Time- and vessel encoded pCASL: a free lunch with all the trimmings

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Introduction.

Visualization of arterial flow territories of the brain can provide essential information in patients with vascular diseases such as occlusive disease or arteriovenous malformation. Combined with cerebral blood flow (CBF) and bolus arrival time (BAT) maps, flow territory mapping delivers a profound insight into the patient's hemodynamics. These maps can all be acquired using pseudo-continuous arterial spin labeling (pCASL); however, this typically requires separate scans and takes around 15 minutes, which is too demanding for clinical practice. With the introduction of time encoded pCASL (te-pCASL)[1, 2] much more flexibility is added to pCASL acquisition and recently it was demonstrated that it enables measurement of CBF and BAT in a single scan without a time penalty[3]. The aim of this study is to investigate the feasibility of acquiring CBF-, BAT- and arterial flow territory maps in a single scan by incorporating vessel encoding (v.e.)[4] into te-pCASL.

Methods.

Five healthy subjects (age 27-41 y; 2f, 3m) were scanned at 3T (Achieva, Philips Healthcare). Three pCASL scans were acquired. A standard pCASL scan (label duration/post labeling delay (PLD) 1.8/1.8 s; background suppression (BS) pulses at 1820/3155 ms; ssEPI imaging, 17 slices, 3x3x7 mm, TR/TE 4.4/0.014s, scan time 7:11 min) served as reference for CBF. For arterial flow territory mapping this scan was repeated with additional v.e. gradients with five conditions: control, tag, AP1, RL, AP2. AP and RL offset of and distance between vessels was measured to optimize v.e. gradients. In the time-encoded vessel-encoded scan (TeVe-ASL) a Hadamard 8 matrix was applied with block durations 1.8, 0.5 and 5 x 0.24 s with a PLD of 0.1 s and BS pulses at 1800/3150 ms. This scheme (fig. 1) was played 4 times with different v.e. gradients (all, AP1, RL, AP2) during block 2, and the whole scheme was repeated 3 times (in 7:23 min scan time) to increase SNR. A separate ssEPI M0 measurement was performed with TR of 2s. Single slice inflow imaging was performed at the level of the labeling slab to spatially define the location of the left (L) and right (R) internal carotid (ICA) and vertebral (VA) arteries. A 1.1 mm isotropic 3D T1 GRE anatomical scan was used for registration and gray matter masking. Raw TeVe-ASL images were averaged and "time-decoded". Perfusion images from block 1 were used to quantify perfusion, as per[6], in the same manner as the standard pCASL images. Vascular territory maps were obtained from both TeVe-ASL block 2 and the separate v.e. scan using a *maximum a posteriori* Bayesian analysis technique[7]. BAT maps were generated using data from all seven blocks (including the non-v.e. images from block 2) by fitting the general kinetic model with a macrovascular component, modified to account for the variable tag duration of each block, using a variational Bayes algorithm[8].

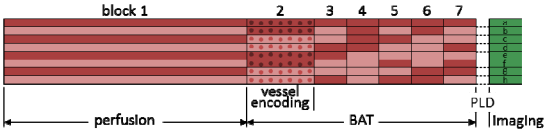


Fig 1. Hadamard encoding scheme of the Te-Ve-ASL scan. To enable flow territory mapping this scheme is repeated 4 times with different vessel encoding gradients during block 2.

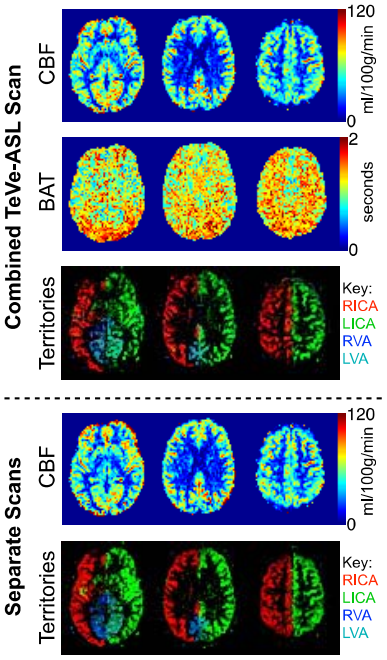


Fig 2. Three slices of the CBF, BAT and vascular territory maps extracted from the TeVe-ASL scan (top), along with those from separate scans (bottom), in a single subject.

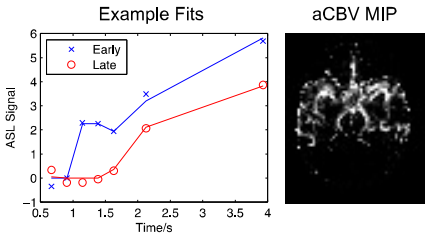
Results and discussion.

The TeVe-ASL acquisition produced CBF and vascular territory maps which qualitatively matched well to those obtained in separate scans in all subjects (fig. 2). There was no significant difference between TeVe-ASL block 1 and standard pCASL in terms of mean gray matter CBF (51 ± 10 vs. 53 ± 8 ml/100g/min, p = 0.46) nor temporal SNR (2.7 ± 0.5 vs. 2.7 ± 0.6, p = 0.85), showing that the additional TeVe blocks did not adversely affect CBF image quality. The modified general kinetic model gave good fits to the data, including the strong macrovascular signal evident at short delay times (fig. 3), resulting in BAT maps that match well with the previous literature. The vascular territory maps produced from the TeVe-ASL acquisition correspond to a shorter post-labeling delay (1.3 s) than the separate v.e. scan (1.8 s), so quantitative analysis was restricted to regions of gray matter with considerable perfusion signal in both sets of maps. In these voxels, assessment of the dominant feeding artery (right internal carotid, left internal carotid or either vertebral artery) was the same in 90% of voxels, demonstrating good agreement between the scans. However, the proposed approach does have some limitations. Firstly, variable signal due to pulsatile flow in large arteries could cause assignment of the signal to the wrong time block or vascular source. Secondly, the temporal resolution is limited for very delayed blood arrival due to the longer durations of blocks 1 and 2. Thirdly, determination of the vascular territories in borderzone regions with delayed arrival may not be possible because of the relatively short PLD of the v.e. block.

Conclusion.

We have demonstrated that the post labeling delay in pCASL, which is normally unused time in the sequence, can be utilized to generate both vascular territory and bolus arrival time maps without adversely affecting CBF quantification, giving a much wider range of information within the same scan duration. The BAT maps could potentially be used to identify regions with very delayed blood arrival where CBF quantification could be biased.

Fig 3. Example data (markers) and fits (lines) of the ASL signal in two voxels with early (blue) and late (red) arriving blood (left). Note the a-typical nature of the fitted curve due to the variable tag duration of each TeVe-ASL block. An axial maximum intensity projection of the arterial cerebral blood volume parameter shows that the macrovascular component is accurately estimated in the large arteries around the circle of Willis (right).



References. 1. Günther, ISMRM perfusion workshop 2007; 2. Dai, MRM 2013; 3. Teeuwisse, MRM 2014; 4. Wong MRM 2007; 5. Gevers AJNR 2012; 6. Alsop MRM 2014; 7. Chappell Med Im Analysis 2012; 8. Chappell MRM 2010

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