The nuts and bolts of implementing a two-coil CASL method for CBF measurement on a 9.4T/30cm scanner

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Introduction: Since its first introduction (1), the continuous arterial spin labeling (CASL) method for cerebral blood flow (CBF) measurement has been studied and improved at several pioneering research sites, and its concept is quite clearly understood. But the transfer of this technique to new sites does not seem as simple and direct as one may think. As CBF signal is intrinsically low in intensity (low volume fraction of blood in brain), any imperfection in the sequence or scanning protocol or system stability can cause loss of valuable sensitivity, and the resulting CBF images may have significant artifacts or poor SNR. We recently implemented the two-coil CASL method on our Bruker Biospin 30cm bore 9.4T animal MRI system, and obtained excellent CBF images and time series. The purpose of this abstract is to share our experience, the challenges we met and present our solutions. We have found that sometimes seemingly trivial details are key to successful implementation. It is our hope that this information can be helpful to more research and application sites in utilizing this powerful technique in fMRI studies.

Material and method: All experiments were performed on a Bruker 30cm bore 9.4T MRI system.

Pulse sequence: The CASL pulse sequence was implemented on the Bruker's Paravision IV platform, based on the standard EPI acquisition method. The ASL tagging was written as a module, which provides interleaved "tag" and "control" repetitions during each scan run. For multi-slice scans, for each TR, all slices were acquired following one single tag module. The tagging pulse was set to 3 sec, with z-gradient at 1G/cm. Initially, for "control image" the module applied no RF or gradient pulses. The relative CBF image, which was generated by subtracting the "tag image" from the "control image", was very poor in quality. We added gradient waveforms identical to those used in the tag TR to the control TR, so that the effects of eddy-current caused by gradients are removed in the CBF images. In order to further remove effects that may be caused by system inconsistency, we made the "control TR" as similar to the "tag TR" as possible, including adding to the "control TR" a null-RF pulse, which is of the same shape as that in the "tag TR" but at very high attenuation (150 dB).

Hardware: Two surface coils were used for this setup - a de-tunable, Tx/Rx 1"x1.5" oval surface coil (imaging coil) was placed at the rat head for brain image acquisition, and a de-tunable 1"x1.5" rectangular surface coil (tagging/labeling coil) was placed at the rat neck for continuous inversion of the blood flowing in the carotid and the vertebral arteries. The detune signals for both coils were supplied through a homemade driver box, which was gated by a TTL signal during the scanning run. The driving TTL signal was generated by the CASL pulse sequence at appropriate times during each TR. Due to the overall small size of the animal setup, the RF cables for both coils were placed very close to each other, which lead to some coupling between these two coils, and artifacts in the images. To reduce this coupling, we installed a 1/4 λ balun at each coil's output location. We connected the labeling coil to the scanner's "decoupler channel", but replaced the decoupler amplifier with one that is identical to the imaging amplifier. This amplifier is capable of providing continuous RF power waveforms at ^{1}H resonance frequencies. We used a directional coupler and an oscilloscope to monitor the RF pulses generated from the "labeling amplifier". By monitoring the RF amplifier output, we found that the time it takes for the amplifier to stabilize and consistently generate the desired pulse shape for the long labeling pulse is on the order of 2-3 minutes. We also found that the preamplifier (which is typical for hookup of all coils) has contributed to this delay. We reduced this delay by directly connecting the labeling coil cable to the RF output and bypassing the preamplifier during CASL experiments where this coil is used as a Tx only coil.

Scanning procedure: In addition to the routine scout scan to determine the desired imaging slices using the imaging coil, a scout scan is performed at the neck region of the rat by temporarily imaging with the labeling coil. From the sagittal scout image, a location is selected where the spine (usually parallel to the main arteries and more identifiable) is closest to parallel to the field, and at the same time, within the maximal sensitivity region of the coil. This step ensures that the labeling is perpendicular to the flow direction (most efficient), and by using the most sensitive region of the labeling coil, results in the efficient use of labeling power and minimizes SAR. In our experience, although individual rats are slightly different, the best tagging locations are generally at 29 - 33 mm away from the center of the rat brain. High-order shimming was performed using an automatic procedure developed in-house. This minimizes distortions and signal loss in the EPI images. Although the theory of adiabatic labeling allows a wide range of RF power levels to achieve spin inversion, it is still desirable to use an optimal power level that both minimizes SAR and maximizes the tag-control contrast. As we are using surface Tx/Rx coils, we have found that the routine automatic method provided by the manufacturer does not consistently find the correct power level to generate a 90 degree spin tip. Instead, we used a multi-echo spin-echo sequence and manually adjust the attenuation in prescan ("gsp") mode to determine the reference power. The attenuation of the labeling pulse was first estimated from power levels used in literature and the specifications of our particular RF amplifier, and then based on that reference, experimentally determined by choosing a power level that resulted in the strongest CBF contrast.

For the CO_2 challenge experiment, the imaging parameters used were: TR/TE = 3700/11.6 ms, matrix = 64 x 64, in-plane resolution = 0.04 cm, labeling pulse length = 3 sec. 5 slices of 2 mm thickness, center-center slice gap = 3 mm. Total scan time = 14 min. At the end of 2 min and 7 min, 7.5% CO_2 was given through the nose cone for 1 min. Room air was given at all other times.

Animal monitoring and handling: Three male Sprague-Dawley rats weighing 350-500g were used in the experiments. The rat was secured by fiberglass earbars. Anesthesia (isofluorine) and gas (air or CO_2) were delivered through a custom-designed nose cone made of fiberglass. In our experience, fiberglass introduces less susceptibility interference than other materials such as plastic. A heated pad using circulated water was used to maintain the rat's body temperature. Animal ECG, respiration, and anal temperature were monitored during each scan.

Results: Fig. 1 shows the CBF image from a single subtraction of a tag-control pair of EPI images during air-breathing. Fig. 2 shows the CBF time-series signal from the 3x3 voxel ROI in the cortex in Fig 1. Fig. 3 shows the correlation map generated using the average times series of the voxels in Fig. 2 as reference, overlaid on a spin-echo image.

Discussion: We have implemented the two-coil CASL method and successfully obtained high SNR CBF image and time-series for functional studies using a CO_2 challenge protocol. The apparent left-right asymmetry in signal intensity may be reduced by better positioning of the rat brain in the sensitive region of the surface coil.

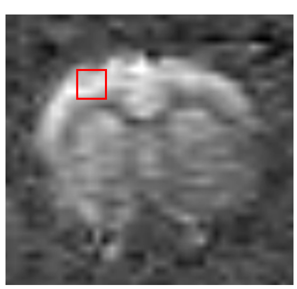

Fig.1. Relative CBF image by subtraction of a single control-tag pair of EPI images.

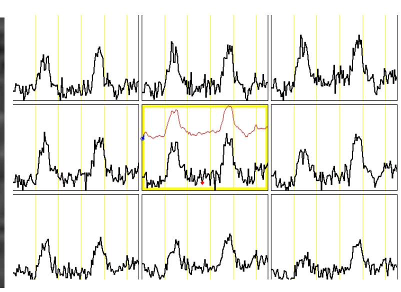

Fig.2. CBF time-series from a region of interest in the cortex (see Fig.1) during CO_2 challenge.

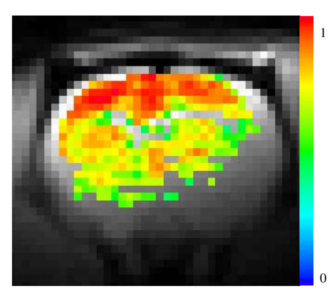

Fig.3. Correlation map showing strength of the CBF changes in response to CO_2 challenge (threashold = 0.4).

References:

1. J.A. Detre, J.S. Leigh, D.S. Williams, A.P. Koretsky, *Magn, Reson. Med.*, **23**, 37-45 (1992)