

The Muscular System

1. Introduction & Basic Terminology

Primary Function:

Responsible for all body movements by contracting (shortening); functions as the mechanical engine of the body.

Cell Structure:

Muscle cells are elongated and referred to as **muscle fibers** (muscle cell = muscle fiber).

Contraction Mechanism.

Movement occurs via the sliding interaction of **microfilaments** (actin and myosin).

Common Prefixes

`myo-`: Refers to muscle

`mys-`: Refers to muscle

`sarco-`: Refers to flesh

2. Functional Properties of Muscle Tissue

Excitability (Irritability)

The capacity of a muscle to receive and respond to a stimulus.

Contractility

The ability of a muscle to shorten forcefully and generate pulling tension.

Extensibility

The ability of a muscle to stretch or extend back to its original resting length.

Elasticity

The ability of a muscle fiber to recoil back to its resting length after being stretched.

3. Comparison of Muscle Types

Feature	Skeletal Muscle	Cardiac Muscle	Smooth (Visceral) Muscle
<u>Location</u>	Attached to skeleton / bones	Heart walls	Walls of hollow organs (GI tract, uterus, blood vessels, eye)
<u>Function</u>	Body movement, heat generation, posture	Pumping blood continuously	Peristalsis, regulation of blood pressure, pupil size, micturition
<u>Microscopic Appearance</u>	Striated, multi-nucleated (eccentric/peripheral), parallel fibers	Striated, single central nucleus, intercalated discs, branching	Non-striated (smooth), single central nucleus, spindle-shaped cells
<u>Control</u>	Voluntary (conscious control)	Involuntary (unconscious control)	Involuntary (unconscious control)
<u>Speed & Endurance</u>	Great force, tires easily	Rhythmic, steady pace	Slow, sustained, and tireless

4. Connective Tissue Coverings & Skeletal Muscle Organization

Epimysium:

Connective tissue sheath surrounding the entire skeletal muscle belly.

Perimysium: Connective tissue surrounding a bundle of muscle fibers (**fascicle**).

Endomysium: Connective tissue layer enclosing an individual **muscle fiber (cell)**.

Muscle Belly (Epimysium)
 → Fascicles (Perimysium)
 → Muscle Fibers (Endomysium) → Myofibrils
 → Microfilaments

Fascia, Tendons, and Aponeuroses

Fascia: Fibrous connective tissue that wraps and separates individual muscles and muscle groups from adjacent structures.

Superficial Fascia (Hypodermis): Layer of adipose and connective tissue directly under the skin.

Deep Fascia: Dense connective tissue located between and surrounding adjacent muscles.

Tendon: Cord-like connective tissue extending from the epimysium to attach muscle to bone (or cartilage).

Aponeurosis: Broad, sheet-like fibrous tendon connecting muscle to muscle or broad connective tissue areas (e.g., palmar aponeurosis).

5. Nerve Stimulus & Contraction Physiology

The Neuromuscular Junction (NMJ)

1. **Axon Terminal:** End of the motor neuron containing synaptic vesicles loaded with **acetylcholine (ACh)**.
2. **Synaptic Cleft:** Small gap filled with interstitial fluid between the nerve terminal and the muscle fiber (no physical contact).
3. **Motor End Plate:** Invaginations of the folded **sarcolemma** containing specific ACh receptor sites.

Action Potential Transmission

Binding of ACh causes **sodium (Na^+)** to rush into the cell, depolarizing the membrane and firing an **action potential**.

"All-or-None" Law:

Once triggered, an action potential across a single muscle fiber cannot be stopped; the individual fiber contracts completely.

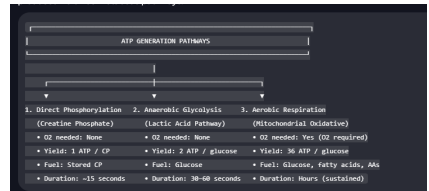
Graded Responses: Whole muscles produce varying degrees of force through:

Adjusting the **frequency** of stimulation (rapid stimulation leads to sustained contraction, known as **tetanus**).

Adjusting the **number of motor units / fibers** recruited (recruiting more fibers increases overall muscle tension).

6. Energy Systems for Muscle Contraction

Muscles maintain a very small resting reserve of ATP (lasting only **4–6 seconds**). Additional ATP is produced via three metabolic pathways:



Muscle Fatigue and Oxygen Debt

Fatigue: Inability of a muscle to contract, primarily caused by **oxygen debt** during prolonged activity.

Mechanism: Lack of oxygen leads to a buildup of **lactic acid** (increasing acidity) and depletion of ATP stores, reducing the muscle's contractile capacity.

7. Muscle Contraction Types & Exercise Actions

Types of Contraction

Isotonic Contraction: Muscle tension remains constant while muscle length changes to perform work.

Concentric: Muscle shortens while producing

tension (e.g., upward phase of a bicep curl).

Eccentric: Muscle lengthens while producing tension (e.g., controlled lowering of a weight).\

Isometric Contraction: Muscle tension increases but muscle length remains unchanged; no external physical work is performed (e.g., pushing against an immovable wall).

Roles of Muscles in Movement

Agonists (Prime Movers):

The primary muscles responsible for causing a specific movement.

Antagonists: Muscles that oppose or reverse a movement; they relax or stretch when the agonist is active.

Synergists / Assistors:

Assist the agonist by adding extra force or stabilizing intermediate joints.

Stabilizers (Fixators): Hold a bone or joint stationary to

provide a stable base for other active muscles.

8. Body Movements and Special Movements

Ordinary Body Movements

Flexion: Decreases the joint angle, bringing two bones closer together.

Extension: Increases the joint angle, straightening a limb or joint.

Abduction: Movement of a limb laterally away from the body's midline.

Adduction: Movement of a limb medially toward the body's midline.

Circumduction: A combination of flexion, extension, abduction, and adduction creating a circular, cone-shaped movement path.

Rotation: Turning of a bone around its own longitudinal axis (e.g., shaking head "no").

Special Movements

Inversion: Turning the sole of the foot medially (inward).

Eversion: Turning the sole of the foot laterally (outward).

Supination: Rotating the forearm laterally so the palm faces anteriorly (radius and ulna are parallel).

Pronation: Rotating the forearm medially so the palm faces posteriorly (radius rotates over the ulna to form an "X").

Dorsiflexion:** Lifting the foot so that its superior surface approaches the shin.

Plantar Flexion: Pointing the toes downward, moving the foot away from the shin.

Opposition: Touching the tip of the thumb to the tips of the other fingers on the same hand.

Elevation: Upward movement of a body part (e.g., shrugging shoulders, closing the jaw).

Depression: Downward movement of a body part (e.g., dropping shoulders, opening the jaw).

Protraction: Moving a bone anteriorly / forward (e.g., jutting out the jaw).

Retraction: Moving a bone posteriorly / backward (e.g., pulling the shoulder blades together).

9. Muscle Tone and Clinical Pathology

Muscle Tone

A state of continuous, partial, and involuntary contraction of skeletal muscles even when at rest. It is maintained by subconscious nerve impulses to help keep the body upright and maintain posture.

Hypotonia (Flaccidity): Decreased or lost muscle tone, making muscles loose and appearing flat.

Hypertonia (Spasticity): Excessively high muscle

tone, leading to stiffness and involuntary spasms.

Clinical Conditions and Neurological Disruptions

Clinical Conditions and Neurological Disruptions

PATHOLOGICAL DISRUPTIONS	
FLOPPY BABY SYNDROME (Botulism)	TETANUS (Lockjaw)
• Cause: Clostridium botulinum spores	• Cause: Clostridium tetani bacteria
• Source: Improperly canned food / honey	• Source: Deep wounds (e.g., rusty nail)
• Effect: Blocks ACh release at NMJ	• Effect: Blocks inhibitory neurotransmitters
• Clinical Sign: Flaccid paralysis, lethargy	• Clinical Sign: Spastic contractions, "devil's grin"

The Muscular System:

1. General Functions & Microscopic Anatomy

Primary Functions

Movement: Works alongside the skeletal system to produce voluntary motion (pulling on bones) and involuntary motion (pumping blood, propelling food through peristalsis).

Protection & Padding: Encloses the skeleton and internal organs of the abdomen, chest, and back.

Microscopic Structures of a Muscle Fiber Muscle Fiber (Cell)

— **Sarcolemma:** Specialized plasma membrane surrounding the cell.

— **Sarcoplasmic Reticulum (SR):** Specialized smooth ER; stores and releases calcium ions (Ca^{2+}) required for contraction.

— **Mitochondria:** Sites of aerobic respiration that generate ATP for contraction.

— **Myofibrils:** Contractile cylinder organelles packed with thick and thin myofilaments.

Sarcomere Architecture & Banding Pattern

Sarcomere

The functional contractile unit of a muscle fiber, extending from one **Z disc** to the next adjacent **Z disc**.

Thick Filaments: Composed of the protein **myosin**; contains **ATPase**

enzymes and myosin heads (cross-bridges).

Thin Filaments:

Composed of the protein **actin**, anchored directly to the **Z disc**.

A Band (Dark Band):

Spans the entire length of the thick myosin filaments.

I Band (Light Band):

Contains only thin actin filaments; centered on the **Z disc**.

H Zone: Central lighter area of the A band containing only thick filaments (no actin overlap at rest).

M Line: Protein meshwork in the exact center of the H zone that anchors thick filaments.

2. Muscle Attachment Points & Motor Units

Sites of Attachment

Origin: Attachment point of a muscle tendon to the **immovable or less movable bone** (remains stationary).

Insertion: Attachment point of a muscle tendon to the

movable bone (moves toward origin during contraction).

Belly: The fleshy, central contractile portion of the muscle located between the tendons of origin and insertion.

The Motor Unit

Motor Unit

Consists of **one motor neuron** and all the skeletal muscle fibers (cells) it stimulates.

Contraction of an individual muscle fiber is **"all-or-none."**

Muscle tension is graded by varying the number of motor units recruited and the frequency of nerve stimulation.

3. Fascicle Arrangements

Arrangement	Description	Examples
Circular	Concentric rings of muscle fibers that surround external body openings (sphincters) to close/open them	<i>Orbicularis oris</i> , <i>Orbicularis oculi</i>
Convergent	Fascicles converge from a broad origin toward a single, slender tendon of insertion (fan/triangular shape)	<i>Pectoralis major</i>
Parallel	Fascicles run parallel along the long axis of the muscle; straplike appearance	<i>Sartorius</i>
Fusiform	Spindle-shaped muscle with an expanded central belly and tapered ends	<i>Biceps brachii</i>
Pennate	Short fascicles attach obliquely (slanted) to a central tendon running the length of the muscle.	
↳ Unipennate	Fascicles insert into only one side of the tendon	<i>Extensor digitorum longus</i>
↳ Bipennate	Fascicles insert into opposite sides of a central tendon (feather-like)	<i>Rectus femoris</i>
↳ Multipennate	Fascicles arrange around multiple internal tendons	<i>Deltoid</i>

4. Muscle Nomenclature (Naming Criteria)

By Direction of Fascicles

Rectus: Parallel to midline (e.g., *Rectus abdominis*)

Transverse: Perpendicular to midline (e.g., *Transversus abdominis*)

Oblique: Diagonal/slanted to midline (e.g., *External oblique*)

By Relative Size

Maximus: Largest (e.g., *Gluteus maximus*)

Minimus: Smallest (e.g., *Gluteus minimus*)

Longus: Long (e.g., **Adductor longus**)

Brevis: Short (e.g., *Adductor brevis*)

Latissimus: Widest (e.g., *Latissimus dorsi*)

Longissimus:
Longest (e.g., *Longissimus capitis*)

Magnus: Large (e.g., *Adductor magnus*)

Major: Larger (e.g., *Pectoralis major*)

Minor: Smaller (e.g., *Pectoralis minor*)

Vastus: Huge / Great (e.g., *Vastus lateralis*)

By Geometric Shape

Deltoid: Triangular

Trapezius: Trapezoid

Serratus: Saw-toothed

Rhomboid:

Diamond-shaped

Orbicularis: Circular

Pectinate / Pectineus:

Comb-like

Piriformis: Pear-shaped***Platys:*** Flat (e.g., *Platysma*)***Quadratus:*** Four-sided / square (e.g., *Quadratus femoris*)***Gracilis:*** Slender**5. Agonist-Antagonist Muscle****Pairs by Joint Action**

Joint	Action	Prime Mover (Agonist)	Antagonist
Elbow	Flexion	Biceps brachii	Triceps brachii
	Extension	Triceps brachii	Biceps brachii
Shoulder	Flexion	Pectoralis major / Anterior deltoid	Latisimus dorsi / Trapezius / Posterior deltoid
	Extension / Hyperextension	Latisimus dorsi / Posterior deltoid	Pectoralis major / Anterior deltoid
	Abduction	Middle deltoid	Pectoralis major / Latisimus dorsi
	Adduction	Latisimus dorsi / Pectoralis major	Middle deltoid
	Horizontal Flexion	Pectoralis major / Anterior deltoid	Latisimus dorsi / Trapezius / Posterior deltoid
	Horizontal Extension	Trapezius / Posterior deltoid	Pectoralis major / Anterior deltoid
Spine	Flexion	Rectus abdominis	Erector spinae
	Extension	Erector spinae	Rectus abdominis
	Rotation	Obliques	Obliques (on opposite side)
	Lateral Flexion	Erector spinae / Obliques	Erector spinae / Obliques (opposite side)

6. Major Skeletal Muscles by Body Region**A. Head and Neck Muscles*****Facial Expression:******-Frontalis:*** Raises eyebrows, wrinkles forehead skin horizontally.***-Orbicularis oculi:*** Closes eyes, squints, blinks, and winks.***-Orbicularis oris:*** Closes and protrudes lips ("kissing muscle").***-Buccinator:*** Flattens the cheek; holds food between teeth during chewing.***-Zygomaticus:*** Raises the corners of the mouth ("smiling muscle").***-Platysma:*** Pulls the corners of the mouth downward (frowning/pouting).***Mastication (Chewing):******-Masseter:*** Closes the jaw and elevates the mandible (prime mover).***-Temporalis:*** Synergist of masseter; aids in jaw closure.***Neck Movement:******-Sternocleidomastoid:*** Bilateral contraction flexes the neck (bows head); unilateral contraction rotates head to opposite side.

B. Trunk & Abdominal Girdle Muscles

Anterior Thorax & Respiration:

-Pectoralis Major: Adducts and flexes the humerus across chest.

-External Intercostals: Elevate rib cage to expand thoracic cavity during inhalation.

-Internal Intercostals: Depress rib cage during forced expiration.

Abdominal Wall (Superficial to Deep):

-Rectus Abdominis: Flexes vertebral column; compresses abdomen (defecation, childbirth, forced expiration).

- External & Internal Obliques. Flex vertebral column, rotate trunk, and perform lateral trunk flexion.

-Transversus Abdominis: Compresses abdominal contents horizontally.

Posterior Trunk:

-Trapezius: Elevates, depresses, adducts, and stabilizes the scapula; hyperextends the head.

-Latissimus Dorsi:** Extends and adducts the humerus ("swimmer's muscle").

Erector Spinae: Group of deep back muscles (*Iliocostalis*, Longissimus, *Spinalis*) acting as prime mover of back extension.

Quadratus

Lumborum: Flexes the spine laterally.

C. Upper Limb Muscles

-Deltoid: Prime mover of arm abduction.

-Biceps Brachii: Prime mover for forearm supination and elbow flexion.

-Brachialis: True elbow flexor; lifts ulna as biceps lifts radius.

-Brachioradialis: Weak synergistic elbow flexor located mainly in forearm.

-Triceps Brachii: Prime mover of elbow extension (antagonist to biceps).

D. Lower Limb Muscles

Hip Joint:

Gluteus Maximus: Prime mover for hip extension (climbing stairs, running).

Gluteus Medius:

Hip abduction; steadies pelvis during walking.

Iliopsoas: Prime mover of hip flexion; prevents trunk from falling backward when standing upright.

Adductor Group: Adducts thighs together.

Knee Joint:

Sartorius: Longest straplike muscle; flexes and laterally rotates thigh ("tailor's muscle").

Quadriceps Femoris

Group: Extends knee joint; consists of *Rectus femoris* (also flexes hip) and three vastus muscles (*Vastus lateralis*, *Vastus medialis*, *Vastus intermedius*).

Hamstring Group: Prime movers of knee flexion and thigh extension; consists of *Biceps femoris*, *Semitendinosus*, and *Semimembranosus*.

Ankle, Foot & Toes: **Tibialis Anterior:**

Dorsiflexion and foot inversion.

Extensor Digitorum

Longus: Toe extension and foot dorsiflexion.

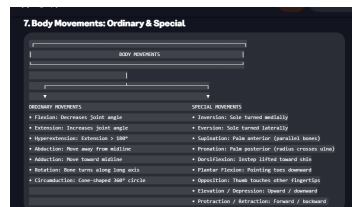
Fibularis (Peroneus)

Muscles: Plantar flexion and foot eversion.

Gastrocnemius & Soleus:

Prime movers of plantar flexion (calf muscles inserting into calcaneus via Achilles tendon).

7. Body Movements: Ordinary & Special



8. Developmental Aspects & Clinical Pathologies

Developmental Milestones

Muscular control depends directly on the maturation of the nervous system.

Gross movements develop before fine motor control.

Peak nervous system control and peak muscle coordination typically occur in the *mid-teens*.

Homeostatic Imbalances & Pathologies

Common Pathology Mistake: Flaccidity vs Spasticity

- **Hypotonia (Flaccid):**

Decreased or absent tone.
Caused by nerve disruption or electrolyte deficits (Na⁺), (Ca²⁺), (Mg²⁺).
Results in loose, flat muscles, absent reflexes, and muscle atrophy.

- **Hypertonia**

(Spastic/Rigid):

Increased tone/stiffness.
Spasticity involves hyperactive reflexes;

Rigidity leaves reflexes unaffected.

Floppy Baby Syndrome

(Infant Botulism):

Cause: Ingestion of *Clostridium botulinum** spores (e.g., from honey or improperly canned food).

Mechanism: Toxin blocks acetylcholine release at the neuromuscular junction
(\(\rightarrow\)) severe flaccid paralysis and lethargy.

Tetanus (Lockjaw):

Cause: Infection by **Clostridium tetani** through deep puncture wounds (e.g., rusty nail).

Signs Uncontrolled spastic contractions, locking jaw, and characteristic facial grimace ("devil's grin").

Muscular Dystrophy.

Mechanism: Genetic, muscle-destroying disease caused by lack of the sarcolemma-stabilizing protein *dystrophin*. Muscle fibers degenerate and are replaced by non-functional fat and fibrous tissue.

Duchenne's Muscular Dystrophy (DMD): X-linked recessive form primarily affecting males; diagnosis often marked by the *Gowers' maneuver* (using hands to walk up one's own legs to stand); typically fatal by young adulthood.

Can be mitigated with regular physical activity and resistance/weight training.

Myasthenia Gravis:

Mechanism: Autoimmune disorder producing antibodies that destroy **acetylcholine** (ACh) **receptors** at the motor end plate of the neuromuscular junction.

Signs: Progressive muscle weakness, ptosis (drooping eyelids), difficulty swallowing (dysphagia), and impaired speech (dysarthria).

Effects of Aging on Muscles:

Relative increase in connective tissue alongside a progressive loss of muscle mass (sarcopenia).

Decreases in body weight and overall strength.