Quantification of arterial and microvascular cerebral blood volume using multiphase TrueFISP based ASL

L. Yan[1], C. Li[2], E. Kilroy[1], F. W. Wehrli[2], and D. J. Wang[1]

[1]Department of Neurology, University of California Los Angeles, Los Angeles, CA, United States, [2]Department of Radiology, University of Pennsylvania, Philadelphia, PA, United States

Introduction : In vivo measurement of cerebral blood volume (CBV) is important in clinical applications such as stroke and brain tumor, as well as in fMRI studies to understand hemodynamic responses. Dynamic susceptibility contrast (DSC) MRI is the most widely used method for clinical studies. However, it requires intravenous injection of contrast agents. Vascular-space occupancy (VASO) [1] contrast provides estimate of relative CBV changes for fMRI, yet contrast agent is still required to quantify absolute CBV. Arterial spin labeling (ASL) with Look-locker EPI readout can be used as a noninvasive means to estimate arterial CBV [2]. However, the signal-to-noise ratio (SNR) is not satisfactory with potential distortions of flow signals in EPI. In this study, we developed a new technique by combining ASL with multi-phase TrueFISP readout to quantify arterial and microvascular CBV without contrast agent.

Method : The pulse sequence consists of segmented multi-phase TrueFISP readout following interleaved slice selective (ss-IR) or non-selective inversion pulses (ns-IR)[3], as in FAIR. Dynamic time courses of flow signals can be obtained by complex subtraction between ss-IR and ns-IR acquisitions at each TI. It has been shown that the longitudinal magnetization of flowing blood spins is not or barely disturbed (besides T1 relaxation) by the TrueFISP $\pm\alpha$ pulse train [4]. Once the spins reach tissue, however, they become quickly saturated by the TrueFISP pulse train with 0 velocity and reduced T2/T1 ratio. Therefore, labeled blood spins behave like an intravascular contrast agent in multiphase TrueFISP scans, and can be used to quantify CBV in a similar way as DSC MRI. In this study, we define the ***preserved flow ratio (PFR)*** as the ratio between the area-under-the-curve of dynamic flow signals acquired using multi- and single-phase TrueFISP readout, and investigate PFR as a function of flip angle (α) and flow velocity (v) using Bloch equation simulation. Experiments were carried out on a Siemens Trio scanner at 3T. Imaging parameters were: FOV=220×165mm, Matrix=96×72, flip angle=40°, TR=3.4ms, TE=TR/2, a single 8mm slice, 27 phases between the TI of 150 to 2542ms with a step of 92ms, scan time=3min. To validate the simulation results, 4 single-phase TrueFISP based ASL scans were performed at the TI of 655/1155/1655/2155ms respectively. To suppress the arterial signals, a delay of 700ms followed by saturation pulses to spoil the label was inserted between inversion pulses and TrueFISP readout, as in QUIPSS II. The subtracted dynamic flow signals, C(t), were measured in each pixel. The arterial input function, Ca(t), was derived from an arterial ROI by thresholding the blood flow image, which was calibrated using the signal in sagittal vein to avoid partial volume effects. CBV was calculated by: $CBV = \int C(t)e^{t/T1a}dt \Big/ C_a(t)e^{t/T1a}dt$, where T1a is blood T1 at 3T (1.6s). For QUIPSS II type multiphase TrueFISP acquisition, Ca(t) was assumed to be a rectangular function with a duration of 700ms.

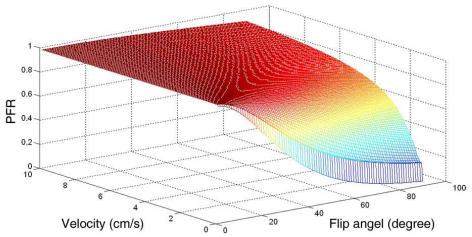

Figure1. Bloch equation simulation of preserved flow ratio (PFR) of multiphase trueFISP as a function of flow velocity and flip angle

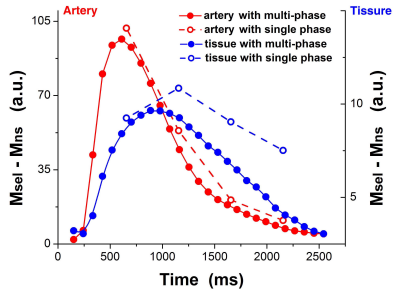

Figure2. Comparison of subtracted flow signals between multi- & single-phase TrueFISP based ASL

Results and Discussion: As shown in Fig. 1 of simulation results, the PFR is above 90% for flowing spins with v>4cm/s, such as those in arteries. As blood spins flow into arterioles and capillaries, the PFR decreases with larger α and slower v. For α of 40-50°, the PFR is >80% for v>2cm/s, ~50% for v=2mm/s and is ~30% for v=0. An α of 40° was chosen as the optimal tradeoff between SNR and SAR in experiments. As shown in Fig.2, compared to the benchmark of single phase TrueFISP measurements, the arterial time courses obtained by multiphase TrueFISP were virtually identical, suggesting little saturation effects. The measured flow signals in tissue, however, suffered greater saturation effects at longer TI with multiphase TrueFISP. Consistent with simulation results, Fig.2 indicates that multiphase TrueFISP based ASL signals largely arise from flowing spins in arteries, arterioles and even capillaries with preserved longitudinal magnetization. Figure 3 exhibits subtracted flow images at 4 representative TIs and calculated quantitative CBV maps using FAIR (a) and QUIPSS II (b) type acquisitions. Both CBV maps are of high quality (due to integral of multiple images) and clearly delineate the arteries and microvasculature. As expected, arterial signals are largely suppressed in Fig3b. The calculated mean CBV is 1.09% and 1.57% for Fig. 3a and 3b respectively, in good agreement with literature [2]. The FAIR approach may underestimate CBV since labeled blood spins in capillaries may not be completely washed out within the acquisition window of TrueFISP readout. The QUIPSS II approach may be more accurate with potential advantages of reduced saturation effects, reduced arterial signal and a well-defined arterial input function.

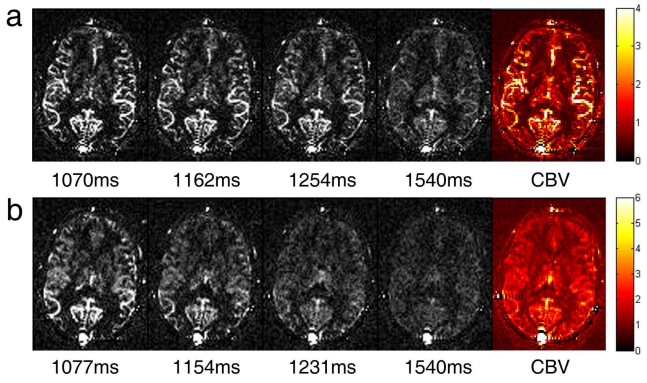

Figure3. Subtracted flow images at 4 representative TIs, and calculated quantitative CBV maps using FAIR (a) and QUIPSS II (b) type acquisitions

Conclusion: The proposed multi-phase TrueFISP based ASL is a promising method to provide noninvasive and quantitative measurement of arterial and microvascular CBV. Future developments include extension to multi-slice or 3D, and validation in clinical populations.

Reference : [1]Lu H et al., MRM 2003. [2]Brookes MJ et al., MRM 2007. [3]Yan L et al., Radiology 2010. [4]Wu W-C et al., MRM 2010.