Biochemistry
Team 434

Aerobic and anaerobic metabolism in muscle

Musculoskeletal Block

Color index

Red= Important
Purple= Addition
Orange= Explanation

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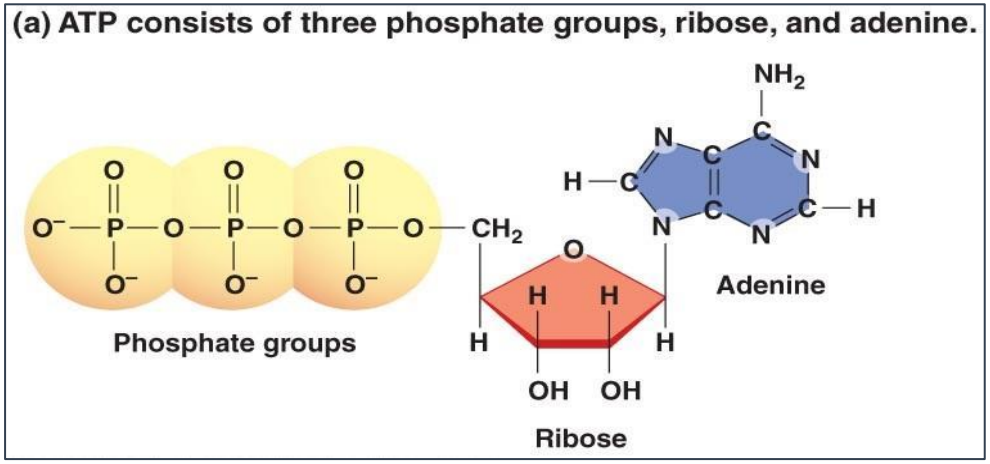
Objectives:

1. Recognize the importance of ATP as energy source in skeletal muscle.

2. Understand how skeletal muscle derive and utilize ATP for energy.

3. Differentiate between energy metabolism in red and white muscle fibers.



Adenosine TriPhosphate

-Adenosine Triphosphate (coenzyme) is the most important form of chemical energy stored in cells.

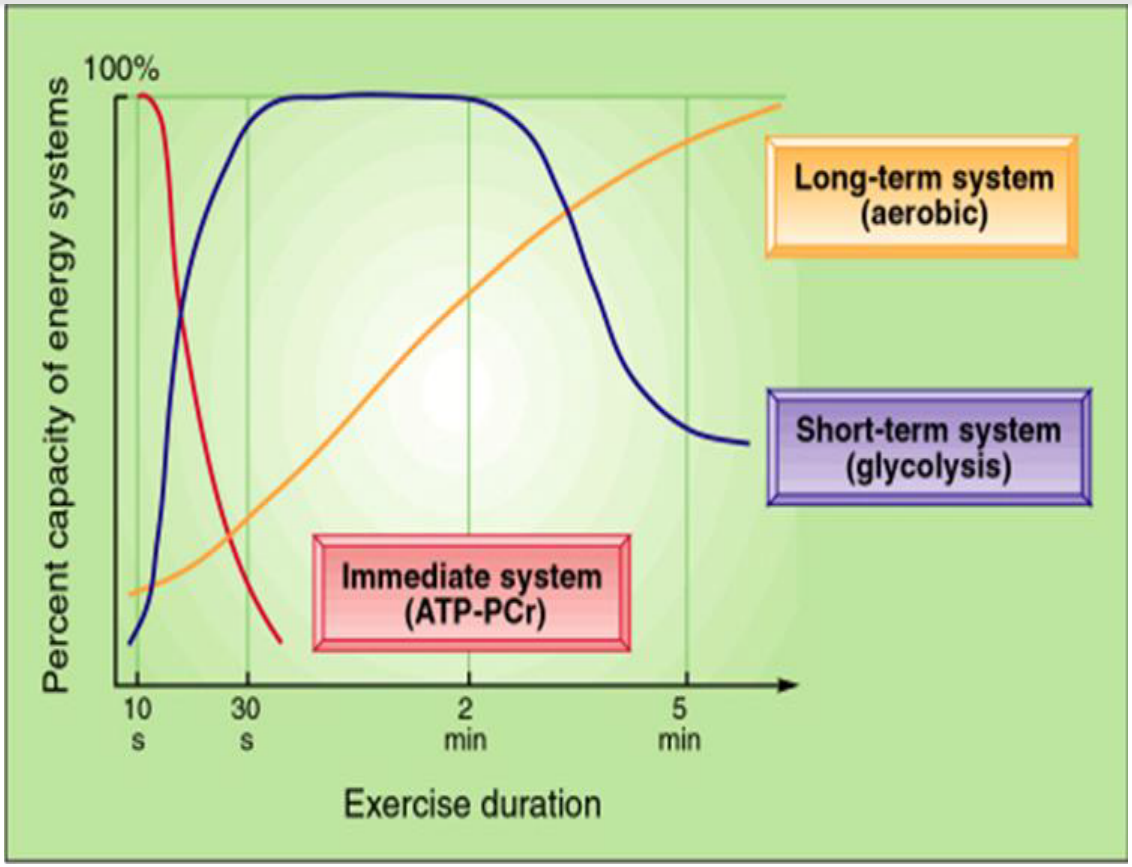
-Breakdown of ATP into ADP+PO4 releases energy, this energy is used for all body function

-Muscles typically store limited amount of ATP enough to power 4-6 seconds of activity.

-Muscle Contraction requires huge amount of ATP. So resting muscles must have energy stored in other ways.

Muscle fibers produce ATP in 3 ways:

1. Creatine phosphate.
2. Aerobic metabolism.
3. Anaerobic metabolism.



- The three energy systems often operate simultaneously during physical activity.
- Relative contribution of each system to total energy requirement differs significantly on exercise (intensity & duration).
- Magnitude of energy from anaerobic sources depends on: person's capacity and tolerance for lactic acid accumulation (Athletes are trained so that they will have better tolerance for lactic acid)
- As exercise intensity diminishes and duration extends beyond 4 minutes, energy become more dependent on (Aerobic metabolism)

Energy Metabolism

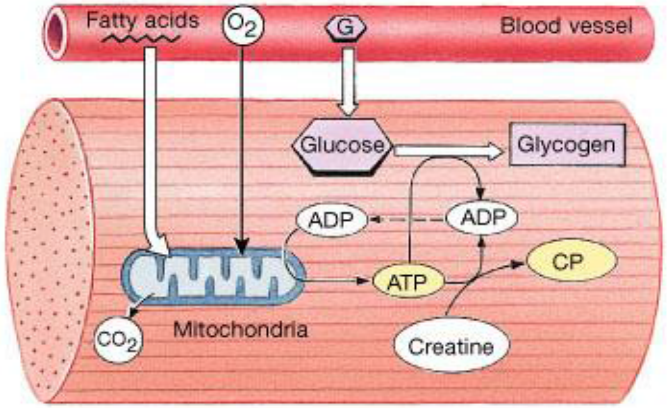
Aerobic

- ✓ With oxygen.
- ✓ Source of energy: mainly fatty acids, then carbohydrate.
- ✓ End products: CO_2, H_2O & ATP.

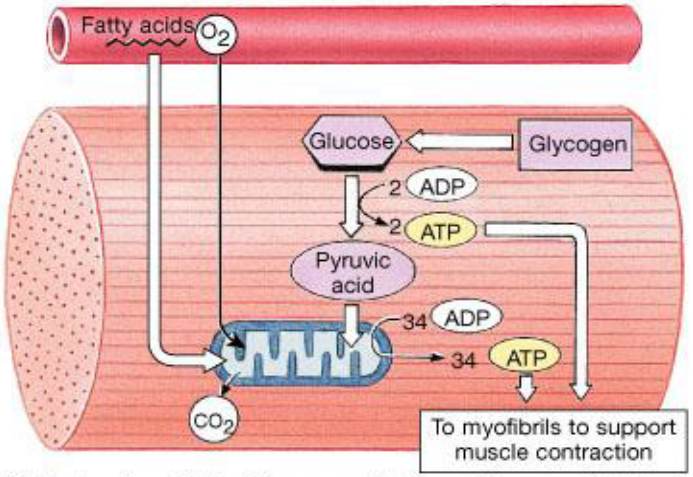
Anaerobic

- ✓ Without oxygen.
- ✓ Source of energy: Carbohydrate (glycolysis).
- ✓ End products: Lactate & ATP.

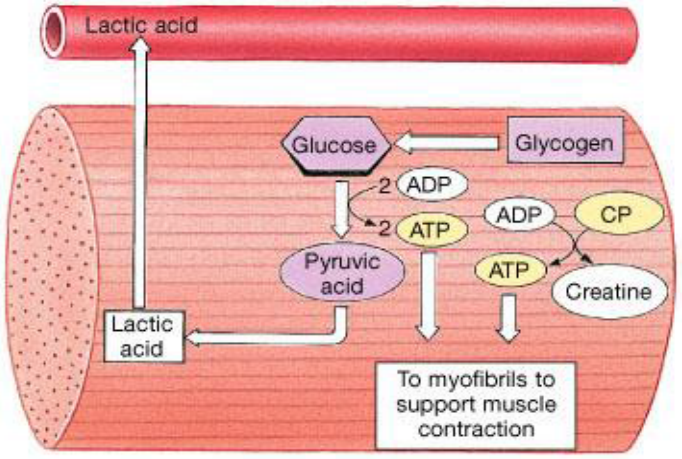
Muscle Metabolism



(a) Resting muscle: Fatty acids are catabolized; the ATP produced is used to build energy reserves of ATP, CP, and glycogen.



(b) Moderate activity: Glucose and fatty acids are catabolized; the ATP produced is used to power contraction.



(c) Peak activity: Most ATP is produced through glycolysis, with lactic acid as a by-product. Mitochondrial activity (not shown) now provides only about one-third of the ATP consumed.

Muscle Fatigue

- Fatigued muscle no longer contracts due to:

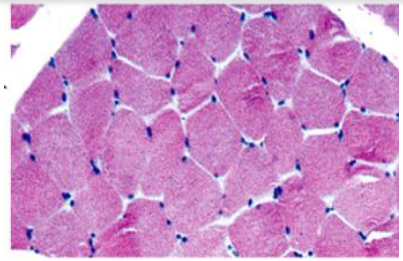
✓ Build up of lactic acid (low pH of sarcoplasm){NOTE: when there is excessive anaerobic metabolism}

✓ Exhaustion of energy resources (↑ADP & ↓ ATP)

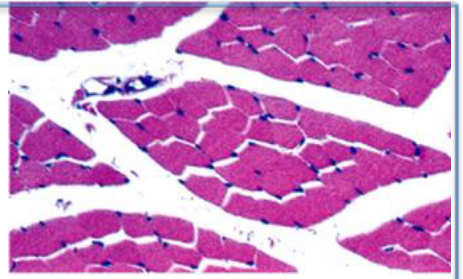
✓ Ionic imbalance

❖ How would a fatigued muscle be able again to contract?

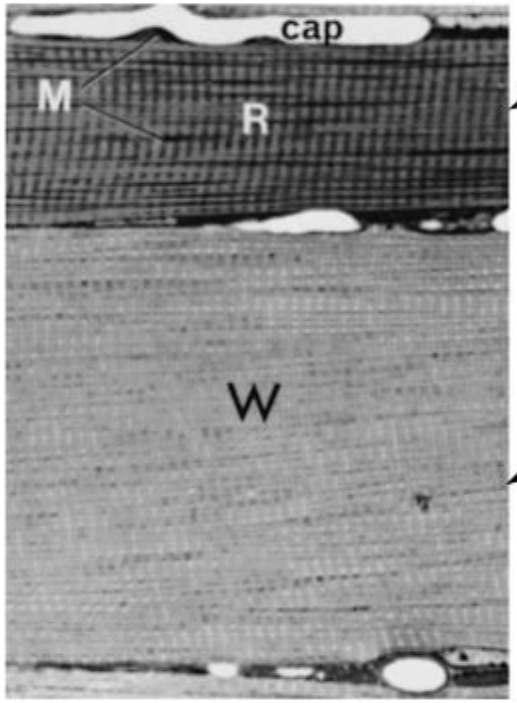
-Recovery period: Begins immediately after activity ends
-Oxygen debt (excess post-exercise oxygen consumption):
  ◦Amount of oxygen required during resting period to restore muscle to normal conditions



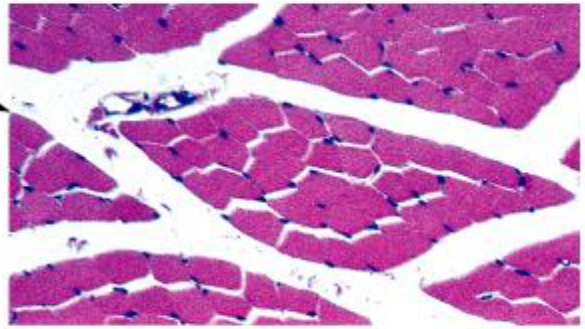
Types of skeletal Muscle Fibers



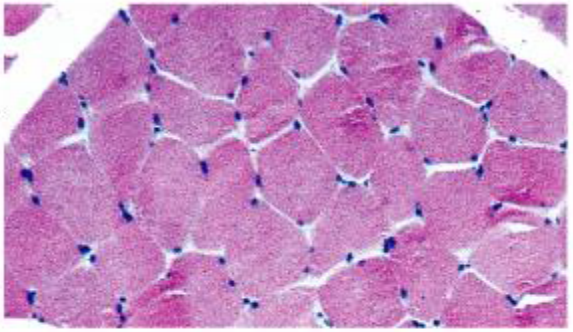
FAST FIBERS(white ,glycolytic)	SLOW FIBERS (Red, Oxidative)
1-Large in diameter	1-Half the diameter of fast fibers
2-Contain densely packed myofibrils	2-Take three times as long to contract after stimulation
3-Large glycogen reserves	3-Abundant mitochondria
4-Relatively few mitochondria	4-Extensive capillary supply
5-Produce rapid, powerful contractions of short duration	5-High concentrations of myoglobin
6-Easily fatigued	6-Can contract for long periods of time
7-Obtain their ATP mainly from **Anaerobic glycolysis**	7-Fatigue resistant
	8-Obtain their ATP mainly from FA - **oxidation, TCA cycle, and the ETC**



Slow-twitch oxidative muscle fibers
Note smaller diameter, darker color due to myoglobin. Fatigue-resistant.



Fast-twitch glycolytic muscle fibers
Larger diameter, pale color. Easily fatigued.



Q-Why do chickens have white breast meat and dark leg meat? Why do migrating ducks have dark breast meat?

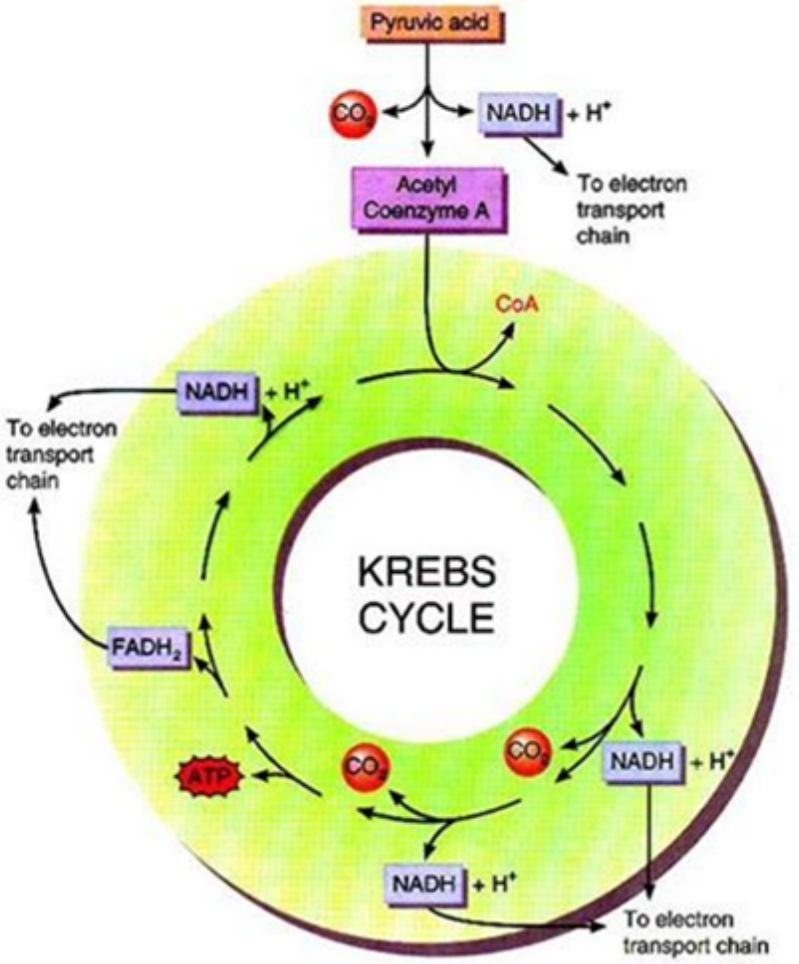
A-because of the myoglobin,blood capillaries and mitochondria ,long term activities need more oxygen,more blood supply and more mitochondria.

صدر البط يكون أحمر لإن البط يعتمد عليه في الهجرة بينما في الدجاج تكون الأرجل حمراء لإنها لا تطير بل تعتمد على المشي بشكل أساسي

أي نشاط طويل المدى يحتاج الأكسجين والميتوكندريا بشكل أكثر فتكون العضلة حمراء والعكس صحيح.

Resting Muscle & the Krebs Cycle

- Resting muscle fibers typically take up fatty acids from the blood stream.
- Inside the muscle fiber, the FA's* are oxidized (in the mitochondria) to produce Acetyl-CoA & several molecules of NADH and FADH2
- Acetyl-CoA will then enter the Krebs cycle (in the mitochondria) → CO2, ATP, NADH, FADH2, and oxaloacetate
- NADH and FADH2 will enter the **Electron Transport Chain**. (in the inner mitochondrial membrane) → synthesis of ATP



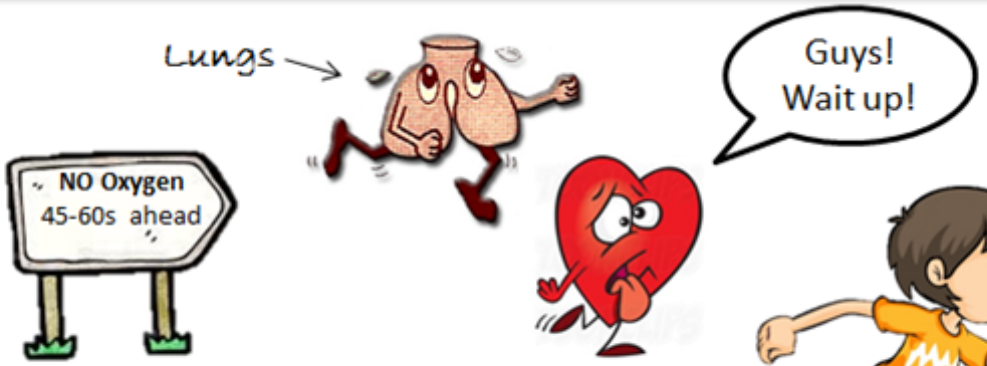
What is going on in a resting muscle?

*FA= Fatty Acid

ATP Use in the Resting Muscle Cell

ATP is necessary for cellular housekeeping duties, e.g.:

- ATP is used for glycogenesis (storage form of glucose)
- ATP is used to create another energy storage compound called creatine phosphate



100m dash
Weight lifting

Basketball

Source of energy

Stored ATP
Immediately used

Creatine-phosphate
For the next 15s

Anaerobic metabolism*
ATP supply for about 45-60s

Aerobic metabolism*
Occurs when the respiratory and cardiovascular systems have "caught up with" the working muscles.

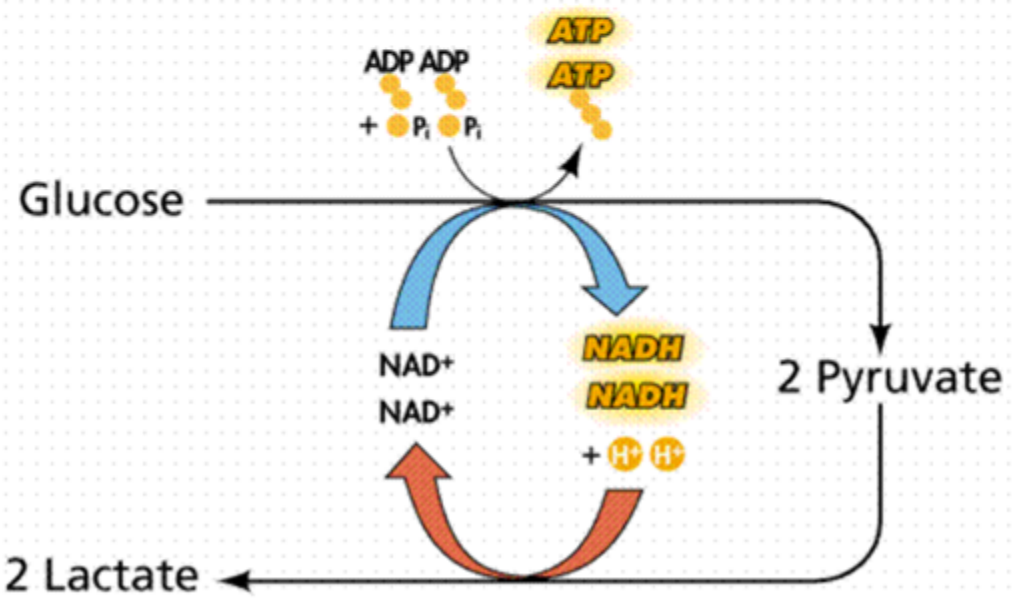
*Explanation follows..

What is going on in a contracting muscle?

Anaerobic Metabolism

(45-60s)

- It usually takes a little time for the respiratory and cardiovascular systems to catch up with the muscles and supply O2 for aerobic metabolism, so the anaerobic metabolism is used meanwhile…
- Glycogen → Glucose → 2 pyruvic acid (2 ATP + 2NADH)
- 2 Pyruvic acid → 2 lactic acid (2 NAD+)
- Lactic acid diffuses out of muscles → blood → taken by the liver → Glucose (by gluconeogenesis) → blood → taken by the muscle again

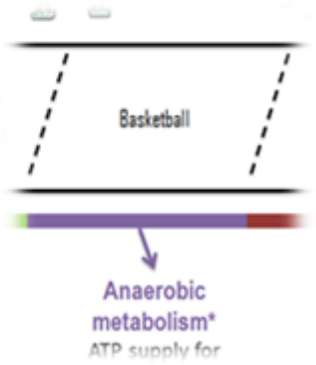


What is going on in a contracting muscle?

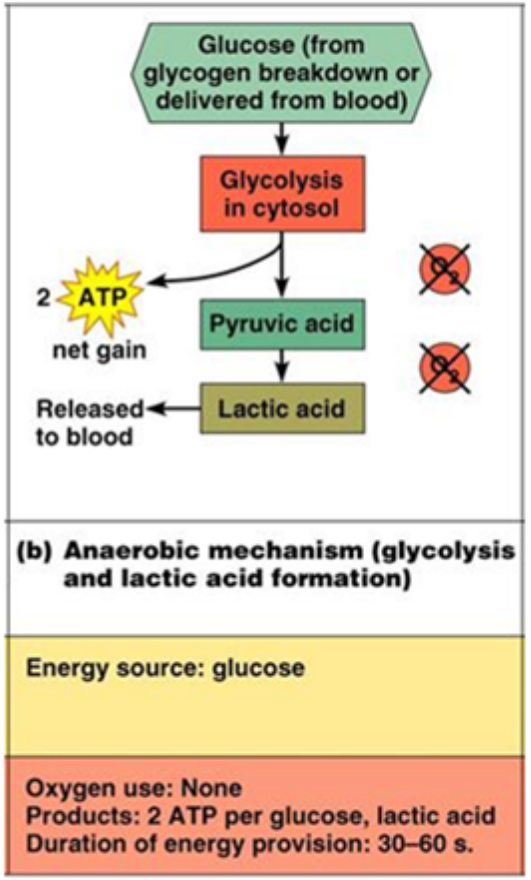
Anaerobic Metabolism

(45-60s)

- **Why is the anaerobic metabolism insufficient?**
  - Large amounts of glucose are used for very small ATP returns.
  - Lactic acid is produced whose presence contributes to muscle fatigue
- **Which type of sports uses anaerobic metabolism?**
  - Sports that require bursts of speed and activity, e.g., basketball.



..You know

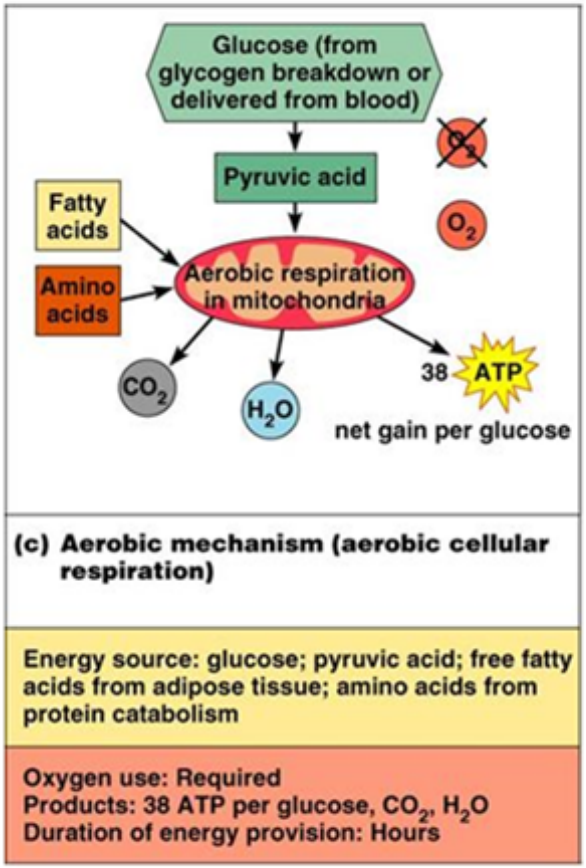


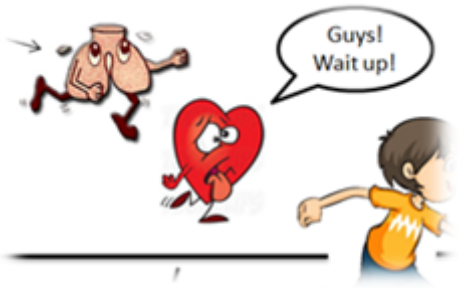
What is going on in a contracting muscle?

Aerobic Metabolism

- Occurs when the respiratory and cardiovascular systems have "caught up with" the working muscles.
  - Prior to this, some aerobic respiration will occur thanks to the muscle protein, myoglobin, which binds and stores oxygen.
- During rest and light to moderate exercise, aerobic metabolism contributes 95% of the necessary ATP.
- Compounds which can be aerobically metabolized include:

  Fatty acids, Pyruvic acid (made via glycolysis), and amino acids.





What is going on in a contracting muscle?

❖ Cycles:

During exercise there are 2 cycles between muscles and liver and both form new Glucose:

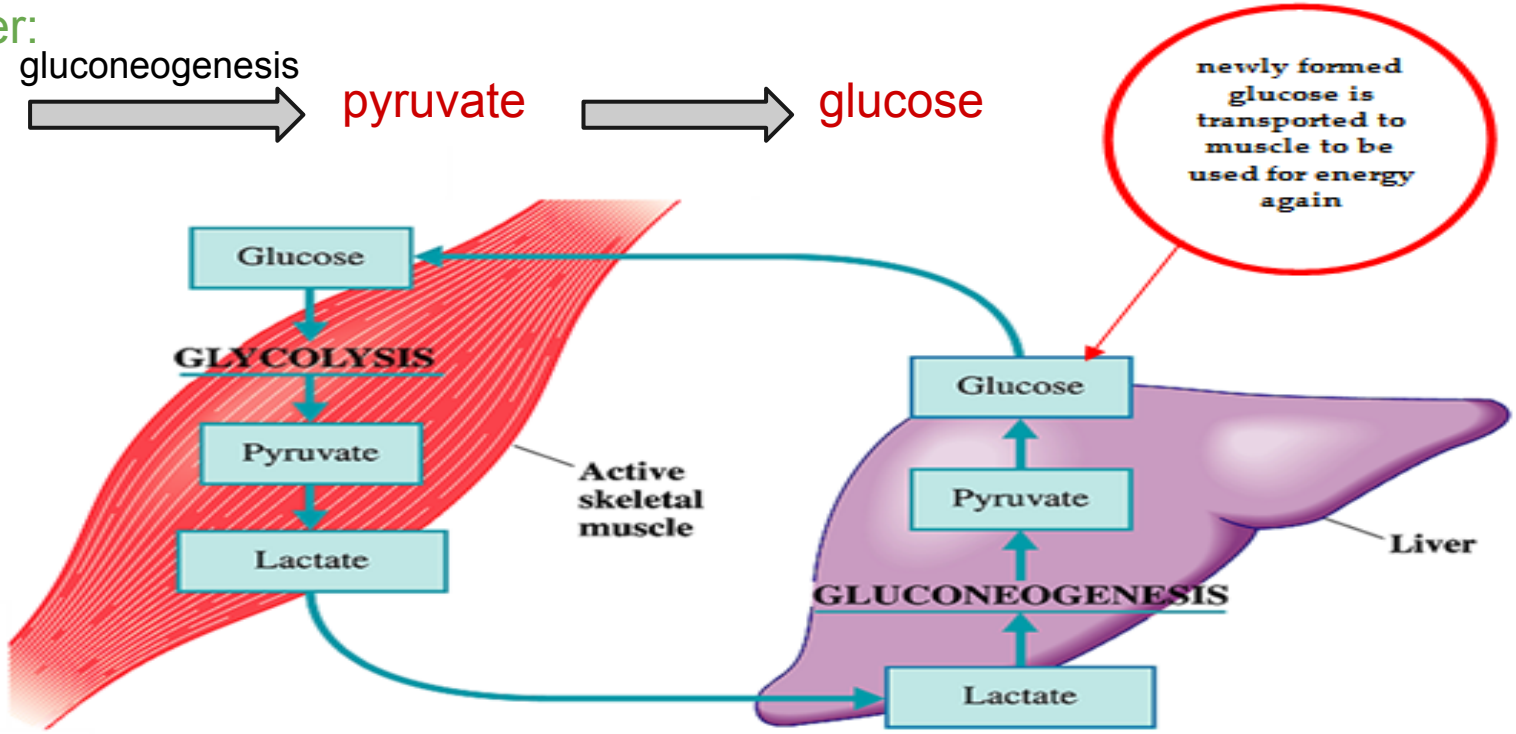
1. The cori cycle:

- muscle:

glucose —(glycolysis)→ pyruvate —(lactate dehydrogenase)→ lactate

- liver:

lactate —(gluconeogenesis)→ pyruvate → glucose



2.The glucose-alanine cycle:

-Do you remember protein degradation??

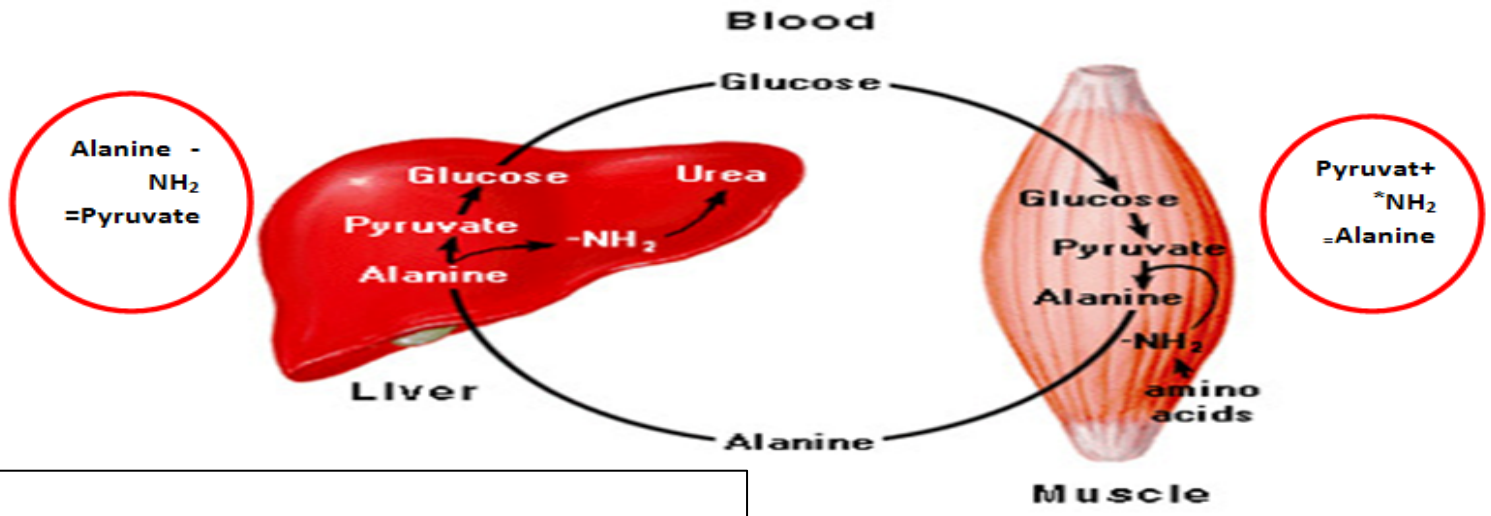
In muscle:

- α amino acid → α keto acid.

this beautiful couple will give NH_2* to the other couple(pyruvate and alanine)

In liver:

New glucose will be formed by deamination of alanine then it will go to the muscle



What will happen to NH2?

- **Liver converts it to urea for excretion (urea cycle)**

- Understand this is picture to know the “butter” of cori and alanine-glucose cycle.

Summary

Production of ATP:
1. Creatine phosphate (stimultaneous) > intermediate
2. Aerobic metabolism > long-term system
3. Anaerobic metabolism > short-term system

operate simultaneously during physical activity

Magnitude of energy from anaerobic sources depends on person's capacity and tolerance for lactic acid accumulation

Muscle Fatigue:
1) Build up of lactic acid = ↓pH of sarcoplasm
2) ↑ADP & ↓ATP
3) Ionic imbalance

Glucose-alanine cycle: (Getting glucose from alanine (amino acid)):
in muscles;
Pyruvate > Alanine
(transported through blood to..)
in liver:
Alanine > Pyruvate > glucose (gluconeogenesis) > to muscle again

Cori's cycle: (Gtting glucose from lactic acid)
Lactate (in exercising) > liver > glucose (gluconeogenesis) > to muscle again.

Aerobic metabolism in Red (Slow) fibers/oxidative	Anaerobic metabolism in White (Fast) fibers/glycolytic
-Suitable for prolonged effort -(fatty acids) are broken down by b-oxidation, TCA cycle, and the respiratory chain -Red color > myoglobin -Releases O2 when O2 level drops	Suitable for fast, strong contractions -mainly obtain ATP from anaerobic glycolysis -Glycogen>glucose-1-PO4> glucose-6-PO4 > glycolysis> ATP -Lactate is formed and converted toglucose in liver (Cori cycle)

Quiz

1- Which of the following systems is exhausted in a very short period of time of muscle activity ?

a) Anaerobic ATP-PCr

b) Anerobic glycolysis

c) Aerobic TCA cycle

2- The enzyme that makes ATP:

a) ATPase

b) ATP synthase

3- What is the fiber type used in a strong contraction?

a) Type I

b) Red

c) Both

d) White

4- Which fuel source does type I depend on?

a) Carbohydrates

b) Amino acid

c) Protein

d) Fat

5- Alanine consists of ?

a) Pyruvate + No2

b) Pyruvate + NH2

ANSWERS:

1- A

2- B

3- D

4- D

5- B

❖ Some videos about Aerobic and anaerobic metabolism in muscles:

- Aerobic System (Aerobic glycolysis)
- Anaerobic System (Anaerobic glycolysis)
- Metabolic Circuits
- Educational video about Muscle Fatigue
- Cori Cycle

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