Fast Susceptibility Weighted Imaging (SWI) using PROPELLER-EPI

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Target audience - Researchers in the field of susceptibility weighted imaging (SWI), fast imaging using EPI, and clinicians interested in applying PROPELLER-EPI.

Purpose - Fast high resolution T_2^*-weighted imaging using *periodically rotated overlapping parallel lines with enhanced reconstruction – echo planar imaging* (PROPELLER-EPI)[1,2] requires phase correction during image reconstruction. As a result, only modified phase information is obtained which prevents applying processing techniques that rely on accurate phase measurements, such as *susceptibility weighted imaging* (SWI)[3,4] or *quantitative susceptibility mapping* (QSM)[5]. In our current work, we propose a PROPELLER-EPI reconstruction technique for processing phase images on the blade level prior to applying the standard PROPELLER-EPI reconstruction. This modified reconstruction pipeline enables creation of susceptibility weighted images based on data acquired with a fast high-resolution PROPELLER-EPI sequence.

Methods - PROPELLER-EPI samples narrow blades which are subsequently rotated around the center of *k*-space. To ensure proper data combination when conjoining the blades, phase correction using filters[6] or complete removal of phase information[2] in image space is typically employed. Additionally, depending on the applied method for correcting geometric distortion image phase can be further modulated or even removed. In order to reconstruct susceptibility weighted images we propose to process data on a blade level before image phase is modified in any way. The extended reconstruction scheme is shown in Figure 1. By inverse Fourier transforming (*IFFT*) the single blades after EPI ghosting correction and GRAPPA reconstruction, complex-valued low-resolution images with unmodified phase information are obtained. For each low resolution complex-valued single blade image, SWI processing was performed using high-pass filtering (Hanning window with 160 x 50 voxels in read and phase encoding dimensions, respectively) and subsequent multiplication (6 times) of the phase mask, created from the weighted high-pass filtered phase images, with the corresponding magnitude[3,4]. After SWI processing the susceptibility weighted images are Fourier transformed back to *k*-space (*FFT*) and the remaining steps of the PROPELLER-EPI reconstruction pipeline are completed.

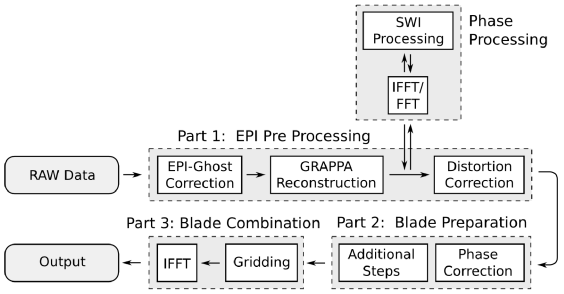

Fig. 1. Image reconstruction pipeline for PROPELLER-EPI. Prior to distortion and phase correction, SWI processing is performed on the blade level. Any additional reconstruction steps like distortion correction, phase correction, sliding-window reconstruction, or keyhole reconstruction are carried out after the SWI processing.

Images were acquired on a clinical 3T system (TIM Trio, Siemens) using a high resolution 10 blade PROPELLER-EPI sequence with acquisition matrix of 320 x 50 for each blade and 2 times GRAPPA acceleration[7]. 40 slices were measured with a thickness of 2.5 mm and no gap between slices. Other acquisition parameters were: TE/TR/FA = 34 ms / 3800 ms / 87°. To reduce T_2^* signal dropouts and geometric distortions originating from the nasal cavities, transverse slices were angulated by 20° towards the coronal orientation. To correct geometric distortions field maps were acquired with a multi-echo gradient echo PROPELLER sequence. Based on the field maps distortion correction was applied on the blade level prior to blade combination using multi-frequency reconstruction[8]. For improved SNR a total of 3 averages were acquired. Total scan time was 11:17 minutes including all pre scans (field map, GRAPPA templates, ghosting correction template, frequency adjustment). Of this time the actual PROPELLER-EPI SWI acquisition took 1:54 minutes including acquisition of the averages.

Results - PROPELLER-EPI images reconstructed using SWI processing provided the typical susceptibility weighted contrast (Fig 2, middle row) with enhanced venous vessels and increased image contrast in iron-laden tissue, such as globus pallidus, putamen and other deep gray matter regions. Resolution of the acquired PROPELLER-EPI images was high enough to depict even small structures, such as subependymal veins. Mean intensity projection images (Fig 2, bottom row) further increased the delineation of vessels.

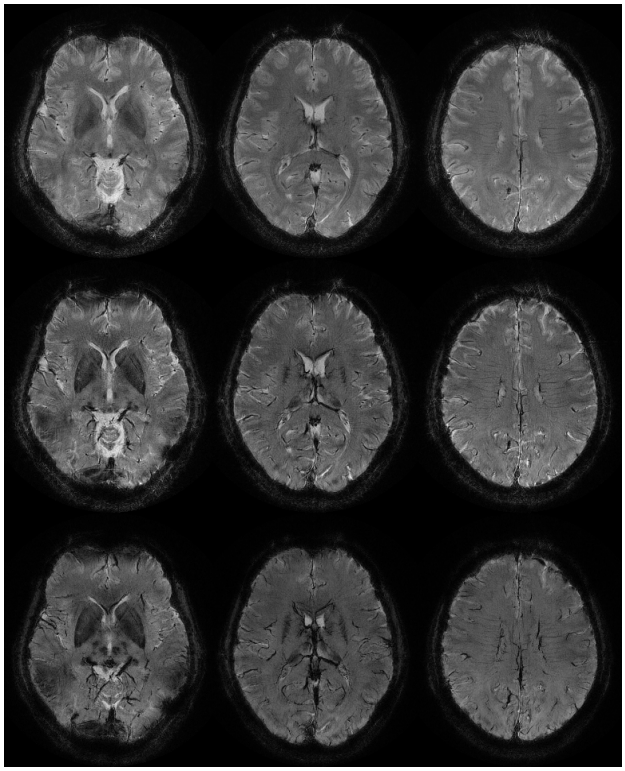

Fig. 2. Magnitude images (top), susceptibility weighted images (middle) and mean intensity projection over 3 slices (bottom).

Discussion - Performing SWI processing on the blade level in PROPELLER-EPI image reconstruction enables harnessing of image phase information which is otherwise lost during the original reconstruction process. Images with a typical susceptibility weighted contrast were obtained with the same high spatial resolutions previously achieved with PROPELLER-EPI[7]. Field mapping currently requires more time than actual acquisition of the PROPELELR-EPI SWI data. However, once field maps have been acquired the proposed technique allows rapid acquisition of susceptibility weighted images. Even though a fast EPI readout is used the PROPELLER segmentation scheme allows for robust acquisition of high resolution images.

Conclusion - PROPELLER-EPI has already been shown to be well suited for *functional magnetic resonance imaging* (fMRI)[2] with high spatial resolution and repetition times suitable for functional experiments. Based on the present work, PROPELLER-EPI may be also used to perform functional SWI with potentially increased sensitivity compared to conventional fMRI due to the incorporation of phase information. Furthermore, the presented framework allows implementation of more sophisticated phase processing algorithms, such as quantitative susceptibility mapping (QSM)[5], in a similar fashion as presented here. Finally, using dynamic geometric distortion correction without static field map acquisition (e.g., PLACE[9] or reversed gradient method[10]) would significantly reduce total scan time. With highly reduced pre-scan duration the technique could be extended to perform susceptibility weighted imaging of non-stationary objects, e.g., allowing application to abdominal imaging.

References - [1] Wang FN *et al.*, MRM 2005; [2] Krämer M *et al.*, MRM 2012; [3] Reichenbach JR & Haacke EM, NMR Biomed 2001; [4] Haacke EM *et al.*, MRM 2004; [5] Schweser F *et al.*, Neuroimage 2011; [6] Pipe JG, MRM, 1999, [7] Krämer M *et al.*, ISMRM 2012, #2658; [8] Man LC *et al.* MRM 1997; [9] Xiang QS *et al.*, MRM 2007; [10] Holland D *et al.*, NeuroImage 2010.