Continuous arterial spin labeling (CASL) in the monkey brain at high magnetic field using a three-coil approach

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Introduction Recent combined electrophysiology and neuroimaging experiments in the monkey made the first step to examine directly the relationship of neuronal activity to the BOLD signal [1]. Perfusion-based MRI may improve even further the electrophysiological investigations of the neurovascular coupling, as perfusion imaging can measure cerebral blood flow (CBF) directly at the capillary level. Moreover, functional CBF changes and interleaved-acquired BOLD data can be combined to compute changes in oxygen consumption rate. Arterial spin labeling is a commonly used CBF technique. Since CBF signal is intrinsically low (1-2%), optimization of the signal-to-noise ratio is critical. Continuous ASL with a separate labeling coil has the advantages of increased SNR, multi-slice capability, and absence of magnetization transfer. The CASL method has been applied successfully in rat and human studies [2,3]. Its wider application especially on routine human MR systems is hindered by the advanced hardware and software requirements. The monkey model reported here provides the unique opportunity to bridge the gap between rodents and human studies in respect of multimodal methodology.

Fig. 1

Methods MR imaging was performed on vertical 7T/60cm and 4.7T/40cm dedicated macaque monkeys systems (Bruker) equipped with a second 1H transmit channel. A saddle-shaped volume coil was used for RF transmission and a 30-35 mm surface coil for reception. For spin labeling, a concave single-loop and a cravat-shaped two-loop surface coil were developed with 40 mm loop size (Fig. 1). All RF coils were actively-decoupled and switched with a self-built logic unit and current driver.

Single-shot, multi-slice GE-EPI was acquired at 0.75 to 1 mm in-plane resolution. The preparation module for ASL consisted of a 1-3 s labeling period with 2.5 mT/m gradient followed by a post label delay (PLD) of 0 - 2 s. For CASL, the labeling frequency was switched in interleaved scans.

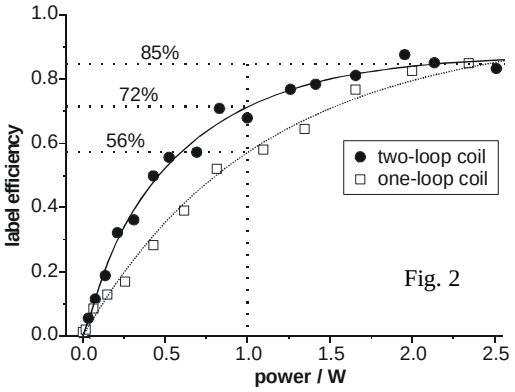

Fig. 2

Results and Discussion Label efficiencies were compared for the one-loop and the two-loop labeling coils. In both cases the maximal achieved label efficiency of 85% was similar. The cravat-shaped coil was able to label both hemispheres with even smaller power consumption (Fig. 2). At a labeling power of 1 W, efficiency reached 66% (one-loop) and 85% (two-loop) of maximum. High resolution angiography of the neck confirmed proper coverage of carotid and vertebral arteries. Distance from imaging to labeling plane was approximately 6 cm. The first CASL experiments were dedicated to optimize parameters like label duration and PLD and to assess transit times for the monkey setup. We found that the label duration of 2 s was sufficient to achieve high SNR throughout the cortex. For the monkey brain a PLD of 0.8 - 1.2 s was optimal for imaging gray matter CBF and attenuation of large vessel CBF, which is similar to studies in human. Excellent quantitative multi-slice CBF maps at high resolution could be acquired in the occipital lobe using a sensitive receive-coil placed on one hemisphere (Fig. 3, 0.75 x 1.25 x 2 mm^3, TE 17 ms, TR 4 s, NA 64, LT 2.3 s, PLD 1.2 s, 4.7 T). High SNR of 25-35 afforded well-resolved CBF signal of gray matter in less than 10 min. The CBF maps in Fig. 3 also demonstrate proper labeling of the deep vertebral arteries, which supply major portions of occipital cortex.

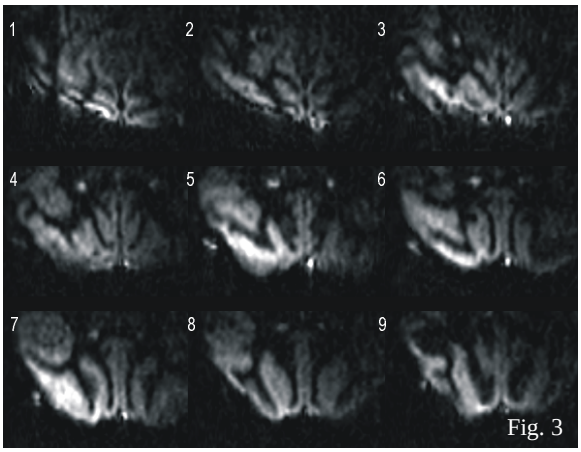

Fig. 3

To conclude, these first *in vivo* data promise that *functional* studies in whole-brain or localized ROIs to measure CBF, BOLD and $CMRO_2$ changes will considerably gain from this setup.

[1] Logothetis et al. *Phil.Trans.R.Soc Lond. B* 357:1003 (2002); *Nature Neurosci* 2(6):555-62 (1999); *Nature* 412:150-57 (2001). [2] Silva,A.C. et al. *Magn.Reson. Med.* 37:58-68 (1997); Zhang,W. et al. *Magn.Reson. Med.* 33:370-6 (1995); Williams,D.S. et al. *Proc.Natl.Acad.Sci,USA* 89:212-6 (1992); [3] Zaharchuk,G. et al. *Magn.Reson. Med.* 41:1093-8 (1999).

This work was supported by the Max-Planck Society