Labeling Efficiency Measurement for Perfusion Quantification in ASL Experiments

Kathrin Lorenz[1-3], Toralf Mildner[2], & Harald E. Möller[2,3]

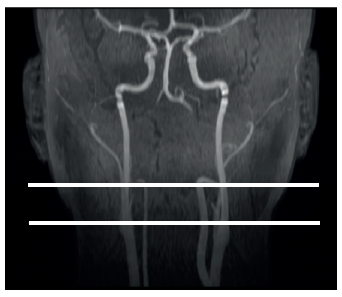
[1]International Max Planck Research School on Neuroscience of Communication, Leipzig, Germany
[2]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
[3]University of Leipzig, Germany

klorenz@cbs.mpg.de

Introduction

The blood supply in the human brain is defined by physiological parameters, such as cerebral blood volume (CBV) and cerebral blood flow (CBF). Arterial spin labeling (ASL), first described by Detre et al. 1992 [1], has developed into a promising method in perfusion imaging. It is a non-invasive technique using magnetically labeled water as an endogenous tracer investigating the blood flow, the bolus passage to the capillary bed, and the tracer distribution in the tissue. Quantification is dependent on physiological conditions, like the transport mechanisms, and on experimental details such as labeling efficiency or labeling position. Purpose of the current study is to address an important issue in perfusion quantification based on the pseudo-continuous ASL (pCASL) method by measuring the labeling-efficiency, i.e. the extent of inversion, achieved by the pCASL pulse train.

1



Angiography of a volunteer showing the labeling and imaging positions.

Methods

- 3-T whole-body scanner (TIM Trio, Siemens, Erlangen, Germany) with built-in body coil for transmission & 12 channel head coil combined with a neck coil for receiving.
- Labeling position between the base of cerebellum and about 80 mm below the circle of Willis, cf. Fig. 1; in agreement with Ref. [2].

Perfusion measurement:

- pCASL sequence with nominal flip angle = 22°, labeling duration = 3000 ms, PLD = 1500 ms and Gradient-echo EPI Readout with TE/TR = 15.5/5500 ms.
- Variation of phase offsets to artificially impair the labeling efficiency: 8° (optimum), 40°, 60°, and 80°.

Labeling-efficiency measurement:

- pCASL sequence with nominal flip angle = 22°, labeling duration = 1500 ms, PLD = 0 ms.
- Gradient-echo EPI with TE/TR = 13.2/1547 ms, partial Fourier 6/8 & GRAPPA with acceleration factor 2.
- Imaging position 10-15 mm above labeling position, cf. Fig. 1.
- Axial slice, nominal resolution 2 x 2 x 6 mm^3.
- Additional scans: angiography to observe the carotid and vertebral arteries; pCASL prescan with phase modulation to estimate a phase offset caused by B_0-inhomogeneities, cf. Fig. 2 & Ref. [3].
- Determination of the labeling efficiency α with the use of the complex signals of control (S_C) and labeling (S_L) conditions by:

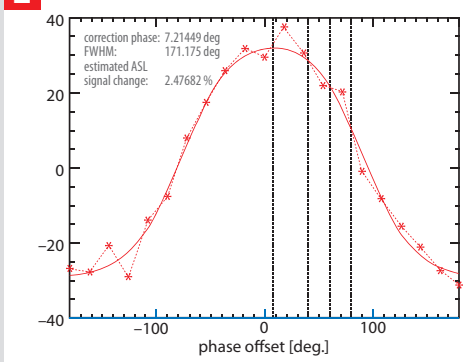
$$\alpha = (S_C - S_L)/2*S_C$$

Results & Discussion

Labeling efficiency and therefore the ASL signal is dependent on the labeling position, i.e. on the orientation of arteries and on the homogeneity of B_1 and B_0 in this region. For a high labeling efficiency, the arteries should go straight along the labeling gradient in z direction (cf. Fig. 1). Fig. 3 shows exemplarily the labeling position and the position where the efficiency data is acquired from an axial view as well as the voxels of the labeling-efficiency map whose standard error is smaller than 3 %. We found a very good agreement of the anatomy with significant voxels, identified as arteries (cf. Fig. 3c and 3b). The labeling-efficiency values that are determined from evaluated regions of interest (ROIs, see Fig. 3d) are given in Table 1. In the labeling position the internal carotid arteries (ICAs) and the vertebral arteries (VAs) are perpendicular to the labeling slice whereas the course of the external carotid arteries (ECAs) is tilted affecting the efficiency of the inversion. Obviously, the inversion was less efficient in the ECAs compared to the ICAs or the VAs.

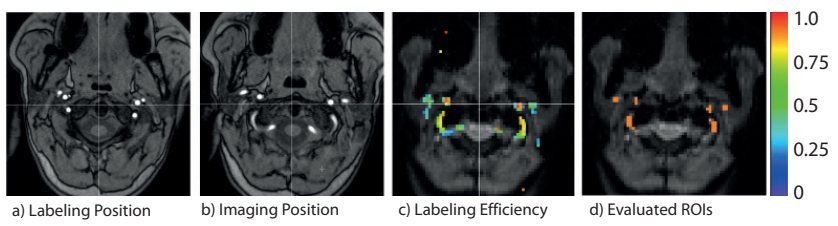
A similar approach was conducted by Jahanian et al. in 2011 [4] where they simulated and measured the labeling efficiency of the pCASL pulse train and verified their correction strategy for magnetic field inhomogeneity. The *in-vivo* labeling efficiency they measured in the carotid arteries is on average 76 % which corresponds nicely with our results (cf. Table 1).
The measurement of labeling efficiency enables to correct perfusion maps for imperfect inversion. To show that, we artificially decreased the labeling efficiency in a single-subject experiment by varying the phase offset, that was usually used to correct for B_0-inhomogeneities at the labeling position and to enhance the ASL signal outcome. Now it is used vice versa to deteriorate the signal by applying other than the optimum phase offset. A plot of the phase distribution in a ROI of the insula is depicted in Fig. 2, displaying the optimum phase offset for correction (i.e. 8°) at the maximum of the curve and the phase offsets employed in the following pCASL scans to degrade the signal (dashed lines at 40°, 60°, 80°). The evaluation of these perfusion data sets is done in two ways: first assuming the labeling efficiency to be 85 % as proposed by literature [5,6], and second using the efficiency value determined in the experiment. The corresponding perfusion maps are shown in Fig. 4. It can be seen that perfusion is underestimated when the real labeling efficiency is lower than the estimated one (see Fig. 4 top row), whereas the perfusion maps are nearly the same, regardless of the phase offset, when the measured efficiency value is used (see Fig. 4 bottom row). The error in perfusion caused by this underestimation amounts to ca. 8 % in case of a small deviation from the optimum measurement conditions and about 30 % if the phase-offset is increased even more. If the phase offset is set in that way that there is almost no signal change, i.e. blood water is not labeled, perfusion can not be determined any longer (see column d of Fig. 4).

2



Distribution of phase offsets in a ROI of the insula in a pCASL image obtained by the prescan. The determined correction phase offset in this example is about 8°. The dashed vertical lines indicate the different phase offsets, i.e. optimum at 8°, 40°, 60° and 80°, that were used to investigate the influence of correctly measured labeling efficiency in perfusion evaluation.

3



a) Labeling Position | b) Imaging Position | c) Labeling Efficiency | d) Evaluated ROIs

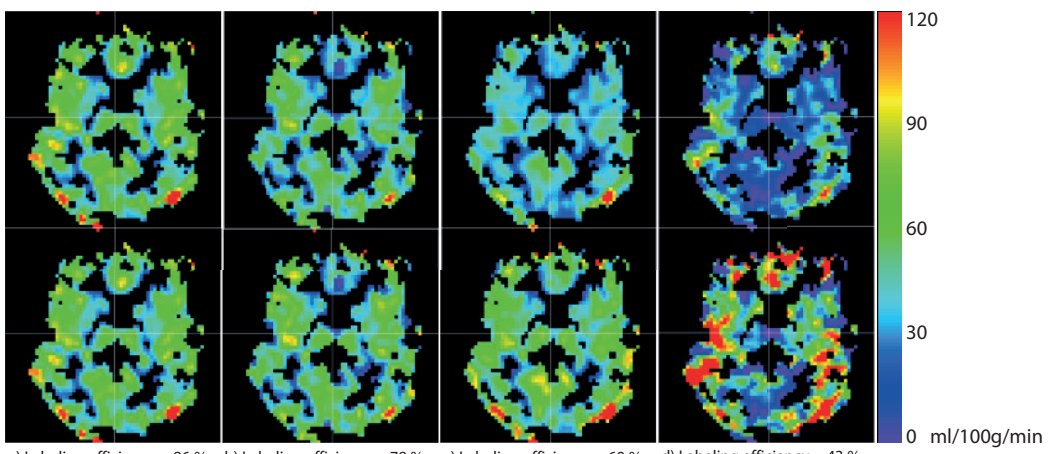
a) Labeling position of the perfusion experiment. b) Position where the ASL signal for the efficiency evaluation is acquired, i.e. 1 cm above the labeling position. c) Labeling-efficiency map masked with standard error values smaller than 3 %. d) Voxels that are evaluated are colored in orange.

Table 1

Labeling Efficiency [%] ± Std. Error [%]	ICA	ECA	VA
ROI left	62.4 ± 1.5	39.7 ± 0.7	75.3 ± 0.8
ROI right	89.8 ± 1.5	43.7 ± 0.8	72.5 ± 0.7

Labeling efficiency values in evaluated ROIs of the internal carotid artery (ICA), the external carotid artery (ECA) and the vertebral artery (VA) for different hemispheres as shown in orange in Fig. 3d).

4



a) Labeling efficiency = 86 % phase offset = 8° (optimum) | b) Labeling efficiency = 78 % phase offset = 40° | c) Labeling efficiency = 60 % phase offset = 60° | d) Labeling efficiency = 43 % phase offset = 80°

Perfusion maps evaluated with an assumed labeling efficiency of 85 % (top row) and with measured labeling efficiencies (bottom row). The maps were acquired by artificially impaired inversion, i.e. the optimum phase-offset of 8° was varied between 8° and 80° (columns a) to d)). The corresponding measured labeling efficiencies were: a) 86 %, b) 78 %, c) 60 % and d) 43 %.

Conclusion

Inversion in ASL experiments and thereby the ASL contrast is dependent on the orientation of supplying arteries in the magnetic field and on the homogeneity of the magnetic field in the labeling plane. If the requirements for perfect inversion are not met, the labeling efficiency is decreased and, hence, it is necessary to measure the efficiency for the quantification of perfusion. In the current work we showed the feasibility of labeling-efficiency measurement whereby we suggested and used minimized TE. Furthermore we obtained reliable and comparable perfusion maps when the ASL contrast is corrected for detected impaired inversion efficiency. Currently, the method of the labeling-efficiency measurement is going to be optimized concerning higher in-plane resolution and faster acquisition. The aim is to establish it as a routine procedure to measure the labeling efficiency within every ASL experiment.

References

[1] J. Detre et al.; *Magn Reson Med* 1992; 23: 37–55.
[2] D.Alsop et al.; *Magn Reson Med* 2014; DOI 10.1002/mrm.25197.
[3] WM. Luh et al.; *Magn Reson Med* 2013; 69: 402–410.
[4] H. Jahanian et al.; *NMR Biomed* 2011; 24: 1202-1209.
[5] WC. Wu et al.; *Magn Reson Med* 2007; 58: 1020-1027.
[6] S. Aslan et al.; *Magn Reson Med* 2010; 63: 765-771.