Effects of Readout Sequence on the Temporal and Spatial SNR of Pseudo-continuous Arterial Spin Labeling

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Introduction

Arterial Spin Labeling (ASL) (1) is a promising perfusion MRI technique that enables non-invasive quantification of cerebral blood flow (CBF) in units of mL · min^{-1} · $100g^{-1}$ of tissue. Recent technical advances, such as pseudo-continuous ASL (pCASL) (2), background suppression (BS) of static tissue signal (3) or single-shot acquisition (4), together with the availability of higher field strengths, have improved the efficiency, sensitivity and reliability of this technique. Combining ASL with spiral imaging is expected to further improve the SNR, due to the advantageous properties of spiral readout, including efficient k-space sampling, start of sampling at the center of k-space, flexibility in the number of interleaves or in the spatial sampling density and relative insensitivity to movement and flow artifacts (5). In this work we have implemented a pCASL sequence with a 3D single-shot fast spin echo with in-plane spiral readout, with an optimized BS scheme, and tested it in five healthy volunteers against a homologous 3D sequence with cartesian readout (GRASE) and a standard 2D EPI sequence, due to its widespread use in the literature.

Materials and Methods

Three different sequences were tested with identical labeling scheme (balanced pCASL, with 1520 selective RF pulses, Hanning window, B1 average=1.8 μT, duration=500 μs, spacing=380 μs, Gaverage=1 mT/m, Gmaximum/Gaverage=8) and post-label delay (PLD) of 1.5s. The 3D sequences also shared a BS scheme consisting of 4 presaturation pulses at the beginning of each TR, a slice-selective C-FOCI pulse played right before labeling plus 2 non-selective hiperbolic secant pulses during the PLD, with timings optimized to suppress the static tissue signal to 10% its original value (Fig. 1). The imaging parameters of each sequence were:

3D FSE Spiral: FOV=256x256x96 mm^3, resolution=4x4x6 mm^3, 16 partitions with 12.5% oversampling acquired with a centric encoding scheme and PF 5/8, TR/TE = 4000/8ms, 2 interleaves, max Slew Rate=120 mT/(m·ms), max G=36 mT/m, 160º refocusing pulses

3D GRASE: FOV=256x224x96 mm^3, resolution=4x4x6 mm^3, 16 partitions with 12.5% oversampling acquired with a centric encoding scheme and PF 5/8, BW=2790 Hz/Px, TR/TE=4000/29ms, 180º refocusing pulses

2D EPI: FOV=256x224 mm^2, in-plane resolution=4x4 mm^2, slice thickness=6 mm, 16 slices with 25% gap acquired in ascending order, TR/TE=4000/18ms

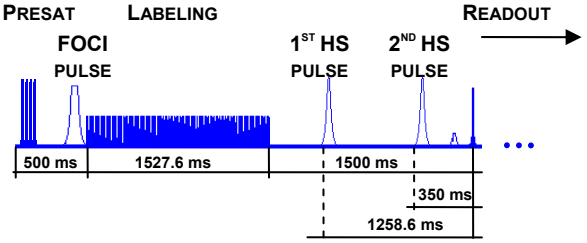

Fig. 1 – *Scheme of labeling and background suppression*

Study design: Five young healthy subjects (2 F, age=31 ± 5) participated in the study, after signing informed consent. The study was performed on a 3T Siemens Trio using a 12-channel head array. An anatomical image was acquired using a T_1-MPRAGE sequence. Phase-contrast velocity MR images were also acquired to calculate total incoming CBF as described in (6), and used later to estimate the individual labeling efficiency of the sequences. The 3 sequences were tested (in pseudorandomized order) as follows: First, task-related activation was assessed. Subjects underwent a task/rest paradigm in which 3 rest blocks of 1.33 min duration alternated with 3 task blocks of finger-tapping and visual stimulation. Next, resting perfusion was assessed with the acquisition of 100 scans (50 pairs of label-control). 10 additional scans were acquired without BS to obtain control images necessary for CBF quantification, except for EPI.

Data preprocessing and analysis (carried out using SPM8 and custom scripts in Matlab): Images were realigned and co-registered to the anatomical dataset before subtraction of label and control. A mean perfusion image and CBF map were computed from the resting scan, using the one-compartment model (7). The temporal SNR (tSNR) of the series was computed as the mean of the whole brain perfusion signal divided by its standard deviation, as well as the perfusion spatial SNR, calculated as the ratio of the whole brain perfusion signal to the background noise level. Also, the contrast ratio between gray matter (GM) and white matter (WM) was assessed in the mean CBF maps using segmented GM and WM masks. In the analysis of the task activation data, CBF maps were computed for every perfusion weighted image, normalized to the standard template and smoothed with an 8mm Gaussian kernel. Voxel-wise analysis was carried out to compare the difference in responses evoked by the two conditions (finger tapping and rest), using the general linear model. The task-activation results were obtained evaluating the t-maps comparing Task > Rest with a significance threshold $p < 0.001$ unc. Maximum t-value and cluster size were collected for every subject and sequence.

Results and Discussion

Fig. 2 shows the resting CBF maps of the three sequences on a representative subject. Table 1 summarizes the main parameters characterizing the sequences during rest, while Table 2 shows the average and standard deviation of the maximum t-statistics (t_{max}) and cluster size (k) of all subjects during the motor-visual activation task. Only 1 out of 5 subjects yielded significant results with EPI in the primary motor area (denoted as (*)) , thus standard deviation could not be computed. 4 out of 5 yielded significant results with 3D GRASE, and 5 out of 5 with 3D FSE Spiral. Perfusion spatial and temporal SNR were increased when BS was employed, at the expense of a slight efficiency loss. The spiral readout yielded a further increase in tSNR, leading to a more stable signal and therefore to the highest t values in the Task-Rest comparison. It is likely that the lower contrast ratio GM-WM in the spiral images is partly due to intrinsic blurring generated by inexact gradient trajectories employed in the reconstruction, although gradient delays, the most relevant cause of trajectory deviations, were estimated and corrected for prior to analysis (8).

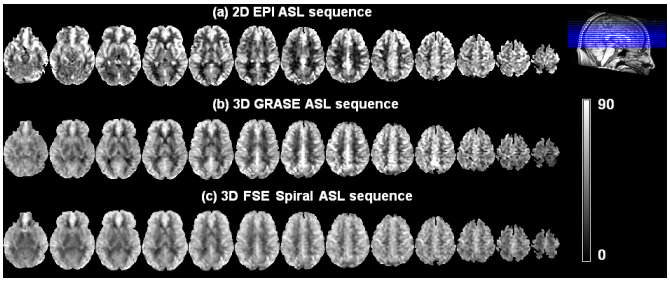

Fig. 2 – *Resting CBF maps of a representative subject acquired with the three ASL sequences, in units of mL · min^{-1} · $100g^{-1}$.*

Table 1 – Comparison of the sequences during resting perfusion

[mean ± std]	Mean CBF [mL·min^{-1}·$100g^{-1}$]	Efficiency [%]	Temporal SNR	Contrast Ratio GM-WM	Spatial SNR
2D EPI	58.5 ± 11.6	87.7 ± 8.1	3.0 ± 1.1	2.9 ± 0.2	12.4 ± 4.5
3D GRASE	56.3 ± 7.5	70.4 ± 14.2	8.8 ± 0.8	2.0 ± 0.2	27.5 ± 4.8
3D FSE Spiral	56.3 ± 7.0	70.6 ± 13.2	10.2 ± 2.5	1.5 ± 0.1	32.3 ± 5.1

Table 2 – Comparison of the sequences during motor-visual activation task

[mean ± std]	2D EPI		3D GRASE		3D FSE Spiral	
	t_{max}	k	t_{max}	k	t_{max}	k
Occip. Lobe (L)	3.7 ± 2.2	537 ± 720	6.2 ± 2.7	1809 ± 1349	6.5 ± 2.0	1643 ± 2083
Occip. Lobe (R)	3.7 ± 1.5	596 ± 637	5.0 ± 1.9	1475 ± 1631	5.6 ± 1.4	1370 ± 2193
1ary Motor A.(L)	2.7(*)	42(*)	4.7 ± 3.3	251 ± 260	6.5 ± 3.0	463 ± 309

Conclusions

Our results show that the use of background suppressed 3D readout sequences greatly increased the temporal and spatial SNR of ASL. The in-plane spiral trajectory yielded a further SNR increase that translated into higher statistical significance in the task-activation study.

Bibliography

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