ORGANIZATION OF SKELETAL MUSCLE

Skeletal Muscle cells are **specialized contractile cells**, also known as **myocytes** or **muscle fibers**.

Skeletal muscle:

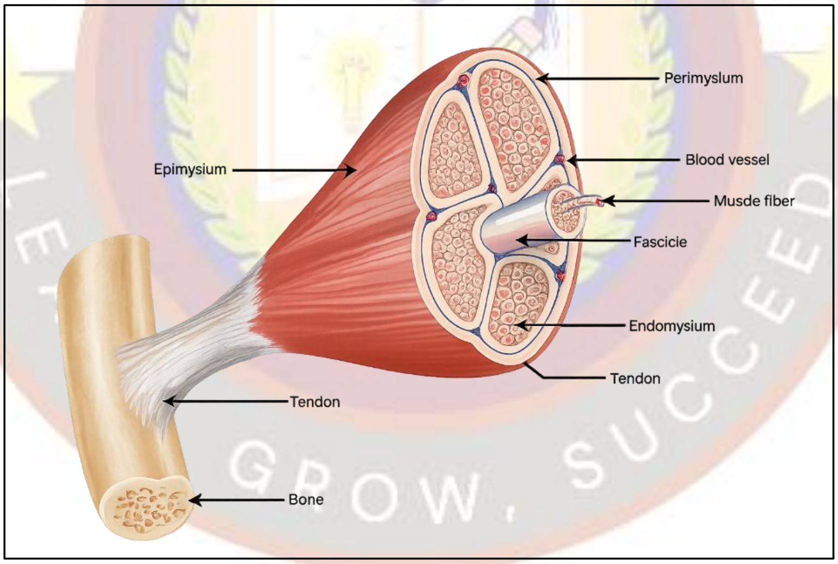
- Is attached to bones through **tendons**
- Helps in **movement of the skeleton**

Each skeletal muscle contains:

- **Hundreds of thousands of muscle fibers**
- **Blood vessels and nerves**
- An extensive **network of connective tissue** that surrounds and protects the muscular tissue throughout the muscle

Connective Tissue Coverings of Muscle

Muscle tissue is protected and strengthened by **three layers of connective tissue**:



Epimysium

- A connective tissue sheath
- Covers the **entire muscle**

Perimysium

- Connective tissue sheath that covers each **fascicle**

- Within a muscle, muscle cells are grouped into bundles of **10–100 or more fibers** called **fascicles**

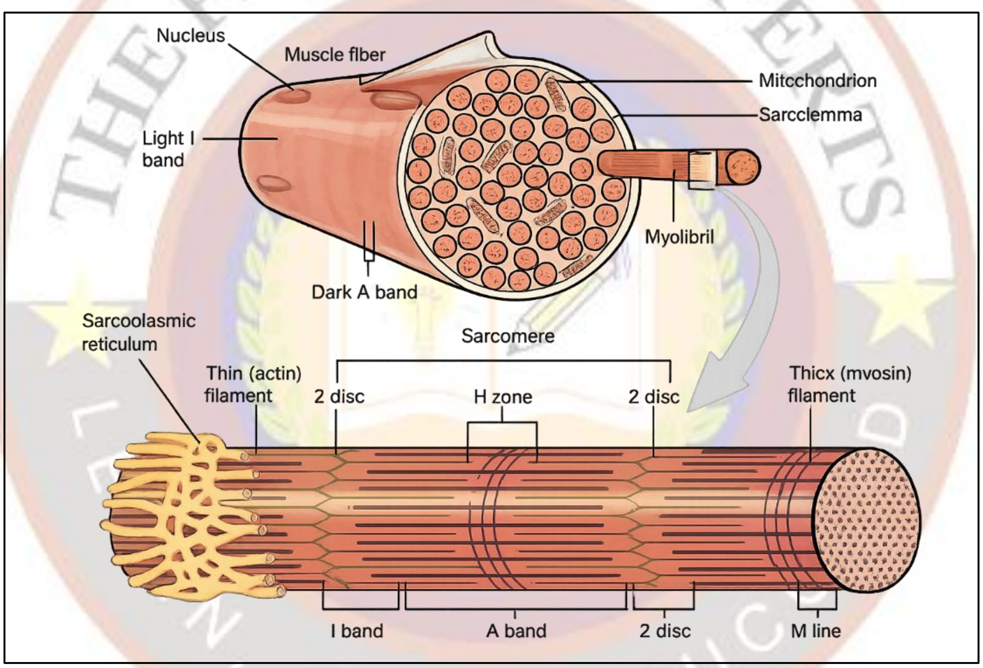
Endomysium

- A fine connective tissue layer
- Wraps **individual muscle fibers** within the fascicles

All three connective tissue layers:

- Run the **entire length of the muscle**
- Unite to form the **tendon**

Microscopic Structure of Skeletal Muscle Fiber



Contraction of the **whole muscle** occurs due to the **coordinated contraction of individual muscle fibers**.

Characteristics of a muscle fiber:

- Each muscle fiber contains **100 or more nuclei**

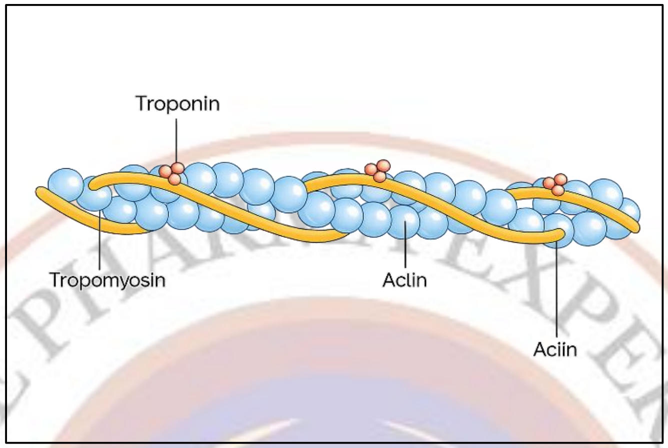
Under a microscope, a muscle fiber shows:

- Cylindrical organelles called **myofibrils** (about **100–1000 per fiber**)

Sarcolemma

- The **cell membrane** of the muscle fiber
- Lies beneath the **endomysium**
- Nuclei are located just beneath the sarcolemma

Sarcoplasm



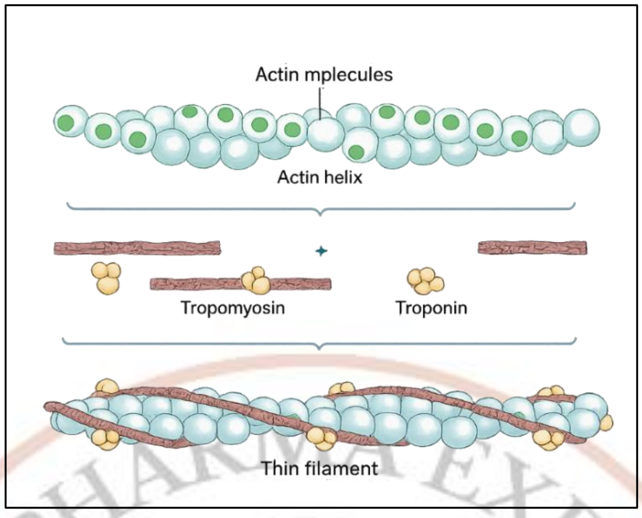
- Cytoplasm of the muscle fiber
- Packed with tiny contractile filaments called **myofilaments**
- Myofilaments run **longitudinally** along the length of the muscle fiber
- Contains:
    - Numerous **mitochondria** for ATP production
    - **Myoglobin**, a specialised oxygen-binding substance

Sarcoplasmic Reticulum

- A network of **fluid-filled membranous sacs**
- Surrounds the myofibrils
- Stores **calcium ions**

Filaments and Sarcomere

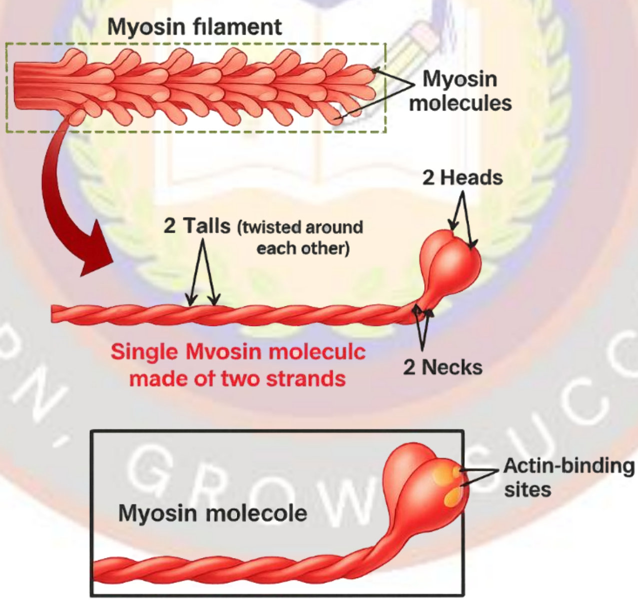
Contractile **myofilaments** are present within myofibrils.
They are of **two types**:



Thin Filaments

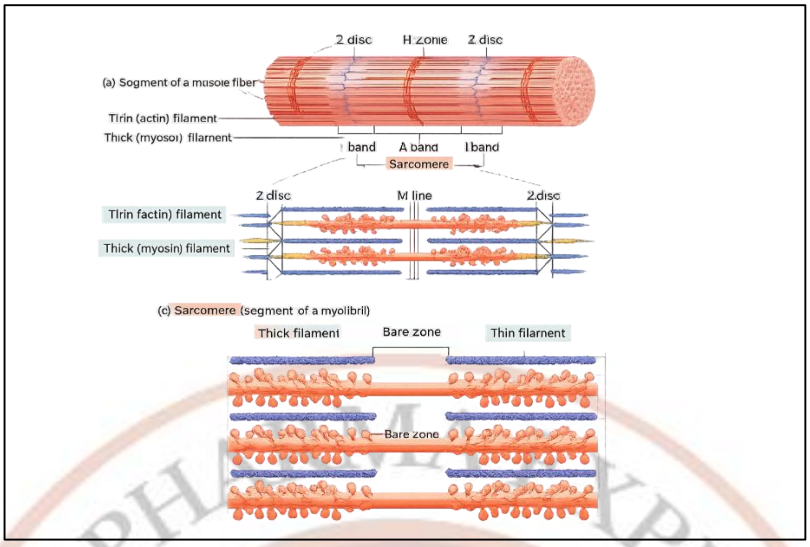
- Composed of the protein **actin**

Thick Filaments



- Composed of the protein **myosin**

Thin and thick filaments are arranged in repeating units called **sarcomeres**, which are the **functional units of myofibrils**.



Sarcomere

- Shows **alternating dark and light bands**
- Extends from one **Z-disc** to the next **Z-disc**
- Actin filaments attach to the **Z-line**
- The center of the sarcomere is marked by the **M-line**
- Myosin filaments project outward from the M-line
- Ends of myosin filaments overlap with ends of actin filaments

Bands and Zones of Sarcomere

A-Band

- Dark middle part of the sarcomere
- Contains thick filaments

I-Band

- Light, less dense region
- Contains thin filaments only

Z-Disc

- Located at the center of each I-band

H-Zone

- Narrow zone in the center of the A-band
- Contains thick filaments only (no thin filaments)

The alternating pattern of dark A-bands and light I-bands gives skeletal muscle its **characteristic striated appearance**.

Thin Filaments

- Main component is **actin**
- Individual actin filaments are twisted into a **helical structure**
- Each actin molecule contains a **myosin-binding site**

Two regulatory proteins are associated with actin:

- **Troponin**
- **Tropomyosin**

Thick Filaments

- Composed of **myosin**
- Each myosin molecule consists of:
  - A **head**
  - A **tail**

Myosin Head

- Contains **two binding sites**:
  - Actin-binding site
  - ATP-binding site
- Projects outward from the filament shaft

In the **relaxed state**:

- Myosin is prevented from binding to actin
- **Tropomyosin** covers the myosin-binding sites on actin
- Tropomyosin is held in position by **troponin**

When **calcium ions bind to troponin**:

- A conformational change occurs
- Tropomyosin moves away from the myosin-binding sites
- Muscle contraction can begin

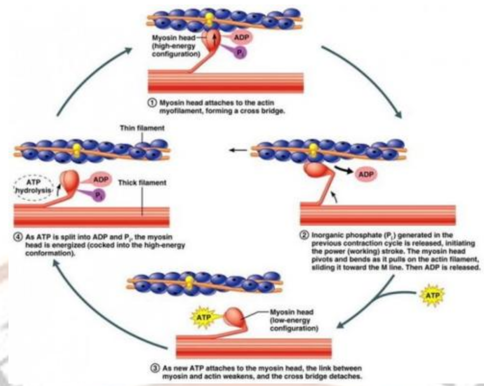
Physiology of Muscle Contraction

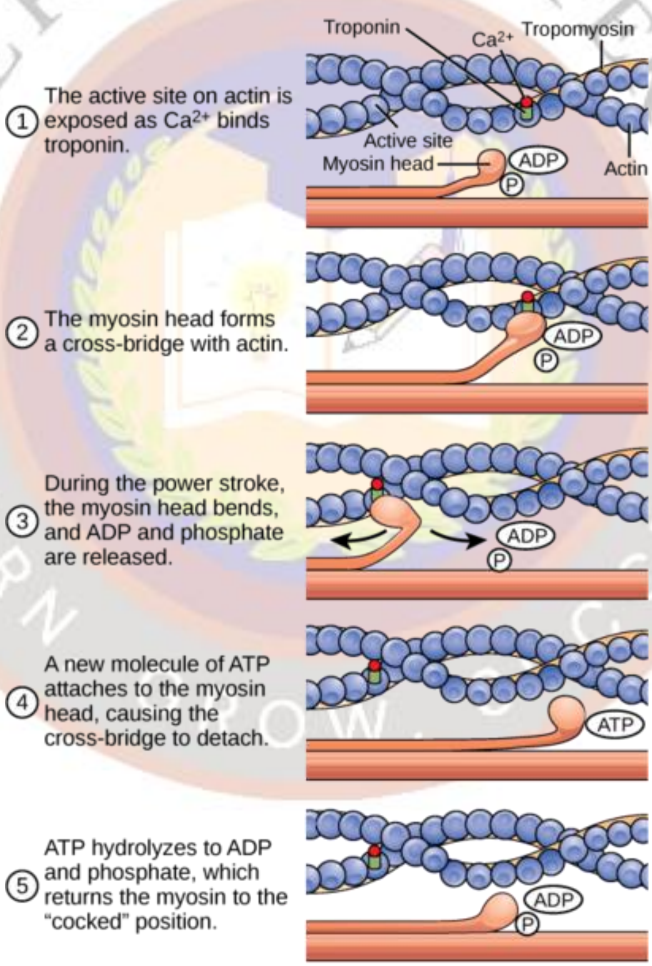
Muscle contraction is explained by the **Sliding Filament Theory**, which is the most widely accepted theory.

According to this theory:

"Muscle contraction occurs by the sliding of thin filaments over thick filaments."

A skeletal muscle fiber contracts in response to stimulation from a **motor nerve fiber**.

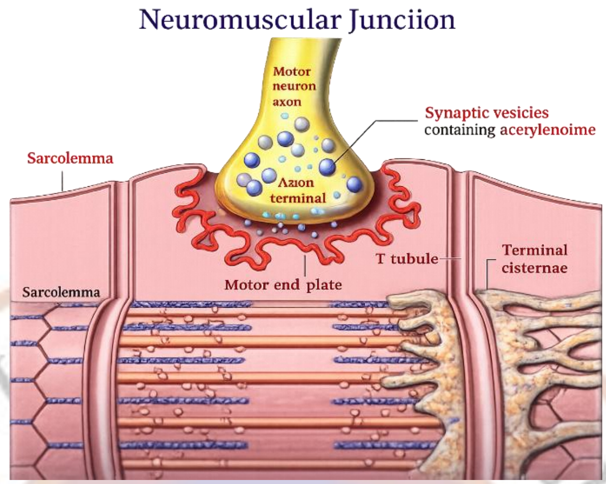




Neuromuscular Junction (NMJ)

The junction between a motor neuron and the sarcolemma of a muscle fiber is called the **neuromuscular junction (NMJ)** or **motor end plate**.

- It consists of a small gap called a **synapse**
- Signals from the CNS reach the NMJ as **action potentials**

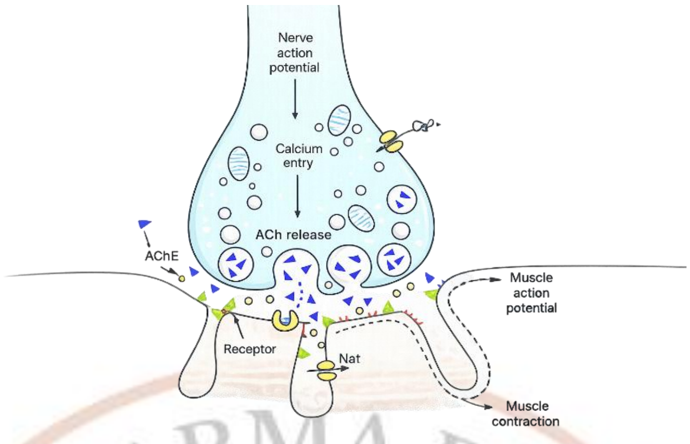


At the NMJ:

- Arrival of a nerve impulse releases a neurotransmitter called **acetylcholine (ACh)**
- ACh causes **depolarization of the sarcolemma**

Sequence of Events in Muscle Contraction

1. Depolarization of the sarcolemma occurs
2. Calcium ions are released from the **sarcoplasmic reticulum**
3. Calcium concentration in the sarcoplasm increases
4. Calcium binds to **troponin**
5. Conformational change occurs and **tropomyosin moves away** from actin binding sites
6. Myosin head hydrolyses ATP and becomes energized
7. Myosin binds to actin forming a **cross-bridge**
8. Actin filaments are pulled toward the center of the A-band (towards the M-line)
9. Z-lines move closer together
10. Sarcomere shortens, producing muscle contraction.



Cross-Bridge Cycle

- ADP and Pi are released, causing tight binding of myosin head to actin
- Myosin remains attached until a **new ATP molecule binds** to the myosin head
- Cross-bridge breaks
- ATP is hydrolysed again
- Cycle of cross-bridge formation and breaking repeats
- Further sliding of filaments occurs

Muscle Relaxation

When the nerve signal stops:

- Calcium ions are no longer released
- Calcium is pumped back into the sarcoplasmic reticulum
- Active sites on actin are masked again
- Z-lines return to their original position
- Muscle fiber relaxes

Changes During Muscle Contraction

- Thin filaments slide inward and overlap at the center of the sarcomere
- I-band and H-zone narrow and may disappear completely during maximal contraction
- Width of the A-band remains unchanged
- Lengths of individual filaments remain unchanged
- Z-discs move closer together
- Sarcomere shortens
- Entire muscle fiber shortens, resulting in contraction of the whole muscle

Detailed Structure of Neuromuscular Junction

- A muscle fiber contracts in response to action potentials transmitted by **motor neurons**
- The synapse between motor neuron and muscle fiber is the **neuromuscular junction**

- A **synaptic cleft** separates the two cells
- Action potentials cannot cross the cleft directly

Communication occurs via **chemical transmission**:

- Axon terminal divides into **synaptic end bulbs**
- Each end bulb contains **synaptic vesicles**
- Vesicles store thousands of acetylcholine molecules
- ACh is released into the synaptic cleft
- Sarcolemma opposite the synapse forms the **motor end plate**
- Motor end plate contains **ACh receptors**

Generation of Muscle Action Potential

1. Release of ACh at the NMJ
2. Activation of ACh receptors
3. Inflow of Na^+ ions into the muscle fiber
4. Inside of the sarcolemma becomes positively charged
5. Muscle action potential is generated
6. Action potential propagates along the sarcolemma
7. Calcium ions are released from sarcoplasmic reticulum
8. Muscle fiber contracts

Termination of Muscle Contraction

- Activity of ACh is terminated by the enzyme **acetylcholinesterase (AChE)**
- AChE breaks down acetylcholine in the synaptic cleft
- No new action potential is generated
- Calcium ions return to the sarcoplasmic reticulum
- Muscle fiber relaxes

Each skeletal muscle fiber usually has only one neuromuscular junction, typically located near the **midpoint of the fiber**.