Optimization of Spinal Cord NODDI Protocol with Multi-band EPI for Clinical Use

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Target audience: Researchers and clinicians who investigate the spinal cord by using diffusion-weighted imaging and diffusion metrics.

Purpose: Neurite orientation dispersion and density imaging (NODDI)[1] is a new diffusion analysis method to investigate microstructural architecture of the brain and spinal cord. The original protocol is 2-shell diffusion data with multiple motion probing gradient (MPG) axes. However, its long acquisition time and complex combination of MPGs seem to be little difficult for daily clinical use, some simplified acquisition data sets have been investigated.[2, 3] Recently, multi-band echo-planar imaging (MB-EPI) technique has been introduced for diffusion-weighted imaging as a promising tool to reduce scanning time[4]. The purpose of this study is to investigate the effect of multi-band reduction factor (MBf) of MB-EPI on NODDI metrics and to compare less number of MPG axes 2-shell protocol NODDI metrics with 2-shell 30 MPG protocol in the cervical spinal cord white matter in vivo.

Methods: Spinal cord diffusion datasets with MBf 2 and 3 were each collected from one healthy volunteer using a 3.0T system (Magnetom Skyra, Siemens AG, Erlangen, Germany) using a 20–channel head/neck receiver coil. Imaging parameters for 2-shell diffusion protocol were as follows: repetition time/echo time, 5000/102.4 (ms/ms); number of signals acquired, one; section thickness, 3 mm; 54 slices; field of view, 150 x 150 mm^2; matrix, 150x 150; imaging time, approximately 6 min; 3 *b* values (0, 1000, and 2000 s/mm^2) with diffusion encoding in 30 directions for every *b* value. Δ = 50.6 ms and δ = 19.2 ms for both shells. Spinal cord dorsal and bilateral funiculus white matter tractography from C2-3 to C4-5 level was obtained with the diffusion toolkit and the TrackVis software (www.trackvis.org) and used as white matter mask for NODDI analysis (Figure 1). Six fitting procedures, consists of 30, 24, 20, 15, 12, 6 MPG axes data, were implemented with the NODDI MATLAB toolbox for both MBf 2 and 3 data to estimate NODDI metrics: intra-cellular volume fraction (ICVF), isotropic volume fraction (IVF) and orientation dispersion index (ODI). Voxels within the white matter masks were extracted. Statistical evaluations were performed by using IBM SPSS Statistics software (version 19.0; SPSS, Chicago, IL). P value less than 0.05 was considered to indicate a statistically significant difference.

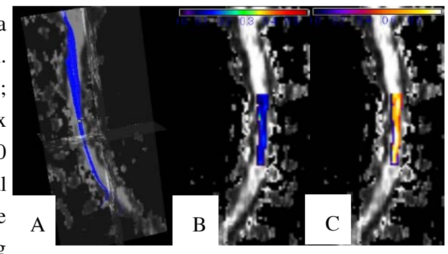

Figure 1: spinal cord dorsal funiculus white matter tractography (A, blue lines), ODI (B) and ICVF(C) of dorsal funiculus white matter on FA map.

Results: Between Mbf 2 and 3 data with 30 MPG axes, there were significant differences in ICVF (mean 0.9554± 0.765 for MBf2 and 0.8234± 0.1793 for MBf3, respectively) ($P< .001$, Mann-Whitney U test) and IVF (0.2467± 0.1530 for MBf2 and 0.2079± 0.1593 for MBf3, respectively) ($P< .001$). However, there was no difference in ODI (0.1676 ± 0.1467 for MBf2 and 0.1604± 0.1375 for MBf3, respectively) ($P=0.472$). Because of mismatch pixels observed in IVF in each MPG axes data, our analysis focused on ICVF and ODI; their values of 30MPG axes and reduced data with MBf2 are shown in Table 1. Pearson's correlation coefficients between 30 MPG axes data ICVF and ODI values and reduced MPG axes data were calculated over the extracted voxels and their results are shown in Figure 2.

	ODI30	ODI24	ODI20	ODI15	ODI12	ODI06
Mean	.1995	.2100	.2147	.1785	.1766	.1182
SD	.1326	.1282	.1353	.0929	.0785	.0738
	ICVF30	ICVF24	ICVF20	ICVF15	ICVF12	ICVF06
Mean	.9554	.9583	.9655	.9501	.9716	.9699
SD	.0765	.0823	.0764	.0943	.0750	.0844

Table 1: ODI and ICVF of each MPG axes data

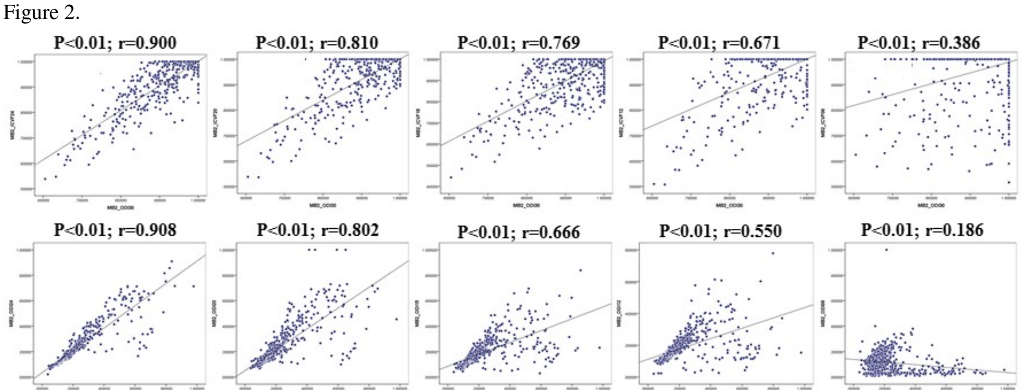

Figure 2: scatter plots and correlations between 30 MPG axes data and less number of MPG data values of ICVF (upper row) and ODI (lower row). In this figure, the X axes represent the 30 MPG data and the Y axes represent corresponding less MPG axes data, 24, 20, 15, 12, 6, from the left to the right.

Discussion and Conclusion: MB-EPI technique is useful technique to reduce scanning time, however, data with higher number of MBf may lead to inappropriate NODDI metrics. Moreover, as less number of MPG axes, ICVF and ODI gradually changes different from 30 MPG data metrics values. More sequence parameters optimization is needed before clinical use, we recommend that more than 24 MPG axes and MBf of 2 for spinal cord NODDI with MB-EPI.

References: 1. Zhang H, et al. NODDI: practical in vivo neurite orientation dispersion and density imaging of the human brain. Neuroimage. 2012;61(4):1000-1016. **2.** Wang Z, et al. The Performance of NODDI Estimation Using a Common 2-Shell Protocol. Proc ISMRM 2014; p.2596. **3.** Grussu F, et al. SINGLE–SHELL DIFFUSION MRI NODDI WITH IN VIVO CERVICAL CORD DATA Proc ISMRM (2014); p.1716. **4.** Xu J, et al. Evaluation of slice accelerations using multiband echo planar imaging at 3T. Neuroimage 2013;83(0):991-1001.