Localization of Perfusion Water Signal in ASL and VASO Techniques

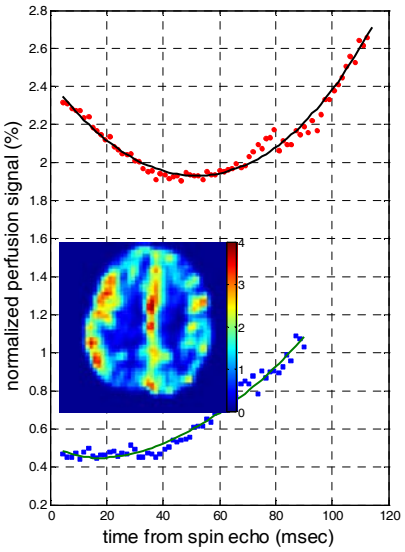
X. He[1] and D. Yablonskiy[1]

[1]Mallinckrodt Institute of Radiology, Washington University School of Medicine, St. Louis, Missouri, United States

Introduction: In arterial spin labeling (ASL) techniques, the signal intensity change between tagged and control images correlates with the tissue perfusion rate. Depending on the tagging time, the tagged (perfusion) water may partially reside inside arteries, capillaries, parenchyma tissue, or even inside venules. Knowing the location of the tagged water is important for creating quantitative perfusion maps. This question is also important for understanding results of recently proposed vascular space occupancy (VASO) technique (1) developed to quantify cerebral blood volume (CBV) changes during neural functional activation.

In this study, we propose a FAIR-GESSE approach to separate perfusion signal into components according to their T2 relaxation properties. The method combines two approaches – FAIR (2) for spin tagging, and Gradient Echo Sampling of Spin Echo (GESSE) (3) for signal sampling. FAIR preparation pulses (slice selective and non-selective inversion recovery) are used to generate tagged and control images. Similar to VASO, inversion time TI is chosen to null a signal from the blood originally located in the imaging slice. GESSE imaging sequence is used to acquire a set of images corresponding to different gradient echo times simultaneously.

Methods: All experiments were performed on 3.0 T Siemens Trio scanner using body transmit RF coil and 12 channel head RF receive coil. Three studies were conducted on healthy volunteers. The MR imaging parameters for FAIR-GESSE are: TR=4 sec, TI=991 msec, spin echo at 40 msec, 89 gradient echoes (7 echoes before spin echo) with echo spacing of 1.5 msec; sampling matrix of 64x64; voxel size of 4x4x6 mm^3; 4 repetitions for tagging or control images. To compensate signal decay due to macroscopic and mesoscopic field inhomogeneities, the perfusion signal for each voxel at each echo time is normalized by the corresponding reference signal obtained with GESSE sequence without FAIR preparation pulses. Because major contribution to the tissue signal is originated from the tissue parenchyma (white matter (WM) or grey matter (GM)), the normalized signal decay rate is also referenced to the tissue parenchyma decay rate. To increase signal to noise ratio, the normalized signals were further averaged for GM and WM areas. To describe the resultant signal, we use a model that separates signal into extra- and intra-vascular components: $S(TE) = S_0 \cdot \left(\lambda \cdot \exp(-\delta R_2^{\,i} \cdot TE) + (1-\lambda) \cdot \exp\left(-\delta R_2^{\,e} \cdot TE\right)\right)$, where λ is the fraction of intravascular signal; $\delta R_2^{\,i} = R_2^{\,i} - R_2^{\,t}$, $\delta R_2^{\,e} = R_2^{\,e} - R_2^{\,t}$ with $R_2^{\,t}$ being the transverse relaxation rate constant of the tissue.



Results: Figure on the right illustrates the averaged normalized perfusion signals from FAIR-GESSE experiment for GM (red circles) and WM (blue squares) at different echo times. The insert shows image of the normalized perfusion signal corresponding to spin echo time. Clear GM/WM contrast can be seen. Due to low SNR for the perfusion signal from WM, echoes beyond 90 msec are omitted. The concave shape of the signal indicates the existence of signal component with faster decay rate than the tissue and the component with slower decay rate than the tissue. The solid curves in the figure demonstrate the fitting results. They are $S = 2.44 \cdot \left(0.19 \cdot e^{0.0140 \cdot TE} + 0.81 \cdot e^{-0.0137 \cdot TE}\right)$ for GM and $S = 0.52 \cdot \left(0.49 \cdot e^{0.015 \cdot TE} + 0.51 \cdot e^{-0.054 \cdot TE}\right)$ for WM.

Discussion: Two models are usually used to describe the perfusion signal. The "well-mixed" model assumes instantaneous equilibrium between the in-flow water and water in the extravascular space. The more realistic two component exchange model (4,5) takes into account the exchange limited by the finite permeability-surface area product of capillaries. In agreement with the assumptions made in (4,5), our results also demonstrate the presence of at least two components in the perfusion signal. Moreover, they allow for further identification of these two components. Our fitting results indicate that T2 for the fast decaying component is about 33 msec in GM and 45 msec in WM; the T2 for the slow decaying component is 330 msec in GM and 600 msec in WM. This allows assigning the fast decaying component as an intravascular signal coming from the microvasculature filled with the deoxygenated blood, more specifically from the capillary network. Indeed, under normal perfusion rate (60 ml/100 g/min), for the inversion time used in this study (less than 1 sec), we can assume that no tagged blood enters venous space. On the other hand, it was reported previously that a substantial and progressive decrease of blood oxygen saturation occurs prior to the capillaries (i.e., in the arterioles) (6). Hence, the capillary blood is expected to be substantially deoxygenated and have T2 similar to T2 of venous blood which is in agreement with our results. The fraction of fast decaying component (intravascular water) that we determined at a given TI (81% for GM and 51% for WM) also agrees well with the predicted fraction of 75% for GM from the two component model (4,5). We also found that the T2 of *extravascular* component of perfusion water signal is much longer than the normal T2 value for parenchyma tissue but is consistent with the T2 of *extracellular* water component (7). This indicates that this part of the perfused water mainly resides in the extracellular space. The lack of perfusion signal from the intracellular space can be explained by the slow (relative to our inversion time) exchange between the intra- and extra-cellular water (~1.8 sec^{-1}) (8).

Conclusion: Using FAIR-GESSE technique, the distribution of perfusion signal has been characterized based on the difference of water transverse relaxation rate constants. Results point out that for a "tagging time" of about 1 sec substantial portion of perfusion blood (81%) remains inside the capillaries and has T2 comparable to the T2 of venous blood. The T2 for perfusion water in extravascular space is comparable to T2 values for extracellular fluid, reflecting the slow exchange between the intra- and extra- cellular water.

Acknowledgement: This work is supported by Mallinckrodt institute of Radiology and NIH Grant P30 NS48056.

References: (1) Donahue, et al., MRM 2006 (online, in print). (2) Kim, et al, MRM 1995; 34(3):293-301. (3) Yablonskiy, MRM 1998; 39(3):417-428. (4) Zhou, et al., JCBFM 2001; 21(4):440-455. (5) St Lawrence and Wang, MRM 2005; 53(2):425-433. (6) Duling and Berne, Circ Res 1970; 27(5):669-678. (7) He and Yablonskiy, Proc ISMRM 2006, 458. (8) Quirk, et al, MRM 2003; 50(3):493-499.