Visualizing Artery-specific Blood Flow Patterns Above the Circle of Willis with Vessel-Encoded Arterial Spin Labeling

Thomas W Okell[1], Michael A Chappell[1,2], and Peter Jezzard[1]

[1]*FMRIB Centre, Department of Clinical Neurosciences, University of Oxford, Oxford, Oxfordshire, United Kingdom,* [2]*Institute of Biomedical Engineering, Department of Engineering, University of Oxford, Oxford, Oxfordshire, United Kingdom*

Introduction: Vessel-encoded pseudocontinuous arterial spin labeling (VEPCASL [1]) is capable of spatially modulating the inversion efficiency to "encode" sets of arteries supplying blood to the organ of interest. Using post-processing to "decode" these images results in vascular territory maps [1] or dynamic angiograms [2], depending on the time delay between the preparation and image readout. VEPCASL is typically used to label three or four brain-feeding arteries in the neck. However, the ability to visualize artery-specific flow patterns above the circle of Willis would allow stenosis or occlusion and collateral flow patterns in these smaller vessels to be studied in greater detail, which may guide therapeutic decisions. In addition, the ability to label larger numbers of small arteries is likely to find application in the study of arteriovenous malformations, where knowledge of the relative blood flow to the lesion from each feeding artery can help guide embolization therapy. Most previous work in the application of VEPCASL above the circle of Willis [3,4] has focused on perfusion imaging with post-processing methods such as clustering which assume each voxel is fed uniquely by one feeding artery, excluding the ability to assess mixed arterial supply. In this work we assess the feasibility of using VEPCASL dynamic angiography and perfusion imaging to study the flow patterns arising from nine intracranial and four extracranial arteries above the circle of Willis in healthy volunteers. We use a Bayesian post-processing method which can account probabilistically for mixed arterial supply and has previously been shown to improve upon clustering methods for assessing perfusion territories above the circle of Willis in a single subject [5].

Methods: Five healthy volunteers (1 female, mean age 30) were recruited and scanned on a Siemens 3T Verio using a 32 channel head coil under a technical development protocol agreed with local ethics and institutional committees. A time-of-flight (TOF) sequence was performed and loaded into a 3D viewer to allow selection of a labeling plane (Fig. 1A), at any arbitrary angulation, which contained three branches of each middle cerebral artery (MCA), the anterior cerebral arteries (ACAs) and the right and left posterior cerebral arteries (RPCA and LPCA). These artery locations within the labeling plane were noted and used to establish seven pairs of vessel-encoding cycles: non-selective tag and control, one left-right encoding, three anterior-posterior encodings of varying spatial frequency, one 45° encoding and one -45° encoding, giving a total of 14 encoding cycles. Vessel-encoded perfusion imaging was performed using a single-shot echo planar imaging (EPI) readout and the following parameters: TE 14ms, TR 3.35s, 6/8ths partial Fourier, tag duration 1.4s, post-labeling delay 1s, voxel size 3.4x3.4x3.3mm, 20 slices, 140 volumes, acquisition time 7:50. Presaturation and two global hyperbolic secant inversion pulses were used for background suppression [6]. Vessel-encoded dynamic 2D angiography (similar to [2]) was performed in a thick transverse oblique slice using identical encoding cycles but with a cardiac gated time-resolved balanced steady-state free precession (bSSFP) readout [7] with the following parameters: TE 2ms, TR 4.35ms, flip angle 30°, voxel size 1.0x1.0x50mm, 6/8ths partial Fourier, GRAPPA factor 2, 14 segments, temporal resolution 60.9ms, 12 cardiac phases, tag duration 800ms, acquisition time ~2:50. Separation of vascular components in the VEPCASL data was performed using a maximum *a posteriori* solution [8] to the Bayesian framework of [5] with one vessel per class, which can account for rigid in-plane subject motion between scans. Extracranial arteries also contributed signal, particularly to the angiographic images, so were also included in the analysis: the right and left superficial temporal arteries (STAs) and occipital arteries (OAs). This gave a total of 13 arteries plus static tissue to separate.

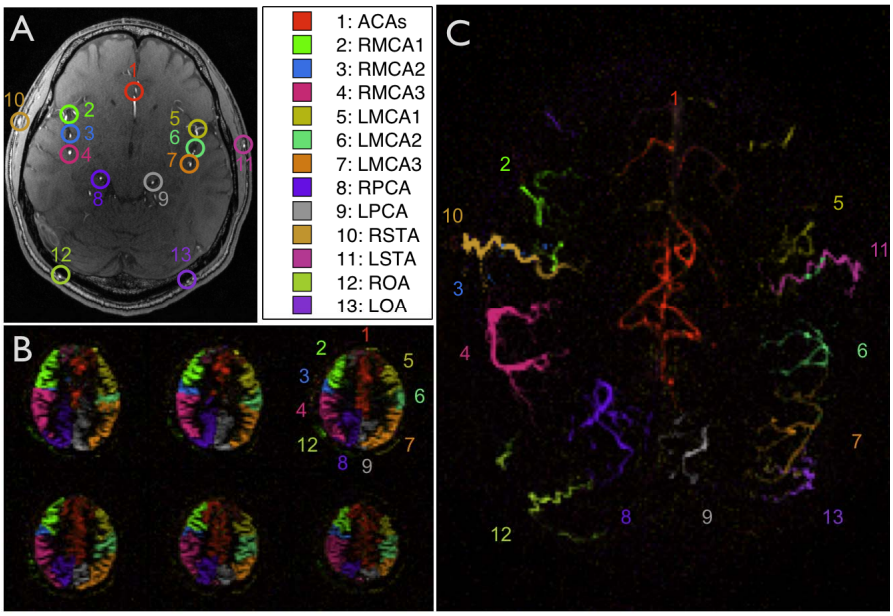

Figure 1: Results from one healthy volunteer: A: TOF image of the labeling plane showing the arteries of interest; B: Selected slices from the VEPCASL perfusion images showing the vascular territories of each artery; C: First frame of the VEPCASL 2D dynamic angiographic acquisition. Color represents the arterial origin of the blood signal (see legend). These are also numbered for clarity.

Results: Examples of artery-specific perfusion maps and a single angiographic frame are given in Fig. 1. The Bayesian analysis method used here effectively separates out the contributions from each feeding artery in both acquisitions, yielding highly specific angiograms and clearly delineated vascular territory maps. The extracranial arteries do not contribute to brain perfusion but are evident in the angiographic images. In this subject and others the flow patterns appear to be somewhat asymmetric across hemispheres.

Discussion: The combination of VEPCASL dynamic angiography and perfusion imaging allows the visualization of blood flow patterns and hemodynamics within large arteries and the resulting downstream perfusion arising from thirteen arteries above the circle of Willis within a reasonable scan time (less than 11 mins for both acquisitions). Although the extracranial arteries do not contribute to brain tissue perfusion in these healthy volunteers, in patient populations collateral flow from extracranial sources could be visualized with this method. The observed asymmetry in the vascular territories may arise partially from the choice of labeling plane, but appears from the angiographic images to be also due to differences in the vascular anatomy. A larger study is necessary to assess the variation in these flow patterns across individuals. In some subjects separation of the MCA territories into three branches was incomplete due to one or two of these branches flowing inferiorly following their passage through the labeling plane. In patient groups, where more motion may be expected, through-plane movements may also modify the number of branches of the MCAs present within the labeling plane. Such difficulties may be avoided by performing multiple acquisitions at a range of labeling plane locations to assess changes to the vascular territories at different levels of arterial branching.

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References:

[1] Wong, MRM 58: 1086-1091 (2007)
[2] Okell, MRM 64: 698–706 (2010)
[3] Wong, ISMRM (2008): #182
[4] Kansagra, ISMRM (2009): #3652
[5] Chappell, MRM 64:1529-39 (2010)
[6] Günther, MRM 54:491-498 (2005)
[7] Okell, ISMRM (2011): #4034
[8] Chappell, ISMRM (2011): #366