Diffusion Tensor Imaging of the Human Optic Nerve in vivo Using SENSE Accelerated Multi-shot 2D Navigated EPI

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INTRODUCTION: Diffusion-weighted imaging (DWI) of the optic nerve has been reported as a useful marker of pathologic changes (1) in, e.g., optic neuritis. Developing quantitative MRI methods to detect subtle changes in the optic nerve, however, is technically challenging because of its motion, small size, proximity to sinuses and confounding signals from surrounding CSF and fat. In addition, when lesions are present, they are often much smaller than the nerve itself. Most methods employed to generate DWI contrast in the human body use single shot (ssh) EPI (2,3), but higher resolution is necessary for studies of the optic nerve. Moreover, ssh DWI/DTI images of the optic nerve suffer residual EPI-related artifacts (blurring and distortions from the long echo train of the EPI acquisition), low SNR and require relatively long acquisition times. In fact, in many cases, ssh DTI of the optic nerve fails to detect the nerve at all. To reduce EPI-related artifacts, we studied DW multi-shot (msh) EPI combined with parallel imaging (SENSE) and 2D navigators for the correction of motion-induced ghosts. Furthermore, with the implementation of 2D navigators, it is possible to correct non-linear phase variations (4). To the best of our knowledge, this is the first report of the use of multi-shot EPI with SENSE and 2D navigators for optic nerve diffusion tensor imaging (DTI).

METHODS: Seven healthy volunteers were studied for both eyes with four repeats using a 3 Tesla Philips Achieva (Philips Medical Systems, Best, The Netherlands) whole body MR scanner with body coil transmission and an 8-element head coil for reception. A diffusion-weighted dual spin-echo 2D navigated SENSE msh EPI sequence and corresponding reconstruction method were developed and applied to this study (5). Prepulses for orbital fat suppression and outer-volume-suppression were used. Imaging parameters were: FOV 100×100 mm, SENSE factor *R*=2, *b*-value=500 s/mm^2, 15 diffusion directions, voxel size (in-plane/slice) 1.5/3.0 mm (ssh,msh) and 1.25/3.0 and 1.25/2.0 mm (msh), TR/TE 2316/39 ms (ssh) and 1790/(68,99) ms (msh image- and navigator-echo) with total scan time of about 7 min for each ssh and msh acquisitions.

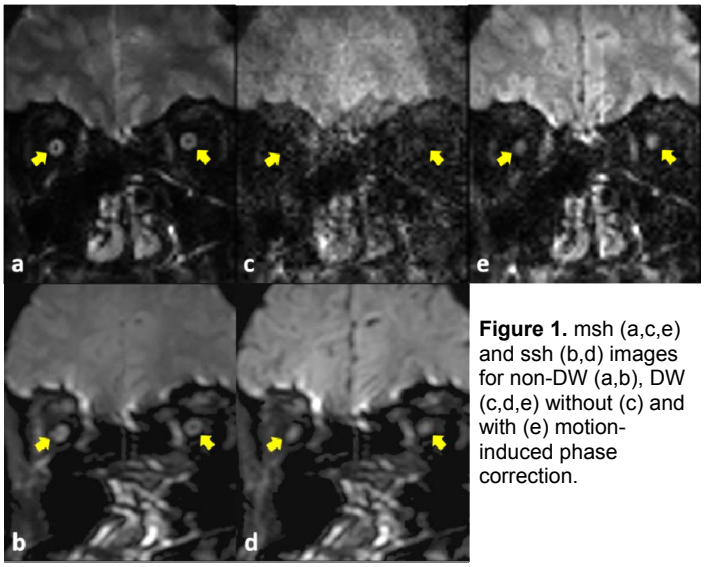

Figure 1. msh (a,c,e) and ssh (b,d) images for non-DW (a,b), DW (c,d,e) without (c) and with (e) motion-induced phase correction.

RESULTS: Figure 1 presents coronal non-DW and diffusion weighted ssh and msh images showing optic nerve regions (yellow arrows). After 2D navigator correction, the msh DW image (e) shows no motion-induced ghosts (as seen in (c)) and much smaller distortions and blurring compared with ssh DW images (d). Mean (MD), parallel ($\lambda_{||}$), and radial ($\lambda_{\perp}$) diffusivities (in μm/ms scale) and FA are presented with standard deviation (in parenthesis) for ssh and msh (1.5/3, 1.25/3, 1.25/2 mm voxels in order) in Table 1. As msh spatial resolution increases, decreased partial volume effects cause diffusivities to decrease and the number of slices visualizing optic nerve increases substantially (data not shown). The average FA across the nerve is expected to be near to what is seen in dense white matter fiber pathways of the spinal cord and brain (FA > 0.6) (6), and as partial volume effects decrease, a concomitant increase in FA (nearer to values for the spinal cord and brain) is seen.

Table 1. Mean MD, FA, $\lambda_{||}$ and $\lambda_{\perp}$.

Data	MD	FA	$\lambda_{||}$	$\lambda_{\perp}$
ssh	1.05 (0.35)	0.56 (0.12)	1.73 (0.55)	0.7 (0.28)
msh	1.37 (0.53)	0.59 (0.14)	2.31 (0.74)	0.92 (0.46)
	1.28 (0.42)	0.62 (0.12)	2.25 (0.75)	0.84 (0.36)
	1.15 (0.37)	0.64 (0.12)	2.04 (0.57)	0.71 (0.33)

DISCUSSION: We demonstrated that a DW 2D navigated msh approach can present clear delineation of human optic nerves *in vivo* within a reasonable scan time. Interestingly, due to decreased artifacts, we can obtain higher resolution (both in-plane and through plane) which decreases the impact of partial volume effects on the observed metrics. It should be pointed out, however, that relatively large inter-scan motion is still possible in msh between diffusion gradients (as in ssh) and shots, and these may affect diffusion measurements. Studies for msh reproducibility are required and currently being performed. We performed all imaging experiments within the same amount of scan time. Therefore, while slower, the msh approaches were not averaged as much as the single shot EPI metrics and had relatively lower SNR. However, we hypothesize that, with increased resolution and robustness to artifact, msh 2D navigated EPI for diffusion MRI can be employed to detect subtle white matter pathology in optic neuritis and multiple sclerosis. Patient studies are currently ongoing which will evaluate the sensitivity of lesion characterization in a cohort of relapsing remitting MS patients.

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