Phase contrast imaging using a dual-pathway steady-state sequence

Cheng-Chieh Cheng[1,2], Lawrence Panych[1], and Bruno Madore[1]
[1]*Department of Radiology, Brigham and Women's Hospital, Boston, MA, United States,* [2]*Graduate Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, Taipei, Taiwan*

Introduction: Phase information from MR images can allow the small susceptibility-induced field variations associated with different tissue types to be detected [1,2]. While field differences acting over a TE period can generate detectable phase shifts, relatively long TE values may be required for small field differences to become detectable in the presence of random noise. For this reason, relatively large TE values are needed when employing gradient-echo signal such as the ‘fast imaging with stead-state precession’ (FISP) magnetization, and the early part of the TR interval may be difficult to exploit in a way that would significantly lower phase noise. Unlike gradient-echo signals, the inverted FISP (or PSIF) magnetization features maximum sensitivity to field offsets early in the TR period [3]. Accordingly, it makes much sense to acquire a PSIF signal early in the TR interval, and FISP signal late in the TR interval when collecting phase information, such as in sensitivity-weighted imaging. In this study, we implemented a sequence capable of sampling both PSIF and FISP signals every TR (see Fig. 1), and used it to detect phase variations in the brain. Both the G_y and G_z gradient waveforms were balanced (i.e., zero total area), while the G_x waveform was designed to generate PSIF and FISP echoes. The main goal was to improve phase contrast by including PSIF signals.

Materials and Methods:

Pulse sequence and experimental designs

A “super-blip” gradient was turned on along the frequency encoding direction between two acquisition windows in our sequence, allowing two pairs of PSIF-FISP signals to be generated. The exact relative size of the five gradient lobes along the frequency direction was 0.75:-1:1:-1:0.75, such that 4 echoes were formed every TR: A PSIF, a FISP, a second PSIF and finally, a second FISP. A sketch plot of the modified 3D sequence is shown in Fig. 1. Images were acquired on a 3.0 T scanner (Siemens Trio, Erlangen, Germany) using a 4-channel head coil (TE/TR/flip angle = 20ms/40ms/45°, field-of-view = 25.6cmx25.6cmx6.4cm, spatial resolution = 1.0x1.0x2.0 mm^3, 130 Hz/pixel, TE_{PSIF1} = 12.5ms, TE_{FISP1} = 16.4ms, TE_{PSIF2} = 23.6ms, and TE_{FISP2} = 27.5ms.) Volunteers were imaged upon obtaining proper informed consent.

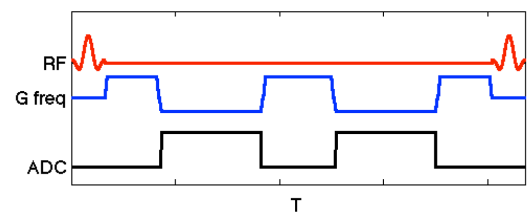

Fig. 1 RF, frequency-encoding and data acquisition waveforms for our sequence.

Data processings

Phase information from all coil elements was combined into a single phase map for each PSIF and FISP magnetization pathway. PRELUDE (FSL, Oxford, UK) was employed to spatially unwrap the phase image from each pathway. The background phase was filtered, and a final phase image was generated by combining all FISP and PSIF signals:

$$\angle I = \sum_{echo=1}^{4} TE_{echo} \times |I_{echo}| \angle I_{echo} \Big/ \sum_{echo=1}^{4} |TE_{echo} \times I_{echo}|$$

where $\angle$ represent a phase, and I_{echo} is one of the 4 acquired signals.

Results: Fig. 2 shows four samples of image phase versus time for our sequence. The dephasing time of those echoes were -27.5 ms, -16.4 ms, 16.4 ms, and 27.5 ms. The magnitude and reconstructed phase images of a given slice are shown in Fig 3 (a) and (b), respectively.

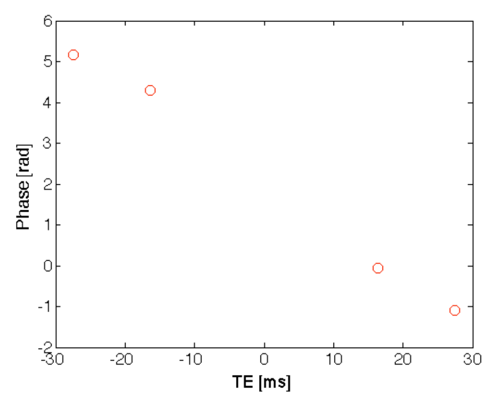

Fig. 2 Typical phase-t plot obtained with our sequence. Notice that for PSIF signals, the effective TE is negative. As a consequence, the range of the collected phase was doubled.

Discussions and Conclusions: The use of PSIF echoes effectively doubles the range of dephasing times observed (Fig. 2), which is expected to lead to improvements in phase SNR. In contrast, usual gradient-echo sequences could only acquire fid-like echo, i.e., dephasing times greater than 0. Such increases in range with a regular sequence would require increases in TE and TR, leading to increases in scan time and increased T2* decay.

The proposed sequence is expected to increase phase SNR, but exact measurements of SNR improvements will require optimizing essentially all imaging parameters for both the proposed sequence and for a reference sequence.

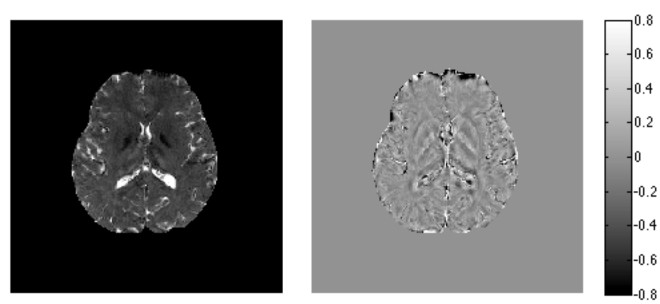

Fig. 3 Magnitude image (a) and reconstructed phase image (b). The color scale for the phase image is shown in radian.

References:

[1] Haacke EM. et al., AJNR 2009.
[2] Schweser F. et al., NeuroImag 2011
[3] Madore B. et al., MRM 2011.

Support from NIH grant R01CA149342 is acknowledged.