Directional Dependence in Velocity Selective Arterial Spin Labeling

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Introduction

Velocity Selective Arterial Spin Labeling (VS-ASL) is dependent upon the application of velocity encoding gradients interspersed between RF pulse elements (1). In previous VS-ASL studies (2,3,4), these gradients have been applied along a single axis. Perfusion is, however, directional and anisotropic and the significance of this in the presence of uniaxial velocity encoding gradients has not been determined. In this study, we have investigated the conditions under which the presence of off-axis flow significantly affects the perfusion image.

Theory

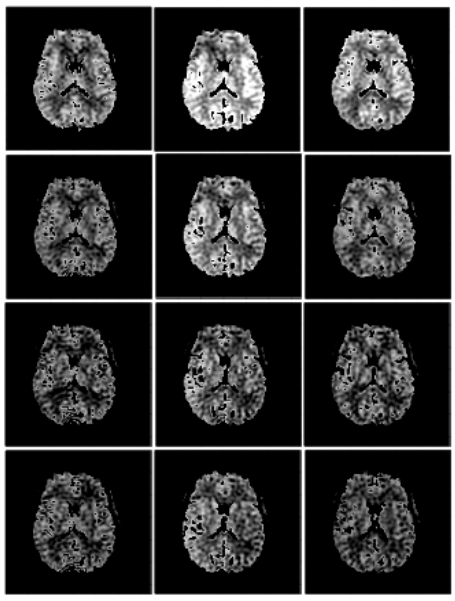
Methods for developing velocity selective pulse trains have been proposed by Norris (1) with one of the simplest trains being 90_x-gradient-180_y-gradient-90_x. This scheme will produce a modulation of the longitudinal magnetization given by $M_z=-M_0\cos(\phi)$ where $\phi = \gamma\bullet\delta\bullet\Delta\bullet G\bullet V\bullet\cos(\theta)$ [1], γ is the gyromagnetic ratio, δ and Δ are the gradient pulse duration and separation, G is the gradient strength and $V\cos(\theta)$ is the projection of the velocity vector onto the gradient axis. The critical condition for velocity selective tagging is that $\theta < \theta_c=\cos^{-1}(V_c/V)$ [2] where V_c is the cutoff velocity of the tagging pulse and V is the flow velocity. From [3] it is seen that for low V_c (e.g. 1cm/s), corresponding to flow in the microvasculature, θ_c can be in excess of 80 degrees, thus including all but nearly orthogonal flow components in the tagging process. For Vc corresponding to larger arteries (ie 10cm/s) θ_c will be closer to 60 degrees and it is expected then that flow anisotropy may become significant.

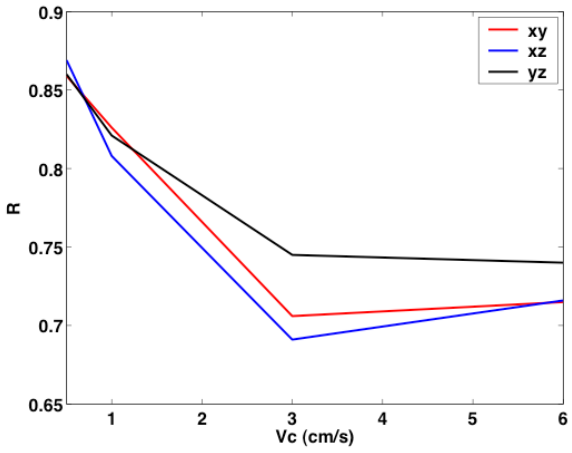
Methods

Data was collected using V_c ={0.5,1,3,6 } cm/s for healthy subjects. Imaging was performed using a 1.5T GE scanner with a single shot spiral EPI readout of resolution 64x64 at FOV=24cm x 8mm with TR=2500ms and Tv=1000ms. Velocity encoding was performed separately for the x (anterior-posterior), y (left-right), and z (superior-inferior) axes and 100 repetitions were taken per axis. A running subtraction and subsequent average over the series was performed ignoring the first 4 images to allow M_z to reach steady state. To analyze the directional dependence, we calculated the correlation between orthogonal directions for axes within each data set. To help ensure that the coefficients were not inflated by outlying data or blood flow in the sinus, a threshold criterion was established where voxels outside 3 standard deviations of the mean were discarded.

Results

The masked images used in the above analysis are seen in Fig1. The correlation coefficients have been plotted for the various V_c in Fig.2.
As one would expect, the highest correlation value corresponds to the lowest V_c however the overall trend deviates from that prediced by equation 2. Specifically, the directional dependence effects appear to reach a threshold over the velocity interval from $1 \leq V_c \leq 3$. It is also interesting to note that the greatest directional dependence appears between directions that involve x.





From left:

Figure1. Masked images used for the correlation analysis. Left to right are x,y and z axes. Top to bottom are V_c 0.5,1,3,6 cm/s.

Figure2. Correlation coefficients between axes for V_c 0.5,1,3,6 cm/s.

Discussion

These preliminary results indicate that directional dependence in VSASL can become significant even when encoding is performed at low V_c. Since θ is maximal when flow velocities $V >> V_c$ it is not surprising that the coefficients in Fig 2 trend down with increasing V_c. The greatest directional dependence is seen between axes that involve the x direction, and this may be due to an alignment between the gradient axis and blood traveling through the anterior and posterior cerebral arteries. The plateau that starts at $V_c = 3$ suggests that there may be a "cutoff" on the effect that flow direction can have.

References

1. Norris et al, JMR **137** p.231,1999
2. Wong et al, ISMRM Abstracts p.621,2002
3. Wong et al, ISMRM Abstracts p.2181,2003
4. Duhamel et al. Magn. Reson. Med. Jul;**50**(1):145 2003**.**