Combined measurement of perfusion and venous oxygen saturation during reactive hyperemia in the leg

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INTRODUCTION. Recent studies suggest that detection of peripheral arterial disease (PAD) may be achieved through MRI measurement of parameters of vascular physiology in the lower extremity during reactive hyperemia [1-2]. Current MRI techniques are limited to the measurement of either macrovascular parameters, such as venous oxygen saturation ($S_O2$) using MR susceptometry [3-5], or microvascular parameters, such as perfusion using arterial spin labeling (ASL) [6]. MR susceptometry is capable of determining oxygen saturation based on differences in phase accumulation between blood and surrounding tissue [3]. Pulsed arterial spin labeling (PASL) has been shown to produce accurate perfusion in skeletal muscle during reactive hyperemia post cuff occlusion [6]. In all ASL sequences, a long post-labeling delay (PLD) is required for tagged spins to enter the imaging slice. To make use of this dead time, we propose to insert a susceptibility sequence into the PLD, and to investigate the sequence during reactive hyperemia in the leg. We aim to demonstrate the capability of a combined PASL and MR susceptibility sequence (PASL/$S_O2$) to measure perfusion and venous oxygen saturation simultaneously.

METHODS. Perfusion imaging was performed using a PASL variant, saturation inversion recovery (SATIR) [6]. Similar to FAIR, control and tag conditions were achieved using a non-selective and slice-selective adiabatic inversion pulse, respectively. ASL image acquisition followed a 930 ms PLD during which susceptometry data were acquired at a slice 3 cm distal to the ASL imaging slice. Because the non-selective inversion pulse disrupts magnetization in the entire coil sensitivity region, only susceptometric images acquired after slice-selective inversion could be used to calculate $S_O2$, though the susceptometry sequence was run every PLD to control for magnetization transfer effects. Reactive hyperemia was induced with a cuff (Aspen Labs A.T.S. 1500 Tourniquet System, Littleton, CO) secured around the superior thigh inflated to 200 mm Hg for 3 mins. Perfusion and $S_O2$ were calculated as:

$$f = \frac{1}{\tau} \ln \left( \frac{M_{max}-M_{tag}}{M_{tag}} \right) + 1$$

$$\% HbO_2 = 1 - \frac{2 \Delta m}{\gamma M_{tag} C_{Hb} (1 - e^{-\tau/T_{2*}})} \times 100$$

An 8-ch Tx/Rx knee coil (Invivo Inc., Pewaukee, WI) was used for image acquisition at 3T with the following parameters: PASL – partial Fourier GRE-EPI with TR/TE=1000/9 ms, FOV=20x20 cm, ST=1 cm, matrix=64x40 (reconstructed to 64x64), BW=1562.5 Hz/pixel; Susceptometry – multi-echo spoiled GRE, with TR/TE/AE=38.75/7.6/3.68 ms, FOV=96x96 mm, ST=1 cm, matrix=96x24 (keyhole, reconstructed with reference scan to 96x96), BW=694 Hz/pixel (Fig 1).

Experimental Protocol. In one healthy subject (F, 24 years), twelve consecutive acquisitions alternating between PASL alone, PASL/$S_O2$ combined, and $S_O2$ alone were obtained, each with 1 min baseline, 3 mins occlusion, 4 mins recovery, and 1 min rest between scans. On a different day, the protocol was repeated with only PASL alone and PASL/$S_O2$ combined. Therefore for PASL experiments there were 8 datasets for PASL alone and 8 PASL/$S_O2$ combined, and for $S_O2$ experiments there were 4 for $S_O2$ alone and 8 for PASL/$S_O2$ combined. $S_O2$ was quantified in the peroneal vein, and washout time and upslope were calculated for each $S_O2$ dataset. Perfusion was calculated in a region of interest in the gastrocnemius (gastroc) muscle for each PASL dataset. A paired Student’s t-test was used to test for differences between measurement methods.

RESULTS. Fig 2a compares average perfusion in the gastroc measured using PASL and PASL/$S_O2$. Table 1 shows mean and standard deviation (SD) of average peak perfusion and time to peak in the gastroc, and upslope and washout time in the peroneal vein. No significant differences were detected. Fig 2b compares $S_O2$ measurements made with susceptibility alone and with PASL/$S_O2$. In Fig 2a and 2b, error bars indicate SD. Perfusion and oxygen saturation time courses are similar for the singular and combined measurement techniques. Fig 2c shows simultaneous perfusion and $S_O2$ from a single acquisition.

DISCUSSION. Measured peak perfusion and time to peak match literature reported values [6]. Calculated upslope and washout time agree with measurements made in young healthy subjects in the femoral vein [5]. One potential concern with our method is interference between the PASL and $S_O2$ measurements. We chose to measure $S_O2$ downstream from perfusion to prevent spins affected by $S_O2$ measurement from flowing into the perfusion slice. This work suggests that simultaneous measurement of $S_O2$ and perfusion is feasible using the hybrid PASL/$S_O2$ sequence. This method quantifies parameters of macrovascular and microvascular physiology in a single study, which may help to better understand the pathophysiology of PAD and aid in the diagnosis and treatment of this disease.