

ADVICE TO DAVE: EXERCISE NOW, BURN FAT LATER

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EXTENDED ABSTRACT ONLY- DO NOT CITE

The metabolic strategies of teleosts may provide important lessons for the weight control program of senior fish physiologists. We employed a biochemical approach to examine the oxidative utilization of carbohydrate and lipid in red and white muscle of rainbow trout (*Oncorhynchus mykiss*) during high- and low-intensity exercise and during recovery from high-intensity exercise. Measurements of the activation state of the flux generating enzymes, glycogen phosphorylase (Phos) and pyruvate dehydrogenase (PDH), and their allosteric regulators (e.g. acetyl-CoA, free ADP) have yielded information on the interaction and regulation of pathways involved in lipid and carbohydrate oxidation in fish muscle.

Briefly, three separate experiments were conducted. In the first experiment, trout were manually chased and white muscle was rapidly sampled by freeze clamping every 10 s until exhaustion. In the second experiment, adult trout were exercised in a similar manner to the first experiment, but upon exhaustion trout were immediately placed into darkened acrylic boxes and white muscle was sampled for up to 32 h recovery. In the third experiment, fish were swum aerobically at 30, 60, and 90% of their critical swimming speed (U_{crit}) and red muscle was sampled for up to 4 hr of swimming.

High-intensity exercise in trout is powered predominately by white muscle. During the first 10 s of exercise, high ATP turnover rates ($3.7 \mu\text{mol}\cdot\text{g}^{-1}$ wet tissue $\cdot\text{s}^{-1}$) are achieved by rapid creatine phosphate (CrP) hydrolysis and glycolysis (Richards *et al.*, 2002a). Activation of glycolysis is achieved by a large transformation of Phos into its active form. Exercise performed from 10 s to exhaustion (52 s) occurs at a lower ATP turnover rate (0.5 to $1.2 \mu\text{mol}\cdot\text{g}^{-1}$ wet tissue $\cdot\text{s}^{-1}$) and is primarily supported by glycolysis. A gradual transformation of PDH into its active form points to a minor contribution of oxidative phosphorylation of carbohydrate to support ATP turnover. The gradual activation of PDH in white muscle during exercise suggests that O_2 is not

limiting during high-intensity exercise and thus anaerobiosis may not be responsible for lactate production in trout white muscle.

Recovery from high-intensity exercise appears to be largely fuelled by lipid oxidation. After exhaustion there is a rapid activation of pathways involved in lipid oxidation to provide ATP for CrP, ATP, and glycogen synthesis (Richards *et al.*, 2002b). A rapid transformation of PDH into its inactive form spares lactate from an oxidative fate (Fig. 1), likely to serve as the substrate for *in situ* glycogen synthesis. Decreases in free carnitine and increases in long-chain fatty acyl carnitine, acetyl-CoA, and acetyl-carnitine indicate an activation of pathways involved in lipid oxidation. Increases in white muscle malonyl-CoA during recovery suggest that malonyl-CoA may not regulate carnitine palmitoyltransferase-1 (CPT-1) in trout white muscle.

Sustainable, “aerobic” exercise at 30 and 60% U_{crit} is characterized by an initial (2 min) oxidative utilization of carbohydrate for ATP production *via* an increase in PDH activity (Richards *et al.*, 2002c). Within 15 min swimming at 30 and 60% U_{crit} , PDH activation returns to resting values, and at 240 min increases in LCFA-carnitine and decreases in malonyl-CoA indicate an overall enhancement of lipid oxidation. Non-sustainable swimming at 90% U_{crit} is characterized by a sustained activation of red muscle PDH. Overall, sustained swimming at 30 and 60% U_{crit} is supported by approximately equal contributions of carbohydrate (~45%) and lipid (~35%) oxidation, whereas non-sustainable swimming is supported primarily by carbohydrate oxidation.

The relative rates of lipid and carbohydrate oxidation by trout red and white muscle are, in part, dictated and coordinated by the regulation of PDH. During periods of high ATP turnover (high-intensity, exhaustive exercise and prolonged swimming at 90% U_{crit}), PDH is transformed into its active form for rapid ATP production and the transformation pattern of PDH may explain lactate production in white muscle. During periods of low ATP turnover (sustained “aerobic” exercise and recovery from high-intensity exercise), PDH is transformed into its inactive form due to the accumulation of allosteric regulators from fatty acid oxidation (e.g. acetyl-CoA, NADH). The inactivation of PDH during enhanced lipid oxidation in fish muscle is similar to the glucose fatty acid cycle proposed by Randle (1998) to explain PDH regulation in mammalian muscle.

References

- Randle, P. J. 1998. Regulatory interactions between lipids and carbohydrates: the glucose fatty acid cycle after 35 years. *Diabetes Metabolism Reviews* 14: 263-283.
- Richards, J. G., Heigenhauser, G. J. F. and Wood, C. M. 2002a. Glycogen phosphorylase and pyruvate dehydrogenase transformation in white muscle of trout during high-intensity exercise. *American Journal of Physiology* 282: R828-R836.
- Richards, J. G., Heigenhauser, G. J. F. and Wood, C. M. 2002b. Lipid oxidation fuels recovery from exhaustive exercise in white muscle of rainbow trout. *American Journal of Physiology* 282: R89-R99.
- Richards, J. G., Mercado, A. J., Clayton, C. A., Heigenhauser, G. J. F. and Wood, C. M. 2002c. Substrate utilization during graded aerobic exercise in rainbow trout. *Journal of Experimental Biology In Press*.

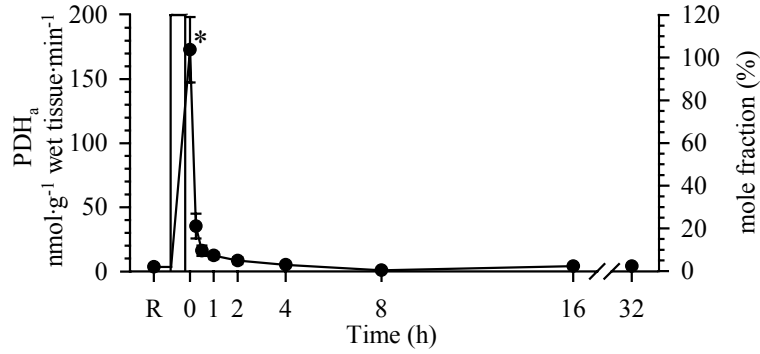
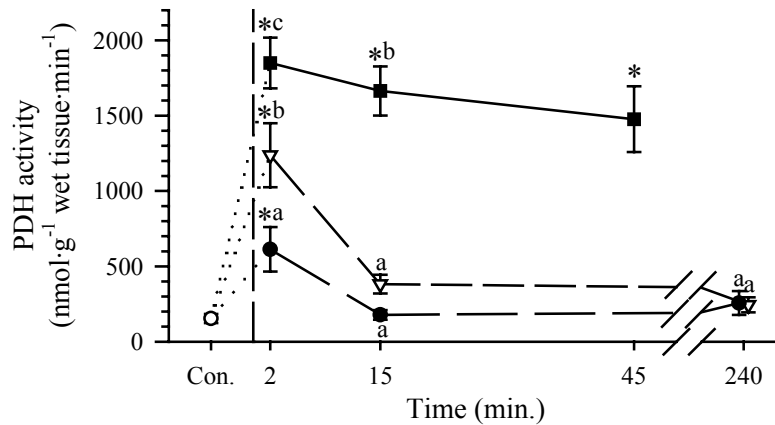


Figure 1: White muscle pyruvate dehydrogenase activity and PDH_a mole fraction at rest (R) and during 32 h recovery from exhaustive exercise. Vertical bar represents 5 min of exhaustive exercise. Data are means \pm SE, n = 8 for each point except at time zero where n = 7. Asterisks represent significant



differences from rest.

Figure 2: Red muscle pyruvate dehydrogenase activity in control fish (○) and in fish swam at 30% U_{crit} (●) and 60% U_{crit} (∇) for up to 240 min and at 90% U_{crit} (■) for up to 45 min. Vertical dashed line represents the start of exercise.

Overlapping data points are offset for clarity. Data are means \pm SE, $n = 8$ for each point. Note the break in the horizontal axis. Asterisks represent significant ($P < 0.05$) differences from control fish and points with different letters are significantly ($P < 0.05$) different within a time period.

