The BOLD effect in upper leg muscles from leg extension exercise using an MRI compatible ergometer

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Introduction:

Blood oxygen level dependent (BOLD) imaging has been applied by many groups to assess skeletal muscles before and after exercise **[1]**. Most in-magnet BOLD exercise evaluations are carried out on the calf muscles, probably due to the ease of exercising these muscles in a confined space. However, since muscle biopsies are commonly taken from the quadriceps to investigate their bioenergetics, a thigh MRI compatible ergometer is a valuable non-invasive tool to evaluate muscle metabolism. We used an MRI compatible ergometer (Lode B.V., Gorningen, The Netherlands) with an up/down exercise build set, to allow the quadriceps to be exercised during MR scanning (**Fig.1**). Since the subject must be in a supine position to exercise in the scanner, we sought to investigate the recruitment of the four heads of the quadriceps femoris in supine ergometer exercises. Specifically, we observed the BOLD signal in the four muscle groups before and after unilateral leg extension exercise using the MRI compatible ergometer to determine the activation pattern in each of the muscles.

Methods:

Scanning was performed using a GE Signa HD 3T short-bore MR scanner and a single channel general-purpose flexible coil (GE Healthcare, Milwaukee, WI). Following localization and the acquisition of anatomical images, three T2*-weighted BOLD slices were collected using a single-shot GRE-EPI sequence (TE/TR =35/250ms, 10mm thickness, α=70°, 64x64 matrix, 1440 time points). The BOLD slices were acquired of the midthigh (located at 50% of the distance from the femoral condyles to the iliac crest) before, during and after an in-magnet exercise protocol using the Lode ergometer. Healthy male subjects (n=3, 28±5 years old) were scanned in the supine position. The dominant thigh of each subject was placed in the ergometer such that it was positioned at 15° relative to Bo. The BOLD imaging protocol consisted of 1 minute of rest, followed by 2 minutes of an intense unilateral supine thigh extension exercise at 50% of the subject's maximal power output and ended with 3 minutes of recovery. A test was performed a few days before the scan to determine the subject's maximal power output for the exercise. Regions of interest (ROIs) from the four heads of the quadriceps femoris were selected using AFNI **[2]**. An in-house program written in Matlab (The MathWorks, Natick MA) was used to extract the data in the ROIs and analyze the BOLD timecourses.

Results and Discussion:

Fig.2 shows an axial slice of the four muscles that were investigated in this study. The BOLD timecourse from two muscle groups, one that showed recovery and one that did not, is shown in **Fig.3**. Percent change in the base-peak signal intensity for the muscles that were activated was calculated and is given in **Table.1**. For all three subjects, the vastus lateralis muscle was not involved in the thigh extension exercise, since the BOLD timecourse did not show a recovery peak following the exercise. The highest activated groups were the vastus intermedius and the rectus femoris muscles, as they had the greatest base-peak signal change. In two of the subjects, the vastus medialis was also involved in the exercise; however, it was not activated to the same extent as the lateralis and intermedius.

Conclusion:

Recruitment of the four heads of the quadriceps femoris in supine thigh extension exercise was investigated using an MRI compatible ergometer. It was noticed that the four muscles were non-uniformly activated, and that the RF and VI played the greatest role in the exercise. Thigh extension, if performed with the foot straight, is expected to activate the middle portion of the quadriceps (RF and VI), as was observed here. Since the VM of 2 subjects was also recruited, it is postulated that the foot of these subjects may have been angled slightly outwards, thus, the inside of the quadriceps (VM) was worked by the exercise. Further testing will be conducted to determine if the various foot placements are responsible for the non-uniform patterns of activation.

References:

[1] Noseworthy *et al.* (2010) *Semin Musculoskelet Radiol* 14:257-268 **[2]** Cox. (1996) *Comput Biomed Res* 29(3):162-73

Fig.1: MRI compatible Lode exercise ergometer

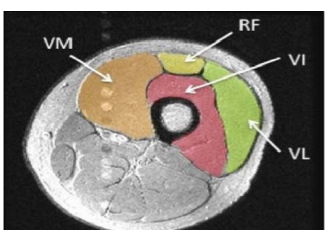

Fig.2: Anatomical slice through the left thigh. Muscles shown: vastus medialis (VM), rectus femoris (RF), vastus intermedius (VI), and vastus lateralis (VL)

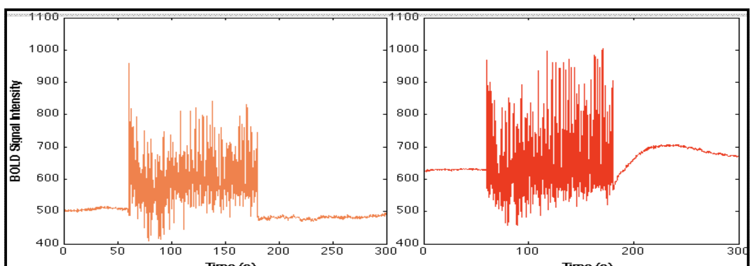

Fig.3: Sample BOLD time series from a muscle that was not recruited in the exercise (orange) and one that was activated and recovered after the exercise (red).

	VL		VM		RF		VI	
	Base-peak signal change (%)	Recovery time (s)	Base-peak signal change (%)	Recovery time (s)	Base-peak signal change (%)	Recovery time (s)	Base-peak signal change (%)	Recovery time (s)
Subject								
1	N/A	N/A	15.2	66.5	23.8	116.2	25.9	81.0
2	N/A	N/A	14.8	48.0	22.7	99.4	29.8	69.0
3	N/A	N/A	N/A	N/A	37.6	98.7	23.4	45.0

Table 1: Percent change in the base-peak signal in the four quadriceps muscles, along with recovery times. N/A indicates that the muscle did not show any recovery.