Accelerated Multi-Shot Diffusion Imaging in Optic Nerve

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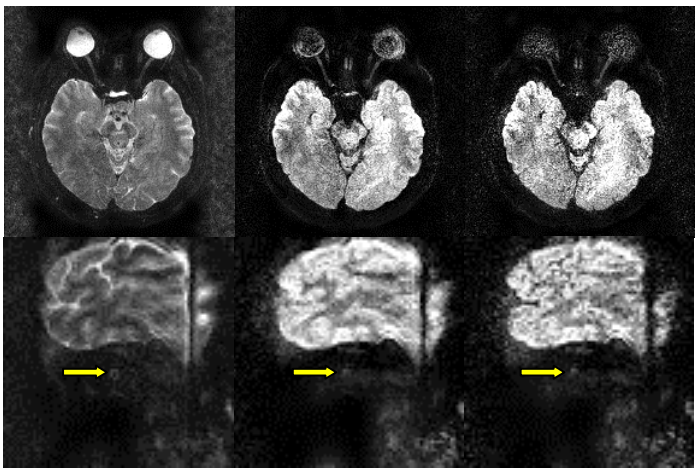
Target Audience: Researchers and physicians interested in fast diffusion imaging of the optic nerve, with improved geometric fidelity.

Purpose: Quantitative MRI of the human optic nerve in vivo is generally quite challenging because of its small size (~3mm), its uncontrolled motion, and the presence of local field inhomogeneities due to large susceptibility variations, such as near the optic chiasm. Diffusion-weighted imaging (DWI) has been used to study the optic nerve because it can reveal microstructural details of white-matter fibers. Single-shot echo-planar imaging (EPI) is employed to obtain diffusion-weighted images within hundreds of milliseconds and is relatively motion insensitive, but images often suffer from significant artifacts such as geometric distortions, signal losses, and blurring. It is due to a low bandwidth acquisition along the phase-encoding direction while local magnetic field variations are present. In addition, high spatial resolution is desirable for optic nerve assessment, which requires longer echo train length that exacerbates severe image artifacts. In this study, we propose to use our recent developed technique, accelerated multi-shot diffusion imaging[1], to achieve high resolution, speed and geometric fidelity in optic nerve imaging. To correct phase inconsistencies caused by rigid body motion or tissue deformation between shots, a low-resolution 2D navigator is collected in each shot, and the phase information is used for motion compensation. Moreover, the magnitude information of the 2D navigator is utilized for regularization purposes during reconstruction in conjunction with accelerated diffusion imaging acquisition. The acceleration is based on the fact that diffusion-encoded data is sparse when represented in the x-y-k_b-k_d space, where k_b and k_d are the Fourier transform duals of b and d, the b-factor and the diffusion direction, respectively. Aliasing artifacts are displaced toward underused regions of the k_b-k_d plane, allowing non-aliased signals to be recovered. Therefore, the accelerated multi-shot diffusion imaging improves image quality, especially in terms of geometric distortion, at potentially no cost in scan time.

Methods: Accelerated multi-shot diffusion EPI scans were performed in three volunteers following IRB-approved informed consent on a 3 Tesla MRI system (MR750w, GE Healthcare) using GEM head/neck coil (GE Healthcare). Imaging parameters were: 11 oblique axial slices to cover both eyes in the same slices, 3mm thickness with no gap, 220mm FOV, 192×192 image matrix size, 1.15×1.15×3mm^3 voxel size, 84.8ms image TE, 167kHz readout bandwidth, 5.86kHz phase encode bandwidth, 32×32 navigator matrix size, 127.8ms navigator TE, 3000ms TR, six-fold segmentation and acceleration. Six-fold segmentation and acceleration improved geometric fidelity without increase in scan time, when compared to conventional single-shot EPI. A total of 12 evenly spaced b-values ranging from 0 to 2,000 s/mm^2, along 6 diffusion directions, were sampled within a total scan time of 3 minutes 45 seconds. Two sets of 15 oblique coronal slices, which were prescribed in perpendicular to the optic nerve in each eye, were also acquired with 4500ms TR. The scan times were 6 minutes 38 seconds each. Total acquisition time was 15 minutes for 3 series, one for oblique axial scan and two for oblique coronal scans.



Results: The diffusion-weighted images with different b-values (b = 0, 545s/mm^2 and 1091s/mm^2, from left to right) shown here are from one of our volunteers. The axial slice which passes though optic nerve of both eyes are shown in the upper raw, and the images show optic nerves clearly with high geometric fidelity. The enlarged coronal diffusion-weighted images are displayed in the bottom of the figure. The positions near subject's left optic nerve are marked with yellow arrows.

Discussion and Conclusion: We have demonstrated that high spatial resolution and low geometric distortion diffusion-weighed images in optic nerve can be obtained with accelerated multi-shot diffusion scans. The coronal images show slightly worse in image quality than the axial images as the high acceleration rate (6-fold) was applied along the AP direction for the coronal scans, and the head/neck coil only has two rings of coil elements along the AP direction. The image quality in coronal view could be improved with 6-fold segmentation and 3-fold acceleration acquisition, which would requires twice of scan time. The scan time can be reduced if fewer slices or less different b-values are needed.

References: [1] Madore et al. Magn Reson Med 2014;72:324.