Imaging CSF Flow using Spin Echo Phase Contrast Velocity Encoded MRI at 3T

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Introduction: Flow sensitive MRI techniques are typically based on gradient echo (GE) imaging. Such techniques are well validated, offer robust image quality, and are relatively insensitive to artefacts related to sources of field inhomogeneities. However, GE offers a relatively low SNR, particularly for imaging cerebrospinal fluid (CSF) which has a long T1 relaxation time and thus low signal and poor velocity-to-noise ratio. In addition, the low CSF flow velocities (below 5 cm/sec) require strong velocity encoding gradients which increases GE TR and thus sensitivity to susceptibility changes. Balanced steady state free precession (bSSFP) offers considerably higher SNR for CSF [1], but the technique is sensitive to field inhomogeneities, an effect which becomes more pronounced at higher fields. To overcome such limitations, we have developed a spin echo (SE) phase contrast (PC) velocity encoding sequence, and compared this to a standard GE sequence using both phantom and *in vivo* experiments. SE imaging is expected to improve the SNR for CSF, and the technique is known to be insensitive to field inhomogeneities due to the intrinsic refocusing properties. To our knowledge, the combination of flow encoding and SE imaging has not been presented to date.

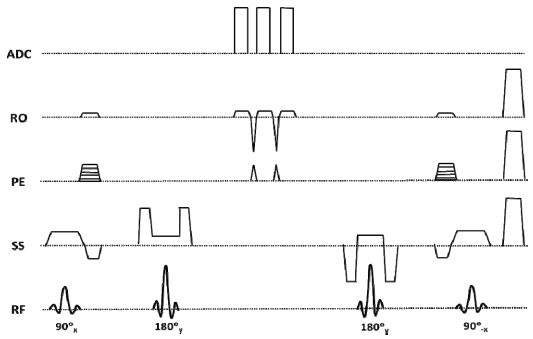

Figure 1. SE pulse sequence with ETL=3 and velocity encoding in the slice select direction.

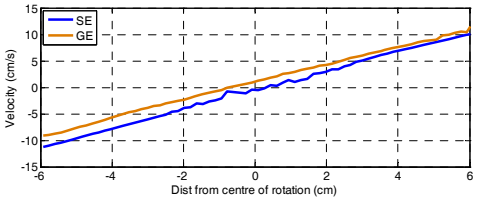

Figure 2. SE and GE velocity encoding pulse sequence comparison using a rigid rotating phantom.

Methods: Achieving a practical scan time is made challenging by the SE refocusing pulse and the long T1 relaxation time of CSF. Turbo spin echo techniques are not suitable for flow imaging because the phase evolution is complex and a coherent velocity encoded phase may not be achievable. Two measures were implemented to decrease the acquisition time: 1. a segmented fly-back echo planar readout; and 2. a driven equilibrium (or restore) sequence [2]. The restore sequence was implemented as a time reversal of the excitation sequence, but with the velocity encoding gradients negated. The pulse sequence diagram is shown in Figure 1. Crusher gradients are typically applied before and after refocusing pulses to eliminate unwanted FID's and stimulated echoes. These are equivalent to the bipolar velocity encoding gradients used in GE imaging, so some velocity encoding is usually inherent in SE imaging. The crushers should be designed to ensure that the minimum phase dispersion within a voxel is about 4π radians [3]. For the imaging parameters used here, this corresponds to a velocity encoding parameter (venc) of about 13 cm/s. This places a limitation on the maximum velocity which can be measured using the SE technique.
A moving phantom was imaged to verify the accuracy of the SE-PC sequence, and a healthy volunteer was imaged in a mid-sagittal view to assess the SNR in regions of stationary and flowing CSF. The moving phantom comprised a rotating 2% agar disc and the speed of rotation was set to include a range of velocities typical for CSF. Images were acquired using a single channel head coil on 3T MRI scanner (Magnetom Allegra, Siemens Medical Solutions, Erlangen). The SE-PC technique was compared to a standard GE-PC sequence. Imaging parameters for the GE sequence were: TR = 46 ms; TE = 7.8 ms; flip angle = 20 degrees; matrix size = 128x128; FOV = 240; slice thickness = 5 mm; venc = 10 cm/s; scan time = 1:30. Parameters for the SE-PC sequence were identical except: TR = 800 ms; TE = 18, 24, and 30 ms for echo train lengths (ETL's) of 1, 3 and 5, respectively, with corresponding scans times of 2:48, 1:00 and 0:36; flip angle = 90 degrees. SE images were acquired with and without the restore sequence. Cardiac gating was applied and only a single time point was obtained for the SE-PC sequence. Measures of SNR were taken from the CSF in the 4th ventricle and adjacent to the spinal cord for slow and fast CSF flow, respectively.

Results: Figure 2 depicts the accuracy results from the rotating phantom, where a good agreement is evident. Figure 3 shows magnitude and phase images from the GE and SE scans, as well as the CSF SNR measurements. For SE imaging with one echo (ETL = 1), considerably improved image quality and SNR was achieved compared to GE. Reduced distortions at air-tissue interfaces and improved velocity background contrast in the flow images can be appreciated in Figure 3 (conventional GE vs. SE, ETL=1). However, for SE-PC with multiple echoes (ETL > 1), susceptibility effects and image distortions were evident and, because of longer TE's, flow artifacts were more apparent. Although the restore sequence should preserve the signal for materials with long T1 and T2, this effect was not evident at the TR's used here.

Conclusions: We have developed a SE-PC velocity encoded sequence, and a 2-3 fold increase in SNR has been demonstrated for CSF when comparing the technique to conventional multi-phase GE-PC imaging. SE-PC is only suitable for measuring slow flow because of the need for refocusing pulse crusher gradients and because the relatively long TE causes flow artifacts. Future work will include extending the technique to acquire multiple time points in the cardiac cycle. The current sequence can be extended to multiple slices without further increasing the scan time, and a non slice selective refocusing pulse may further improve the SNR for single slice imaging.

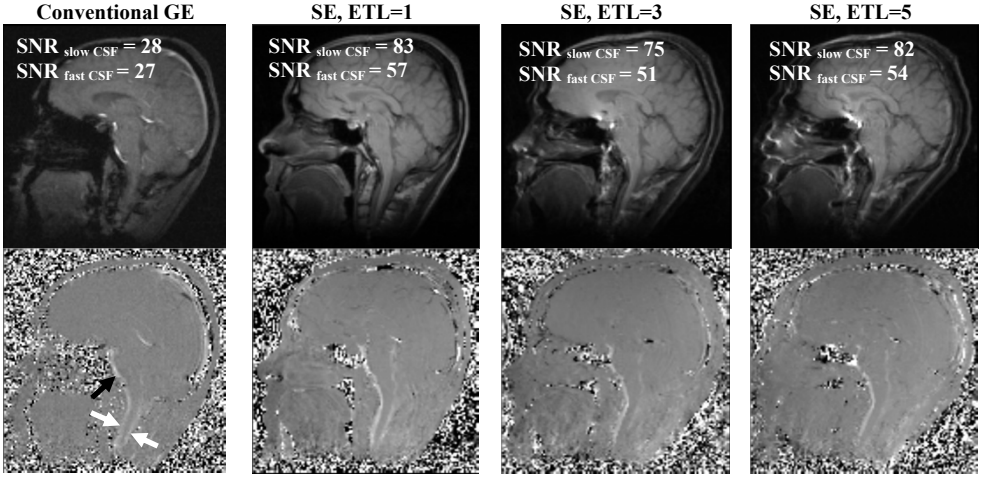

Figure 3. Comparison of a standard GE-PC sequence with the SE-PC sequence. Velocity is encoded in a head-foot direction and CSF flow can be seen in the basal cisterns (black arrow) and around the spinal cord (white arrows).

References:

1. McCormack et al. MRM 2007; 25: 172–182.
2. Hennig JMR 1988; 78: 397-407.
3. van Uijen & den Boef MRM 1984; 1:502-507.

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