بِسْم الله الرحمن الرحيم

# Aerobic and anaerobic metabolism in muscle

Biochemistry Team 437


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# Objectives:

- 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:

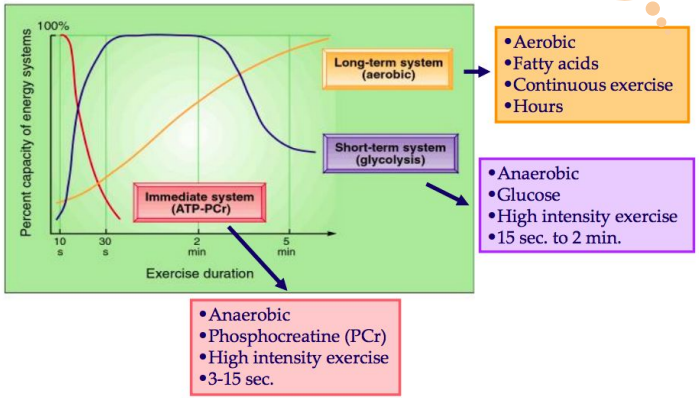
- Three systems of energy transfer
- ATP as energy source
- Aerobic metabolism: red muscle fibers
- Anaerobic metabolism: white muscle fibers
- Cori cycle ·Glucose-alanine cycle
- Muscle fatigue and endurance in athletes

# Systems of energy transfer

8-10 seconds — 1-Phosphocreatine system

1-1.5 minutes — 2-Anaerobic

Infinite — 3-Aerobic




From 436

| Type of system: | Immediate system (ATP-PCr) | Short term system (glycolysis) | Long term system (aerobic) |
|---|---|---|---|
| Type of metabolism: | Anaerobic | Anaerobic | Aerobic |
| Type of energy source: | Phosphocreatine (PCr) | Glucose | Fatty acid |
| type of exercise: | High intensity exercise | High intensity exercise (it happens when the muscle is contracting) | Continuous exercise (less intensity) |
| Duration: | 3-15 sec | 15 sec. to 2 min. | hours |

Notice that the three systems are overlapping

# ATP as an 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.)

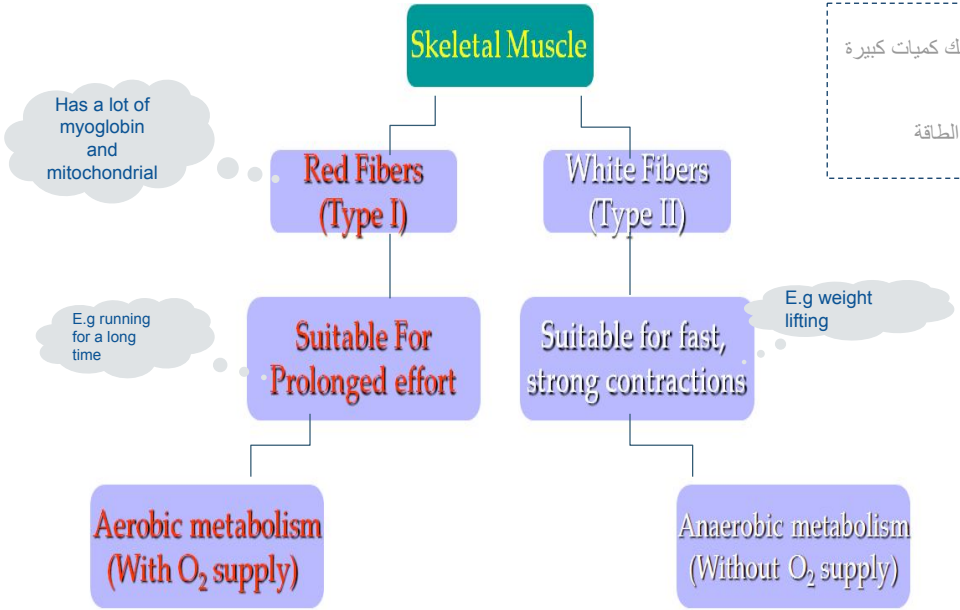
The main pathway for ATP synthesis is oxidative phosphorylation catalyzed by the respiratory chain ATP synthase catalyzes the synthesis of ATP

**ADP+Pi ——> ATP**

*ATP SYNTHASE*

# 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

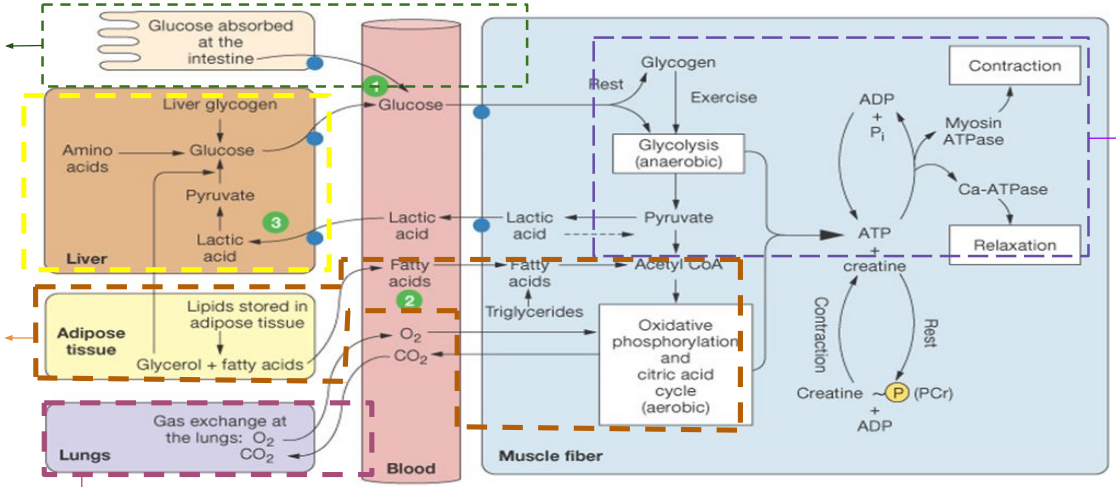



جزيئات ATP
تخزن بكمية محددة ووقت محدد وانقباض العضلات يستهلك كميات كبيرة من الطاقة ، وبدون اعادة تصنيع ، لن يكون متوفر ATP
وبالتالي لايمكن القيام بعملية انقباض العضلات لعدم توفر الطاقة

# Overview of Energy Metabolism in Skeletal Muscle

during rest, when you eat food, glucose gets absorbed at the intestine to blood, then it gets stored in the muscle as glycogen

adipose tissue will give fatty acid > goes to blood stream > goes to muscle fibers > get converted into Acetyl CoA> undergoes oxidative phosphorylation + O2 produced from the lung (aerobic pathway) to give ATP




Gas exchange happens at the lungs- when exercising, breathing increases for more O2 supplying. O2 is transferred through the blood as -bicarbonate, which is a major physiological buffer-

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.

Liver will give glucose from its stored glycogen or amino acid or by undergoing gluconeogenesis using fatty acid. -glucose then will go to blood stream then to the muscle fibers

During exercise, the glycogen will be burnt aerobically or anaerobically depending on the level of oxygen to produce pyruvate or lactate. And all of this metabolism will produce ATP, which will be used in muscle contraction to convert it to ADP

Summary : aerobic & anaerobic systems will produce ATP for muscle contraction through multiple systems

# Aerobic metabolism in red muscle fibers

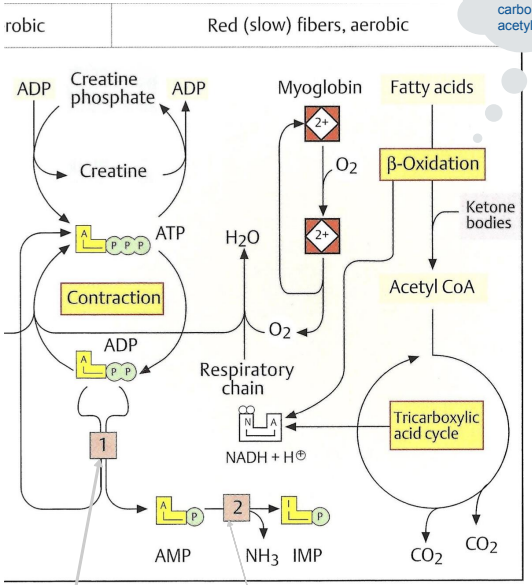
- Red muscle fibers are suitable for prolonged muscles activity
- Their metabolism is mainly Aerobic and Depends on adequate supply of Oxygen .
- They obtain ATP mainly from fatty acids.
- Fatty acids are broken down by b-oxidation,Krebs cycle, and the respiratory chain.

- The Red color of the muscle is due to myoglobin. "It has a lot of mitochondria as well"
- Myoglobin has higher oxygen affinity Than hemoglobin
- It releases oxygen when its level drops

- 1) Fatty acid are broken down by B-oxidation to produce acetyl CoA
- 2) Acetyl CoA enters the tricarboxylic acid cycle and produce NADH
- 3) NADH enters the respiratory chain
- 4) In the respiratory chain the final acceptor of the electron is oxygen which gets converted to water and makes ATP

- Another way to produce ATP molecule : (produce ATP in less amounts)
- Adenylate kinase (1) takes 2ADP joins them to make 1ATP and 1AMP

the process of degrading fatty acids by cutting the chains into units made of 2 carbons, making acetyl CoA



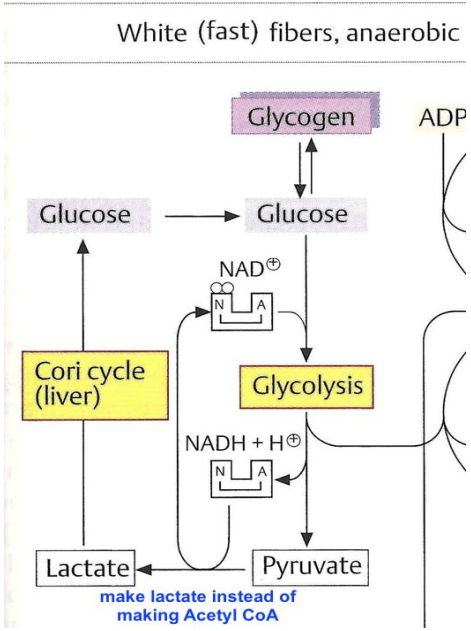

**Adenylate kinase:** joins 2 ADP molecules to make 1 ATP and 1Amp

**AMP deaminase:** part of the auxiliary system of energy along with adenylate kinase

# Anaerobic Metabolism in White Muscle Fibers

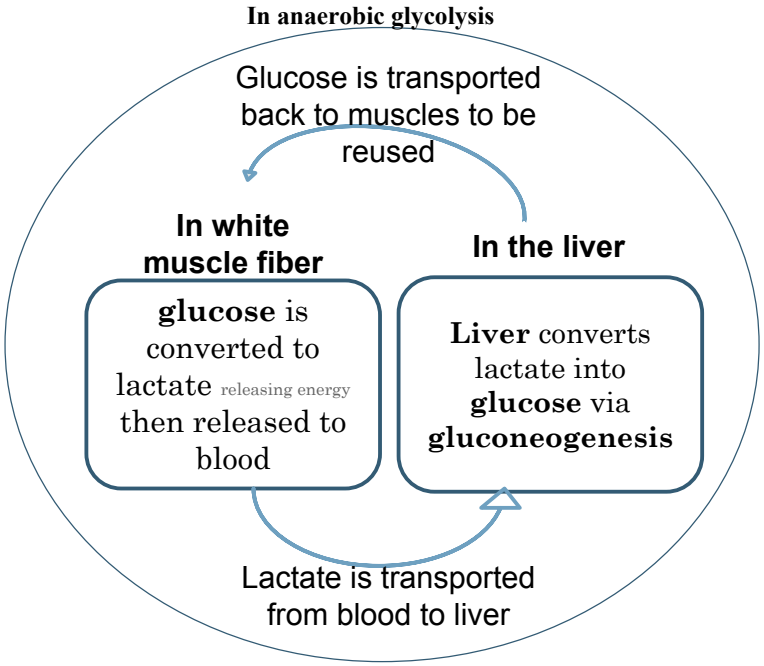
- White muscle fibers are suitable for fast, strong contractions
- They mainly obtain ATP from anaerobic glycolysis.
- During intense muscle activity (weightlifting, etc.) O2 supply from blood quickly drops, then the muscle will use anaerobic glycolysis.
- They have supplies of glycogen that is catabolized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

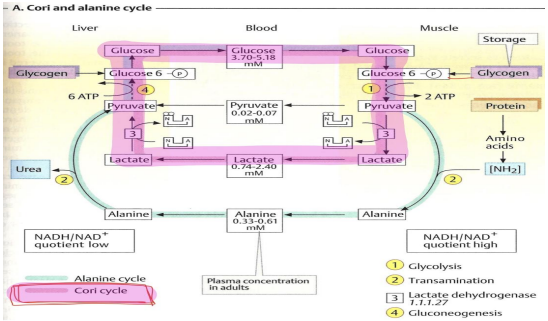
- Glycogen → glucose-1-PO4 → glucose-6-PO4 → glycolysis → ATP
- NADH+H+ is **re-oxidized** to maintain glucose degradation and ATP formation.
- Anaerobic glycolysis produces **lactate**
- Lactate is **resynthesized** into glucose in the liver by **Cori cycle**



# The Cori Cycle :

the **resynthesize** of Lactate into glucose in the liver




**skeletal muscles can ’t produce new glucose from lactate because:**

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

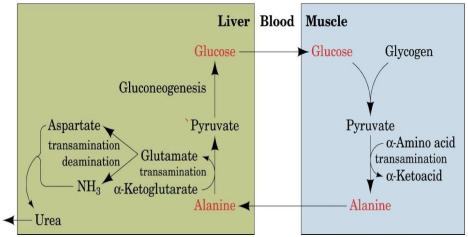
تصنيع الجلوكوز يتطلب طاقة عالية ما تقدر تصنعها عمليات الجلايكولسس بالعضلات

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

Therefore, liver always has sufficient ATP for gluconeogenesis

ولان الكبد ما يحصل فيه نقص بالاكسجين حتى خلال التمارين المكثفة فهو مصدر عالي للطاقة وهو المكان المناسب لتصنيع الجلوكوز من اللاكتيت

# The glucose-alanine cycle




Glucose

**In Muscle**

1)Glycolysis during exercise produces

⇩

Pyruvate

⇩

2)**Pyruvate + NH2** converted to **= Alanine**

⇩

3)Alanine transported to liver

Glucose

Alanine

**In Liver**

4) Glucose is transported back to muscles

⇧

3) Pyruvate is used in gluconeogenesis "glucose is synthesized "

⇧

2) Alanine - **NH2 = pyruvate**

⇧

1) Alanine converted back to pyruvate

Normal Protein degradation "Transamination" produces:

"α-keto acid depending on the protein"

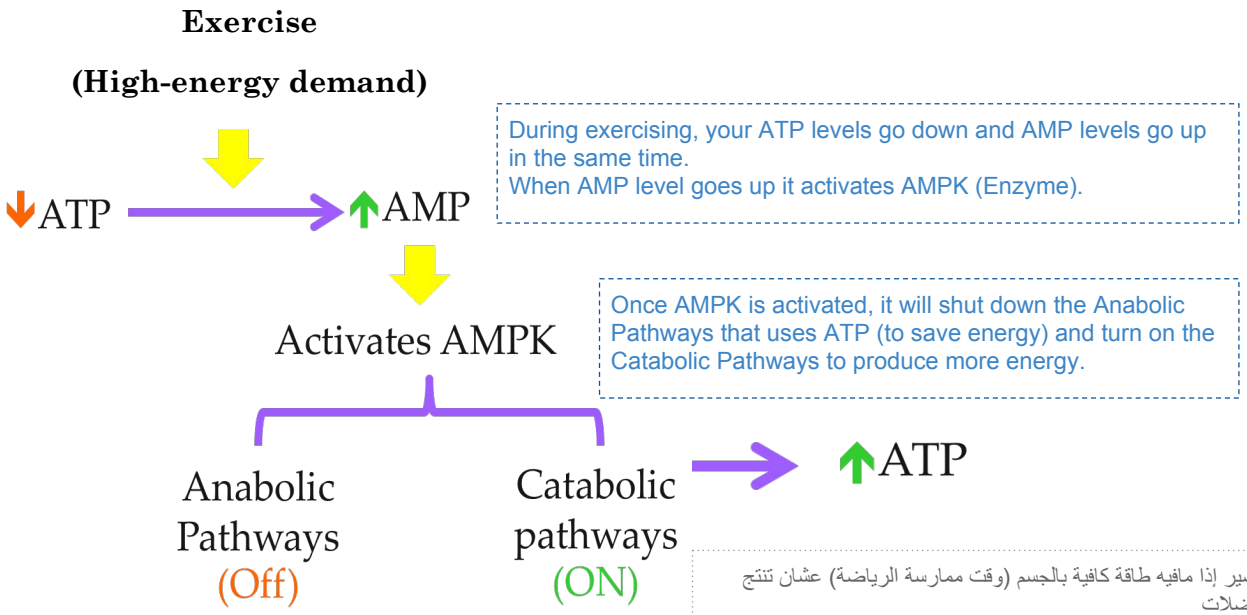
Amino nitrogen (NH2)

α-keto glutamate receives the NH2 to produce glutamate

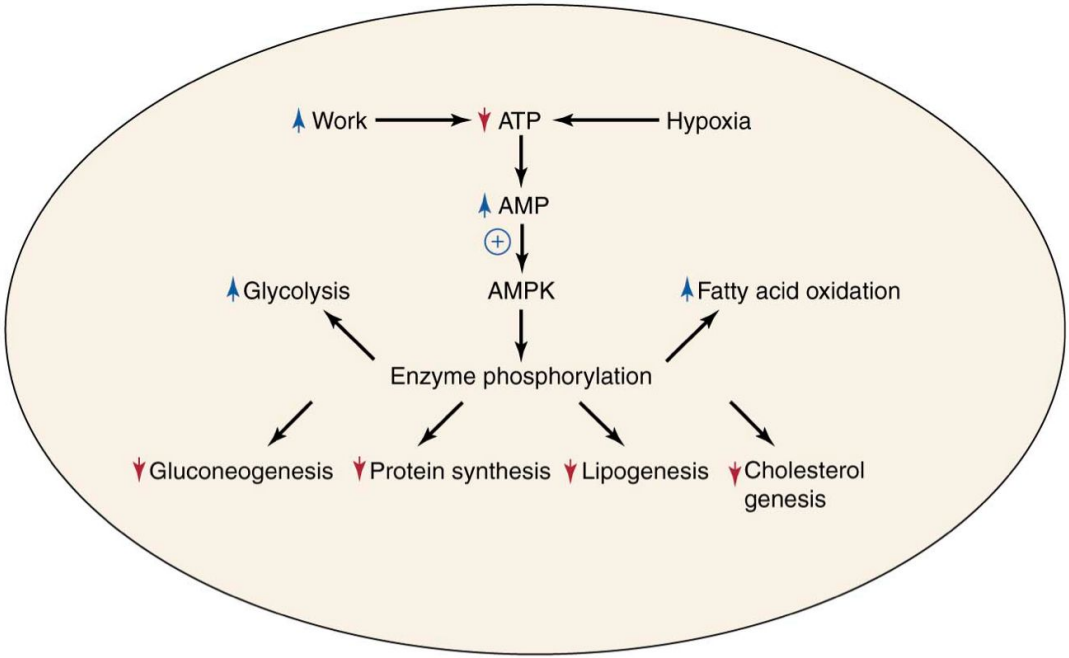
1-alanine is deaminated "remove amino group" to produce pyruvate
2- α-keto glutamate receives an amino group to make glutamate.
3-Glutamate is Removed by the urine, while pyruvate is used in gluconeogenesis in the liver.

# Exercise and AMPK

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




يعني ببساطة هذي العملية تصير إذا مافيه طاقة كافية بالجسم (وقت ممارسة الرياضة) عشان تنتج طاقة أكبر بحيث ما تجهد العضلات




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.

muscle damage ⟷ **Caused by:** ⟷ accumulation of lactic acid.

- Athletes are able to change the proportions of red and white muscle fibers by targeted training.
- The expression of muscle proteins (and enzymes) can also change during the course of training.
- **This provides them with:**
- High endurance during muscle activity.
- Efficient energy producing and consumption.
- Delayed fatigue.

**436:**

Athletes should train to have more red muscle fibers also they can convert white muscle fibers to red The red muscle fibers are better for them because it is suitable for prolonged effort + it is an aerobic which doesn't cause lactic acid formation which leads to muscle fatigue .

# Take home messages

- 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

# Summary

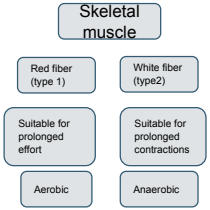
## Three systems of energy transfer

| **Type of system**: | Immediate system (ATP-PCr) | Short term system (glycolysis) | Long term system (aerobic) |
|---|---|---|---|
| **Type of metabolism**: | Anaerobic | Anaerobic | Aerobic |
| **Type of energy source**: | Phosphocreatine (PCr) | Glucose | Fatty acid |
| **type of exercise:** | High intensity exercise | High intensity exercise | Continuous exercise |
| **Duration** | 3-15 sec | 15 sec. to 2 min. | hours |

## ATP

- The main pathway for ATP synthesis is oxidative phosphorylation catalyzed by the respiratory chain
- The nucleotide coenzyme adenosine triphosphate (ATP) is the most important form of chemical energy stored in cells
- Without constant re synthesis, the amount of ATP is used up in less than 1 sec. of contraction.

## Energy metabolism in muscle




## there are 4 ways for muscle fibers to get energy

1- aerobic by red fibers
2-anaerobic by white fibers
3-creatine phosphate
4- by the enzyme adenylate cyclase;
(will take two ADP and produce 1 ATP & 1AMP)

**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.

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

**Muscle fatigue** Inability of muscles to maintain a particular strength of contraction over time. Causes: muscle damage, accumulation of lactic acid.

# MCQs

1. Which one is the shortest system of energy transfer

A) ATP-PCr  B) glycolysis  C)aerobic

2. Fatty acid are broken down by

A) alpha oxidation  B) beta oxidation  C) gamma  oxidation

3. Red color in red muscle fiber due to the rich of

A) hemoglobin  B) myoglobin  C) Oxygen

4. What is the normal fate of lactate in muscle

A) gluconeogensis in muscle  B) released into bloodstream  C) accumulate in muscle

5. Pyruvate  and ..... is converted to alanine

A) NH3  B) NH2  C) NH

Answers :

1. A
2. B
3. B
4. B
5. B

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