A Three Coil System for Improving the Performance of Arterial Spin-Labeling Studies on Concious Animals

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Introduction

Functional neuroimaging is a powerful tool for mapping the activity of a living brain under normal and pathological conditions. Arterial Spin Labeling (ASL) is a recent technique whereby arterial blood water in the carotid artery is labeled by various methods, allowing a quantitative measurement of perfusion through individual regions of the brain. The ASL method is an improvement over previously used blood oxygen level dependant (BOLD) methods because of its higher contrast and insensitivity to the physiological changes that occur during drug studies.

ASL experiments are performed using a transmit-only coil in proximity to the neck that is responsible for labeling arterial blood water. Previously, a surface coil was then used to image the region of interest (ROI) [1]. Surface coil only imaging scans, however, suffer from poor depth filling caused by uneven excitation due to an inverse-square drop off in signal intensity. The result is poor image quality and decreased contrast far away from the surface coil, which has previously restricted the ability to measure changes in the basal regions of the brain [2].

A three-coil ASL imaging system has been constructed to achieve superior experimental performance by combining an arterial spin labeling coil with a volume coil for uniform excitation within the ROI, a specialized surface coil for obtaining maximum SNR; with all three integrated into an animal restrainer system appropriate for imaging fully conscious rats.

Methods

The labeling coil was constructed as a small, oblong loop of copper wire. A PIN diode detune circuit was added to prevent coupling to the volume coil during the image acquisition scan. The labeling coil was fitted to the headpiece of an integrated restrainer and dual RF coil system specifically designed for conscious animal imaging (Insight Neuroimaging Systems, Worcester, MA, USA). Specialized switching electronics were constructed to actively decouple the three coils. The TTL signals used to activate the RF amplifiers during transmit were split and fed to the switching electronics. The switch was designed such that an active signal on either TTL line would tune the appropriate transmit coil, with the surface coil being tuned in the absence of an active TTL signal.

To test the system initially, a dead rat was placed in the restrainer and the entire system was inserted into the magnet. Labeling coil transmit power was calibrated by running single coil scans in which the labeling coil was used to transmit and receive. In these scans the power was set such that the carotid arteries received optimum adiabatic excitation. The effective field of view (FOV) of the labeling coil was set to a depth of 5mm and a longitudinal extent of 15mm. Care was taken to ensure there was no significant excitation of the brain, thereby avoiding magnetization transfer contrast (MTC) effects caused by the saturation of macromolecules in the brain, which degrade perfusion measurements in ASL experiments [1].

Once confident the system was functioning properly, hypercapnic challenges were performed on a fully conscious rat using 5 and 10% CO_2 concentrations according to the methods of previous studies [2] such that the results could be meaningfully compared. Cerebral blood flow (CBF) measurements were performed using the continuous ASL technique [3] with single-shot, gradient-echo, echo-planar-imaging acquisition. Paired images were acquired alternately: one with ASL, and the other without (control). The MR parameters were: matrix = 64 x 64, FOV = 2.8 x 2.8 cm^2, six 1.5mm slices, TE = 15ms, and TR = 2s.

Results

To demonstrate improved homogeneity, SNR measurements were taken in the cortical region and the hypothalamus of a rat using both conventional two-coil, and our improved three-coil systems. SNR was taken as the mean pixel intensity divided by the standard deviation of pixel intensity for two ROIs chosen in near and far proximity to the surface coil, as illustrated in Figure 1. SNR in the two-coil system was measured to be 10.4 in the cortical region, and 5.2 in the hypothalamus. In the three-coil system the SNR was 15.4 in the cortical region, and 15.0 in the hypothalamus.

Global response to hypercapnic challenge as measured with the three-coil system (52% and 137% CBF increase for 5% and 10% CO_2, respectively) were similar to previous studies with a two-coil system (51% and 158% CBF increase for 5% and 10% CO_2, respectively [2]). Labeling in the cortical regions was consistent for both the two-coil and the three-coil system. The sensitivity to changes in the hypothalamus (blue ROI in Fig 1), however, is markedly increased (Fig 2B) over the previous two-coil system (Fig 2A). A CBF increase of 61% was measured in the hypothalamus in response to a 5% CO^2 challenge, and a 10% challenge caused a 135% CBF increase.

Conclusion

A three-coil configuration consisting of volume, surface, and labeling coils with accompanying active switching electronics has been constructed and tested. Significant gains in SNR and homogeneity have been achieved, with a marked improvement in basal brain response detection. These improvements will be valuable in experiments involving fMRI measurements of the basal brain region where BOLD responses are affected by the physiological changes caused by experimental variables such as drug dosing.

[1] Silva, A et al, MRM 1995; 33:209-214
[2] Sicard, K. et al, J Cereb Blood Flow Metab 2003; 23:472-481
[3] Silva A. et al, J Cereb Blood Flow Metab 1999; 19:871-879

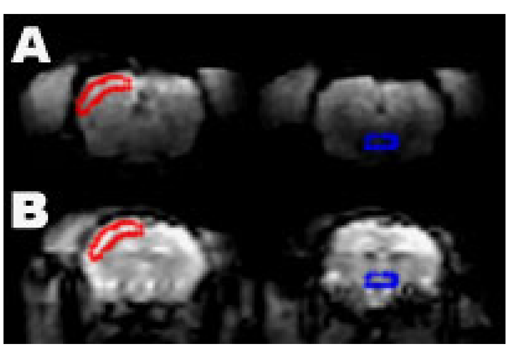

Figure 1: ASL images of a fully conscious rat performed using a 2 coil system (**A**) and a 3 coil system (**B**). Signal fall off in the 2 coil images prohibits study of the entire brain.

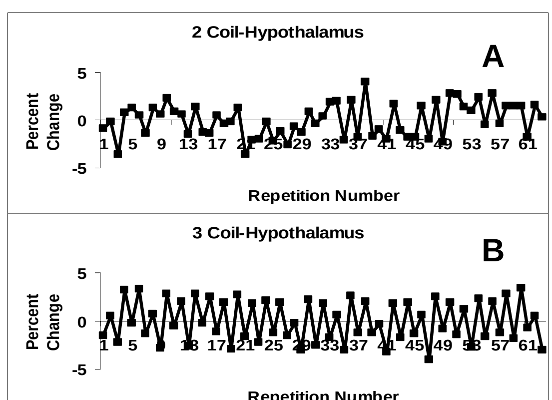

Figure 2: Time course of alternating labeled and unlabeled acquisitions in the hypothalamus. **A**) Labeling with the 2 coil system is inconsistent, while **B**) labeling with the 3 coil system is consistent and robust.