In Vivo Human Spinal Cord Diffusion Tensor Imaging Using Rician Noise Filter

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Introduction: Diffusion tensor imaging (DTI) has been used to successfully show changes in white matter structure and connectivity in human spinal cord for various diseases such as multiple sclerosis [1] and neuromyelitis optica [2]. However, spinal cord DTI suffers from low signal-to-noise ratio (SNR) which plays a large role in yielding the erroneous tensor estimation due to the bias induced by Rician nature of random noise. In this study, we aimed to improve the accuracy of DT-derived metrics by implementing a Rician nonlocal means (NL Means) filter which is known to provide efficiency of noise removal while the fine structures and details of images are well preserved [3].

Methods: Five healthy volunteers (1 male, 4 females; mean age, 32 ± 7years) were studied after signed, informed consent. All studies were approved by the local institutional review board. All scans were performed on a Philips 3T MRI Achieva scanner (Philips Healthcare, Best, The Netherlands) with a body coil excitation and a 16-channel neurovascular coil for reception. Two imaging volumes covered upper and lower portions of cervical spinal cord, C1-C3 and C4-C6, respectively. Four averaged minimally weighted (b_0) and 15 diffusion-weighted (DW) volumes (b=500 s/mm^2) were acquired using single-shot EPI sequence. The imaging parameters were: TR/TE=3000/58ms, nominal resolution=1x1.26 mm^2, 20/10 slices (upper/lower), slice thickness=2.5/5 mm (upper/lower), and total scan time=10/3 min. (upper/lower). All DW images (DWIs) were co-registered to b_0 image using a 6-degree-of-freedom, rigid body transformation procedure supplied in automated image registration (AIR) [4]. Prior to tensor estimation, registered DWIs were denoised by an optimized blockwise NLmeans filter described elsewhere [5]. Subsequently, Rician denoised data were smoothed by additional Gaussian filter with the full width at half maximum of 2.5 mm. The DT was estimated as described in Basser et al [6]. Fractional anisotropy (FA) and parallel/perpendicular/mean diffusivity ($\lambda_{\parallel}$, $\lambda_{\perp}$, MD) were derived using DtiStudio (Johns Hopkins SOM, Baltimore, MD, USA). Chi-square was calculated in a voxel-by-voxel basis to estimate the goodness of fitting using a custom written program in Matlab (Mathworks, Natick, MA, USA). The regions-of-interest (ROIs, Area=1.563 mm^2) of lateral and dorsal columns were manually drawn in FA map using ImageJ (National Institutes of Health, Bethesda, MD, USA) (Fig. 1) and then transferred to the rest of the DT-derived maps in order to compute the average and error measures within the ROIs for each subject. All statistical analyses were performed using commercially available software (SPSS version 18.0.0, Chicago, IL, USA). P-values of 0.05 were considered to be significant.

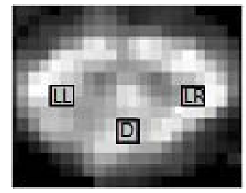

Fig.1. Location of ROIs on the FA map (LL, lateral left; LR, lateral right; D, dorsal).

Results and Discussion: Fig. 2 shows that the averaged Chi-square values over 5 subjects significantly decreased in C1-C6 of Rician denoised data ($p<0.001$ for all ROIs). For lateral column, SNR significantly increased to 67.04% and 107.46% in C1-C3 and C4-C6, respectively ($p<0.001$). Similarly, for dorsal column, SNR significantly increased to 106.10% and 96.39% in C1-C3 and C4-C6 respectively ($p<0.001$). Table 1 indicates that mean FA values significantly decreased (3.64%, $p<0.001$) while MD, $\lambda_{\parallel}$ and $\lambda_{\perp}$ significantly increased (8.21%, $p<0.001$ and 3.79%, 23.70% with $p<0.05$ respectively) with Rician denoising. Our results on reduced mean FA with increased SNR agree well with reports in the literature [7] suggesting that Rician denoising using NLmeans filter reduced estimation error and may provide the capability to more accurately quantify tissue properties in human spinal cord.

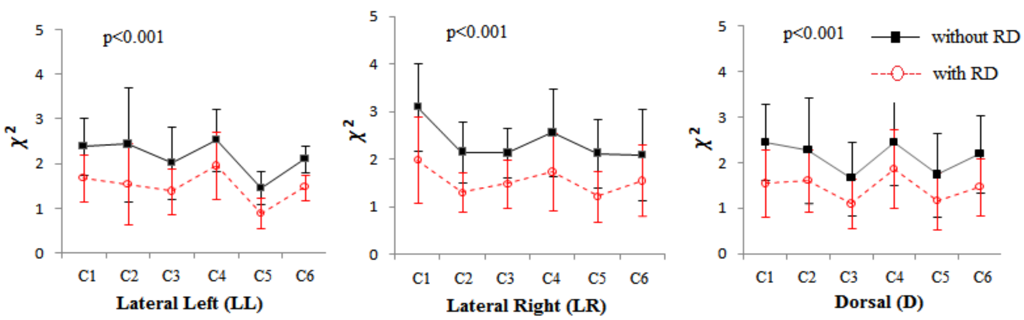

Fig. 2. Chi-Square values (mean ± S.D.) with and without Rician denoising (RD) in the LL, LR and D columns in C1-C6.

	FA[a]			MD[b]			$\lambda_{\parallel}$[b]			$\lambda_{\perp}$[b]		
	LL*	LR*	D*	LL*	LR*	D*	LL*	LR**	D**	LL*	LR*	D*
without RD	0.82 (0.09)	0.81 (0.09)	0.84 (0.07)	0.85 (0.19)	0.84 (0.18)	0.87 (0.18)	1.92 (0.35)	1.88 (0.32)	2.06 (0.34)	0.31 (0.15)	0.31 (0.16)	0.27 (0.15)
with RD	0.79 (0.08)	0.78 (0.09)	0.81 (0.07)	0.93 (0.17)	0.91 (0.15)	0.93 (0.14)	2.01 (0.29)	1.96 (0.25)	2.11 (0.28)	0.38 (0.15)	0.38 (0.16)	0.34 (0.13)

Table 1. Averaged DTI metrics (C1-C6 of 5 subjects) with and without Rician denoising (RD) in the LL, LR and D columns (* $p<0.001$, ** $p<0.05$), a: dimensionless, b: unit, μm^2/ms.

Conclusion: We have demonstrated that Rician denoising filter improved the accuracy of tensor estimation and DTI-derived measures in healthy volunteers. As this technique may be useful to monitor the microstructural changes in human spinal cord while it is easy to implement, future studies should be directed towards the evaluation of ability of DTI in combination with Rician denoising in investigating clinical/neuroscientific applications.

References: [1] Rovaris et al., Neurol, 2005. [2] Qian et al., JMRI, 2011. [3] Coupe et al., TMI, 2008. [4] Woods et al., JCAT, 1998. [5] Wiest-Daessle et al., MRI, 2007. [6] Basser et al., JMRB, 1996. [7] Farrell et al., JMRI, 2007.