Large intramuscular vessel artifact in ASL: effect on calf muscle perfusion measurements and a velocity-selective solution

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INTRODUCTION: ASL MRI is increasingly used for measuring perfusion outside the brain. Akin to a cardiac stress test, calf muscle perfusion during exercise-recovery in patients with claudication may improve diagnostic and therapeutic management of PAD patients (1,2). With its relatively high temporal and spatial resolution, ASL is suitable for monitoring capillary perfusion in muscle during exercise recovery. However, ASL estimates of perfusion face challenges, including the erroneous effects of tissue voxels containing large blood vessels. In a large vessel, tagged blood flows through the voxel rapidly, artificially increasing the estimated perfusion and also distorting the temporal pattern of muscle perfusion (**Fig. 1**). While large vessels can be excluded using selective regions of interest, vessels with diameter smaller than voxel size (thus not detectable in an anatomic image) are still problematic. In this study, we simulated ASL signals of blood vessel using a flow phantom, and using the obtained velocity-perfusion relationship, developed a velocity-selective method for excluding large vessel voxels from muscle perfusion maps.

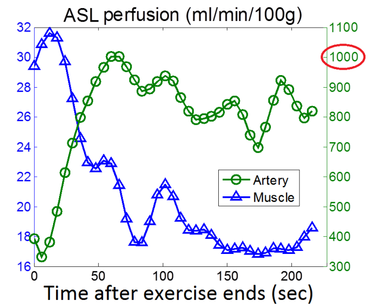

Fig. 1. ASL "perfusion" of artery voxel is huge, and has a different pattern from muscle voxels during exercise recovery

METHODS: All phantom and human experiments were performed at 3T (TimTrio, Siemens) with a knee coil, using a FAIR-EPI sequence: TE 13 ms, TR 6 s, TI 1.2 s, FA 15°, matrix 64×64, FOV 16×16 cm. In post-processing, perfusion was estimated from ASL signals using a conventional formula (3). Flow-phantom scan: The flow phantom was driven by an adjustable flow pump (4) attached to a tube with diameter ~5 mm. In this experiment, we repeated ASL scans at 8 different flow rates and used phase-contrast (PC) MRI to measure the velocity within the tube. ASL was applied to estimate perfusion. From this experiment, we determined the relationship between flow velocities and corresponding ASL 'perfusion' values. Exercise-recovery subject scan: For a healthy subject (male, 24 yrs, 64 kg), ASL scans were performed for an axial slice of calf muscle immediately after plantar flexion exercise (with 6 lbs load, 1 Hz for 1 min), and continued for 4 min. From 40 acquisitions with 6 sec intervals, perfusion was estimated. Velocity-selective exclusion: Using the velocity-perfusion relationship obtained in flow phantom experiment, the calf perfusion maps were converted to velocity maps. To determine if a voxel is contaminated by large-vessel artifact, we used two criteria: i) the velocity is within the range 10-50 cm/sec; ii) velocity decreases during recovery. To demonstrate the performance of the method, we applied it to the entire calf muscle of the subject (Fig. 2(a)).

RESULTS: Flow phantom results show that ASL perfusion estimated from the pure-water voxels was extremely high, and decreased as velocity increased. This agrees with what we had observed for artery voxels of calf muscle (**Fig 1**). Based on the phantom results, we obtained a regression formula: ***velocity (cm/s) = 135×perfusion***$^{-0.276}$. **Fig. 2**(c) shows the effect of excluding the large-vessel voxels for a healthy subject: muscle perfusion decreased as expected during recovery. The generated mask of large vessel voxels is displayed in **Fig. 2**(b). The method excluded not only the main arteries (red arrow), but also the smaller intramuscular vessels (green arrow).

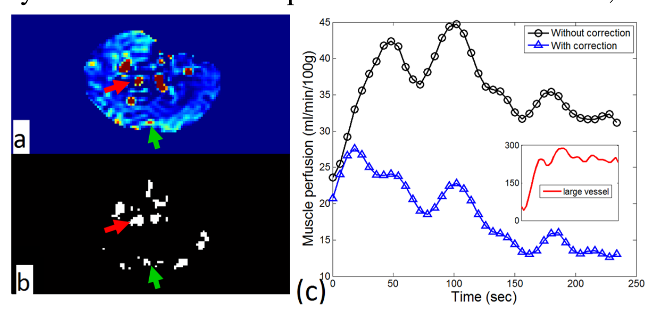

Fig. 2 (a) Perfusion map; (b) Large-vessel mask produced by the proposed method detects both main arteries (red arrow) and intramuscular vessels (green arrow); (c) averaged calf-muscle perfusion, with and without correcting the artifact. Averaged perfusion of excluded voxels is shown as the red curve.

DISCUSSION: Large-vessel artifacts in ASL have been mostly reduced by applying strong bipolar gradients, which take additional acquisition time (5). As a post-processing step, our method excludes voxels based on objective criteria derived from physiologic features of blood velocity. In conclusion, the proposed method is effective in eliminating large-vessel artifact in calf-muscle ASL, and thus may improve the perfusion accuracy.

Reference: 1. Pollak et al. JACC Cardiovasc imaging 5(12):1224, 2012. 2. Lopez et al. J Cardiovasc Magn Reson 15:216, 2013. 3. Raynaud et al. MRM46(2):305, 2001. 4. Mendes et al. MRM 69(5):1276, 2013. 5. Pollock et al. Magn Reson Imaging Clin N Am. 17(2):315, 2009.