Continuous Artery-Selective Spin Labeling (CASSL)

R. Werner[1], D. G. Norris[2], K. Alfke[1], H. M. Mehdorn[3], O. Jansen[1]

[1]Section of Neuroradiology, University Hospital of Schleswig-Holstein, Campus Kiel, Germany, [2]FC Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands, [3]Department of Neurosurgery, University Hospital of Schleswig-Holstein, Campus Kiel, Germany

Introduction

Arterial Spin Labeling (ASL) techniques are widely used to measure cerebral blood flow [1]. Several authors reported on a spatially selective application, which selectively label blood in individual arteries and image these arteries' perfusion territories. Many clinical questions have been posed, that might possibly be resolved by such new techniques, including the origin of the emboli in embolic stroke, evaluation of collateral flow in ischemic diseases, and the functional significance of vasculopathies in general. The spatial selectivity has been achieved with both continuous (CASL) and pulsed ASL (PASL) in a number of different ways, but all of them face difficulties in terms of limited selectivity [2-4] or relatively poor SNR [5]. Here, we present a new spin labeling mechanism named Continuous Artery-Selective Spin Labeling (CASSL). As first applications, selectively labeled images of the cerebral perfusion territories of the left- and right-sided internal carotid arteries (ICA), the basilar artery (BA), both anterior cerebral arteries (ACA) as well as of the left- and right-sided middle cerebral arteries (MCA) are presented.

Materials and Methods

The selective labeling mechanism is based on CASL with an amplitude-modulated control experiment [6]. In addition to the fixed labeling gradient component aligned with the flow direction, a second, orthogonal component is added, which is rotating with a frequency f_{rot}. The labeling RF-pulse is frequency-modulated to match the resonance frequency at the position of the artery to be labeled. As illustrated in Fig. 1, this leads to an oscillatory motion of the labeling plane. The resonance condition is always fulfilled at the same spatial position for the selected artery, but for any other adjacent artery the locus of resonance will vary in time, giving rise to a pseudo-random behavior of indiviudal spins when they move through the plane several times. On average, this causes a saturation of the magnetization in a non-selected artery in both labeling and control experiments. The sequence was implemented on a clinical 1.5 T Philips Intera MR system (Philips Medical Systems, Best, The Netherlands).

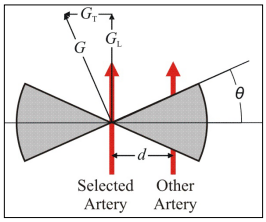

Fig. 1) Illustration of the moving labeling plane.

A phantom study evaluated the CASSL mechanism. The custom-made flow phantom consisted of two parallel tubes, embedded in agarose gel at a distance of 20 mm. The signal intensity in both tubes was measured distal to the position of the CASSL-label and compared to the related intensities of a regular CASL scan with fixed labeling plane.

Further MR images were acquired from 8 healthy volunteers. For planning of the labeling position, 2D inflow angiography was performed. In a study of 7 volunteers, labeling was applied to the right-sided ICA, the left-sided ICA, and the BA in three consecutive scans. Parameters were: f_{rot}, 120 Hz; θ, 12°; Labeling duration, 2.2 s; post labeling delay, 0.8 s, spin-echo EPI acquisition; FOV 220x176 mm; scan matrix 80x71; TR/TE, 3600/42 ms; 7 slices; thickness, 9 mm; gap, 3 mm; 40 labeled and 40 non-labeled acquisitions; scan time 4:58 min; SAR, 1.87 W/kg. In one further volunteer, both the left- and the right-sided MCAs were labeled, at a distance of ~5 mm from the Circle of Willis, and both ACAs were labeled close to the anterior communicating artery (θ, 8°; 5 slices).

Results

In the phantom studies (Fig. 2), a labeling efficiency of 80% compared to the regular CASL approach was consistently achieved for the selected artery, while the signal intensity in the subtraction images in the region of the non-selected tube was at noise level. The level of selectivity could be adjusted by the choice of f_{rot} and θ.

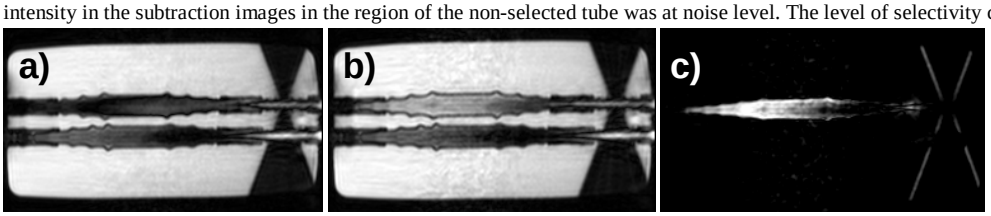

Fig. 2) Typical images of the phantom study. Flow direction was from right to left. At the labeling position (artifact to the right), the embedded tubes had an inner diameter of 6 mm which is growing towards the middle section to facilitate a measurement of the signal intensities by reducing the flow velocity. In the labeling experiment (a), the upper (=selected) tube was inverted distal to the labeling position, in the control experiment (b), it underwent a double inversion. The magnetisation in the lower (=non-selected) tube was saturated in both experiments. The complex subtraction image showed only the selected tube.

Typical results from one of the seven volunteers of the ICA/BA-study are shown in Fig. 3. The selectively labeled images clearly showed delineated perfusion territories of the left- and right-sided ICA and of the BA with good grey/white matter contrast. Fig. 4 shows the results from the volunteer studied with a selection of the left- and right-sided MCA and of both ACAs. Again, clearly delineated perfusion territories were obtained. As it was not possible to apply labeling in such a manner that an intersection with all of the imaging volume was avoided, large, dark artifacts appear in the subtraction images. As these do not impinge on the perfusion territory, the artifacts are only cosmetic.

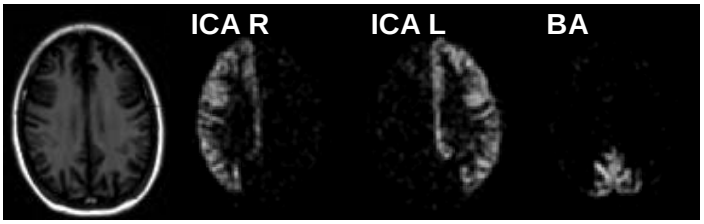

Fig. 3) Anatomical and perfusion territory images of ICA and BA. Only the 4th out of 7 slices is shown.

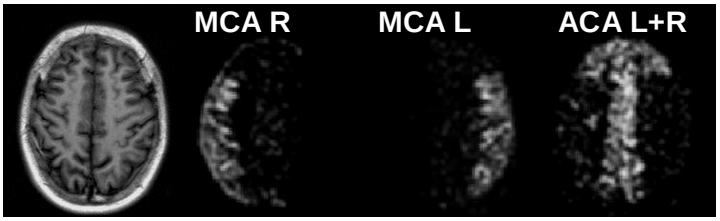

Fig. 4) Anatomical and perfusion territory images of the intracranial arteries distal to the Circle of Willis. Only the 3rd out of 5 slices is shown.

Discussion

The ability to continuously label blood in a single artery allows an application to many geometrical situations that are not accessible by pulsed techniques, which need to invert the magnetization of a significant amount of blood in a larger inversion volume [3]. This is especially true wherever an artery of interest is branching from a larger artery and is supplying the tissue at a short distance from the branching-point, as is the case for example in the cerebral arteries distal to the Circle of Willis. Consequently, the CASSL technique allowed to acquire images of the perfusion territories of these arteries in vivo for the first time.

Acknowledgements

The authors thank Tobias Schaeffter for helpful discussions.

References

1. Barbier, E.L., et al., J Magn Reson Imaging, 2001. 13(4): p. 496-520.
2. Werner, R., et al., Magn Reson Med (in press).
3. Hendrikse, J., et al., Stroke, 2004. 35(4): p. 882-7.
4. Zaharchuk, G., et al., Magn Reson Med, 1999. 41(6): p. 1093-8.
5. Davies, N.P., et al., Magn Reson Med, 2003. 49(6): p. 1133-42.
6. Alsop, D.C. et al., Radiology, 1998. 208(2): p. 410-6.