THE MUSCULAR SYSTEM
MUSCLES

- Muscles are responsible for movement of the human body.
WORKS WITH SKELETAL SYSTEM

- Tendons attach muscles to bones.
- Muscles contract, or shorten, pulling on tendons which pull on bones to accomplish movement at joints.
Humans have somewhere between 650 and 700 skeletal muscles.

It’s difficult to count them all and it depends on how you count them.
3 TYPES OF MUSCLE TISSUE

- Smooth
- Cardiac
- Skeletal
Anatomy of the Muscular System
SMOOTH MUSCLE

- Mostly in walls of hollow, visceral organs
- Involuntary, no striations
- Spindle-shaped cells in sheets or layers
- Slow, sustained contractions move substances through the organ or along a tract
SMOOTH MUSCLE LAYERS

Usually arranged in two layers:

- Circular
- Longitudinal
CARDIAC MUSCLE

- Found only in the heart
- Involuntary
- Striations
- Branching chains of cells
- Intercalated discs
- Steady, rhythmic contractions
THE HEART

• The heart is a muscular organ that pumps or squeezes blood throughout the body.
• Heart muscle tissue is called myocardium.
SKELETAL MUSCLE

- Attached to bones
- Voluntary
- Striated
- Single, long, cylindrical multinucleate cells
- Strong, rapid contraction
- Not rhythmic
MUSCLE CELL = MUSCLE FIBER

Structure of a Skeletal Muscle

- bone
- perimysium
- blood vessel
- muscle fiber
- tendon
- epimysium
- endomysium
- fascicle
SKELETAL ORGANS

• Skeletal muscle fibers are packaged into organs called skeletal muscles.
CONNECTIVE TISSUE WRAPPINGS

- Each muscle fiber: **ENDOMYSIUM**
- Each fascicle: **PERIMYSIUM**
- Each muscle: **EPIMYSIUM**

A fascicle is a bundle of muscle fibers.
TENDONS

- Epimysia blend into strong, cord-like tendons to attach muscle to bone.

Structure of a Skeletal Muscle:
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FASCICLE ARRANGEMENTS

- Circular
- Convergent
- Unipennate
- Parallel
- Bipennate
- Parallel fusiform
- Multipennate
ORIGIN & INSERTION

- The **origin** is the attachment to the immovable (or less movable) bone.
- The **insertion** is the attachment to the movable bone.
- When a muscle contracts, the insertion moves towards the origin.
MUSCLE NAMES

Skeletal muscles are named based on many different factors including:

• Direction of the Muscle Fibers
• Relative Size
• Location of the Muscle or its Origin & Insertion
• Number of Origins
• Shape
• Function or Action
EXAMPLES OF NAMES

• The gluteus maximus is the largest muscle of its group.
• There is also a gluteus minimus and a gluteus medius.
ANOTHER EXAMPLE

• The biceps brachii muscle is named for two features:
  • Biceps refers to the fact that it has two origins
  • Brachii refers to the muscle being in the brachial area
Muscles

Sternocleidomastoid
Pectoralis Major
Brachioradialis
Flexor Carpi Radialis
Palmaris Longus
Gluteus Medius
Tensor Faciae Latae
Rectus Femoris
Pectineus
Sartorius
Vastus Lateralis
Gracilis
Gastrocnemius
Extensor Digitorum Brevis
Trapezius
Deltoid
Biceps
Extensor Digiti Minimi
Latissimus Dorsi
Serratus Anterior
Rectus Abdominus
External Oblique
Adductor Longus
Vastus Medialis
Tibialis Anterior
Peroneus Longus
Soleus
Extensor Hallucis Brevis
GROUP ACTIONS

• Most body movements are the result of two or more muscles acting together or against each other.
• Whatever one muscle can do, others can reverse.
• The prime mover or agonist is the muscle that produces a particular movement.
• The antagonist produces the opposite effect on the same bones.
BICEPS & TRICEPS EXAMPLE

- The biceps muscle is the prime mover or agonist when flexing the arm.
- The triceps is the antagonist.

![Diagram of biceps and triceps muscles](image)
Synergists are muscles that help stabilize a movement.

- They either produce the same movement or reduce undesirable movements.
**FIXATORS**

- **Fixator** muscles stabilize the origin of a prime mover.
- For example, when you bend over to pick up something heavy, fixators in the trunk help you maintain your balance.
MICROSCOPIC ANATOMY

- Each muscle fiber is a cell
- **Sarcolemma** is the cell membrane
- Fibers are made of myofibrils
- Mitochondria supply energy for contraction
Muscle cells are stimulated by electrochemical signals that travel along the sarcolemma.

- **T-Tubules** carry the signal into the fiber.
- **Sarcoplasmic reticulum** stores calcium ions needed for contraction.
MYOFIBRILS & MYOFILAMENTS

- **Myofibrils** – long, ribbon-like fibers of a muscle cell
- **Myofilaments** – threadlike proteins in the myofibril, two types:
  1. **Myosin** – thick filament
  2. **Actin** – thin filament
• The **sarcomere** is the functional unit of muscle fibers; made of actin & myosin.
• Thin actin filaments (light green) and thick myosin filaments (purple) will bind together during muscle contraction.
ACTIN AND MYOSIN

- Myosin molecules (purple) have a club-shaped head that will extend toward and bind to actin (green).
- Actin contains myosin binding sites (dark green) that are covered by regulatory proteins (orange) until calcium ions are present.
Physiology of the Muscular System
Muscle tissue has special properties that enable it to perform its functions:

- **Irritability** – ability to receive and respond to a stimulus
- **Contractility** – ability to shorten
MUSCLE FUNCTIONS

1. Producing Movement
2. Maintaining Posture
3. Moving Substances
4. Generating Heat
The primary function of skeletal muscles is to produce movement: locomotion and manipulation. Facial muscles move to express emotion.
MAINTAINING POSTURE

• Holds body upright against gravity
• Stabilizes joints
• Maintains balance
Cardiac and smooth muscles are responsible for transporting substances like blood or food from one part of the body to another.
GENERATING HEAT

• Heat is a by-product of muscle activity
• Maintains body temperature
MUSCLE ACTIONS

• Muscles cross at least one joint. (There are a few exceptions.)
• The bulk of the muscle is usually proximal to the joint crossed.
• All muscles have at least two attachments: the origin and the insertion.
• Muscles can only pull; they never push.
• During contraction, the muscle insertion moves towards the origin.
SKELETAL MUSCLE ACTIVITY

Single Fibers:
• Must be stimulated by nerve impulses to contract
• Once stimulated to contract, a muscle fiber will contract completely

Whole Muscles:
• Are composed of thousands of muscle cells
• They react to stimuli with graded responses or different degrees of shortening
MOTOR UNIT

One motor neuron and all the skeletal muscle cells it stimulates.
• The end of each motor neuron branches into axon terminals (1).
• Each axon terminal forms a junction with the sarcolemma (2) of a muscle cell.

3. vesicles; 4. receptors; 5. mitochondria
• The neuromuscular junction is the **synapse** where the neuron & muscle cell meet.
• The synapse (a) is actually a space between these two structures.
• **Acetylcholine** or ACh, the neurotransmitter responsible for muscle contraction, will be released into the synapse.
ACETYLCHOLINE

- Stored in vesicles in the axon terminal
- Released when a nerve impulse reaches the axon terminal
- Diffuses across the synaptic cleft to bind with receptors on the sarcolemma
MEMBRANE AT REST

- The excitability of muscle & nerve cells is due to the resting potential or charge difference on the membrane.
- The net charge is positive outside the cell relative to the inside of the cell.

Na\(^+\) and K\(^+\) are responsible for membrane resting potential.
If enough ACh is released, the sarcolemma temporarily becomes more permeable to Na\(^+\) and K\(^+\).

Sodium ions rush into the cell as potassium ions diffuse out.

However, more Na\(^+\) enters the cell than K\(^+\) leaves, so the charge on the membrane is “upset” or reversed.
ELECTRICAL CURRENT

Outside of cell:
- **K⁺** (low concentration)

Inside of cell:
- **Na⁺** (low concentration) → **Na⁺** (high concentration)
- **K⁺** (high concentration)

The diagram illustrates the flow of electrical current through a cell membrane, highlighting the concentration gradients of potassium (K⁺) and sodium (Na⁺) ions. Potassium ions are more concentrated outside the cell, while sodium ions are more concentrated inside the cell, driving the current through the membrane.
The electrical current generated by the “upset” or change in charge across the muscle cell membrane is called an **action potential**.

Once generated, the action potential continues over the entire surface of the sarcolemma.

Result is contraction of the muscle cell.
• The action potential stimulates the sarcoplasmic reticulum to release Ca$^{2+}$ into cytoplasm.

• Ca$^{2+}$ ions trigger the binding of myosin to actin by interacting with regulatory proteins.
CROSSBRIDGES

• Myosin heads attach to binding sites on actin.
• These attachments are called **crossbridges**.
• Energized by ATP, each crossbridge attaches and detaches many times during a contraction.
CONTRACTION

• As myosin heads attach and detach, the actin filaments are pulled towards the center of the sarcomere.

• As this occurs in sarcomeres throughout the cell, the thin and thick filaments slide past each other.

ATP provides the energy to release and reset each myosin head so it’s ready to attach to the next site.
The **sliding filament theory** states that the sarcomere shortens when thin and thick myofilaments slide past each other.
STEPS TO MUSCLE CONTRACTION

1. Nerve impulse reaches the axon terminal
2. Acetylcholine (Ach) is released into synapse
3. ACh crosses synapse & binds to receptors on sarcolemma
4. ACh causes change in membrane permeability; Action potential is generated
5. Calcium ions are released from sarcoplasmic reticulum
6. Ca\(^{2+}\) binds to regulatory proteins on actin, exposing binding sites for myosin
7. Myosin heads bind to actin forming crossbridges
8. Actin filaments pulled toward center of the sarcomere
9. The sarcomere shortens and the muscle contracts
ACETYLCHOLINESTERASE

- A single nerve impulse produces only one contraction because ACh is broken down by this enzyme to prevent further contraction of the muscle cell.
• Muscle does not have time to relax completely between stimuli
• Successive contractions are added together to produce a smooth, sustained contraction
When the action potential ends:

• Calcium ions are reabsorbed into sarcoplasmic reticulum
• Regulatory proteins cover binding sites on actin; myosin can no longer attach to form crossbridges
• Muscle relaxes; returns to original length
• Resting potential is restored
• Na\(^+\) and K\(^+\) ions move back to their initial positions through the active transport mechanism of the sodium-potassium pump which restores the resting state.
ALL-OR-NONE LAW

- When stimulated adequately, the muscle cell will contract to its fullest extent
- It NEVER partially contracts
GRADED RESPONSES

- Graded responses involve different degrees of shortening or contraction
- Two ways that graded responses may be produced:
  1. By changing the frequency of muscle stimulation
  2. By changing the number of muscle cells being stimulated
HOW DOES A MUSCLE RESPOND TO A STRONGER STIMULUS?

• How forcefully a muscle contracts depends on HOW MANY cells are stimulated.

• Fewer cells are stimulated when you move a pen than when you swing a baseball bat.
ATP PROVIDES ENERGY FOR MUSCLE CONTRACTION

3 ways ATP is generated:
1. Aerobic cellular respiration
2. Creatine phosphate
3. Anaerobic respiration – glycolysis

[Diagram showing ATP structure with phosphate groups and energy release for cell metabolism]
MUSCLE FATIGUE

• Caused by oxygen debt that occurs during prolonged muscle activity
• Muscle becomes unable to contract even when stimulated
• How long a muscle can work depends largely on blood supply.
ISOTONIC VS. ISOMETRIC CONTRACTIONS

A) Isotonic contractions occur when the muscle shortens and movement occurs.

B) Isometric contractions occur when the muscles do not shorten; no movement occurs.
MUSCLE TONE

- State of continuous partial contractions
- Toned muscles are firm, healthy, and constantly ready for action.
- Regular exercise increases muscle size, strength and endurance.
MUSCLE ATROPHY

• Muscles that are not used regularly will lose tone and begin to atrophy or waste away.
AEROBIC EXERCISE

- Muscles become stronger
- More flexible
- Greater resistance to fatigue
- Not much increase in size
RESISTANCE TRAINING

- Increases muscle size and strength
- Enlargement of individual muscle cells occurs as new contractile filaments are made.
Developmental Aspects
INFANTS AND TODDLERS

• Only gross reflex movements are seen in infants.
• As the nervous system matures, babies gain more control of fine muscle movements.
• Skeletal muscle control continues to develop throughout childhood and reaches its peak by mid-adolescence.
• Muscles become more stringy as we age because the amount of connective tissue increases and the amount of muscle tissue decreases.

• Muscle mass and strength also decrease with age.
Diseases and Conditions
MUSCLE CRAMP

• A sudden, involuntary contraction of one or more muscles
• May be caused by
  • Overuse of a muscle
  • Dehydration
  • Muscle strain
  • Holding a position for a prolonged period
MUSCLE PULL

- Muscle strain, muscle pull, or a muscle tear refers to damage to a muscle or its attaching tendons.
- Damage is in the form of tearing (part or all) of the muscle fibers and attached tendons.
- Picture shows bruising from a torn hamstring.
PARALYSIS

• If the nerve supply to a muscle is destroyed, the muscle is no longer stimulated and becomes paralyzed.

• The muscle will soon become flaccid (soft and flabby) and eventually atrophy.
MUSCULAR DYSTROPHY

• A group of genetic diseases in which muscle fibers are unusually susceptible to damage

• Muscles become progressively weaker.

• The most common and serious type is Duchenne MD which is inherited as an x-linked recessive disorder.
THE MUSCULAR SYSTEM