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

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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 O_2 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). During 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 (90º-180º -90º) for the non-selective inversion.

Results and Discussion

The first set of EPI images were used to calculate T2* and correct for changes in M_0 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 $2cm^2$ 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

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References

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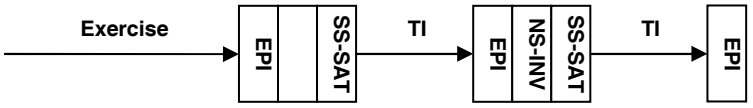


Figure 1. Basic sequence used in this work. A period of exercise (or rest) is followed by the acquisition of dual echo EPI images and then a slice selective saturation pulse (SS-SAT). After a prescribed inversion time a second set of dual echo EPI images are acquired followed by a nonselective inversion (NS-INV) and a slice selective saturation. After a final inversion time a third set of dual echo EPI images are acquired.

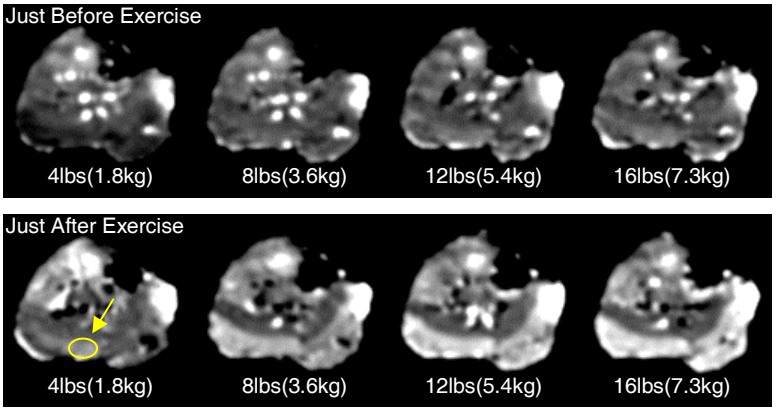
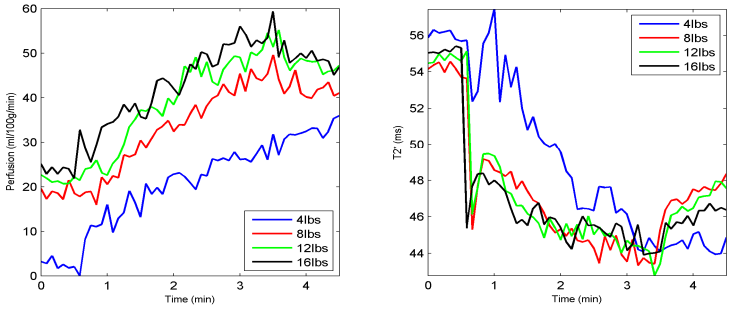


Figure 2. Perfusion maps of a healthy male (40yr old) before (top row) and after (bottom row) exercise. Each row contains four different workloads of 4lbs, 8lbs, 12lbs and 16lbs respectively from left to right. The arrow indicates the region of interest used in Figure 3.



(a) (b)

Figure 3. Perfusion and T2* measurements during graded exercise routines are shown in (a) and (b) respectively. Exercise began at about 0.5min and ended at 3.5min.