Functional ^{31}P-MR Chemical Shift Imaging in Lower Back Muscles During Isometric Load

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Target audience Researchers in MR physics and physiology

Purpose Muscular fatigue is influenced by several physiological factors [1,2]. One important reason of this phenomenon is the limited ability to supply sufficient ATP for the muscle activity [3]. Functional ^{31}phosphorus (^{31}P) magnetic resonance spectroscopy represents a unique opportunity to estimate *in vivo* high-energy phosphate metabolism non-invasively [4,5]. In general, ^{31}P-MRS spectra of skeletal muscles exhibit seven resonances as shown in Fig. 1. Intracellular pH values can be estimated by the chemical shift of the Pi peak [5]. Chemical shift imaging (CSI) can be applied to obtain localized multi-voxel ^{31}P-MR spectra with respect to the underlying anatomy. The aim of this study was to demonstrate the feasibility of applying ^{31}P-CSI in lower back muscles in volunteers during an isometric load to detect and quantify changes of PCr, Pi and pH.

Methods Functional ^{31}P-MRS data were acquired in 14 healthy volunteers (male, 20-30 years old) using a clinical 3 T whole-body MR scanner (TIM Trio, Siemens Healthcare, Erlangen, Germany). Images acquired to determine and optimize the position of the spectroscopic volume as well as MRS data were all collected with a flexible double-tuned ^{1}H/^{31}P transmit/receive coil (RAPID Biomedical GmbH, Würzburg-Rimpar, Germany) with the volunteers in prone position. All ^{31}P-MR spectra were acquired in coronal direction at the height of the intervertebral disk L3-L4. In order to obtain MR spectra of voxels covering the inner (*M. multifidus*, MF, blue) and outer (*M. erector spinae*, ES, white) region of the lower back muscles, the CSI slice was aligned to the spine (illustrated in Fig. 2). CSI-FID data (8 × 8 voxels with a size of 30 × 30 × 25 mm³, TR = 920 ms) were acquired with an initial temporal resolution of TA = 26.9 s. A series of CSI acquisitions was acquired prior (n = 22), during (n = 20) and post exercise (n = 36). The exercise was performed over a time period of 10 min and was arranged as a modified Sørensen test [5]. A MR-compatible ergometer including an adjustable counterweight was used to support the subjects with 50 % of their upper body weight. For post-processing a MATLAB routine was applied, including frequency-, phase- and baseline-correction, averaging of two voxels in H-F direction (see red coloured voxels in Fig. 2) and averaging by a sliding-window procedure. The latter was performed with a kernel size of 5 dynamic measurements of the time course of the MRS data. Finally, spectra were quantified using "Amares" (www.mrui.uab.es). Mean PCr and Pi intensities in rest, minimum PCr and maximum Pi intensity during exercise as well as pH values [5] were determined for each subject.

Results Fig. 3 illustrates the typical time course of ^{31}P-MR spectra for a single CSI voxel in the lower back muscle. Significant changes were observed at 4.9 ppm (increasing Pi) and at 0 ppm (decreasing PCr), while the ATP resonances remained essentially constant. Mean values of the quantitation results of all spectra are summarized in Tab. 1 and shown Fig. 4. The latter illustrates the time courses of PCr and Pi which yield increasing SDs during exercise. Furthermore, due to sliding window averaging an early PCr decrease and Pi increase is detectable. Compared to mean pH values at rest (7.04 ± 0.05) no significant changes of pH values during load were observed.

Discussion and Conclusion This work demonstrates the feasibility of performing functional ^{31}P-CSI in lower back muscles to analyse load-induced changes of phosphorus metabolites. Increased SDs of quantified PCr and Pi intensity is assumed to reflect inter-individual differences for metabolic changes and thus for varying degrees of muscle fatigue. Future studies will compare these results to the results of patients suffering from chronic back pain.

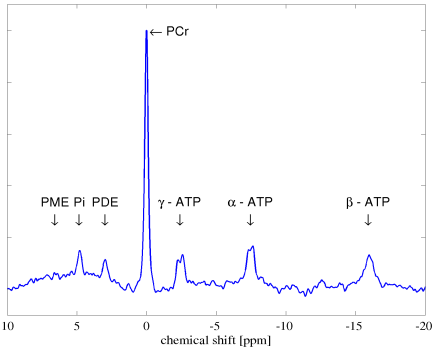

Fig. 1 *Mean baseline ^{31}P-MR spectrum of a single CSI voxel (right MF, blue box in Fig. 2).*

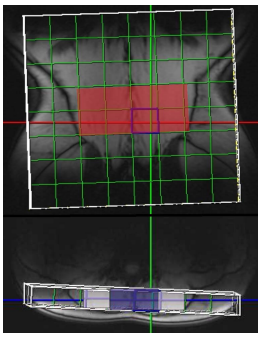

Fig. 2 *Location of CSI slice (red coloured voxels cover the muscle-related ROIs).*

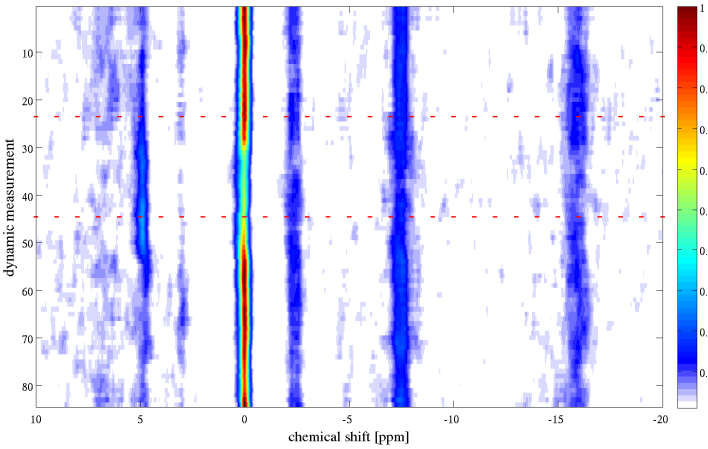

Fig. 3 *Time course of spectra acquired in the left MF of a single subject. Intensities were normalized to mean PCr intensity in rest. Dashed red lines mark the beginning (n = 22) and end (n = 43) of exercise.*

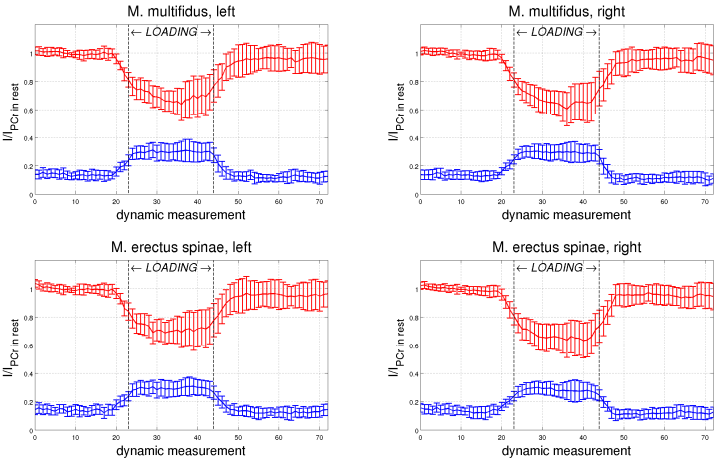

Fig. 4 *Mean time courses of PCr and Pi intensities determined in lower back muscles for 14 subjects. The error bars indicate the SD.*

Tab. 1 *Metabolic changes (mean ± SD) during load.*

ROI	min PCr [%]	max Pi [%]	min pH [a.u.]
left ES	37.4 ± 11.7	18.7 ± 6.5	6.92 ± 0.08
left MF	38.8 ± 12.6	19.9 ± 6.5	6.92 ± 0.08
right MF	39.5 ± 13.9	20.1 ± 6.7	6.91 ± 0.09
right ES	37.6 ± 13.1	18.7 ± 6.6	6.92 ± 0.09

References

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