# POCS-based reconstruction of multiplexed sensitivity encoded MRI (POCSMUSE): a general algorithm for reducing motion-related artifacts

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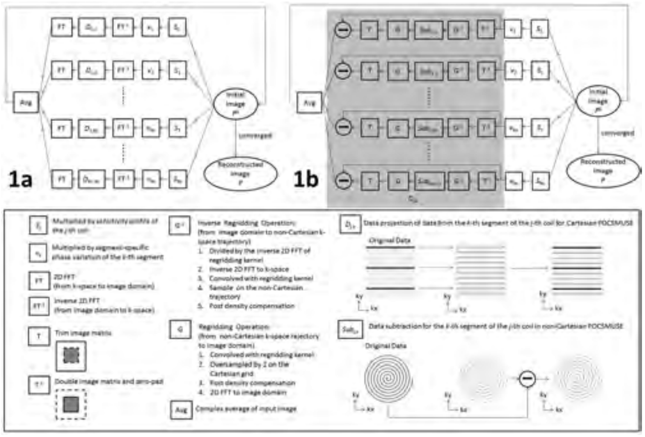
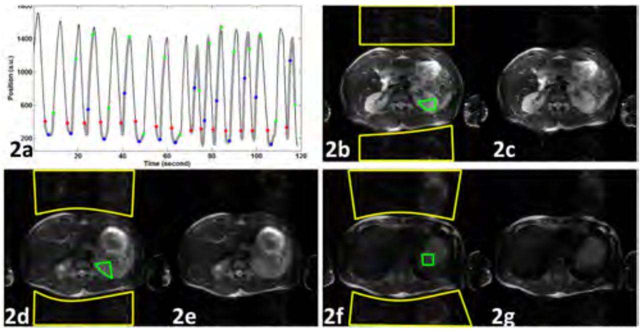
**TARGET AUDIENCE:** Researchers who are interested in motion-insensitive and high-quality MRI.

**PURPOSE:** Although motion artifacts can be reduced with existing technologies, there is still a strong need for further developing and improving motion artifact correction algorithms for the following reasons. First, the residual artifacts in MRI data corrected with conventional procedures may still degrade clinical MRI quality. Second, many existing artifact reduction methods rely on specific pulse sequences. To address this need, here we report a general post-processing algorithm: projection onto convex sets reconstruction of multiplexed sensitivity encoded MRI (POCSMUSE) [1], which uses RF coil sensitivity profile as a constraint to minimize motion-induced inconsistencies among different portions of the k-space data.

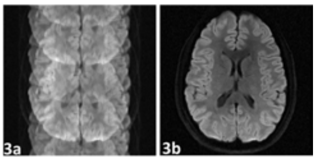
**METHODS:** As shown in Fig. 1a, the POCSMUSE framework 1) starts with an initial guess of source image ($P^0$), 2) applies the sensitivity profiles and segment-specific phase variations to produce a set of simulated images ($D_{i,j}$), 3) replaces parts of the simulated data with experimentally acquired k-space data (i.e., data projection), 4) demodulates the data produced by step 3 with known sensitivity profiles and shot-to-shot phase variations to generate an updated source image $P^n$, which is further used as the input of step 1 until the iterative processes converge. Note that when the phase variation among k-space segments is insignificant, the sensitivity profile is the only constraint for POCSMUSE procedures (Figure 1a with $v_k$ =1). In certain applications (e.g., multi-shot EPI based DWI), the significant shot-to-shot phase variation should be included in POCSMUSE as an additional constraint. In this case, segment-specific phase variations can be estimated from the POCSENSE [3] reconstruction of an individual k-space segment by applying smoothing operation. Since the POCSENSE method must first be used to estimate significant shot-to-shot phase variations, the number of segments cannot be larger than the number of receiving coil elements in the POCSMUSE reconstruction that takes shot-to-shot phase variations into consideration. [2] To further address this limitation, we propose to use an additional phase smoothness constraint in the POCSMUSE reconstruction procedure. As schematically illustrated in Fig. 1b, the POCSMUSE algorithm can be applied to non-Cartesian k-space data, after making two modifications to the procedure. 1) A k-space data regridding operation is included in the algorithm. 2) The data projection for non-Cartesian POCSMUSE is implemented in image domain rather than k-space domain.

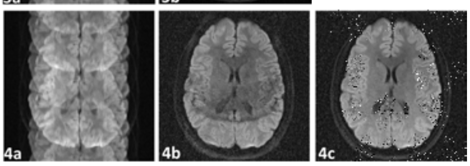


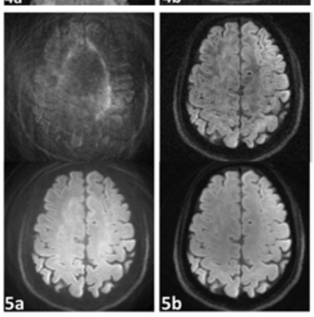


The developed POCSMUSE technique was evaluated with human MRI experiments, using a 3 Tesla system. **1) *Abdominal T2-weighted FSE imaging: respiratory-triggered acquisition*:** FSE data were acquired from 3 healthy volunteers, using an 8-channel coil, with in-plane matrix size = 256x256 and echo train length = 16. Fig. 2a shows the respiratory waveforms (thin line), the scan trigger points (red), and MRI acquisition window (thick line) for one of the subjects. **2) *Interleaved EPI based DWI*:** DWI data were acquired with a 4-shot interleaved EPI sequence from 3 healthy volunteers using an 8-channel coil with matrix size = 256x256. We performed POCSMUSE method on the following data: a) fully-sampled data from four segments and eight coils, b) fully-sampled data from four segments and only three selected coils, **3) *Brain DWI with spiral k-space trajectory*:** Multishot spiral DTI data from a healthy volunteer were acquired with a single spin-echo spiral sequence and a 32-channel phased-array head coil with matrix size = 256×256. The k-space trajectory was a six-shot constant-density spiral-out trajectory with 10,892 data points per interleaf.

**RESULTS: 1) *Abdominal T2-weighted FSE imaging*:** As shown in Fig. 2a, the k-space data of the first slice (red dots) were acquired at time points corresponding to approximately the same respiratory phase. Because of the changes in respiratory frequency during scans, the k-space data of other slices (e.g., the 4th slice: blue dots; the 9th slice: green dots) were acquired at time points corresponding to different respiratory phases indicative of more k-space data inconsistency. Fig. 2b, 2d, and 2f show images of the 1st, 4th and 9th slices, respectively, reconstructed with 2D Fourier transform. It can be seen that there are substantial aliasing artifacts despite respiratory triggering, and the GSRs in these 3 slices are 0.38, 0.45 and 0.61, respectively. The ROIs for ghost and parent-image-signal measurements are outlined by yellow and green lines, respectively. Fig. 2c, 2e, and 2g show that the aliasing artifacts can be significantly reduced with the POCSMUSE algorithm, and the GSRs in these 3 slices are 0.22, 0.23 and 0.32, respectively. The ratios of the artifact reduction are 43.1%, 45.1% and 46.2% for the three selected slices, after applying POCSMUSE. **2) *Interleaved EPI based DWI*:** Fig. 3a shows 4-shot DWI images (8-channel coil) reconstructed with 2D Fourier transform. Because of shot-to-shot phase variations, these images are corrupted by aliasing artifacts. As shown in Fig. 3b, the aliasing artifacts can be effectively removed by POCSMUSE. Fig. 4 compares images reconstructed with (a) 2D Fourier transform, (b) the POCSMUSE, and (c) the POCSMUSE method with phase smoothness constraint from data with ill-conditioned reconstruction matrices (4-shot DWI; 3-channel coil). As expected, images reconstructed with 2D Fourier transform are corrupted by aliasing artifacts (Fig. 4a). Although the aliasing artifacts can be reduced with POCSMUSE (Fig. 4b), the residual artifacts are pronounced due to ill-conditioning. Using the POCSMUSE with phase smoothness constraint, the reconstructed images have significantly improved quality (Fig. 4c). The SNRs of POCSMUSE and POCSMUSE with phase smoothness constraint produced images are 6.88 and 8.69. **3) *Brain DWI with spiral k-space trajectory*:** Fig. 5 compares (a) uncorrected interleaved spiral DWI images and (b) POCSMUSE-produced spiral DWI images, for one selected diffusion directions (the top row) and the mean DWI (the bottom row). It can be seen that the aliasing artifacts in interleaved spiral DWI can be effectively removed by non-Cartesian POCSMUSE.







**DISCUSSION:** POCSMUSE is a robust algorithm capable of reducing motion artifacts of various patterns (e.g. breathing-induced artifacts in abdominal FSE imaging; aliasing artifacts in interleaved DWI), using the RF coil sensitivity profile as a constraint. The POCSMUSE is complementary to existing motion artifact reduction strategies, and can be used to further reduce residual artifacts in data produced from existing methods. The new POCSMUSE method is generally compatible with data obtained with different k-space sampling trajectories, pulse sequences, and contrasts. Various constraints can be easily incorporated into the POCSMUSE method to further improve the robustness of the reconstruction.

**References**: [1] Chu, ML *ISMRM* 2014; 0739. [2] Chen,NK *NeuroImage* 2013; 72:41 [3] Samsonov, AA *MRM* 2004; 52:1397.