High-quality and self-navigated diffusion-weighted imaging enabled by a novel interleaved block-segmented (*iblocks*) EPI

Hing-Chiu Chang[1], Mei-Lan Chu[1], Mark Sundman[1], and Nan-Kuei Chen[1]
[1]*Brain Imaging and Analysis Center, Duke University Medical Center, Durham, North Carolina, United States*

Target Audience: Researchers and clinicians who are interested in high-quality and high-resolution DWI

Purpose: High-resolution and high-quality DWI can be achieved by using different multi-shot EPI acquisition techniques, such as interleaved EPI[1], Propeller EPI[2], and readout segmented EPI[3]. In these multi-shot DWI protocols, shot-to-shot phase variations can be measured using a self-navigated method or navigator echoes so that motion-induced aliasing artifacts can be removed in phase-corrected DWI data. Recently, the multiplexed sensitivity-encoded reconstruction method[4] (MUSE) was developed to remove aliasing artifacts in interleaved DW-EPI without requiring external navigator echoes. Furthermore, MUSE is further improved with a projection onto convex sets framework[5] (POCSMUSE), which enables high-resolution DWI even obtained with arbitrary k-space trajectories (e.g., interleaved spiral DWI). In this study we introduce, first, a novel interleaved block-segmented (*iblocks*) EPI based DWI with 1) inherent and self-navigated phase variation correction and 2) reduced geometric distortion is developed; second, the new POCSMUSE algorithm is used to reconstruct the *iblocks* DW-EPI data with inherent phase correction.

Materials and methods: *Data acquisition:* A four shot interleaved DW-EPI pulse sequence was modified to acquire different patch patterns of *iblocks* DW-EPI, as shown in Figure 1. Each patch pattern includes three blocks (green numbers 1 to 3) that were acquired consecutively after each RF excitation to cover portions of k-space. The interleaved segment was achieved along the phase encoding direction, similar to conventional four-shot EPI, except with variable k_x data coverage. To reduce acquisition time, only two interleaved segments (i.e., two RF excitations) were acquired for each patch pattern and thus each patch data set had an acceleration factor of 2. As shown in Figure 1, all portions of k-space were covered by different patch patterns, and the spin-echo time was invariably aligned to the second block (green number 2). In patch patterns #4 and #5, the phase encoding line was reset to the bottom of block #3 (green arrows) at the end of acquiring block #2 in order to maintain a consistent (e.g., bottom-up) phase encoding direction for all blocks. *iblocks* DW-EPI data (b=0 and b=800 s/mm^2) with five patch patterns (shown in Figure 1) were acquired with a 3T MRI scanner using an 8-channel coil with parameters: TE/TR=75/4000ms, echo-spacing time (ESP)=0.6ms, FOV=25.6 x 25.6 cm^2 , matrix size of each patch=100x264 with full echo train length (ELT). Two segments of 4-shot interleaved-EPI (along the phase encoding direction) were acquired for each patch pattern, with targeted reconstruction matrix size =256x256. *Data reconstruction:* First, a 1D Nyquist correction was applied to all *iblocks* EPI segments to minimize the phase errors between odd and even echoes. Second, images free from motion-related artifacts were reconstructed from the center k-space portion (block #2 for patch pattern #1~3; block #3 for patch pattern #4~5) of each interleaved segment using the conventional SENSE algorithm. Third, shot-to-shot phase variations were calculated from images produced in step 2 and then spatially smoothed. Fourth, additional 2D phase terms, reflecting susceptibility induced phase errors, for block #3 in patch pattern #4 and #5 were derived from T2 *iblock* EPI data then removed from the measured phase variation map corresponding to DWI segment data. Fifth, the POCSMUSE framework was used to reconstruct artifact-free images from all patch data, comprising four steps: 1) starting with an initial guess of source image (P^0) by re-gridding all *iblocks* segments into k-space then averaged; 2) applying the sensitivity profiles and segment-specific phase variations to produce a set of simulated images ($D_{i,j}$); 3) replacing parts of the simulated data with experimentally acquired *iblocks* k-space data (i.e., data projection); 4) demodulating the data produced in step 3 with known sensitivity profiles and shot-to-shot phase variations to generate an updated source image P^n, which was further used as the input of step 1 until the iterative processes converge. Since the #3 blocks in patch #4 and #5 revealed extra T2*-weighting, these two blocks were discarded in data reconstruction.

Results and Discussion: Figure 2 shows the *iblocks* T2 and DWI images reconstructed by direct combination of k-space data by re-gridding (a, d), 1st iteration of POCSMUSE (b, e), and full POCSMUSE (c, f). As compared with conventional interleaved DW-EPI acquisition scheme, the developed *iblocks* DW-EPI acquisition can further reduce geometric distortions by shortening the ESP (e.g., 0.6ms in *iblocks* DW-EPI vs. 1.1ms in conventional interleaved DW-EPI with the same reconstruction matrix size and scan parameters). There are major advantages of *iblocks* DW-EPI: 1) the self-navigation inherently removes aliasing artifacts without relying on external navigator echoes; 2) similar to Propeller-EPI, the oversampling of low k-space data (blocks #2 in patch #1~3) can further improve the SNR. Our experimental results demonstrate that the POCSMUSE algorithm can eliminate aliasing artifacts derived from shot-to-shot phase variations in *iblocks* DW-EPI data. Note that the patch pattern of *iblocks* EPI may be further improved to enhance the scan efficiency. Furthermore, the number of segments in each patch pattern may vary to further accelerate the scans. In conclusion, the integration of a novel *iblocks* DW-EPI pulse sequence and the POCSMUSE algorithm can further reduce geometric distortion compared with interleaved DW-EPI while also eliminating the aliasing artifact due to shot-to-shot phase variation.

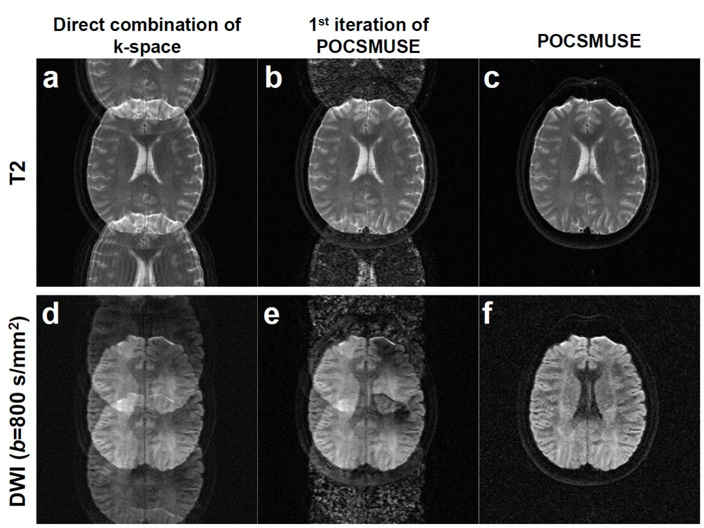

Fig.2 The *iblocks* T2- and DW- EPI images reconstructed by direct combination of k-space data (a, d), 1st iteration of POCSMUSE (b, e), and POCSMUSE (c, f).

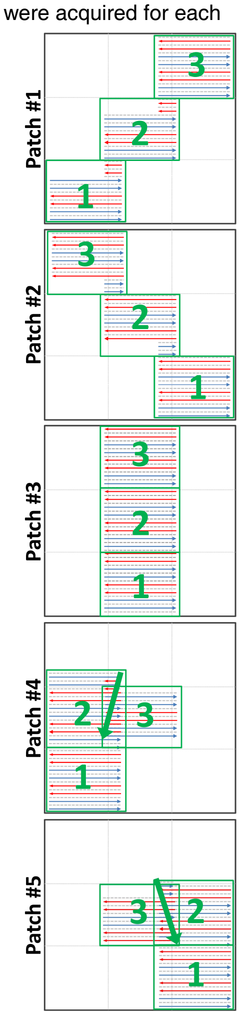

Fig.1 Different k-space patch pattern with 3 block-segments.

References: [1] MRM(31);67, 1994. [2] MRM(54);1232, 2005. [3] MRM(62);468, 2009. [4] Neuroimage(72);41, 2013. [5]. Chu, ML *ISMRM* 2014; 0739.