Simultaneous Measurement of Perfusion and BOLD changes in Calf Muscle during Exercise

Jason K Mendes¹, Christopher J Hanrahan¹, Gwenael Layec², Corey Hart³, Russell S Richardson³, and Vivian S Lee³

¹Radiology, University of Utah, Salt Lake City, Utah, United States, ²Internal Medicine, University of Utah, Salt Lake City, Utah, United States, ³School of Medicine, University of Utah, Salt Lake City, Utah, United States

Target Audience

Clinicians and researchers who wish to assess perfusion and oxygenation in calf muscle, which has been shown to be beneficial in determining severity of peripheral arterial disease (PAD) and monitoring response to therapeutic interventions.

Purpose

There is compelling evidence that mobility and exercise tolerance can be modulated by alterations in muscle O₂ delivery. Thus, conditions such as aging, PAD or chronic heart failure that impair muscle perfusion result in reduced mobility, which is associated with poor quality of life and greater healthcare utilization. Due to this central role of perfusion on muscle function, clinical methods to assess muscle perfusion and tissue oxygenation in PAD patients are beginning to be developed (1,2). Recently a pulse sequence, simultaneous acquisition of quantitative arterial spin labeling and T2∗ (SQUAB), was proposed to simultaneously measure quantitative perfusion maps and BOLD changes in skeletal muscle after exercise (3). However, we have observed that imperfections in the saturation/inversion pulses during data acquisition can cause significant errors in the measurement of perfusion. This work demonstrates the feasibility of a modified version of SQUAB (mSQUAB) that accounts for imperfect saturation/inversion pulses in the measurement of perfusion. Given the well-known linear increase in blood flow with increasing work rate, the modified sequence was applied in volunteer studies with a graded exercise routine.

Method

The sequence block shown in Figure 1 was repeated every 5 seconds during the experiments. The inversion time was 0.8s, leaving about 3 seconds to exercise every repetition interval (TR). Each three second exercise window, the volunteer was asked to plantar flex three times with a specified weight load. This method of interleaved exercise and imaging allowed for an adequate buildup of muscle perfusion while still allowing measurements to be made during the exercise phase itself rather than just during the recovery. Each experiment began with some baseline measurements (where the volunteer rested during each 3 second exercise window) followed by three minutes of exercise (interleaved with perfusion/BOLD measurements) and two minutes of recovery (no exercise). Four separate experiments were conducted with varying amounts of weight, typically 4lbs(1.8kg), 8lbs(3.6kg), 12lbs(5.4kg) and 16lbs(7.3kg), each separated by an additional 5 minutes of rest to allow perfusion to return to baseline. All studies were performed on a Siemens Trio 3T MRI scanner with a 4 element flex coil. All human studies were approved by the institutional review board and informed consent was obtained from all subjects. Dual echo EPI images were acquired at TE=23/58ms, FOV=160mmx160mmx10mm, 64x64 pixels, a 7-lobe Sinc slice selective saturation pulse and 3 composite pulses (90°-180° -90°) for the non-selective inversion.

Results and Discussion

The first set of EPI images were used to calculate T2∗ and correct for changes in M₀ during the experiment. The second and third set of EPI images are used in the calculation of perfusion. Figure 2 shows the perfusion maps for an axial slice through the calf before and after exercise. After exercise, there is a graded increase in perfusion in the gastrocnemius muscle corresponding to the graded work load. The average perfusion and T2∗ from a 2cm² area (arrow in Figure 2) in the gastrocnemius is plotted in Figure 3. A graded increase in perfusion is observed during exercise as well as a decrease in T2∗ due to increased deoxygenated blood.

Conclusion

Simultaneous measurements of both perfusion and BOLD changes can be successfully interleaved with an exercise protocol.

Acknowledgments

This work has been supported by NIH grant R01 HL092439 as well as grants from the Ben B. and Iris M. Margolis Foundation.

References