# Time Efficient CSF Suppressed Velocity Selective ASL using a $T_2$-FLAIR Preparation

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## *Introduction*

In Velocity Selective ASL (VS-ASL) (1,2), the tag pulse creates a velocity selective modulation of the longitudinal magnetization of blood. Velocity selective pulse trains necessarily produce diffusion related attenuation, and generally produce phase and/or magnitude modulations in the presence of coherent flow as well. In the brain, diffusion and flow in CSF can produce significant artifacts in VS-ASL (2). The degree of velocity selectivity in current implementations of VS-ASL is characterized by the velocity at which slowing spins are fully saturated, or the cutoff velocity ($V_c$) (2). There exists a tradeoff in $V_c$ wherein at lower $V_c$ the tag is applied closer to the target tissue while higher $V_c$ reduces CSF and motion related artifacts. We present here a time efficient method for CSF suppressed VS-ASL that allows for VS-ASL imaging at lower $V_c$.

## *Methods*

The pulse sequence used in this work is shown schematically in Figure 1, along with the calculated magnetization history for CSF and blood. For CSF suppression, a $T_2$-FLAIR preparation scheme (3) was used to null the magnetization of CSF at the time of the tag/control pulse. A simple $90^o_x$-gradient-$180^0_y$-gradient-$90^0_x$ pulse train was used for tag generation, which results in a sinc-shaped profile of longitudinal magnetization vs. flow velocity in the presence of laminar flow. After a delay $T_v$ to allow for inflow, single shot spin echo spiral images were acquired with flow weighting gradients on either side of the refocusing RF pulse. The flow weighting gradients are adjusted to the same $V_c$ as the tag pulse, resulting in an ASL signal that only includes blood that is tagged at velocities above $V_c$, and decelerates to a velocity below $V_c$ prior to imaging. With this configuration the ASL signal is proportional to CBF*$T_v$. The sequence was simulated and optimized to maximize the blood magnetization and null the magnetization of CSF at the time of the tag pulse. Because the difference between tag and control images is generated at the time of the tag pulse, it is important that the CSF be nulled at that time. Optimization parameters included $T_1/T_2$=4200/2000ms for CSF and 1300/120ms for arterial blood. The calculated SNR efficiency (blood magnetization/ sqrt(TR)) yields a broad peak for TR from 4.5-7.5s and a $T_2$-FLAIR $\tau$ of 100-200ms. Across this range of parameters, the SNR efficiency of the $T_2$-FLAIR preparation is stable to within ±1.3% and is approximately 25% higher in SNR efficiency than CSF suppression using simple inversion pulses (2), which peaks at a TR of 6.5-11s. However, this method is 40% less SNR efficient than unsuppressed images. For this study imaging parameters included: FOV=24cm x 8mm, $T_v$=1000ms, $V_c$={0.5, 1.0, 2.8, 6.3}cm/s, $T_{T2\text{-}FLAIR}$=1400ms, $\tau_{T2\text{-}FLAIR}$=100ms, and TR=4500ms. For comparison, non-CSF suppressed images were acquired without $T_2$-FLAIR preparation with a TR of 2500ms. Imaging was performed on a 1.5T GE echospeed system on healthy volunteers.

## *Results*

CSF suppressed and unsupressed VS-ASL images are shown in Figure 2. The Table shows the b factor associated with each Vc, as well as the calculated diffusion related attenuation in CSF and brain tissue caused by the tag pulse train. In the unsuppressed images, there are CSF artifacts clearly visible in the horns of the lateral ventricles for $V_c$ up to at least 2.8cm/s. Residual signal in the ventricles in the CSF suppressed images at low $V_c$ are consistent with choroid plexus. For higher $V_c$, CSF suppressed and non-suppressed images are very similar in appearance, but the focal nature of the signal suggests that the tagging is occurring far enough up the arterial tree that the tagged blood is not reaching target tissues.

## *Conclusions*

Significant CSF artifacts are present in VS-ASL images for $V_c$ up to at least 2.8cm/s. For quantitative measurement of tissue perfusion, lower $V_c$ is recommended, and CSF suppression is necessary. The use of $T_2$-FLAIR based CSF suppression is more time efficient than simple inversion based suppression.

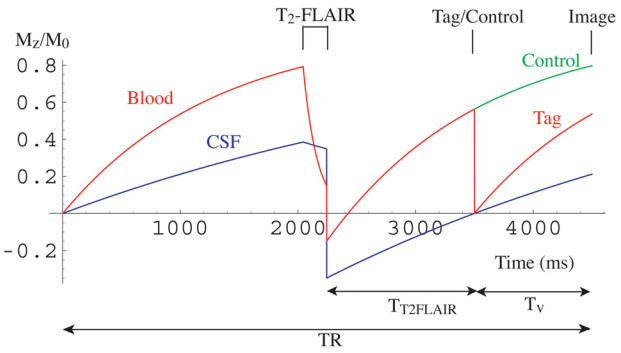


**Figure 1.** Schematic of pulse sequence.

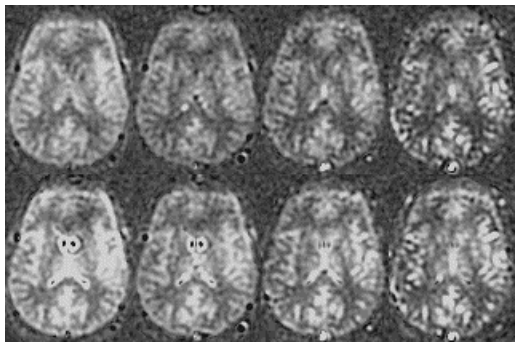

**Figure 2.** Top: CSF suppressed, Bottom: Unsuppressed. From left: $V_c$={0.5, 1.0, 2.8, 6.3}cm/s.

| Vc (cm/s) | 0.5 | 1.0 | 2.8 | 6.3 |
|---|---|---|---|---|
| b (s/mm$^2$) | 8.5 | 2.8 | 0.61 | 0.16 |
| 1-$e^{-bD}$ (CSF) | 2.1% | 0.71% | 0.15% | 0.04% |
| 1-$e^{-bD}$ (brain) | 0.85% | 0.28% | 0.061% | 0.016% |

## *References*

1. Wong et al, ISMRM Abstracts p.621, 2002.
2. Duhamel et al. MRM **50**(1): p.145, 2003.
3. Wong et al. MRM **45**(3): p.529, 2001