Dual Gradient-Echo Imaging of Ischemia/Reperfusion in Skeletal Muscle

B. M. Damon[1,2], J. L. Hornberger[2], J. A. Kent-Braun[3]

[1]Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, United States, [2]Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States, [3]Exercise Science, University of Massachusetts, Amherst, MA, United States

Introduction

Transient MRI signal intensity (SI) increases can be observed after brief isometric contractions (1, 2, 3) and are potentially useful in examining changes in vascular function due to training (3), aging, and disease. Although these increases have been shown to relate to the degree of occlusion during a contraction (1), blood flow measurements made using strain-gauge plethysmography (1), and post-exercise blood oxygenation changes (2), their exact mechanism is unknown. One potential reason for this uncertainty is that the studies reporting these SI transients have used different imaging parameters. The purpose of this study was to test the hypotheses that 1) gradient-echo signals acquired using a short echo time (6 ms) would be more strongly associated with changes in blood volume and 2) gradient-echo signals acquired using a long echo time (46 ms) would be more strongly associated with changes in blood oxygenation (*i.e.*, the BOLD effect).

Methods

After providing written informed consent, four healthy subjects (3 male; age 21-40 years) were tested on two occasions. On each day, the subjects lay supine with the leg elevated slightly above the heart. A blood pressure cuff was placed around the thigh and inflated to 240 mmHg using a rapid cuff inflator (Hokanson, Bellevue WA). The duration of blood flow occlusion was 5 min. On one day, MR images were obtained at the maximum cross-sectional area of the anterior tibialis (AT) muscle using a 3T Philips Achieva MR imager/spectrometer and an 8-channel SENSE knee coil. Dual gradient-echo echo-planar images (repetition time/echo time/flip angle = 1000 ms/6, 46 ms/90º) were obtained for 30s before, during, and 150s after cuff occlusion. On a different day, near infrared spectroscopy (NIRS) measurements of total hemoglobin concentration and oxyhemoglobin saturation ([TotalHb] and %OxyHb, respectively) were acquired from the same location on the AT using an ISS (Champaign IL) oximeter.
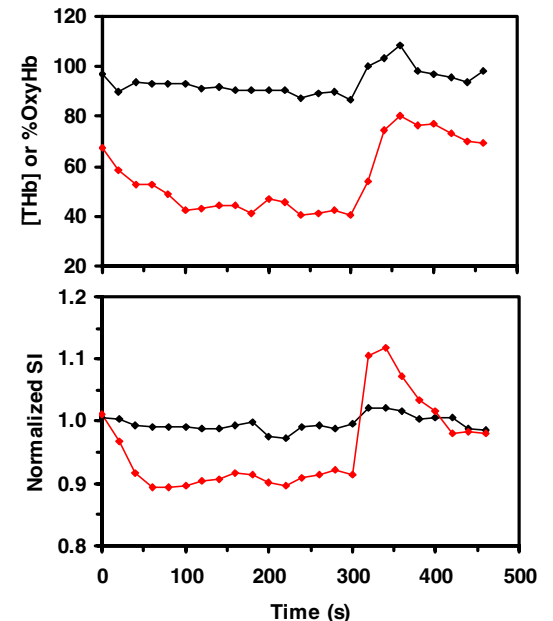
A region of interest was drawn in the AT muscle and the mean SI values for the 6 and 46 ms echoes (SI_{6ms} and SI_{46ms}, respectively) were normalized to the baseline SI value. The MRI and NIRS data were characterized at intervals of 20 s. To avoid spuriously low correlations caused by the plateau of MRI and blood parameters during the last 3 min. of ischemia (Figure 1), datasets comprised of the first 120s of ischemia and the post-ischemia hyperemia were formed. The correlations among [THb], %OxyHb, SI_{6ms} and SI_{46ms} were calculated. The correlations of [THb] with SI_{6ms} and SI_{46ms} were also calculated for the hyperemic period, when the greatest dynamic range of [THb] existed. The correlations were calculated separately for each subject, to account for apparent variations in the [THb] resulting from variations in subcutaneous fat layer thickness.

Results

Typical time courses for the MRI and NIRS data are shown in Figure 1. [THb] did not change significantly from baseline during the ischemic period but increased significantly by 13.6 (SD 2.4)% during hyperemia. Similar behavior was observed in the SI_{6ms} data, which was unchanged during ischemia but increased significantly by 4.8 (SD 3.3)% during hyperemia. More dramatic changes were seen in %OxyHb, which decreased by 23.6 (SD 12.4)% during ischemia and increased by 15.5 (SD 7.1)% during hyperemia. Similarly, SI_{46ms} decreased by 11.4 (SD 6.2)% during ischemia and increased by 8.7 (SD 4.4)% during reperfusion. The correlations among the signals are presented in Table 1. When only the hyperemic period was considered, the correlation of [THb] with SI_{6ms} increased to 0.60 (SD 0.20), while the correlation of [THb] with SI_{46ms} remained low (0.40 SD 0.34).

Discussion

The signal behavior of the 6ms echo was similar to the behavior of [THb] during and following suprasystolic cuff occlusion, while the signal behavior of the 46ms echo was similar to the changes in %OxyHb. Significant correlations between pairs of NIRS and MRI variables were observed. Overall, these data support the hypotheses that short gradient-echo signals reflect changes in blood volume during and following periods of blood flow occlusion, while long gradient-echo signals reflect changes in blood oxygenation. These conclusions are consistent with the expected contributions of changes in blood volume and oxygenation to T_1- and T_2*-weighted signals, respectively.

Table 1. Correlations among blood parameters and short- and long-echo signals.

	SI_{6ms}	SI_{46ms}
[THb]	0.46 (SD 0.24)	0.66 (SD 0.30)
%OxyHb	0.48 (SD 0.14)	0.80 (SD 0.12)

References

1. Wigmore, et al. (2004). *J Appl Physiol* 97: 2385.
2. Meyer et al. (2004). *NMR Biomed* 17: 392.
3. Towse et al (2005). *J Appl Physiol* 99: 715.

Acknowledgements

Figure 1. Typical NIRS (top panel) and MRI (bottom panel). NIRS data: [THb] shown in black and %OxyHb shown in red. MRI data: SI_{6ms} shown in black and SI_{46ms} shown in red.