A Comparison of 3D-GRASE and EPI for Vessel-Encoded Arterial Spin Labeling

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Introduction: Vessel-Encoded Pseudo-Continuous Arterial Spin Labeling (VEPCASL) allows the visualization of vascular territories in the brain by spatially modulating the labeling efficiency across the labeling plane [1]. This method has applications in cerebrovascular disease where the contribution to brain perfusion from stenosed arteries can be assessed along with the amount of collateral blood flow and which vessels are responsible. Other applications include determination of which blood vessels are supplying a tumour. Previous vascular territory imaging studies have generally used 2D readout methods such as spiral [1] or echo planar imaging (EPI) [2]. However, 3D readouts such as 3D-GRadient And Spin Echo (3D-GRASE) have both an increased signal-to-noise ratio (SNR) and the ability to capture images at essentially one time point, which can simplify cerebral blood flow (CBF) quantification [3]. One potential problem with such a long echo train readout is blurring in the second phase encoding direction due to T2 decay of the signal, which is of particular concern in vascular territory imaging where it is important to be able to distinguish boundaries between territories. Parallel imaging allows reduction of the echo train length, reducing this effect. The purpose of this study was to assess the performance of a 3D-GRASE readout with parallel imaging against a conventional 2D multi-slice EPI readout.

Theory: In VEPCASL transverse gradient blips applied between the standard PCASL radio-frequency (RF) pulses and RF phase cycling allow the inversion efficiency to be modulated across one direction within the labeling plane. 'Tag' and 'Control' locations can be defined where spins flowing through the labeling plane are inverted or unperturbed, respectively. Vessels that lie between the 'Tag' and 'Control' positions are intermediately labeled and the spatial modulation is periodic. Collection of multiple encoding 'cycles' allows the subsequent analysis to separate the contributions from each vessel by using a matrix formalism [1] and estimating the labeling efficiency for each vessel on each cycle. These estimates can be extracted from the data using a histogram of labeling efficiency for selective cycles compared to non-selective cycles and assigning peaks in this histogram to each vessel [1]. However, this method assumes that for each vessel there is a considerable region of tissue that is supplied solely by this vessel. Where considerable mixing of blood occurs (e.g. the blood arising from the two vertebral arteries) it may be more appropriate to assume labeling efficiencies derived from simulations of the Bloch equations, using the known vessel locations within the labeling plane and details of the selective cycles used.

Methods: Six healthy volunteers with no known neurological deficit were scanned under a technical development protocol agreed with local ethics and institutional committees. All data were acquired on a Siemens 3T scanner using a 12 channel head receive coil and body coil for transmission. The protocol consisted of a 3D time-of-flight (TOF) acquisition for vessel localisation and labeling plane selection, followed by two VEPCASL acquisitions with EPI and 3D-GRASE readouts respectively. Eight VEPCASL cycles were performed to establish vascular territories for both right and left internal carotid arteries (RICA and LICA) and right and left vertebral arteries (RVA and LVA). These cycles consisted of two non-selective acquisitions (tag and control), two left-right encodings, two anterior-posterior encodings and two oblique encodings to label diagonally opposed vessels. Each pair of cycles was complementary (e.g. Cycle 3: tag right vessels whilst controlling left and Cycle 4: tag left vessels whilst controlling right). All imaging and VEPCASL parameters were kept constant between these acquisitions (TR: 3500 ms, TE: 23 ms, Slices: 18, Slice Thickness: 5 mm, Matrix size: 64x64, Flip angle: 90°, Averages: 10 per VEPCASL cycle, fat saturation: on, Bandwidth: 2004 Hz/pixel, VEPCASL tag duration: 1400 ms, post-labeling delay: 1000 ms, background suppression as in [3] with optimal suppression, limited by acquisition constraints to species with T1 = 400 and 800 ms), except that for the 3D-GRASE readout parallel imaging was used with a GRAPPA factor of 2, 5/8 partial Fourier in the slice direction and centric re-ordering of slice phase-encoding (i.e. the central plane of k-space is acquired first to minimise the echo time). The total acquisition time was 4 min 40 s in each case. Vascular territories were calculated using the matrix formulation described by Wong [1]. Labeling efficiencies were derived from simulations of the Bloch equations (assuming laminar flow with a mean velocity of 30 cm/s) in order to separate both vertebral artery territories, as mentioned above.

Results: Colour coded vascular territory images from a typical subject are shown in Fig. 1 for both EPI and 3D-GRASE readouts. General features of the vascular territories are clear and comparable in both readouts, such as the right internal carotid artery being the main contributor to the right posterior cerebral artery territory. This is confirmed by strong filling of the right posterior communicating artery in the TOF data (not shown). Qualitatively it is clear the SNR is higher for the 3D-GRASE readout. This is confirmed by quantitative measurements performed by assuming the "signal" is the 90th percentile signal intensity after summing all vascular components, and measuring the "noise" as the standard deviation in a region of interest offset from the brain in both phase encoding directions to avoid ghosts: mean and standard deviations in SNR over all subjects are 3D-GRASE: 15.3 ± 3.4 and EPI: 7.2 ± 0.9. Some blurring of the 3D-GRASE data into adjacent slices is especially evident in the most inferior and superior images and is likely to be the reason that the central slices appear brighter. This is also apparent in the coronal section shown in Fig. 2, where the vertebral arteries' supply to the cerebellum is less clear than in the EPI images due to the internal carotid artery territories merging from superior slices. Another advantage of the 3D-GRASE sequence is its spin-echo nature which significantly reduces signal drop-out near, for example, the frontal sinuses.

Discussion: This study demonstrates that 3D-GRASE is a viable option for vascular territory imaging using VEPCASL. It boasts approximately twice the SNR and reduced signal drop-out relative to EPI, although still suffers from some blurring in the slice direction despite the use of parallel acceleration in one phase-encoding direction. This may be problematic where clear borders between vascular territories are desired. In further work we hope to test the 3D-GRASE sequence with parallel acceleration in both phase encoding directions (which requires a receive coil with a greater number of channels) to further reduce the readout duration and therefore the blurring effect. However, it should be noted that the blurring effect may artificially increase the SNR due to the effect of averaging noise across slices, so more highly accelerated 3D-GRASE readouts should be tested to ensure the SNR benefit over EPI remains. Other work includes combining this approach with a multiple inversion time experiment to provide both vascular territory images and quantitative CBF measurements that are difficult with a 2D multi-slice readout such as EPI. Further SNR gains could be made by using a more sophisticated analysis method such as the Bayesian classification approach described by Chappell *et al* [4].

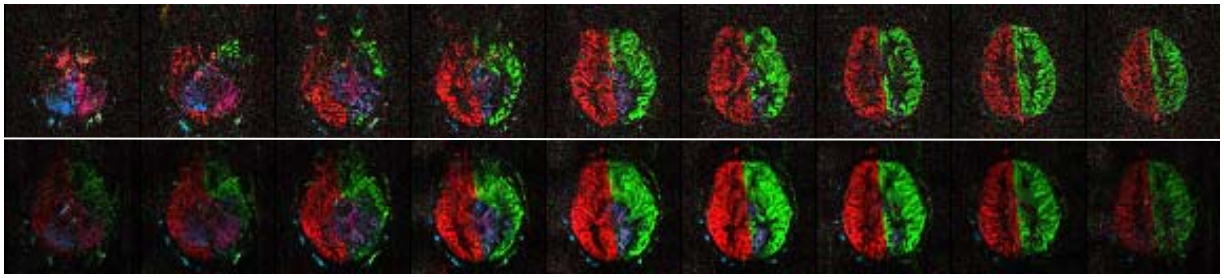

Figure 1: Axial vascular territory images acquired using EPI (top) and 3D-GRASE (bottom) readouts. Colour is used to represent the origin of the blood signal (red = RICA, green = LICA, blue = RVA, purple = LVA). Images are normalised to the maximum intensity in each 3D volume to aid comparison. Alternate slices are shown, running from inferior (left) to superior (right). Image right is subject's left.

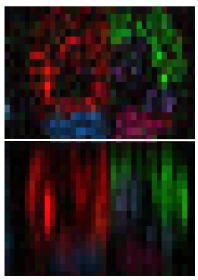

Figure 2: One coronal section of the data shown in Fig. 1.

References:
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