Improving CBF MRI using a Background Suppression in cASL with a Separate Labeling Coil

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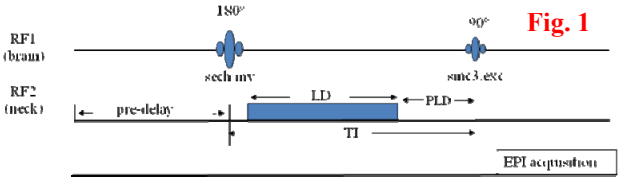
INTRODUCTION In arterial spin labeling (ASL) MRI of cerebral blood flow (CBF), pair-wise subtraction of adjacent non-labeled and labeled images often could not achieve complete cancellation of the background static tissue signal because of temporally fluctuating physiological noise. While background suppression (BS) by inversion nulling has been shown to improve CBF temporal stability (1–5), imperfect post-labeling inversion pulses compromise perfusion contrast. We previously proposed a background suppression in conjunction with continuous ASL approach (IR-cASL) (6), in which an inversion pulse was applied before the continuous labeling of arterial spin. In this work, we further developed this approach to include CBF quantitative for multi-slice acquisitions in which the amount of background suppression varies due to T1 recovery with multislice acquisition. Comparisons with cASL were made in the same animals. In addition, we tested the efficacy of improving CBF accuracy in stroke rats.

METHODS Diagram of ir-cASL sequence is shown in **Figure 1**. A nonselective adiabatic 180 degree inversion pulse (sech, 20ms pulse length) in the RF1 channel was added before the spin labeling pulse in the RF2 channel. The labeling duration (LD) and the post-labeling delay (PLD) together constitute the inversion recovery delay (TI). Standard GE EPI acquisition was employed.

Fig. 1



Twelve male SD rats were anesthetized with ~1.2% isoflurane in air, 6 of them were subjected to permanent or 30-min transient MCA occlusion (7). Body temperature and respiration rate were continuously monitored and maintained within normal ranges. MRI experiments were performed on a 7-T/30-cm magnet. A surface coil (2.3-cm ID) with active decoupling was used for brain imaging and a neck coil for perfusion labeling.

CBF was acquired using variable LD on a single horizontal slice or fixed LD on 7 transverse slices. Single-shot gradient-echo EPI acquisition was used. MR parameters were: data matrix=64x64, FOV = 3x3 cm, 1.5-mm slice thickness, TE = 10.2 ms. For single slice scans, TR = 6 s and typical variable labeling durations of 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.8, 1.9, 2.0, 3.0 s. For multi-slice scans, TR = 3 s and LD = 1.4 s. The stroke rats were scanned using the same parameters as multi-slice scans.

Multi-slice CBF of both cASL and IR-cASL were calculated by

$$f(n) = \frac{\lambda}{T_{1app}} \bullet \frac{S_{non-labeled} - S_{labeled}}{2\alpha S_b^0 (1 - e^{-LD/T_{1app}})} \bullet e^{(n-1)*T_s/T_{1blood}} \quad (1) \quad ,$$

where, f is CBF, γ is brain/blood partition coefficient, α is the labeling efficiency, T_{1app} is estimated as $1/T_{1app} = 1/T_1 + f/\lambda$ when $f = 1$ ml/gram/min, the non-labeled images of cASL (without inversion pulse, TR = 6 s) were used to be an estimation of S_b^0, n is the slice number, T_s is the data readout time for one image slice, and the term $e^{(n-1)*T_s/T_{1blood}}$ compensates for the labeling efficiency loss due to the labeled blood signal T_1 relaxation as a function of time during multi-slice acquisition. Stability of perfusion contrast measure was compared between cASL and IR-cASL using both normal and stroke rats by using standard deviation maps of normalized ΔS ($\Delta S/\overline{\Delta S}$) of CBF scans.

RESULTS **Figure 2A** shows the normalized whole-brain signal intensities of non-labeled and labeled signals from one animal as function of different labeling durations. The raw signal intensities of IR-cASL signal were substantially lower than those of cASL because of BS. The difference between $S_{non\text{-}labeled}$ and $S_{labeled}$ (ΔS) increased slightly with increased labeling durations, but did not appear to differ between cASL and ir-cASL. The sign of ΔS reversed at LD below the inversion null point (i.e., < 1 s) as expected. **Figure 2B** shows the group-averaged $\Delta S/S_{non\text{-}labeled}$ in percentage changes were larger for IR-cASL compared to cASL (5~24% *vs* 2~4%). **Figure 3** showed quantitative multi-slice CBF images acquired using IR-cASL. Group-averaged whole-brain CBF values were similar across different labeling durations with or without inversion (**Figure 4**). Temporal standard-deviation (SD) maps of normalized perfusion contrast $\Delta S/\overline{\Delta S}$ of a stroke rat (after reperfusion) and CBF map were shown in **Fig. 5**. The temporal SD of IR-cASL was significantly smaller than that of cASL, especially in low CBF area. IR-cASL yielded 2.2, 2.6 and 2.9 times better CBF temporal stability in normal CBF, low CBF (0.1~0.6 ml/gram/min) and white matter tissues.

Fig. 2

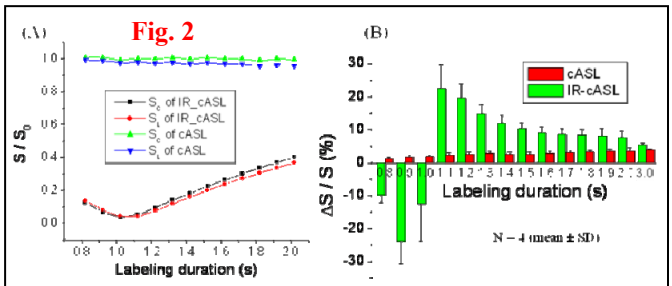


Fig. 3

Fig. 4

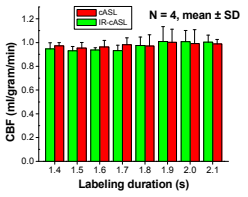
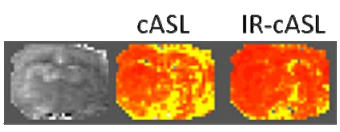


Fig. 5



DISCUSSION & CONCLUSION This study presents a novel IR-cASL approach to achieve background static tissue signal suppression without compromising arterial spin labeling efficiency caused by imperfect BS inversion pulses. Multi-slice quantitative CBF map using IR-cASL was possible by taking into account variable BS and labeling efficiency. Increased CBF sensitivity of IR-cASL was demonstrated to achieve improved CBF measurement in stroke. The current IR-cASL scheme offers some unique advantages for rodent studies where the arterial transit time is short (~200 ms). In human, the long arterial transit time (~1 s) necessitates a long post-labeling delay and is incompatible with IR-cASL in its current form.

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