Post-Contractile Blood-Oxygenation Level Dependent (BOLD) Contrast in Skeletal Muscle at 7T

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Target Audience

Muscle physiologists and imaging scientists interested in muscle functional MRI and imaging at 7 Tesla.

Introduction

Post-isometric contraction proton density and T_2*-weighted signal transients acquired at 3T have been used to characterize muscle microvascular function in both the normal (1-4) and pathologic (5,6) states. At 7T, muscle BOLD contrast is expected to be more influenced by extravascular BOLD mechanisms than is observed at 3T, where muscle BOLD contrast is dominated by intravascular mechanisms (1,5,7). Therefore, if similar exercise paradigms could be translated to 7T, then BOLD-sensitive data might be made sensitive to different or greater levels of contrast. The purpose of this study was to evaluate the feasibility of using BOLD-sensitive data, acquired at 7T, to assess the physiological responses to *in vivo* muscle exercise.

Methods

Four subjects (2 females), aged 31.3±9.6 years, 172.1±6.4 cm tall with a body mass of 63.4±12.3 kg, participated in the study. All subjects gave written informed consent in accordance with the local Institutional Review Board prior to participation. All subjects were free from physician-diagnosed chronic disease. Subject reported to the lab on two occasions, which included a habituation session and an experimental testing session. On the initial visit, subjects read and signed the informed consent document, completed a health-history questionnaire and a magnetic materials safety screening form. Subjects were familiarized with the exercise procedures and his/her maximum isometric plantarflexor contraction force was measured. *MRI procedures:* Scanning was performed on a Philips 7T scanner using a transmit/receive volume coil. The subject was positioned supine in the scanner with the largest portion of their calf muscle positioned in the center of the coil. The subject foot was secured in a custom-built MR-compatible exercise device capable of measuring plantarflexion force. Localizers and high-resolution anatomical images were acquired for planning purposes. Functional images were acquired continuously for 14 mins (multi-shot, turbo field echo, echo-planar images (TFE-EPI) *TR*/*TE* 1000/18 ms, 64x64, 10 mm slice thickness) while the subjects performed 7, 2-s maximal isometric plantarflexior contractions every 2 mins. Two subjects repeated the exercise protocol at a *TR* of 2500 ms to determine if inflow effects influenced the magnitude of the post-contractile BOLD response. Force data were acquired continuously during the exercise protocol and each subject received feedback after each contraction regarding the level of contraction force. *Data Analysis:* Images were analyzed in Matlab (The MathWorks®, Cambridge, MA) using custom written code. Regions-of-interest (ROI's) 2-3 cm^2 in size were drawn in the soleus muscle with care to exclude resolved vessels and connective tissue. Peak signal intensity (SI) was calculated as the highest percentage increase from baseline, excluding the movement artifact, see Fig. 2, left panel. For each post-contractile transient the baseline was taken as the average SI in the 5 s prior to the contraction. Muscle force was calculated as the highest force achieved during each contraction.

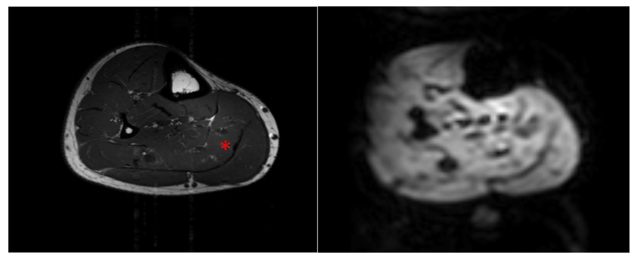

Figure 1: High-resolution anatomical (left) of a subject's right leg at mid calf and a corresponding functional (right) image acquired at the same anatomical location. ROI's (2-3 cm^2) were drawn in the soleus muscle (*) with care to avoid resolved vessels.

Results and Discussion

Post-contractile BOLD transients on the order of 3-5% peak change were observed in the soleus muscles following a 2-s maximal isometric plantarflexion contraction. Although preliminary (n=2), the magnitude of the response does not appear to be different when acquired at a *TR* of 1000 ms versus 2500 ms (4.36 ± 0.8 vs. 4.27 ± 0.9 %, respectively), which is consistent with previous reports at lower field strengths (1). The force during the two exercise protocols was similar (647.6±48.7 and 664.4±41.3 N for *TR*=1000 and *TR*=2500 ms, respectively).

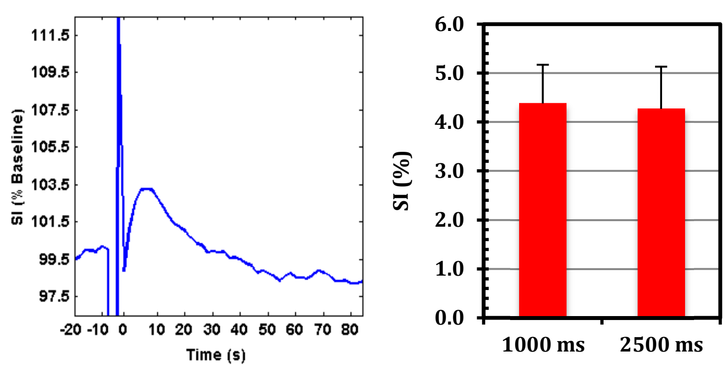

Figure 2: Typical post-contractile BOLD transient (left) measured in the soleus muscle following a 2-s maximal isometric plantarflexion. Spikes in SI are motion artifacts that occur during the muscle contraction. Peak post-contractile responses (right, % above baseline, n=2) acquired at *TR*s, 1000 & 2500 ms.

Conclusions

Studies of the BOLD responses to muscle contractions are feasible at 7T and may afford greater insight into microvascular dysfunction by offering greater specificity to microvascular-scale structures and a higher contrast-to-noise ratio than are achieved at lower field strengths. Preliminary data do not support the existence of an inflow effect on the magnitude of the post-contraction BOLD response.

References

1.) Meyer RA et al, *NMR Biomed* 17:6(2004): 2) Wigmore DB, et al, ,*J App Physiol*, 97:6(2004) [3] Towse TF, et al, *J App Physiol*, 111:1(2011); 4) Damon BM, et al, *MRM* 57:4(2007): 5) Slade JM, et al, , *J App Physiol*, 111:5(2011); [6] Sanchez OA, et al, *Am J Physiol Heart Circ Physiol*, 301:2(2011): [7] Sanchez OA, et al, *MRM*, 64:2(2010)