Relaxation time mapping in skeletal muscle during reactive hyperemia

M. Klarhöfer[1], P. Madörin[2], and K. Scheffler[1]

[1]MR-Physics, Department of Medical Radiology, University of Basel, Basel, Switzerland, [2]Department of Medical Radiology, University Hospital Basel, Basel, Switzerland

Introduction

MRI studies on reactive hyperemia (RH) result in consistent signal changes in T_2 or T_2^* weighted images (1-3). However, a recent publication showed that measured BOLD signal changes depend on initial vascular filling (4). In contrast, simultaneously performed ASL perfusion measurements did not show this dependency. It was therefore concluded that care has to be taken when interpreting BOLD signal changes because they may depend on many factors which are not yet fully understood. To obtain further information on the origins of the measured BOLD signal changes, the purpose of the present study was the dynamic measurement of the relaxation times T_1, T_2 and T_2^* during an ischemia/reactive hyperemia protocol on the human calf. T_1 measurements were performed after global inversion, therefore actual longitudinal relaxation time was measured instead of an inflow weighted T_1,app acquired after slice selective inversion.

Materials and Methods

5 healthy volunteers participated in this study. Short-term ischemia and reactive hyperemia were provoked by a cuff-compression paradigm (Fig.1). A conventional leg sphygmomanometer was fixed at mid-thigh level of the right leg. Cuff-compression with a pressure of 50 mm Hg above the individual brachial systolic blood pressure was applied during the ischemic phase for 5 minutes. MR experiments were performed on a whole body 1.5 Tesla system (Avanto, Siemens Medical, Erlangen, Germany). Subjects were lying in supine position for at least 15 minutes prior to the compression paradigm. Coronal and sagittal TrueFISP imaging was used to localize the largest extension of the calf. At this position the following dynamic parametric imaging was performed on both calfs: FOV of 380 x 238 mm^2, matrix size: 192x144, inplane spatial resolution: 2x2.6 mm^2, slice thickness: 6mm for T_2 and T_2^* experiments and 8 mm for the T_1 experiment. To avoid inflow effects in the T_2 and T_2^* experiments, saturation bands of 100 mm thickness were positioned in parallel on both sides of the imaging slice. A multi-echo spin-echo sequence with the following parameters was used for T_2 measurements. TR=900ms, TE=13.1, 26.2, 39.3, 52.4, 65.5, 78.6, 91.7, 104.8 ms, acquisition time: 85 seconds. T_2^* was measured using a segmented multi-echo EPI sequence with α=30°, TR=120ms, TE=13.0, 34.8, 56.6, 78.4ms, acquisition time: 11 seconds, fat saturation. For T_1 measurements a segmented inversion recovery snapshot-FLASH sequence was used. After a first inversion, all even lines of 12 consecutive images with effective inversion times of TI=110, 285, 460, 634, 809, 983, 1158, 1333, 1507, 1682, 1856, 2031ms were acquired. This first segment was followed by 10 seconds of recovery period before a second inversion was applied after which all odd k-space lines were acquired. This acquisition scheme allowed a closer spacing of the inversion times and higher spatial resolution than a single inversion technique after which all necessary data is acquired. Global inversion pulses were used in order to measure actual tissue T_1 and not an apparent T_1 affected by inflow effects.

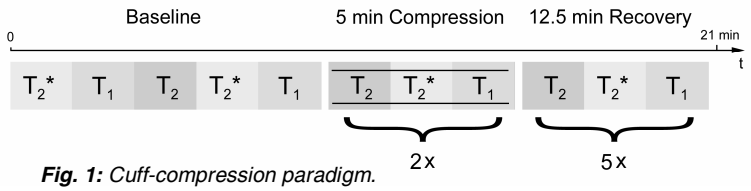

Fig. 1: *Cuff-compression paradigm.*

Results

Acquired spatial resolution allowed exclusion of large vessels from the ROI analysis. Fig. 2 shows the time courses of T_1, T_2, T_2^* and I_0 (obtained from T_2^* fit) averaged over ROIs in three different muscle groups and over all 5 volunteers. No significant changes in T_1 were observed. The expected increase in T_2 and T_2^* during RH was found in soleus and gastrocnemius muscles. M. tibialis exhibited only slight changes. The calculated initial signal intensity I_0 is dominated by spin density since inflow effects are minimized by saturation bands. It dropped significantly during ischemia but did not exhibit a strong overshoot during RH that is present for T_2 and T_2^*.

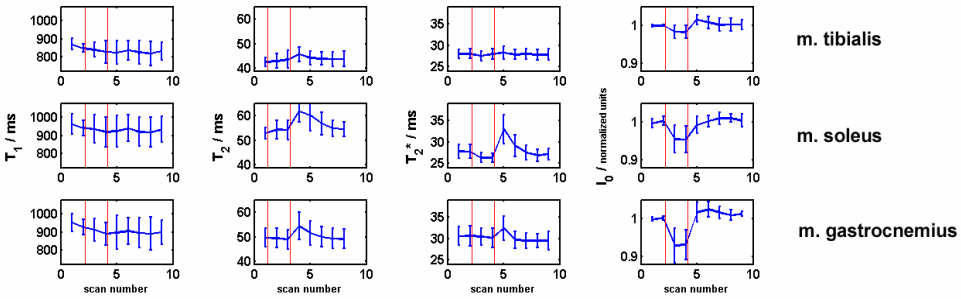

Fig. 2: *Time courses of relaxation parameters obtained in different muscle groups.*

Discussion

T_2 and T_2^* time courses showed the expected behavior during ischemia and reactive hyperemia. No paradigm related changes in T_1 were observed. The reduced I_0 during ischemia can be explained with a lower blood volume and therefore lower spin density. The pressure applied during cuff-compression possibly did not fully prevent venous outflow. The lack of an overshoot of the initial intensity after release of the cuff-compression excludes a short term increase of blood volume as a reason for the longer transversal relaxation times observed during RH. This demonstrates that not only relaxation times but also the initial intensity, should be considered in the evaluation of dynamic relaxation studies of reactive hyperemia. However, for a more complete understanding of measured signal changes during RH perfusion data seem to be essential.

References

1. Donahue KM, Van Kylen J, Guven S, El-Bershawi A, Luh WM, Bandettini PA, Cox RW, Hyde JS, Kissebah AH. Simultaneous gradient-echo/spin-echo EPI of graded ischemia in human skeletal muscle. J Magn Reson Imaging 1998;8:1106.
2. Lebon V, Brillault-Salvat C, Bloch G, Leroy-Willig A, Carlier PG. Evidence of muscle BOLD effect revealed by simultaneous interleaved gradient-echo NMRI and myoglobin NMRS during leg ischemia. Magn Reson Med 1998;40:551.
3. Ledermann HP, Heidecker HG, Schulte AC, Thalhammer C, Aschwanden M, Jaeger KA, Scheffler K, Bilecen D. Calf Muscles Imaged at BOLD MR: Correlation with TcPO2 and Flowmetry Measurements during Ischemia and Reactive Hyperemia--Initial Experience. Radiology 2006;241:477.
4. Duteil S, Wary C, Raynaud JS, Lebon V, Lesage D, Leroy-Willig A, Carlier PG. Influence of vascular filling and perfusion on BOLD contrast during reactive hyperemia in human skeletal muscle. Magn Reson Med 2006;55:450.