# FACTORS THAT DETERMINE WHOLE MUSCLE CONTRACTION

# 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

note: 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

**B.The tension developed by each contracting fiber.**

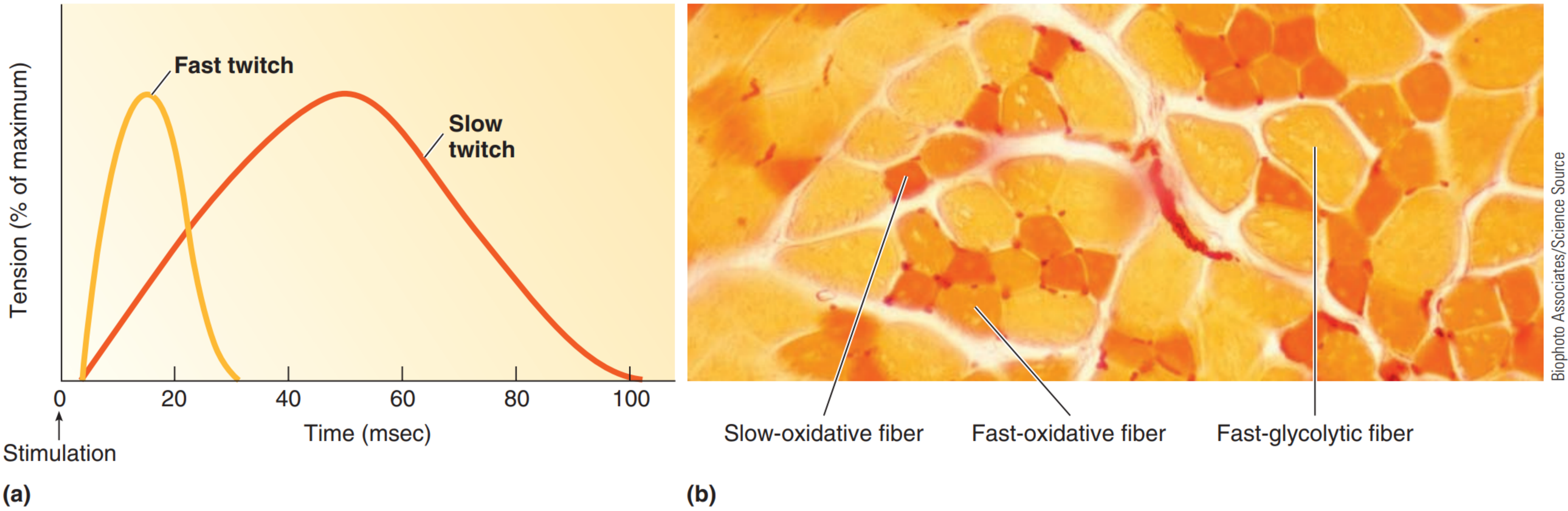
- 1. Stimulation Frequency
- 2. Length of the fiber at the onset of contraction
- 3. Extent of fatigue
- 4. Thickness of the fiber

** The 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



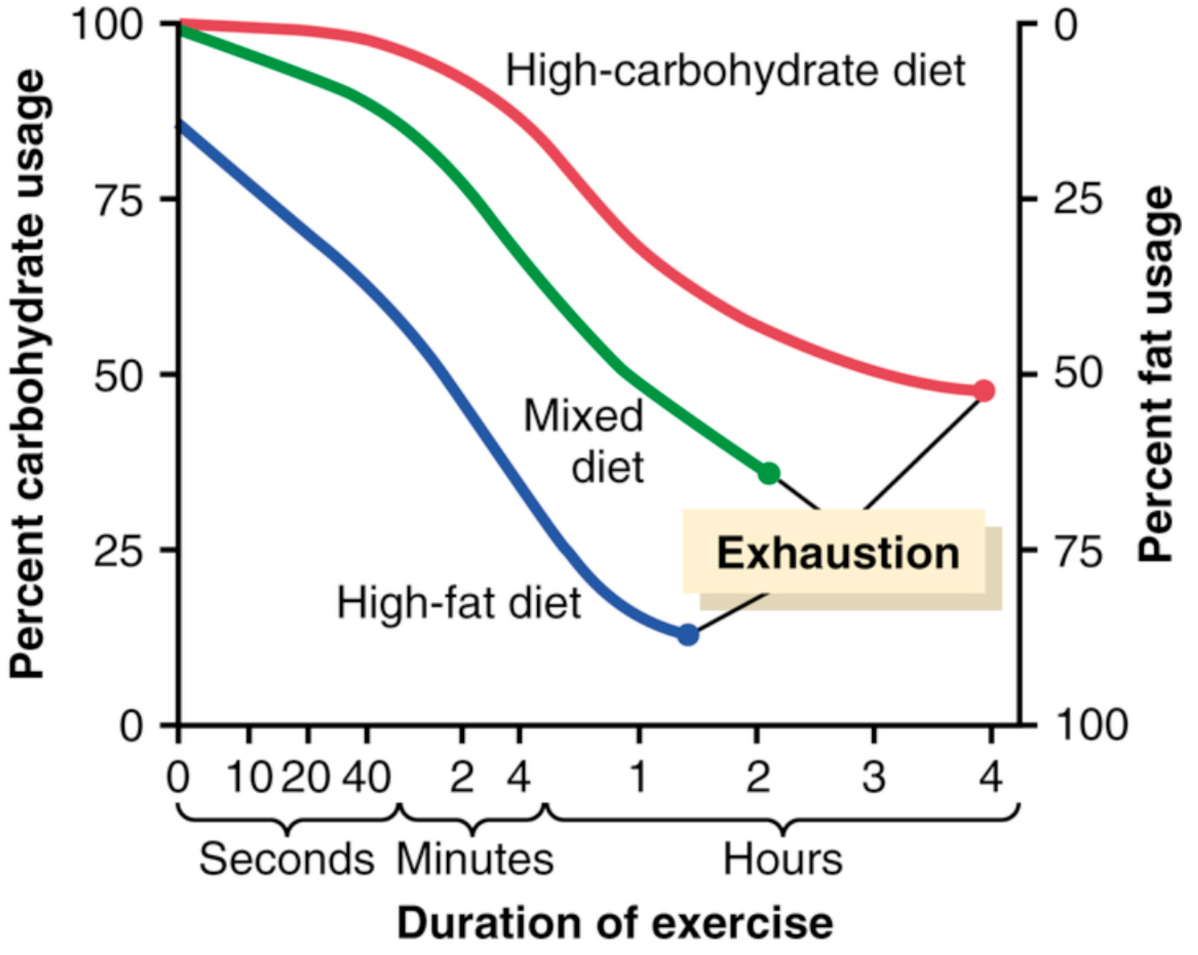

note: speed of contraction (slow or fast)
Fast Versus Slow Fibers Fast fibers have higher myosin ATPase (ATP-splitting) activity than slow fibers do. The higher the ATPase activity, the more rapidly ATP is split and the faster the rate at which energy is made available for crossbridge cycling. The result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

# 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.

# MUSCLE METABOLISM _ SOURCES OF GLUCOSE:



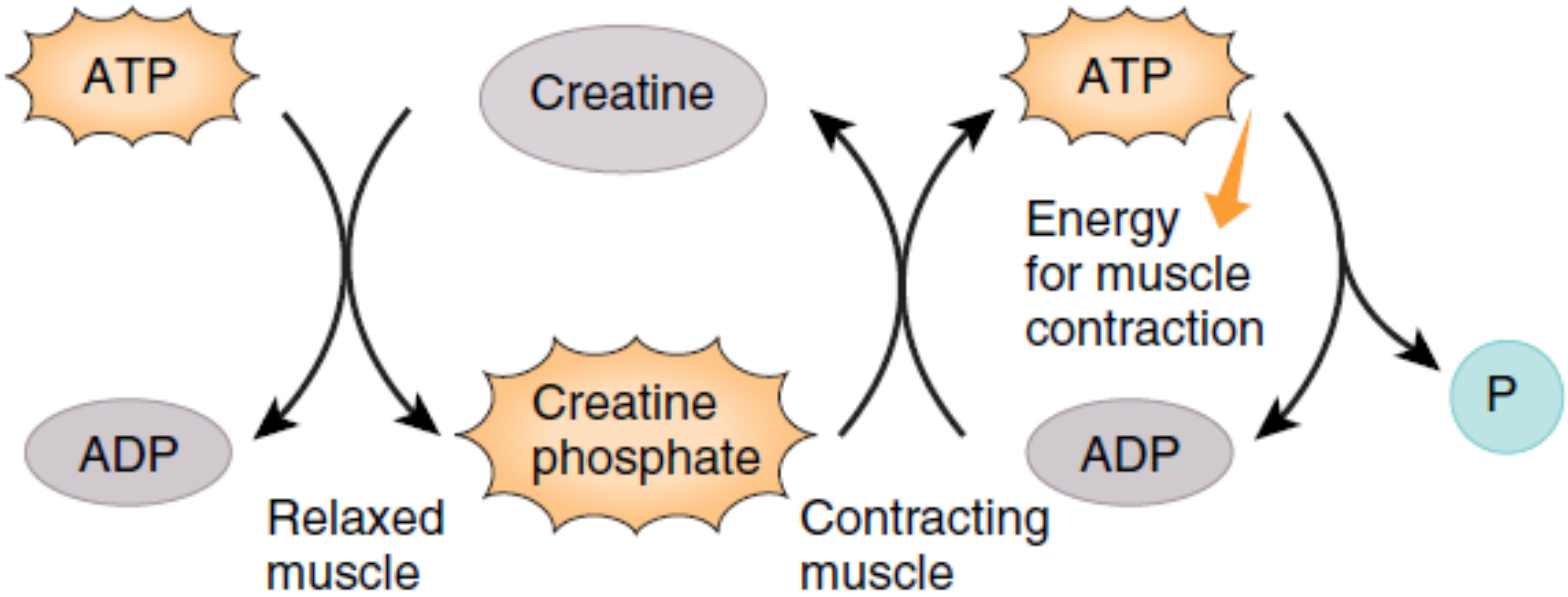
# MUSCLE METABOLISM _ PRODUCTION OF ATP

Muscle fibers have three ways to produce ATP:

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

note: A huge amount of ATP is needed to:
Power the contraction cycle
Pump Ca+2 into the SR
**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.

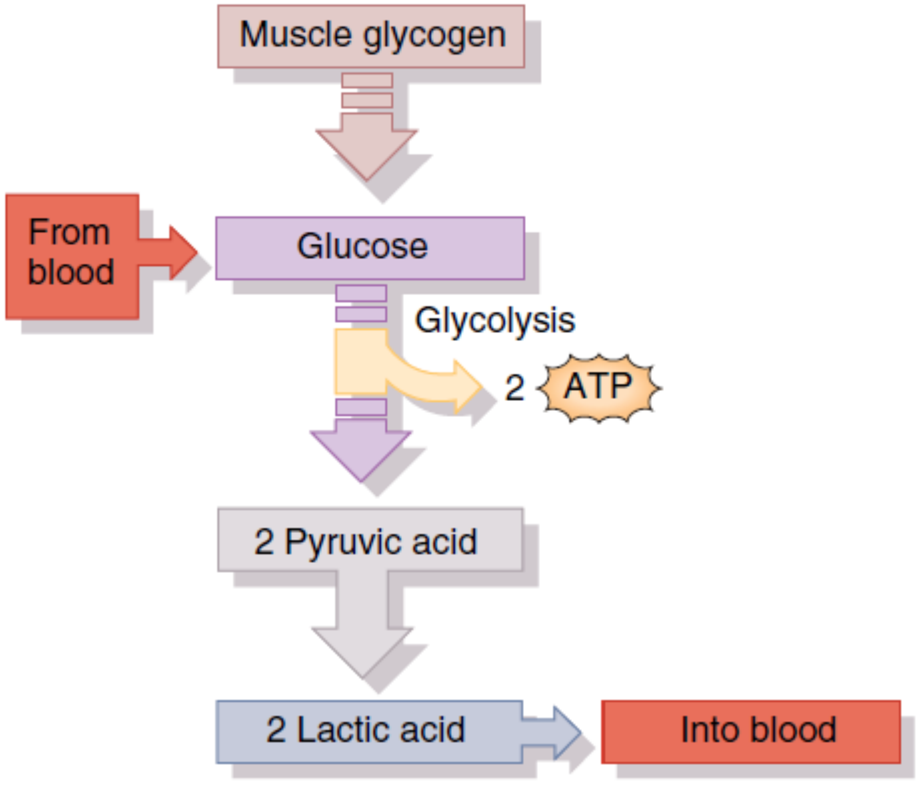
# PRODUCTION OF ATP_ CREATINE PHOSPHATE



Note

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.
** 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.
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 15 seconds.

# PRODUCTION OF ATP_ ANAEROBIC RESPIRATION



Notes

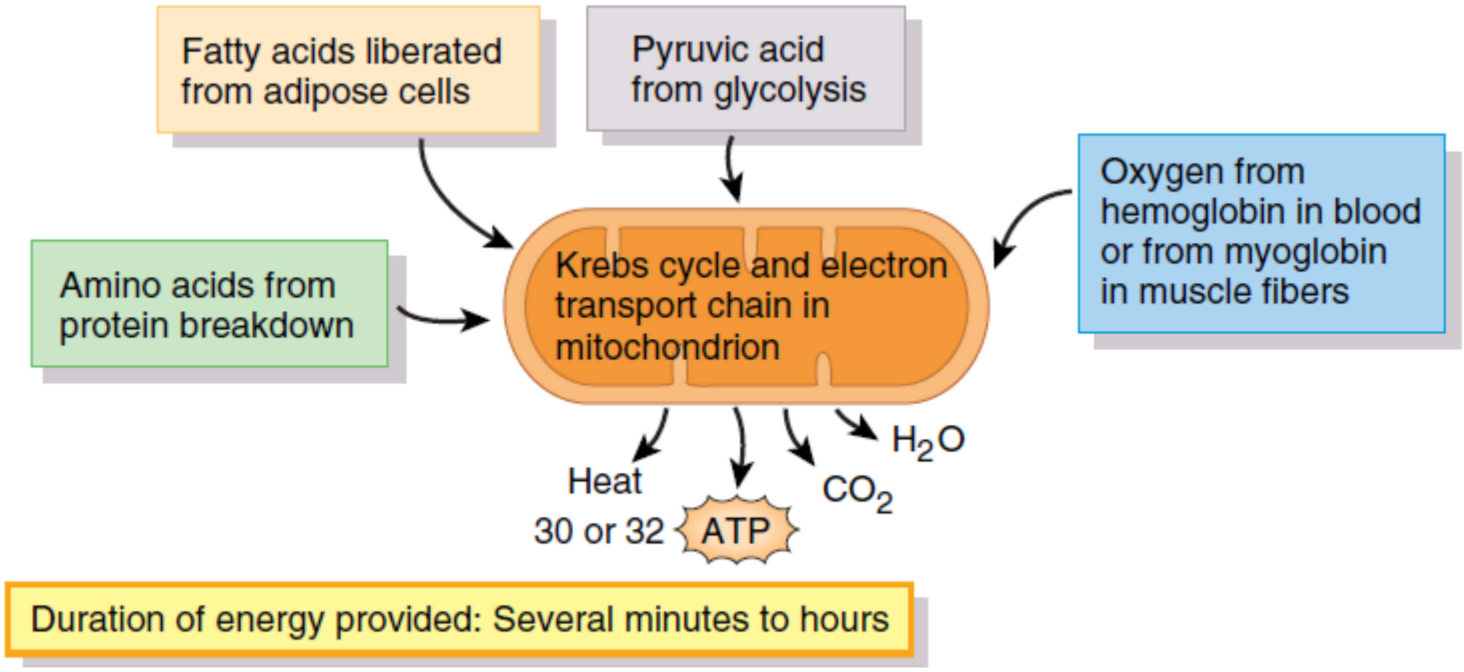
**Glucose passes easily from the blood into contracting muscle fibers via facilitated diffusion, and it is also produced by the breakdown of glycogen within muscle fibers.
**Glycolysis: breaks down each glucose molecule into two molecules of pyruvic acid. Glycolysis occurs in the cytosol and produces 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 02 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 02 availability to the muscle fibers. Even when 02 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

Notes

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.

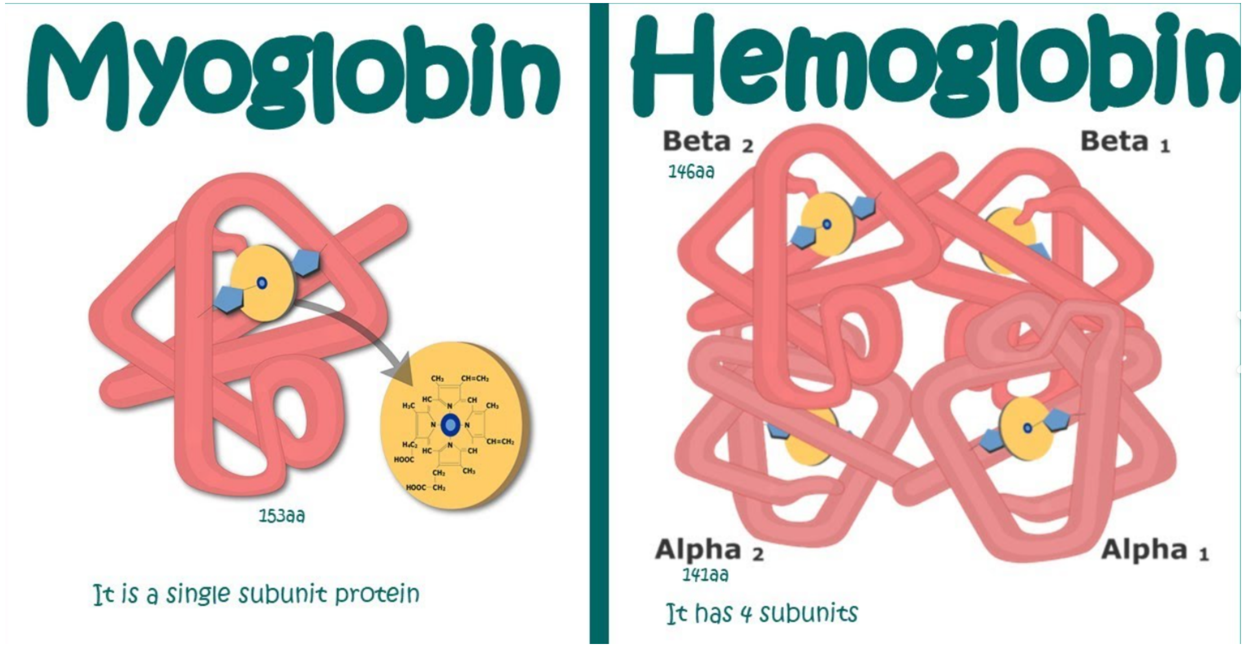
The third and final source of energy is oxidative metabolism, which means combining oxygen with the end products of glycolysis and with various other cellular foodstuffs to liberate ATP. More than 95% of all energy used by the muscles for sustained long-term contraction is derived from oxidative metabolism. 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.

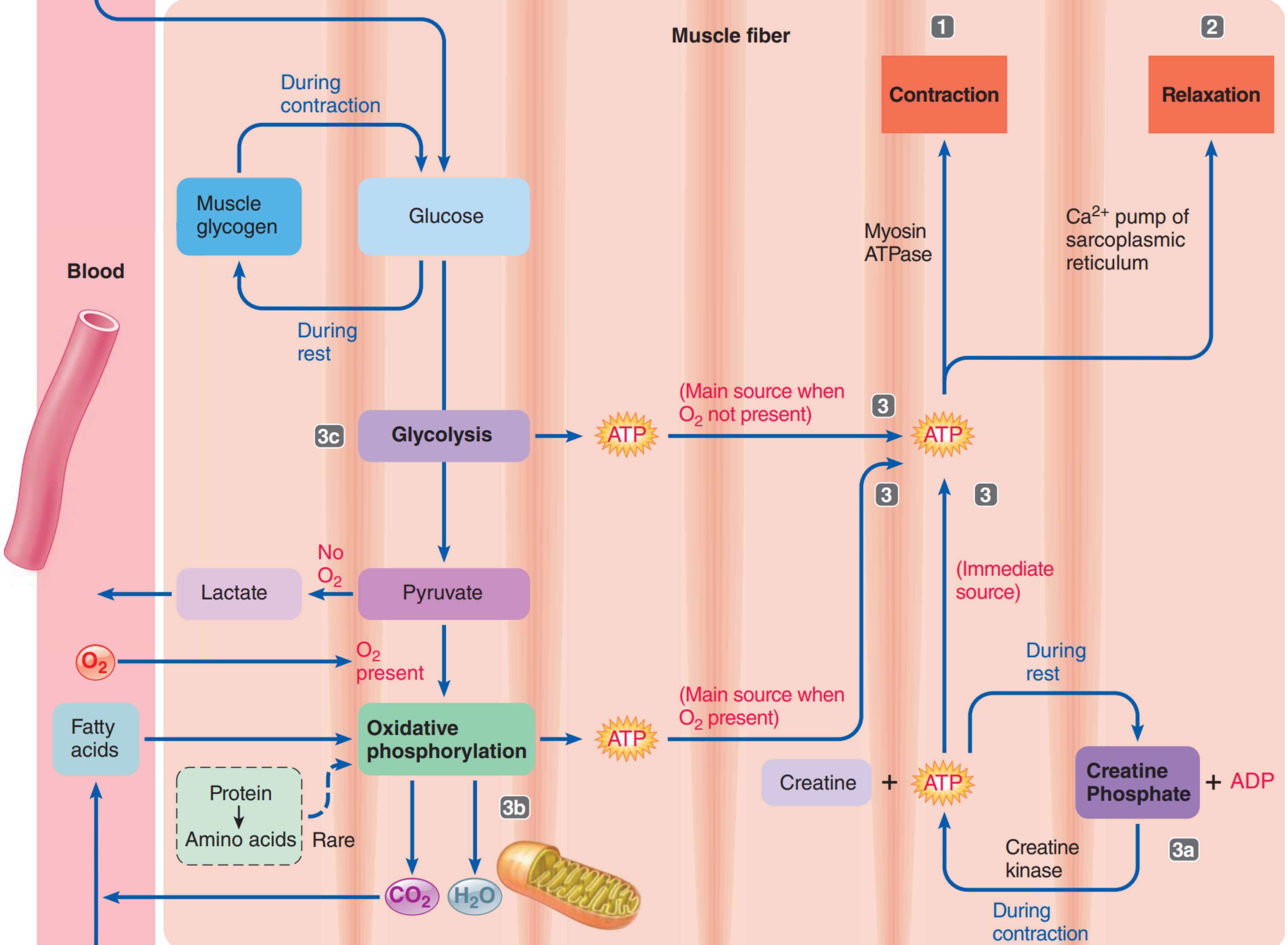
During light exercise (such as walking) to moderate exercise (such as jogging or swimming), muscle cells can form enough ATP through oxidative phosphorylation to keep pace with the modest energy demands of the contractile machinery for prolonged periods. To sustain ongoing oxidative phosphorylation, exercising muscles depend on delivery of adequate 02 and nutrients to maintain their activity. Activity supported in this way is aerobic ("with 02") or endurance-type exercise

# MUSCLE METABOLISM _ SOURCES OF OXYGEN:

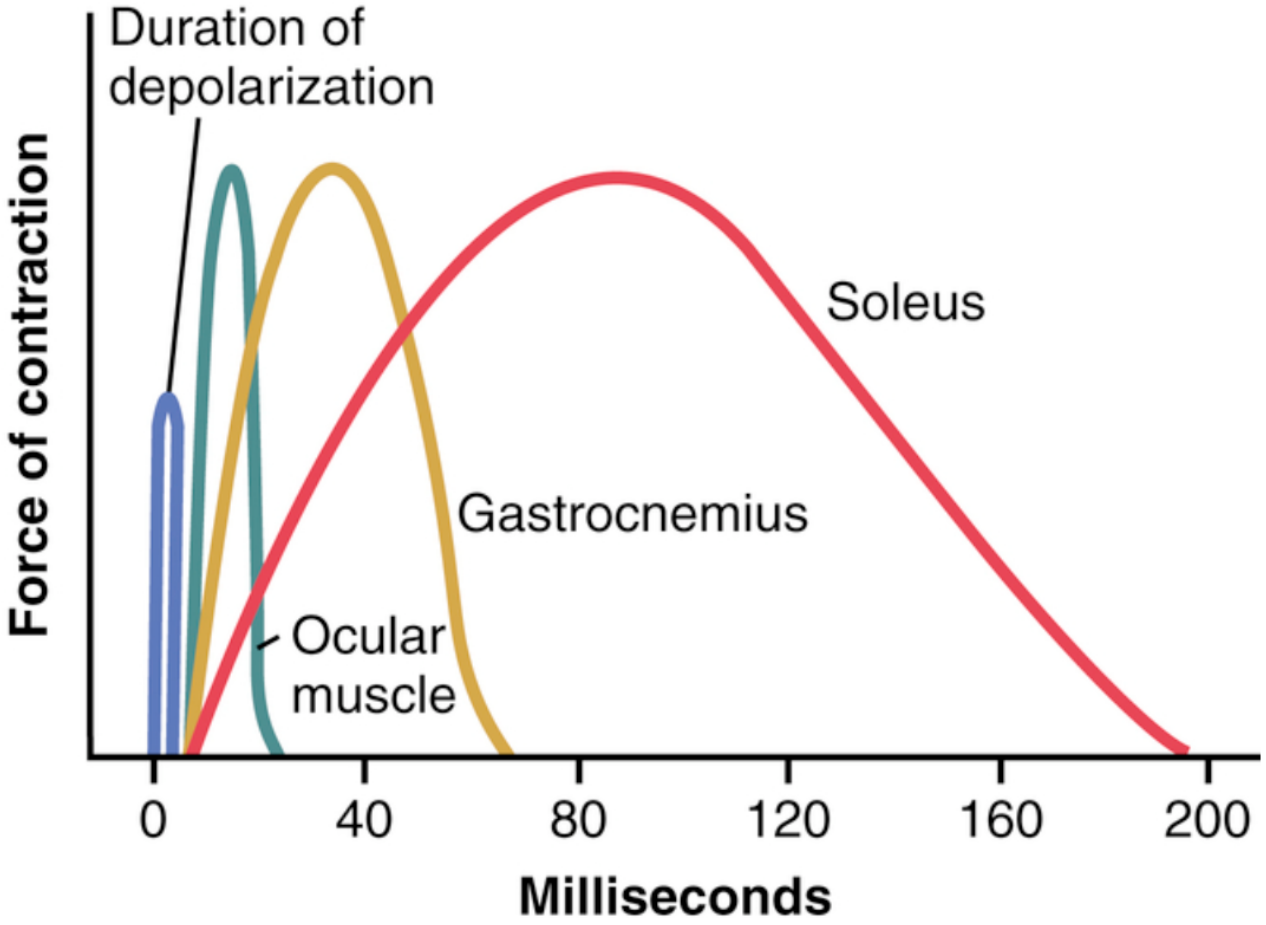
- (1) oxygen that diffuses into muscle fibers from the blood
- (2) oxygen released by myoglobin within muscle fibers.

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




Muscle fiber
Blood
1
2
Contraction
Relaxation
During contraction
Muscle glycogen
Glucose
During rest
Myosin ATPase
$Ca^{2+}$ pump of sarcoplasmic reticulum
3c
Glycolysis
ATP
(Main source when $O_2$ not present)
3
ATP
3
3
No $O_2$
Lactate
Pyruvate
(Immediate source)
$O_2$
$O_2$ present
During rest
Fatty acids
Oxidative phosphorylation
ATP
(Main source when $O_2$ present)
Creatine
+
ATP
Creatine Phosphate
+ ADP
Protein
Amino acids
Rare
3b
Creatine kinase
3a
$CO_2$
$H_2O$
During contraction

# DURATION OF CONTRACTION



# 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.

# 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.

Note: 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

# EXERCISE- INDUCED FIBER MODIFICATIONS

● Improvement in Oxidative Capacity:

- Regular aerobic endurance exercise, such as long-distance jogging or swimming.
- Increase the number of mitochondria and the number of capillaries.

# EXERCISE- INDUCED FIBER MODIFICATIONS

● Muscle Hypertrophy:

- Regular bouts of anaerobic, short-duration, high intensity resistance training, such as weight lifting.
- The resulting muscle enlargement comes primarily from an increase in diameter.
- Results from increased synthesis of myosin and actin filaments.
- Increases the muscle’s contractile strength.

# 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

Note: 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.

# REFERENCES

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2. Lauralee Sherwood. Human Physiology: From Cells To Systems (9th Edition).
3. Gerard J. Tortora and Bryan Derrickson. Principles Of Human Anatomy & Physiology (15th Edition)