Both oxygen supply and phosphocreatine recovery rate show proximo-distal gradients along the human tibialis anterior after exercise

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Introduction: The phosphocreatine (PCr) recovery rate (k_{PCr}) of muscles after exercise, reflecting their oxidative capacity[1], varies between subjects and muscles[2,3]. Recently, we demonstrated that k_{PCr} also varied substantially within a single muscle, i.e. in the tibialis anterior (TA)[4]. As k_{PCr} depends on muscles' capacity to utilize O_2 for ATP production and O_2 supply, we wondered if O_2 supply also varied spatially within the TA. Therefore, we applied near infra-red spectroscopy (NIRS) to study the temporary imbalance of O_2 supply and utilization, intravoxel incoherent motion imaging (IVIM) for muscle perfusion and ^{31}P-MRS during and after isometric exercise of the TA.

Methods: In two sessions twelve healthy male volunteers (age: 26±3y) performed isometric dorsiflexion of the right ankle until exhaustion at 30% of their maximum voluntary contraction. During the first session, oxyhemoglobin (O_2Hb) changes were measured with NIRS (OxyMon, Artinis) simultaneously at seven positions along the TA during rest, exercise, and recovery (Fig1). The rate of O_2Hb recovery was fitted by: $O2Hb(t) = O2Hb_0 + \Delta O2Hb(1 - e^{-k_{O2Hb} \times t})$. During the second session, measurements were performed in a 3T MR system (Primsafit, Siemens). We acquired nine transverse diffusion-weighted (DW) slices (Fig1; SE-EPI; SPAIR; TR/TE=2000/40ms; voxel size = 2.75x2.75x10mm^3; gap=11.3mm; acquisition time=1min18s; b=0,5,10,15,20,40,60,80,100,150, 200,400,600s/mm^2). The signal decay on these DW images was fitted with a bi-exponential model[5,6] $S_b = S_0\left((1 - F_p)e^{-b \times D} + F_p e^{-b \times D^*}\right)$. From this the blood flow related parameter $F_p \times D^*$ during rest and recovery was determined. Second, we collected ^{31}P-MR spectra (pulse-acquire; FA=48°; TR=2060ms; NA=2; 1 spectrum/coil element; NOE) using a home-built ladder-shaped ^{31}P-phased array coil containing five coil elements positioned on the TA for reception (Fig1; signal localization through the coil element sensitivity profiles). The k_{PCr} was fitted by: $PCr(t) = PCr_0 + \Delta PCr(1 - e^{-k_{PCr} \times t})$. Linear mixed models were used to assess the linear dependence of k_{O2Hb}, $F_p \times D^*$, and k_{PCr} along the length of the TA.

Results: The k_{O2Hb}, $F_p \times D^*$, k_{PCr} all showed significant linear relationships with optode position ($p=0.01$), slice position ($p=0.031$) and coil element ($p<0.01$), respectively (Fig 2,3 and 4). All three outcome measures were higher proximally than distally.

Discussion and Conclusion: We observed higher post-exercise perfusion and faster phosphocreatine and oxyhemoglobin recovery proximally than distally in the TA. This indicates that also O_2 supply recovers faster proximally than distally.

References: [1]Kemp(2015) Acta Physiol (Oxf). [2]Larsen(2009) J Appl Physiol. [3]Fleischman(2010) J Clin Endocrinol Metab. [4]Boss(2018) J. Physiol. [5]Le Bihan(1988) Radiology. [6]Federeau(2012. Radiology

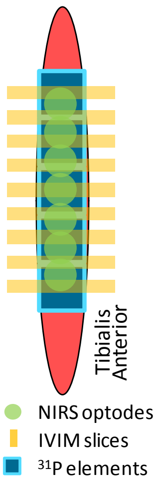

Figure 1: Optode, slice and coil element positioning along the TA

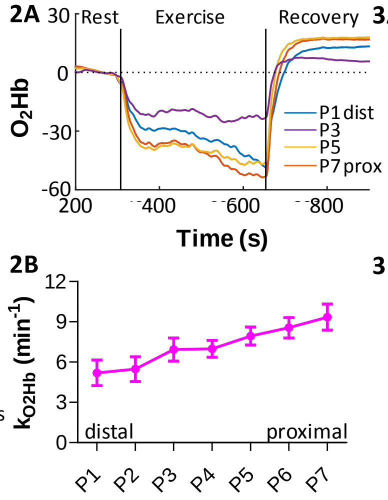

Figure 2: NIRS results. A) Typical O_2Hb signal during rest, exercise and recovery at four positions. B) k_{O2Hb} along the TA.

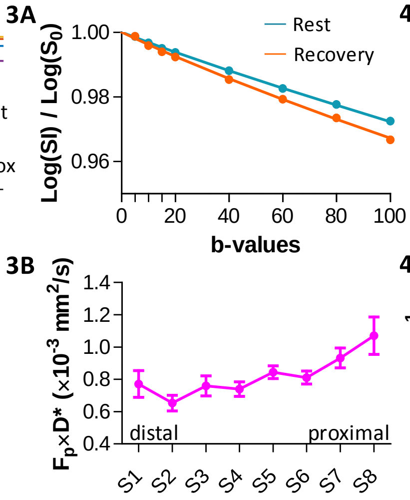

Figure 3: IVIM results. A) Typical signal decay curve of the DW signal in the TA during rest and recovery. B) $F_p \times D^*$ along the TA.

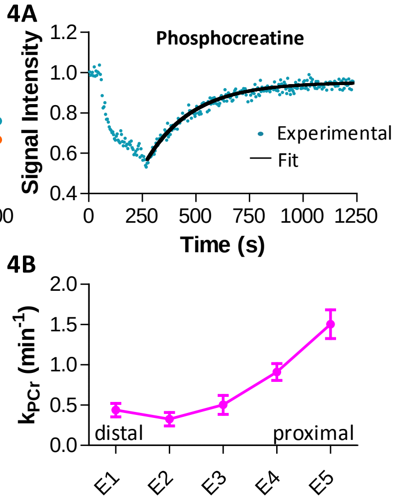

Figure 4: ^{31}P-MRS results. A) Typical phosphocreatine signal during rest, exercise and recovery. B) k_{PCr} along the TA.