High resolution PROPELLER EPI with reversed phase encoding distortion correction

I. Teh[1]
[1]Clinical Imaging Research Centre, Singapore, Singapore, Singapore

Introduction
Standard single-shot EPI (ssEPI) is resolution limited due to T_2* and prone to geometric distortion. These can be mitigated by shortening the echo train length using multi-shot EPI (msEPI) and parallel imaging. The reversed phase encoding (PE) method [1] has also been employed to correct for distortions in EPI data in functional and diffusion-weighted MRI [2]. By acquiring a repeat dataset, with the phase encoding in the reversed direction, k-space is traversed in the opposite manner, resulting in a second dataset where the distortions are reversed. Using suitable algorithms, both datasets can be combined to produce a dataset with much reduced distortion.

Periodically Rotated Overlapping ParalEL Lines with Enhanced Reconstruction (PROPELLER) has previously been used in high resolution imaging by employing a multi-shot self-navigated approach that samples the centre region of k-space repeatedly [3]. It is typically used in fast spin echo (FSE) applications due its inherent robustness to distortion. Using distortion-free data is crucial as data from multiple blades are combined to produce a composite image. However, EPI sampling can be more time efficient, and groups have attempted to combine PROPELLER with EPI by (i) using parallel imaging to reduce the echo train [4], and (ii) by orienting the readout along the narrower width of the PROPELLER blade [5]. This ‘short-axis’ approach increased the speed of k-space traversal in the PE direction, increased the pseudo-bandwidth and reduced the distortions. However, both methods did not completely remove visible distortions.

It is proposed that the reversed PE distortion correction method can first be used to effectively correct for distortions within individual blade pairs. The corrected blades can then be combined using PROPELLER to enable high resolution, distortion-free EPI.

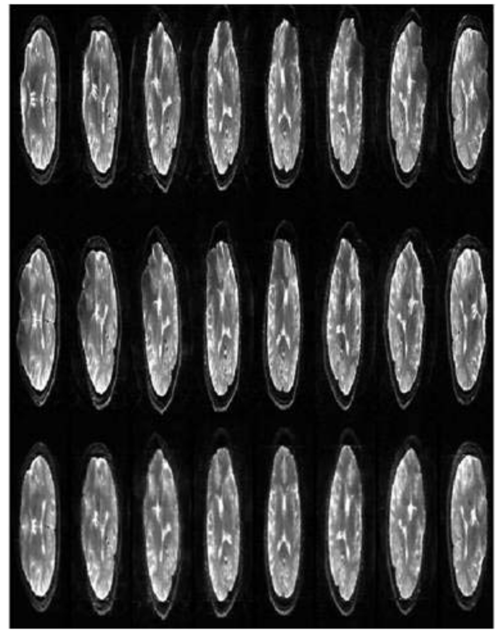

Figure 1. Images from PROPELLER blades 1-8 (left to right) using forward (top) and reversed (middle) phase encoding acquisitions in a given slice demonstrate geometrically opposed distortions. Combined blade images (bottom) with distortion correction.

Methods and Materials
Data from 2 healthy male volunteers were acquired using a Siemens 3T Trio scanner (Erlangen, Germany). PROPELLER-EPI data were acquired with phase encoding directions aligned along the width of each blade, in the positive and negative directions (TR = 6000ms, TE = 72ms, FOV = $256mm^2$, Blade Matrix = 256x64, Reconstructed Matrix = 256x256, Blades = 8, GRAPPA factor = 2). The individual blade pairs were corrected in image space based on the matching of cumulative signals across one phase encoding profile at a time. K-space from the corrected blades were then gridded onto a Cartesian grid using NUFFT [6] and the Fourier transform applied to obtain the final image. All data were processed offline using Matlab r2009b (Mathworks, Natick, USA). T_2-weighted Cartesian FSE (Matrix = 256x256) and ssEPI (Matrix = 128x128) data with GRAPPA factor = 2 were acquired for comparison.

Results and Discussion
Figure 1 illustrates individual blade images for a given slice in the brain of one volunteer. The data acquired with forward PE direction is seen to exhibit equal and geometrically opposed distortions compared to the data acquired with reversed PE direction. Applying the correction results in improved individual blade images. Since the PE direction is rotating along with the blades, the distortions manifest differently in each acquired blade. The combination of uncorrected blades using PROPELLER gives rise to distortions, particularly in regions prone to susceptibility and chemical shift artifacts. These can be seen as streaking artifacts and misplaced contrast in Figure 2. Combination after correction yields images that are robust to distortion.

Reversed PE distortion correction with PROPELLER enables high resolution EPI, reduced echo trains and shorter TE at a cost of increased acquisition time. PROPELLER could potentially correct for motion across blades, although individual blade pairs must be free from motion with respect to each other. This method may be useful, for example, in obtaining high resolution diffusion data where addressing distortions could outweigh the cost in acquisition time. It may also supplement or substitute in situations where parallel imaging reduction factors are limited.

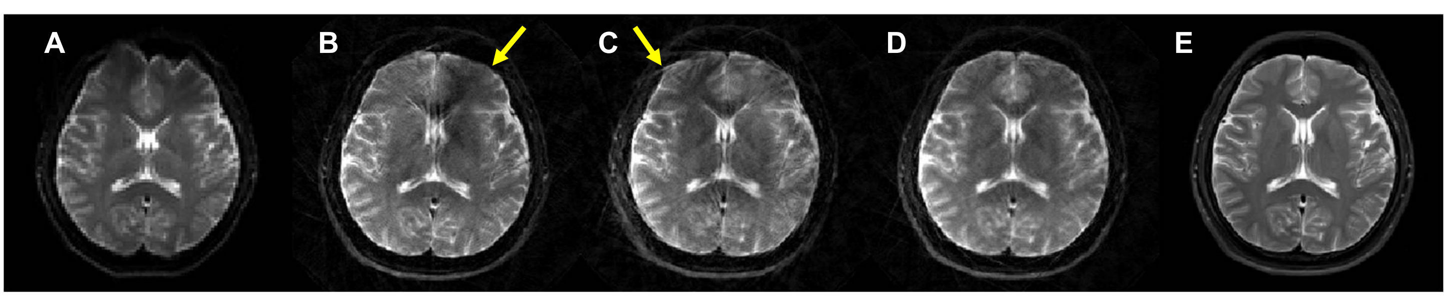

Figure 2. (A) Cartesian ssEPI image, reconstructed PROPELLER images using (B) forward, (C) reversed and (D) combined phase encoding data, and (E) Cartesian FSE image. Distortions in uncorrected PROPELLER data are highlighted.

References [1] Bowtell R., et al, Proc 2nd ISMRM, 1994; [2] Embleton K.V., et al. HBM. 2010; 31:1570-1587; [3] Pipe J.G. MRM, 1999; 42:963-969; [4] Chuang T.C., et al. MRM, 2006; 56:1352-1358; [5] Skare S., et al, MRM, 2006; 55:1298-1307; [6] Fessler J.A., et al, IEEE T-SP, 2003; 51:560-574. The author wishes to acknowledge the Agency for Science, Technology and Research, Singapore and the National University of Singapore for funding.