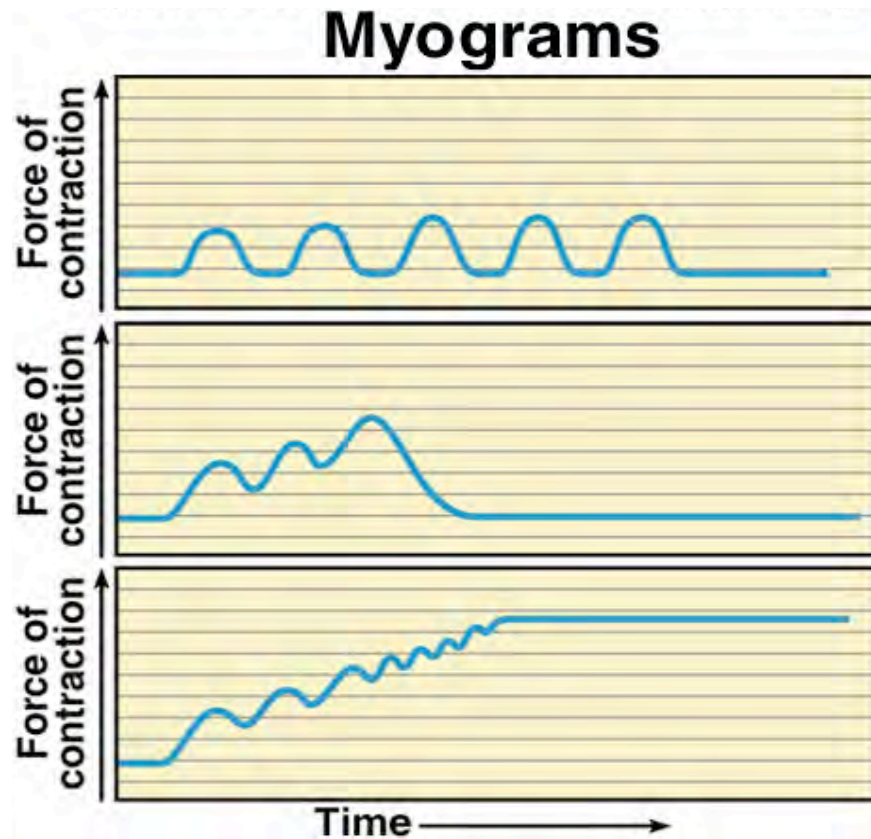


**BIO 211:**  
**ANATOMY & PHYSIOLOGY I**



**CHAPTER 09**

**MUSCULAR**  
**SYSTEM**

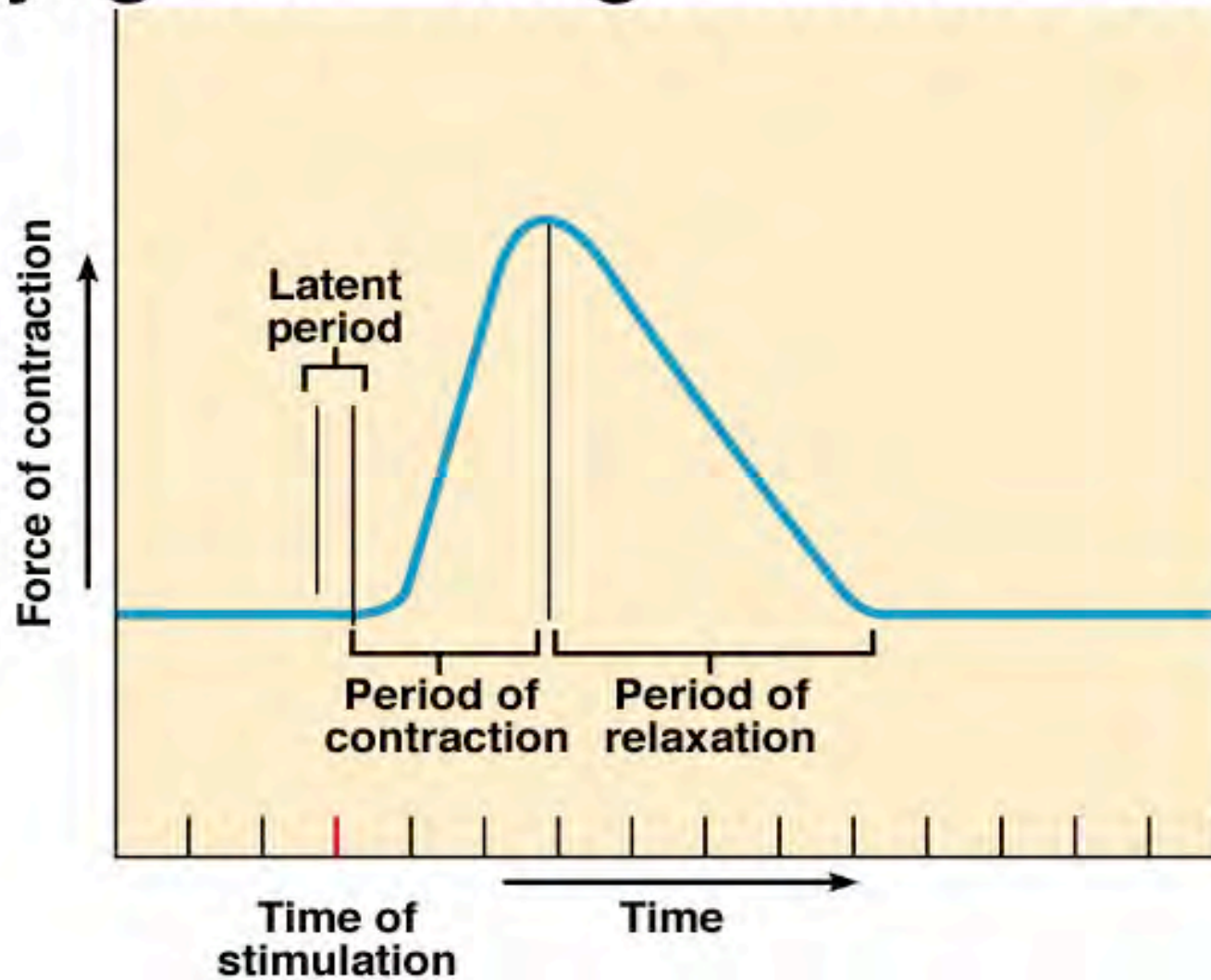
**Part 2 of 2**

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*Some illustrations are courtesy of McGraw-Hill.*

# Myogram — Single Muscle Twitch



## Behavior of Whole Muscles

### A. Threshold, Latent Period, and Twitch

*See the previous slide !*

1. Muscles have a threshold, or *minimal voltage necessary to produce a muscle contraction*.
2. If a muscle is given a **single, brief stimulation**, it will show a **cycle** of contraction and relaxation, called a twitch.  
During the **twitch**, it has a **contraction phase** followed by a **relaxation phase**.
3. Latent period (brief) exists between two successive **twitches** in which the **muscle cannot contract**.

## Behavior of Whole Muscles

### B. Graded and "ALL or NONE" response

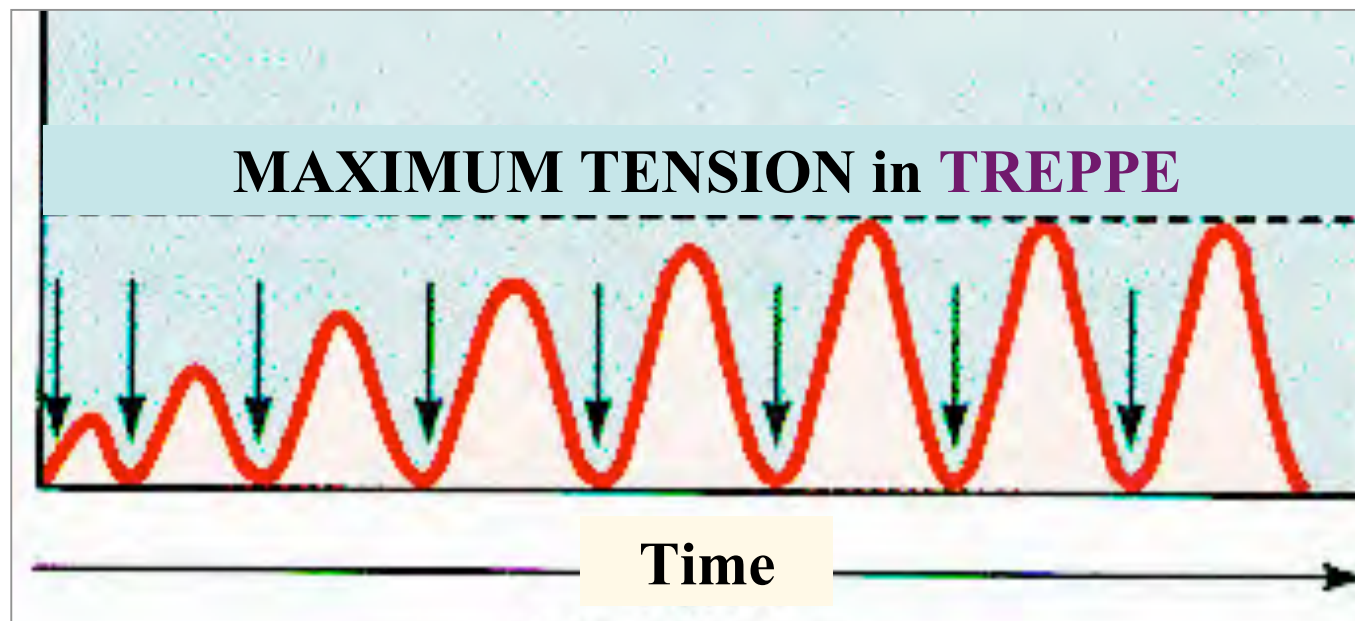
1. The muscle **fiber** (not the whole muscle!) exhibits a **maximum contraction response** or it **exhibits none at all**, a phenomenon called the *all-or-none law*.
2. The **strength** of contraction of a **whole** muscle is **graded** as more *motor units join in*.  
*Recall Motor Unit from Part 1:*  
*A motor neuron + all the fibers it innervates*

## Behavior of Whole Muscles

### C. TREPPE

Muscle cells exhibit treppe, or the *staircase phenomenon*, in response to a series of stimuli of the same strength.

*This is probably due to the inability of the muscle cells to fully return calcium to the sarcoplasmic reticulum.*

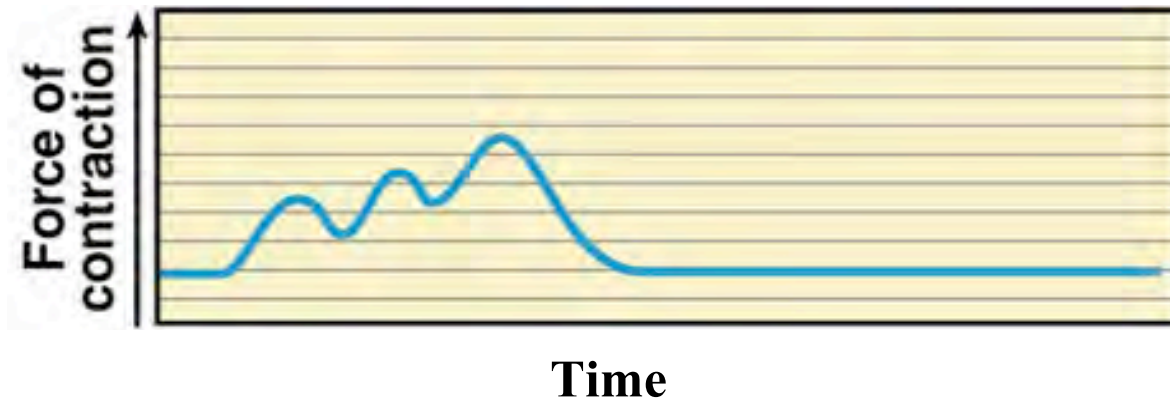


From  
Martini text

## Behavior of Whole Muscles

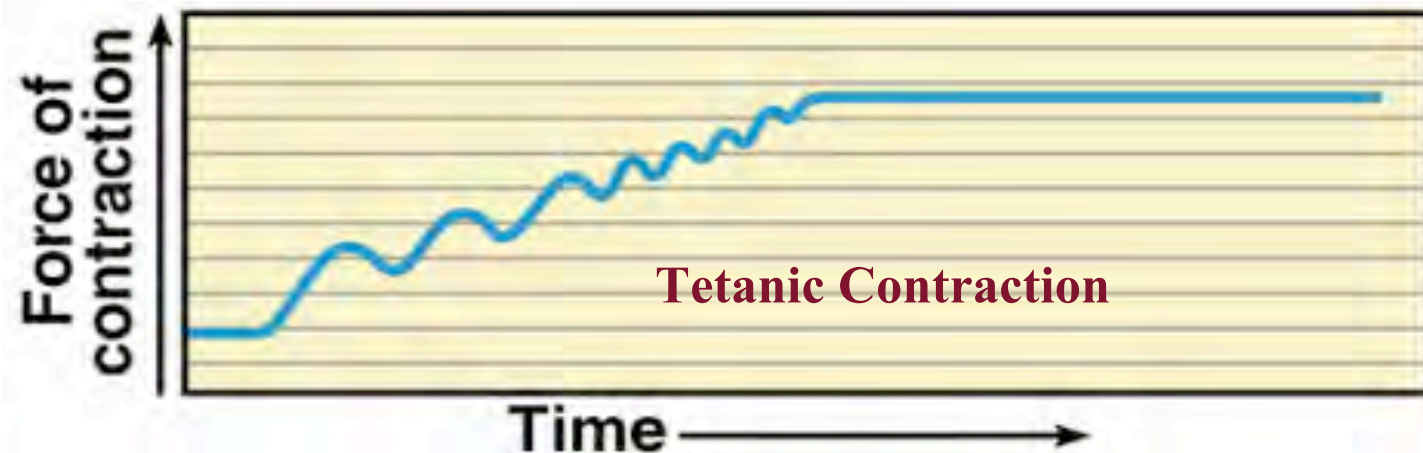
### D. Refractory Period, Temporal Summation, and Tetanus

1. After a twitch, a short refractory period exists when *the muscle cannot respond to another stimulus.*
2. If a second stimulation arrives **before** the end of the refractory period, the muscle will achieve temporal summation (or wave summation) and achieve a *higher level of tension.*



## Behavior of Whole Muscles

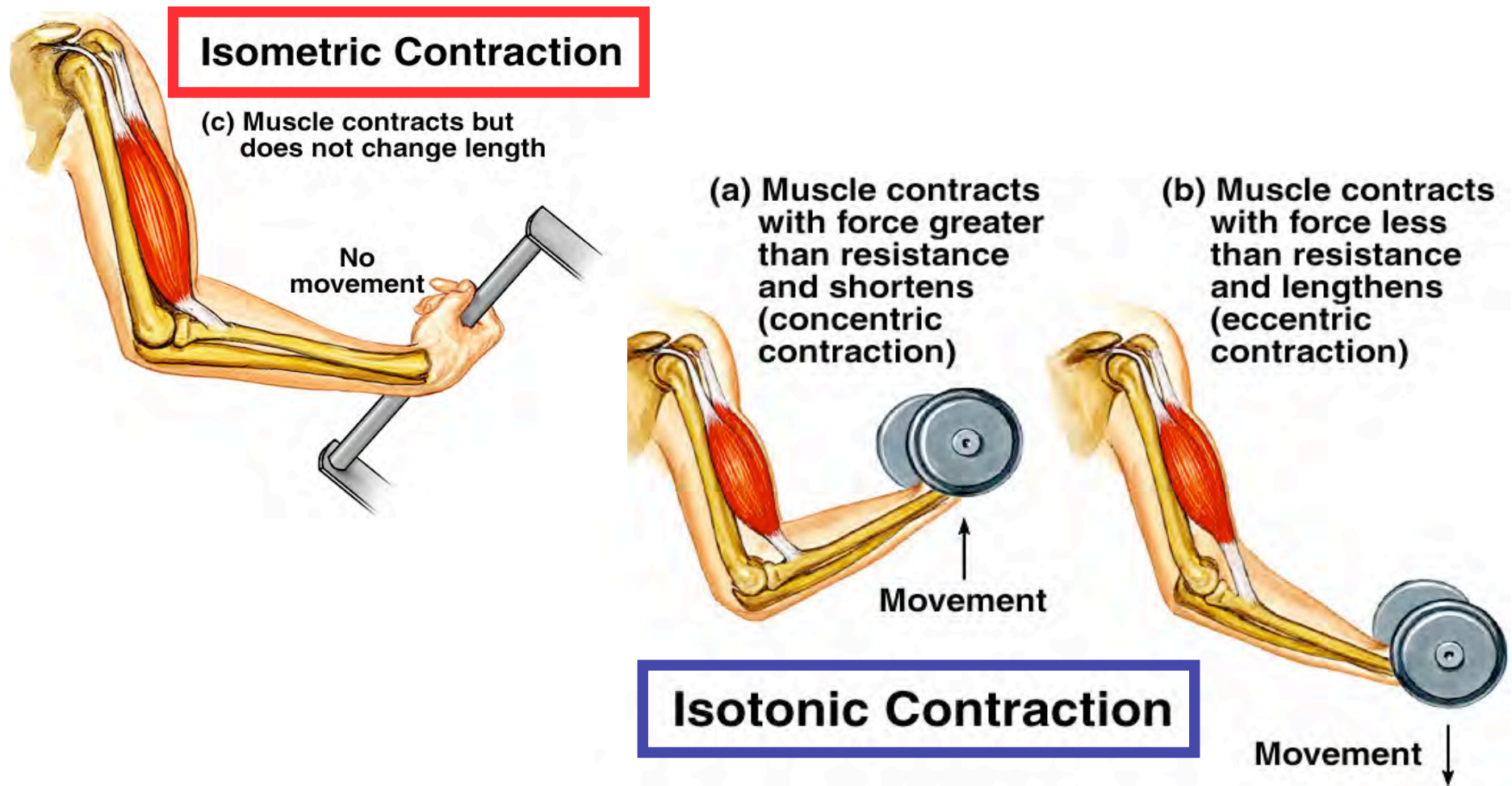
### D. **Refractory Period**, **Temporal Summation**, and **Tetanus**



3. If the stimuli are **frequent** enough that the muscle **cannot relax completely in between**, a state of **incomplete tetanus** is reached.  
If there is **no time to relax *at all*** between stimuli, **complete tetanus** is achieved.

## Behavior of Whole Muscles

### E. **Isometric vs. Isotonic Contraction**



# Muscle Metabolism

## A. Energy Transfer

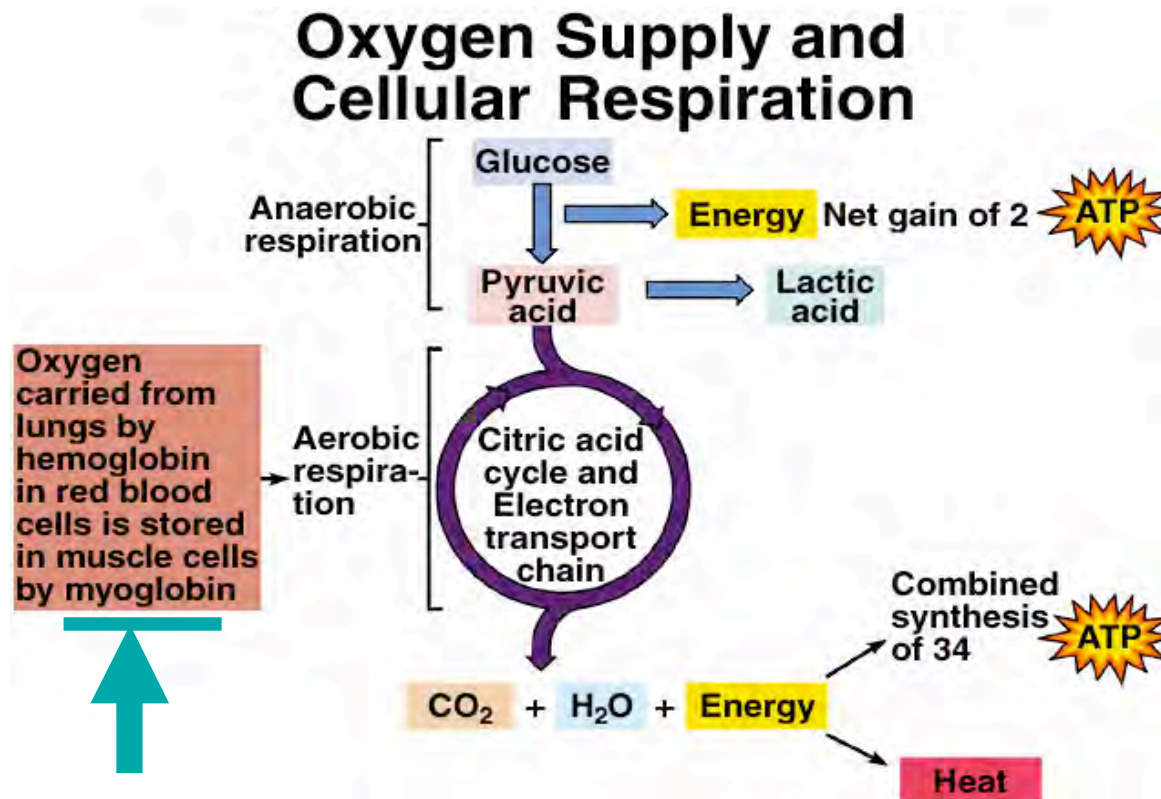
1. During exercise, muscles use energy produced by **aerobic respiration** (when there is an adequate supply of oxygen) and **anaerobic fermentation**, when oxygen is limited, and **lactic acid** accumulates.
2. Immediate Energy  
For short, quick spurts of energy, muscle tissue relies on the **phosphagen system** to supply ATP. This includes **myokinase** and **creatine kinase** that *recruit phosphate groups*.
3. Short-Term Energy  
After the phosphagen system is exhausted, muscles rely temporarily on the **glycogen-lactic acid pathway** for ATP to supply energy for 30-40 seconds.

# Muscle Metabolism

## A. Energy Transfer

### 4. Long-Term Energy

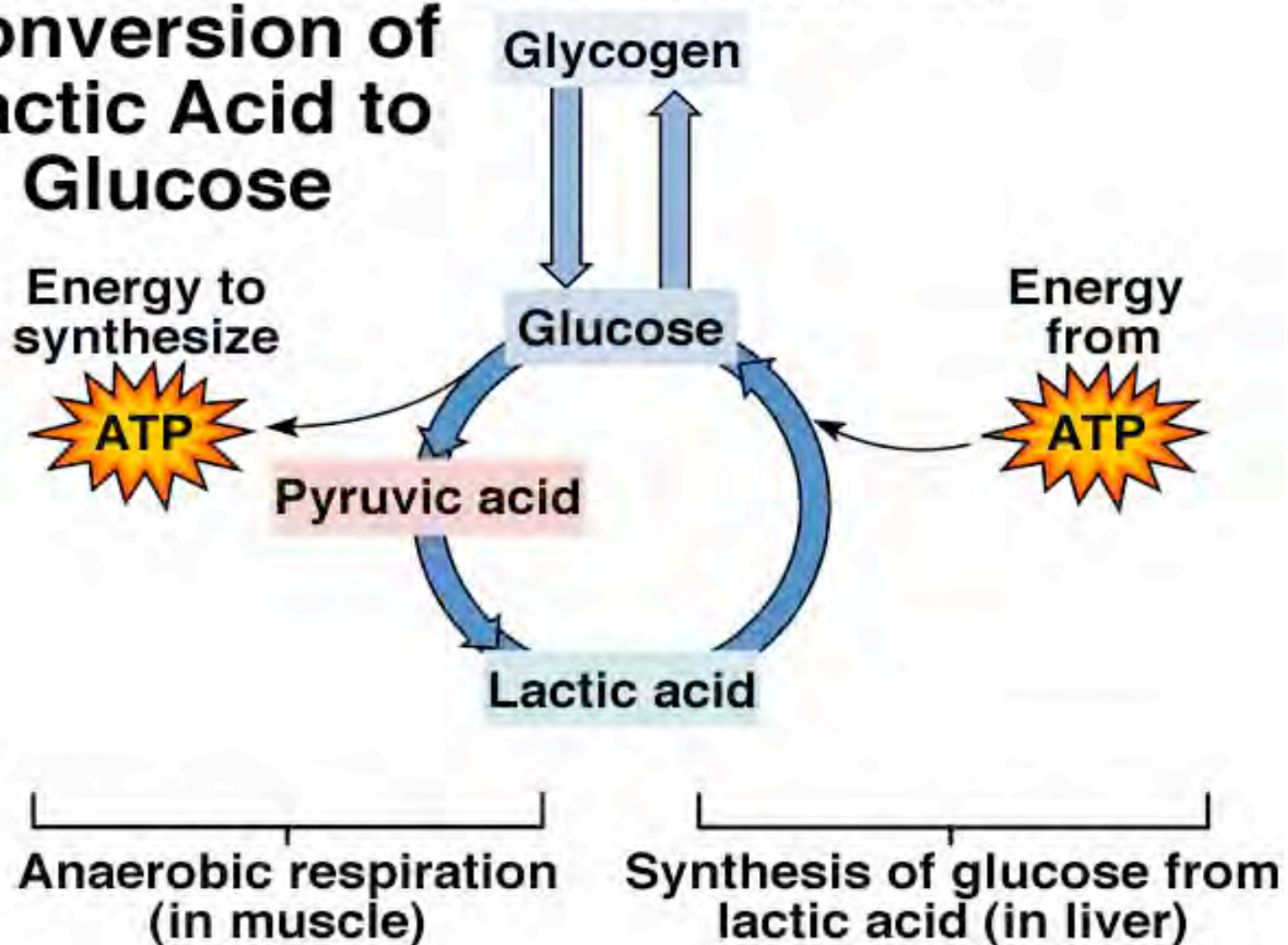
After 40 seconds, the respiratory and cardiovascular systems catch up and deliver enough oxygen to meet the demands of aerobic respiration. **Aerobic respiration** can supply muscle demands for **longer periods** of activity. (see **Myoglobin** below)



## Muscle Metabolism

### A. Energy Transfer

#### Conversion of Lactic Acid to Glucose



## Muscles: Other Factors and Considerations

### A. Fatigue and Endurance

1. Muscle fatigue, the progressive weakness and loss of contractility, is due to a variety of causes;

**ATP synthesis declines** as glycogen is consumed, the ATP shortage slows down to **maintain** the resting membrane potential (**remember  $\text{Na}^+/\text{K}^+$  pump??**)

**lactic acid lowers the pH of the sarcoplasm and impairs the action of enzymes;**

**accumulation of potassium ions reduces the membrane potential;**

**motor nerve fibers use up their ACh, and the CNS fatigues for unknown reasons.**

2. Physical endurance depends on the maximum **oxygen uptake** of the athlete & the supply of **organic nutrients**.

## Muscles: Other Factors and Considerations

### B. Oxygen Debt

1. **Oxygen debt** is the *difference* between the **resting state of oxygen consumption** and the **elevated rate following an exercise**.
2. Oxygen inhaled **after exercise** is used to replace the body's oxygen reserves, replenish the phosphagen system, oxidize lactic acid, and serve the now elevated metabolic rate

### C. Muscular Strength

*Muscle strength depends on:*

**muscle size**

**fascicle arrangement**

**size of active motor units**

**multiple motor unit summation (recruitment).**

**temporal summation (wave summation).**

## Muscles: Other Factors and Considerations

### D. **Slow-** and **Fast-Twitch** Fibers

1. **Slow-twitch fibers** are **small** and produce twitches up to 100 msec long. They have **more mitochondria and capillaries**, and are **high-endurance fibers**. Impart a **red**, or "**dark-meat**" quality to muscles.
2. **Fast-twitch fibers** are **larger** and produce twitches as short as 7.5 msec. They produce **quick energy** (phosphagen system) for stop-and-go activities. These fibers impart a **white appearance** to muscles.
3. **Individuals are born with different ratios of slow to fast- twitch fibers.**  
**Athletic conditioning cannot change the genetic component of ability.**

## E. Muscular Conditioning and Atrophy

1. **Resistance** exercise (weight lifting) is the contraction of muscles **against a load** that resists movement, and is enough to **stimulate muscle growth**. Growth results mostly from **cellular enlargement**, *not cell division*.
2. **Endurance (aerobic) exercise** improves the fatigue-resistance of the muscles.  
**Slow-twitch fibers acquire a greater density of blood capillaries.**
3. Optimal performance and skeletomuscular health require **cross - training**, which incorporates elements of **both types** (*endurance* + *resistance*).

## Muscles: Other Factors and Considerations

### F. Delayed Onset Muscle Soreness

Delayed onset muscle soreness is unusual pain, stiffness, or tenderness that is felt several hours to a day **after** strenuous exercise.

This is due to muscle **microtrauma**.

### G. Cramps

The **central nervous system** (Brain + Spinal Cord) occasionally triggers painful, **spasmodic contractions (cramps)**. These are initiated by:

**extreme cold**

**heavy exercise**

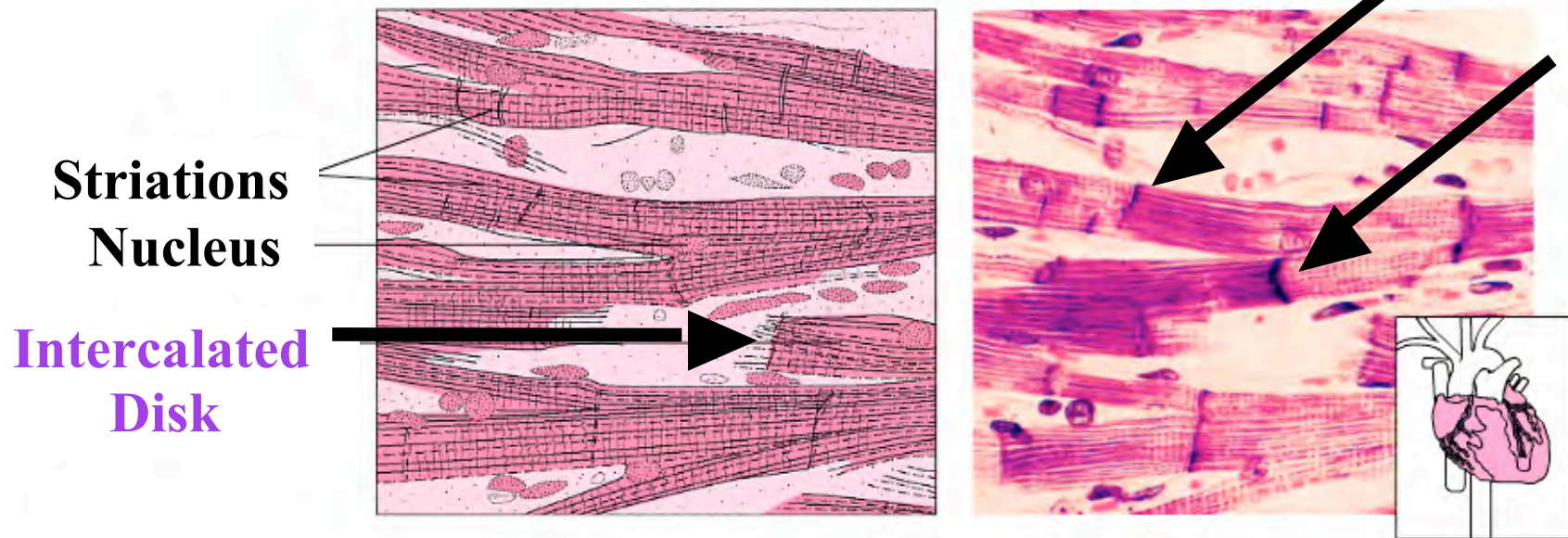
**lack of blood flow**

**electrolyte depletion**

**dehydration**

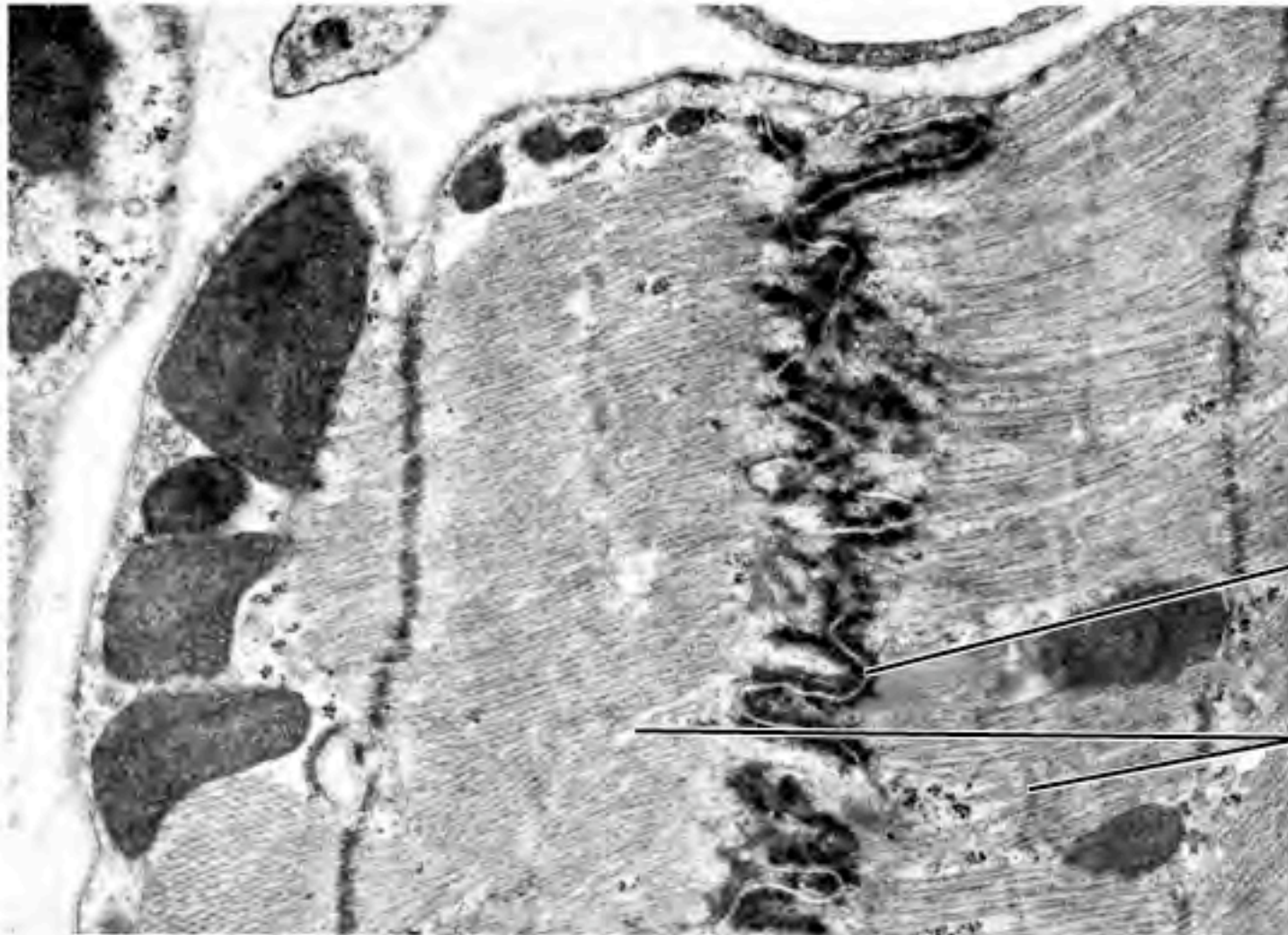
**low blood glucose.**

# CARDIAC MUSCLE



Cardiac muscle tissue is only in the heart. Its cells, which are striated, are joined end-to-end. The resulting muscle fibers are **branched** and connected in complex networks. Each cell within a cardiac muscle fiber has a **single nucleus**. Where it touches another cell is a specialized intercellular junction called an **intercalated disk**, seen **only in cardiac tissue**.

# Intercalated Disks of Cardiac Muscle



Inter-  
calated  
disk

Cardiac  
muscle  
cells

# Smooth Muscle

## A. Types and Functions

1. **Multiunit smooth muscle** occurs in *some* arteries and pulmonary air passages, in the arrector pili, and iris. The terminal branch of an **axon synapse with individual muscle cells and form a motor unit**.
2. In **single-unit smooth muscle**, a nerve fiber *does not synapse with a particular cell* but rather releases **neurotransmitter at several points** within the tissue. Single-unit smooth muscle cells also communicate electrically with each other through **gap junctions**. This type of muscle is also called **visceral muscle**.
3. Within the digestive tract, an inner circular layer and outer longitudinal layer of **visceral muscle** produce **peristalsis**.

# Smooth Muscle

## B. Microscopic Anatomy

1. A smooth muscle cell is **fusiform**, **short**, and **uninucleate**.

There are **no visible striations**; Z discs are absent. Instead, thin filaments attach to dense bodies.

2. *There is scanty (little) sarcoplasmic reticulum, and no T tubules.*

*Calcium enters through channels in the sarcolemma.*

Smooth Muscle is innervated in an involuntary fashion by the ANS (Autonomic Nervous System).

We will cover that network during our final chapter of BIO 225.

## Smooth Muscle

### C. Gap Junctions and Pacemakers

1. Single-unit muscle cells *can electrically stimulate each other through their gap junctions*, producing a wavelike contraction in the tissue as a whole.
2. The **first cells to contract** act like pacemakers, setting off nearby cells.

### D. Contraction and Relaxation

1. **Contraction** is triggered by an **influx of calcium ions**; most of it comes in **from extracellular fluid**.
2. There is **no troponin** in smooth muscle; there is calmodulin instead to which calcium ions attach.

Smooth muscle has a latch-bridge mechanism that enables the myosin to remain attached to the actin for some time **without** expending more energy from ATP. Smooth muscle is **very resistant to fatigue**, allowing for smooth muscle tone.

*Postscript:*

**Muscular dystrophy** is a collective term for a number of hereditary diseases causing muscles to degenerate. The most common form is **Duchenne muscular dystrophy**, caused by a sex-linked recessive gene.

Last  
Plate