Biochemistry Team 435

جامعة الملك سعود
King Saud University 1957

Aerobic and anaerobic metabolism in muscle

Color index:
- Important
- Extra explanation

"THE SECRET OF SUCCESS ID CONCEALED IN LOVE WITH YOUR WORK"

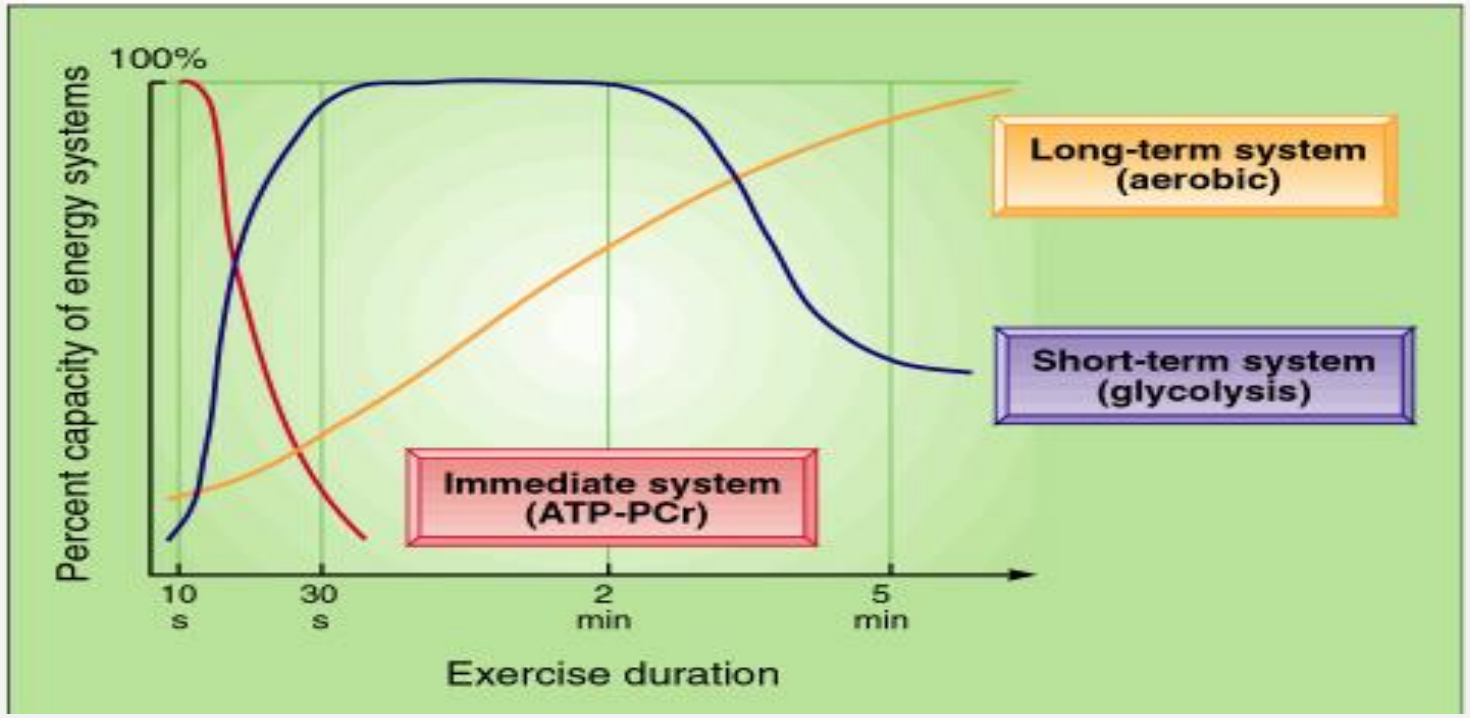
*ملاحظة: المحاضرة تحتوي على إختلافات بين سلايدات الطالبات والطلاب.

OBJECTIVES:

- 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

Biochemistry Team 435

THREE SYSTEMS OF ENERGY TRANSFER



الـ anaerobic يستخدم في الاشياء الي تحتاج ATPبشكل فوري مثلا اذا بتشيل غرض

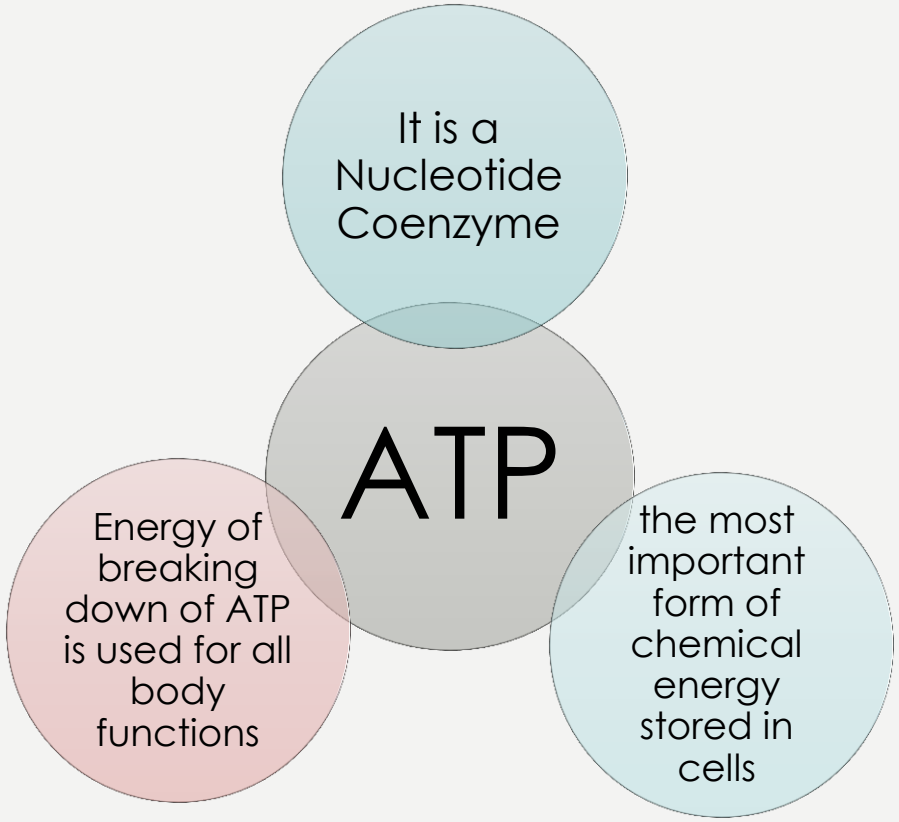
- Anaerobic
- Phosphocreatine (PCr)
- High intensity exercise
- 3-15 sec.

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

- Aerobic
- Fatty acids
- Continuous exercise
- Hours

Note : all these 3 systems are simultaneous

ATP AS ENERGY SOURCE



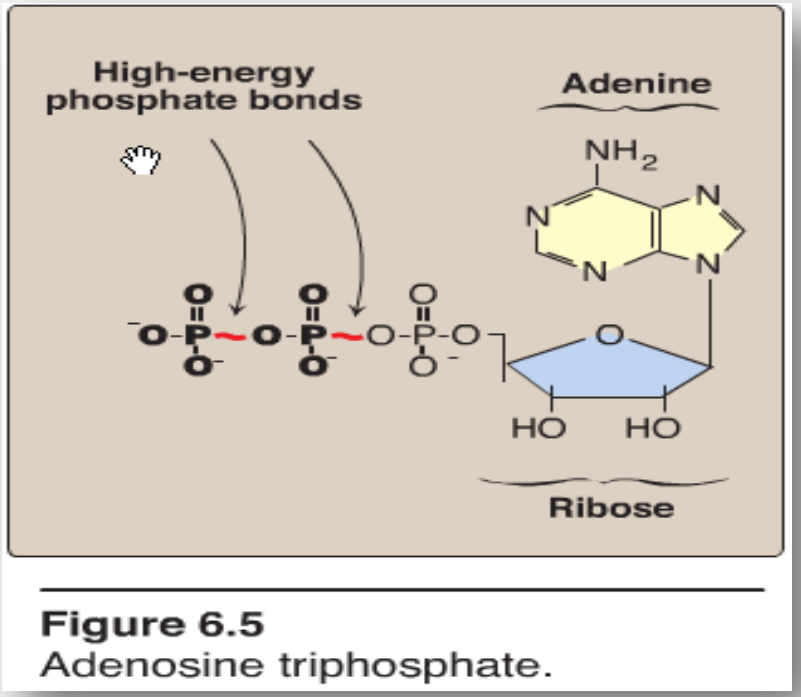


Figure 6.5
Adenosine triphosphate.

" ATP stored in cells for 1sec In specific level "

- The main pathway for ATP synthesis is oxidative phosphorylation catalyzed by the respiratory chain
- Synthesis of ATP: ADP + Pi → ATP
  responsible Enzyme : ATP synthase
- Breakdown of ATP : ATP → ADP + Pi + Energy

Muscles typically store limited amounts of ATP–enough to power **4-6s** of activity, Therefore, resting muscles must have energy stored in other ways.

ENERGY REQUIREMENTS

- The three energy systems often operate **simultaneously** during physical activity.
- Relative contribution of each system to total energy requirement differs markedly depending 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 becomes more dependent on: aerobic metabolism.

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 إعادة التصنيع ، لن يكون ATP متوفراً وبالتالي لا يمكن القيام بعملية انقباض العضلات لعدم توفر الطاقة

-Muscle fibers produce ATP three ways:

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

AEROBIC AND ANAEROBIC METABOLISM

Aerobic:

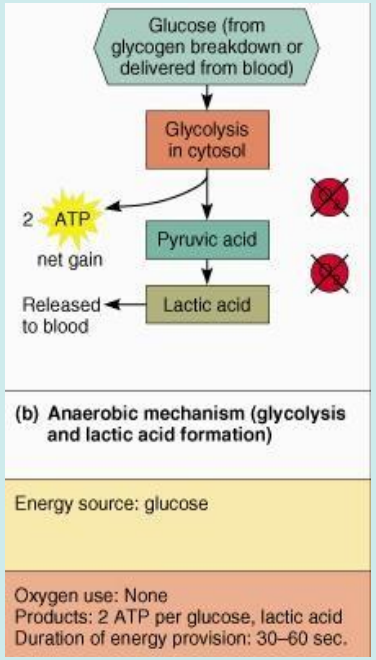
- With oxygen.
- **Source of energy:** mainly fatty acids, then carbohydrate.
- **End products:** CO2,H2O & ATP.
- **Anaerobic metabolism is inefficient, because:**

- Large amounts of glucose are used for very small ATP returns.

-Lactic acid is produced whose presence contributes to muscle fatigue.

- **Type of sports that uses anaerobic metabolism:**

-sports that require bursts of speed and activity, e.g. basketball



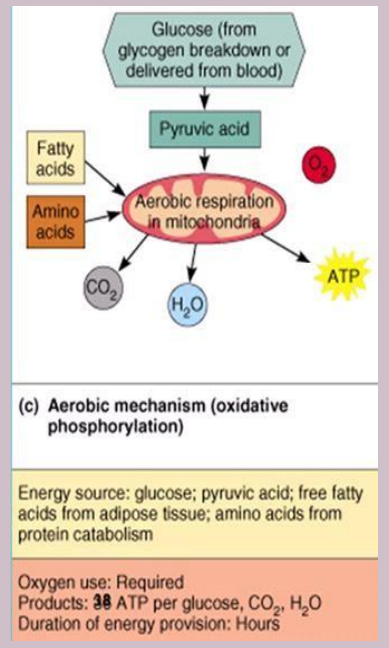
Anaerobic:

- Without oxygen.
- **Source of energy:** Carbohydrate (glycolysis).
- **End products:** Lactate & ATP.
- **When does it occur?**

When the respiratory and cardiovascular systems have "caught up" with the working muscle.

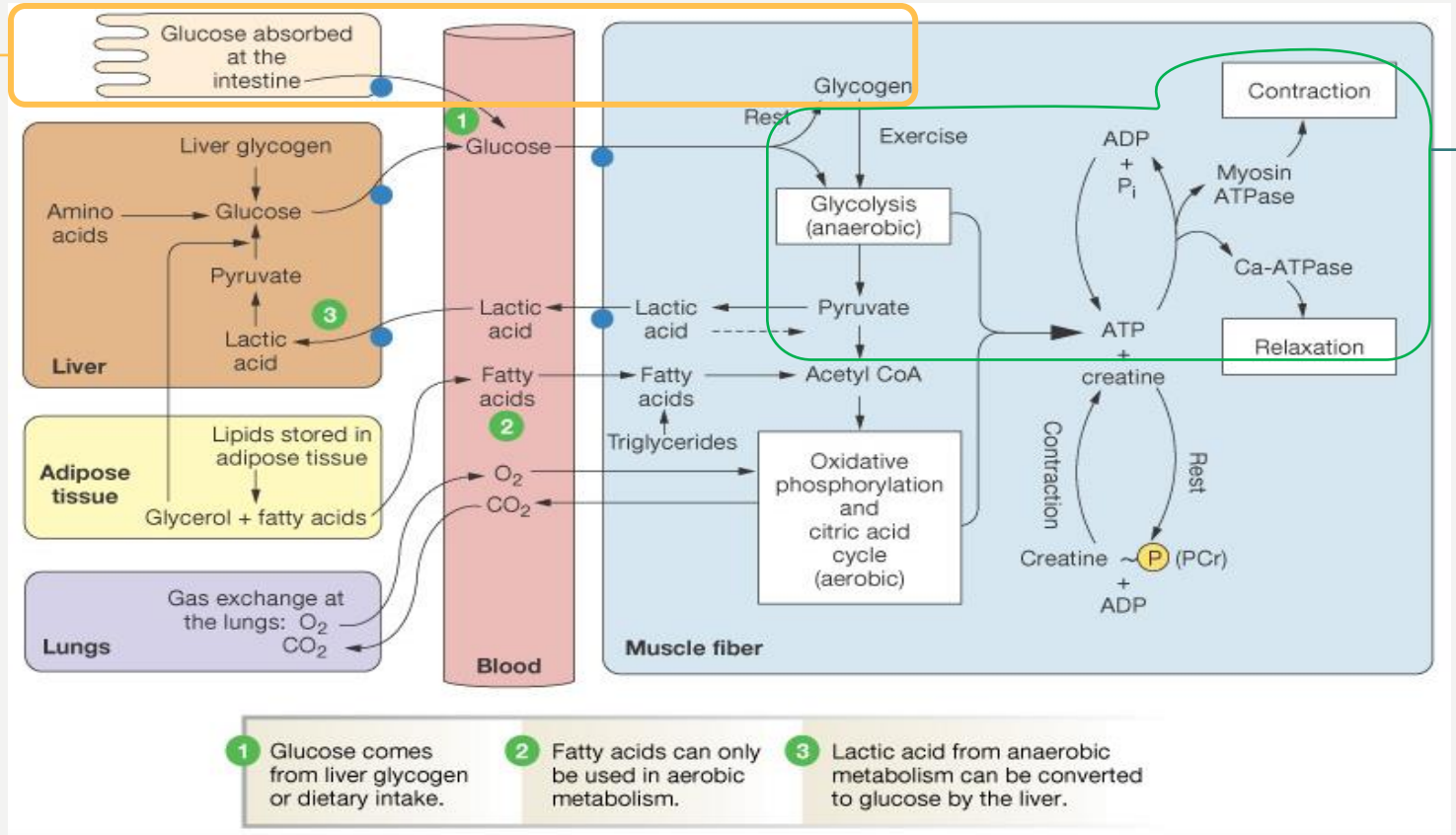
- **During rest and light to moderate exercise, aerobic metabolism contributes 95% of the necessary ATP.**
- **Compounds that can be aerobically metabolized:**

  - Fatty acids.
  - Pyruvic acid (made via glycolysis)
  - Amino acids.



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

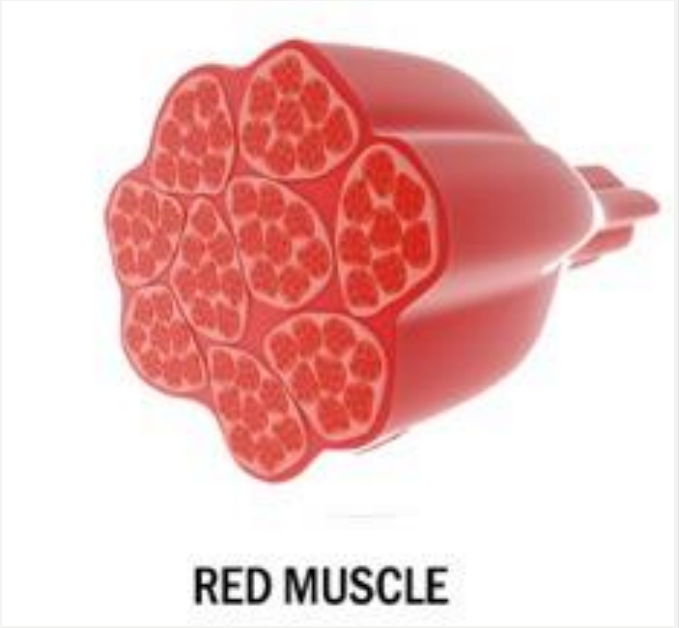


During exercise, the glycogen will be burnt aerobically or anaerobically depending on the level of oxygen to produce pyruvate or lactate. And all of this metabolism will produce ATP, which will be used in muscle contraction to convert it to ADP

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

TYPE I : RED FIBERS

- **Color** : red, why?
  due to presence large amount of protein called Myoglobin which has higher affinity to O_2 than hemoglobin. Myoglobin releases in O_2 muscle when O_2 level drops.

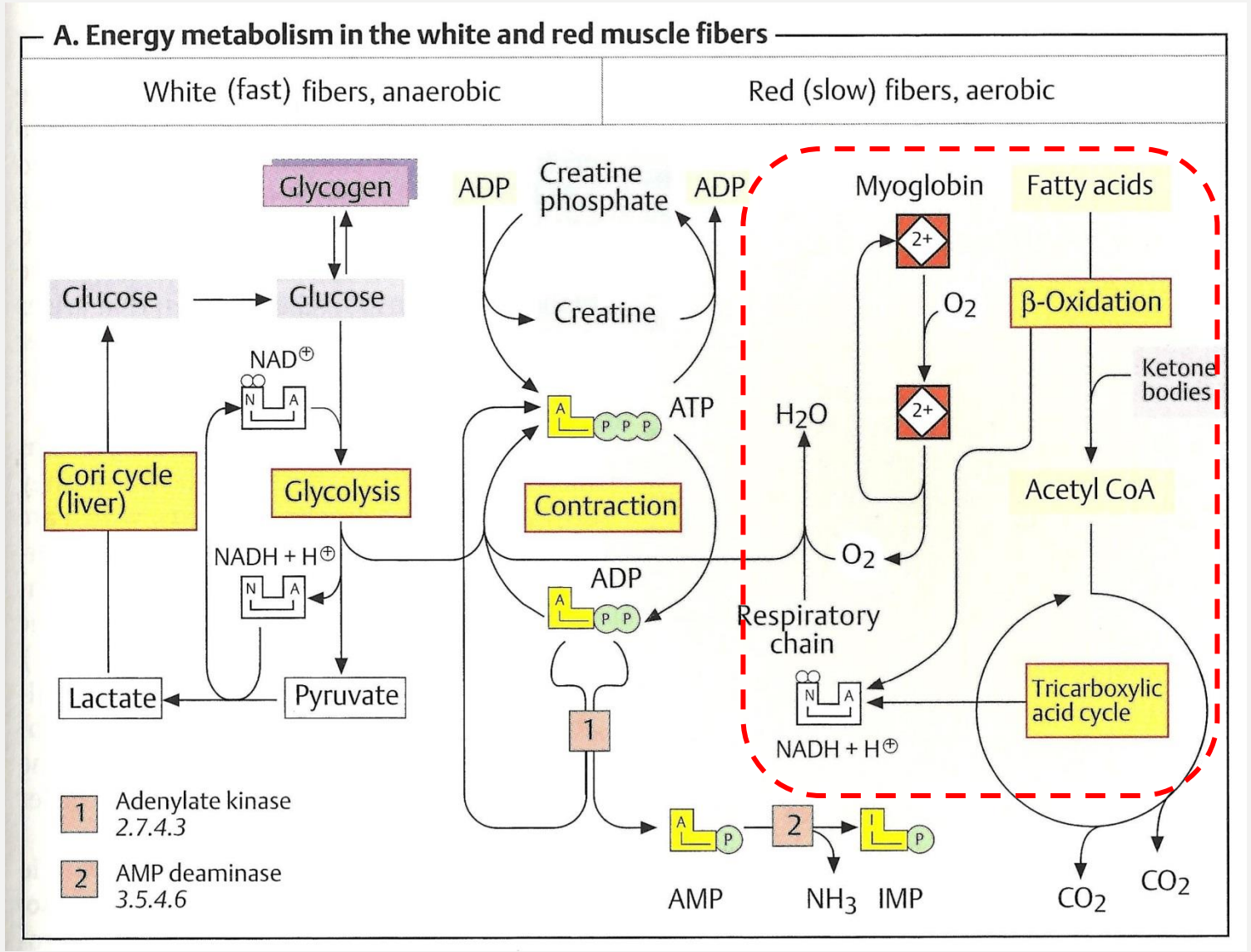


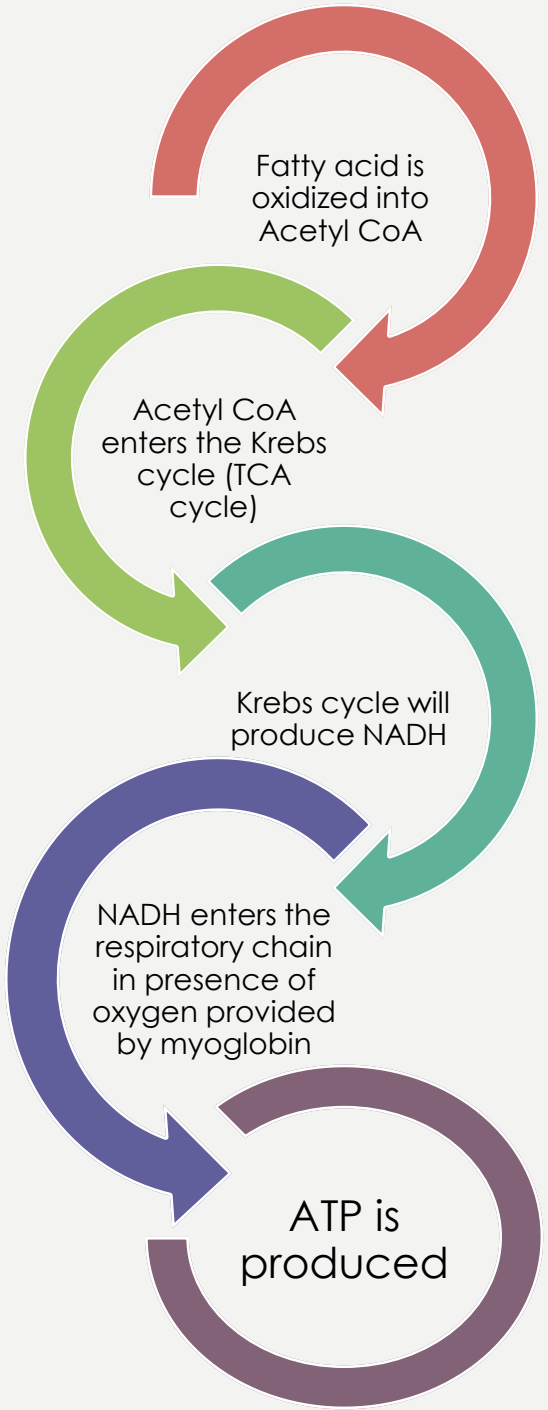
- **Type of metabolism** : Aerobic (O_2 is available)
- **Suitable for** : prolong effort, like marathon race .
- **ATP SOURCE** : mainly from fatty acids, which are broken down by β-oxidation TCA cycle & respiratory chain.
- **Example** : Beef

Notes :

- Myoglobin : similar to hemoglobin, and is used for storing oxygen in the muscles to provide O_2 to aerobic cycles
- β-oxidation : A process in which the fatty acids are degraded into other components and then energy is produced.
- TCA cycle : TriCarboxylic Acid cycle (Krebs cycle).
- Affinity means: binding.

TYPE I : RED FIBERS

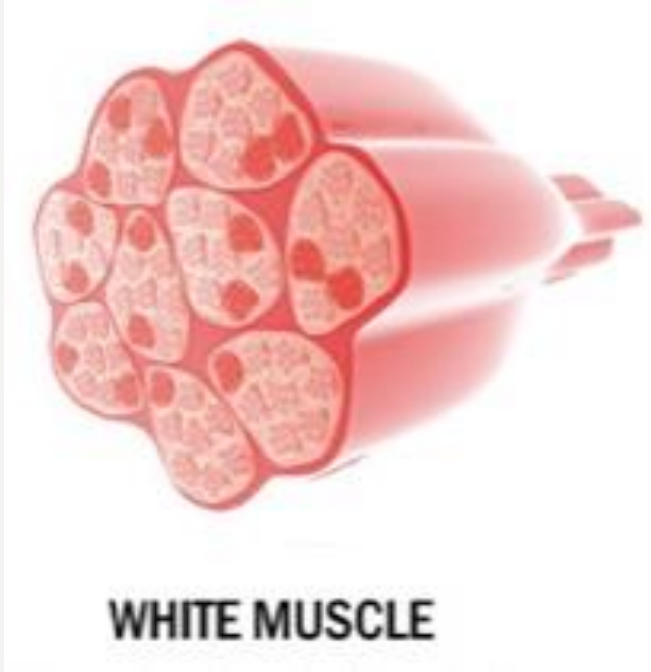




TYPE II: WHITE FIBERS

- **Color** : white , why?

  due to presence of small amount of Myoglobin.
- **Type of metabolism** : Anaerobic (O_2 is unavailable)
- **Suitable for** :fast & strong contractions, like weight lifting
- **ATP SOURCE** : mainly from anaerobic glycolysis .
- **Example** : chicken breast



- O_2 supply from blood quickly drops

- $NADH+H^+$ is reoxidized to maintain glucose degradation and ATP formation
- Lactate is formed and converted to glucose in liver (Cori cycle)
- **Pathway is :** Glycogen → glucose-1-PO_4 → glucose-6-PO_4 → glycolysis → ATP

Biochemistry Team 435

Types of skeletal muscle fibers

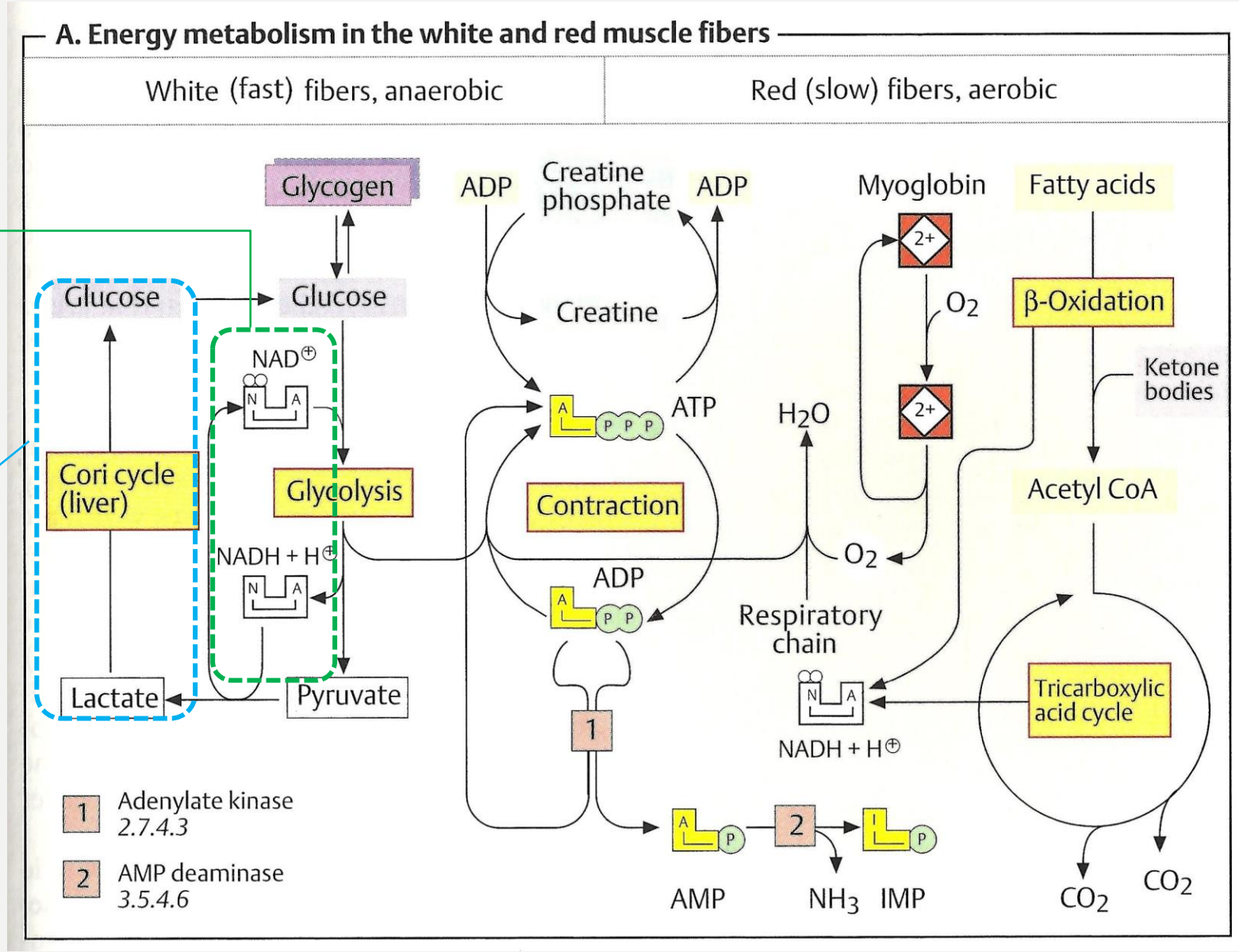
Type I	Type II
Slow	Fast
Red (dark)	White (pale)
Oxidative	Glycolytic
Aerobic metabolism	Anaerobic metabolism
Half the diameter of fast fibers	Large in diameter
Extensive capillary supply	Contain densely packed myofibrils
High concentrations of myoglobin, which make it dark in color	Large glycogen reserves
Abundant mitochondria	Relatively few mitochondria
Take three times as long to contract after stimulation, Can contract for long periods of time	Produce rapid, powerful contractions of short duration
Fatigue resistant	Easily fatigued, because lactate is formed.
Obtain their ATP mainly from Fatty Acids oxidation, TCA cycle, and the ETC	Obtain their ATP mainly from Anaerobic glycolysis
Suitable for prolong effort, like marathon race.	Suitable for fast & strong contractions, like weight lifting
E.g. : Beef, chicken's leg, migrating ducks breast	E.g.: Chicken's breast meat

Biochemistry Team 435

TYPE II: WHITE FIBERS

NADH is reoxidized to maintain glucose degradation and ATP formation

Lactate is formed and converted to glucose in liver (Cori cycle)



RESTING MUSCLE

- **ATP Use in the Resting Muscle Cell:**

fatty acids are taken up from the blood stream by resting muscle.

Inside the muscle fiber, the Fatty acids are oxidized (in the mitochondria) to produce:

Actyl-CoA :

Enter the Krebs cycle(in the mitochondria)

- **CO2**
- **ATP**
- **NADH**
- **FADH2**
- **Oxaloacetate**

NADH & FADH2

Enter the ETC (in the inner mitochondrial membrane)

Synthesis of ATP

- **Resting Muscle and the Krebs Cycle:**

ATP is necessary for cellular **housekeeping duties** ,examples:

- ATP is used for **glycogenesis** (formation of glycogen which is the storage form of glucose).

- ATP is used to create **"creatine phosphate"** which is another source of energy.

العضلة في حالة سكونها تأخذ الفاتي أسيد من مجرى الدم ومن ثم تقوم بأكسدته داخل الخليه العضيلة ، حتى تنتج شيئين مهمين:

- استيل كو أي: الذي يدخل حلقة كريبس وينتج الأشياء المذكورة.

- ناد اتش وفاد اتش: الذين بدورهم يدخلون إلى سلسلة النقل النشط لينتجون الأي تي بي.

والآن ياترى مذا سيحدث للاي تي بي المنتج؟ الخلية في وضع سكون مما يعني أنها لا تنقبض!

الخلية العضيلة ستأخذ هذا الاي تي بي وتقوم بتخزينه بصوره جلايكوجين و كيرياتين فوسفات ، حتى تستخدمهم عند الحاجة.

« القرش الأبيض لليوم الأسود»

WORKING MUSCLE

As we begin exercise, we almost immediately use our stored ATP.

For the next 15 seconds or so, we turn to the creatine-phosphate.

After the phosphagen system is depleted, the muscles must find another ATP source.

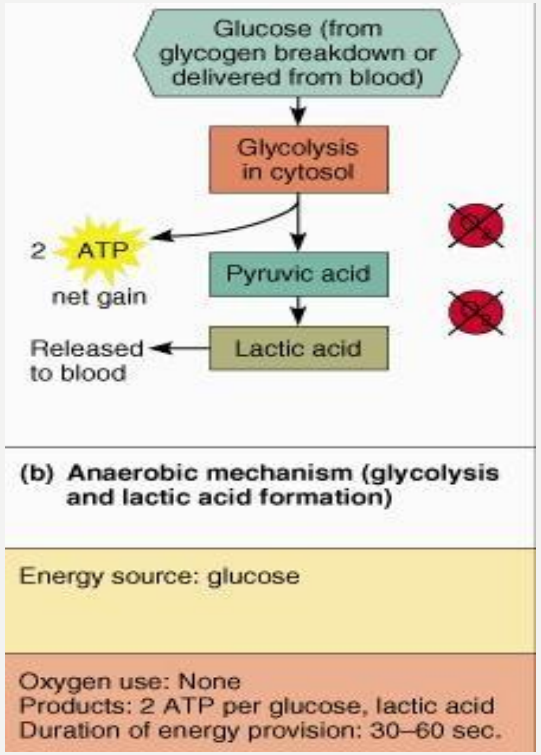
The process of anaerobic metabolism can maintain ATP supply for about 45-60s.

- Glycogen → Glucose → 2 pyruvic acid (2 ATP + 2 NADH)
- 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

**It usually takes a little time for the respiratory and cardiovascular systems to catch up with the muscles and supply O_2 for aerobic metabolism*

عندما تبدأ العضلة بالعمل فإنها ستستخدم الطاقة التي قامت بتخزينها في حالة سكونها، بعد فترة زمنية ستقل الطاقة المخزنه وبالتالي العضلة ستبحث عن طريقة أخرى للحصول على الطاقة ، من ٤٥ إلى ٦٠ ثانيه ستستخدم عملية التنفس الخلوي اللاهوائي .

العضلة ماتدخل في الهوائية بسبب الأكسجين ، فعوضا عن إنتظارها للأكسجين تدخل في اللاهوائي لحد مايجيها الأكسجين من الجهاز التنفسي والجهاز القلبي.



THE CORI CYCLE

- **There are 6 steps :**

➢ **First 2 in the Muscle:**

1- White muscle fibers (Fast & Strong contraction) obtain ATP from Anaerobic glycolysis.

2- In Anaerobic glycolysis glucose is converted to lactate.

➢ **second 2 in the blood stream:**

3- Lactate in muscle is released into blood.

4- Transported to the liver.

➢ **Last 2 in the Liver :**

5- Liver converts lactate into glucose via gluconeogenesis*.

6- the newly formed glucose is transported to muscle to be used for energy again " complete cycle ".

* Gluconeogenesis : is a metabolic pathway that results in the generation of glucose from non-carbohydrate carbon substrates such as pyruvate, Lactate, glycerol and glycogenic amino acids.

Summary:

Liver converts lactic into glucose via gluconeogenesis, then the newly formed glucose is transported to be used for energy.

THE CORI CYCLE

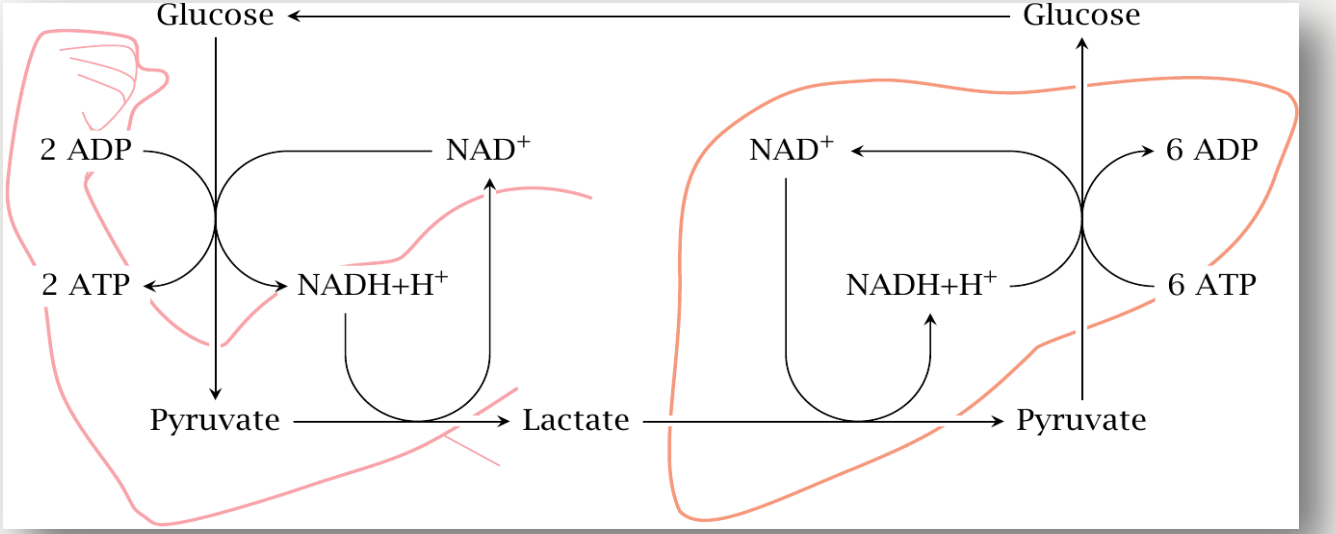
- **Why muscles can't produce new glucose from lactate?**

Because:

1- **Gluconeogenesis** requires much more ATP

2- **O_2 deficiencies** do not arise in the liver even during intense exercise

- Therefor , liver always has sufficient ATP for gluconeogenesis, so it can converts lactate to glucose many times



Glucose-alanine cycle

1- In muscle

- **Muscle produces**:

- **pyruvate** from glycolysis

- **Amino Nitrogen NH_2(toxic)** from normal protein degradation.

- Pyruvate with NH2 is converted to Alanine

Pyruvate + NH_2 ⟹ Alanine

2- In blood

- Transported to liver with normal concentration in blood 0.33-0.61mM

3- In liver

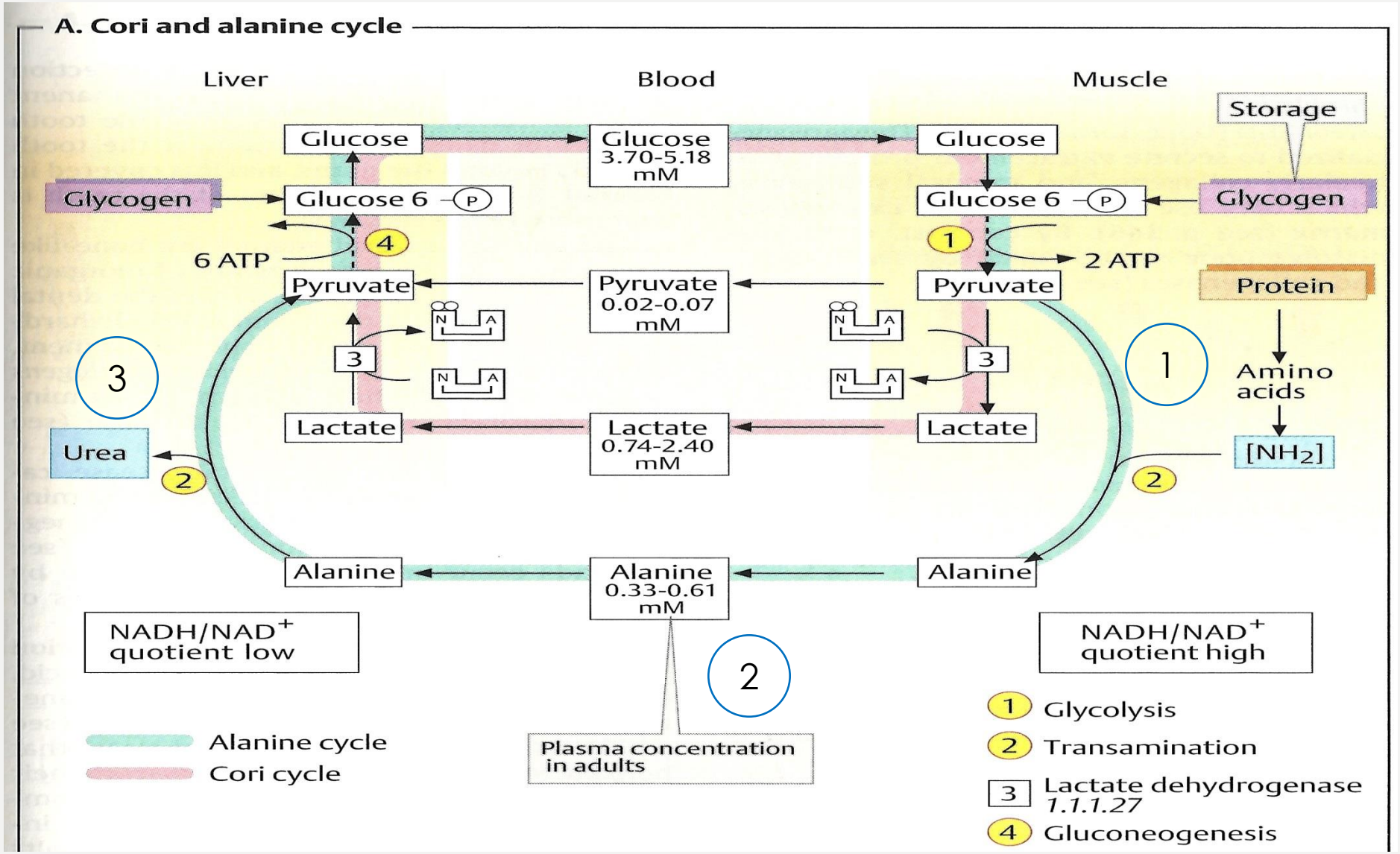
- Liver converts alanine back to pyruvate

Alanine – NH_2 ⟹ Pyruvate

NH_2 is Converted to urea which is excreted later.

- Pyruvate is used in gluconeogenesis
- The newly formed glucose is transported to muscle to be used for energy again

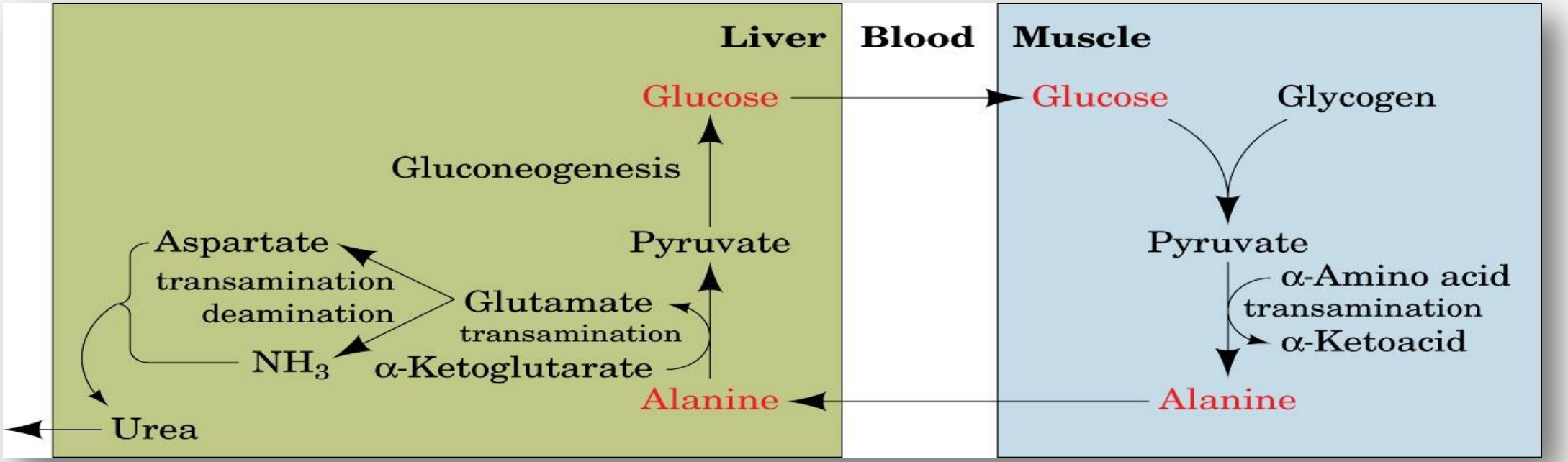
GLUCOSE-ALANINE CYCLE



GLUCOSE-ALANINE CYCLE

- Conversion of pyruvate to alanine, والعكس is coupled with the conversion of an alpha-amino acid like glutamate to an alpha-keto acid like alpha-ketoglutarate.

- Glutamate in the liver is then deaminated producing urea.



- **What happens to NH_2?**

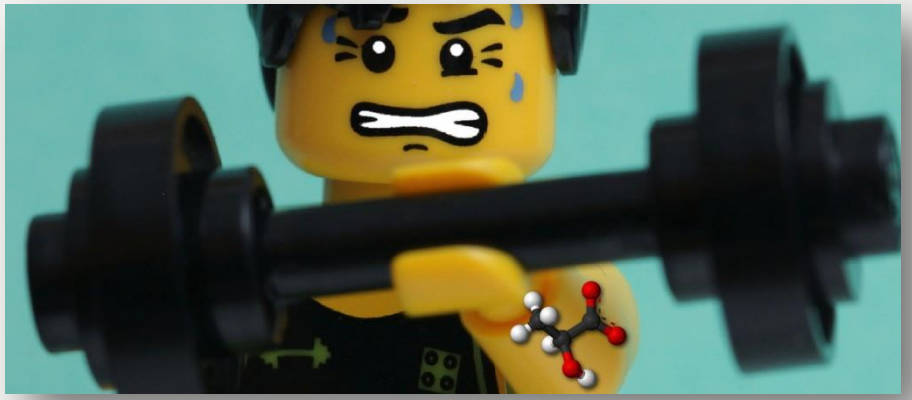
Liver converts it to urea for excretion.

MUSCLE FATIGUE AND ENDURANCE IN ATHLETES

- **Muscle fatigue:**

Inability of muscle to maintain a particular strength of contraction over time

- **Causes:**



1- muscle damage

2- accumulation of lactic acid

3- Build up of lactic acid (low pH of sarcoplasm).

4- Exhaustion of energy resources (ADP & □ ATP)

5- Ionic imbalance.

- Athletes are trained to achieve high endurance and delayed fatigue

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.

VIDEOS

aerobic https://www.youtube.com/watch?v=PQMsJSme780

anaerobic https://www.youtube.com/watch?v=uCmNQQWlrc0

comparison between aerobic and anaerobic https://www.youtube.com/watch?v=uB357EX-fdc

SAQs

1-Which movement is suitable for type II fibers , give an example ?

strong and fast, weight lifting

2- Describe the cori cycle

the end product of glycolysis in muscle is lactate when it accumlates in muscle, it goes to blood stream then it will go to the liver, liver will convertes it via gluconeogenesis into glucose then it will back in blood stream then to muscles.

3- what is the fate of amine group in protein degradation ?

during protein degradation in muscles, amine group is released, but because it is toxic, the body will adds it to pyruvate to make alanine which will go to liver, then liver will remove amine group and convert it to urea.

Click here for QUIZ

Team Members:

- نوره الرميح.
- لينا الشهري.
- بدور جليدان.
- جواهر الحربي.
- علا النهير.
- أفنان المالكي.
- نوف التويجري.
- لولوه الصغير.
- خوله العريني.
- دلال الحزيمي.
- وضحى العتيبي.
- رزان السبتي.
- دانيا الهنداوي.
- رهف بن عباد.
- غاده القصيمي.
- أسماء العمار.
- مهند الزهراني .
- خالد النعيم .
- إبراهيم الشايع.
- أحمد الرويلي .
- محمد الصهيل.
- عبد الله الشنيفي .
- زياد العنزي .

Team Leaders:

- شهد العنزي.
- عبدالعزيز المالكي.

* نستقبل اقتراحاتكم وملاحظاتكم على:

@435biochemteam

435biochemistryteam@gmail.com

@biochemteam435