Highly efficient accelerated acquisition of perfusion inflow series by Cycled Arterial Spin Labeling

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Introduction: **A**rterial spin labeling (ASL) (1-4) technique provides quantitative estimation of haemodynamic parameters including cerebral blood flow (CBF) without the need for extrageneous contrast agent. ASL typically consists of two phases, one labeling and one control. In the labeling phase, blood spins flowing into a slab of interest are inverted upstream by RF pulses at a given time. After an inflow time TI an image of the slab is acquired. In the control phase, the inflowing blood spins remain uninverted before the image is acquired after TI. The data sets of both phases are subtracted to cancel out signal of stationary tissue and only yield signal of the inflowing blood. Varying the inflow time TI the inflow of the tagged blood into the arterial tree within the imaging region can be sampled and haemodynamic parameters can be extracted from this data. However, this is very time consuming due to the low signal-to-noise ration (SNR) of the ASL method. Here, we present a novel technique which allows the acquisition of ASL time series at a measurement time usually needed for acquisition of a single time step. It extends the concept of cycled ASL used for spatial encoding in vascular territory imaging [1] to temporal encoding for sampling inflow curves of tagged blood.

Materials and Methods: The basic idea is to prepare multiple blood boli for one image readout (not only one as in conventional ASL). The boli will be prepared subsequently and therefore have different inflow times TI_1, TI_2 … TI_N. The acquired dataset is then a mixture of the signal of all boli. By varying control and label phase of each boli over different acquisitions with an appropriate scheme, it is possible to separate the contribution of each bolus and yield the sampled inflow of labeled blood at inflow times TI_1 to TI_N. This sampled inflow curve of the tagged blood can then be used to adjust haemodynamical parameters to an arbitrary underlying model like in conventional ASL. The preparation scheme, which was used in the experiment, is shown in Fig. 1. It utilizes Hadamard encoding to provide efficient distribution of label and control phases for each cycling phase.
To prove the theoretical considerations a flow phantom experiment was performed. A flexible tube was helically wrapped around a water bottle and water was pumped through it. A single-shot 3D-GRASE sequence [2] was used for image readout (26 slices, resolution 5×5×4mm^3, acquisition time 420ms, TE 21 ms, centric reordered, TR 8s) at a clinical 1.5T MR scanner (Magnetom Sonata, Siemens, Erlangen, Germany). A sixteen gradient cycle was employed (yielding 15 different inflow samples). Tagging was achieved by pseudo-continuous labeling [3] using a bolus duration of ~500 ms each. Thus, inflow times ranged from 500 ms to 7.5s.

Results: Figure 2 presents the results of the phantom experiment. The arrival of the labeled bolus at each voxel is color coded. Three different transverse slices are shown containing different loops of the tube helix along with a coronar view.

Discussion: Cycled ASL can be thought of as a mixture of pulsed and continuous ASL (CASL). Cycled ASL is not a steady state technique like CASL but uses a relatively short bolus length. On the other hand inflowing blood is prepared over a period of time comparable to CASL. In this regard cycled ASL can be viewed as encoding the long CASL bolus and decoding it at the delivery side.
By proper selection of the preparation scheme (e.g. Hadamard encoding) it is possible to use all acquired datasets for reconstruction of each time step dataset yielding maximum SNR. As an example, acquiring a 16 gradient cycle scheme requires 16 acquisitions and reconstructs to 15 different time steps. This corresponds to 8 averages of a single time frame in conventional ASL at the same SNR. Using a TR of 3.5s a complete time series can be acquired in under a minute. However, instead of using long bolus duration in conventional ASL, cycled ASL uses short boli. This might not be a disadvantage, since perfusion modeling becomes simpler for short bolus durations.
Use of cycled ASL for *in vivo* studies need more work since only constant flow in a defined geometry was considered here. Cardiac triggering can minimize errors from pulsatile flow but a constant heart rate is also required since the preparation phase extends over multiple heart beats.

Conclusions: Cycled ASL samples the inflow curve of tagged water spins in considerably less time than conventional ASL with no reduction of SNR. This technique may be useful to acquire haemodynamical parameters at an extreme speed-up of acquisition not previously possible.

References: 1.) Günther M: *Magn Reson Med* **56**: 671-675 (2006). 2.) Günther M, Oshio K, Feinberg DA: *Magn Reson Med* **54**, 491-8, (2005). 3.) Fernández-Seara et al. *Magn Reson Med* **54**:1241-7 (2005).

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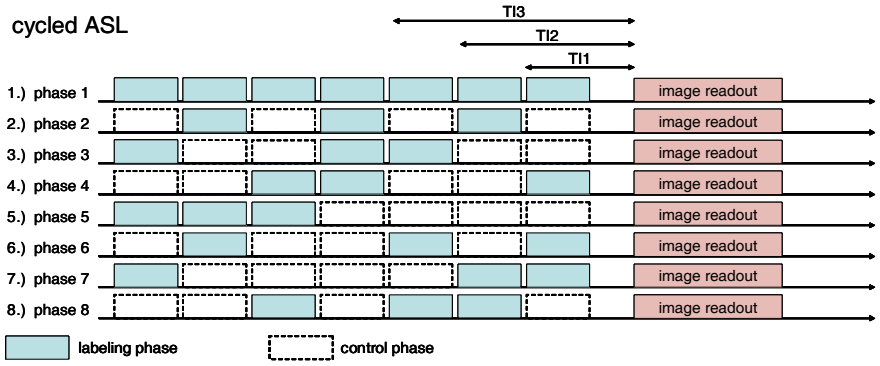

Fig.1 Labeling and control phases for an eight-phase cycle: Seven boli are produced at different times before image acquisition (corresponding to inflow time TI). One data set is acquired for each phase consisting of different combinations of label and control preparation for separate bolus. The preparation scheme uses Hadamard encoding. All acquired data is used for reconstruction of each time step yielding most efficient SNR per measurement time.

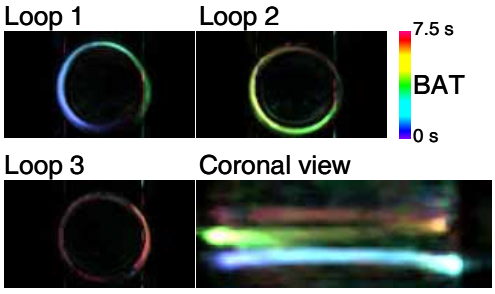

Fig.2 Cycled ASL on flow phantom (tube helix with water flowing through). Three transverse planes containing different loops of the helix are shown and in cross section view. The inflow of the labelled water can be seen clearly. The streak artefact results from improper phase correction algorithm.