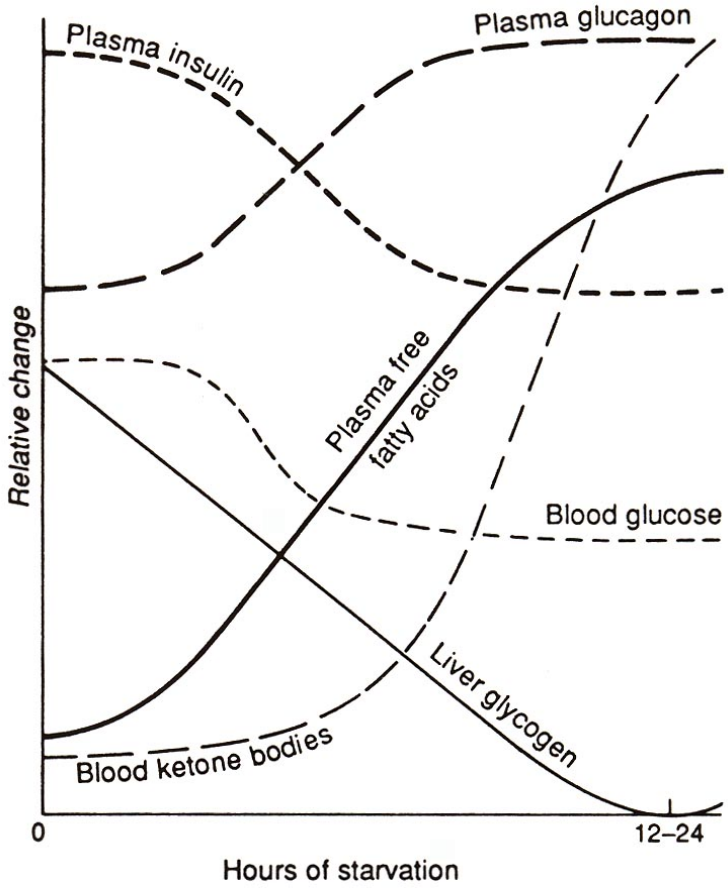
ANSC/FSTC 607
Physiology and Biochemistry of Muscle as a Food
Exercise, Starvation, and Muscle Metabolism

I. Effects of starvation and exercise on substrate utilization by muscle

A. During exercise or starvation/fasting:

1. Liver glycogen is depleted.
2. Blood glucose decreases.
3. In response to decrease in blood glucose, insulin decreases and glucagon release from pancreas is increased.
4. Nonesterified fatty acids increase in blood.

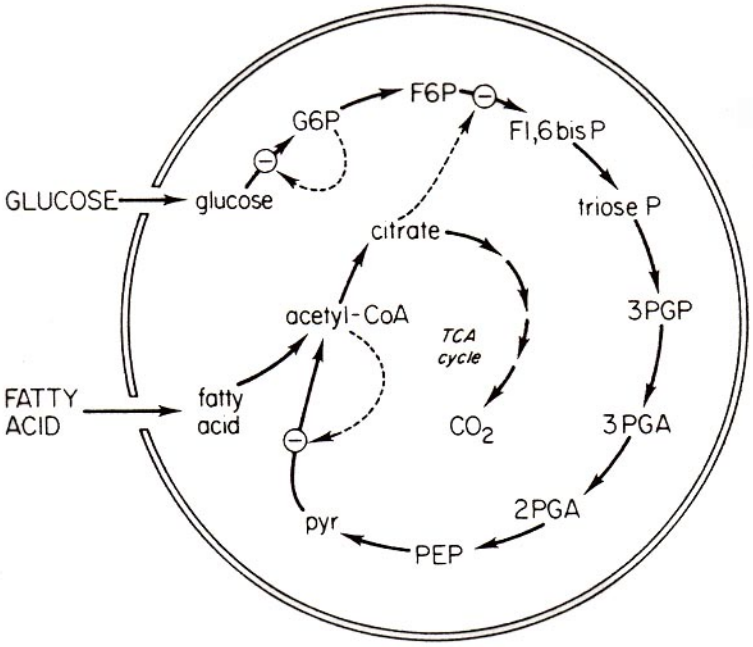


II. Glucose:fatty acid cycle

A. Type I and Type IIA myofibers prefer ketone bodies (especially!) and fatty acids over glucose for metabolism.

1. Ketone bodies are water soluble, and are activated in mitochondria where they are metabolized (very fast).
2. The metabolism of ketone bodies and fatty acids elevates mitochondrial acetyl-CoA.
   a. This elevates mitochondrial citrate.
   b. Citrate exits mitochondria, elevates sarcoplasmic citrate.
3. Citrate and fatty acyl-CoAs inhibit 6-PFK.
   a. Inhibition at 6-PFK causes increase of F-6-P and G-6-P.

b. Elevation of G-6-P inhibits hexokinase, spares glucose for other tissues.



III. Regulation of 6-PFK activity by citrate during exercise

A. Exercise increases citrate concentrations in muscle

B. Citrate causes a decrease in the mass action ratio for 6-PFK.

	Rest	**Post-exercise**
Plasma, μmol/mL		
Glucose	5.2 ± 0.4	4.4 ± 0.4*
Lactate	1.0 ± 0.2	2.6 ± 0.4*
Non-esterified fatty acids	0.37 ± 0.05	1.89 ± 0.12*
β-Hydroxybutyrate	0.74 ± 0.10	1.57 ± 0.10*
Soleus intermediates, nmol/g		
Glycogen	18 ± 2	17 ± 3
Citrate	231 ± 21	440 ± 20*
Glucose 6-phosphate	90 ± 20	287 ± 50*
Fluctose 6-phosphate	25 ± 5	64 ± 11*
Fructose 1,6-bisphosphate	25 ± 4	15 ± 4
High energy phosphates, μmol/g		
ATP, μmol/g	3.1 ± 0.1	3.5 ± 0.1
Phosphocreatine, μmol/g	8.8 ± 0.9	10.3 ± 1.0
ADP	1.0	0.6
MAR for 6-PFK	0.32	0.04

Effect of 1 h swimming on metabolite concentrations in plasma and soleus muscles for 48 h-starved rats
Values are means ± S.E.M. for six to 20 observations per group. Rats swam for 1 h with a weight (4% of body wt.) tied to their tails in water maintained at 33-35° C. They were anaesthetized immediately after exercise. Plasma

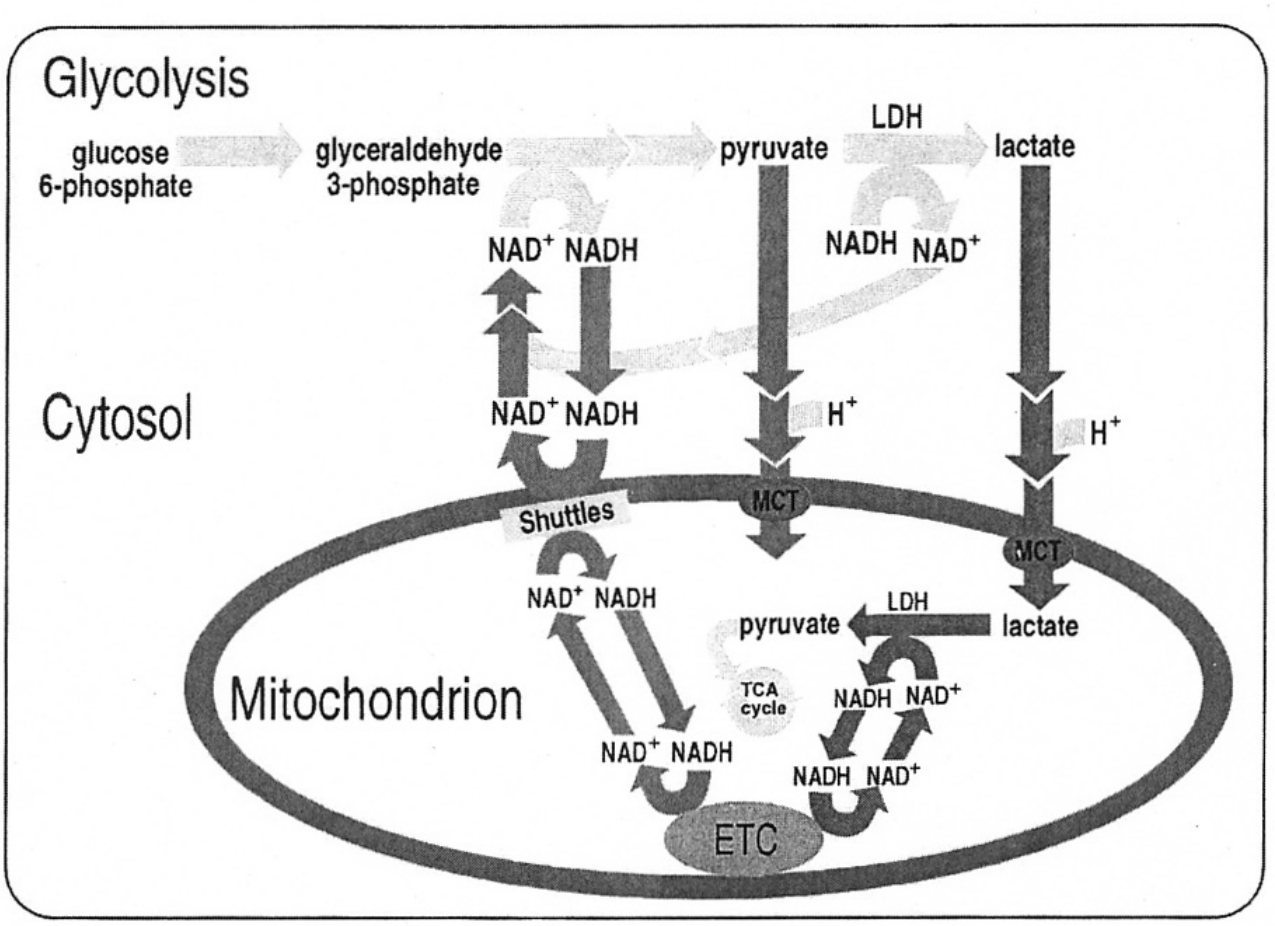
metabolites are expressed in μmol/ml and solus metabolites in nmol/g, except for ATP and phosphocreatine, which are in μmol/g. *Value significantly different from that of the resting group, at $P < 0.05$.

IV. Regulation of 6-PFK by lactate

A. Lactate enters mitochondria via the monocarboxylic shuttle.

B. Lactate is converted to pyruvate via mitochondrial LDH and enters the TCA cycle.

C. The accumulation of NADH inhibits ICDH, and increases citrate levels.



V. Muscle glycogen concentrations (mg/g wet weight) in biceps femoris muscle of horses fed fat supplements, before and after an exercise test

Diet	Pre-test	Post-test[1]	Amount used
Control	15.77 ± 0.52	8.78 ± 1.40	6.99 ± 0.75
	n = 5	n = 4	n = 4
Fat supplemented	22.89* ± 0.42	9.81 ± 0.81	13.08* ± 0.43
(10% fat)	n = 6	n = 6	n = 6

*Different from control

[1]The exercise test consisted of four, 600 m gallops, interspersed with 5 min resting intervals. The test was performed at a speed to increase heart rates to 210 beats per minute. The horses were accelerated as fast as possible. From Oldham et al. (1990).

VI. Humans

A. Infusion of epinephrine in humans causes a rapid rise in phosphorylase$_a$ and a rapid decline in glycogen synthase I.

1. Caused by activation of protein kinases.
2. Effects are reversed soon after epinephrine infusion ceases.

B. However, there is only a small change in muscle glycogen.

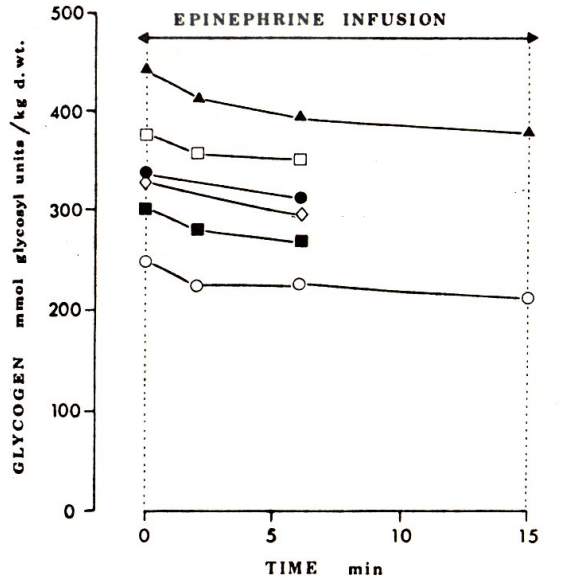


FIG. 3. Muscle content of glycogen during epinephrine infusion. Each *symbol* represents values from same subject. Four subjects (■, ▲, □, ○) are same as in Fig. 2.

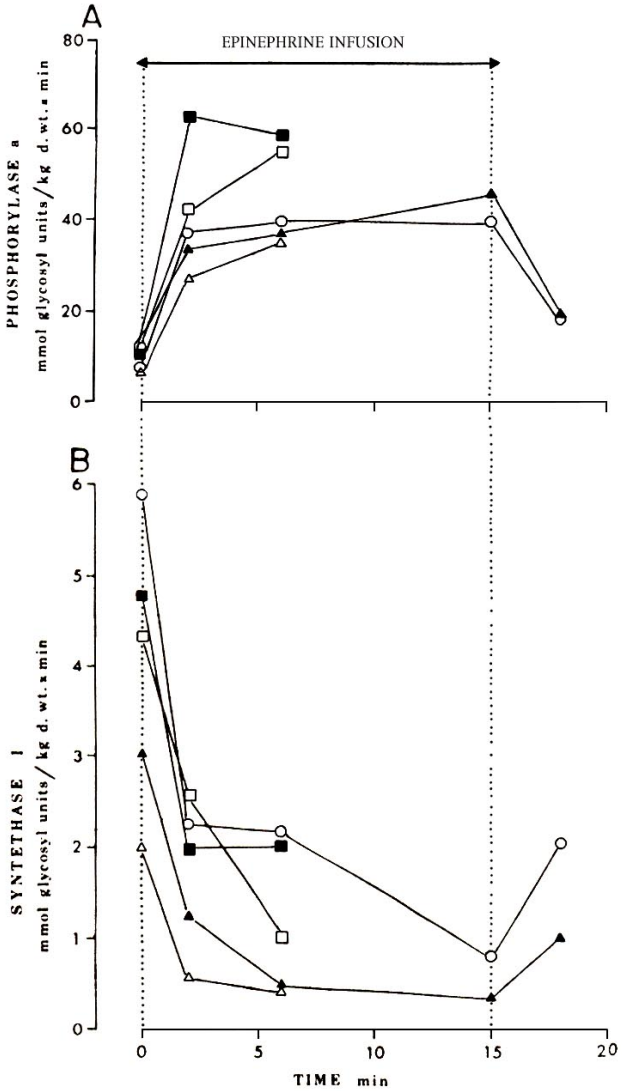


Figure A/B: Effect of epinephrine infustion on phosphorylase a and synthase activity in muscle. Each symbol represents values from same subject.

VII. Cattle

A. Starvation markedly reduces glycogen in bovine muscle.

B. Repletion requires several days.

C. Electrical stimulation of muscle has no significant effect on muscle glycogen, although epinephrine significantly reduces muscle glycogen.