Quantitative Analysis of the Post-Contractile BOLD Effect in Human Skeletal Muscle

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Introduction:

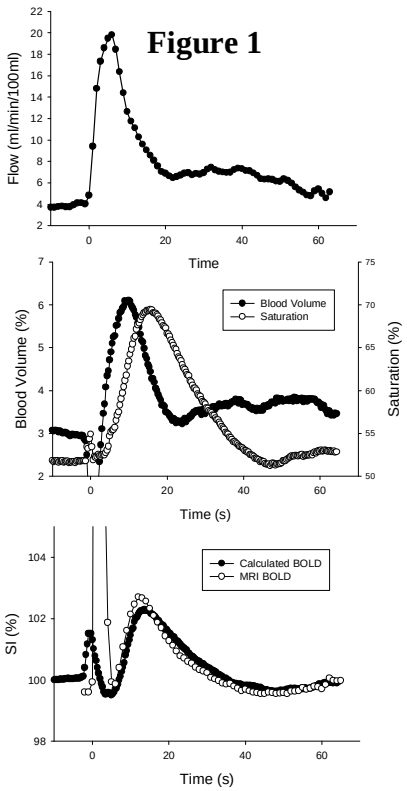
Previous studies showed that transient increases in MRI signal intensity (SI) occur in human muscle following single, brief contractions, and that these changes are related to changes in muscle blood volume and oxygenation (1,2), analogous to the brain BOLD effect. However, unlike in the brain (3), the magnitude of the post-contractile BOLD transients observed in muscle are dramatically larger in physically active compared to sedentary subjects (4). The aims of this study were, first, to examine if post-contractile BOLD transients are quantitatively explained by changes in blood volume and hemoglobin saturation (measured by near-infrared spectroscopy [NIRS]) over a range of subjects with widely varying activity levels, and second, to examine if these changes are quantitatively explained from post-contractile changes in blood flow and oxygen consumption.

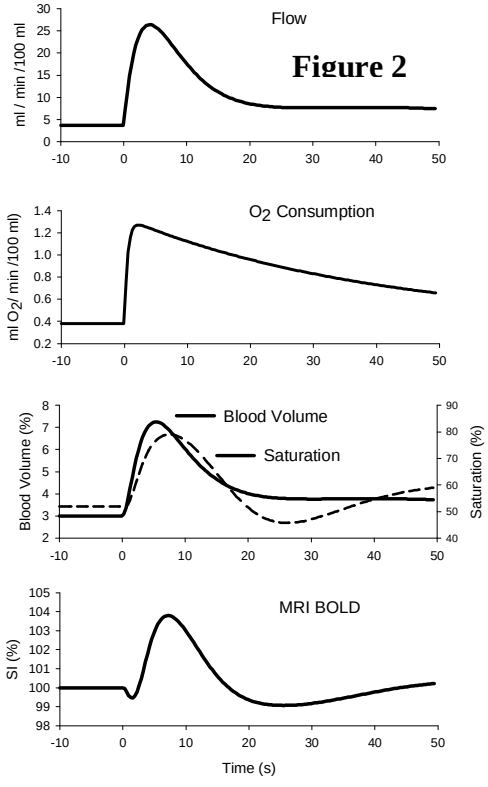
Methods:

Healthy adult subjects (6 male, 1 female, age 18-36 yr) were recruited from the university community and gave informed, written consent. Subjects were selected to cover a range of self-reported activity levels, and activity level was confirmed over a 7 day period using an accelerometer. Single-shot echo-planar images (3T Excite, GE Medical, Milwaukee WI; TR 1000, TE 35, 60^{o} pulse, 64x64 matrix, 16 cm FOV, 1 cm slice) were continuously acquired while subjects performed single, 1s duration maximum isometric ankle dorsiflexion contractions at 60 s intervals for up to 8 min. In a separate testing session at the same time on a different day, subjects performed the same series of contractions while anterior muscle hemoglobin saturation and relative blood volume were measured by NIRS (LED imager, Near Infrared Monitoring Inc., Philadelphia PA), and beat-to-beat blood flow in the anterior tibial artery was measured by Doppler ultrasound (LOGIQ Book, GE Medical, Milwaukee, WI). Intravascular BOLD effects were calculated from changes in blood volume and saturation as described previously (1), using the blood R2* values recently reported by Zhao et al (5), and assuming a pre-contraction blood volume of 3%. The dependence of blood volume, saturation and SI on post-contractile blood flow and oxygen consumption was computed using a simple one-compartment dynamic vascular model implemented in Stella (ISEE systems Lebanon, NH).

Results:

Figure 1 (top panel) shows the mean anterior tibial artery flow (linearly interpolated to 1 s intervals for averaging), mean blood volume and saturation (middle), and mean MRI-measured changes in SI (bottom, open circles) after single contractions in the seven subjects. Also shown in the bottom panel (filled circles) is the mean SI change calculated from the individual NIRS results for each subject. As expected from a previous study (4), the responses varied widely between subjects depending on activity level. Nonetheless, there was an excellent correlation (r = 0.8, slope=1, intercept =0) between the individual MRI-measured peak SI changes (103±2% range 100-106) and the peak SI changes calculated from the individual NIRS volume and oxygenation measurements. Figure 2 shows the result of modeling the mean changes, assuming similar flows, and assuming recovery oxygen consumption estimated from phosphocreatine recovery rate measured after similar contractions (6).





Discussion:

The results show that the time course and magnitude of the post-contractile BOLD transients in muscle are quantitatively explained by the combined effect of changes in both blood volume and saturation. Those changes depend quantitatively on the increases in both flow and oxygen consumption after the single contractions. The larger post-contractile BOLD transients in muscle of active subjects are due in part to larger flow responses, but may also reflect faster recovery oxygen kinetics in these subjects.

References:

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