Cardiac triggering and label-control transition profiles in Hadamard encoded pseudo-continuous arterial spin labeling

W. Teeuwisse[1], M. Helle[2], S. Rüfer[2], and M. J. van Osch[1]
[1]Radiology, C.J. Gorter Center for High Field MRI, Leiden University Medical Center, Leiden, Netherlands, [2]Institute for Neuroradiology, Christian-Albrechts-Universität, UK-SH, Kiel, Germany

Introduction: Multiple delay imaging has proven to provide essential information, such as transit time, in pulsed arterial spin labeling (ASL). This approach facilitates not only correction for transport times, but also enables dynamic angiography (1,2). Multiple delay imaging is of little use in continuous ASL, because the long labeling duration limits the temporal information. However, an alternative method of multi delay acquisition involves subdividing the labeling period according to a Hadamard encoded scheme (3, 4). Whereas this approach has successfully been applied in rats, it has not been demonstrated in humans. This may be explained by the influence of the cardiac cycle that may blur the encoded profile. Furthermore, pseudo CASL (pCASL) is replacing traditional CASL due to higher SNR and ease of use, but pCASL might demonstrate a slower switching between label and control condition than CASL. This also may negatively affect Hadamard encoding and is studied in this work.

Methods: Matlab simulations were performed to investigate switching profiles in pCASL and the influence of the cardiac cycle on Hadamard encoding. Mz transition profiles were calculated for different velocities and characterized by the transition width (ms) (time interval between $0.95*_{Mz,ctrl}$ and $0.95*_{Mz,labeling}$). To evaluate the encoding integrity, a vessel was simulated while assuming laminar flow. Velocities during the cardiac cycle were taken from in vivo measurements. The labeling time of 800 ms was divided into 8 blocks with alternating labeling and control condition, followed by a delay of 400 ms. Maximum velocity of 40 cm/s was assumed at the vessel center for the R-peak of the cardiogram. Simulation characteristics: width of label plane 50mm, pCASL in a 4 mm diameter vessel. Final M_z as function of position was plotted on a longitudinal cut through the vessel for 5 different timings of the labeling w.r.t. the cardiac cycle, i.e. each representing cardiac triggered acquisitions with a different trigger delay. Non-cardiac triggered measurements were simulated by averaging all cardiac phases. In vivo dynamic angiography of the cerebral arteries was performed on a 1.5T scanner (Philips), with and without cardiac triggering using the same encoding scheme.

Results: Fig.1a shows transitions from control to labeling condition for different spin velocities. Transition width decreases with increasing velocity (see Fig.1b), reaching a plateau of approximately 50ms, thereby representing the minimal switching time of pCASL. Fig. 2a shows the applied Hadamard sequence: alternating labeling (blue) and control (red). Similarly color coded, Figs 2b-f show spin M_z for 5 cardiac phases, demonstrating that the encoding profiles and label efficiency are significantly affected by velocity variations. When no triggering is applied, encoding will take place randomly distributed over the cardiac cycle leading to pattern averaging as demonstrated in 2g. Fig. 3 shows in vivo images of Hadamard encoded ASL angiography. The non-triggered image (a) shows a shorter vessel trajectory than the triggered image (b). In Fig 3c, the protrusion of a label sub-bolus into a control bolus is clearly appreciated.

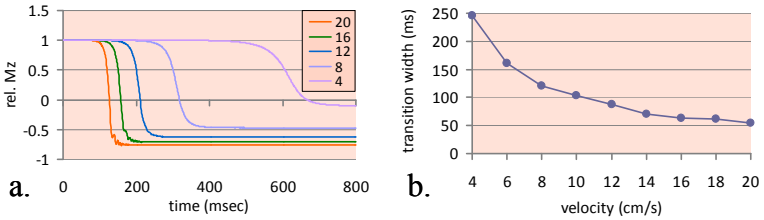

Figure1: Longtidunial magnetization evolution for transitions from 'control' to 'labeling' condition. a) Transition profiles for different velocities (cm/s). b) Transition width (ms) as function of flow velocity.

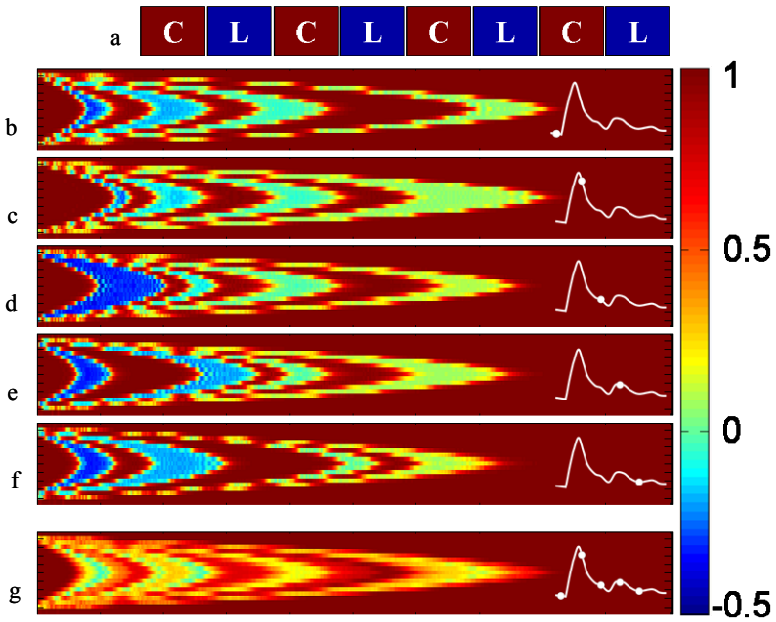

Figure 2: Longitudinal magnetization after 800ms labeling with alternating labeling and control. a) simulated Hadamard encoding scheme, b-f) Longitudinal magnetization in cross section along the vessel, the dot on the cardiogram indicates the timing in the cardiac for start of the simulation. g) Resulting longitudinal magnetization without cardiac triggering, i.e. by averaging of all cardiac cycles.

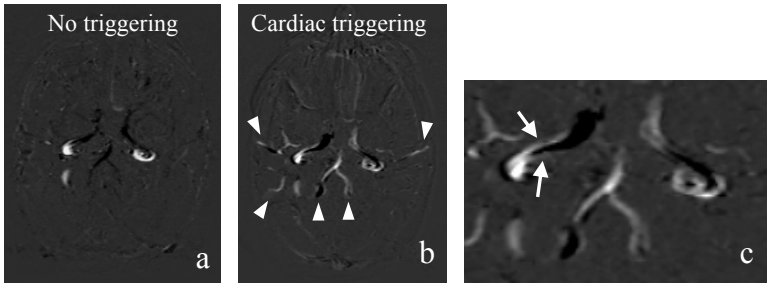

Figure 3: Examples of in vivo Hadamard encoded pCASL angiography. Image without with cardiac triggering (a) shows a shorter trajectory of vessels than with (b). Detail of the circle of Willis (c) demonstrates parabolic protrusion of a 'label' bolus in a 'control' bolus (see arrow).

Discussion and conclusions: Integrity of Hadamard encoded pCASL strongly depends on (changes in) flow velocity. Considering an average velocity 20 cm/s, a transition width of 50 ms is found. This warrants for a minimum sub-bolus duration of 100ms. Averaging of repeated scans acquired over different cardiac phases leads to deterioration of the Hadamard encoding scheme which can be strongly reduced by application of cardiac triggering. This study also shows that cardiac triggered time-encode pCASL enables dynamic ASL angiography in humans.

1) Günther et al, MRM 46:974-984 (2001). 2) v Osch et al, Med Im Ana 10:59-70 (2006). 3)Wells et al, Magn. Reson.Med. 63:1111-1118 (2010)
4) Gunther M.. ISMRM Workshop on Cerebral Perfusion and Brain 2007