Application of geometry distortion corrected SEPI sequence

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Introduction: Geometric Distortion Corrected Segmented EPI (GDC-SEPI) utilizes a center out k-space trajectory and a phase map derived from the center segment of k-space to smooth the phase discontinuities between segments. GDC-SEPI speeds up the acquisition while minimizing the distortion and fat shift associated with SEPI. Another benefit of GDC-SEPI sequence is that the arterial signal is bright compared with dark signal normally seen in a SEPI sequence. One particular application of this method is to Susceptibility Weighted Imaging (SWI) which has a long TE and a long TR. SWI is a new type of image contrast and is best when run with a high resolution 3D gradient echo acquisition. In SWI it is important to keep the arteries bright so that they do not interfere with the hemorrhagic or venous signal being dark. In this study, we compare the phase contrast and vessel visibility from GDC-SEPI, SEPI, and the conventional SWI sequence which is a fully velocity compensated. Another potential application area for GDC-SEPI is high resolution DTI. Using the 2D iterative phase correction technique for GDC-SEPI, we expect that the technique will dramatically reduce the distortion artifacts in high resolution DTI albeit taking somewhat longer than normal to collect.

Materials and methods: Figure 1 is the simulated sequence diagram for GDC-SEPI. A fly-back gradient structure in readout ensures flow compensation in that direction. This also makes it possible to focus on the phase error caused by the static off-resonance effects including: B_0 field inhomogeneity $\Delta B(x, y)$ and chemical shift. A center out k-space trajectory makes it possible to use the calibration echo at the front of the echo train (there is no phase encoding between the calibration echo and the first data echo) to estimate the low frequency version of the phase error $\Delta\varphi$ between two adjacent segments, which is given by:

$$\Delta\varphi = -\ \gamma\,(\Delta B(x, y)\ + 2\pi f/\gamma)\ T_{es} \qquad (2)$$

where T_{es} is the echo spacing. Simple complex division of the two complex images from first two echoes results in the phase error $\Delta\varphi$. This estimated phase error can then be applied in imaging space pixel-wise to eliminate the phase discontinuities between segments iteratively *throughout the entire image*. After the iterative phase correction, each segment now acts as if it had been acquired at the longest echo time. Therefore, there is no longer any phase dispersion or geometric distortion.

Results: Fig. 2 is a magnitude image acquired with a SEPI sequence (bottom up k-space trajectory coupled with an echo train shifting (ETS) technique). The arrow points the large multi-pixel fat shift. It should also be noted that the arterial and venous signals are all dark. Fig.3a and 3b are two magnitude images reconstructed without and with the proposed phase correction. The horizontal arrows point to the bright arterial signal. Now arteries will appear bright in SWI as they should and veins will appear dark. Phase correction sharpens the vessel as well. The vertical arrow in Fig. 3a show the high false amplitude caused by distortion near the sinus which is seen to be significantly reduced in Figure 3b. The residual image between Fig. 3a and 3b shows improved edges after phase correction. On 1.5T, GDC-SEPI sequence has a speed up factor of 4 compared with standard SWI sequence while achieving equivalent SNR and phase contrast. With built in flow compensation gradients, GDC-SEPI has less flow related artifacts compared with the normal SEPI sequence.

Discussion and Conclusion: GDC-SEPI is able to correct on a point-by-point basis geometric distortion in the phase encoding direction. Arteries remain bright because the center of k-space is fully flow compensated. Another key aspect of this approach is that the ability to sample over short TE windows gives us phase encoding data almost for free in the sense that we do not lose SNR despite speeding up the imaging time by a factor of 4. This speed up factor will increase for higher resolution images allowing us whole brain coverage for SWI in the matter of 5 minutes when used in conjunction with parallel imaging. The resolution then will be 0.5mm x 0.5mm x 2mm with 64 slices. Overall, we find that GDC-SEPI is a good sequence to speed up SWI acquisition in a clinical environment.

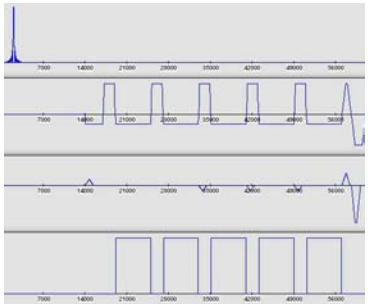

Figure 1

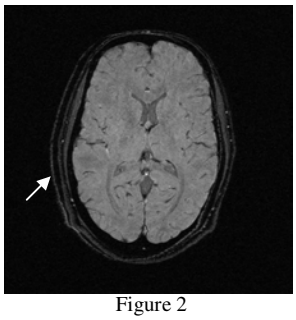

Figure 2

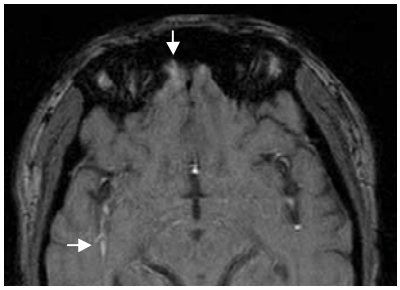

Figure 3a

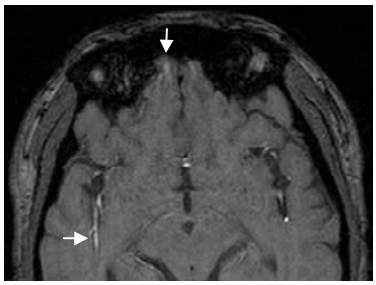

Figure 3b

Fig. 1 Simulated sequence diagram. Fig. 2 Magnitude image of SEPI. Fig. 3a and 3b magnitude images without and with iterative phase correction.

References: 1. Feinberg, DA and Oshio K, MRM, 1994, 32:535-539. 2. Jezzard P and Bababan RS, MRM 1995, 34:65-73. 3. Chen NK and Wyrwicz, MRM 1999, 41:1206-1213. 4. Haacke, E.M, Xu Y., Cheng N. and Reichenbach J., MRM 52:612-618. 5. Xu Y. and E.M. Haacke, ISMRM 13th, 2005, Miami, USA.