Assessment of longer post-labeling delays to measure CBF using pseudo-continuous ASL with background suppression

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Purpose

(1) Arterial spin labeling

Cerebral artery steno-occlusive lesions cause prolonged arterial transit time (ATT) that is required for delivery of the arterial water to the imaging plane [1]. The choice of post-labeling delay (PLD) and the range of ATT values can affect accurate cerebral blood flow (CBF) measurements that are taken using arterial spin labeling (ASL).

(2) Post-labeling delay and T1 decay

There have been several reports of CBF measurements using ASL in diseases featuring hypoperfusion [2-6]; however, when the PLD is extended to accommodate a severe ATT delay, the signal-to-noise ratio (SNR) decreases relative to the T1 decay of the labeled blood during the PLD and erroneous CBF values can result.

(3) Pseudocontinuous arterial spin labeling with background suppression

Pseudocontinuous ASL (PCASL) has the advantage of signal acquisition with a prolonged PLD compared with the other subtype of ASL due to long labeling duration and high labeling efficiency contributing to high SNR [7]. Background suppression technique incorporated with PCASL is expected to reduce the noise from motion and other system instabilities, although a prolonged PLD leads to substantially increased background noise [8].

(4) Purpose

The purpose of this study is to confirm that PCASL with background suppression provides consistent CBF measurements even in the presence of prolonged PLD.

Methods and Materials

(1) Participants

The local Ethics Committee of the Hokkaido university hospital approved the study protocol and all participants gave written informed consent after the nature of this study
had been fully explained. Nine healthy subjects (6 males and 3 females; mean age, 33.6 ± 7.4 years) were recruited from May 2011 to October 2011.

Inclusion criteria included healthy state, age > 20 years, and no history of the diseases which might affect central nervous system.

Exclusion criteria included absolute contraindication for magnetic resonance imaging (MRI) and the presence of an obvious abnormality on routine MRI sequences or magnetic resonance angiography of the brain.

(2) MR imaging and the acquisition parameters

In all, a total of 12 different single-phase PCASLs were performed in all subjects using a 3T scanner (Achieva, Philips Healthcare, Best, The Netherlands) equipped with a 32-channel head coil (Fig. 1 on page 5). They consisted of single-phase PCASLs at 6 different PLD values (900, 1200, 1500, 1800, 2100, and 2400 ms) with background suppression and single-phase PCASLs at the 6 different PLDs without background suppression.

The single-phase PCASLs acquisition parameters included: TR/TE, 4600/10 ms; EPI factor, 27; NEX, 20; SENSE factor, 2.5; FOV, 240 mm; acquisition matrix, 64´64; in-plane resolution, 3´3 mm²; number of slices, 10; slice thickness, 7 mm; duration of labeling, 1650 ms (1650 RF pulses); PLD, 900, 1200, 1500, 1800, 2100 or 2400 ms; acquisition time for a single slice, 35 ms. Labeling was performed 20 mm below the bottom of the imaging slices.

Background suppression technique consists of 2 non-selective inversion pulses [8]. The timing of the first pulse was fixed just after the selective inversion pulse to label the arterial water. The timing of the second pulse was chosen to standardise all of the labeled arterial water moduli with different PLDs at the time of image acquisition.

Background suppression parameters: first nonselective inversion pulse, 1710 ms; second nonselective inversion pulses, 2360 ms (PLD 900), 2550 ms (PLD 1200), 2760 ms (PLD 1500), 2970 ms (PLD 1800), 3200 ms (PLD 2100), or 3435 ms (PLD 2400).

A multiphase PCASL was acquired to calculate ATT map on a pixel-by-pixel basis. Multiphase PCASL parameters: TR/TE, 200/9.6; NEX, 16; duration of labeling, 1000; phase interval, 200 ms; number of phases, 14.
An M0 image was acquired for each single-phase PCASL to measure the equilibrium longitudinal magnetization of the brain using the single-phase PCASL sequence without the labeling pulse trains.

T2WI and MR angiography were done as well to exclude any abnormal lesions within the brain.

(3) CBF quantification

CBF maps were calculated using a one compartment model taking the tagging duration, background suppression, and T2* relaxation into account [9,10], and the ATT in each pixel was calculated from a separate multiphase PCASL with a nonlinear least squares fit procedure. CBF measured from a PCASL signal with background suppression can be expressed by the following equations:

\[
#M = 2 \cdot #_{\text{inv}} \cdot M_{0,\text{CSF}} \cdot T_{1a} \cdot f/(6000 \cdot #) \cdot \exp(-#/T_{1a}) \cdot [1 - \exp(-# \cdot \text{slice time} \cdot (z-1)+#)/T_{1a}] \cdot \exp(-\text{TE}/T_{2*})
\]

\[
# > #
\]

\[
#M = 2 \cdot #_{\text{inv}} \cdot M_{0,\text{CSF}} \cdot T_{1a} \cdot f/(6000 \cdot #) \cdot \exp(-#/T_{1a}) \cdot \exp(# \cdot \text{slice time} \cdot (z-1)-#)/T_{1a} \cdot [1 - \exp(-#/T_{1a})] \cdot \exp(-\text{TE}/T_{2*})
\]

\[
# < #
\]

where #M is the difference in signal intensity between the control and the labeled image, # is the labeling efficiency (0.85) [10], #_{inv} is correction of labeling efficiency due to the background suppression (0.83), M_{0,\text{CSF}} is the equilibrium signal intensity of CSF measured from the lateral ventricle, T_{1a} is the longitudinal relaxation time of blood (1680 ms), l is the water content of blood (0.76), d is arterial transit time, w is post-labeling delay time, t is duration of the labeling pulse (1650 ms), slice_time is the readout duration of a single slice (35.2 ms), z is the number of the particular slice, TE is the echo time (10ms), and T_{2*} is the transversal relaxation rate of arterial blood (50 ms).

(4) Statistical analysis

Regions of interest (ROIs) were used for comparing the CBFs at 6 different PLDs with and without background suppression. The polygonal ROIs were manually selected along the
cortex on each subject's CBF map in the same size and form by a single neuroradiologist (Fig. 2 on page 5). The mean CBF values in the ROIs of all subjects were then calculated for each PLD.

Two-way repeated measures of analysis of variance (ANOVA) were used to determine statistically significant differences in the values of mean regional CBF, which were then tested using Tukey's HSD multiple comparisons correction. Values of $P < 0.05$ were considered significantly different in all statistical tests.

**Images for this section:**

![Fig. 1: Cerebral blood flow maps acquired from single-phase pseudocontinuous arterial spin labeling images, with and without background suppression at 6 different post-labeling delay values (900, 1200, 1500, 1800, 2100, and 2400 ms) are shown.](image)
Fig. 2: Cortical regions of interest on a pseudocontinuous arterial spin labeling image.
Results

The mean CBF and the SD values in the ROIs are presented in Table 1 on page 7. A CBF in which the PLD is equal to 2400 ms without background suppression represents a higher mean CBF and wider SD value than the others.

With 2-way repeated ANOVA, a significant main effect of the PLDs and a significant interaction of the PLDs with background suppression ($P < 0.05$, each) were found; however, background suppression had no significant main effect ($P = 0.20$).

Tukey's test showed a significant difference in CBF at a PLD = 2400 ms without background suppression ($P < 0.05$) and a tendency to increase, whereas no other CBFs showed significance and PCASL with background suppression demonstrated stable CBFs regardless of PLD duration (Fig. 3 on page 7).

Images for this section:

![Box plot showing cerebral blood flow (CBF) at different post-labeling delays (PLDs) with and without background suppression.](image)

**Fig. 3:** There was a significant difference in cerebral blood flow at post-labeling delay of 2400 ms without background suppression ($P < 0.05$).
Table 1: The mean CBF and the SD values in the ROIs.

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<th>PLD</th>
<th>900</th>
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<th>1500</th>
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<td>BS</td>
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</table>
Conclusion

(1) Clinical implications

ASL is expected to be used more often as a repeatable and non-invasive physical screening method for assessing CBF in various disease states, especially those with delayed ATT. The background suppression technique is expected to be effective for obtaining a reliable CBF measurement in cerebrovascular diseases even if the labeled blood signal is too small to detect or fails to arrive in time at the imaging plane owing to the prolonged PLD.

(2) Limitation of this study

1. Prolonged PLD increases the flow of labeled blood into the tissue and out through the veins, so the ASL signal reflecting the CBF might lose part of the practical CBF amount.

2. The range of our PLD setting was limited to within 2400 ms.

3. The accurate effect of delayed ATT should be confirmed in patients although the participants were healthy subjects in the present study.

4. The acquisition of multiple slices can lead to differences in the efficiency of the background suppression during the different slices.

(3) Conclusion

PCASL with background suppression showed consistent CBF values even when PLD was extended and has the potential to permit longer PLDs for patients with severe ATT delay.

References


Personal Information

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