BOLD MRI and NIRS Detection of Transient Hyperemia After Single Skeletal Muscle Contractions.

Ronald MEYER[1], Kevin MCCULLY[2], Robert W Reid[3], Barry Prior[3]
[1]Michigan State University, Department of Physiology, East Lansing, MI USA; [2]University of Georgia, College of Education, 115F Ramsey Center, Athens, Georgia United States; [3]Michigan State University, Dept. of Physiology, East Lansing, MI USA;

Introduction

Previous studies show that transient increases in limb blood flow occur after single muscle contractions (1), and one preliminary report (2) suggests that this transient hyperemia is associated with a BOLD (Blood-Oxygenation-Level-Dependent) effect in muscle. While BOLD effects have been reported in skeletal muscle during ischemia and reactive hyperemia (3), these effects have not been exploited in functional muscle studies. Instead, functional MRI studies of muscle have typically relied on the larger but more slowly developing increase in muscle T2 associated with the accumulation of osmotically-active metabolites during repetitive exercise (4).

In this study we confirm, using both MRI and near infrared spectroscopy (NIRS), that a transient increase in muscle oxygenation develops within seconds after single, one second duration muscle contractions. This muscle BOLD phenomenon can be used to map the location of recruited muscles using standard functional MRI cross-correlation analysis, and might be exploited as a simple, non-invasive test of peripheral vascular reactivity.

Methods

Subjects (6 female, 4 male, age 19-46 yrs.) were positioned supine, with the foot firmly taped to a rigid isometric force transducer. One-shot gradient-echo echo-planar images (TR 2000, TE 40, 90 degree pulse, 16 cm field-of-view) were acquired from a single axial slice transecting the belly of the anterior tibialis muscle via a standard linear extremity coil on a GE Horizon system (GE Medical Systems, Milwaukee, WI). Images were continuously acquired for 5.5 min (165 images). Subjects performed a 1 second duration maximum isometric ankle dorsiflexion every 30 seconds, using the scanner sound as an aural cue (i.e., contract after every 15th ping). In subsets of three subjects, this protocol was repeated, using either a spin-echo echo-planar sequence (same TR/TE), or using gradient-echo with TR 500 (480 images). After application of a 2D motion correction algorithm (5), signal changes in the anterior tibialis muscle were computed from a 2-3 cm2 region-of-interest, with care taken to exclude resolved vessels. Finally, the specificity of the response to the anterior compartment muscles was examined by applying a cross-correlation analysis of voxel intensities vs. a smoothed, pulsatile waveform.

In a separate series of experiments (conducted in GA), five subjects (2 female), performed the same contraction sequence (1 s contractions at 30 s intervals), while NIRS sum and difference spectra (760 and 850 nm) were recorded at 2 Hz from the anterior lower leg on a Runman CW2000 (Nim Inc., Philadelphia, PA.).

Results

Figure 1 shows the image intensity averaged across a region-of-interest within the anterior tibialis muscle of one subject. Similar results were obtained in 9 of the 10 subjects (mean signal increase 2.4±0.4 %, n=10). Figure 2 shows the NIRS difference signal (a measure of hemoglobin saturation) acquired from the anterior muscles of another subject during the same protocol. The time course of the response measured by the two methods was similar:

	MRI (n=10)	NIRS (n=5)
Time to Peak (s)	8.0±0.6	9.5±0.5
Recovery Half-Time (s)	4.3±0.7	5.8±0.7

There was no significant increase in the magnitude of the MRI response when TR was reduced from 2000 to 500 ms, suggesting that it does not arise from inflow effects per se. There was also no significant change in the magnitude of the MRI response using the spin-echo vs. gradient-echo methods, provided that large venous structures were excluded from the region-of-interest. In all cases, cross-correlation of the gradient-echo results confirmed that the change was confined to the anterior compartment muscle and its draining veins.

Discussion

These results confirm that a BOLD response can be measured in skeletal muscle after single, very brief contractions. The delayed time course of the response suggests that it arises from reflex vasodilatation, and not simply from the mechanical effect of the contractions. The response can be used to map the location of active muscle using methods identical to those commonly used in brain functional MRI studies. In contrast to the T2 increase observed in muscle after moderate to intense exercise, the BOLD response occurs during extremely light exercise, and therefore may be more suitable for studies of patients for whom intense exercise is not advisable. Furthermore, insofar as the response reflects reflex vasodilatation, it might be exploited as an simple, non-invasive test of peripheral vascular reactivity in diabetic and other patients.

References

1. Brock RW, et al, J. Appl. Physiol. 85: 2249-2254, 1998.
2. Hennig J, et al, Intl. Soc. Magn. Reson. Med. 8th Ann. Meet., p122, 2000.
3. Donahue KM, et al, JMRI, 8: 1106-1113, 1998.
4. Meyer RA, et al, Ex. Sport Sci. Rev. 28: 89-92, 2000.
5. Cox RW, Comput. Biomed. Res. 29: 162-73, 1996.

Figure 1 MRI Signal Intensity

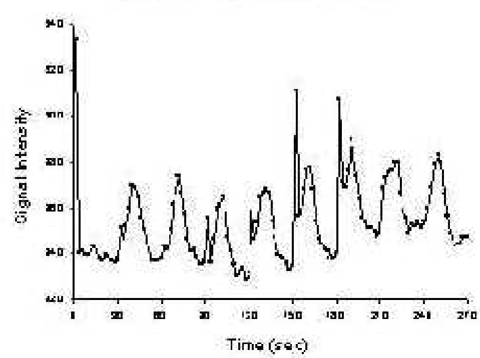
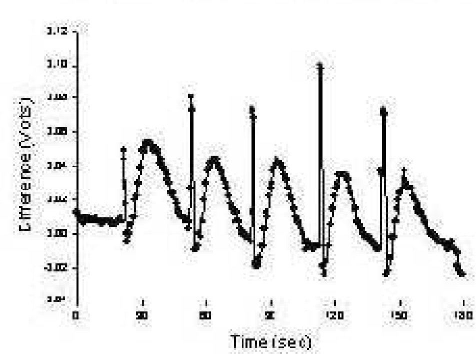


Figure 2: NIRS difference (relative Hb saturation)



Figures