Enhancing diffusion weighted image (DWI) quality with Navigator-MUSE

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Target Audience: Researchers and clinicians who are interested in high-quality diffusion weighted imaging (DWI) with limited distortions and improved resolution.

Purpose: DWI is an important MRI modality with numerous clinical and research applications. DWI data is typically obtained with single-shot echo-planar imaging (EPI) in order to limit the aliasing artifacts that are often caused by even the slightest movements because of the strong diffusion-sensitizing gradients used in DWI scans. Single-shot EPI based DWI scans, however, have limited spatial resolution and are highly susceptible to geometric distortions (1). Recently, navigated multi-shot DWI approaches have been developed to address these limitations in order to achieve DWI data of higher spatial resolution and accuracy (2,3). However, image quality of multi-shot DWI may still be degraded by residual artifacts resulting from phase variations of high spatial-temporal-frequency. In this work, we propose an improved multi-shot DWI technique that minimizes the residual artifact in high-resolution DWI and is more feasible within clinical time constraints. Specifically, 1) a parallel navigator acquisition is incorporated into multi-shot EPI to measure shot-to-shot phase variations of high spatial-frequency; 2) high-quality DWI images are reconstructed from multi-shot EPI data and navigator-produced phase information using the MUSE algorithm (4), in which coil sensitivity profiles are used as the constraint to stabilize the reconstruction and to suppress residual artifacts due to phase variations of high temporal-frequency. We believe this novel approach, termed navigator-MUSE, will be superior to existing navigated multi-shot DWI methods especially in regions of the human brain like the brainstem that are highly susceptible to artifacts and distortions.

Methods: Data were acquired from healthy adult volunteer using a standard 3T Clinical MRI scanner (General Electric, Waukesha, WI, USA). 16 shot DWI data were acquired with an 8 channel coil. A pulse sequence with parallel-navigator echo (with an acceleration factor of 4) was used to measure shot-to-shot phase variations at high resolution. The 16 shot DWI reconstruction is performed by 1) removing Nyquist artifacts in both 16-shot DWI and navigator-echo EPI, 2) processing navigator signals using SENSE to produce full-FOV navigator echoes in order to estimate shot-to-shot phase variations, and 3) using the MUSE algorithm to reconstruct high-quality DWI images from the 16-shot DWI data with known coil sensitivity profiles and navigator-produced phase variations as the constraints. Since DWI data were acquired with partial-fourier transform, the k-space data were multiplied by a ramp function, termed Homodyne-MUSE (5), before being used as the input of the MUSE reconstruction. Scan parameters for this 16-shot DWI included: TE=50.9 msec, TR= 5 sec, number of overscan k_y lines for partial Fourier acquisition=32, in-plane matrix size= 256 x 256 (after partial-Fourier reconstruction), navigator echo matrix size= 96 x 96 (after SENSE reconstruction), FOV = 21 x 21 cm^2, thickness = 3 mm, and *b*-value= 800 s/mm^2 (axial-plane) and 600 s/mm^2 (sagittal-plane). The total scan time for 1 baseline T2-weighted EPI and 3 DWI images (corresponding to different diffusion gradient directions) was 5 min and 20 sec.

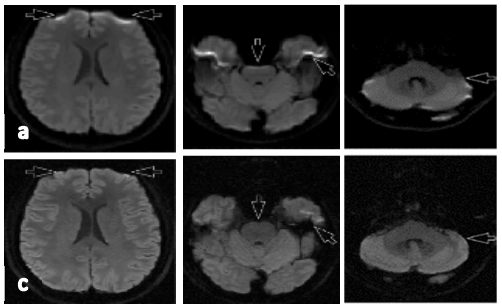

Fig 1. Comparison of DWI data obtained with a) conventional single-shot parallel EPI (2x2x3mm) and c) newly developed navigated-MUSE method (0.8x0.8x3mm)

In addition to 16-shot DWI, two sets of single-shot DWI data (1 x 1 x 3 mm^3 and 2 x 2 x 3 mm^3) were acquired with the conventional single-shot parallel EPI sequence. The imaging parameters for the single-shot EPI DWI included: TE = 65 msec and 79.4 msec, TR= 5 sec, number of overscan k_y lines for partial Fourier acquisition=16, in-plane matrix size= 256 x 256 and 128 x 128 (after partial-Fourier reconstruction), FOV = 25.6 x 25.6 cm^2, thickness = 3 mm, parallel acceleration factor= 2, and *b*-value= 600 s/mm^2. The total scan time for 1 baseline T2-weighted EPI and 3 DWI images (corresponding to different diffusion gradient directions) was 20 sec. Single-shot DWI images were reconstructed using SENSE after correcting for the Nyquist artifact.

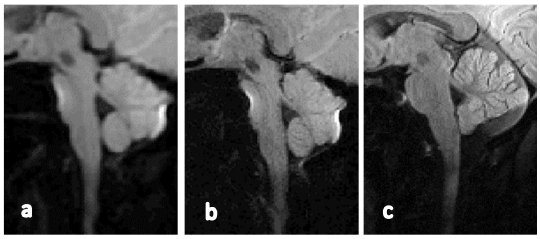

Figure 2. Sagittal view comparison data obtained with a) single-shot EPI (2x2x3 mm^3), b) single-shot EPI (1x1x3 mm^3), and c) navigated-MUSE multi-shot method (0.8x0.8x 3mm^3).

Results: Figures 1 and 2 highlight the advantages of 16-shot navigated MUSE compared to conventional techniques. It can be seen that both the spatial resolvability and accuracy are much improved in the navigated-MUSE images. Specifically, geometric distortions in brain regions affected by susceptibility field gradients are significantly reduced when acquired with the navigated-MUSE DWI technique.

Discussion and Conclusion: The two major concerns with conventional single-shot EPI based DWI protocols are 1) limited spatial-resolution, and 2) pronounced geometric distortions. The experimental data presented above demonstrate that the new navigated-MUSE technology simultaneously addresses both of these limitations to enable higher resolution and minimally-distorted DWI. Typically, due to the time-gap between navigator echoes and actual DWI signal acquisition, phase errors of high temporal-frequency (e.g., due to brain pulsation) may not be accurately measured by the navigator echoes, which results in more pronounced artifacts in certain regions of the brain (e.g., brainstem). One method to minimize these pulsation related artifacts is cardiac gating, but this is done at the expense of scan throughput. Alternatively, we demonstrate here that the navigator-MUSE algorithm, which uses coil sensitivity profiles as the constraint, can suppress the aliasing artifacts due to brain pulsation in multi-shot DWI, even in highly vulnerable regions like the brainstem (Fig 1 and 2). However, to make this technique more clinically feasible, we plan on 1) further reduce scan time for navigator-MUSE DWI by incorporating the multi-band strategy (which is also compatible with the MUSE algorithm), and 2) improve computation time. The navigated-MUSE reconstruction for the whole-brain DWI data was about 5 min, using Matlab on an Apple Macbook Pro laptop (2.7GHz CPU; 16 GB memory). We expect this reconstruction time could be further reduced with C/C++ based implementation in addition to high-performance and parallel computation using a general purpose GPU. In the future, we hope to better investigate the brainstem by utilizing this navigated-MUSE high-resolution multi-shot DWI. It is well established that the brainstem is significantly affected by pathology in a number of neurodegenerative diseases and we believe this is an unexploited area that could yield tremendous insight into the onset and progression of these conditions with the potential to expose reliable preclinical biomarkers. Figure 2 illustrates the improved spatial resolution and increased SNR with limited SNR as compared with conventional single-shot EPI techniques, which suggests that this method has the potential to have an immediate impact on neuroscience research.

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