Biochemistry

Aerobic & Anaerobic metabolism in muscle

Color index:
-Main text -Girls' slides -Boys' slides
-Important - Dr's notes -Extra

Editing File

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

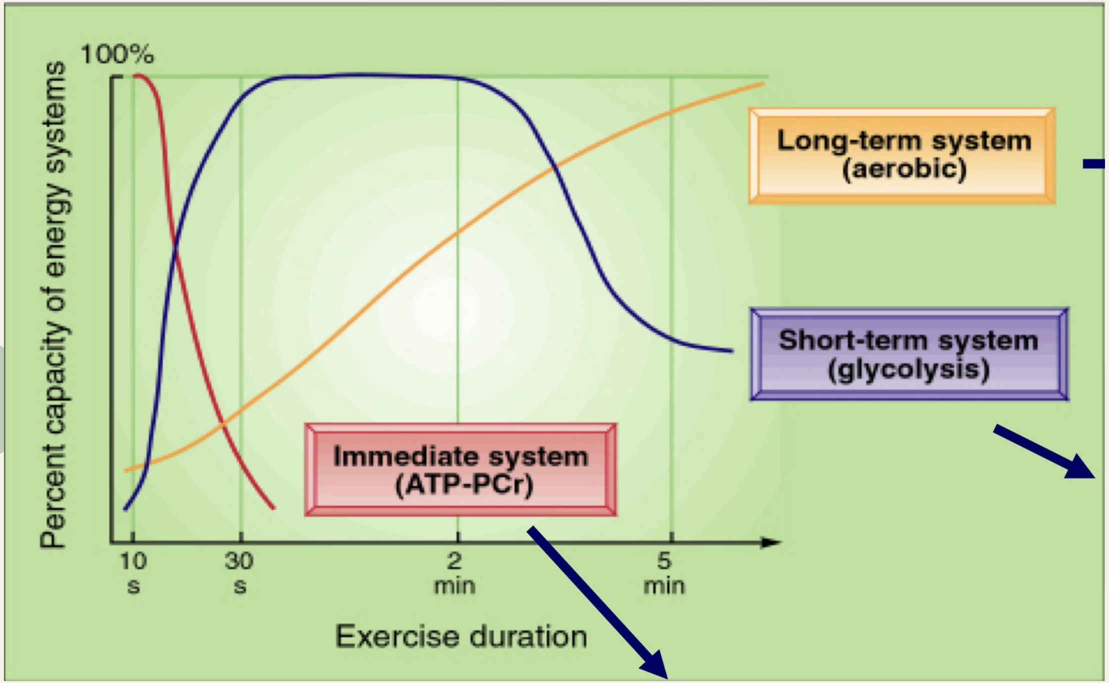
SAQ: every system with its properties

Systems of Energy Transfer

- All systems happen in the same time, but the predominant system in each duration/phase is:

	Immediate System (ATP-PCr)	Short-Term System (Glycolysis)	Long-Term System (Aerobic)
Type of Metabolism:	Anaerobic	Anaerobic	Aerobic
Energy Source:	PhosphoCreatine (PCr)	Glucose (Glycogenolysis)	Fatty acids
Type Of Exercise:	High intensity exercise	High intensity exercise	Continuous exercise
Duration:	3 - 15 sec	15 sec - 2 min	Hours

<u>SAQ:</u> every system with its properties



443: -you should know a couple of examples of high intensity and continuous exercise in case that you got a question with a different context.

High intensity exercise: (weight lifting)
Continuous exercise: (marathon race)

442: (الترتيب مهم)

ATP as Energy source

(The main pathway that produces large amount of energy is the aerobic)

1

The nucleotide coenzyme Adenosine TriPhosphate (ATP) is the most important form of chemical energy stored in cells

2

Breakdown of ATP (ATP → ADP+PO4) releases energy (7.3kcal/mol)

3

This energy from ATP is used for all body functions (biosynthesis, membrane transport, muscle contraction, etc.)

4

Main pathway for ATP synthesis: oxidative phosphorylation catalyzed by the respiratory chain (need O2) (Electron transport chain)

5

ATP synthase catalyzes the synthesis of ATP

$ADP + P_i \rightarrow ATP$

Energy Metabolism in Muscle

- Muscle contraction requires high level of ATP consumption.
- No constant resynthesis → amount of ATP (immediate) is used up (consumed) in less than 1 sec of contraction.

Skeletal Muscle

Red Fibers (Type I / slow twitch)

Suitable for:

Prolonged effort
e.g. marathon running

Metabolism:

Aerobic metabolism (with O2 supply)

White Fibers (Type II / Fast twitch)

Suitable for:

Fast, strong contractions
e.g. weight lifting

Metabolism:

Anaerobic metabolism (without O2 supply)

White fibers have a lot of glycogen
↓
Anaerobic metabolism
↓
Produce lactate
↓
Lactate accumulate causing pain
↓
Can't exercise for a long duration

Overview of Energy Metabolism in Skeletal Muscle

1

In intestines: glucose is absorbed → enters blood circulation → enters muscle fibers

2

In muscles:

At rest: glucose is converted into glycogen

When exercising: glucose undergoes anaerobic glycolysis (glucose → pyruvate → lactic acid)

1st method to generate ATP

- Lactic acid is transported to the liver through the blood

3

In liver: glucose is produced either from:

1. Lactic acid from step 2 (by anaerobic glycolysis)
2. Liver glycogen
3. Amino acids

4

In muscles: acetyl CoA in muscles is produced either from:

1. Pyruvate from step 2 (if the glycolysis was aerobic)
2. Fatty acids from lipids in adipose tissues (β-Oxidation)

Acetyl CoA + O_2 (from lungs) → enter Krebs/Citric acid cycle (aerobic metabolism)

2nd method to generate ATP

5

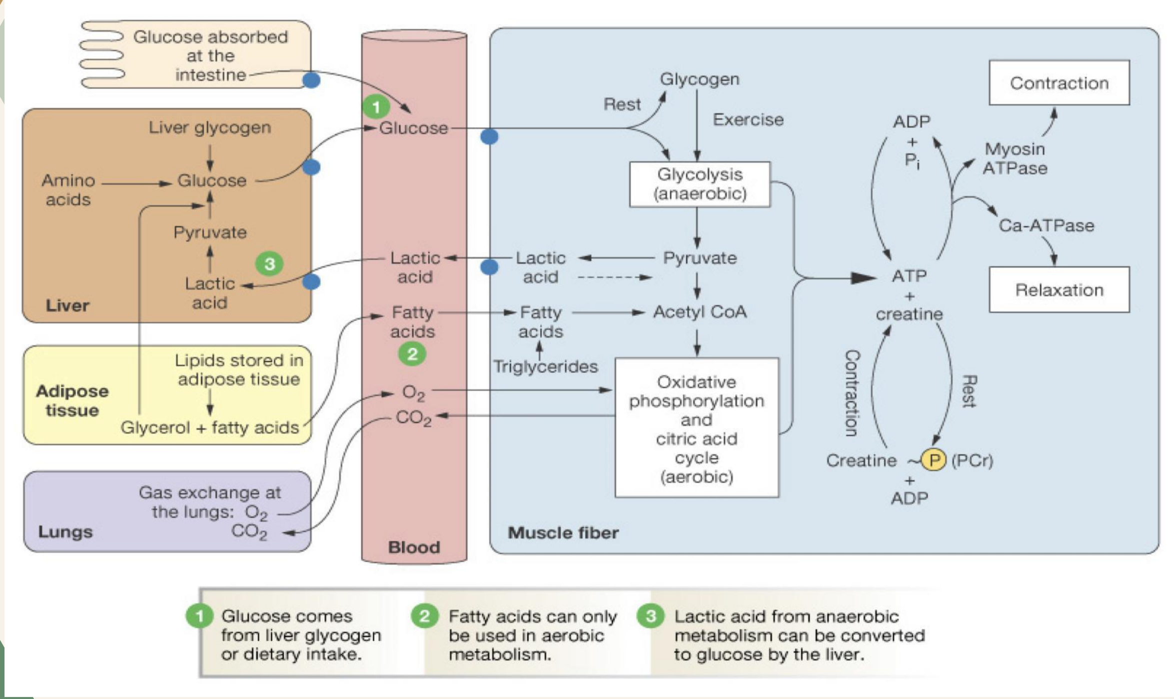
Fate of ATP in muscles:

At rest: converted into creatine phosphate (PCr)

When exercising:

1. Creatine phosphate is converted back into ATP + Creatine
2. ATP is converted into ADP
   - ATP is utilized (used) by:
     - Myosin-ATPase (in contraction)
     - Ca-ATPase (in relaxation)

443: An Extra Slide from Doctors' Explanation



441:
NB:
- glucose can enter krebs cycle if the glycolysis was aerobic ONLY.
- if it was anaerobic glycolysis it will be converted into lactate.
- Fatty acid can only be used in aerobic metabolism (β-Oxidation)

Aerobic Metabolism in Red Muscle Fibers

Red muscle fibers have a lot of blood vessels and mitochondria

1. Suitable for: prolonged muscle activity

2. Metabolism:
   - Mainly Aerobic
   - Depends on adequate supply of O2

3. Obtain ATP mainly from: fatty acids

4. Fatty acids are broken down by: B-oxidation, Krebs cycle, and Respiratory chain

5. Red color is due to myoglobin

6. **Myoglobin:**
   - Higher O2 affinity than hemoglobin.
   - Releases O2 when its level drops

IMPORTANT: compare

Hemoglobin:	Myoglobin:
function: transport O2	Function: Storage of O2
Oxygen: Have 4	Oxygen: Have 1
Location: in blood	Location: in muscles

1

In red fibers:
Fatty acids break down by β-Oxidation producing acetyl CoA
Acetyl CoA enters krebs cycle producing NADH + H^+

2

NADH and O2 (from myoglobin) enter electron transport chain to produce ATP

3

The fate of ATP in muscle fibers was explained in: overview of energy metabolism in skeletal muscle, step 5

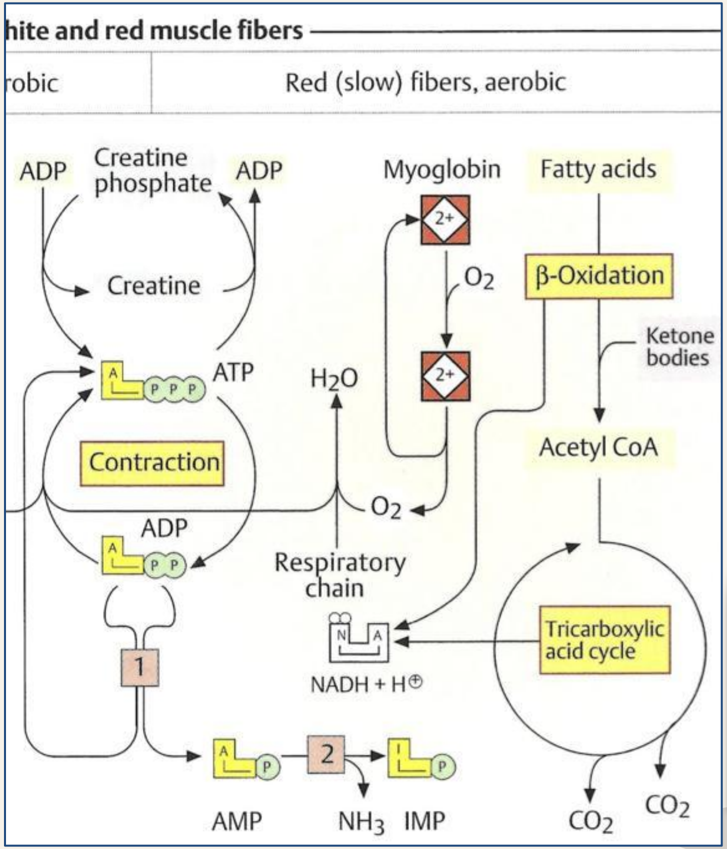
441:

<u>The muscle fiber at rest:</u>

- Glucose → glycogen
- ATP → creatine phosphate

<u>The muscle fiber during exercise:</u>

- Glycogen → glucose → pyruvate
- Creatine phosphate → ATP + creatine
- ATP → ADP



AMP deaminase is important

Anaerobic Metabolism in White Muscle Fibers

NB: when we say glycogen we mean glucose also, because glycogen will be catabolized into glucose

1

Suitable for:
fast, strong contractions

2

Intense muscle activity (weightlifting) → O_2 supply from blood quickly drops

3

Obtain ATP mainly from:
anaerobic glycolysis

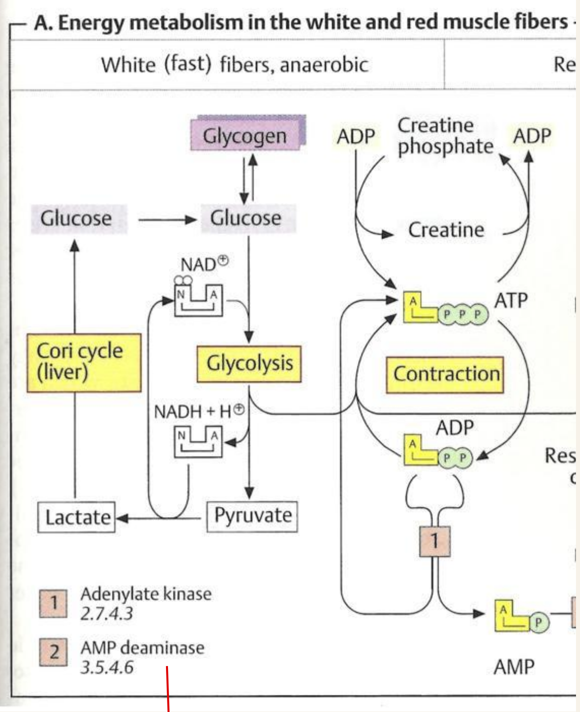
4

Have supplies of glycogen that is catabolized & undergoes glycolysis

Click here to watch an example of intense muscle activity

Ronnie : Light Weight

1	Glycogen → glucose-1-PO4 → glucose-6-PO4 → ATP (by glycolysis).
2	NADH and H+ are re-oxidized into NAD+ (by converting pyruvate into lactate) to maintain glucose degradation + ATP formation. (the reason why pyruvate is converted to lactate -it's important to know why-)
3	Anaerobic glycolysis produces lactate
4	Lactate is resynthesized into glucose in the liver by Cori cycle (next slide).



the enzyme responsible of converting pyruvate into lactate is **Lactate dehydrogenase**

AMP deaminase is important

The Main Process:

Glycogen → glucose → glucose-1-PO4 → glucose-6-PO4 → glycolysis → pyruvate → lactate → go to liver "**Cori cycle**"

glycolysis → ATP

pyruvate → bind with NH2 → alanine

The cori cycle

I

In the muscle: glucose is converted into lactate by anaerobic glycolysis.

II

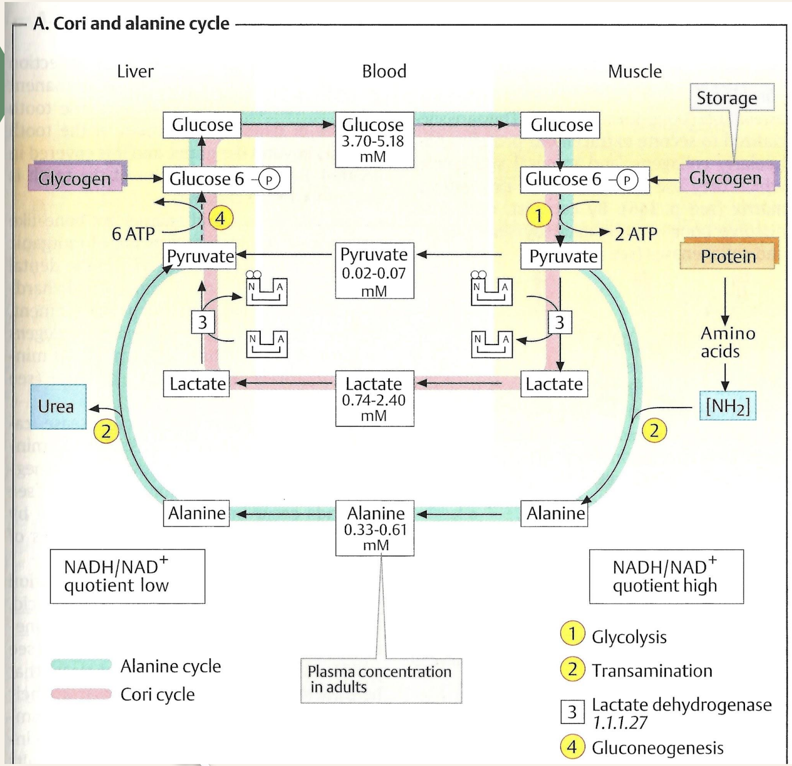
Lactate is released into the blood and is transported to the liver.

III

In the liver: Lactate → glucose (gluconeogenesis).

IV

The newly formed glucose is transported to the muscles (for energy again).



Lactate dehydrogenase is important

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

•Gluconeogenesis requires (6 ATP) much more ATP than is supplied by glycolysis (2 ATP) in muscle.

• O2 deficiencies don't arise in liver even during intense exercise → liver always has sufficient ATP for gluconeogenesis.

the enzyme responsible of converting pyruvate into lactate is **Lactate dehydrogenase**

Glucose-Alanine Cycle

Muscles produce:

1. Pyruvate From glycolysis, during exercise.
2. Amino Nitrogen NH2 from normal protein degradation (Toxic)

Med43:Pyruvate is either converted into lactate and enters cori cycle, or binds with NH2 forming alanine entering the Alanine cycle

Start

Pyruvate is converted to alanine in muscles

Pyruvate + NH2 →Alanine

2

Alanine is transported to the liver

3

Liver converts alanine back to pyruvate

Alanine – NH2 → Pyruvate

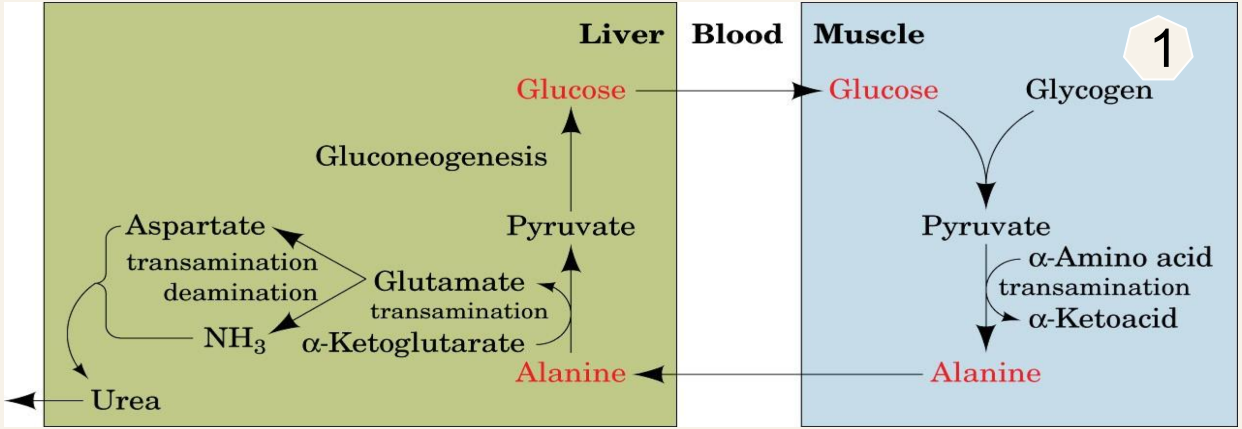
4

Pyruvate forms glucose by gluconeogenesis in liver

Pyruvate → Glucose

End

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



Med44:

Transamination convert a-amino acid to a-ketoacid and produce NH2, NH2 with pyruvate become alanine, the alanine transport by the blood to the liver, in liver the transamination convert a-ketoglutarate to glutamate by add NH2 from the alanine, glutamate enters in urea cycle

Exercise and AMPK

Exercise
(High-energy demand)

↓ ATP → ↑ AMP

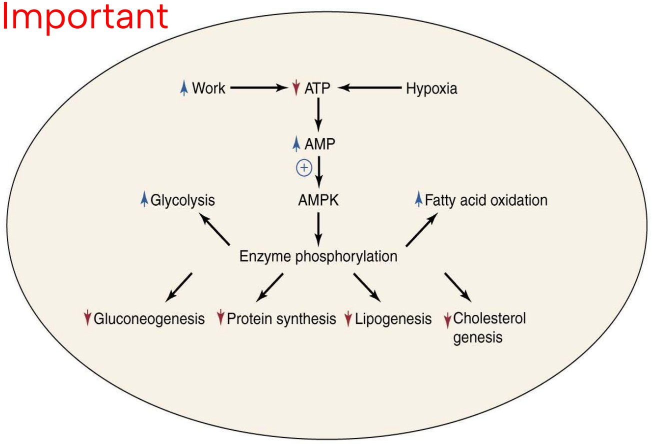
Activates AMPK

Anabolic Pathwas (Off)

Catabolic pathways (ON) → ↑ ATP

- Exercise = high energy demand.
- During exercise, metabolic enzymes are regulated through phosphorylation by AMP-activated protein Kinase (AMPK).
- AMPK activation shuts down ATP-requiring (they are decreased, not completely stopped) processes (anabolic) & stimulates ATP-producing (catabolic) processes.

Important



Muscle Fatigue and Endurance in Athletes

Muscle Fatigue

Definitions

Muscle fatigue: Inability of muscles to maintain a particular strength of contraction over time

Causes

- muscle damage
- accumulation of lactic acid

Muscle Fatigue and Endurance in Athletes cont..

Effects of Training

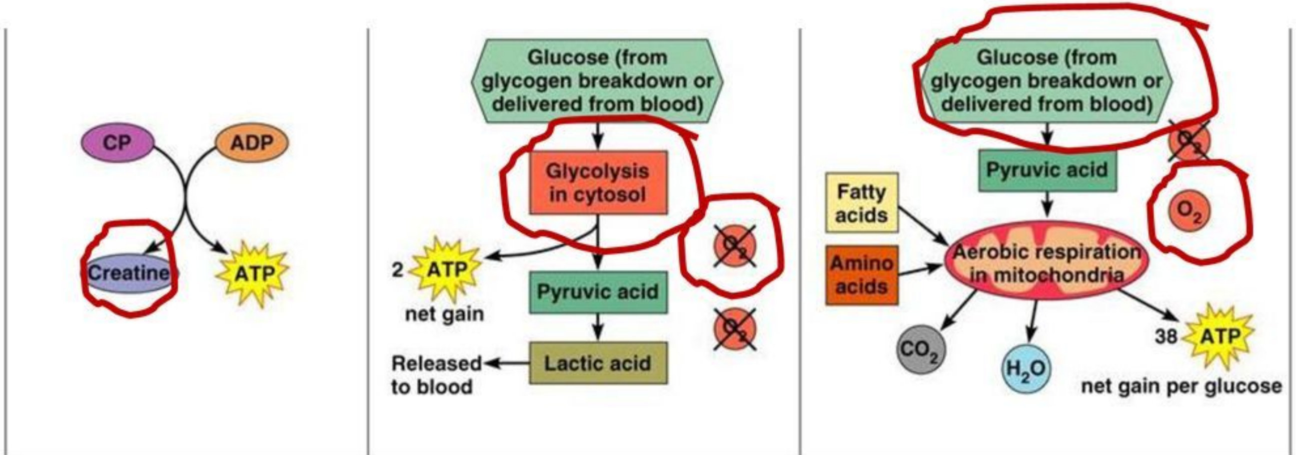
Target training can change the properties of red & white muscle

The expression of muscle proteins can also change during the course of training, provides them with:

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

Girls' slides

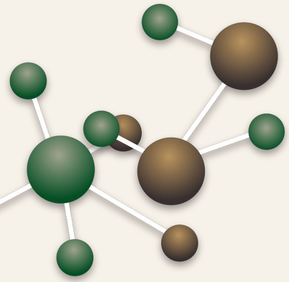
Muscle Metabolism

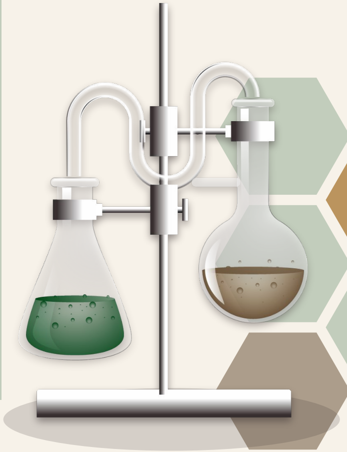


(a) Direct phosphorylation [coupled reaction of creatine phosphate (CP) and ADP]	(b) Anaerobic mechanism (glycolysis and lactic acid formation)	(c) Aerobic mechanism (aerobic cellular respiration)
Energy source: CP	Energy source: glucose	Energy source: glucose; pyruvic acid; free fatty acids from adipose tissue; amino acids from protein catabolism
Oxygen use: None Products: 1 ATP per CP, creatine Duration of energy provision: 15 s.	Oxygen use: None Products: 2 ATP per glucose, lactic acid Duration of energy provision: 30–60 s.	Oxygen use: Required Products: 38 ATP per glucose, CO_2, H_2O Duration of energy provision: Hours

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





Multiple choice questions

1

Q1:Which of the following structures or forms that red muscle fiber uses as a source of ATP?

A)Fatty acids oxidation	B) Glycogen	C) Amino acids	D) Glucose

2

Q2:What is the source of O2 in red muscles fiber?

A) Alanine	B) Myoglobin	C) Fatty acids	D) Glucose

3

Q3:What is the source of energy in white muscles fiber?

A) creatine	B) Fatty acids	C) Glycogen	D) Both A&C

4

Q4: :AMPK activation will shuts down all of these processes except:

A) Lipogenesis	B) glycolysis	C) protein synthesis	D) gluconeogenesis

MCQ Answers : 1)A 2)B 3)D 4)B

Meet our Team

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