2012, 3589.