MSS

physiology

LEC no. 4

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FACTORS THAT DETERMINE WHOLE MUSCLE CONTRACTION

In the previous lec we talked about the factors that can influence the magnitude of contraction (motor unit, stimulation frequency, length of fiber)

And now we will complete them (extent of fatigue and thickness of fiber)

Contractions of a whole muscle can be of varying strength

A. The number of muscle fibers contracting within a muscle

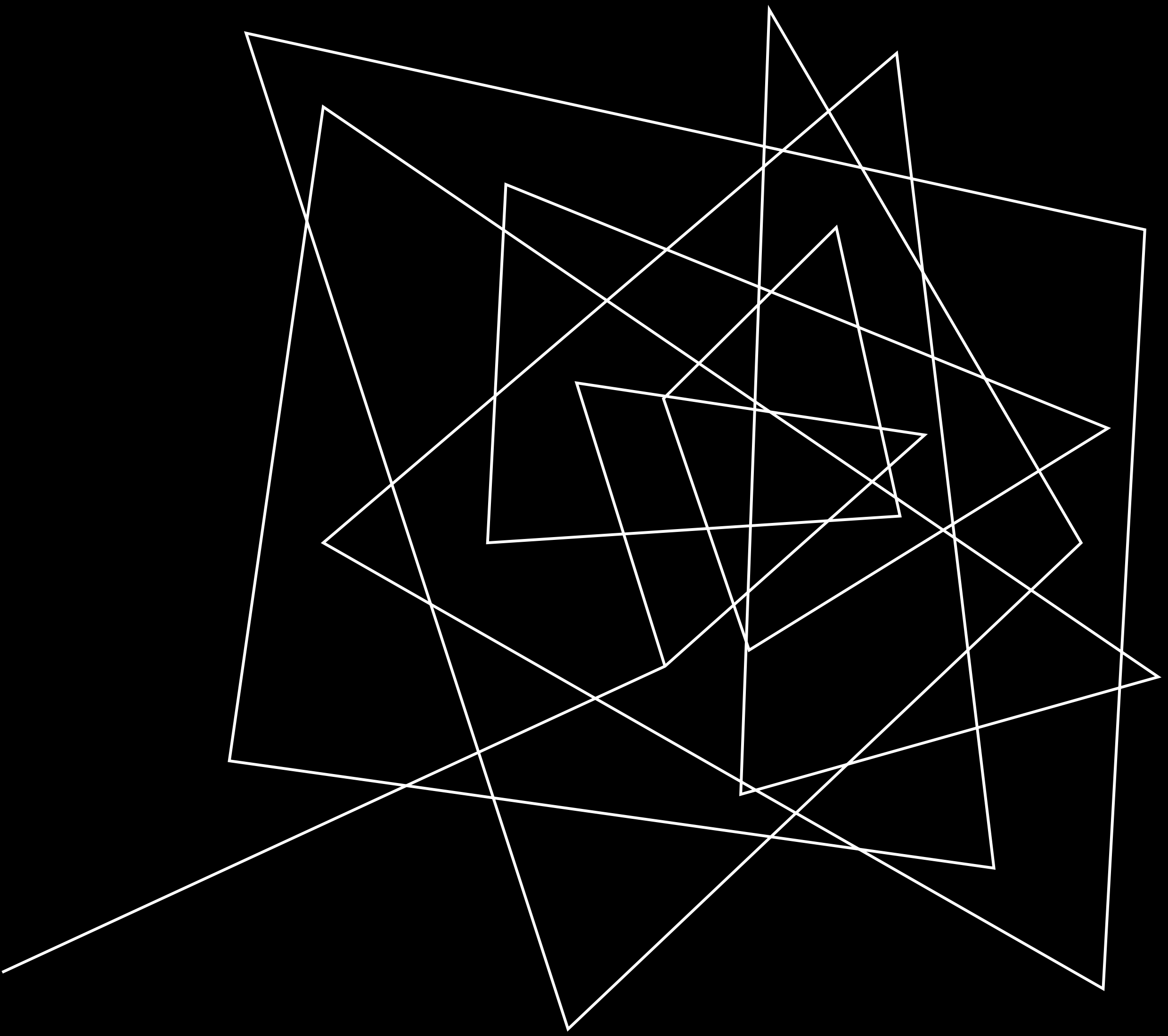
- Extent of motor unit recruitment

B.The tension developed by each contracting fiber.

- 1. Stimulation Frequency
- 2. Length of the fiber at the onset of contraction
- 3. Extent of fatigue
- 4. Thickness of the fiber

** The two main factors subject to control to accomplish gradation of contraction are the number of motor units stimulated and the frequency of their stimulation. The areas of the brain that direct motor activity combine tetanic contractions and precisely timed shifts of asynchronous motor unit recruitment to execute smooth rather than jerky contractions

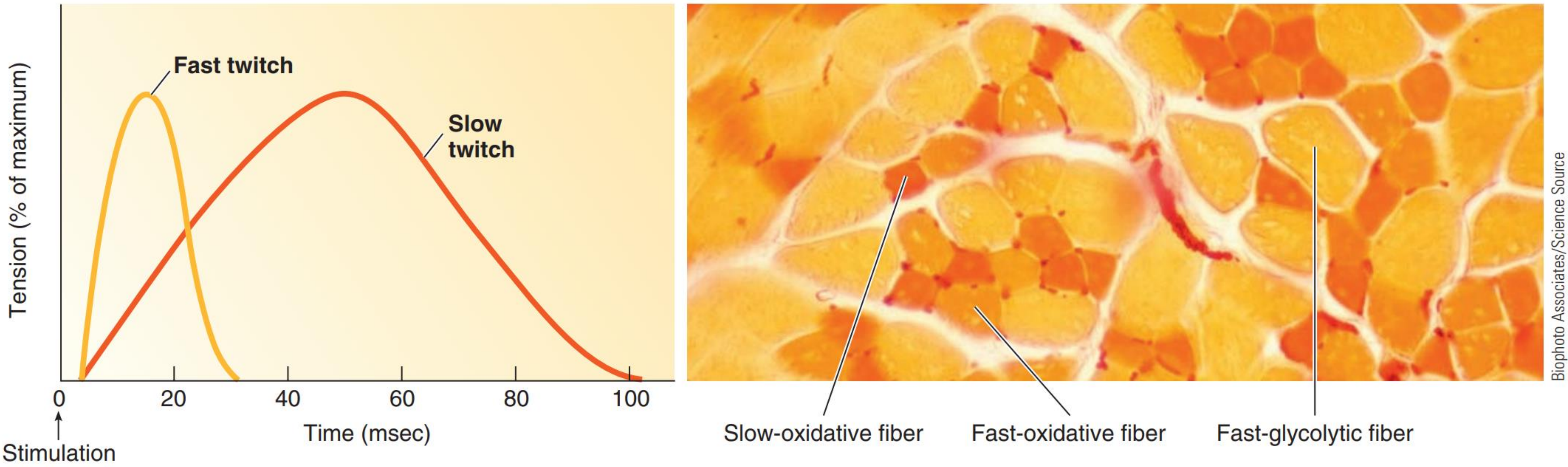
** The frequency of stimulation and the muscle length at onset of contraction—can vary from contraction to contraction. Other determinants of muscle fiber tension—how resistant the muscle fiber is to fatigue and how thick the fiber is—do not vary from contraction to contraction but depend on the fiber type and can be modified over time



SKELETAL MUSCLE

Types of muscle fibers

Fast Vs. Slow Muscle Fibers



(a) (b)

speed of contraction (slow or fast)

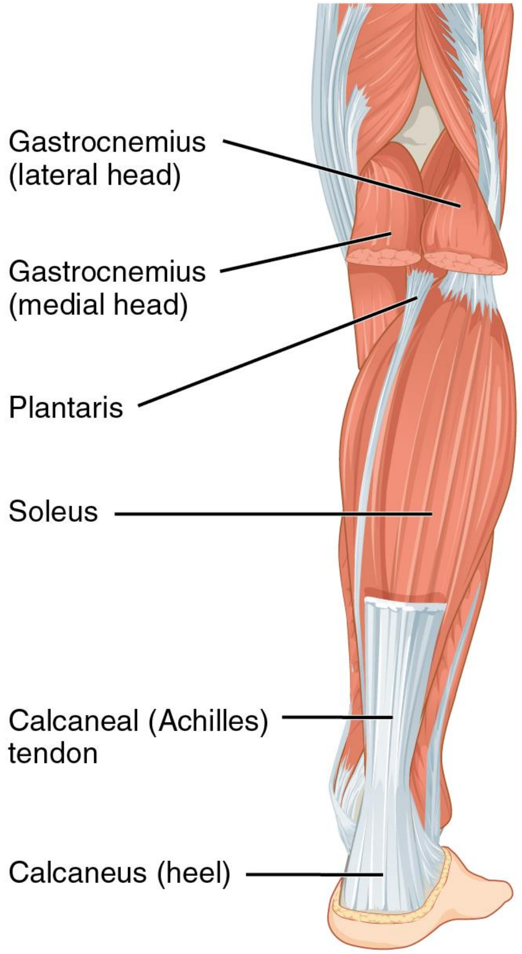
Fast fibers have higher myosin ATPase (ATP-splitting) activity than slow fibers do. The higher the ATPase activity, the more rapidly ATP is split and the faster the rate at which energy is made available for crossbridge cycling.

The result is a fast twitch compared to the slower twitches of those fibers that split ATP more slowly

All muscles have varying percentages of fast twitch and slow twitch of muscle fibers, and that depend on their contraction speed.

This difference (slow vs fast) is due to the different in their biochemical capacities for example gastrocnemius muscle has a fast twitch fibers which gives it the capability of forceful and rapid contraction (like in jumping)

In contrast the soleus muscle has a slow twitch fibers because is used for prolonged lower leg muscle activities.



SKELETAL MUSCLE METABOLISM

MUSCLE METABOLISM _ SOURCES OF GLUCOSE:

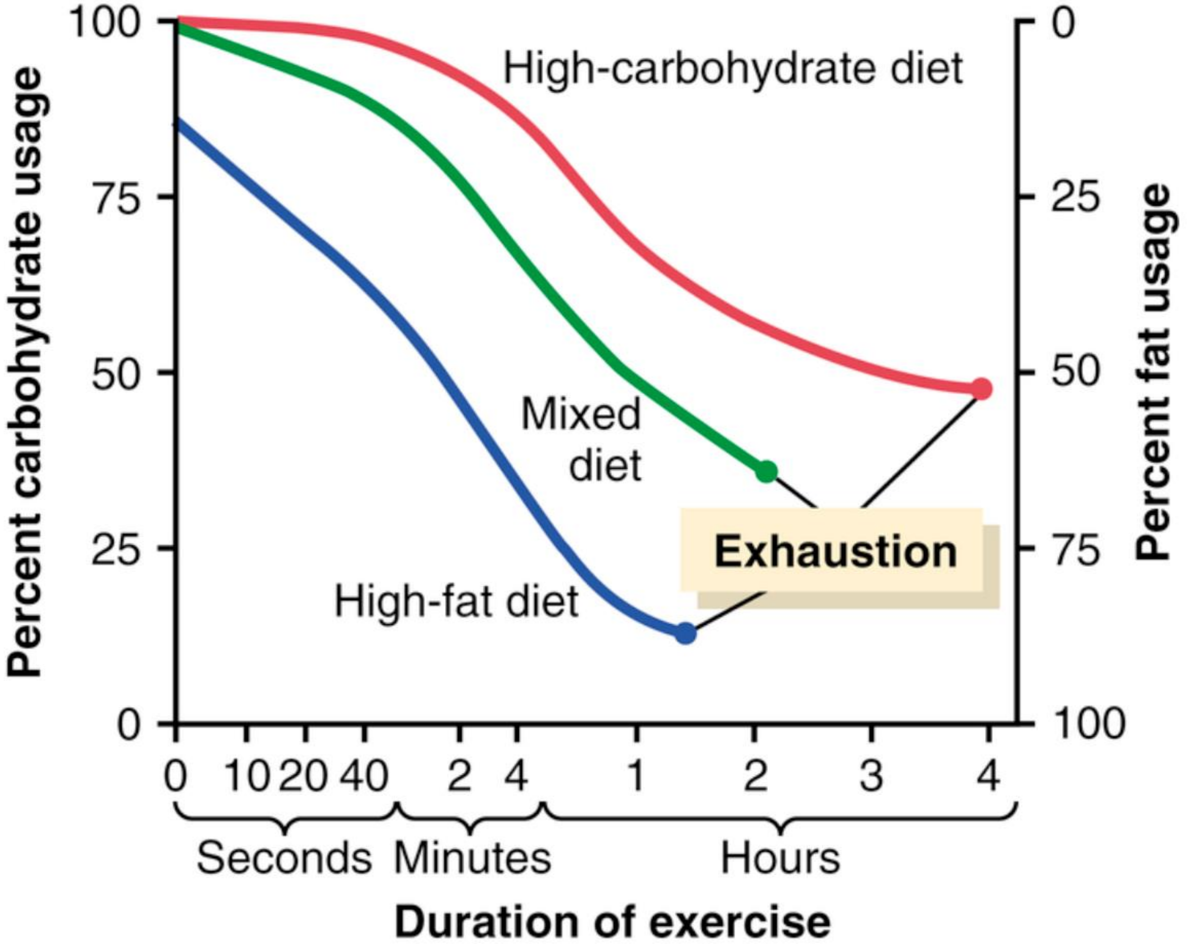
- After absorption into a cell, glucose can be used immediately for release of energy to the cell, or it can be stored in the form of glycogen, which is a large polymer of glucose.
- Muscle cells can store up to 1% to 3% of their weight glycogen. This reflect high muscle demand which will insure glc is always available.

Almost all cells in the body can store some glycogen, but some can storge larger amount.

However not all the carbohydrates use for energy is derived from stored muscle glycogen. In fact the liver stores nearly as much glycogen as the muscles do and this glycogen can be released into the bloodstream as glc, which then use as an energy source.

In the initial phases of physical activity a part of carbs use as source of energy, but that not the only source, it also consumes fat in the form of fatty acids and acetoacetic acid and to lesser degree proteins in the form of amino acid.

MUSCLE METABOLISM _ SOURCES OF GLUCOSE:



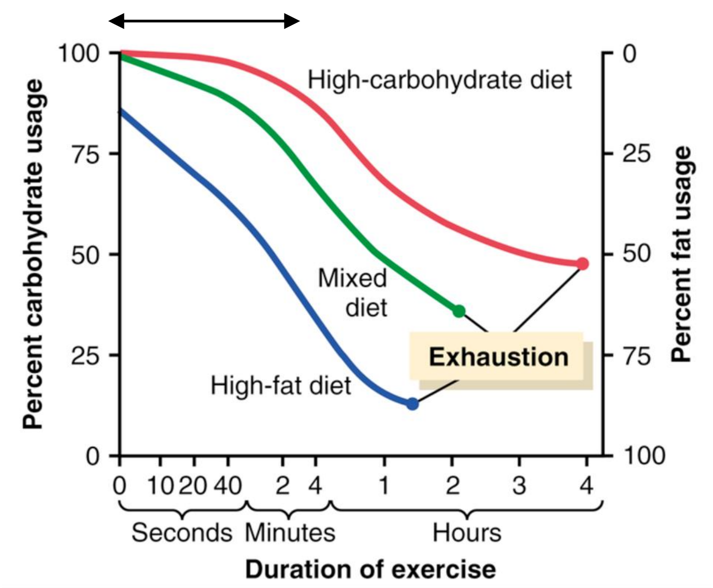
for the previous figure:

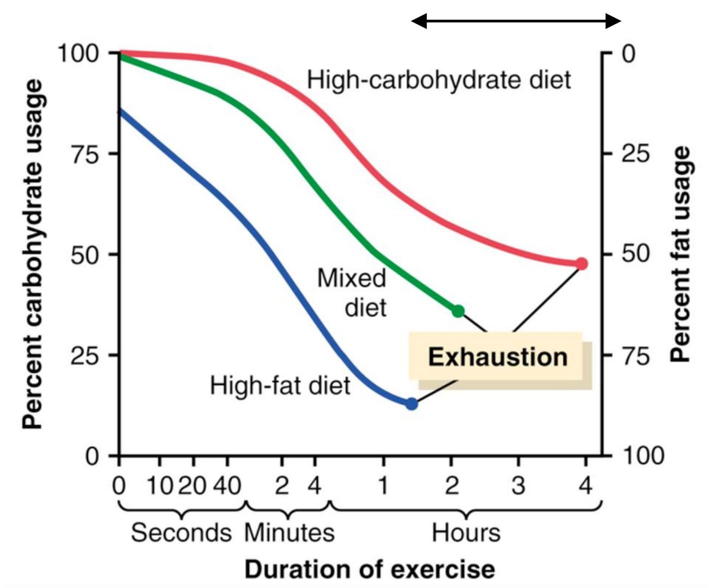
It is show the relation between the duration of exercise and the source of energy used for each duration(either carbs or fat).

You should note that there is three types of diet
1-high fat diet (notice it uses carbs not only fat, but in amount lesser than other types)
2-mixed diet
3-high carbs diet (notice it uses fat not only carbs, but in amount lesser than other types)

It should be noted that during the initial moments or minutes of he exercise the majority of energy is obtained from carbs for the 3 types

When the muscle starts to be exhausted after hours, 60%-85% of energy is obtained from fats instead of carbs





MUSCLE METABOLISM _ PRODUCTION OF ATP

Muscle fibers have three ways to produce ATP:

1) From creatine phosphate
2) By anaerobic cellular respiration
3) By aerobic cellular respiration

However the ATP within the muscle is only adequate to power contractions for a few seconds, if contraction continue the muscle must make more ATP, that's why muscles have 3 ways to produce ATP.

**The use of creatine phosphate for ATP production is unique to muscle fibers, but all body cells can make ATP by the reactions of anaerobic glycolysis and aerobic respiration.

**A huge amount of ATP is needed to:

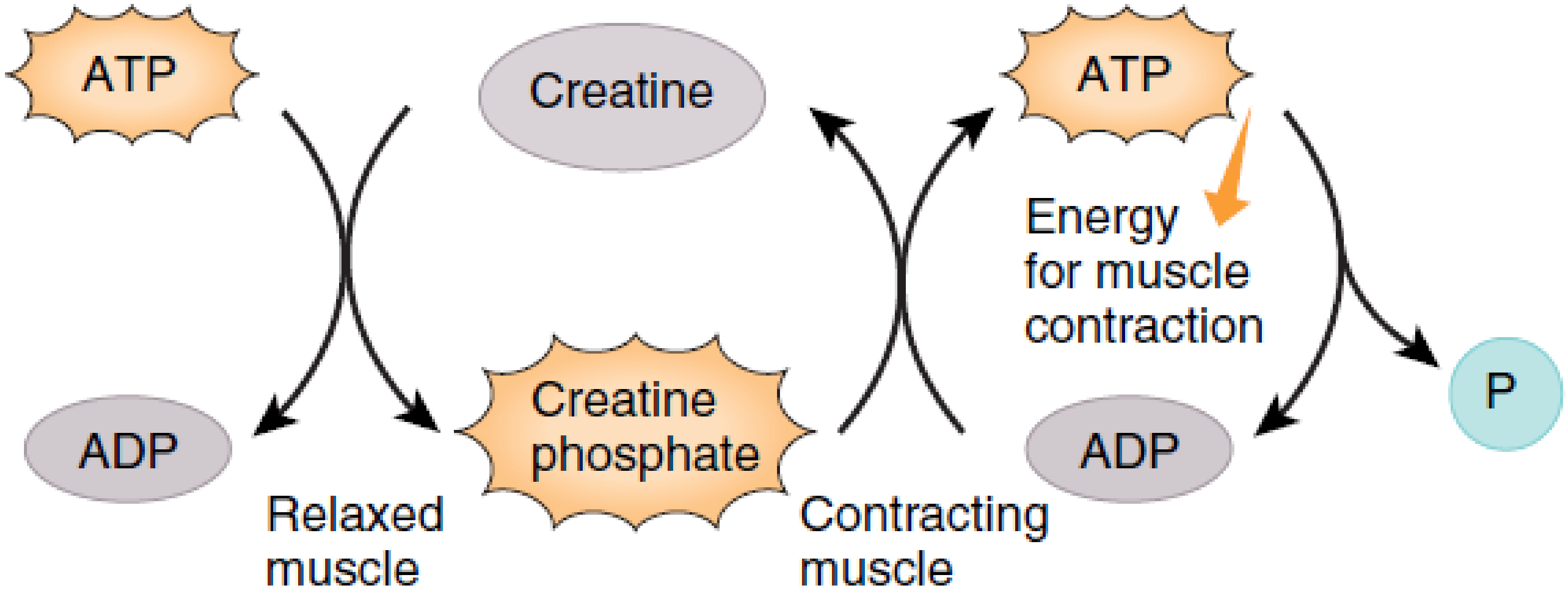
1-Power the contraction cycle

2-Pump Ca+2 into the SR

3-Pump Na and K to maintain the appropriate ionic environment for action potential

4-Perform other metabolic rxns involve in muscle contraction

PRODUCTION OF ATP_ CREATINE PHOSPHATE



While muscle fibers are relaxed, they produce more ATP than they need for resting metabolism. Most of the excess ATP is used to synthesize **creatine phosphate.
Creatine is a small amino acid-like molecule, the sarcoplasm of relaxed muscles has three to six times more creatine phosphate than ATP.

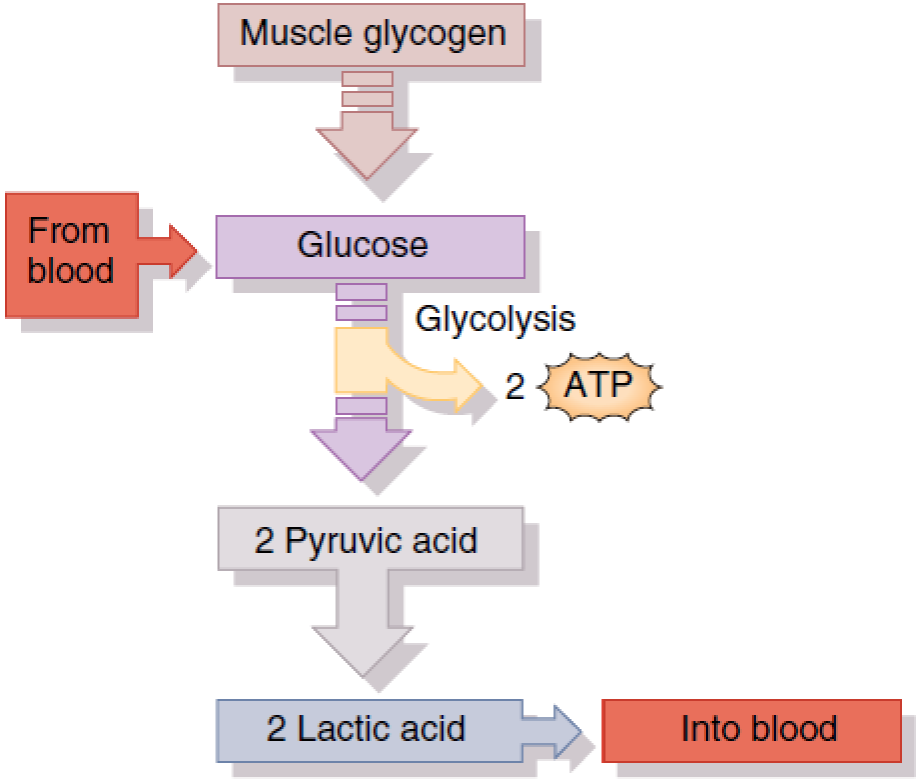
****** The enzyme creatine kinase (CK) catalyzes the transfer of one of the high-energy phosphate groups from ATP to creatine, forming creatine
phosphate and ADP. This enzyme be activated when the muscles contract causes a new phosphate ion to link to ADP making ATP

The first source of energy that is used to reconstitute the ATP is the substance phosphocreatine, which carries a high-energy phosphate bond similar to the bonds of ATP.

The high-energy phosphate bond of phosphocreatine has a slightly higher amount of free energy than that of each ATP bond. Therefore, phosphocreatine is instantly cleaved, and its released energy causes bonding of a new phosphate ion to ADP to reconstitute the ATP.

However, the total amount of phosphocreatine in the muscle fiber is also small, only about 5 times as great as the ATP. Therefore, the combined energy of both the stored ATP and the phosphocreatine is enough to energy muscles to contract maximally for about 5-8 seconds.

PRODUCTION OF ATP_ ANAEROBIC RESPIRATION



**Glucose passes easily from the blood into contracting muscle fibers via facilitated diffusion, and it is also produced by the breakdown of glycogen within muscle fibers.

**Glycolysis: breaks down each glucose molecule into two molecules of pyruvic acid. Glycolysis occurs in the cytosol and produces a net gain of two molecules of ATP. Glycolysis does not require oxygen

** Under anaerobic conditions, the pyruvic acid generated from glycolysis is converted to lactic acid.

** Buildup of lactic acid is thought to be responsible for the muscle soreness that is felt during strenuous Exercise.

**There are limits as to how much O_2 the lungs can pick up and the circulatory system can deliver to exercising muscles. Furthermore, in near-maximal contractions, the powerful contraction almost squeezes closed the blood vessels that course through the muscle, severely limiting O_2 availability to the muscle fibers.

Even when O_2 is available, the relatively slow oxidative phosphorylation system may not be able to produce ATP rapidly enough to meet the muscle's needs during intense activity.

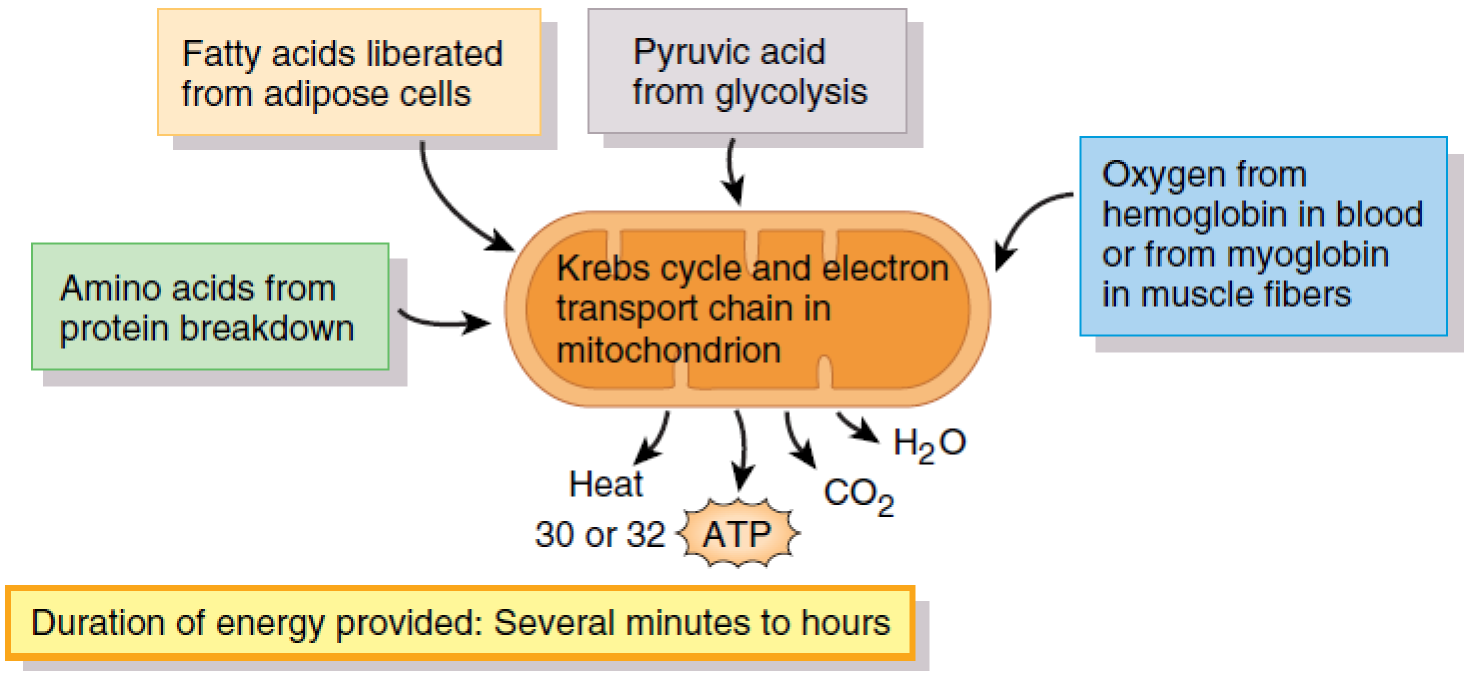
Although glycolysis extracts considerably fewer ATP molecules from each nutrient molecule processed, because of its speed its rate of ATP production can exceed the rate of generation of ATP by oxidative phosphorylation as long as glucose is present.

Activity that can be supported in this way is anaerobic or high-intensity exercise.

The second important source of energy, which is used to reconstitute both ATP and phosphocreatine, is a process called glycolysis—the breakdown of glycogen previously stored in the muscle cells. Rapid enzymatic breakdown of the glycogen to pyruvic acid and lactic acid liberates energy that is used to convert ADP to ATP; the ATP can then be used directly to energize additional muscle contraction and also to re-form the stores of phosphocreatine.

The importance of this glycolysis mechanism is twofold. First, glycolytic reactions can occur even in the absence of oxygen, so muscle contraction can be sustained for many seconds and sometimes up to more than 1 minute, even when oxygen delivery from the blood is not available. Second, the rate of ATP formation by glycolysis is about 2.5 times as rapid as ATP formation in response to cellular foodstuffs reacting with oxygen. However, so many end products of glycolysis accumulate in the muscle cells that glycolysis also loses its capability to sustain maximum muscle contraction after about 1 minute.

PRODUCTION OF ATP_ AEROBIC RESPIRATION



(c) By aerobic cellular respiration

If sufficient oxygen is present, the pyruvic acid formed by glycolysis enters the mitochondria, where it undergoes aerobic respiration, a series of oxygen-requiring reactions (the Krebs cycle and the electron transport chain) that produce ATP, carbon dioxide, water, and heat.

Oxidative phosphorylation produces a high yield of 32 ATP molecules per glucose molecule.

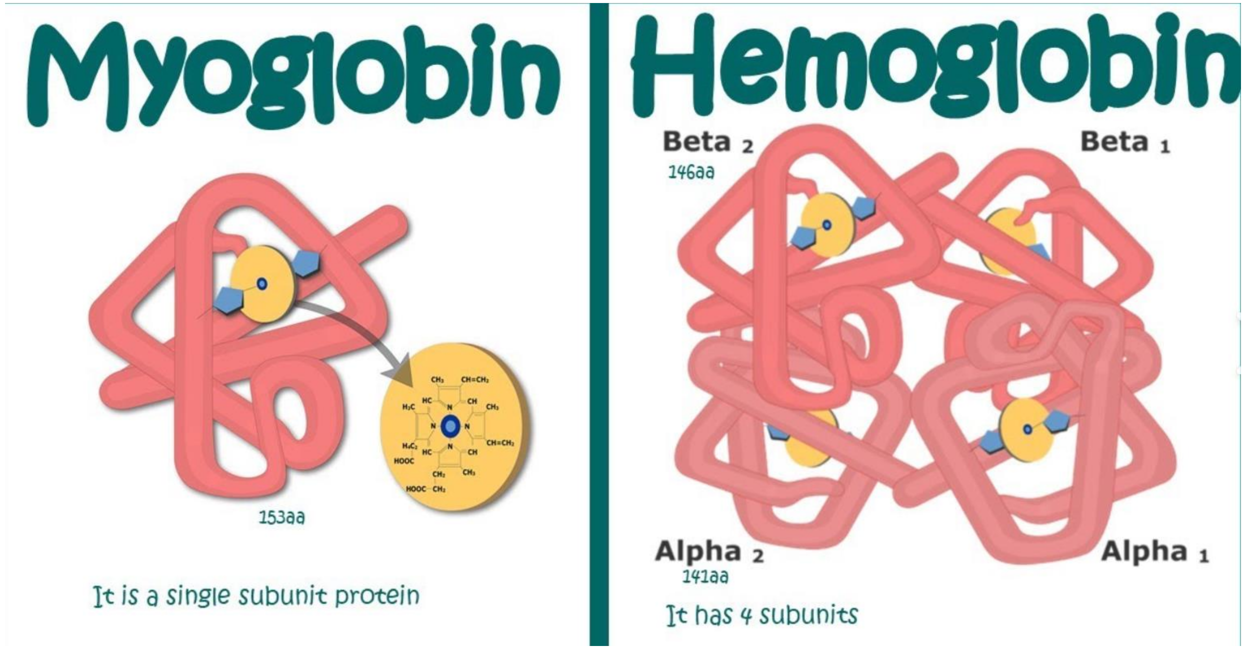
The third and final source of energy is oxidative metabolism, which means combining oxygen with the end products of glycolysis and with various other cellular foodstuffs to liberate ATP. More than 95% of all energy used by the muscles for sustained long-term contraction is derived from oxidative metabolism. The foodstuffs that are consumed are carbohydrates, fats, and protein. For extremely long-term maximal muscle activity—over a period of many hours—the greatest proportion of energy comes from fats but, for periods of 2 to 4 hours, as much as one half of the energy can come from stored carbohydrates.

During light exercise (such as walking) to moderate exercise (such as jogging or swimming), muscle cells can form enough ATP through oxidative phosphorylation to keep pace with the modest energy demands of the contractile machinery for prolonged periods.

To sustain ongoing oxidative phosphorylation, exercising muscles depend on delivery of adequate O2 and nutrients to maintain their activity. Activity supported in this way is aerobic ("with O2") or endurance-type exercise

MUSCLE METABOLISM _ SOURCES OF OXYGEN:

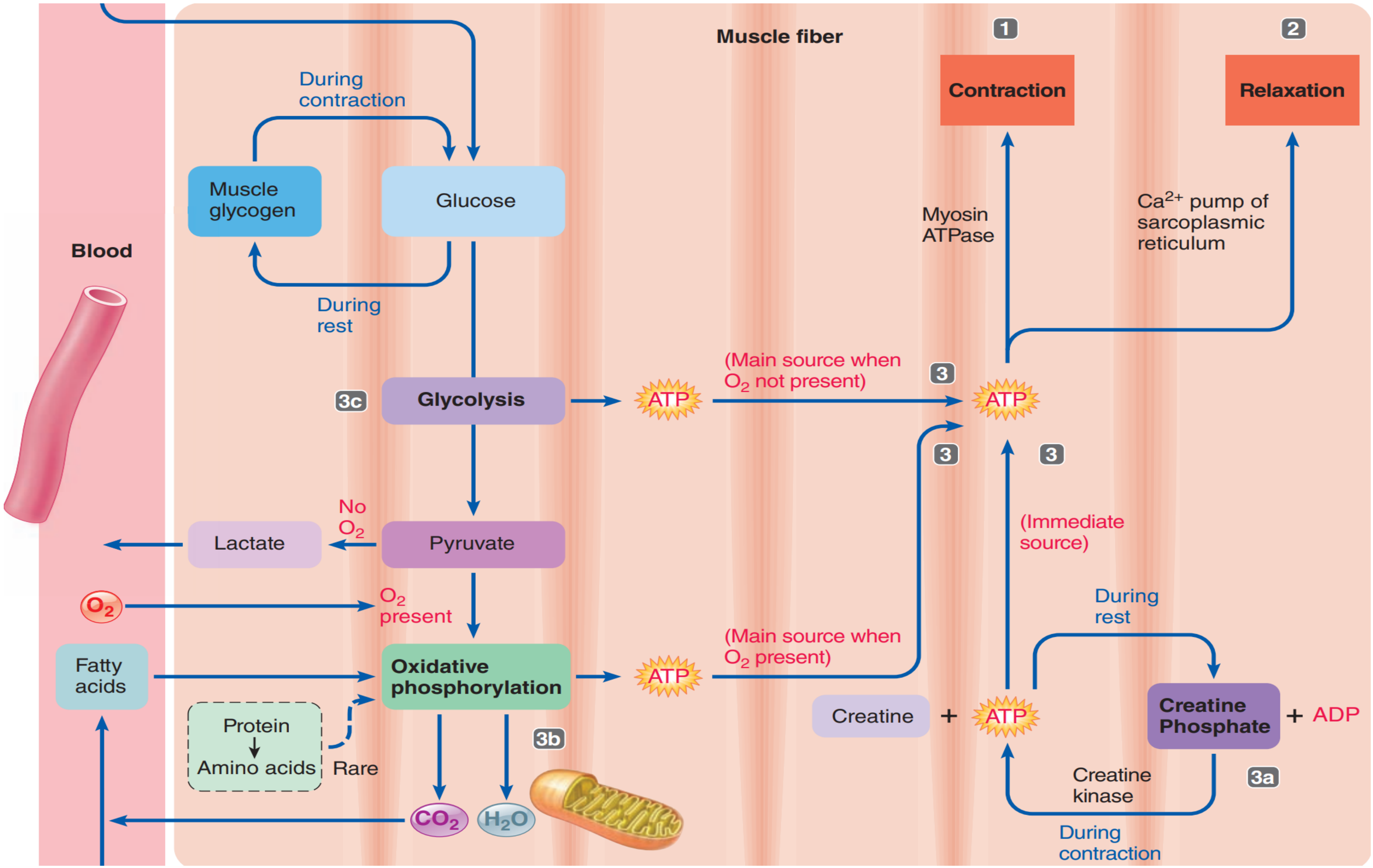
- (1) oxygen that diffuses into muscle fibers from the blood
- (2) oxygen released by myoglobin within muscle fibers.



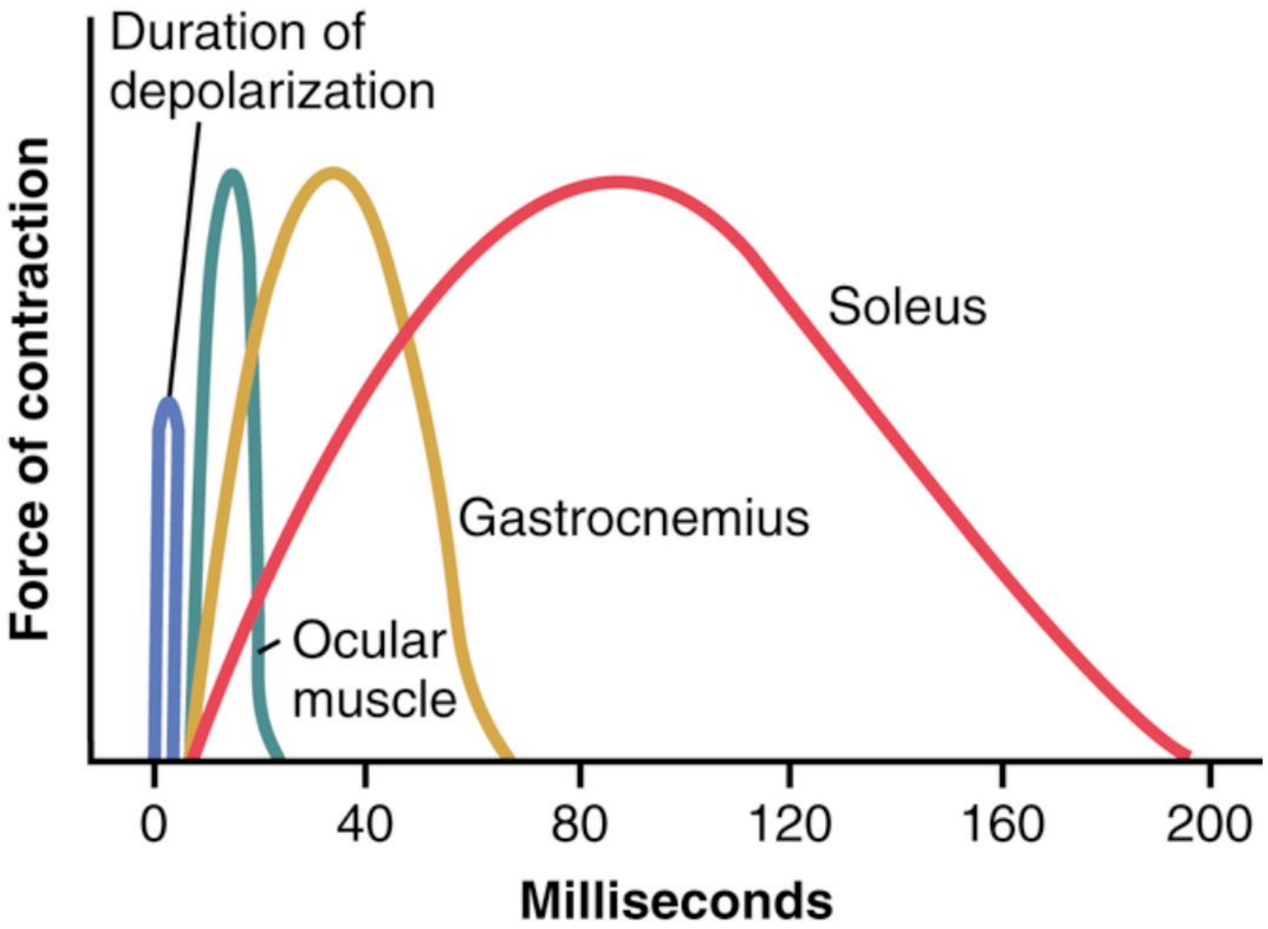
**Both myoglobin (found only in muscle cells) and hemoglobin (found only in red blood cells) are oxygen binding proteins. They bind oxygen when it is plentiful and release oxygen when it is scarce.

Myoglobin combines with oxygen and stored until needed, which also greatly speeds oxygen transport to mitochondria

The three means of how cells produce ATP are summarised here: creatine phosphate, anaerobic glycolysis and aerobic respiration



DURATION OF CONTRACTION



This graph shows records of isometric contractions of three types of skeletal muscle, an ocular muscle, which has a duration of isometric contraction of around 20 milliseconds, the gastrocnemius which has a duration of contraction of about 70 milliseconds, and soleus muscle which has a duration of contraction of about 200 milliseconds.

These duration of contraction are highly adapted to the function of the respective muscles, for example, ocular movements must be extremely rapid to maintain fixation of the eyes on specific objects to provide accuracy of vision.

The gastrocnemius muscle must contract moderately rapidly to provide sufficient velocity of limb movement for running and jumping.

And the soleus muscle is concerned principally with slow contraction for continual long-term support of the body against gravity.

This difference in contraction duration usually results from different composition and proportions of fast versus slow muscle fibre.

SLOW FIBERS (TYPE 1, RED MUSCLE)

- The following are characteristics of slow fibers:
- 1. Slow fibers are smaller than fast fibers.
- 2. Slow fibers are also innervated by smaller nerve fibers.
- 3. Slow fibers have a more extensive blood vessel system.
- 4. Slow fibers have greatly increased numbers of mitochondria.
- 5. Slow fibers contain large amounts of myoglobin.

More details about the last three points :
3. Slow fibers have a more extensive blood vessel system and more capillaries to supply extra amounts of oxygen compared with fast fibres.

4. Slow fibres have greatly increased numbers of mitochondria to support high levels of oxidative metabolism.

5. Slow fibres contain large amounts of myoglobin, which combines with oxygen and stored it until needed.

This greatly speeds oxygen transport to the mitochondria.

presence of myoglobin, gives the slow muscle, a reddish appearance, hence the name red muscle.

FAST FIBERS (TYPE II, WHITE MUSCLE)

- The following are characteristics of fast fibers:
- 1. Fast fibers are large for great strength of contraction.
- 2. Fast fibers have an extensive sarcoplasmic reticulum for rapid release of calcium ions to initiate contraction.
- 3. Large amounts of glycolytic enzymes.
- 4. Fast fibers have a less extensive blood supply than slow fibers.
- 5. Fast fibers have fewer mitochondria than slow fiber.
- 6. Deficient in myoglobin.

Fast fibers have higher myosin ATPase (ATP-splitting) activity than slow fibers do. The higher the ATPase activity, the more rapidly ATP is split and the faster the rate at which energy is made available for crossbridge cycling. The result is a fast twitch compared to the slower twitches of those fibers that split ATP more slowly.

More details about the last four pints:

3. Large amounts of glycolytic enzymes are present in fast fibres for rapid release of energy by the glycolytic process.

4. Fast fibres have a less extensive blood supply than slow fibres; because oxidative metabolism is secondary importance.

5. Fast fibres have fewer mitochondria than slow fibres; also because oxidative metabolism is secondary.

6. A deficit of red myoglobin in fast muscle gives it the name white muscle.

EXERCISE- INDUCED FIBER MODIFICATIONS

❖Improvement in Oxidative Capacity:

- Regular aerobic endurance exercise, such as long-distance jogging or swimming leads to metabolic changes in muscle fibers, including:
- Increase the number of mitochondria and the number of capillaries network.

Muscle fibres can altered significantly in response to stresses impose on them.
Muscle fibres can undergo long-term alteration in both oxidative capability and their diameter (hypertrophy).
Muscles that have been properly modified may use oxygen more efficiently, allowing them to perform longer periods of activity without fatigue

EXERCISE- INDUCED FIBER MODIFICATIONS

❖Muscle Hypertrophy:

- Regular bouts of anaerobic, short-duration, high intensity resistance training, such as weight lifting **can improve muscle size over time**
- The resulting muscle enlargement comes primarily from an increase in diameter known as hypertrophy.
- Results from increased synthesis of myosin and actin filaments **which permits a great opportunity for cross-bridge interaction and consequently increases the muscle’s contractile strength**
- Increases the muscle’s contractile strength.
- **Vigorous weight training can double or triple a muscle size, the resultant bulging muscles are better adapted to activities that require intense strength for brief periods**

الي مكتوب بالبولد كلام الدكتورة في
المحاضرة زيادة شوي عن النقاط الي
بهاي السلايدة

MUSCLE FATIGUE

- Inability of muscle to maintain force of contraction after prolonged activity
- Factors that contribute to muscle fatigue:
    - Depletion of glycogen
    - Failure of the motor neuron to release enough acetylcholine
    - Insufficient oxygen (decreased blood supply)
    - Inadequate release of calcium ions from the SR
    - Depletion of creatine phosphate
    - Buildup of lactic acid and ADP

Muscle fatigue occurs when an exercising muscle can no longer respond to stimulation with the same degree of contractile activity. Muscle fatigue is a defense mechanism that protects a muscle from reaching a point at which it can no longer produce ATP.

The inability to produce ATP result in rigor mortise(التصلب بعد الموت), obviously not an acceptable outcome of exercise.

Another condition known as central fatigue occurs when a person quits exercising or slows down even though their muscles are still functional, a common cause of central fatigue is psychological, which can be due to experiencing pain or discomfort

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