Variability analyses of Track Density Imaging

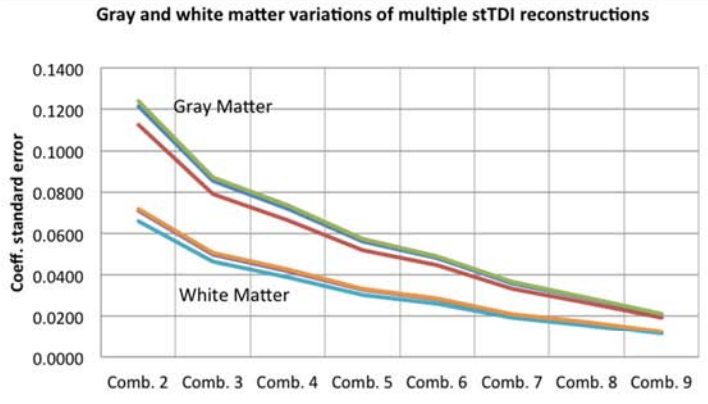
Javier Urriola Yaksic[1], Nyoman Dana Kurniawan[1], Zhengyi Yang[2], and David Charles Reutens[1]
[1]*Centre for Advanced Imaging, The University of Queensland, Brisbane, Queensland, Australia,* [2]*Information Technology and Electrical Engineering, The University of Queensland, Brisbane, Queensland, Australia*

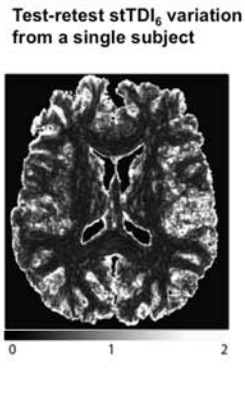
Background: Track density imaging (TDI) mapping method has been developed to dramatically increase the spatial resolution of diffusion-weighted imaging (DWI) data beyond the acquired resolution (*1*). Besides clear visualization of white matter tracks, TDI produces superior visualization of brain microstructures such as the thalamic nuclei and cortical gray matter compared to diffusion tensor parametric maps and T_1-weighted images. However, it is not clear if TDI maps can be used to reliably to quantify differences in brain populations as different profiles were obtained when multiple TDI reconstructions were performed on a single dataset (*2*).

Purpose: To determine the characteristic of short track TDI (stTDI) (*3*) in terms of stability and reproducibility as a quantitative tool for group comparison of brain structures. stTDI was chosen over full-length tracks TDI to minimize cumulative error produced in long-range probabilistic fibertracking.

Methods: DWI data of 3 healthy adult subjects were acquired using a Siemens 3T Trio Tim MR scanner (Siemens, Erlangen, Germany) using 32 channel head coil. High angular resolution diffusion-weighted images (HARDI) were acquired using a twice-refocused bipolar diffusion spin-echo sequence, with 2.5 mm isotropic resolution, TE/TR = 112/9400ms, partial FT 6/8, GRAPPA acceleration factor 2, 64 diffusion gradients with the b = 3000 s/mm^2. The HARDI acquisition time was 10 min 41 s. This acquisition was performed twice to measure intra-subject reproducibility. HARDI data were processed using MRTrix 0.2.10 constrained spherical deconvolution (CSD) with maximum harmonic level (l_{max}) 8. In each dataset, five-million whole-brain short-tracks were generated 10 times using probabilistic fibertracking with step size = 0.25 mm, curvature = 45^o, FOD cutoff 0.1, and min/max track length 5/25 mm. Each corresponding stTDI maps were reconstructed using a grid size of 0.25 mm. Subsequently, average and standard deviation images were calculated in eight trials. Each trial consists of five synthetic datasets, each created from an average of 2 to 9 randomly selected stTDI maps. The variability of TDI values in each trial was calculated as a coefficient of standard error in each voxel, which is defined by the standard error of the five synthetic datasets divided by their mean value. Eighteen brain regions consisted of the whole brain white and gray matter regions and sixteen structural regions from FSL's Harvard-Oxford subcortical structures and the JHU white matter atlases were used to measure regional stTDI coefficient of standard errors.

Results: The combinations of multiple stTDI reconstructions (trial 1-8) showed that the coefficient of standard error decreased as the number of averaged maps increased. The gray matter demonstrated greater variability compared to the white matter, but both achieved the coefficient of standard error < 0.05 when six or more stTDI were averaged (stTDI$_6$). The graphical profile of stTDI standard error suggests the presence of Gaussian random noise that can be reduced by averaging multiple stTDI reconstructions of a single DWI dataset. The comparison of intra-subject variability measured from stTDI$_6$ maps of repeated acquisitions showed that the white matter structures can be reproduced with much lower variability than gray matter structures. For the white matter structures, the test-retest variance on a single subject appeared smaller than inter-subject variances.





	INTRAsubject variance		INTERsubject variance	
ROI	Brain1	Brain2	ACQ1	ACQ2
Body CC	0.000	0.214	1.494	2.822
Brainstem	0.421	0.015	1.317	0.143
Genu CC	0.003	0.717	1.633	0.240
Gray Matter	1.368	3.760	0.192	1.458
L ATR	0.688	0.164	4.494	0.785
L CST	0.109	0.979	5.189	0.917
L Hippocampus	0.529	0.768	5.123	5.821
L Putamen	0.398	0.008	0.043	0.266
Left Thalamus	1.332	0.120	3.761	1.281
M Cerebellar Ped.	0.343	0.160	0.243	0.242
R ATR	0.308	0.038	0.951	0.378
R Caudate	0.000	0.332	0.002	0.404
R CST	0.151	0.683	2.700	0.183
R Hippocampus	0.234	0.539	1.717	2.435
R Putamen	0.066	0.332	4.004	1.364
R Thalamus	1.007	0.132	3.149	1.287
Splenum CC	0.098	0.482	0.073	1.633
White Matter	0.003	0.136	2.578	1.657
	average	0.462	average	1.722

Figure 1. Variability analyses of stTDI. Left: The uncertainty in stTDI can be reduced by averaging multiple stTDI reconstructions. Comb. # indicates the number of averaged stTDI in each combination trial. Middle: stTDI$_6$ test-retest on a single subject, showing the ratio of the absolute differences in stTDI$_6$ between both acquisitions divided by their mean value. High variances in the grey matter/CSF boundaries were observed compared to the white matter. Right: Brain1 and Brain2 correspond to regional variances measured in the stTDI$_6$ within each subject between two MRI acquisitions (intra-subject variance). ACQ1 and ACQ2 correspond to regional stTDI$_6$ intensity variations between Brain1 and Brain2 measured in two MRI acquisitions (inter-subject variance).

Conclusion: For quantitative stTDI, multiple stTDI reconstructions of a single dataset need to be generated then averaged to minimize variability resulting from probabilistic fibertracking.

References: (1). Calamante F. *et al*., Track-density imaging (TDI): super-resolution white matter imaging using whole-brain track-density mapping. NeuroImage. 2010;53(4):1233-43. (2) Dhollander T. *et al*., Track-density imaging & noise: when super-resolution quality does not yield accuracy. ISMRM abstract 2012. (3). Calamante F. *et al.*, Super-resolution track-density imaging studies of mouse brain: comparison to histology. Neuroimage. 2012;59(1):286-96.