A 31P MRS study of the effects of exercise-induced acidosis on phosphocreatine recovery kinetics in three muscle groups in a single cohort of human subjects

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Introduction: It is now largely acknowledged that mitochondrial function can be assessed *in vivo* from PCr resynthesis during the transition from exercise to rest. This has been evidenced by the absence of phosphocreatine resynthesis in human calf muscle during ischaemic recovery [1], the relationships between aerobic enzyme activities measured *in vitro* and rates of PCr resynthesis [2], the reduced rate of creatine phosphorylation in relation to an impaired aerobic function [3] and as a result of chemical thyroidectomy [4], the enhanced rate in subjects involved in aerobic training and in rats submitted to a training regimen. In addition, the independence of creatine phosphorylation from muscle mass [5] and exercise intensity [6,7] further indicate that mitochondrial ATP production can be reliably investigated from PCr kinetics. However, several studies have pointed out that end-of-exercise conditions could influence the kinetics of post-exercise recovery and bias the characterization of mitochondrial function in controls, trained and diseased subjects. A linear relationship between end-of-exercise pH and the rate of PCr resynthesis has sometimes been reported for different muscles in humans providing a normalisation frame. ***Purpose***: The purpose of the present study was to analyze the relationship between end-of-exercise pH and PCr recovery rates in forearm, calf and thigh muscles in a single group of subjects in order to determine whether a common normalisation frame could be adopted for different muscles.

Methods: Eight subjects (7 male, 35 ± 9 years, 175 ± 7.8cm, 67 ± 11 kg) were studied after written informed consent was provided. The forearm flexors, plantar flexors and knee extensors were investigated though appropriate dynamic rest-exercise-recovery protocols. Protocol standardisation was based on PCr consumption (50%) throughout the plantar flexion exercise (PI) and was related to MVC for the forearm flexor (PII, 15%) and thigh (PIII, 35-40%) muscles.

P	Exercise, muscle	Spectrometer field, manuf.r	Coil diam, manuf.r	Rep. time	Sweep width	Data points	Averages/ spectrum	Time resolution
I	Plantar flexion, calf	1.5 T. GE Signa	20.5/7.5-cm, GE	5 s	2.5 kHz	2048	2	10 s
II	Finger flexion	4.7-T.Bruker 47/30, Biospec	5-cm, double-tuned	1.5 s	10 kHz	1024	11	18 s
III	Knee-extension, quadriceps	1.5 T. Siemens Vision Plus	27 / 14 cm, Siemens	2 s	32 kHz	4096	4	8 s

Data were processed by a time domain fitting routine using the AMARES algorithm. The PCr recovery time constant (τ) was determined from a fitting of the PCr time-dependent changes during the recovery period to a single exponential curve.

Results : The relative PCr consumption measured in forearm and plantar flexors was similar whereas the exercise-induced intracellular acidosis was significantly larger (see Table). Intracellular acidosis at the end of knee extension exercise was slightly less and linked to a reduced PCr consumption. However, power output during the knee extensors exercise was 10 times that recorded for the forearm. The PCr recovery time constant was significantly longer after arm exercise than for leg and thigh exercise. Considering the whole dataset, a highly significant relationship was observed between end-of-exercise pH and τ values.

Table. Group mean ± sd exercise and recovery parameters

P	PCr cons.	Acidosis	Power output	τ (s)
I	65 ± 5%	6.88 ± 0.09	8.1 ± 1.6	32 ± 14
II	64 ± 17%	6.6 ± 0.1	1.6 ± 0.3W	80 ± 43
III	32 ± 14%	6.9 ± 0.1	20 ± 7W	43 ± 17

Discussion: From the point of view of PCr changes, forearm and plantar flexors were comparable whereas the exercise-induced changes were reduced in the thigh muscles. As expected considering their higher oxidative capacity, knee extensor muscles displayed the smallest PCr consumption and intracellular acidosis. Interestingly, the inverse linear relationship between end-of-exercise pH and τ values, already reported for forearm [8]and plantar flexor muscles [9], in groups of different subjects [8,9]and for measurements performed in the same subjects [10] was further documented in the present study with data from three different muscles. From a physiological point of view, this relationship might illustrate the direct effects of low intracellular pH on mitochondrial ATP production *in vivo* or indirect effects considering ion pumping reactions which can consume up to 40% of the total ATP produced. Although additional studies should be performed in order to clarify the metabolic basis of this relationship, the present results clearly illustrate that, whatever the muscle investigated, low end-of exercise pH is systematically related to a slower PCr recovery kinetics.

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