Skeletal Muscle Perfusion Measured with Pseudo-Continuous Arterial Spin-Labeling MRI After Dorsiflexion Contractions

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Introduction: Arterial spin labeling MRI enables quantification of perfusion without the use of exogenous contrast agents, and several variations of this technique have been developed, including pseudo-continuous arterial spin labeling (pCASL). pCASL has advantages of providing superior labeling efficiency and is readily compatible with clinical scanner's body coil RF transmission hardware[1]. In this study we tested the feasibility of pCASL to measure changes in skeletal muscle perfusion following a short high-intensity dorsiflexion exercise protocol. In addition, we tested the day-to-day variability of the measure and examined the relationship with another MRI method of measuring microvascular function using the MRI blood oxygenation level dependent (BOLD) response after brief muscle contractions[2].

Methods: MR data were acquired from four male subjects (37.8±11.6 yrs, 70.1 ±7.1 kg) using a 3T Philips Achieva MR system. Subjects were positioned supine with their right leg extended in a 16-channel volume extremity coil placed around the mid belly of their lower leg with their foot secured to an exercise apparatus (foot plate at 120°) containing a load cell for monitoring force during contractions (Figure 1).

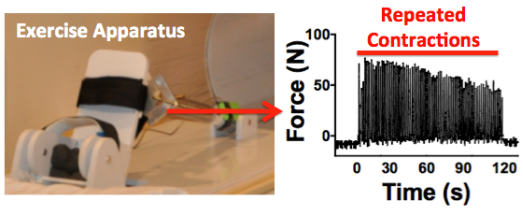

Figure 1. Exercise apparatus with example force trace during repeated isometric dorsiflexion muscle contractions (1Hz) for two minutes.

MRI data were acquired dynamically using pCASL (single-shot gradient echo EPI with fat suppression using SPIR; TR/TE/α=5s/11ms/90°; 2.8mmx2.8mmx6mm voxels; 5 slices; labeling duration = 2s; post labeling delay = 2s; The labeling plane was 6 cm above the top slice) for three minutes at rest, two minutes of exercise, and ten minutes of recovery (15 minutes total). During the exercise, the subjects performed repeated maximal isometric dorsiflexion contractions for 2 minutes with the pacing set by a metronome (1Hz). Data were analyzed using a custom written matlab program using a standard ASL model[1]. In addition, we acquired dynamic single shot multi-slice gradient echo-planar images (TR 1000 ms; TE 35 ms, matrix: 64X64, 1cm slice thickness) to measure the BOLD response following brief maximal dorsiflexion contractions[2]. During this acquisition, subjects performed five maximal 2-s dorsiflexion contractions each separated by 1 minute (6 min total).

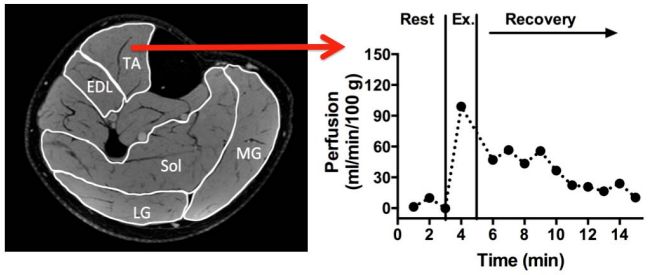

Figure 2. Anatomical axial Dixon image of the lower leg showing the tibialis anterior (TA), extensor digitorum longus (EDL), soleus (Sol), lateral grastrocnemius (LG), and medial gastrocnemius (MG). Example perfusion measured with pCASL in the tibialis anterior (TA) at rest, during 2 minutes of maximal isometric dorsiflexion exercise (Ex), and 10 minutes of recovery.

Results and Discussion: During the repeated isometric dorsiflexion contractions, force decreased by an average of 34.4±5.0%, indicating considerable fatigue over the two minutes of exercise (Figure1). The primary active muscles during dorsiflexion exercise are the tibialis anterior and extensor digitorum longus, and perfusion was increased significantly in these muscles after the contractions (Table 1;Figure 2). The perfusion values were consistent with the values reported in the literature for skeletal muscle contractions using other ASL techniques[3,4]. In the less active muscles during dorsiflexion, including the soleus and gastrocnemius muscles, there was no significant increase in perfusion after the contractions. The perfusion values after exercise were observed to have excellent day-to-day reproducibility in the active muscles (coefficient of variation range = 1-5%). Some images acquired during the two minutes of high-intensity exercise showed significant motion, and therefore we did not use the data collected during the two minutes of contractions for comparisons among muscles (Table1). Furthermore, perfusion after exercise in the tibialis anterior measured with pCASL was associated (r=0.80, p<0.05) with the peak post-contractile BOLD response in the tibialis anterior following brief isometric dorsiflexion contractions.

Table 1. Skeletal muscle perfusion measured using pCASL

Perfusion (ml/min/100g)	*Rest*	*Post-Exercise (0-3 min)*	*Post-Exercise (4-7 min)*	*Post-Exercise (8-10 min)*
Tibialis Anterior	4.1±3.8	33.1±9.8*	23.5±11.8	15.9±7.7
Extensor Digitorum Longus	1.8±3.2	31.6±8.7*	16.3±11.6	14.5±10.5
Soleus	9.4±1.5	1.2±2.1	-4.6±4.6	5.6±3.4
Medial Gastrocnemius	8.5±3.1	9.1±7.1	-1.0±3.5	6.2±6.2
Lateral Gastrocnemius	5.5±5.9	3.4±3.3	-3.9±4.1	6.5±2.0

Values are mean±SEM. * denotes significantly different (p<0.05) than rest.

Conclusion: This study shows the feasibility of applying pCASL to measure skeletal muscle perfusion after isometric fatiguing dorsiflexion contractions in healthy human adults. Future studies may benefit from applying this technique to evaluate peripheral blood flow in those with compromised vascular function.

Research Support: University of Florida Opportunity Research Seed Fund. UF CTSI (UL1 RR029890)

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