Investigation of physiological parameters for pulsed ASL in calf muscles.

Hou-Jen Chen[1,2], and Graham A Wright[1,2]

[1]*Sunnybrook Research Institute, Toronto, Ontario, Canada,* [2]*Medical Biophysics, University of Toronto, Toronto, Ontario, Canada*

Introduction: The goal of this work is optimization of Arterial Spin Labeling (ASL) for peripheral limbs. In ASL, the transit delay of labeled blood is critical for perfusion quantification. The blood velocity in the arteries, on the other hand, determines sequence efficiency. In pulsed ASL, fast repetition is allowed if the arterial blood flow is fast enough to refresh the upstream labeling region. Pulsed ASL has been used to study lower leg perfusion using SATIR sequence, which is a FAIR strategy plus a magnetization reset (or saturation) pulse before the inversion and a single-shot fast spin echo for acquisition [1]. The transit delay wasn't clear in that study. The first paper providing detailed assessment of transit delay in skeletal muscle was for continuous ASL [2]. These ASL studies involved physiological perturbations of vaso-reactivity through either exercise or the use of an inflatable cuff, both of which drastically change the blood velocity profile in the arteries, and perhaps transit delay as well; however, information about transit delay for pulsed ASL and arterial velocity change in the calf in response to perturbations is limited in the literature.

In this work, we adapted FAIR (flow-sensitive alternating inversion recovery, a pulsed ASL) and SSFP, together with background suppression (BGS), to quantify hyperemic perfusion in the calf muscles. BGS was used to minimize the error from signal change in static tissues. One aim was to measure transit delay for pulsed ASL in calf muscles after exercise, which provides more accurate perfusion quantification and reference for the ideal choice of post-labeling delay (PLD). We also used CINE Phase-Contrast MRI (PC-MRI) to measure blood velocity in the three main (Anterior Tibial, Posterior Tibial, and Peroneal) arteries in response to exercise. Velocity profiles provide a reference for optimizing the spatial extent of the labeling region and sequence repetition time.

Methods:
This study included 4 healthy young male volunteers, age range 23~27 years. Experiments were performed on a 3T scanner (GE MR750) with a 5-inch surface coil for signal reception. An air-cuff (Viasys) on the thigh was inflated to 220mmHg for 3 minutes to study velocity and perfusion changes. During the cuff period, volunteers were asked to perform plantar flexion exercise in the scanner roughly at 1.5Hz to exhaustion for this study. In a separate transit delay experiment (performed on one subject), the volunteer performed the same exercise for the first minute in a 2-min cuff period; the ASL measurement (~72s, 10 pairs of tag and control) was started after release of the cuff. Nine periods of 1-min exercise without the cuff inflated followed by the 72-s ASL measurement with varying PLD times were then performed.

ASL was performed on an axial mid-calf slice that clearly showed three arteries and distinct muscle groups, with slice thickness of 8mm, FOV 16cm, matrix 64x64, SSFP acquisition with flip angle of 70°, TR/TE=3.8/1.7 (ms), and a center-out phase encoding order. The labeling pulse was a 15ms hyperbolic secant (μ=52, β=260) inversion pulse, which in control repetitions selectively inverted a 25mm slab centered at the image slice. The ASL sequence was repeated every 3.5s with PLD=1.6s. In the transit time experiment, PLD was sampled at 1.0 s after the cuff release then at the following values over the subsequent periods {0.6, 1.0, 1.4, 1.8, 2.2, 0.8, 1.2, 1.6, 2}s. In the velocity experiment, PC-MRI was performed with FOV of 8cm, matrix 160x160, flip angle 25°, and TR/TE=8.5/3.7 (ms). Only flow in the S/I direction was measured, with VENC of 80cm/s, 8 cardiac phases resolved, and 16 views per segment. The acquisition took 12s. The measurement was taken twice before perturbation, once when exercise stopped (but cuff still on), and every 30s after the cuff was deflated (see Fig 1).

Results: In the 3-min cuff paradigm, all volunteers were exhausted after 90~105s of exercise. Associated arterial and perfusion responses are plotted in Fig 1 for one subject. The repeated 1-min exercise periods for the transit time measurement maintained a hyperemic state without causing substantial discomfort. All exercise induced strong perfusion mainly in the lateral compartment (LC), lateral gastronemius (LG), and deep posterior compartment (DPC). As shown in Figure 2, PLD of 1~1.2 was optimal to observe perfusion enhancement. Transit delay and perfusion values were calculated based on the general ASL model (peak signal is at transit delay + bolus duration) [3] and least-square curve fitting. The transit delay was estimated to be 538 and 513 ms and steady state perfusion 32.9 and 98.3 ml/100g of tissue/min in LC and LG respectively.

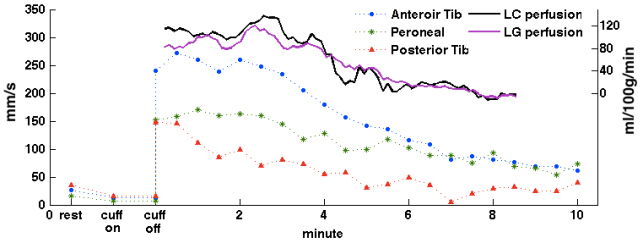

Figure 1: Reactive arterial mean velocity (mm/s) and perfusion (ml/100g of tissue/min) responses to exercise during short ischemia.

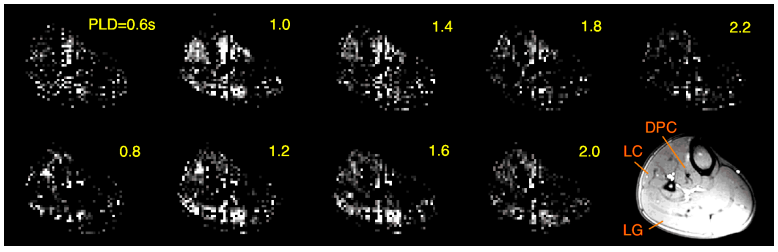

Figure 2: Difference of control and labeled images (9 pairs averaged) with different PLD in pulsed ASL. Masks were used to exclude pixels of bone and vessels.

Discussion and Conclusions: Our PC-MRI data showed that peripheral mean arterial velocity at rest was below 50 mm/s with pulse peaks slightly above 100 mm/s. This slow flow is consistent with previous papers [4]. If the goal is to quantify peak perfusion in the first few minutes after cuff release, ASL can be performed at a higher repetition rate, roughly every 3s based on higher velocities at this stage shown in Fig 1, providing better temporal resolution or more images for averaging and better SNR. It has been recognized that plantar flexion exercise mainly involves gastrocnemius, with weak involvement of lateral muscles and DPC is used for stabilization. These muscle activities all correspond to regional perfusion enhancement shown in Fig 2. This study provides data of PLD sample images in pulsed ASL. In addition to using such images to identify transit delay, one could also apply a saturation pulse at the tail of labeled bolus at a specific time point and restrict bolus duration (QUIPSS method [5]), which reduces sensitivity to the variation of transit delay in different muscles. Both approaches lead to more accurate quantification of perfusion. This study also reports a protocol design for maintaining the hyperemic state following microvascular perturbation with ischemia. This protocol is much more efficient than repeating paradigms such as 5-min ischemia [2] or ischemic exercise [1]. Therefore, it is useful for tuning sequence parameters such as PLD, repetition time, spatial extent of labeling region, and thickness of labeling slab. All these lead to physiological optimization of pulsed ASL sequence in skeletal muscle.

References: [1] Raynaud et al. MRM, 2001; [2] Wu, et al. JMRI, 2008; [3] Buxton et al. MRM, 1998; [4] Pena et al. AJR, 1996; [5] Wong et al. MRM, 1998.