# Arterial Volume Imaging by Saturation (AVIS): A MRI Method for Dynamic Cerebral Blood Volume Imaging

A. Vazquez[1], G. Lee[1], L. Hernandez-Garcia[1], D. Noll[1]
[1]fMRI Laboratory, University of Michigan, Ann Arbor, MI, United States

## Introduction

The ability of MRI to acquire images that are sensitive to physiological parameters, such as blood flow and blood oxygenation has made this modality a very valuable tool in fields like neuroscience and neurophysiology. Blood flow MRI methods offer the possibility of characterization of the perfusion response dynamics that result from brain activation and BOLD contrast MRI provides some information about the blood oxygenation response to activation (though due to a complex signal relationship this is often not quantitative). Measurements of blood volume are necessary in order to fully understand the dynamics of cerebral hemodynamics, oxygen delivery and the BOLD response. The objective of this work was to implement a MR acquisition scheme that is sensitive to changes in CBV and is able to capture these changes with good spatial and temporal resolution (i.e. similar to BOLD). This approach is particularly sensitive to the changes in the arterial blood volume and will be referred to as AVIS, arterial volume imaging by saturation.

## Methods

The AVIS approach is based on a MR angiography technique where selective saturation of the water signal in a slice is followed by non-selective adiabatic inversions in order to image only in-flowing blood protons (1) (Figure 1, left). Water signal saturation was achieved by applying slice-selective 90-degree RF pulses followed by dephasing gradients, as in a CHESS scheme. Saturation was followed by a "mixing time" period (TM) where non-saturated blood spins are allowed to enter the imaging slice. Four non-selective inversion pulses were used to image at their null point (species with T1s between 0.7s and 3.0s) and keep the background protons from contributing to the AVIS signal. Since the protons that enter the imaging slice experience T1 decay as a function of the mixing time, there is a trade-off between signal amplitude and the vascular penetration of the blood protons. Also, the protons that flow into the imaging plane are not restricted to the vascular compartment, so that longer mixing-times times allow blood protons to penetrate further in the vascular tree and diffuse into tissue. To measure the amount of tissue signal contribution, flow-spoiling gradients were used to spoil spins with average speeds of 1 cm/s or greater ($b = 240$ mm$^2$/s). Various saturation-to-imaging times, or mixing times, were tested to maximize the AVIS signal (Figure 1, middle). The shorter mixing times, while larger in overall signal, are dominated by larger vessels. To allow further vascular penetration to smaller vessels while not loosing substantial blood signal due to T1 decay, a longer mixing-time of 800 ms was selected.
Five subjects were scanned in a GE 3T scanner using the AVIS method. To study the temporal evolution of the AVIS signal the subjects were instructed to perform a motor task (finger tap) with stimulation and resting periods of 60s each. The AVIS (spin-echo) imaging parameters were: TR=2s, TE=40ms, TM=800ms. Every other TR in the AVIS acquisition included flow-spoiling gradients. A spin-echo FAIR acquisition was also used to assess the differences between the AVIS and perfusion signals. The imaging parameters were: TR=4s, TE=20ms, TI=1700ms and 2300ms. The duration of the motor stimulation and resting periods for the FAIR acquisitions were 40s each.

## Results

The AVIS acquisition (TM=800ms) produced individual images with SNR of 2.3 (ratio of the average signal inside/outside the brain). The functional FAIR acquisition exhibited signal changes of 73% and 38% (TIs of 1700ms and 2300ms, respectively), while the AVIS acquisition exhibited signal changes of 37% (Figure 1, right). The AVIS signal was observed to quickly increase with stimulation onset followed by a slower increase in signal until stimulus cessation.

## Discussion

The AVIS approach is similar to a perfusion acquisition scheme because the signal consists of protons that originated in the blood and are not confined to the vascular space. The FAIR signal arises from the decrease in signal that takes place due to the inflow and exchange of inverted spins, while the AVIS signal consists of the amount of blood spins that entered the imaging slice (and for the most part appear to remain in the vasculature). The tissue signal contribution to the AVIS signal did not exceed 23%. The relative amplitude change of the functional FAIR signal was consistently higher in comparison to the functional AVIS signal. If the tissue signal contribution is subtracted from the AVIS data, the functional AVIS signal changes drop to 31%. Mandeville reported changes in CBF and CBV of approximately 64% and 19%, respectively, during a 30 s rat forepaw stimulation experiment and mono-exponential and bi-exponential temporal features for the blood flow and blood volume responses, respectively (2). The presence of a slower increase during long periods of activation (and a slower offset decay) in the blood volume response has been attributed to venous visco-elastic properties. Its presence in the stimulation period of the AVIS signal suggests there is either a small venous contribution to the signal or that arterioles/capillaries possess some slower elastic properties or visco-elastic properties. The blood volume signal change predicted using Grubb's relationship would be 25% using the FAIR (TI=1700ms) signal change (3). This suggests confirmation that the AVIS signal captures the changes in blood volume, where any discrepancies are due to venous volume changes that are probably not captured by the AVIS scheme and tissue signal contamination. If the FAIR signal with TI of 2300 ms (reduced arterial signal contribution) were considered as a better indicator of the true changes in perfusion (4), the estimated change in total CBV using Grubb's relationship would be 14%. Lee reported a 31% change in total CBV and a 79% change in arterial CBV in a hypercapnia experiment (5). Using the same arterial-to-total CBV ratio would predict a 34% change in arterial CBV, which is consistent with the AVIS results. The AVIS and FAIR temporal dynamics are similar and given the role of arterioles in flow regulation, this is expected. However, these methods are measuring fundamentally different phenomena – the AVIS signal is dominated by blood volume signal while the FAIR signal is dominated by tissue perfusion. The data presented demonstrates that the AVIS approach is very sensitive to changes in CBV and can be used to make non-invasive measurements of CBV, particularly arterial CBV, with good temporal resolution.

This work was supported by the Raynor Foundation.

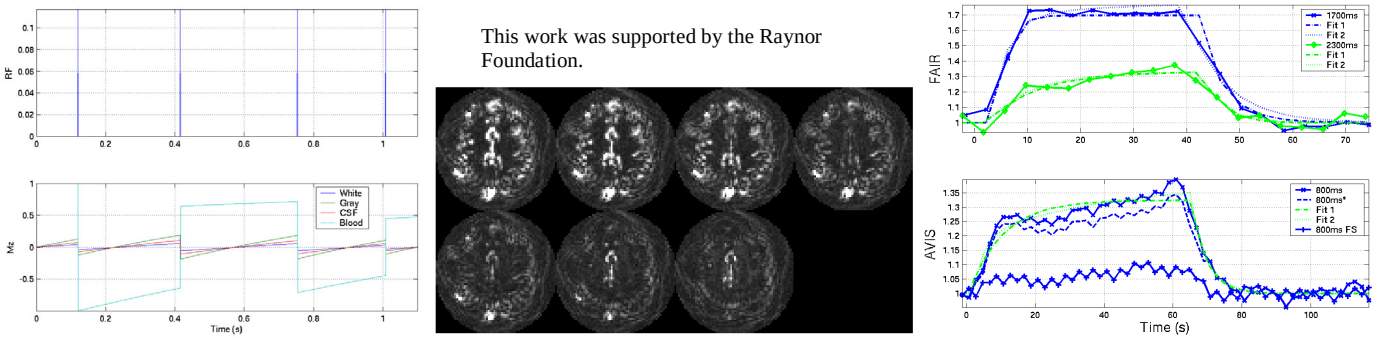


Figure 1: (Left) Bloch simulation of the AVIS scheme. Saturation is followed by the in-flow of relaxed blood protons and inversion pulses are used to keep the stationary signal nulled. (Middle) Averaged AVIS images with TMs of 200, 400, 600, 800, 1000, 1200 and 1400ms (left-to-right,top-to-bottom). (Right) Average functional FAIR (40s stimulus, 40s rest) and AVIS signals (60s stimulus, 60s rest). The FAIR time series with TI of 1700ms and 2300ms are presented in the top panel and the regular and flow-suppressed AVIS time series are presented in the bottom panel. The tissue signal contribution was subtracted from the regular AVIS signal (dashed-line).

**References**: [1] Mani S, et al., MRM 37: 898 (1997); [2] Mandeville JB, et al., JCBFM 19: 679 (1999); [3] Grubb RL, Stroke 5: 630 (1974); [4] Kim SG, et al., MRM 34: 293 (1995); [5] Lee SP, et al., MRM 45: 791 (2001).