Strategies for Increasing Spatial Coverage of Balanced Steady-State Free Precession Arterial Spin Labeling

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Introduction

Arterial spin labeling (ASL) is an MRI technique that measures blood perfusion noninvasively by inverting the magnetization of the arterial blood water with radiofrequency (RF) pulses. Previously, non-EPI based ASL readouts such as gradient and spin echo (GRASE) [1] and rapid acquisition with relaxation enhancement (RARE) [2, 3] have been proposed to overcome the distortion or signal dropouts from EPI. Because of limitation in the spatial coverage, ASL with GRASE and RARE has been performed with segmented 3D approach [1-3]. On the other hand, pseudo-continuous ASL (pCASL) with balanced steady-state free precession (bSSFP) readout has been developed to acquire perfusion images with reduced susceptibility artifacts at a relatively high spatial resolution and SNR, while maintaining the advantages of current non-EPI based ASL readout approaches [4]. A preliminary trial for improving spatial coverage of the pCASL-bSSFP sequence with compressed sensing (CS) has been recently proposed [5], but requires further improvements. In this study, we propose segmented 3D acquisition as a new strategy to increase spatial coverage of pCASL-bSSFP and also show improved results for the pCASL-bSSFP-CS approach with optimization of the CS algorithm.

Materials and Method

All experiments were performed on a 3T whole body scanner (Siemens Medical Solutions, Erlangen, Germany) with a circularly polarized 12-element head coil. Three healthy volunteers (male, 25-29 years old) were examined for both segmentation and CS study, and one meningioma patient (female, 23 years old) was additionally examined for the CS study. The study protocols were approved by the Institutional Review Board (IRB). All ASL images were acquired using pCASL with bSSFP readout and the same labeling parameters as in [4] were used. The imaging parameters for each study are summarized in Table 1. Additional imaging parameters were: image plane = axial; flip angle = 30°; acquisition bandwidth = 592 Hz/pixel; excitation RF pulse bandwidth and duration = 4.27 kHz/1.5 ms; slice partial Fourier = 6/8; delay between acquisitions = 0.6 sec.

For the segmentation study, in-plane segmented acquisitions (i.e. number of segments applied in PE1 direction) were implemented separately for different number of segments. For the CS study, a temporally varying down-sampling scheme with a fixed down-sampling factor (R) of 4 was used [5]. A CS framework that exploits temporal redundancy in dynamic MRI data was used [6] and solved using a variant form of alternating direction method of multipliers (ADMM) algorithm [7]. The reconstruction parameters were confirmed via retrospective simulation studies with a full-sampled data before application to in vivo data. For data analysis, whole gray matter (GM) and a noise region with no brain signal were manually segmented from the baseline image. SNR was calculated from the GM region of the perfusion subtraction image, as mean of the signal divided by standard deviation of the noise signals.

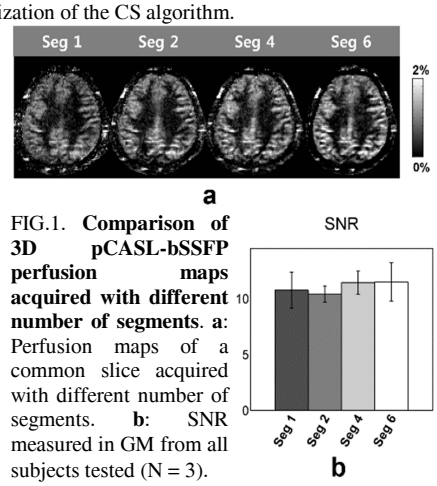

FIG.1. **Comparison of 3D pCASL-bSSFP perfusion maps acquired with different number of segments**. **a**: Perfusion maps of a common slice acquired with different number of segments. **b**: SNR measured in GM from all subjects tested (N = 3).

Results and Discussion

Overall, both segmented 3D acquisition and CS approach for pCASL-bSSFP acquired perfusion maps well. The 3D perfusion maps acquired with different number of segments showed similar image quality (Fig. 1a) and SNR (Fig. 1b) from a common slice, proving that the spatial coverage of bSSFP-ASL can be efficiently increased up to near full-brain coverage while maintaining the same level of SNR and scan time (Fig. 2). The pCASL-bSSFP-CS approach reconstructed baseline and perfusion images well for both normal (Fig. 3a) and meningioma patient (Fig. 3b) with minimal impact on the image quality. For the meningioma patient, pCASL-bSSFP-CS approach mapped blood flow in the tumor core region well (arrows in Fig. 3b).

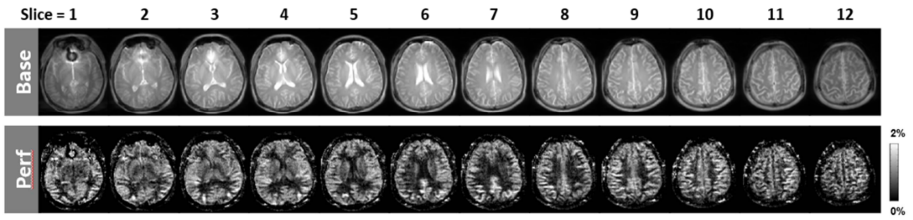

FIG. 2. **Baseline and perfusion images of pCASL-bSSFP acquired with # Segment = 4**. ST = 5.3 min.

Number of averages for a given scan time decreases with number of segmentation but the spatial coverage also increases with number of segmentation. The two factors counteract each other to maintain the SNR (Fig. 1). Based on this, the segmented 3D approach for bSSFP-ASL can be a good strategy for high-resolution whole brain perfusion mapping. CS approach for bSSFP-ASL can also show good perfusion maps for in vivo studies with no change in the temporal resolution, and thus may be useful when the number of averages is limited in situations of breath-hold scan [4] or when ASL requires high temporal resolution with wider coverage such as fMRI [4]. The two approaches (segmented 3D and CS) can potentially be combined for even better performance, which can be investigated in the future studies.

Conclusion: Both segmented 3D acquisition and CS approach work well for bSSFP-ASL and are potentially beneficial for perfusion imaging.

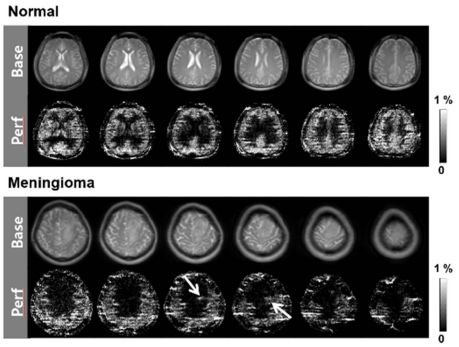

FIG.3. **In vivo mapping of cerebral blood flow using pCASL-bSSFP-CS**. **a-b**: Perfusion maps from a healthy subject **(top)** and a meningioma patient **(bottom)**.

References: 1. Feinberg et al, Proc. Intl. Soc. Mag. Reson. Med. 17: 622 (2009). 2. Ye et al, Mag. Reson. Med. 44(1):92-100 (2000). 3. Dai et al, Mag. Reson. Med. 60(6):1488-1497 (2008). 4. Park et al, Mag. Reson. Imag. 31:1044-1050 (2013). 5. Han et al, Proc. Intl. Soc. Mag. Reson. Med. 22: 4560 (2014). 6. Jung et al, Mag. Reson. Med. 61(1):103-116 (2009). 7. Afonso et al, Image Processing, IEEE Trans. on 20(3):681-695 (2011)

Table 1. Imaging Parameter Information

	Segmentation Study				CS Study
No. of Segments or CS Factor (R)	None	Seg. No. = 2	Seg. No. = 4	Seg. No. = 6	R = 4
No. of Slice	4	8	16	24	8
NEX	36	18	9	6	30
FOV (mm^3)	230 × 173 × 20	230 × 173 × 40	230 × 173 × 80	230 × 173 × 120	220 × 220 × 40
Matrix Size	128 × 128 × 4	128 × 128 × 8	128 × 128 × 16	128 × 128 × 24	128 × 128 × 8
TR / TE (ms)	4.07 / 1.8	3.99 / 1.75	3.98 / 1.75	3.96 / 1.74	4.02 / 1.77
Scan Time (min)	~5.3	~5.3	~5.3	~5.3	4.2