Simultaneous time-resolved measurement of blood flow, perfusion and oxygen consumption in lower leg during recovery from exercise.

Adil Bashir[1], Robert Gropler[1], and Jie Zheng[1]
[1]*Mallinckrodt Institute of Radiology, Washington University, St. Louis, MO, United States*

Introduction:

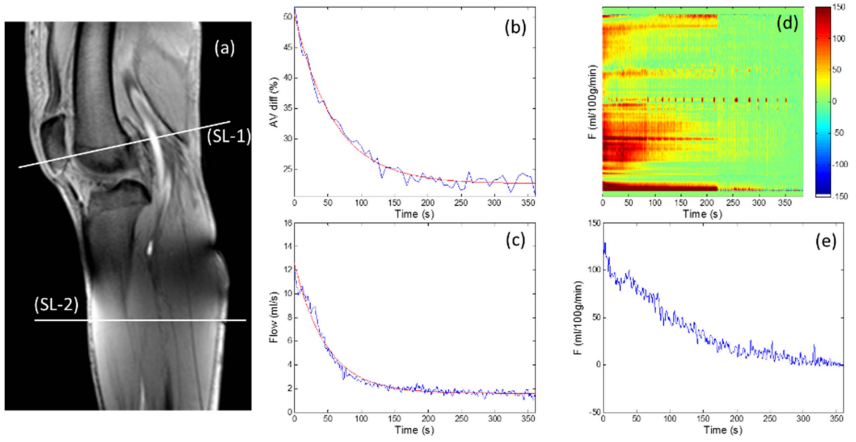
Skeletal muscle (SKM) blood flow (BF) and perfusion are significantly elevated during exercise and can change over a remarkably large range. These increases are required to meet the enormous demands for oxygen and substrates by active muscles. Chronic disease such as heart failure, diabetes, peripheral artery disease etc. negatively impact SKM flow/perfusion and thereby lead to metabolic disorders, diminished exercise capacity and tissue loss. Variety of techniques (near infrared spectroscopy, positron emission tomography, Doppler ultrasound) have been developed to measure these parameters however have several limitations (low penetration, radioactive tracers, limited to large vessel flow). Dynamic simultaneous measurement of BF and venous oxygen saturation (SvO2), and BF and perfusion by MRI have been demonstrated in two separate studies[1,2]. In this work, we developed a time-resolved method to measure BF, perfusion and oxygen consumption simultaneously in lower leg during recovery from plantar flexion exercises. This method will shed light on the interplay between muscle function, substrate delivery and metabolism and will lead to new pathways to exploit for diagnostics and therapeutics. The feasibility and reproducibility of the proposed method is demonstrated in six healthy subjects.

Methods:

Studies were done on Siemens 3 T TRIO magnet (Siemens Erlangen). Subjects were placed supine in MR compatible ergometer with flex coil secured under the leg with straps. Pulse sequence was developed to simultaneously acquire data from two slices (Fig (a)). Velocity encoded projections were acquired using phase contrast MRI with a temporal resolution of 64 ms to determine popliteal artery blood velocity[3]. Blood flow was calculated from velocity using the diameter of popliteal artery. Arteriovenous oxygen difference (AVO2) was determined from blood oxygen saturation (SVO2) using susceptometry-based oximetry with a multi-echo GRE pulse sequence[4]; 5 mm slice thickness, 1 mm in plane resolution and 6.1 sec temporal resolution. The amount of oxygen in the blood was calculated using standard formula: 1.34 x Hb * SO2 + 0.003 x PO2 where 1.34 is the oxygen carrying capacity of hemoglobin, Hb is the hemoglobin concentration and PO2 is the partial pressure. Perfusion was calculated as changes from resting state using Saturation Inversion Recovery (STAIR) pulse sequence with slice selective tagging pulse. Tagged perfusion projections were acquired with 1D spatial resolution of 1 mm and temporal resolution of 0.9 sec. Data was constantly acquired over 8 minutes; 1 minute rest, then 30 sec of plantar flexion exercise at 0.5 Hz at ~ 50% MVC and recovery for at least 6 minutes. All subjects (n = 6) were scanned twice in the same sessions.

Results:

Fig (a) shows sagittal scout and location of two axial slices for BF and AV differences (SL-1) and perfusion (SL-2) measurements. Figure also shows typical AV differences (b) and BF (c), perfusion map (d) and time course of perfusion (e) during post exercise recovery. Time constants for BF and AV difference recovery were 38.8 ± 7.7 s and 72.5 ± 13.2 s respectively whereas perfusion recovered slowest. Oxygen extraction fraction (defined as consumed/delivered) was = 36.57 ± 5.97. Good correlation was found between O2 consumed and O2 delivered (r^2 = 0.84), BF and perfusion (r^2 = 0.79), and oxygen consumed and perfusion (r^2 = 0.67). We found good reproducibility with coefficient of variation ranging between 9 and 15 % for different parameters.



Discussions:

We have demonstrated a method for dynamic simultaneous measurement of BF, oxygen consumption and perfusion in leg. Even though BF recovers to baseline, oxygen consumption and microvascular perfusion were still elevated and recover more slowly to resting values. The reasons for mismatch between the time course of changes in BF and oxygen uptake are not completely known and shows that BF is not directly regulated by need for oxygen in exercised muscle. Various disease lead to altered skeletal muscle recovery dynamics and detailed insight into the systemic parameters is required for effective treatment of these diseases.

References:

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3. Thompson et al. Magnetic Resonance in Medicine 50:1248–1255 (2003)
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