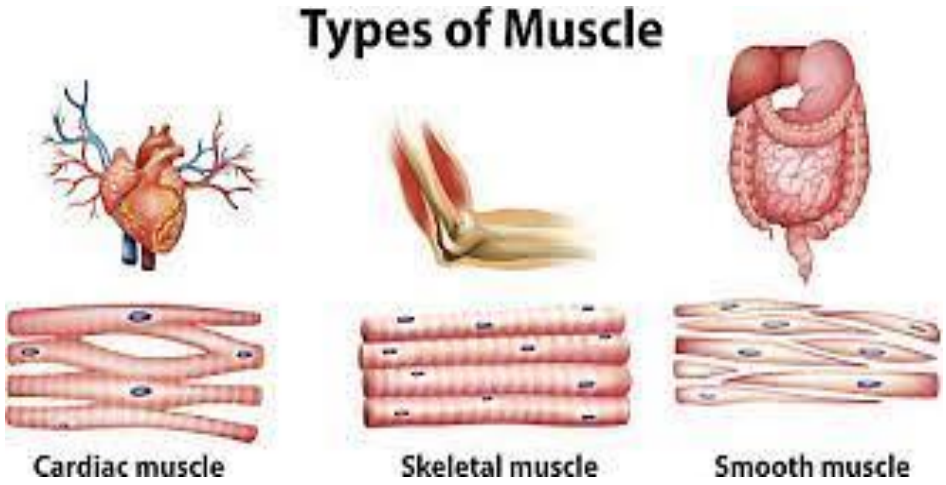
1st YEAR MEDICAL STUDENTS
PHYSIOLOGY (LECTURE 18)
COMPARISON OF THREE TYPES OF MUSCLES



BY

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TYPES OF MUSCLES

Three types of muscles:

(1) Skeletal muscle.

(2) Cardiac muscle.

(3) Smooth muscle.

TYPES OF MUSCLES

(1) Skeletal muscle:

- ✓ It makes up the **great mass of the somatic musculature**.
- ✓ It has well-developed cross-striations **(striated muscle)**.
- ✓ It **lacks anatomic and functional connections between individual muscle fibers**.
- ✓ Contraction is initiated by action potentials in **somatic motor neurons** of the nervous system and is **usually under voluntary control**.

(2) SMOOTH MUSCLE

- Smooth muscle is a type **of non-striated muscle**.
- As in other types of muscle, **actin–myosin interactions are the basis of contraction**.
- They contain less actin and myosin than do skeletal muscle cells.
- **Contractile proteins are not organized as sarcomeres in smooth muscle**. **As a result, smooth muscle cells are not striated**.
- **Smooth muscle cells contract more slowly than skeletal muscle cells**. **The smooth muscle form of myosin has a very low rate of ATPase activity** less than that of skeletal muscle myosin.
- **Smooth muscle is under involuntary control**.

TYPES OF SMOOTH MUSCLE

Smooth muscle can be subdivided into **two** broad types: **unitary (or single-unit or visceral) smooth muscle and multiunit smooth muscle**.

Single Unit (Unitary) smooth muscle

- It is far more abundant and is found in the walls of blood vessels, the bladder and the gut, among other organs.
- The cells have **gap junctions** between them, allowing **rapid and direct spread of action potentials**. Thus, **all smooth muscle cells tend to function as a unit and contract at the same time (functional syncytium)** producing a synchronous contraction.
- The **RMP is unstable and averages – 50 mV (pacemaker cells)**. As a result, **smooth muscle cells can periodically and spontaneously generate action potentials that cause smooth muscle cells to contract**. The resulting **periodic spontaneous contraction of smooth muscle is called auto-rhythmicity**.

- **Smooth muscle contraction** can occur in response to **signals from the autonomic nervous system, hormones such as those that regulate the digestive system, autocrine or paracrine signals.**
- **It shows plasticity (relation of length to tension).**

Multiunit smooth muscle:

- It is **organized into motor units** similar to those in skeletal muscle.
- **Cells are electrically isolated from each other** (there are **no gap junctions**), allowing for fine motor control.
- This type of muscle is found in a few specific regions such as the ciliary muscle of the eye, large airways of lung, and the piloerector muscles in the skin.

Single-Unit vs Multi-Unit Smooth Muscle

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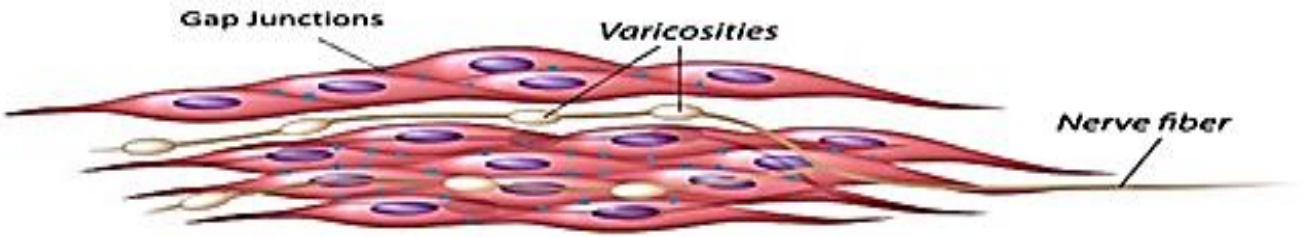
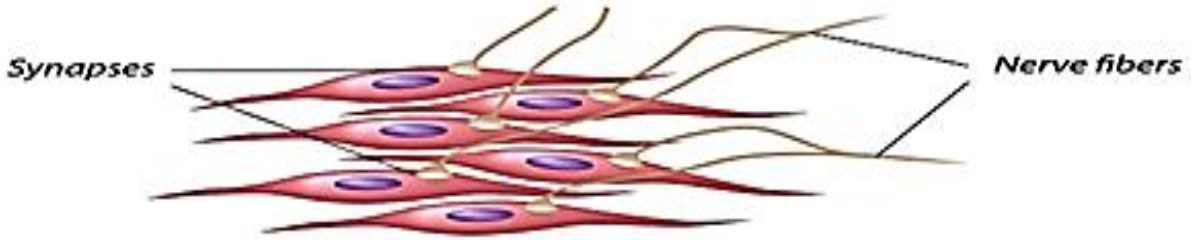


Single-Unit Smooth Muscle



Multi-Unit Smooth Muscle

MECHANISM OF SMOOTH MUSCLE CONTRACTION

- **Smooth muscle contraction is controlled by multiple neurotransmitters and other chemical ligands that affect cytosolic Ca^{2+} concentration**.
- Some of these substances produce **depolarization of the cell membrane, resulting in opening of voltage-gated membrane Ca^{2+} channels and release of Ca^{2+} from intracellular stores**, in a process similar to that in skeletal muscle.
- **Binding of a ligand to a membrane receptor produces an increase in intracellular Ca^{2+} concentration, and thus smooth muscle contraction, without altering membrane potential**.
- **Therefore, depolarization or binding of a ligand to a membrane receptor leads to elevation of intracellular Ca^{2+} → the common signal in smooth muscle contraction.**

Cross-bridge activation

The following sequence of events occurs after an increase in cytosolic Ca^{2+} in a smooth muscle fiber:

(1) **Ca^{2+} binds to calmodulin**, a **Ca^{2+}-binding protein** that is present in the cytosol and whose structure is related to that of troponin.

(2) **The Ca^{2+}–calmodulin complex** binds to another cytosolic protein, **myosin light-chain kinase**, thereby **activating the enzyme**.

(3) **Active myosin light-chain kinase** then **uses ATP to phosphorylate myosin light chains in the globular head of myosin**.

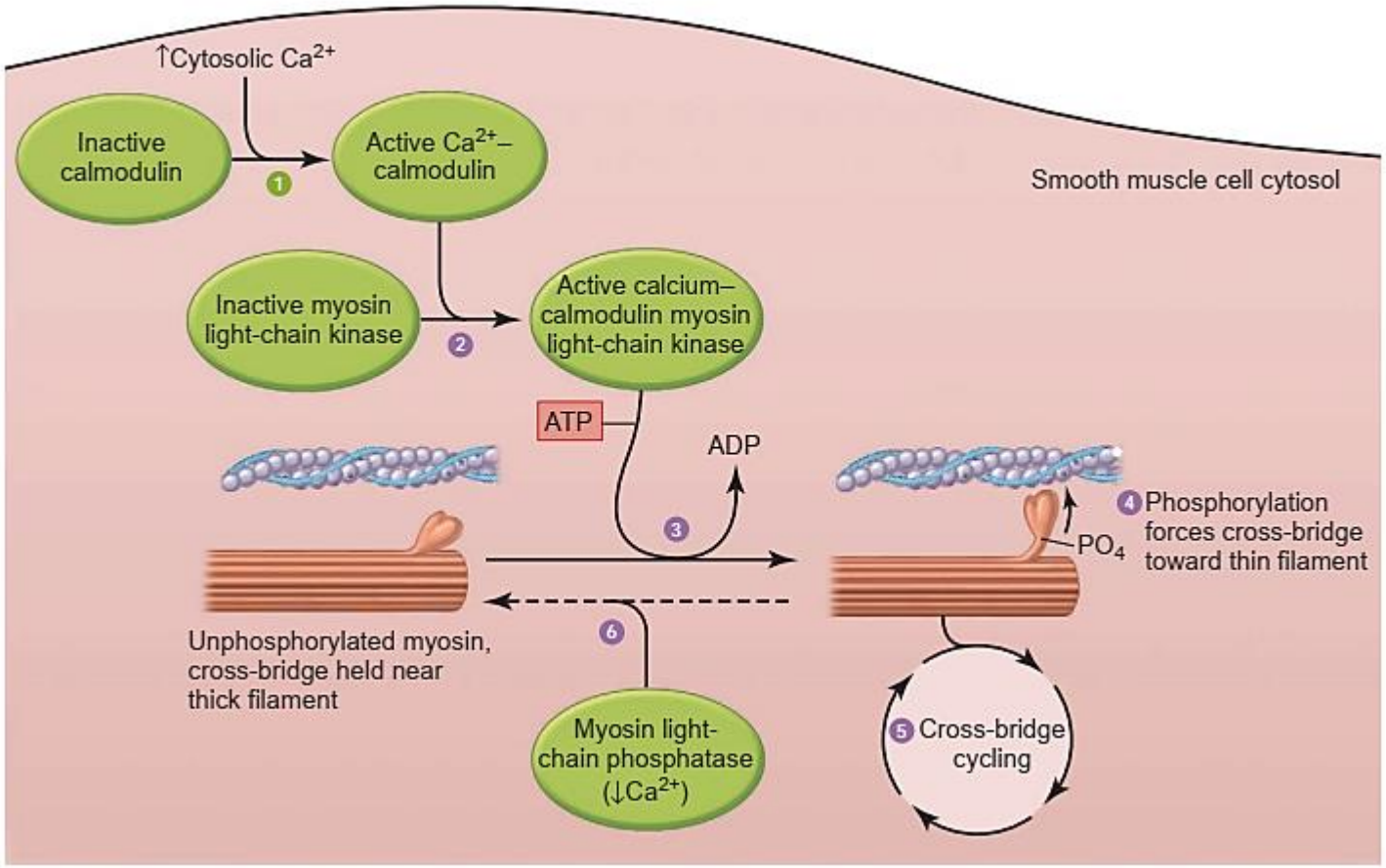
(4) **Phosphorylation of myosin** drives the **cross-bridge** away from the thick filament backbone, allowing it to **bind to actin**.

(5) **Cross-bridges go through repeated cycles of force generation as long as myosin light chains are phosphorylated**.

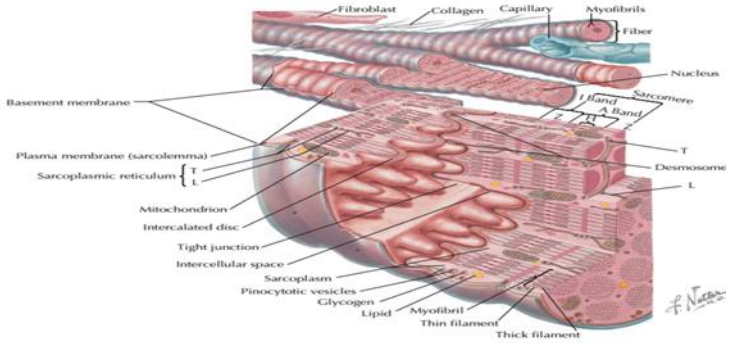
- ✓ A key difference here is that **Ca^{2+}-mediated changes in the thick filaments turn on cross-bridge activity in smooth muscle, whereas in striated muscle, Ca^{2+} mediates changes in the thin filaments**.

MECHANISM OF SMOOTH MUSCLE RELAXATION

- To relax a contracted smooth muscle, **myosin must be dephosphorylated** because dephosphorylated myosin is unable to bind to actin.
- This dephosphorylation is mediated by the enzyme **myosin light-chain phosphatase**, which is continuously active in smooth muscle during periods of rest and contraction.
- When **cytosolic Ca^{2+} concentration increases, the rate of myosin phosphorylation by the activated kinase exceeds the rate of dephosphorylation by the phosphatase** and the **amount of phosphorylated myosin in the cell increases**.
- When the **cytosolic Ca^{2+} concentration decreases, the rate of phosphorylation decreases below that of dephosphorylation and the amount of phosphorylated myosin decreases, producing relaxation**.


↑Cytosolic Ca^{2+}
Inactive calmodulin
1
Active Ca^{2+}–calmodulin
Smooth muscle cell cytosol
Inactive myosin light-chain kinase
2
Active calcium–calmodulin myosin light-chain kinase
ATP
ADP
3
4 Phosphorylation forces cross-bridge toward thin filament
PO_4
Unphosphorylated myosin, cross-bridge held near thick filament
6
Myosin light-chain phosphatase (↓Ca^{2+})
5 Cross-bridge cycling

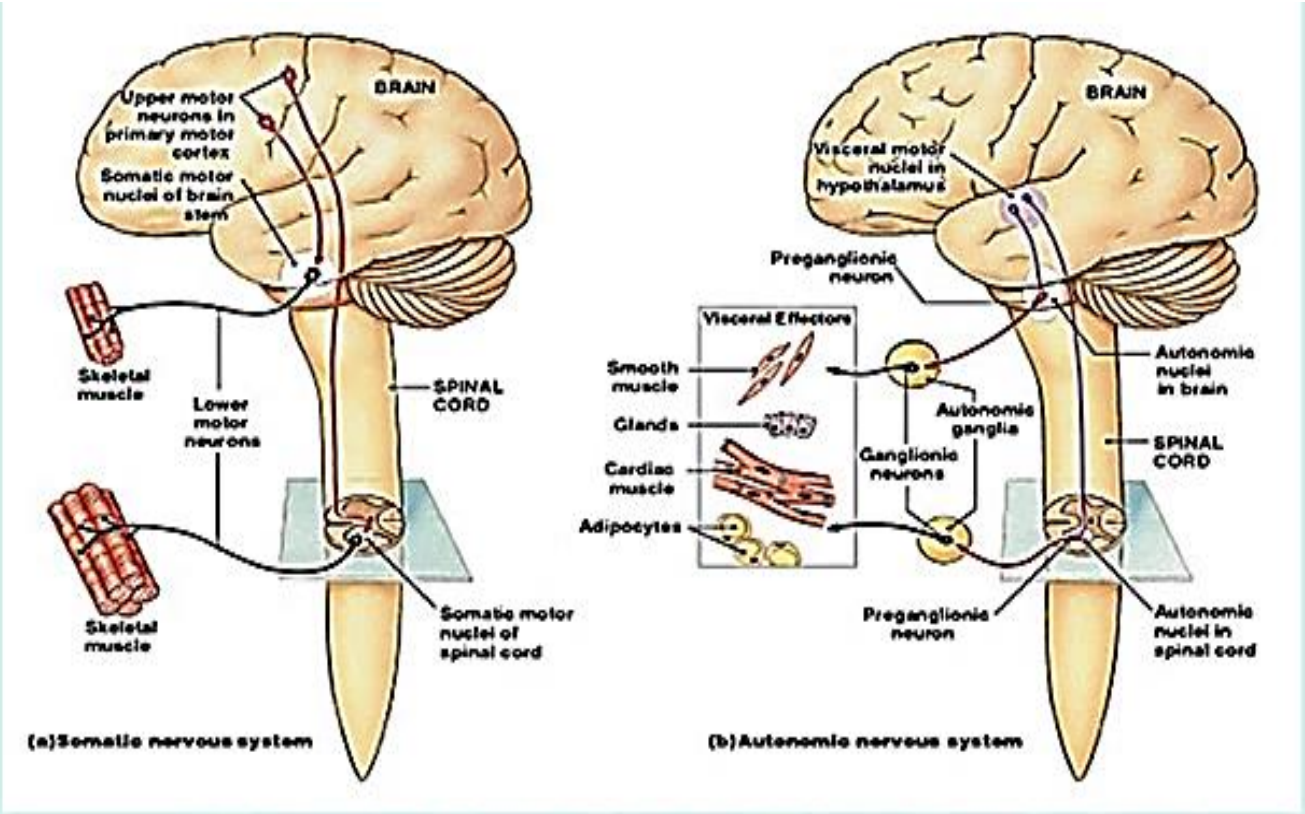
(3) CARDIAC MUSCLE



- ✓ It is the **muscle of the heart**. Its **contraction generates the pressure that propels blood through the circulatory system**.
- ✓ **Cardiac muscle shares some characteristics with both skeletal and smooth muscles.**
- ✓ Cardiac muscle cells are long, striated and branching with usually only one nucleus per cell.
- ✓ **The actin and myosin myofilaments are organized into sarcomeres ,** but the distribution of myofilaments is not as uniform as in skeletal muscle. **As a result, cardiac muscle cells are striated, but not as skeletal muscle.**
- ✓ **Contraction of cardiac muscle is involuntary that can be modulated via the autonomic nervous system and is auto-rhythmic.**

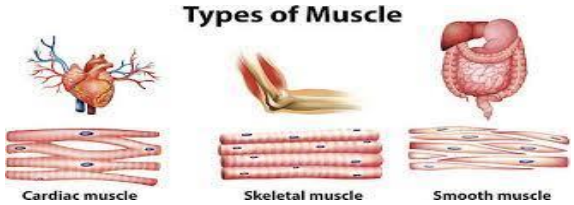
- ✓ **Both unitary smooth muscle and cardiac muscle have the capability for spontaneous electrical activity; cardiac contraction is normally under control of cardiac pacemakers cells in the sinoatrial (SA) node.**
- ✓ **Cardiac muscle cells are connected to one another by intercalated disks. intercalated discs are specialized structures that include gap junctions and that facilitate action potential conduction between cells.**
- ✓ **This cell-to- cell connection allows cardiac muscle cells to function as a unit (syncytium). As a result, an action potential in one cardiac muscle cell can stimulate action potential in adjacent cells, causing all to contract together.**
- ✓ **As with smooth muscle, cardiac muscle is influenced by hormones such as epinephrine.**

- **Cardiac muscle contraction is slower than that of skeletal muscle, but more rapid than contraction in smooth muscle**.
- **Cardiac and smooth muscles utilize both intracellular and extracellular sources of Ca^{2+}, whereas the only Ca^{2+} source for contraction of skeletal muscle is intracellular (from the sarcoplasmic reticulum)**.
- As in skeletal muscle, **Ca^{2+} in cardiac muscle binds to troponin C to initiate cross-bridge formation**.



Organization Similarities of SNS and ANS

Comparison of Three Types of Muscle



Structure	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Location	Attached to bone	Heart	Unitary: Walls of hollow organs, Blood vessels and glands. Multiunit: eye (e.g. ciliary muscle) and piloerector muscle in skin.
Morphology	Long and cylindrical	branched	Spindle-shaped or fusiform
Thick and thin filaments	Yes	Yes	Yes
Nuclei	Multiple, peripheral	One, central	One, central
Sarcomere	Yes, Striated	Yes, Striated	No
SR	Well-developed	Moderately - developed	Poorly - developed
T-tubule	Yes; forms triad with sarcoplasmic reticulum	Yes; forms dyad with sarcoplasmic reticulum	No; caveolae
Electrical coupling of cells	No	Yes; intercalated discs contain gap junctions	Yes; gap junctions in unitary type

Physiology	Skeletal Muscle	Cardiac Muscle	Smooth Muscle
Function	Move the whole body	Contract heart to propel blood through the body	Compress organs, ducts, tubes and so on.
Source of activating Ca^{2+}	SR	Extracellular and SR	Extracellular and SR
Extracellular Ca^{2+} required for contraction	No	Yes	Yes
Site of Ca^{2+} regulation	Troponin	Troponin	Myosin
Regulation of cross-bridge formation	Ca^{2+} binding to troponin C	Ca^{2+} binding to troponin C	Ca^{2+}- calmodulin activation of myosin light chain kinase and phosphorylation of myosin.
Speed of Contraction	Fast-Slow	Slow	Very slow
Control of contraction	Motor neurons; voluntary	Autonomic nerves; β-adrenergic agonists; involuntary	Autonomic nerves; hormones. involuntary
Effect of nerve stimulation	Excitation	Excitation or inhibition	Excitation or inhibition
Physiological effects of hormones on excitability and contraction	No	Yes	Yes
Summation of twitches by increased stimulus frequency	Yes	No	Yes
Chronaxie	Shorter than cardiac and smooth muscles	Shorter than smooth muscle	Longest

Thank You