Depiction of muscle activation induced by Electromyostimulation in the calf muscle by using T2-weighted MRI at 3.0 T

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Target audience: Researchers in MR spectroscopy and muscle physiology

Purpose: Physiologic and metabolic adaptation processes in skeletal muscles on physical exertion can be suitable investigated by functional MRI and MRS. Observed changes are commonly correlated to the level of exercise and depends both on the muscular performance as well as on the motivation to give the maximum effort and the use of individual load sharing strategies between synergistic muscles, which are difficult to measure. In contrast, electromyostimulation (EMS) induced muscle activity is independent on motivation and individual motoric skills. Consequently the application of EMS to induce muscle contractions can be used to generate defined activation levels in distinct muscles. MR measurements can be negatively affected by unsuited electrodes with susceptibilities far from muscle tissue or by high-frequency interferences emitted by lead wires. However both sources of interference can be avoided by using carbonized rubber electrodes and low-pass filters[1]. Moreover, unlike voluntary contractions, the recruitment pattern of EMS-induced contractions does not follows the size principle order[2]. Furthermore it's not clear, which regions of muscles were stimulated by the electrodes. T_2-weighted MRI offers an opportunity to map muscle activation by the reduced T_2-relaxivity caused by a metabolic induced shifting between different water fractions within the muscles[3]. Generally our study aims to question whether EMS is suited for selective activations of distinct muscles. In particular our aim was to investigate by functional T_2-MRI whether activation is limited to the M. gastrocnemius also in the case of strong electric stimulations. The level of activation should be assessed by the PCr/Pi ratio, estimated by simultaneous performed ^{31}P-MRS and by decreasing pedal forces as a sign of fatigue.

Methods and Materials: Four healthy volunteers (m, 25-60y) were investigated within a 3T whole body sanner (Magnetom TIM TRIO, Siemens Healthcare) during an EMS-exercise (2 min). They were placed on a MR-compatible pedal ergometer, designed to perform dynamic contraction exercises of the human calf muscle[4] (Fig.1). Electrical stimulation was delivered by the stimulator (DS7A) and trigger generator (DG2, Digitimer Ltd. England). Stimulation was carried by pulse trains consisting of 500 s single pulses interrupted after 1s by breaks of 1s (Fig. 2). Electrodes (carbonized rubber, coated with a conductive gel) were placed underneath the Fossa poplitea and one on the bulg of the M. gastrocnemius. Stimulation intensity was set to pedal forces of ca. 50% of the maximum volitional isometric contraction (MVIC). A flexible double-tuned ^{1}H/^{31}P transmit/receive coil (size: 22x33 cm; Biomedical Rapid GmbH, Würzburg, Germany) fixed with velcro stripes around the calve was used for MRI (after) and ^{31}P-MRS (during stimulation). A 2D-EPI-SE sequence (TR:100 ms, TE:34-64 ms (N=6); VOV: 590 x 969 mm; N_{slice}:10) was used for T_{2w}-MRI and a 2D-CSI sequence (TR:290 ms; FOV: 352 x 200 mm; d:50 mm; matrix:8x8).

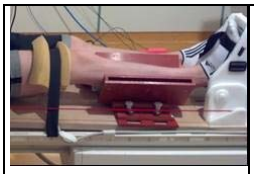

Fig. 1: Positioning of the right calf in the support frame of the pedal ergometer

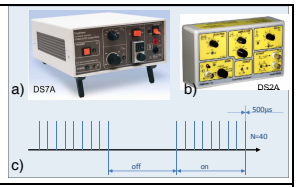

Fig. 2a-c: Stimulator (a), trigger generator (b) and sequence of pulse trains (c) consisting of 40 single pulses and 1 s duration

Results: The comparison of T_{2w}-MRI prior and after stimulation and the corresponding T_2-maps, estimated by means of the six TE, shows a clear delimited area of higher T_{2w}-intensity and T_2-map values, which beneath the electrode follows the contours of the M. gastrocnemius (Fig. 2a-e). As illustrated by Fig. 3a-e the high level of exercise intensity is indicated by the fast decrease of the pedal force and the strong depletion of PCr to ca. 60% of its initial value. However, data also indicate that the recovery starts already before the stimulation ends (Fig. 3e).

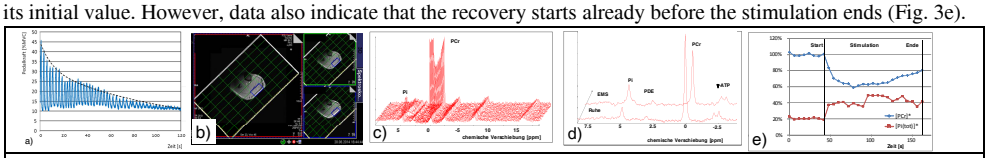

Fig. 3a-e*: Time course of EMS induced pedal forces (a) of an individual measurement, position of the 2D-CSI slice (b), Stackplot (c) and single spectra at rest and during stimulation (d) as well as time couses of the PCr- und Pi-Intensity during exercise (e)*

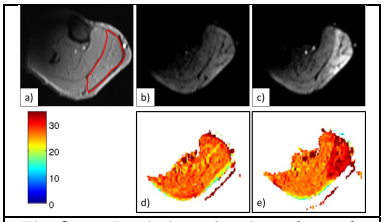

Fig. 2a-e: Depiction of activated muscle area by hyper intensity in T_{2w}-MRI (c) and higher T_2-values in the T2-maps (e) within the red marked region of medial M. gastrocnemius (a) prior (b, d) and after stimulation (c, e).

Discussion and conclusion

It's well known that PCr decrease in isometric exercise changes in proportion to the needed force[5]. A high strain level is indicated by the PCr decrease to 60% of its initial value, which is clearly below 80%, expected for constant work rates that can be sustained without a progressive depletion of muscle high-energy phosphates[6] and by the fast decreasing pedal force. However a declined excitability seems likewise affect the induced pedal forces indicated by the slight PCr increase before the expiry of 120s stimulation. As EMS-induced contractions does not follows the size principle order more large type II motor units are activated with higher anaerobic metabolic activities, a higher production of lactate and a higher acidification. These processes were expected to provide main contributions to osmotic effects causing shifts between intra- and extra-cellular water fractions as well as between different intra-cellular fractions (free and protein bounded), which is reflected by increased T2 values . The T_{2w} MRI as well as the T_2 maps indicates that these processes are only accelerated in the M. gastrocnemius and not in adjacent regions of the M. soleus. As the fiber type composition may vary across different muscles the possibility of selective activation of individual muscles is important for many experiments. Our experiments indicate, that EMS induced muscle activation not simply depends on the distance to the electrode but also on the muscle over that electrodes are placed and that EMS may be helpful for functional investigations of individual muscles.

References: 1. Russ, D. W., *et al.* 2002. Endocrinology and metabolism. 282: E448-457. 2. Gregory, C. M. & C. S. Bickel. 2005. Physical therapy. 85: 358-364. 3. Damon, B. M., *et al.* 2002. Magnetic resonance in medicine 47: 14-23. 4. Tschiesche, K., *et al.* 2014. Medical engineering & physics. 36: 933-937. 5. Witte, H., et al. 1997. Biomedizinische Technik. Biomedical engineering. 42 Suppl: 79-80. 6. Jones, A. M., *et al.* 2008. American journal of physiology. Regulatory, integrative and comparative physiology. 294: R585-593.