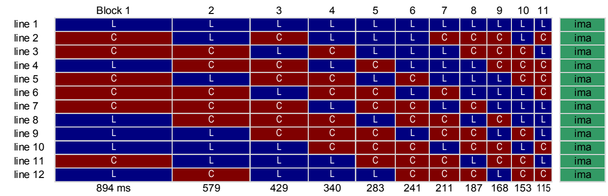
Implementation and validation of time encoded pseudo Continuous Arterial Spin Labelling for human applications.

Wouter M Teeuwisse[1], Ilya M Veer[2], Andrew Webb[1], and Matthias J.P. van Osch[1]

[1]*C.J.Gorter Center for High Field Magnetic Resonance, Radiology, Leiden University Medical Center, Leiden, ZH, Netherlands,* [2]*Radiology, Leiden University Medical Center, Leiden, ZH, Netherlands*

Introduction: Gunther recently proposed time encoding in pseudo Continuous Arterial Spin Labeling (pCASL) as a method to extract Arterial Transit Times (ATT) in a highly time-efficient manner [1]. In this method, the labeling period is divided into blocks and a Hadamard encoding scheme is applied to vary the label/control condition of blocks both within a labeling period and over subsequent acquisitions. By using an appropriate subtraction scheme of perfusion images in post-processing, images with different post labeling delays (PLD) can be calculated. Although already demonstrated in animals [2], time encoded pCASL is more challenging in humans due to lower flow rates, increased bolus dispersion and a wider ATT range. The aim of this study is to implement time encoded pCASL (te-pCASL) on a clinical 3T system and compare results with existing techniques. For te-pCASL, a 12 x 11 encoding scheme was chosen comprising 12 encoding patterns, each dividing the labeling train into 11 blocks. Two scans were made, one with fixed block duration (te-pCASL_fix) and one in which block duration was adjusted such that the number of spins labeled during a block compensates for T1 decay of the label signal (te-pCASL_adj), rendering equal SNR per block. To evaluate te-pCASL performance, a standard pCASL sequance was also run as well as a QUASAR scan for evaluation of ATT's.

Materials and methods: Eight healthy volunteers (age 22 – 28 y, 7 female 1 male) were scanned at 3T (Achieva, Philips Healthcare). General te-pCASL protocol: total label duration 3600 ms, divided into 11-blocks, post labeling delay 49 ms, 108 acquisitions (9 sets of 12 encodings) and an imaging module with single shot FFE-EPI, 3×3×7 mm voxel size, 17 slices, TR/TE/fa = 4311/14/90˚. Scan time was 8:37 min. Block duration was 327 ms for all blocks in te-pCASL_fix and 894, 579, 429, 340, 283, 241, 211, 187, 168, 153 and 115 ms in te-pCASL_adj (see fig. 1 for the encoding scheme in te-pCASL_adj). Identical scanning parameters were chosen for standard pCASL, except for non-encoded labeling (label duration/-delay of 1955/1695 ms). No background suppression was applied. Results from the first 6 blocks in te-pCASL_fix and first 3 blocks in te-pCASL_adj were summed to achieve equal label duration and PLD as in the standard pCASL scan. As a reference for ATT estimation, a QUASAR [3] sequence was run: SS FFE-EPI, 7 slices with 7 mm gap, voxel size 3.75×3.75×7 mm, 10 phases with 250 ms interval, delay 100ms, scan time 8:06 min. All scans were motion corrected with FSL (FMRIB, Oxford) and registered to a 3DT1. A grey matter mask extracted from the 3DT1 served for selecting grey matter in ASL scans. Grey matter perfusion signal, standard deviation over time and SNR(t) were calculated voxel-wise. 6 consecutive label and control subtractions were averaged in standard pCASL to keep the number of averages equal to the time encoded scans. ATT was estimated voxel-wise at the time point of maximum signal, after convolution with the time-derivative of a Gauss function (FWHM 75 ms), i.e. the time of maximum inflow of labeled spins.



	Block 1	2	3	4	5	6	7	8	9	10	11	
line 1	L	L	L	L	L	L	L	L	L	L	L	ima
line 2	C	L	C	L	L	L	C	C	C	L	C	ima
line 3	C	C	L	C	L	L	L	C	C	C	L	ima
line 4	L	C	C	L	C	L	L	L	C	C	C	ima
line 5	C	L	C	C	L	C	L	L	L	C	C	ima
line 6	C	C	L	C	C	L	C	L	L	L	C	ima
line 7	C	C	C	L	C	C	L	C	L	L	L	ima
line 8	L	C	C	C	L	C	C	L	C	L	L	ima
line 9	L	L	C	C	C	L	C	C	L	C	L	ima
line 10	L	L	L	C	C	C	L	C	C	L	C	ima
line 11	C	L	L	L	C	C	C	L	C	C	L	ima
line 12	L	C	L	L	L	C	C	C	L	C	C	ima
	894 ms	579	429	340	283	241	211	187	168	153	115	

Figure 1. Labeling scheme for time encoded pCASL, with block duration adjusted for T1 decay of label signal. Numbers below columns indicate block duration. Blue = label. red = control.

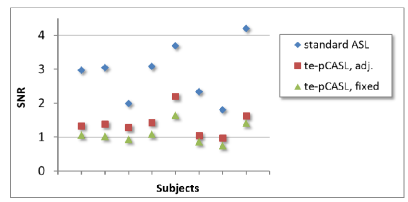


Figure 2. SNR in each subject for standard ASL and time encoded pCASL scans.

Results: Figure 2 shows grey matter SNR(t) for the ASL scans in each subject. SNR(t) in standard ASL is 2.1 (± 0.3) times higher than in te-pCASL_adj and 2.6 (± 0.3) higher in comparison with te-pCASL_fix. This is consistent for all subjects. Figure 3 shows representative perfusion images at the level of the basal ganglia at subsequent time points in a single volunteer, demonstrating arrival of signal in large vessels followed by enhancement of tissue. Subsequent filling of the posterior flow territory can also be seen. Quantitative ATT maps are shown in figure 4, demonstrating similar patterns for QUASAR and time encoded ASL.

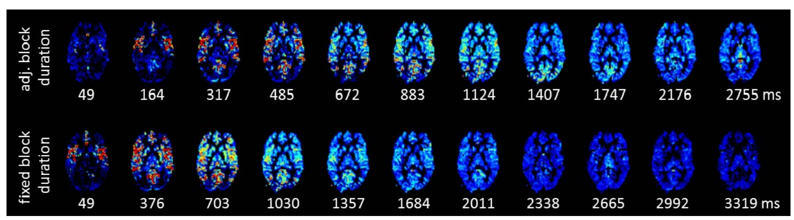


Figure 3. Perfusion maps for subsequent time points in a single volunteer. The number below each map indicates post labeling delay. Top: te-pCASL_adj, bottom te-pCASL_fix.

Discussion and conclusion:

In this study, time encoded pCASL is demonstrated in humans at 3T. SNR is adequate but lower than standard ASL, with slightly but significantly better results for te-pCASL_adj than for te-pCASL_fix. The SNR can be improved by reducing the number of encoding blocks, but at the expense of time resolution. Perfusion maps clearly demonstrate the temporal behavior, including local and global variation in arterial filling and tissue enhancement over time. ATT maps acquired with time encoded pCASL demonstrate the flow territory border zones with patterns similar to those acquired with QUASAR. ATT maps of te-pCASL_fix are measured at a lower effective sampling rate (327 ms) compared to approx. 200 ms of te-pCASL_var for typical ATT-values, resulting in less noisy maps, but also with lower temporal resolution. In conclusion, te-pCASL enables efficient acquisition of perfusion maps at different time points and should prove to be an important tool in evaluation of cerebral heamodynamics, especially in patients with large vessel disease.

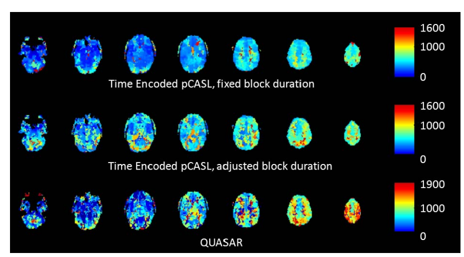


Figure 4. Arterial Transit Time maps for time encoded pCASL and QUASAR. Similar patterns can be discerned, although time encoded ASL suffers from lower SNR.

References: 1.Günther, ISMRM 2007; 2. Wells et al, MRM 2010; 3. Petersen et al MRM 2006