Accelerated 3DPCASL using compressed sensing

Li Zhao[1], Samuel W. Fielden[1], Xiao Chen[1], John P. Mugler III[2], Josef Pfeuffer[3], Manal Nicolas-Jilwan[2], Max Wintermark[2], and Craig H. Meyer[1]

[1]Biomedical Engineering, University of Virginia, Charlottesville, Virginia, United States, [2]Radiology, University of Virginia, Charlottesville, Virginia, United States, [3]Siemens, Erlangen, Germany

Purpose: Dynamic ASL can provide important diagnostic information, such as CBF and ATT, for stroke and tumor patients. Acquiring data at multiple observation times (OTs) permits the tracking of a tagged bolus as it flows through the image. However, the inherent low SNR of ASL makes acquisition of dynamic ASL data sets time-consuming and the resulting parameter maps unreliable. The 3D TSE stack-of-spirals pulse sequence can achieve improved SNR by efficiently acquiring data. SPIRiT [1] is an iterative non-Cartesian parallel image reconstruction method that can be combined with compressed sensing (CS). CS is known to suppress noise by enforcing sparsity through nonlinear image reconstruction. In dynamic ASL, the images from different OTs have similar structure except for gradual changes in intensity. By enforcing sparsity in the time domain, it should be possible to improve image quality and parameter map accuracy. The goal of this study is to combine 3D spiral TSE, parallel imaging, and compressed sensing to yield rapid whole-brain perfusion maps with high SNR in two settings: high-resolution single-PLD PCASL and rapid multi-OT dynamic PCASL.

Methods: A general constrained image reconstruction can be described by the following regularization equation:

$$\hat{x} = \arg\min : \|Fx - y\|^2 + \lambda |Tx|_p$$

The first part of the equation enforces data fidelity. x is the target image, y is the sampled data, and F is the Fourier transform. F includes the spiral trajectory and an undersampling mask. The second part of the equation enforces prior knowledge, which in CS is a sparsity constraint. In this work, T includes constraints corresponding to SPIRiT, spatial total variation (TV), wavelets, spatial SVD and temporal SVD [2] in different image reconstructions.

All experiments were performed on SIEMENS Trio 3T scanners. The ASL blood bolus was tagged by balanced PCASL with Hanning RF pulses. k-space was sampled by a 3D stack-of-spirals. The proposed method was first tested on single-PLD PCASL with high resolution. Bolus duration = 2s and PLD = 800ms. A constant density spiral with 7 interleaves provided 2mm×2mm×4mm resolution. 24 slices covered the whole brain. 6 averages and 3.5s TR resulted in a total scan time of about 5 min. Next, dynamic PCASL data with 9 OTs was acquired. Design bolus = 2s. Dual-density spiral readouts were used with 100% of Nyquist sampling during the first 1/4 of the readout and 33% during the rest of the readout. Three such spiral interleaves were acquired with equal rotation in k-space, resulting in an in-plane resolution of 4.5mm×4.5mm. 24 slices, thickness=4.5mm, averages=4, TR =5s.

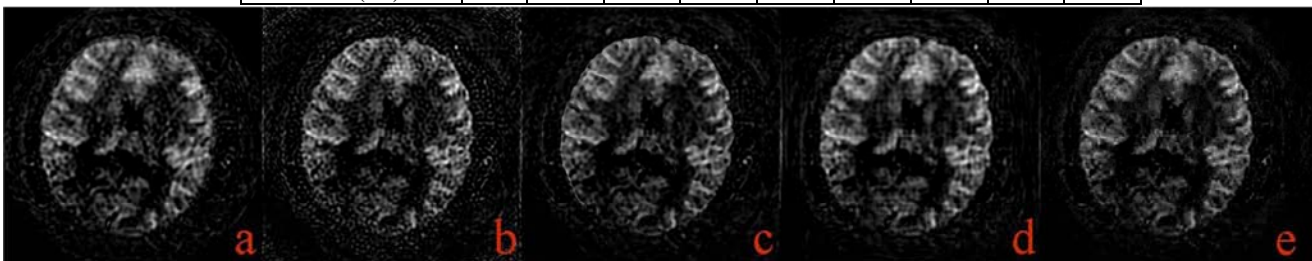| Design OT (ms)	600	1100	1600	2100	2600	3100	3600	4100	4600
Bolus duration (ms)	500	1000	1500	2000	2000	2000	2000	2000	2000
Real PLD (ms)	100	100	100	100	600	1100	1600	2100	2600

Figure 1. Comparison of reconstruction methods: (a) gridding, (b) SPIRiT, (c) SPIRiT and TV, (d) SPIRiT and SVD, (e) wavelet.
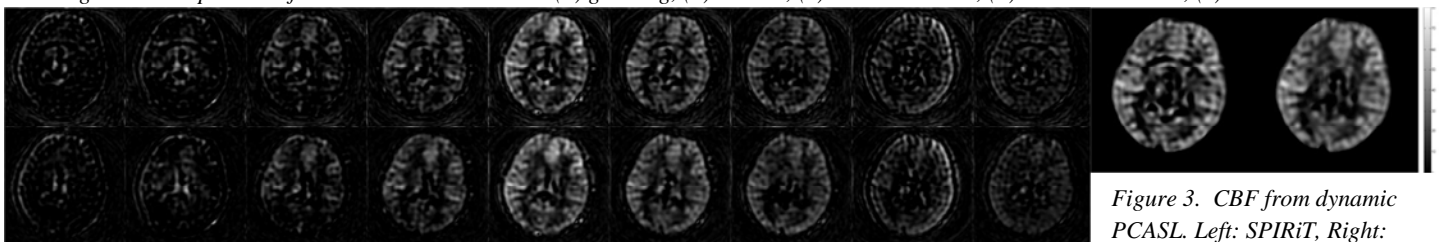

Figure 2. Dynamic PCASL with different PLDs. Top: SPIRiT. Bottom: SPIRiT with CS.

Figure 3. CBF from dynamic PCASL. Left: SPIRiT, Right: SPIRiT with CS

Results and Discussion: As shown in Fig. 1, gridding (a) produces a perfusion image with low SNR at this relatively high spatial resolution. SPIRiT (b) improves the visualization of some structures, but amplifies the noise in some regions. The CS reconstructions (c-d) show improved SNR, because of the nonlinear image reconstruction. The regularization parameter λ controls the tradeoff between the noise reduction and preservation of structures in the image. The SVD (d) and wavelet (e) reconstructions preserve the structures more naturally. Figure 2 shows the results of a dynamic experiment. Enforcing temporal sparsity using CS helps to suppress both motion and noise. Significant improvement from CS can be seen in the CBF map calculated from this data (Fig. 3).

Conclusion: Compressed sensing improves SNR and reduces artifacts in 3D PCASL, enabling higher spatial resolution for single-PLD imaging and rapid dynamic ASL with improved CBF estimation.

Reference: 1. Lustig M, Pauly J. SPIRiT: Iterative self-consistent parallel imaging reconstruction from arbitrary k-space. MRM. 2010; 64:457-471. 2. Lingala S, Hu Y, Dibella E, et al. Accelerated Dynamic MRI Exploiting Sparsity. IEEE TMI. 2011; 30(5): 1042-1054.