Changes in oxidative metabolism of skeletal muscle induced by loaded vibration exercise under vascular occlusion

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Introduction

Strength and endurance training have become major components in the daily routine of athletes and are indispensable tools in rehabilitation and prevention of functional disabilities of the musculoskeletal system. Such disabilities include sarcopenia, osteoporosis or lower-back pain as well as high blood pressure and malfunctioning of the glucose metabolism [1] and metabolic syndrome. These disorders are widespread in the population of industrial countries and are partly caused by a lack of physical activity. However, to improve training paradigms with regard to time-efficiency and effectiveness, it is important to understand the underlying molecular, cellular, and systemic adaptations. ***In this study***, we have developed a novel, highly efficient exercise paradigm that combines three modalities that are known to positively influence strength and endurance. Molecular, cellular, and systemic adaptations have been assessed by dynamic ^{31}P spectroscopy (Pi, PCr, pH, PCr recovery time after exercise), muscle biopsies (capillary-to-fiber ratio, fiber types and sizes), dual X-ray absorptiometry (DXA, total and segmental body composition), and by determining maximal oxygen consumption (VO_2max), lactate concentration, and related functional parameters such as peak power.

Materials and Methods

Our novel exercise training paradigm was composed of high-intensity (75-80% one-repetition maximum) resistance exercise, whole body vibration (WBV) and vascular occlusion. For the training regime, we used a multipower device (Technogym, Italy) to apply external load during squat and calf raise exercises, a Galileo® vibration platform (Novotec Medical, Germany) to induce WBV, and inflatable tourniquet cuffs (VBM Medizintechnik, Germany) to impose vascular occlusion. All three stimuli were applied concurrently. 21 female participants with a sedentary lifestyle were recruited, of which 12 (age: 23.5 yrs (SD 3.0), BMI: 21.6 (SD 2.6) kg/m^{-2}) and 9 participants (age: 24.5 yrs (SD 3.8), BMI: 21.8 (SD 1.7) kg/m^{-2}) were randomly assigned to the training and control group, respectively. Structural and metabolic muscle properties, VO_2max, blood lactate concentration and voluntary ”strength” output were assessed preceding and following 5.5 weeks of training. The training group completed 3 training sessions per week, each lasting 24 min. Muscle biopsy samples were obtained from the middle region of the soleus muscle. Fiber types and sizes were determined based on consecutive sections of muscle fibers stained for mATPase after alkaline and acid preincubations. The capillary-to-fiber ratio was calculated by dividing the number of CD31-positive cells by the number of muscle fibers. Body composition was assessed using DXA. In vivo ^{31}P spectroscopy measurements of the nondominant calf were performed at rest and during isometric force production at 85% (for 30 s) and 70% (for 120 s) of maximal voluntary force, using a custom-built ergometer [2]. All MRS measurements were performed on a 3T Philips whole-body magnet (Philips Healthcare, Best, the Netherlands) using a ^{31}P transmit/receive surface coil placed under the posterior compartment of the participant's lower leg. Spectra were acquired using a pulse-acquire technique and excitation was performed with an adiabatic BIR-4 pulse. Relaxed spectra were acquired using a repetition time of 16 s and 30 signal averages. Stimulation-Recovery experiments were performed using a TR of 1.5 s and 3 signal averages per time point, leading to a temporal resolution of 6 s. Five dummy scans were performed before 20 scans in the resting state were acquired. A 6 Hz apodization filter was applied prior to Fourier transformation of the FIDs. Millimolar concentrations of PCr and Pi were obtained by assuming a constant ATP concentration of 8.2mM. The level of significance for the statistical evaluations of the paired t-tests was set to 0.05.

Results and Discussion

Significant increases in capillary-to-fiber ratio (mean = 1.83±0.39PRE/ 2.09±0.47 POST, $p < 0.001$), calf lean mass (mean = 1.699±0.264 kg PRE/ 1.803±0.275 kg POST, $p < 0.00001$), muscle peak power (mean = 161±25W PRE/ 174±19W POST, $p < 0.001$), resting pH (mean = 7.03±0.01 PRE/ 7.05±0.01 POST, $p < 0.05$, Figure 1), resting Pi (mean = 4.6±0.8 mM PRE/ 5.9±1.1 mM POST , $p < 0.001$) and PCr (mean = 37.5±3.5 mM PRE/ 39.5±4.3 mM POST, $p < 0.05$, Figure 1) concentrations were found in the trained participants, while differences regarding recovery constants of the PCr replenishment (Figure 2) as well as VO_2max and pH during exercise remained statistically insignificant. The higher PCr concentrations might indicate an increase of the initial energy buffer capacity of the muscle to compensate for the ischemia-induced impaired regeneration of ATP through oxidative phosphorylation. This adaptation is paralleled by an increased capillary-to-fiber ratio, reflecting the higher demand of oxygen delivery to the muscle tissue. Our results show strength- and endurance-type adaptations in the muscle. These adaptations are of great magnitude and were induced in a short period of time. **In conclusion,** we have shown that 5.5 weeks of combined weight lifting, whole body vibration and vascular occlusion leads to orchestrated changes in resting energy metabolism which are paralleled by increased capillarization. These adaptations might be indicative of increased buffer capacity and more efficient matching of perfusion to muscle tissue requirements.

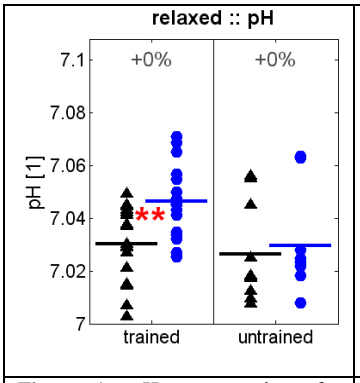

Figure 1a pH concentrations for trained (N=12) and untrained (N=9) women before (black triangles) and after (blue circles) 5.5 weeks of training.

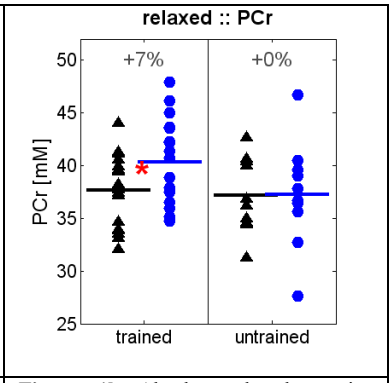

Figure 1b Absolute phosphocreatine (PCr) concentrations were obtained by assuming a constant 8.2mM ATP concentration for trained (N=12) and untrained (N=9) women before (black triangles) and after (blue circles) training.

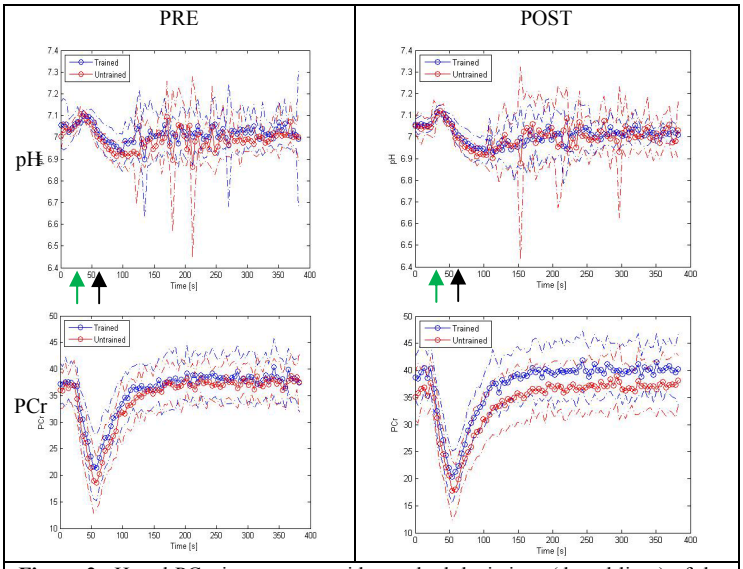

Figure 2 pH and PCr time courses with standard deviations (dotted lines) of the 30s exercise pre (left) and post training for 12 (trained) and 9 (untrained) women. The curves between control (red) and intervention (blue) groups show identical behavior except for the offset in initial pH value and PCr concentration. The noise in the pH after the exercise is due to an undershoot in inorganic phosphate (Pi), which results in an almost invisible Pi peak with a badly determined resonance frequency. The onset (green) and end (black) of the exercise are indicated with arrows.

References

[1] Winett et al., Prev Med 33:503-513 (2001)
[2] Heinzer-Schweizer *et al.*, Proc. ISMRM *1935* (2009)