Time resolved observation of BOLD effect in muscle during isometric exercise

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Introduction

The BOLD-contrast mechanism arises from the change of blood oxygenation during cortical activation as a consequence of the increased arterial blood supply, which is most likely due to the increased oxygen demand. It has been originally suggested for the observation of neuronal activation (1). Recently it could be demonstrated, that changes in blood oxygen level can also be used for the observation of myocardial perfusion. In skeletal muscles an increase in perfusion as been observed by Frank using arterial spin label (ASL) techniques (2). The purpose of this study was to demonstrate, whether a BOLD-effect arises during muscle exercise and to assess its temporal signature.

Methods

All experiments were performed on a 1.5T system (Siemens Magnetom Symphony) equipped with ultragradients (20 mT/m, 40 T/m/s risetime). A fat suppressed single slice EPI-sequence with TE = 49 ms, matrix size 64x64 and FOV=18 cm with outer volume suppression in order to reduce signals from large vessels and to minimize inflow effects was used.

The BOLD signal was observed on muscles of the lower leg. Both lower legs where placed in the standard head coil. Fixation of the legs was achieved by placing the feet on a footrest and fixing the knee at a holder with an approximate bending angle of 15 degrees. Muscle exercise was performed by selfpaced isometric tension of the soleus and gastrocnemicus groups. Exercise was always performed in one leg only. 6 Experiments have been performed so far.

For block paradigms the EPI-experiment was performed with a repetition time of 3s. Muscle tension was performed in the intervals between subsequent scans in order to minimize motion artifacts. For single event observation, a TR of 1 s was chosen in order to achieve appropriate time resolution. Muscle tension was performed for 3s, images acquired during exercise were discarded.

For data evaluation spatial smoothing was applied in order to reduce the artifacts arising from residual displacement. Signal time courses were observed in areas of homogeneous signal intensity as a further precaution against motional effects.

Examinations with severe motional displacement were discarded from further evaluation.

Results

Fig.1 shows signal time courses from one subject in the soleus muscles (2) compared to signal from anterior muscles (1), which were

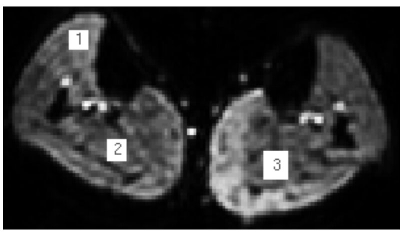
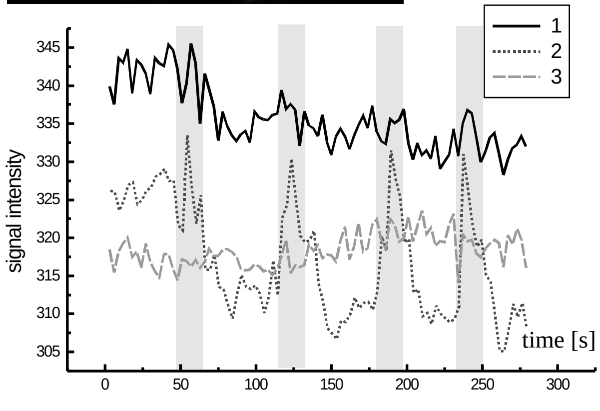


Fig.1 EPI-image (left) and BOLD-signal time courses during isometric muscle exercise (shaded areas).



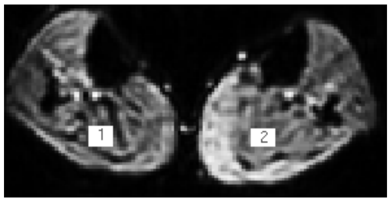
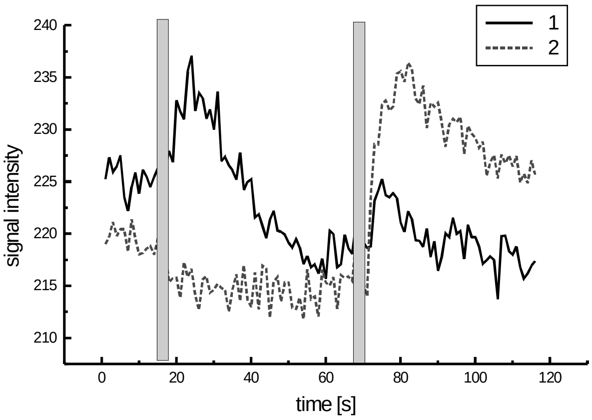


Fig.2 'single event'-experiment with alternating exercise in the right(1) and left(2) leg.



not used in the exercise and from the contralateral resting leg (3). A signal increase during the exercise is clearly demonstrated.

The results from a single event paradigm is shown in Fig.2. Muscle tension was performed in alternation on the right and left leg. The residual response in the right leg after the second exercise is probably due to imperfect lateralization of the task performance.

Discussion

It is not unexpected, that the increased oxygen demand during muscle exercise leads to a BOLD-effect reflected the locally increased blood flow. In view of the significant difference in energy metabolism between muscles and cortical tissue it is nevertheless somewhat surprising, that the inherent time constants of the hemodynamic response are very similar. Further examinations are required in order to assess, whether this is an intrinsic feature caused by a common mechanism, by which the hemodynamic response is linked to the local oxygen demand or whether this is a purely coincidal result of different regulatory mechanisms.

Conclusion

The feasibility of observing time resolved BOLD-effects in muscles has been demonstrated. The preliminary nature of this feasibility study forbids farreaching conclusions about possible applications. Apart from the possible impact of such studies to the examination of regulatory mechanisms of the hemodynamic response it is tempting to speculate about possible practical applications for examinations of muscle physiology (i.e. in combination with time resolved 31P-spectroscopy). Potential clinical applications include examinations on patients with vascular disease and in sports medicine. Such applications will certainly require more sophisticated fixation device and external stimulation (i.e. with electrodes) to improve the reproducibility and reliability of the exercise.

References

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(1) Frank LR, Wong EC, Haseler LJ, Buxton RB. Dynamic imaging of perfusion in human skeletal muscle during exercise with arterial spin labeling. Magn Reson Med 1999 Aug;42(2):258-67