Aerobic and anaerobic metabolism in muscle

Musculoskeletal Block

Objectives

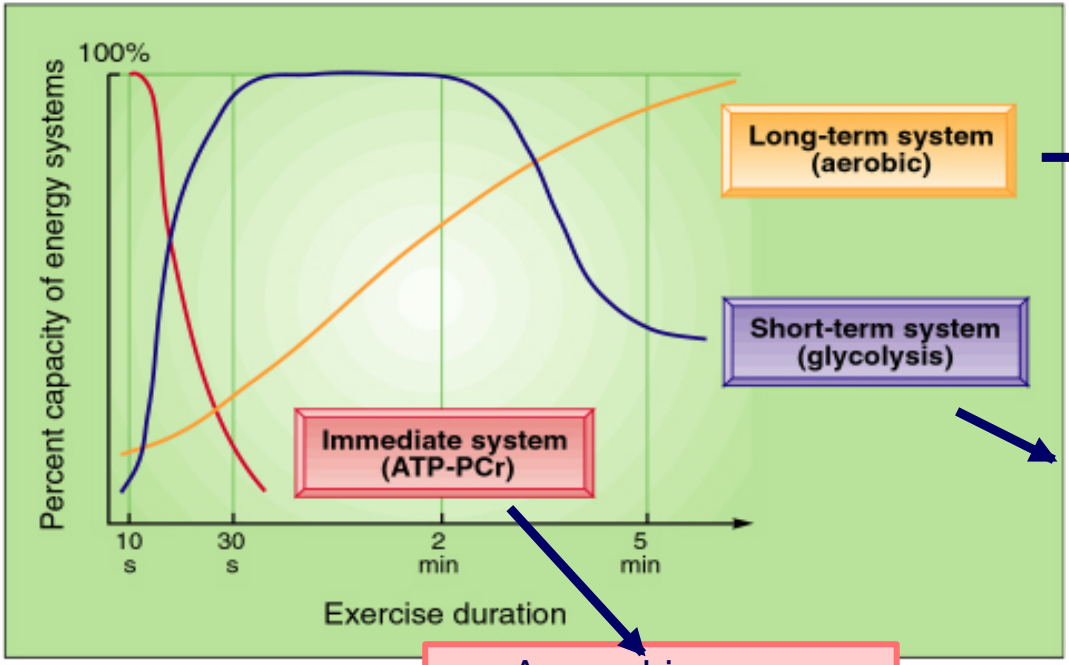
By the end of this lecture, the First year students will be able to:

- Recognize the importance of ATP as energy source in skeletal muscle
- Compare three systems of energy transfer in the body
- Differentiate between energy metabolism in red and white muscle fibers
- Understand how skeletal muscles derive ATP from aerobic and anaerobic metabolism
- Discuss the importance of Cori and glucose-alanine cycles in energy metabolism

Overview

- Three systems of energy transfer
- ATP as energy source
- Aerobic metabolism: red muscle fibers
- Anaerobic metabolism: white muscle fibers
- Cori cycle
- Glucose-alanine cycle
- Muscle fatigue and endurance in athletes

Three systems of energy transfer



- Aerobic
- Fatty acids
- Continuous exercise
- Hours

- Anaerobic
- Glucose
- High intensity exercise
- 15 sec. to 2 min.

- Anaerobic
- Phosphocreatine (PCr)
- High intensity exercise
- 3-15 sec.

ATP as energy source

The nucleotide coenzyme adenosine triphosphate (ATP) is the most important form of chemical energy stored in cells
Breakdown of ATP into ADP+PO4 releases energy
This energy is used for all body functions (biosynthesis, membrane transport, muscle contraction, etc.)

ATP as energy source

The main pathway for ATP synthesis is oxidative phosphorylation catalyzed by the respiratory chain

ATP synthase catalyzes the synthesis of ATP

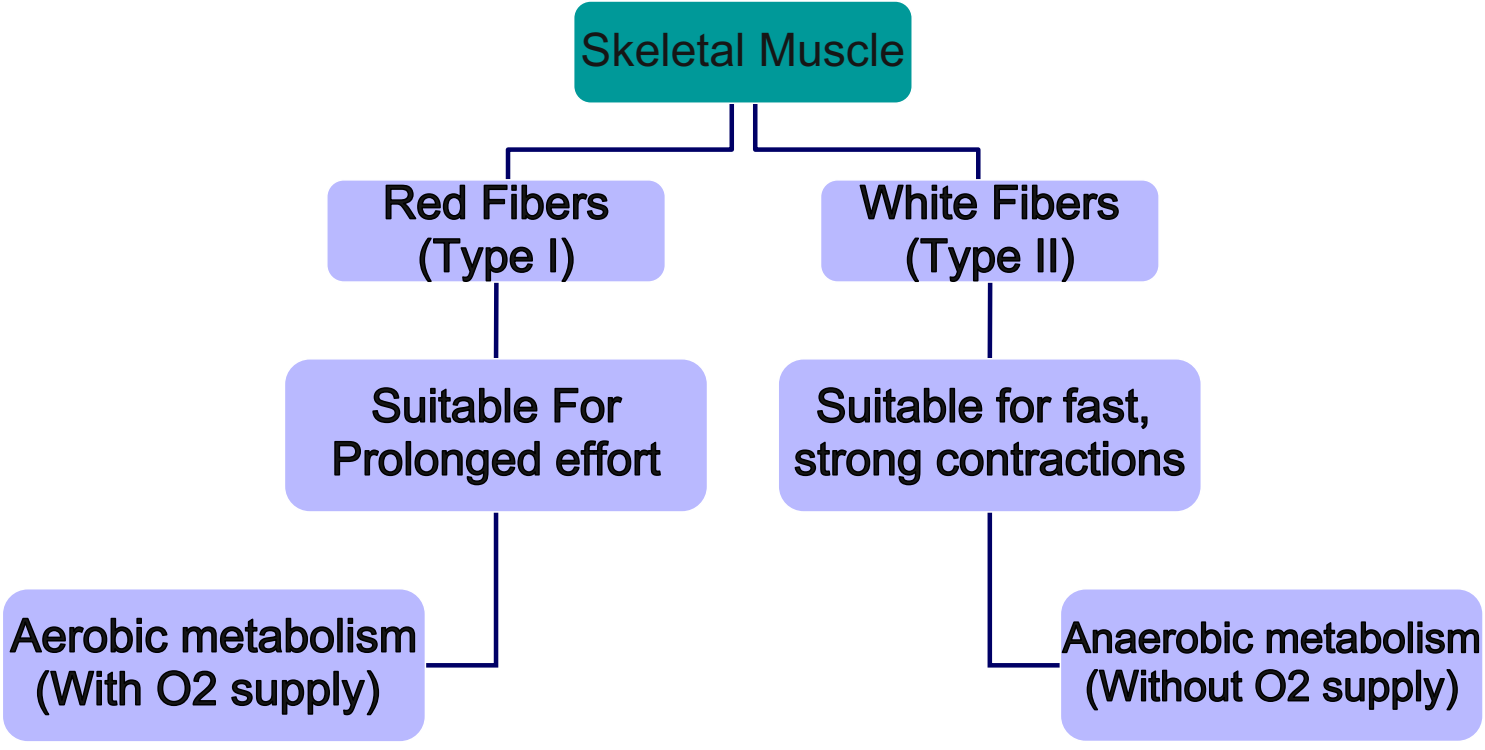
ADP + Pi ? ATP

Energy metabolism in muscle

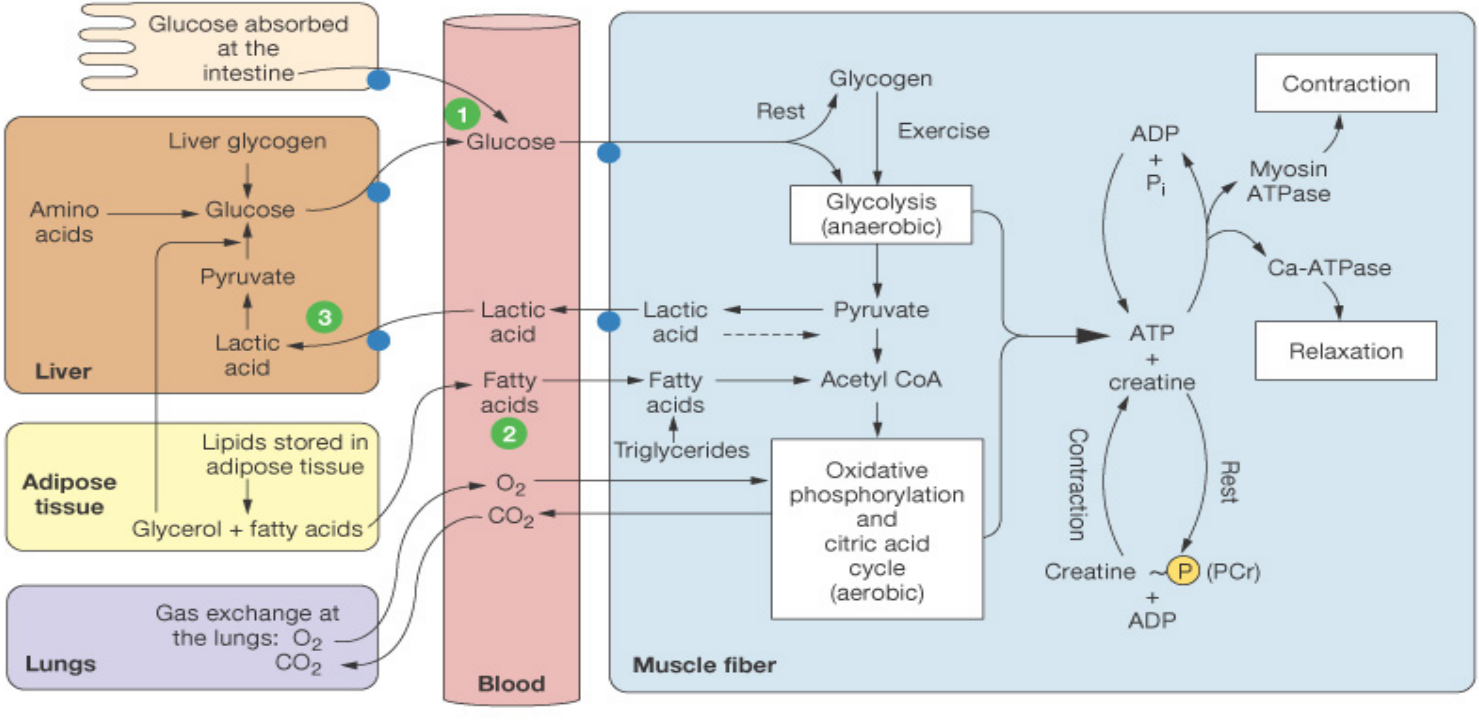
Muscle contraction requires high level of ATP consumption

Without constant resynthesis, the amount of ATP is used up in less than 1 sec. of contraction

Energy metabolism in muscle



Overview of Energy Metabolism in Skeletal Muscle



1. Glucose comes from liver glycogen or dietary intake.
2. Fatty acids can only be used in aerobic metabolism.
3. Lactic acid from anaerobic metabolism can be converted to glucose by the liver.

Aerobic metabolism in red muscle fibers

Red muscle fibers are suitable for prolonged muscle activity

Their metabolism is mainly:

- Aerobic and
- Depends on adequate supply of O2

They obtain ATP mainly from fatty acids

Fatty acids are broken down by b-oxidation, Krebs cycle, and the respiratory chain

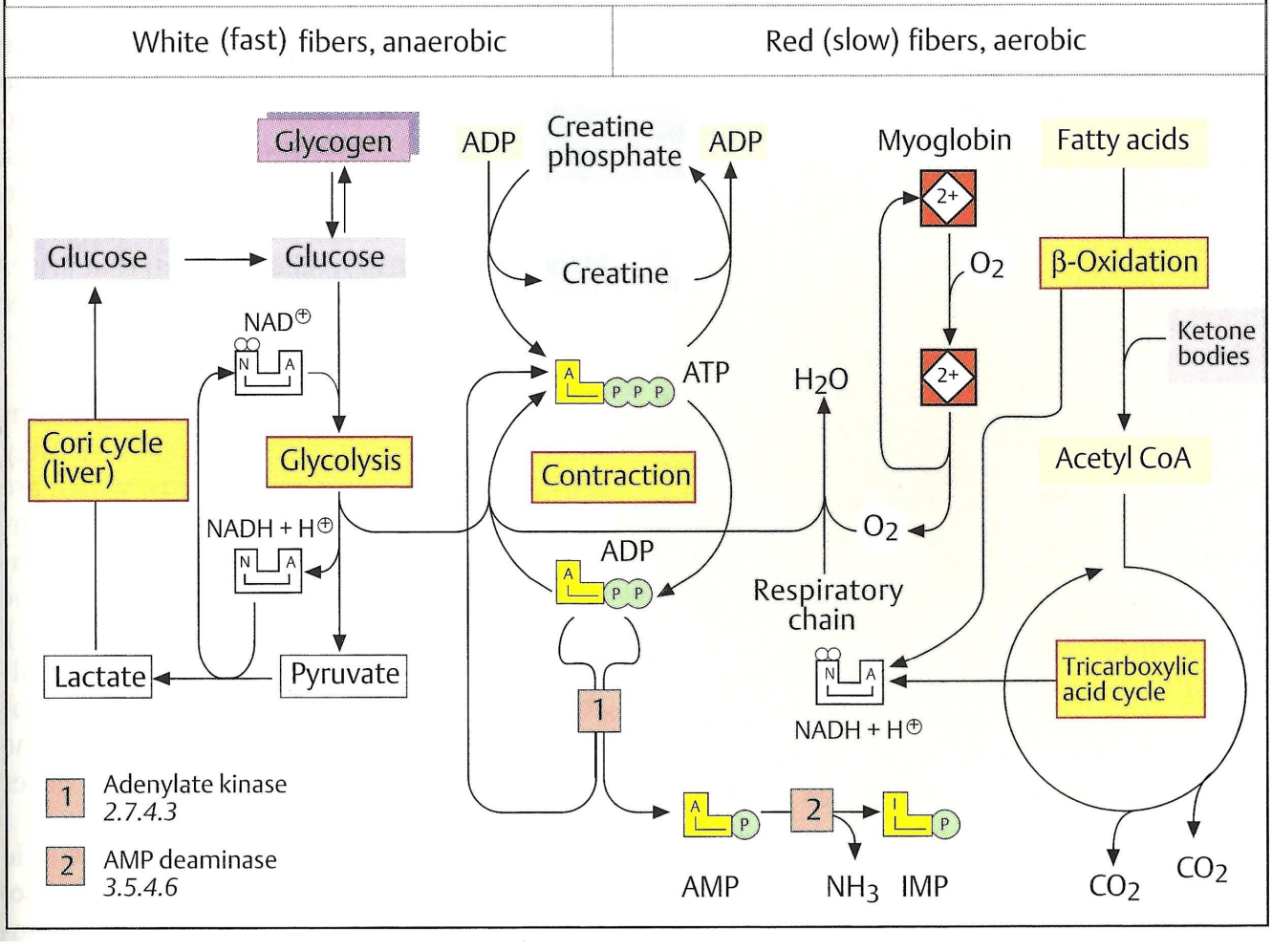
Aerobic metabolism in red muscle fibers

Red color is due to myoglobin

Myoglobin has higher O2 affinity than hemoglobin

It releases O2 when its level drops

A. Energy metabolism in the white and red muscle fibers



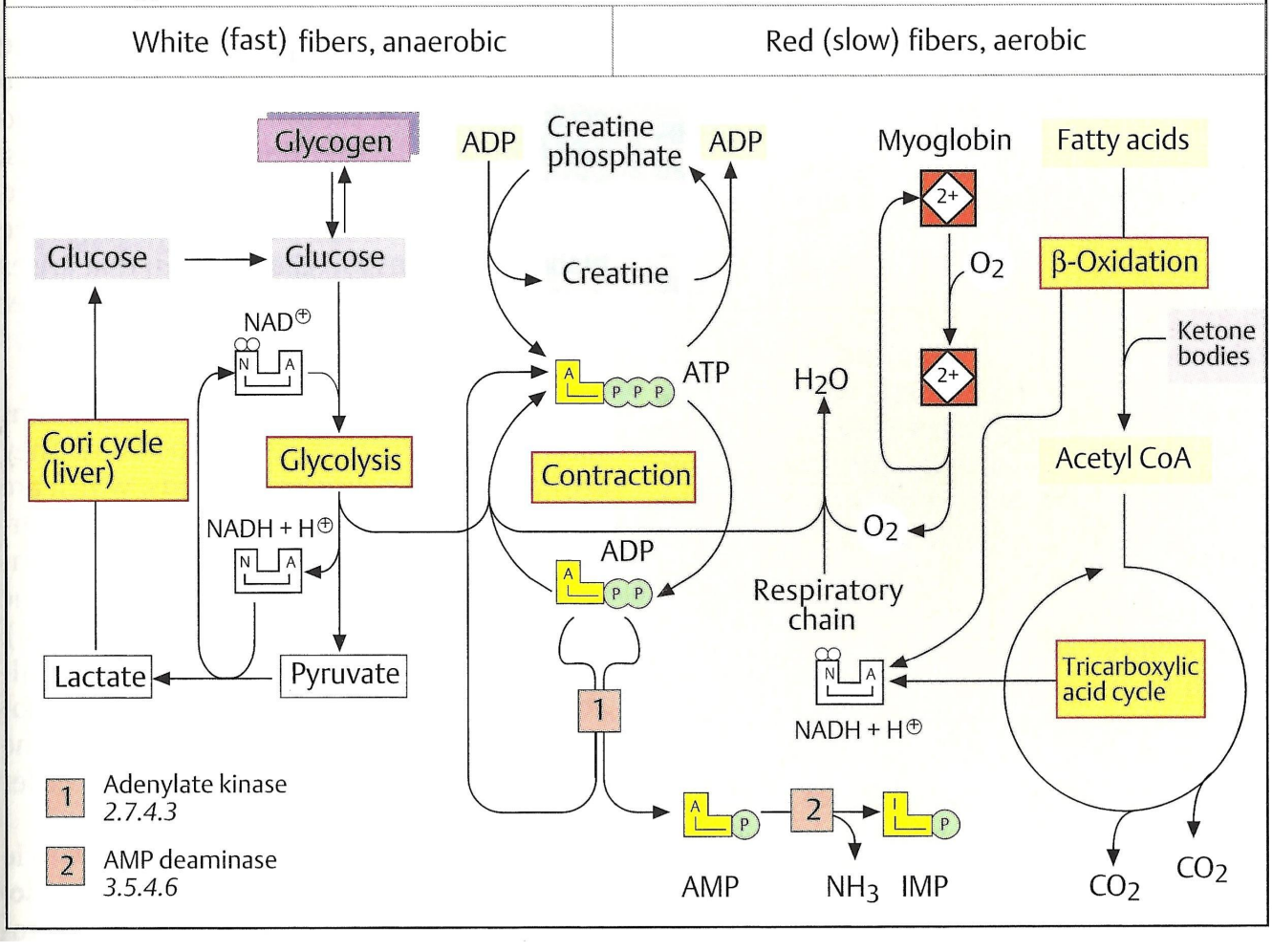
Anaerobic metabolism in white muscle fibers

White muscle fibers are suitable for fast, strong contractions
During intense muscle activity (weightlifting, etc.) O2 supply from blood quickly drops
They mainly obtain ATP from anaerobic glycolysis
They have supplies of glycogen that is catabolized and undergoes glycolysis

Anaerobic metabolism in white muscle fibers

Glycogen → glucose-1-PO4 → glucose-6-PO4 → glycolysis → ATP
NADH+H+ is re-oxidized to maintain glucose degradation and ATP formation
Anaerobic glycolysis produces lactate
Lactate is resynthesized into glucose in the liver by Cori cycle

A. Energy metabolism in the white and red muscle fibers



The Cori Cycle

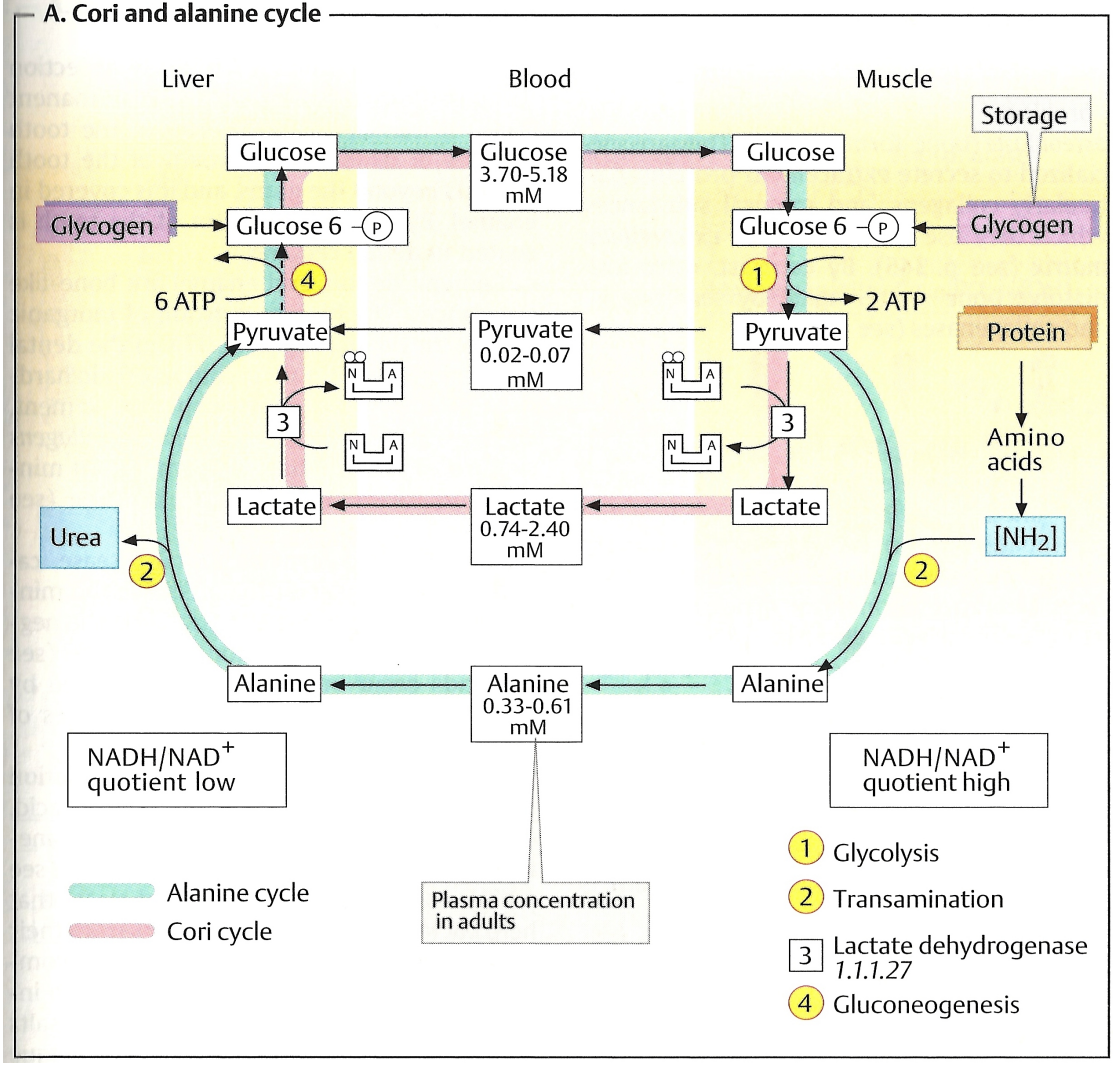
In anaerobic glycolysis, the glucose is converted to lactate

Lactate in muscle is released into blood

Transported to the liver

Liver converts lactate into glucose via gluconeogenesis

The newly formed glucose is transported to muscles to be used for energy again


A. Cori and alanine cycle
Liver
Blood
Muscle
Storage
Glucose
Glucose 3.70-5.18 mM
Glucose
Glycogen
Glucose 6 P
Glucose 6 P
Glycogen
6 ATP
4
1
2 ATP
Pyruvate
Pyruvate 0.02-0.07 mM
Pyruvate
Protein
N A
3
Amino acids
Lactate
Lactate 0.74-2.40 mM
Lactate
Urea
[NH2]
2
2
Alanine
Alanine 0.33-0.61 mM
Alanine
NADH/NAD+ quotient low
NADH/NAD+ quotient high
Alanine cycle
Cori cycle
Plasma concentration in adults
1 Glycolysis
2 Transamination
3 Lactate dehydrogenase 1.1.1.27
4 Gluconeogenesis

The Cori Cycle

Why skeletal muscles can't produce new glucose from lactate?

Because:

Gluconeogenesis requires much more ATP than is supplied by glycolysis in muscle

O2 deficiencies do not arise in the liver even during intense exercise

Therefore, liver always has sufficient ATP for gluconeogenesis

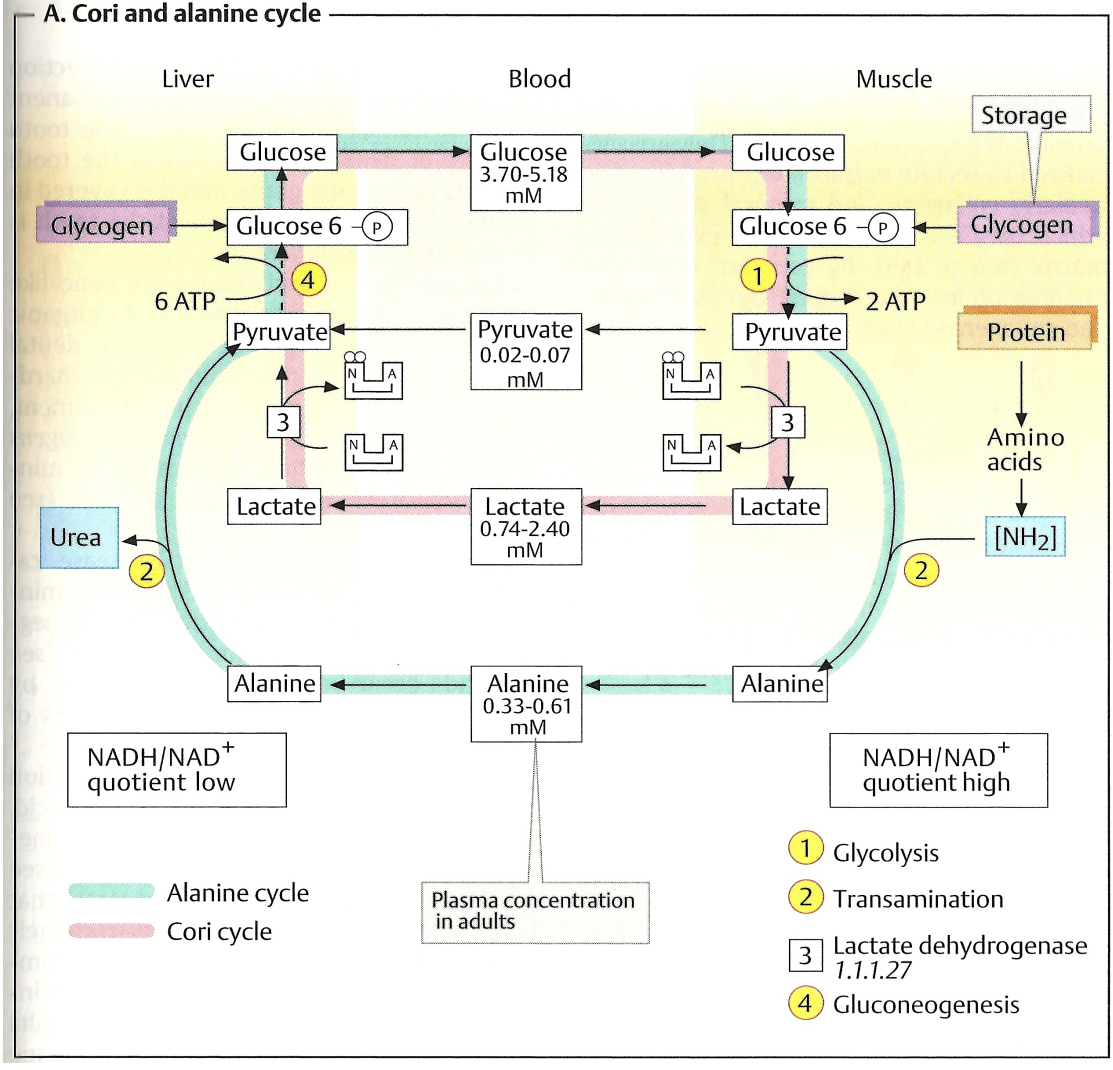
The glucose-alanine cycle

Muscles produce:

- Pyruvate from glycolysis during exercise and
- Amino nitrogen (NH2) from normal protein degradation

Pyruvate is converted to alanine in muscles

- Pyruvate + NH2 ? Alanine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The glucose-alanine cycle

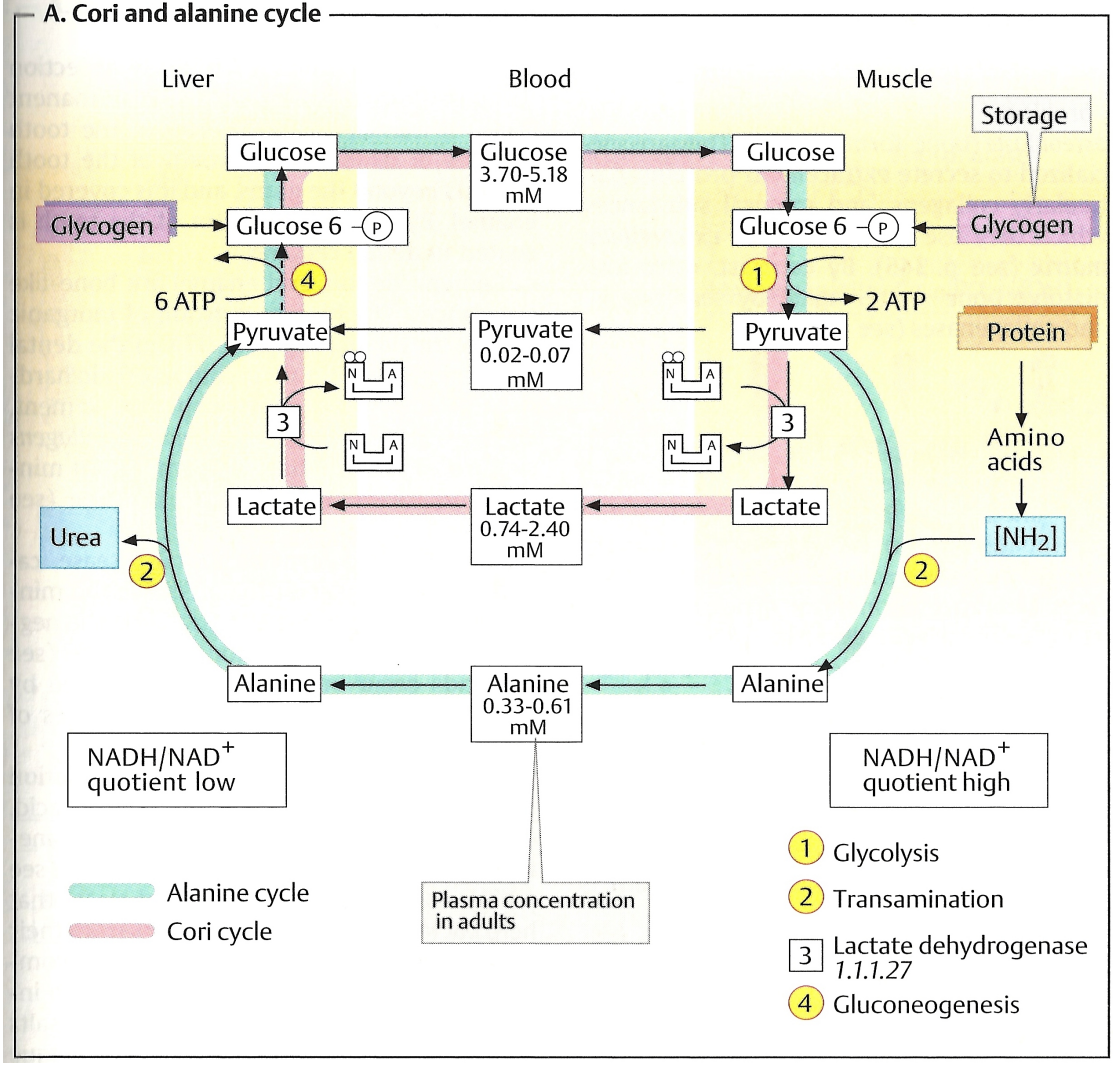
This alanine is transported to liver

Liver converts alanine back to pyruvate

- Alanine – NH_2 = Pyruvate

Pyruvate is used in gluconeogenesis

The newly formed glucose is transported to muscle to be used for energy again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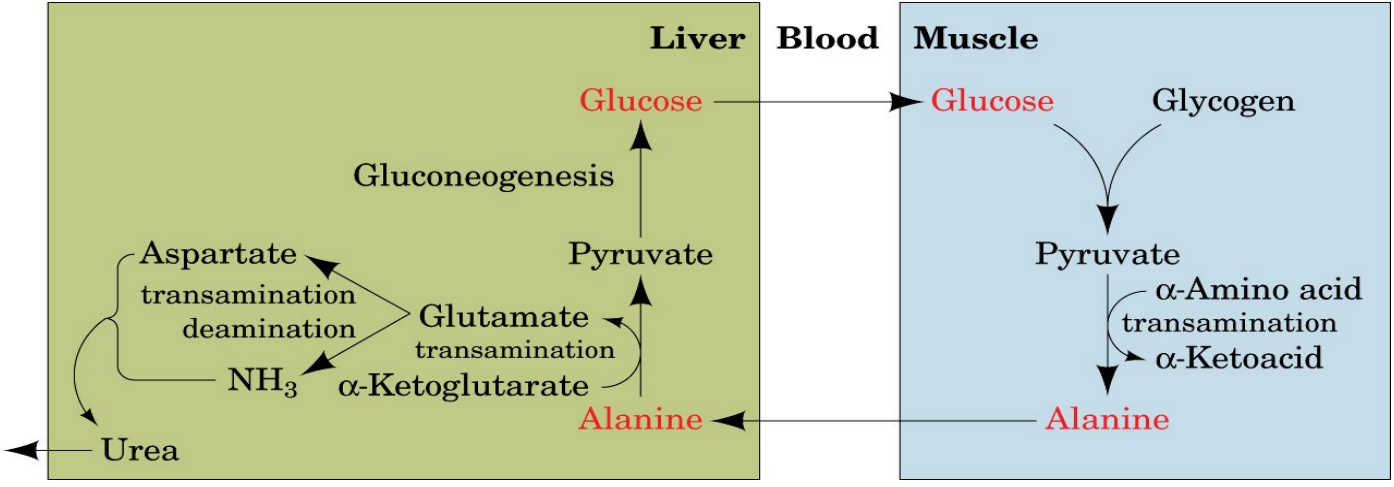
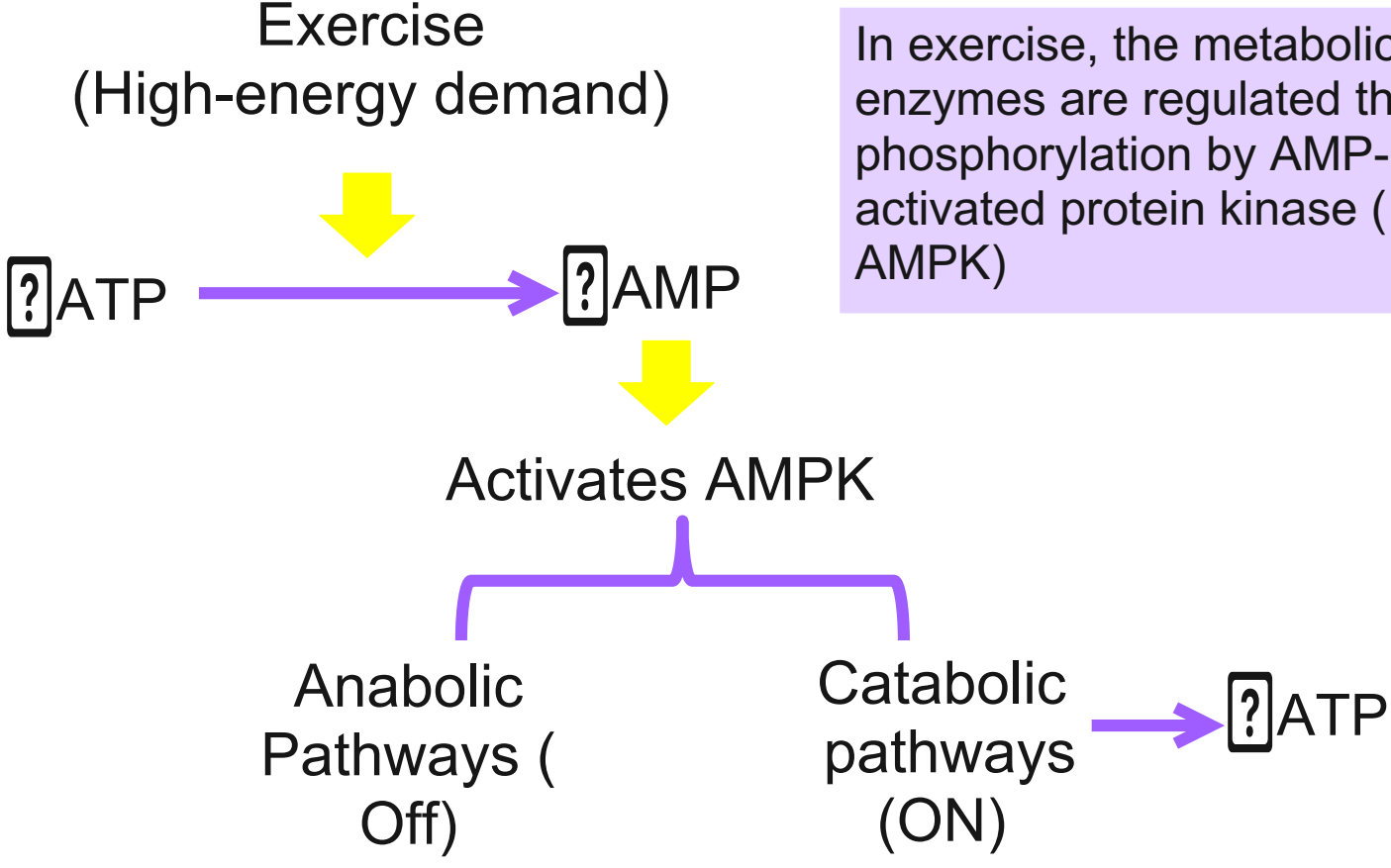


The glucose–alanine cycle

Exercise and AMPK



In exercise, the metabolic enzymes are regulated thru phosphorylation by AMP-activated protein kinase (AMPK)

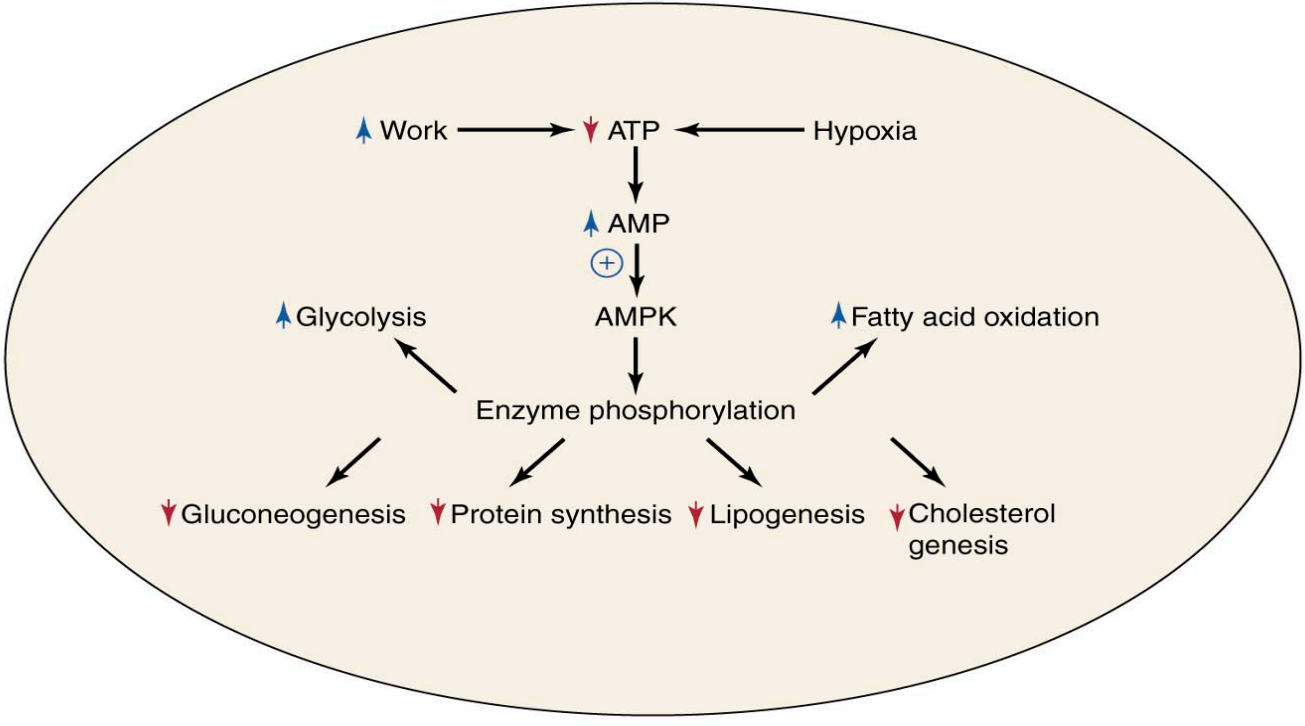


Figure 22.15. Activation of AMPK shuts down ATP-requiring processes and stimulates ATP-producing processes

AMPK activation shuts down ATP-requiring processes and stimulates ATP-producing processes

Muscle fatigue and endurance in athletes

Muscle fatigue:

- Inability of muscles to maintain a particular strength of contraction over time

Causes: muscle damage, accumulation of lactic acid

Athletes are able to change the proportions of red and white muscle fibers by targeted training

Muscle fatigue and endurance in athletes

The expression of muscle proteins can also change during the course of training

This provides them with:

- High endurance during muscle activity
- Efficient energy production and consumption
- Delayed fatigue

Take home message

ATP is an important source of chemical energy needed by the cells to perform body functions
Muscular activity requires constant supply of ATP for energy either from aerobic or anaerobic metabolism
Cori and glucose-alanine cycles play an important role in regenerating glucose for energy
Athletes are able to change proportions of their red and white muscle fibers with appropriate training

References

Koolman, J., Roehm, K.H. Color Atlas of Biochemistry, Second Edition, 2015, Thieme New York, pp. 336–339

Textbook of Biochemistry with Clinical Correlations by Thomas M. Devlin, 6th Edition, pp. 866-868