Quantitative Vessel-Encoded Arterial Spin Labeling Reveals Collateral Blood Flow in Hyper-Acute Stroke Patients

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Introduction: Collateral flow is known to be crucial for sparing brain tissue in stroke patients[1], but most non-invasive imaging modalities are unable to visualize this phenomenon. In a recent consensus statement, serial imaging studies of stroke patients using techniques capable of assessing collateral flow and hemodynamics have been prioritized[2]. Recently it has been shown that multi-postlabeling delay vessel-encoded pseudocontinuous arterial spin labeling (VEPCASL)[3] is capable of generating quantitative maps of cerebral blood flow (CBF) and bolus arrival time (BAT) arising from each major brain-feeding artery separately, with signal-to-noise ratio equivalent to standard ASL techniques[4]. Its non-invasive non-contrast nature make it ideally suited to repeated imaging studies. In this work we present the first use of this technique to serially study hyper-acute stroke patients, demonstrating its utility for observing evolving collateral flow patterns and hemodynamics.

Methods: Acute ischemic stroke patients (within six hours of symptom onset) were recruited and scanned at 3T under a protocol approved by a national ethics committee. Repeat scans at 1 day and 1 month were also performed. Imaging sequences included VEPCASL perfusion imaging as previously described[4] (EPI readout, voxel size 3.4x3.4x4.5 mm, six postlabeling delays from 0.25s–1.5s, 96 volumes, 6.5 mins, separate labeling of the right and left internal carotid arteries, ICAs, and vertebral arteries, VAs), T1-weighted structural imaging and fluid attenuated inversion recovery (FLAIR) at 1 month to assess the final infarct. Patients with lacunar stroke were excluded from this analysis, leaving 17 patients with VEPCASL imaging. 14% of the data sets had severe motion artefacts and were also excluded.

Results: Figures 1 and 2 show example data from two patients with initial perfusion deficits in the right middle cerebral artery (RMCA) territory. In both cases regions with collateral flow appeared to be spared from infarction and the vascular territories reorganized following recanalization. Such collateral flow to the affected region was observed in 29% of patients. In addition, the BAT maps demonstrated delayed blood arrival around the lesion compared to a mirrored region of interest on the contralateral side at the initial scan ($p = 0.03$), which persists at 1 month ($p = 0.02$).

Discussion: Multi post-labeling delay VEPCASL perfusion imaging appears to be a promising technique for serially imaging collateral flow patterns and studying hemodynamics in acute stroke patients. The sparing of tissue from infarction by collateral flow and reorganization of vascular territories over time warrants further study in a larger cohort of patients. The considerably delayed blood arrival found around the perfusion deficit highlights the importance of collecting multiple post-labeling delay data to accurately quantify CBF. In addition, the ability to generate BAT maps may provide extra information on cerebral hemodynamics in this patient group[5]. Elevated BAT levels might be indicative of other stenoses or partial occlusions in nearby arterial branches as well as delayed arrival due to collateral flow. This technique does have a number of limitations, however: collateral flow originating from a different branch of the same tagged artery will not be separately resolved, unless the labeling plane is repositioned to encompass a greater number of arterial branches[6,7]; very delayed blood arrival will not be visualized due to T1 decay; and motion artefacts were problematic in some patients, although we hope to alleviate this in future work using prospective motion correction. We hope this technique will prove useful in understanding the pathophysiology of acute stroke and has potential as a diagnostic and prognostic tool in this patient group.

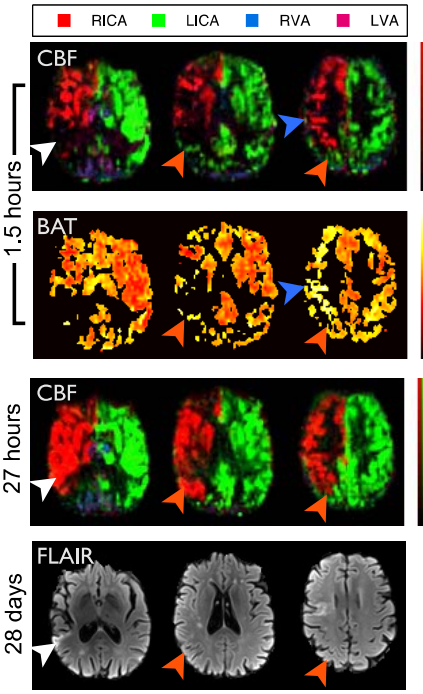

Figure 1: Quantitative VEPCASL CBF maps in one patient reveal an initial perfusion deficit in the RMCA territory which, despite spontaneous reperfusion by 27 hours post-stroke, goes on to infarct (white arrows), as shown in the follow-up FLAIR images. However, part of the RMCA territory receives later arriving collateral flow originating from the LICA, probably via the anterior cerebral arteries (orange arrows), until the RMCA recanalizes, which appears to spare the tissue from infarction. Interestingly, the blood supply to the distal RMCA territory is also delayed (blue arrows), perhaps due to a distal partial occlusion.

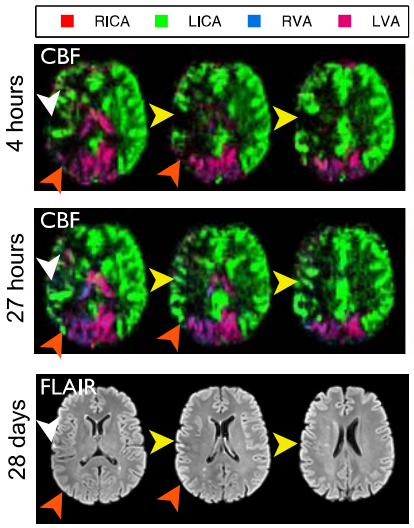

Figure 2: A patient with RICA occlusion and collateral flow from the LICA into the RMCA and right anterior cerebral artery territories. Some hypoperfused regions are reperfused by 27 hours post-stroke, sparing the tissue (yellow arrows) whereas others are not, resulting in infarction (white arrows). Collateral flow from the VAs seems to spare tissue in the posterior RMCA territory until recanalization occurs (orange arrows).

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