Aerobic and anaerobic metabolism in muscle

Musculoskeletal Block

Objectives

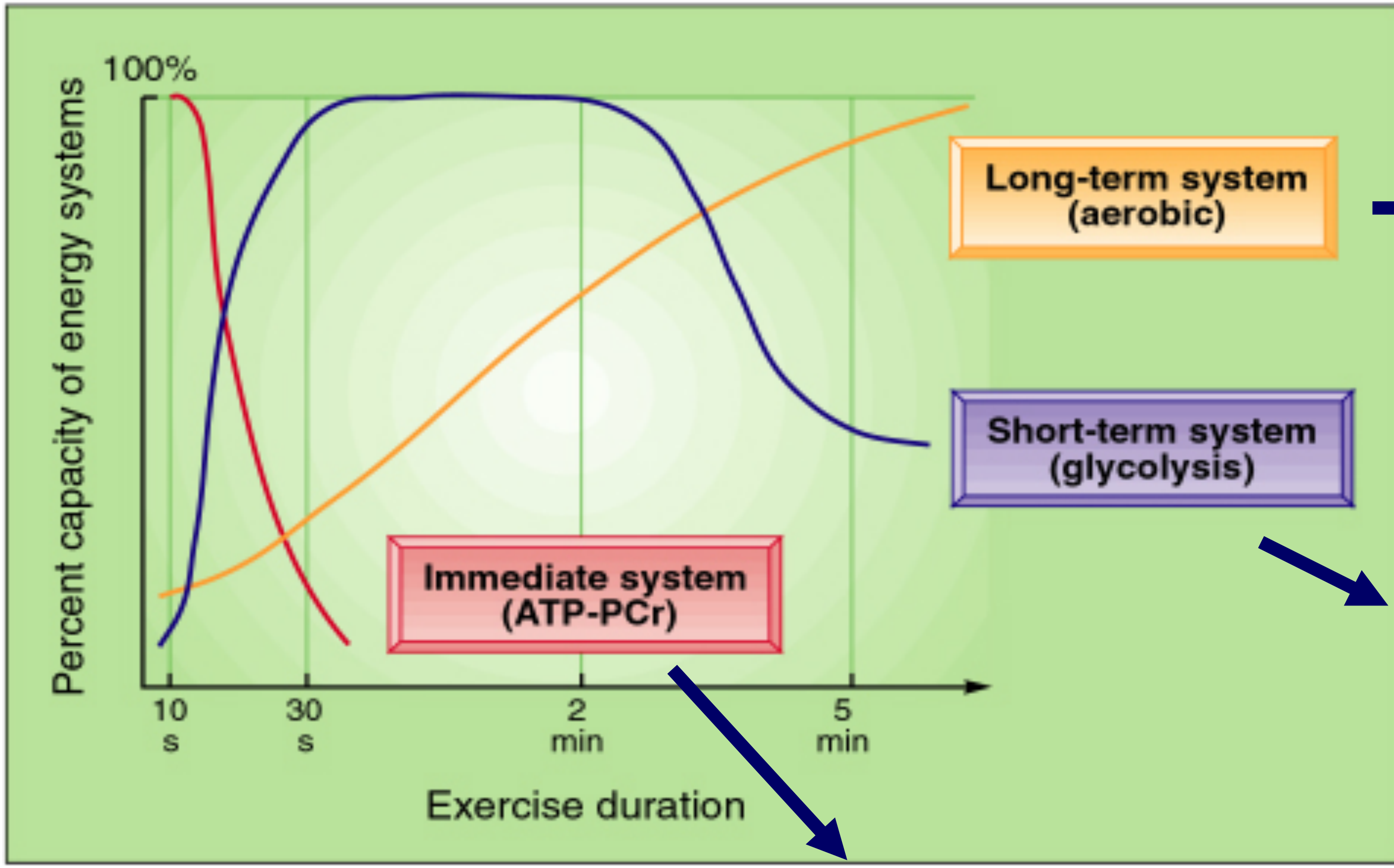
By the end of this lecture, the First year students will be able to:

- 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+PO_4 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

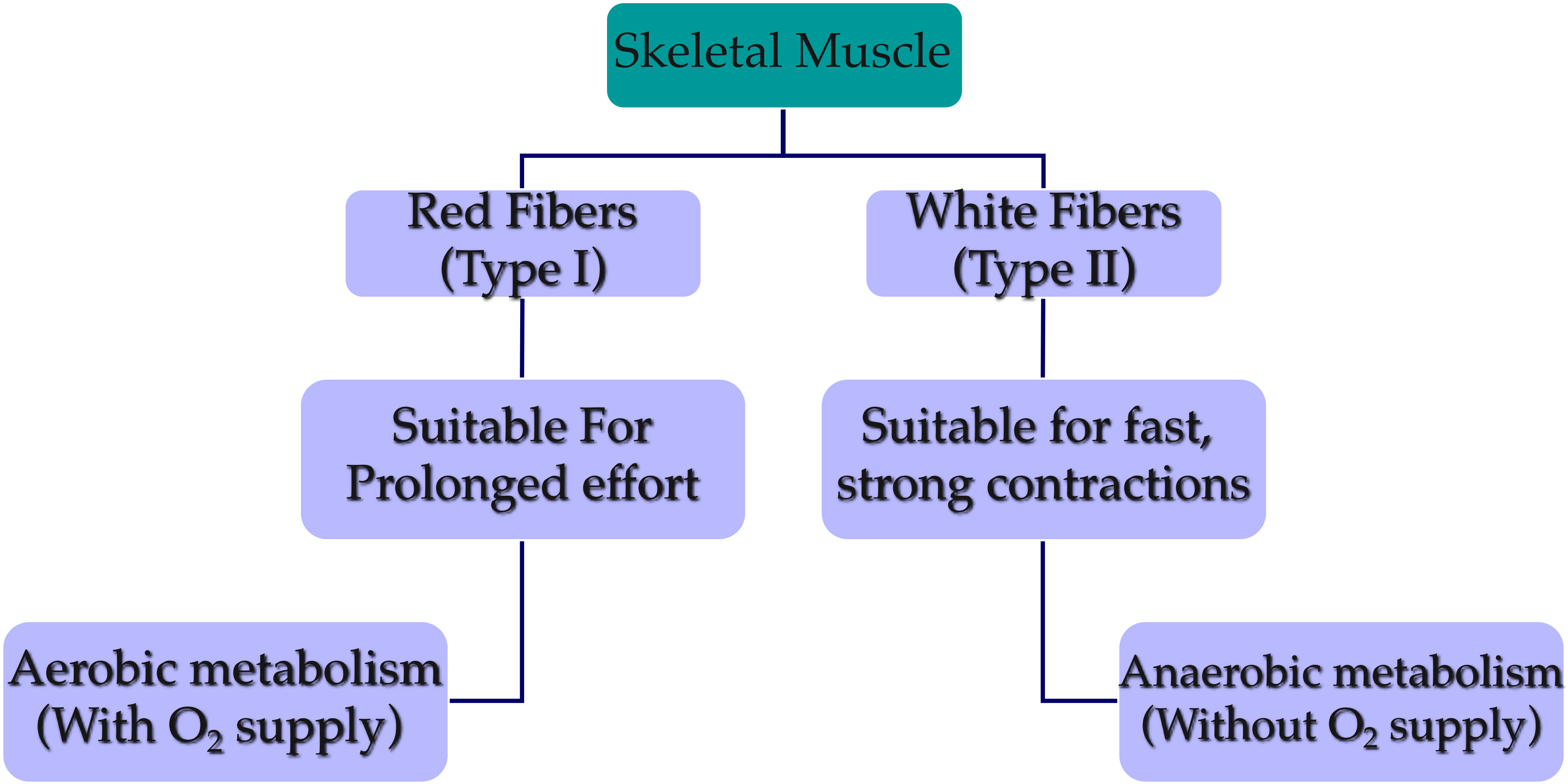
- ATP synthase catalyzes the synthesis of ATP

$$ADP + Pi \rightarrow ATP$$

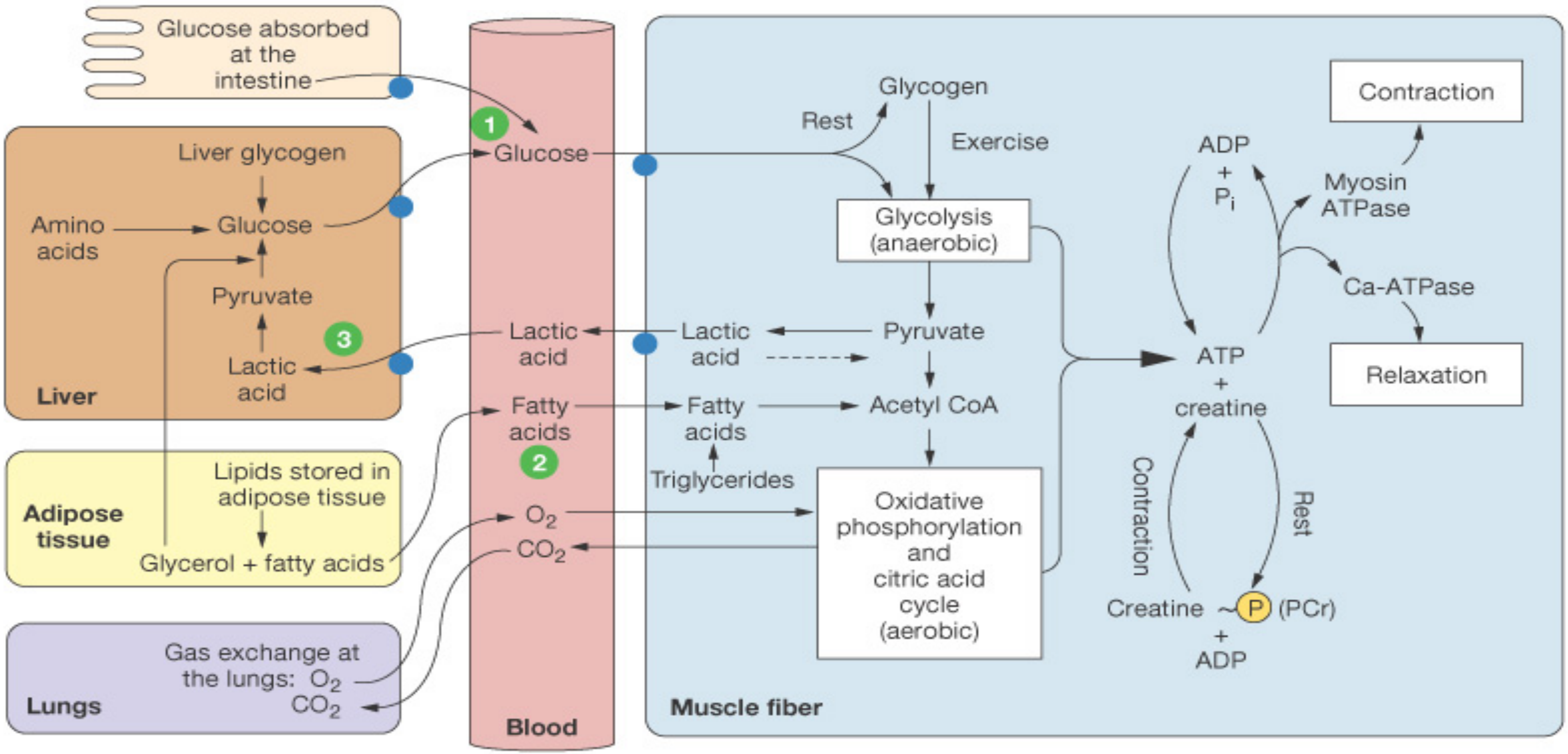
Energy metabolism in muscle

- 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.

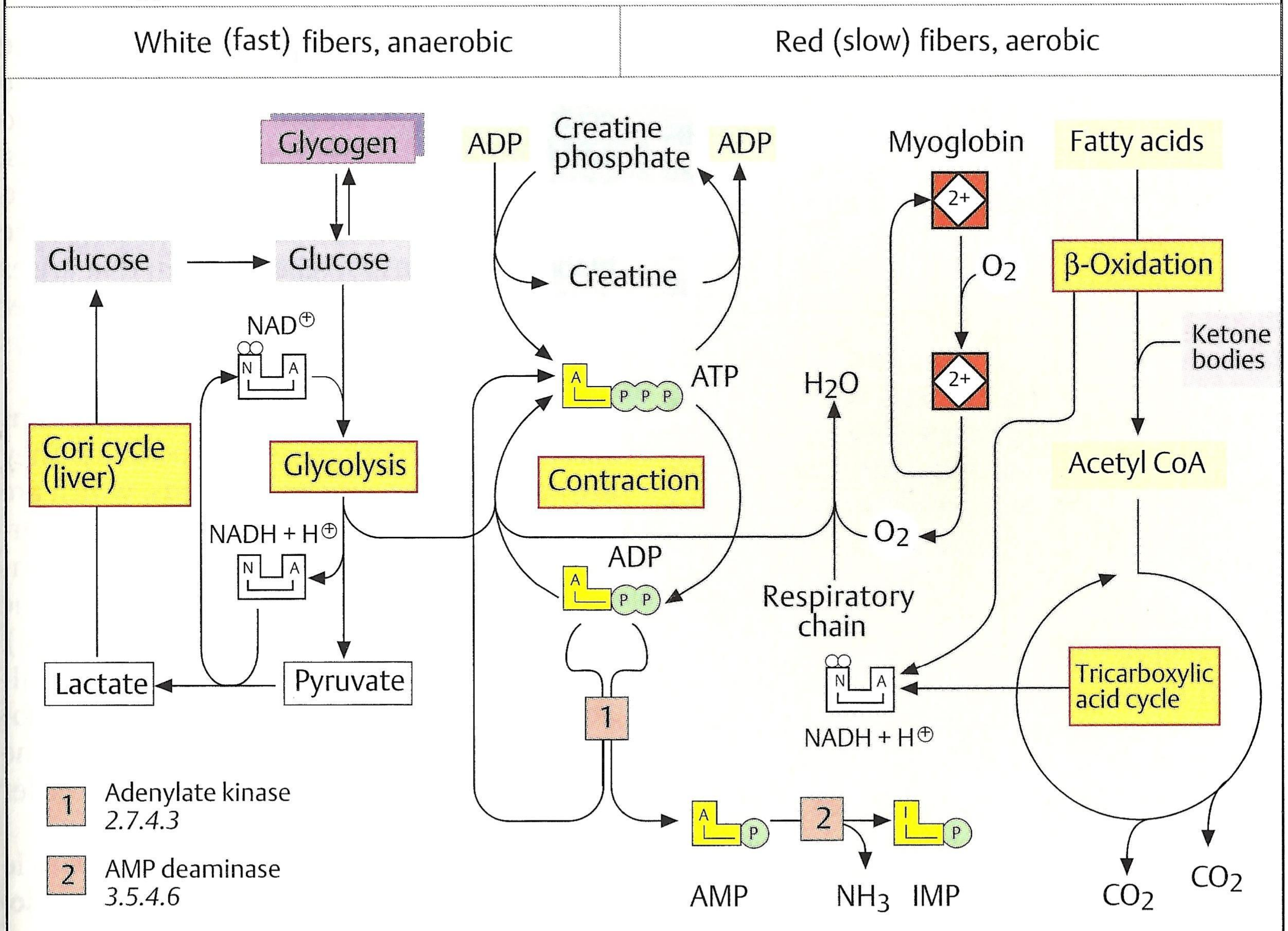
Aerobic metabolism in red muscle fibers

- Red muscle fibers are suitable for prolonged muscle activity
- Their metabolism is mainly:
  - Aerobic and
  - Depends on adequate supply of O_2
- They obtain ATP mainly from fatty acids
- Fatty acids are broken down by β-oxidation, Krebs cycle, and the respiratory chain

Aerobic metabolism in red muscle fibers

- Red color is due to myoglobin
- Myoglobin has higher O_2 affinity than hemoglobin
- It releases O_2 when its level drops

A. Energy metabolism in the white and red muscle fibers



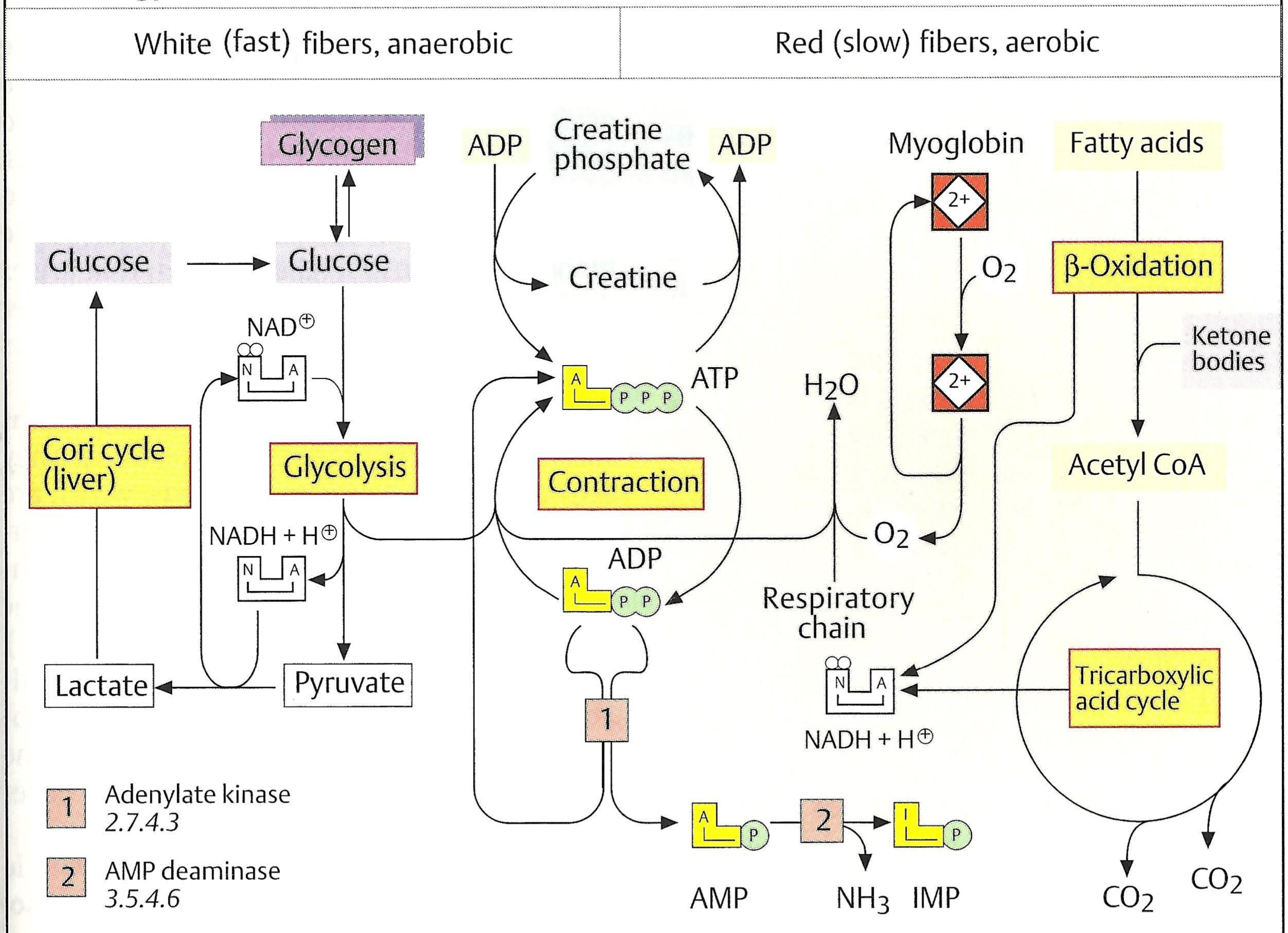
Anaerobic metabolism in white muscle fibers

- White muscle fibers are suitable for fast, strong contractions
- During intense muscle activity (weightlifting, etc.) O_2 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-PO_4 → glucose-6-PO_4 → 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

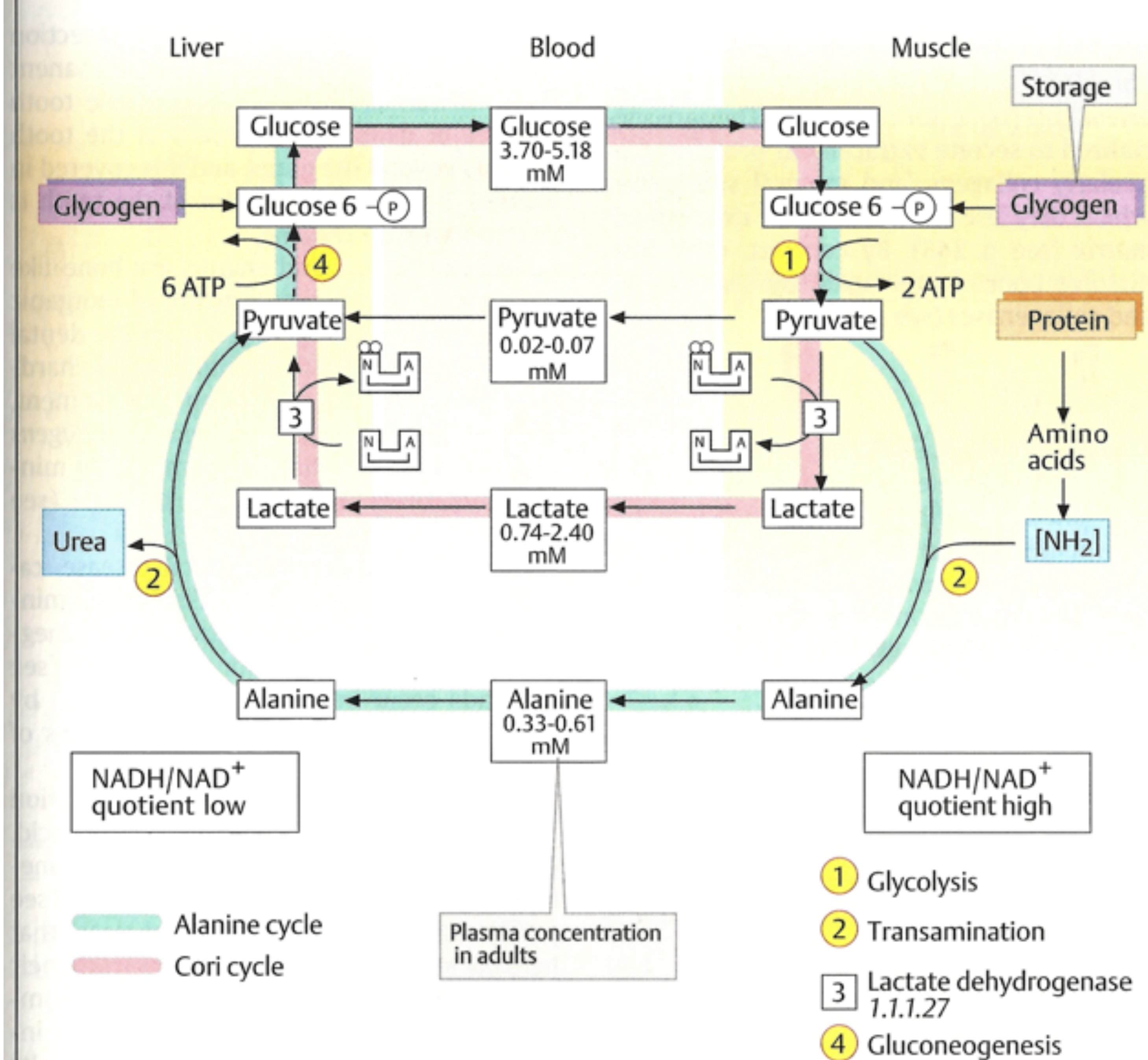
A. Energy metabolism in the white and red muscle fibers



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



The Cori Cycle

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

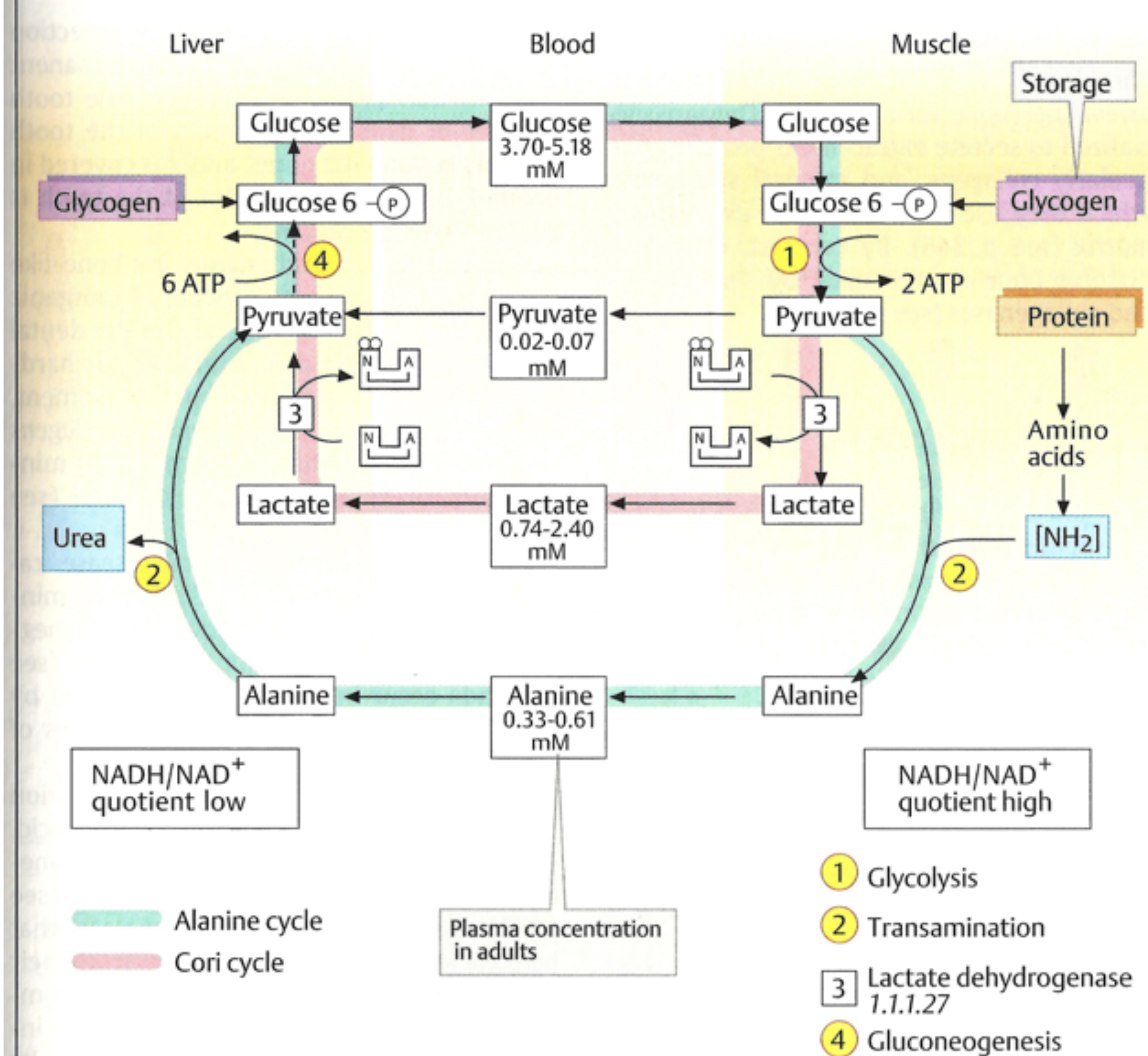
Because:

- Gluconeogenesis requires much more ATP than is supplied by glycolysis in muscle
- O_2 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 (NH_2) from normal protein degradation
- Pyruvate is converted to alanine in muscles
  - Pyruvate + NH_2 → Alanine

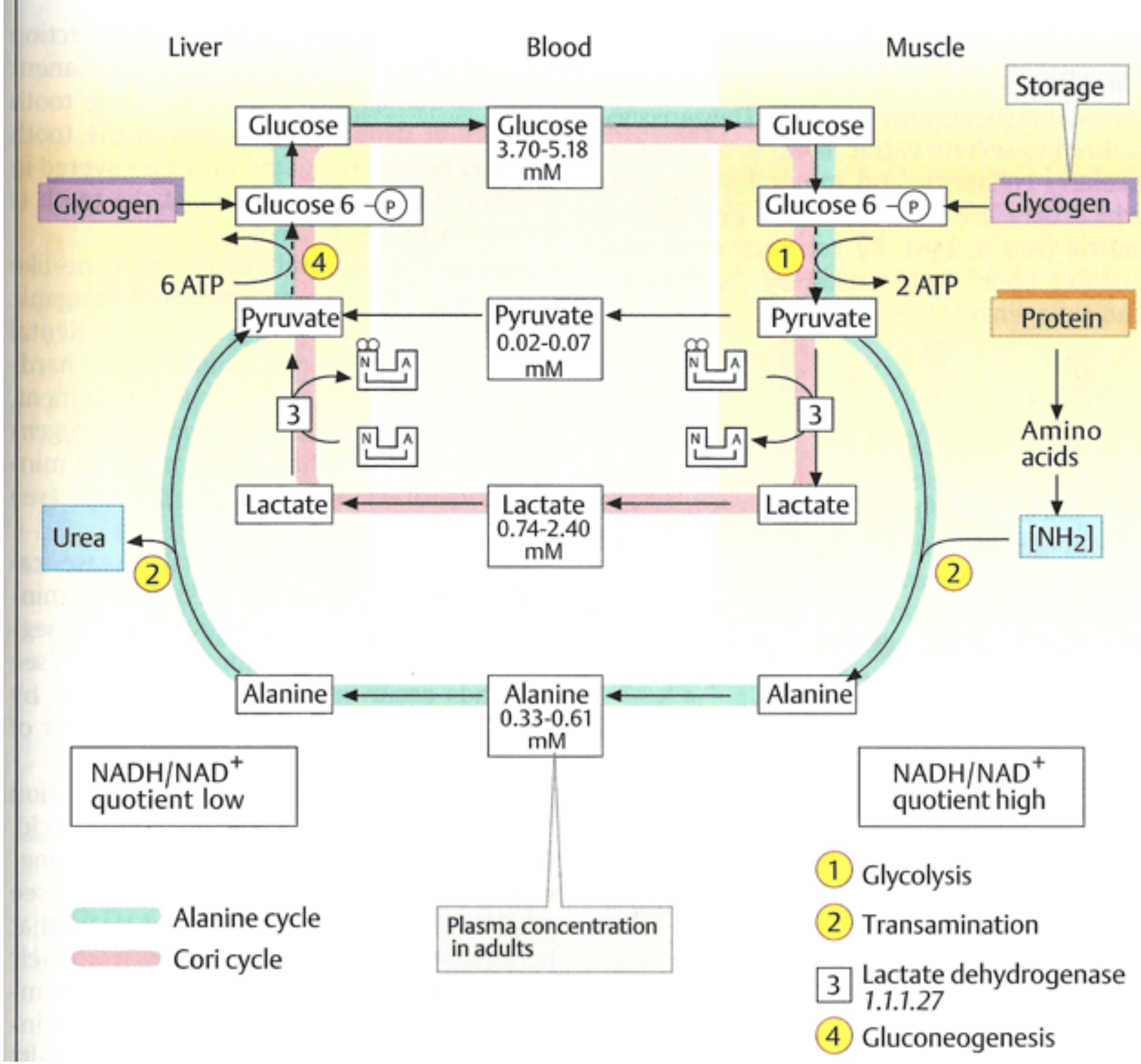
A. Cori and alanine cycle

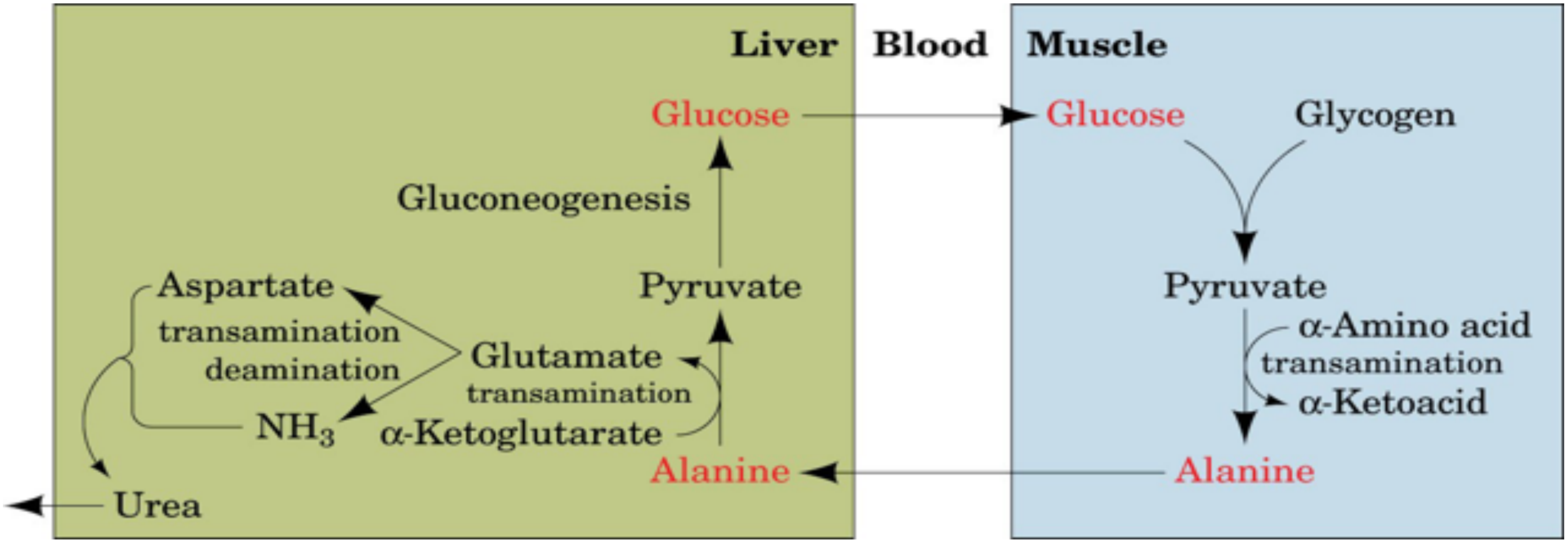


The glucose-alanine cycle

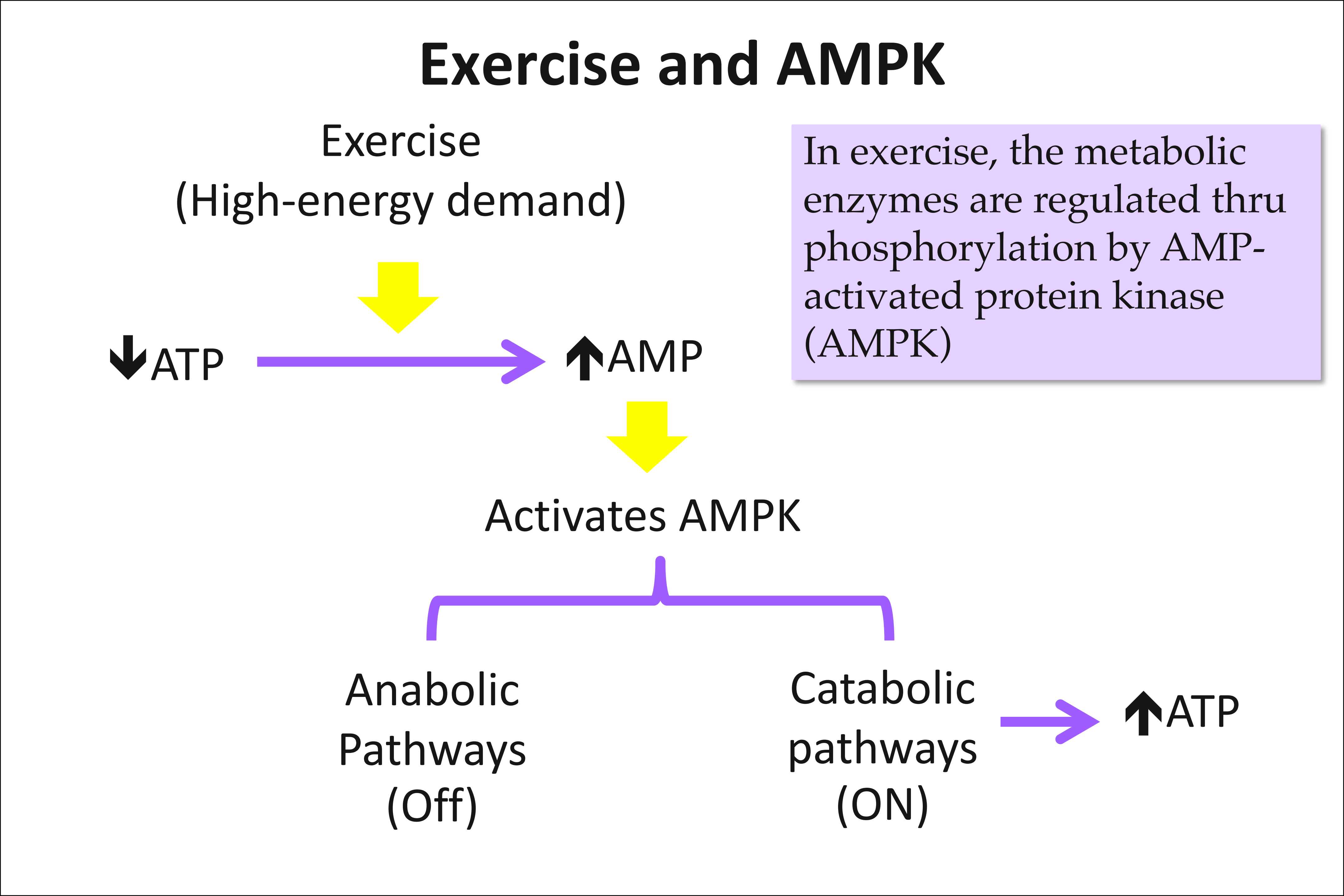
- This alanine is transported to liver
- Liver converts alanine back to pyruvate
  - Alanine – NH_2 = Pyruvate
- Pyruvate is used in gluconeogenesis
- The newly formed glucose is transported to muscle to be used for energy again

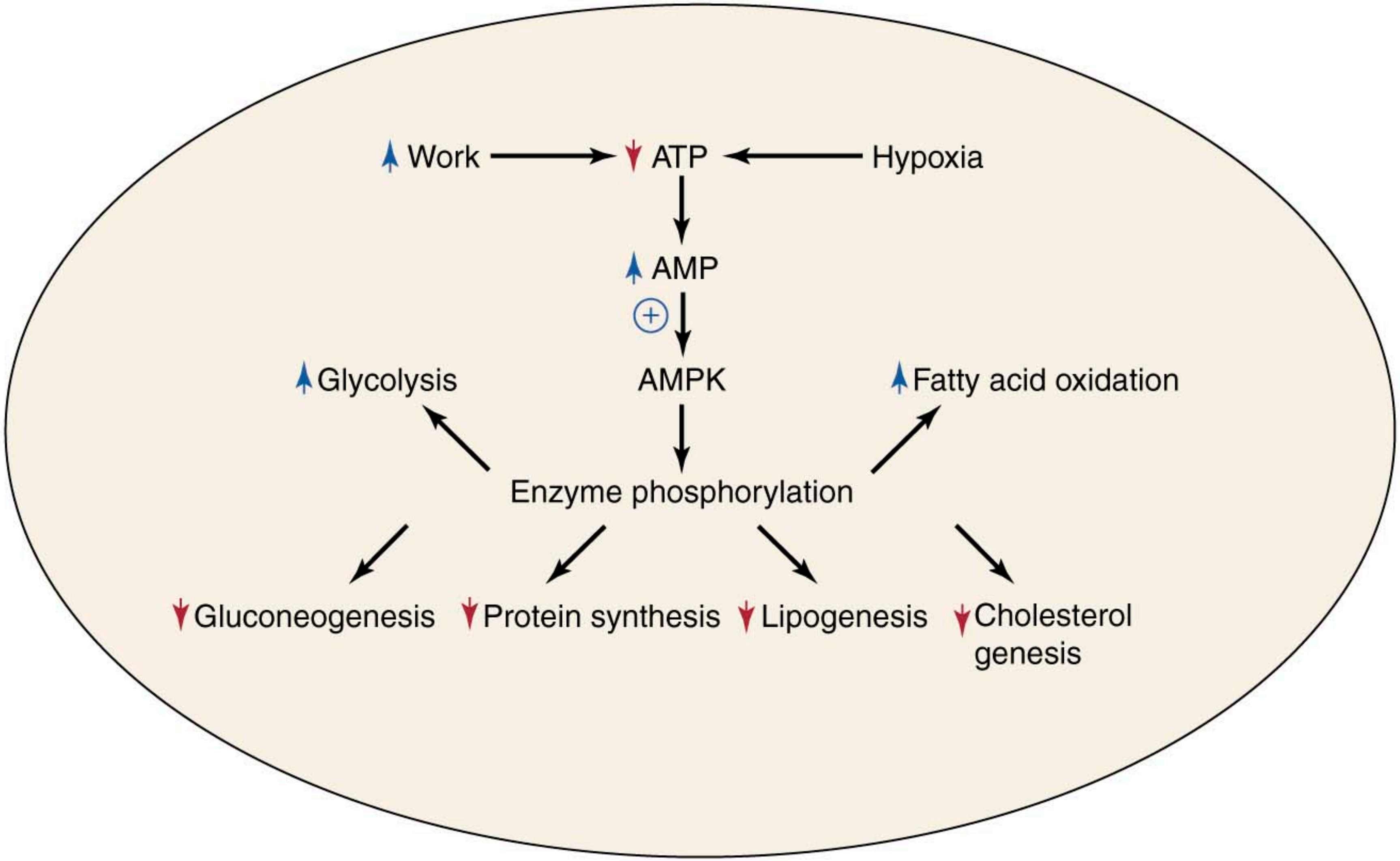
A. Cori and alanine cycle





The glucose–alanine cycle


Exercise and AMPK
Exercise
(High-energy demand)
↓ATP
↑AMP
Activates AMPK
Anabolic Pathways (Off)
Catabolic pathways (ON)
↑ATP
In exercise, the metabolic enzymes are regulated thru phosphorylation by AMP-activated protein kinase (AMPK)



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