Fast cerebral flow territory mapping using vessel selective dynamic arterial spin labeling

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Target audience: Researchers interested in new acquisition approaches for arterial spin labeling

Purpose: Vessel selective arterial spin labeling (VS-ASL) provides important clinical information by mapping the flow territories of the main cerebral arteries[1]. In current clinical protocols, this standard VS-ASL takes about 5 minutes[2]. Territory information might especially be beneficial in acute stroke patients, e.g. to identify the source artery of emboli. However, for the acute setting, imaging should be performed much faster to be clinically acceptable. Traditional VS-ASL sequences are time-consuming because an additional non-selective perfusion map is required to calculate relative labeling efficiency maps and it employs delay times on the order of 1.5s to allow the label to reach the brain tissue[3]. To achieve faster flow territory mapping, we propose the use of dynamic ASL (DASL[4]) combined with VS-ASL (VS-DASL).

Methods: DASL is based on alternate continuous labeling and non-labeled condition interleaved with imaging. A single dynamic in DASL consists of 5-20 repetitions of interleaved labeling (200-400ms) and imaging (35ms) modules and an equal number of control and imaging modules[4]. The main concept behind VS-DASL is to create a continuous stream of label/control blocks, whose inflow into the brain tissue is monitored continuously, with different encoding patterns for each feeding artery. This approach leads to unique signal fluctuations for each flow territory enabling reconstruction of flow territories by means of clustering techniques[1, 3] or independent/principal component analysis. The main differences with traditional VS-ASL are that imaging is performed at a much higher sampling rate (every 200-400ms) and that a continuous inflow of spatially encoded label is achieved. VS-DASL was implemented on a 3T MRI scanner (Philips Healthcare) using a 32ch head coil with a label duration of either 200 or 400ms, post labeling delay 11ms, flip angle 25°, single slice (80x80 matrix), total scan time of 4min, vessel selectivity was changed according to the scheme illustrated in Figure 1. VS-DASL was compared in six healthy subjects to traditional vessel selective ASL (see Figure 1): label duration 1650ms, post labeling delay (PLD) 1525ms, flip angle 90°. The study was approved by the local IRB.

Fig.1. Traditional VS-ASL (upper) and VS-DASL (down): the labeling efficiency is varied in different directions such as anterior-posterior (AP) and right-left (RL); imaging is represented by (I)

The traditional VS-ASL was considered the gold standard. To compare VS-DASL results to the standard VS-ASL, a common mask was created based on the global perfusion (CBF) weighted image taken from the traditional VS-ASL scan. Signal time curves (after mean subtraction and scaling of standard deviation to unity) of all voxels in the mask were clustered by means of k-means clustering with the voxel coordinates as additional features. Flow territory mapping of VS-DASL was initially limited to only the first dynamic, thereafter more and more dynamics were included in the analysis to determine the shortest possible scan duration. Evaluation was based on the percentage of correctly classified voxels. Because VS-DASL does not provide a global CBF map and clustering results tend to improve considerably when limited to the gray matter (i.e. tissue with large perfusion and thus large signal changes), a frequency map was created by Fourier transforming the raw VS-DASL data and selecting the power at the DASL frequency to create a mask for the clustering analysis.

Results: Figure 3 shows the results of VS-DASL when using 200ms and 400ms blocks. The percentage of correctly classified voxels ranged from 78% (only one dynamic, i.e. 10s) to 94% (averaged over all dynamics) for 400ms VS-DASL, and from 67% to 88% for 200ms VS-DASL. Figure 2 shows the frequency map (Figure 2b) compared with the CBF map from the traditional VS-ASL sequence (Figure 2a): gray matter and white matter can be easily distinguished in this frequency map thereby enabling the creation of a gray matter mask. Flow territory maps of VS-DASL achieved by using the frequency-based mask and CBF-based mask are in good agreement (Figure 2d and Figure 2c, respectively).

Discussion: The percentage of correctly classified voxels shows that VS-DASL can provide similar flow territory information as standard VS-ASL in a scan time of only 30-60s. With longer scan times, the results are more accurate, but our results show that the degree of accurately-classified voxels has reached 78% when only the first dynamic was used. Shorter DASL-block size of 200ms led to worse results, probably because the inflowing magnetization accumulates in brain tissue while gradually decaying according to T_1; the accumulation of label effectively dampens the encoded signal variations when the effective block length (five times 200ms) becomes short compared to the T_1 of the label. Currently VS-DASL is restricted to a single slice, since multi-slice imaging would increase the readout time and thus the delay between two DASL-blocks. Furthermore, multi-slice imaging will disrupt the encoding pattern for more distal slices. Single-shot 3D sequences might provide a good basis for volume coverage.

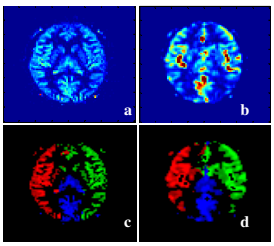

Fig.2. a) CBF map, b) frequency map, c) flow territory map derived from CBF map, d) flow territory map derived from frequency map

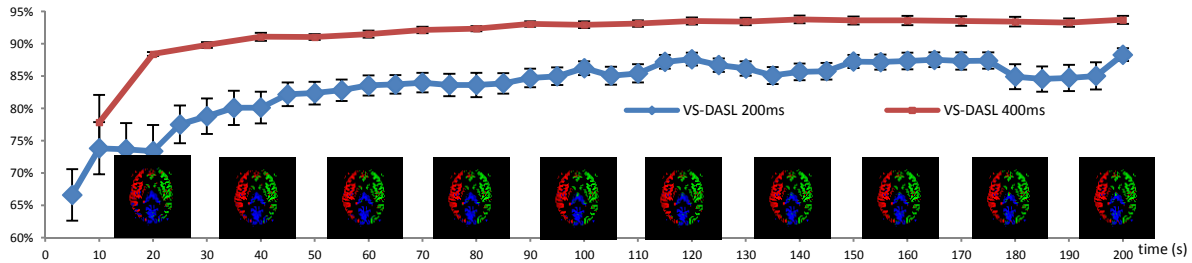

Fig.3. Percentage and standard error of correctly classified voxels of the flow territory map obtained by VS-DASL (200ms and 400ms) versus the gold map acquired by traditional VS-ASL , and estimated flow territory maps (400ms VS-DASL) using CBF mask over time.

Conclusion: VS-DASL has the potential to map the flow territories in a short scan time (~30-60s), enabling use in, for example patients with acute stoke. This sequence enables fast flow territory mapping due to a high sampling rate combined with a continuous inflow of spatially encoded label. The use of a frequency map of the raw dynamic signal enables the creation of a gray matter mask.

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