CSF-suppression improves signal stability of ASL time series

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Introduction

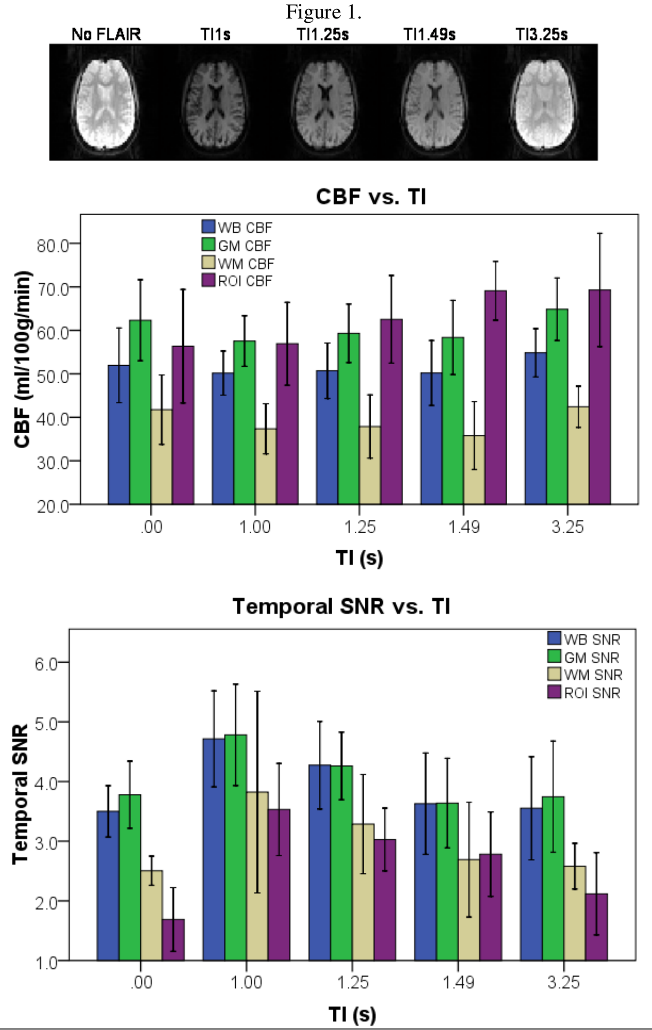
Arterial spin labeling is an entirely noninvasive method for measuring quantitative blood flow. Since ASL relies on subtraction between a control and tag state, it suffers from very low signal to noise ratio [1] and typically requires averaging for reliable quantification. In recent years, ASL has been applied to functional MRI as studies have shown that blood flow is more tightly coupled to neural activity than BOLD and ASL can provide more accurate localization of functional activity [2,3]. Signal fluctuations in the ASL time series can seriously affect the sensitivity for the detection of functional activation. A major source of signal fluctuation in ASL is cerebral spinal fluid (CSF), which has the highest signal on echo-planar images (EPI), the most commonly used acquisition method for ASL data. This problem is exacerbated in the typically low resolution used for ASL acquisitions, where partial volume between gray matter and CSF leads to fluctuations in areas of functional activation. In this study, we use a FLAIR-type preparation to null the CSF signal and investigate its effects on the ASL time series.

Methods

Simulation: Optimal inversion time was determined by minimizing the CSF signal using the equation: $M = 1 - 2e^{-TI/T1} + e^{-TR/T1}$. TR was set to 4s, T1 of CSF, GM and WM were assumed as 3.9s, 1.33s and 0.8s [4]. CSF null point was determined to be 1.5s.

Imaging: Data from five healthy subjects were collected on a 3T whole-body scanner (Siemens Trio, Erlangen, Germany) equipped with an eight-channel receive-only head coil. Pseudo-continuous ASL (pCASL) with gradient-echo EPI readout sequence was modified to include a selective inversion pulse applied to the imaging slab either before or after the labeling period. Imaging parameters were: TR/TE=4s/17ms, post labeling delay=1.5s, labeling period=1.5s, 16 slices (5 mm thickness, 1 mm gap). Five scans were collected from each subject, including a standard pCASL scan without any inversion preparation, and four inversion-prepared pCASL scans with inversion times (TI) 1s, 1.25s, 1.49s and 3.25s (applied before labeling). Temporal signal to noise ratio (SNR)—defined as the ratio of mean signal and time series standard deviation—of whole brain (WB), gray matter (GM), white matter (WM) from the 5 scans were compared using Analysis of Variance (ANOVA). To demonstrate the effect of small region-of-interest typically used in fMRI, data from a $3x3x5cm^3$ region of interest (ROI) placed near the edge of the brain were also included.

Figure 1.



Results

Sample EPI images for the five scans from a representative subject are shown in Figure 1. High CSF signal seen in the no FLAIR image is clearly suppressed with TIs of 1s to 1.49s. Despite the different contrast exhibited in the EPI images, the quantitative CBF values from the different scans were almost identical (middle figure).

Temporal SNR for the different scans averaged over all subjects are plotted in the bottom figure. Error bars represent inter-subject standard deviations (SD). For the ROI selected, temporal SNR at TIs of 1s ($p=0.002$) and 1.25s ($p=0.03$) were significantly higher than the unsuppressed case. At the optimal TI of 1s, temporal SNR in the ROI increased by 109% compared to the unsuppressed case. The longest TI did not improve temporal stability as expected, since CSF signal was clearly not suppressed.

Discussion

The results successfully demonstrated how CSF-suppression reduces fluctuations in the ASL time series. The experimental optimal TI is 1s, which is shorter than the simulated result of 1.5s. This is because the current study is a two-dimensional acquisition method. The actual TI for each slice is incremented by the slice acquisition time, which is approximately 45ms. For the slice location shown in Fig. 1, the actual TIs are 1.4s, 1.65s, 1.9s and 3.65s respectively. This is a limitation of the current implementation, which can be avoided by using a three-dimensional acquisition.

Another limitation of this implementation is that TI is limited by the postlabeling delay. Therefore selection of optimal TI and postlabeling delay for a given study must be considered carefully.

Although this method is conceptually similar to background suppression (BS), the main goal in this study is to null only CSF signal. In the case of BS, a combination of selective and nonselective inversions is used to null multiple tissue types, and pulse imperfections can lead to an attenuation of the ASL signal [5]. The CSF-suppression method proposed in this study, on the other hand, uses a single selective inversion pulse applied to the imaging slab, and the results demonstrate minimal effect on the quantitative CBF values. The improved time course stability provided by CSF-suppressed ASL is beneficial for applications of ASL in functional MRI.

References

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