جامعة البصرة
كلية الطب البيطري
فرع الفسلجة والادوية والكيمياء

Muscle Physiology

BY

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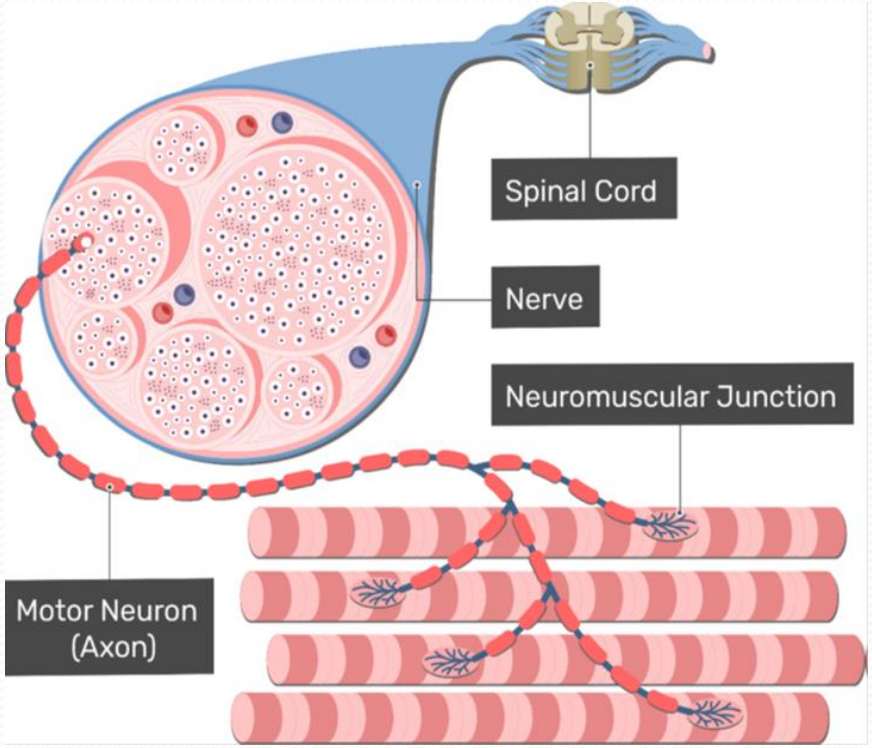
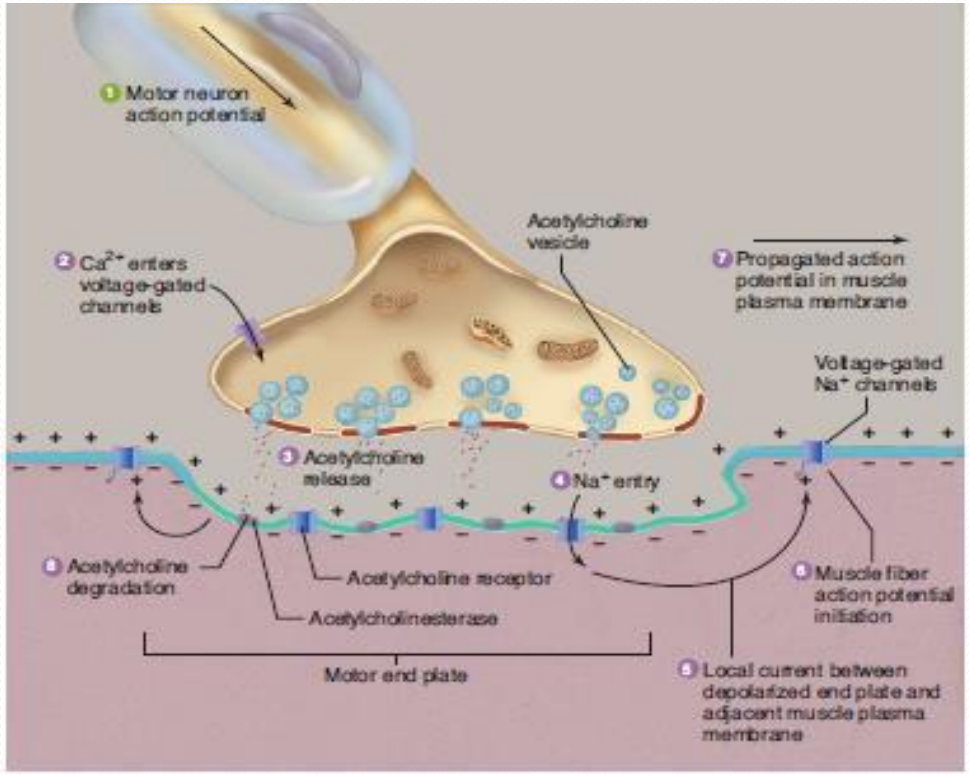
Muscle Physiology

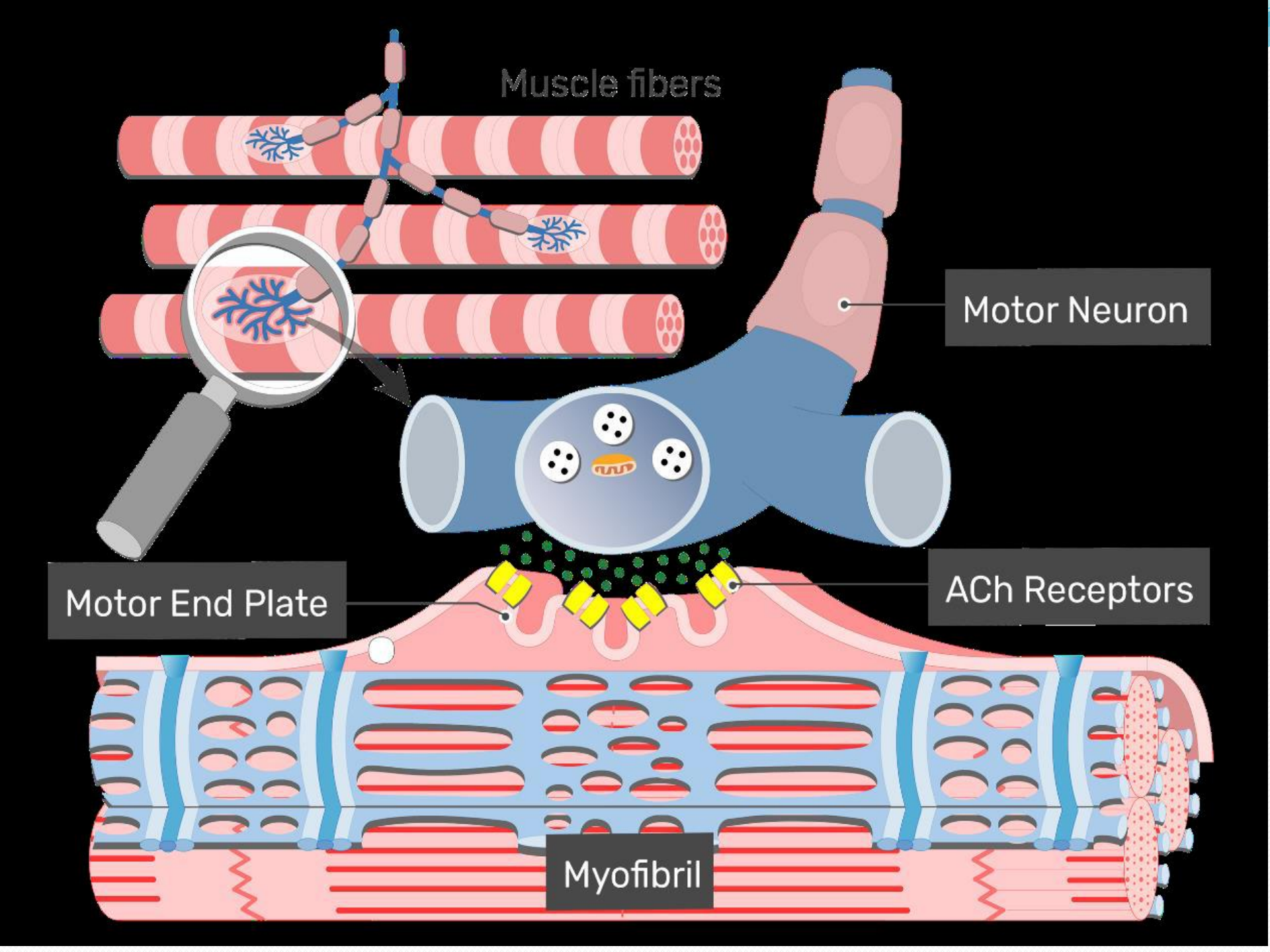
Neuromuscular junction:

It is the specialized portion of a muscle fiber immediately under a terminal nerve fiber. The nerve fiber invaginates a muscle fiber but lies outside the muscle fiber plasma membrane. The entire structure is called the motor end-plate.

The skeletal muscle fibers are innervated by myelinated nerve fibers. The nerve terminals. The terminals fit into depression in the motor endplate (The thickened portion of the muscle fiber membrane). The axon terminals have vesicles containing acetylcholine. The axon terminal and motor endplate are known as a neuromuscular junction.



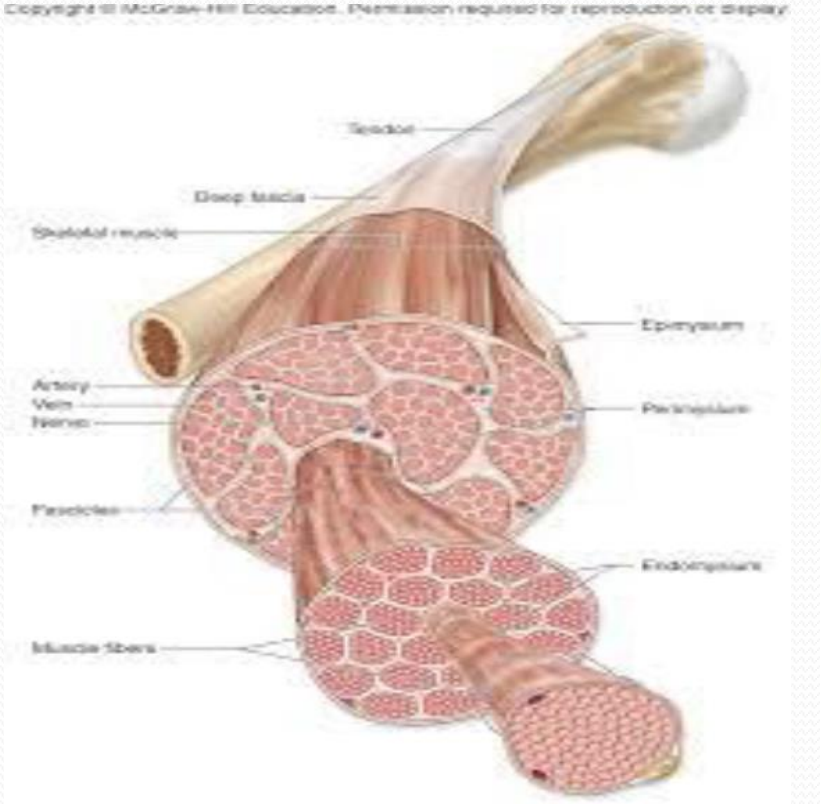


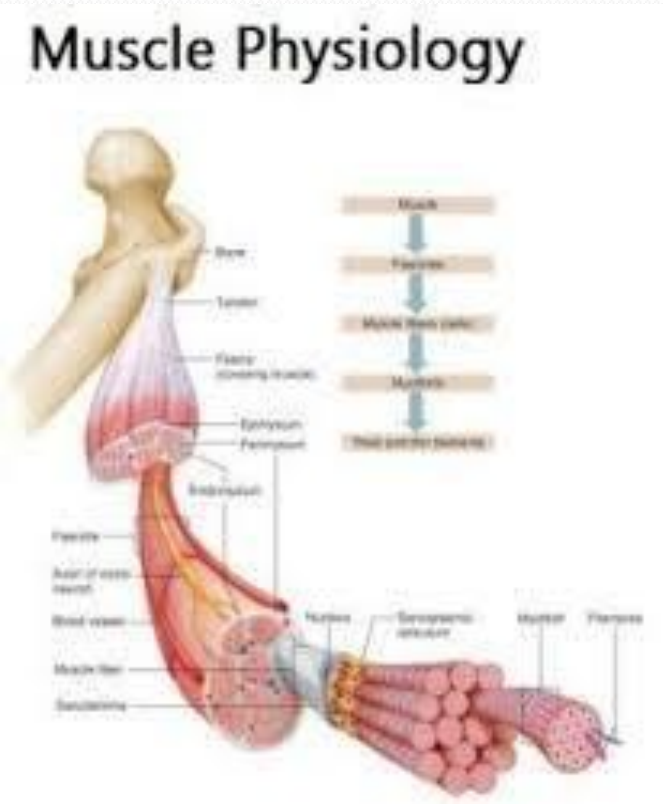

Muscle fibers
Motor Neuron
Motor End Plate
ACh Receptors
Myofibril

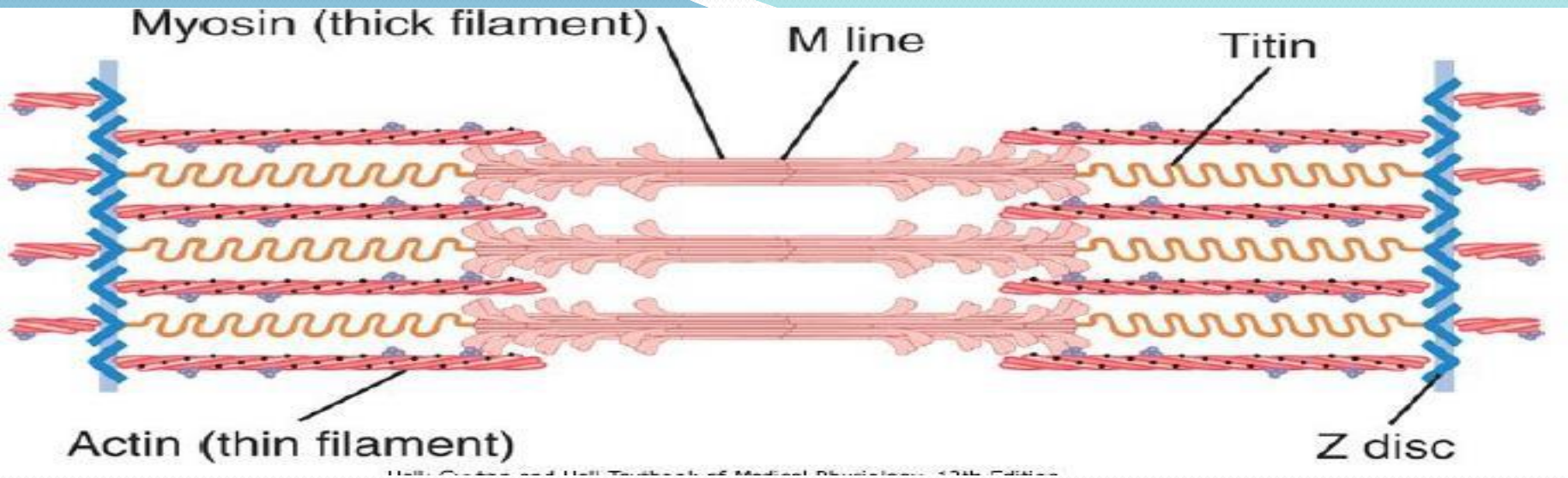
Skeletal Muscle Physiology

It is made up of muscle fibers. The muscle fiber is a single cell, multinucleated and surrounded by a cell membrane (sarcolemma). The muscle fibers are made up of fibrils, and the fibrils are divisible into filaments. The filaments are made up of the contractile proteins. The cross- striation is due to differences in the refractive indexes of the various parts of the muscle fibres. The parts of the cross striation are identified by letters

TheI bands are isotropic to polarized light. The A bands are filaments are made up of myosin. Myosin is a complex protein made up of 2 heavy chain and 4 light chains.







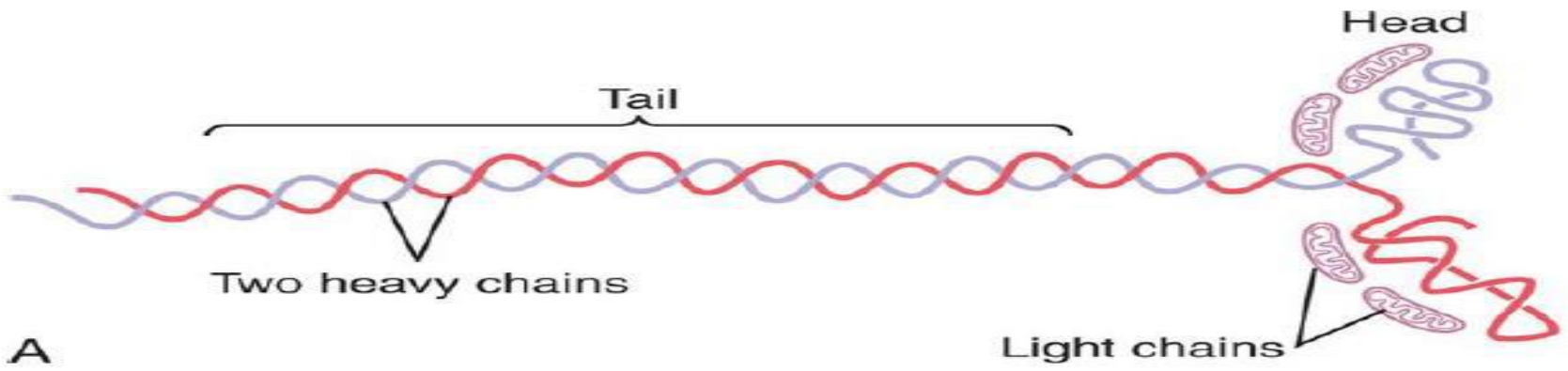
The heads of myosin contain:

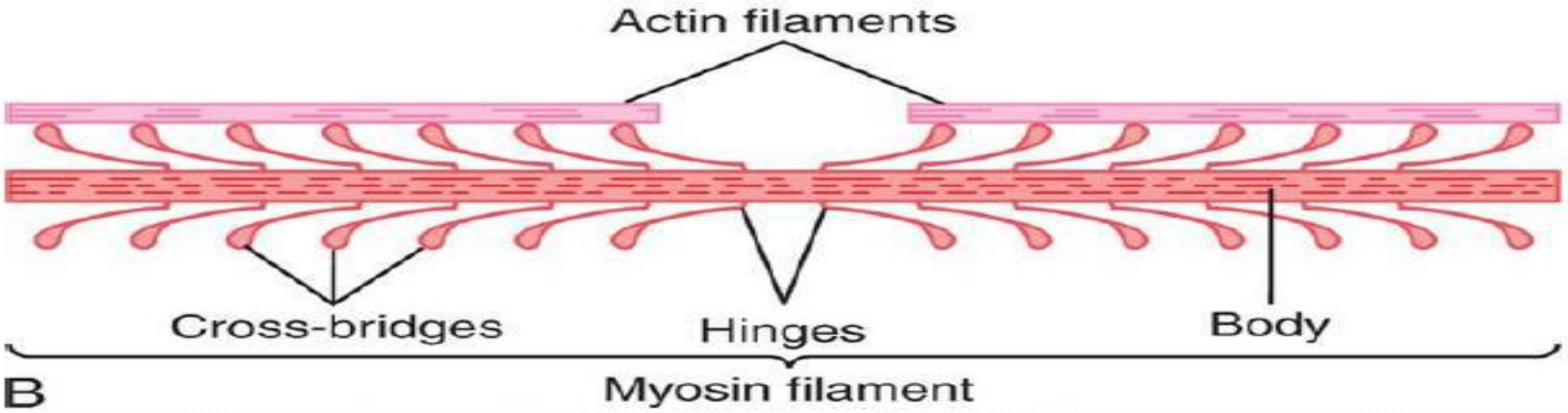
1- Actin binding site.

2- The catalytic site that hydrolyzes ATP (myosin head functions as an ATPase enzyme)

The myosin head from across – bridges to the actin molecules

The thin filaments are made up of actin, tropomyosin and troponin. It consists of two strands of actin molecules that form a long double helix.





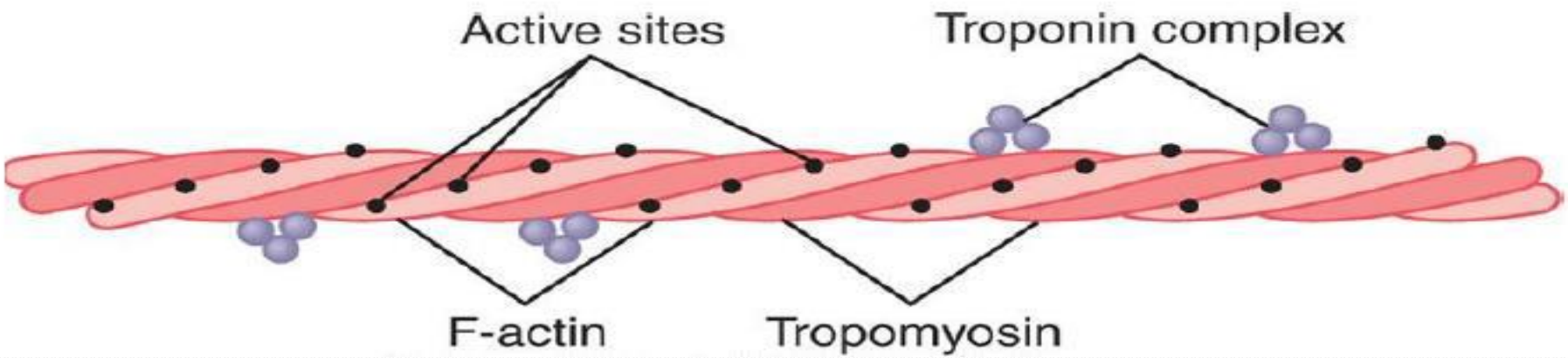
Tropomyosin molecules are long filaments located in the groove between the two chains in the actin.

Troponin is made up of 3 subunits:

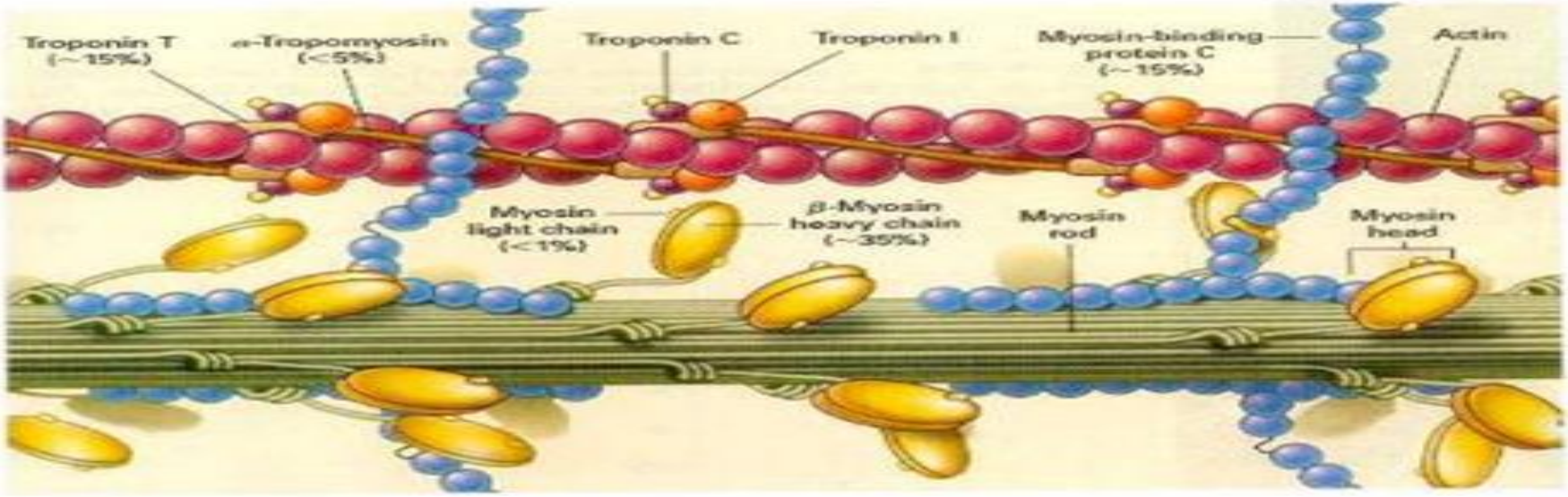
1- Troponin T binds the other troponin component to tropomyosin.

2- Troponin I inhibits the interaction of myosin with actin.

3- Troponin C contain binding sites for Ca+2 ions that initiate contraction

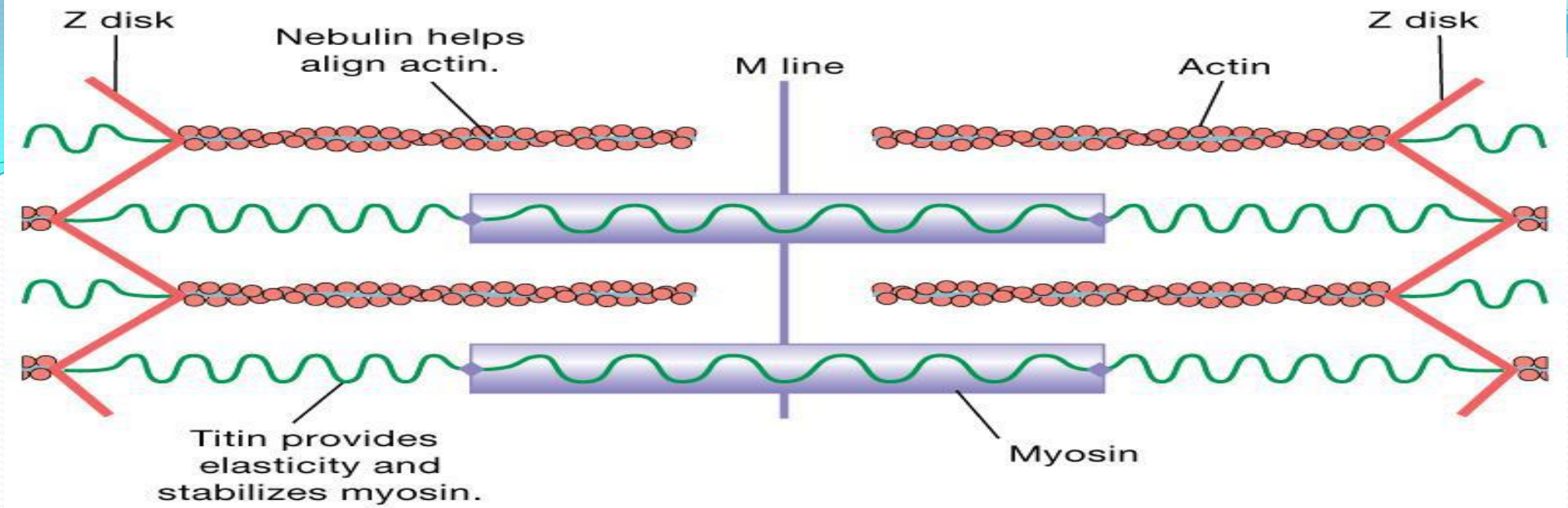


The thick filaments are made up of myosin. Myosin is a complex protein made up of 2 heavy chain and 4 light chains



Actinin: binds actin to the Z lines.
Titin: connect the Z line with the M line; it has two functions:
1- Its stabilizes the position of the contract filaments (myosin).
2- Its elasticity returns the stretch muscle to their resting length.

Nebulin: bear along sides thin filaments & attaches to the Z line. It helps align actin filaments.



Sarcotubular system

It is a series of membranous vesicles and tubules that surround the muscle fibrils.

The sarcotubular system is made up of:

1- Transverse system (T system).

T system is continuous with the sarcolemma.

 The function of the T system is the transmission of the action potential from the cell membrane to all the fibrils in the muscle.

2- Sarcoplasmic reticulum.

It has calcium storage sacs (terminal cisternae) containing Ca2+ ions.

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1. General Mechanism of Muscle Contraction

The initiation and execution of muscle contraction occur in the following sequential steps

1. An action potential travels along a motor nerve to its endings on muscle fibres.
2. At each ending, the nerve secretes a small amount of the neurotransmitter substance *acetylcholine.* At motor endplate.
3- Binding of acetylcholine to the nicotinic receptor.
4- Increase sodium ions conduction in the endplate membrane.
5- Generation of endplate potential.
6- Generation of the action potential in muscle fibre.
7- Transmission of action potential to all the fibrils via T- system.
8- Release of calcium ions from the terminal cisterna of sarcoplasmic reticulum.
9- Binding of calcium ions to troponin C.
10- The binding of troponin I to actin is weakened.
11- Tropomyosin moves laterally & this movement uncovers binding sites for the myosin head.
12- ATP is split to ADP. The hydrolysis of ATP is catalyzed by myosin (function as ATP enzyme).
13- The energy release is transverse to myosin producing energized myosin

$M + ATP \rightarrow M^*.ADP.Pi$

14- The energized myosin cross-bridges bind to actin (A).

$A + M^*.ADP.Pi \rightarrow A.\ M^*.ADP.Pi$

This binding triggers the release the energy storage in myosin producing movement of the cross-bridges.

A. $M^*.ADP.Pi + Pi \rightarrow A.M + ADP + Pi$

15- New molecules of ATP bind to myosin to break the link between actin & myosin.

$A.M + ATP \rightarrow A + M.ATP$

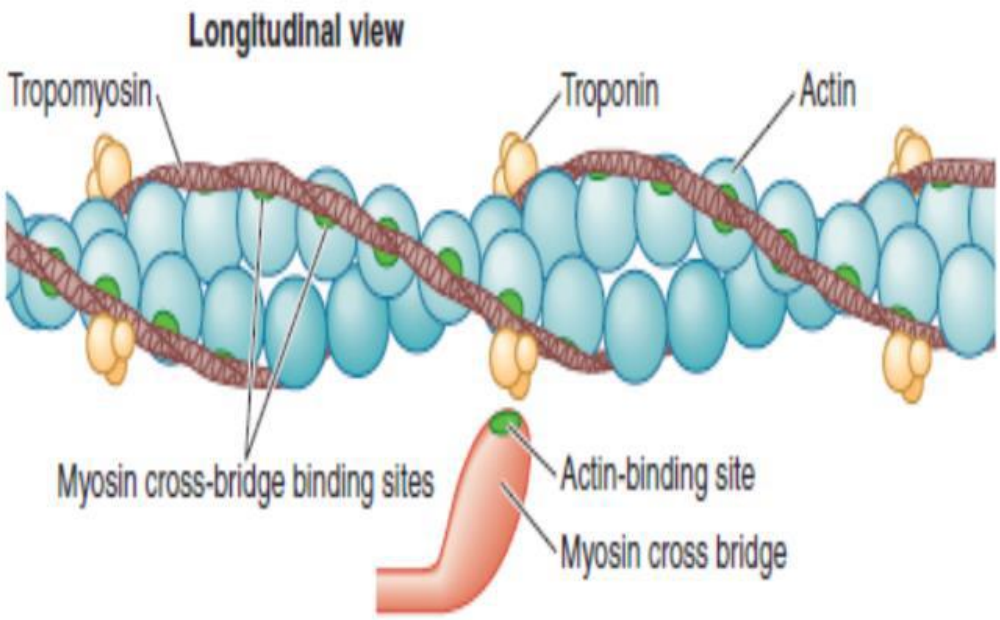
16-The ATP bound myosin is split & transferring energy to myosin cross-bridges producing energized cross bridges.
17- The cross-bridges repeat the cycle producing movement of the thin filament over the thick filament

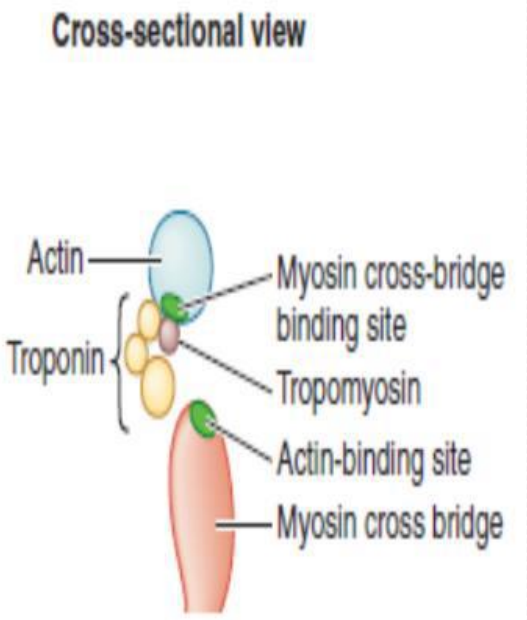
The sequence of events in relaxation:

1- Ca+2 ions are actively pumped into the sarcoplasmic reticulum.

2- Release of Ca+2 from troponin C

3- Cessation of interaction between action myosin.





➢ Physiology of Cardiac Muscle:

- Cardiac muscle, like skeletal muscle & neurons, is an excitable tissue with the ability to generate an action potential.
- Most cardiac muscle is contractile (99%), but about 1% of the myocardial cells are specialized to generate action potentials spontaneously. These cells are responsible for a unique property of the heart: its ability to contract without any outside signal
- Cardiac muscle is an electrical syncytium (acts as a single unit): an action potential, once initiated, travels as far as possible via cell-to-cell conduction through low resistance gap junctions (intercalated disks)
- The heart can contract without an outside signal because the signal for contraction is myogenic, originating within the heart itself.
- The heart contracts, or beats, rhythmically as a result of action potentials that it generates by itself, a property called auto rhythmicity (auto means "self")
- The signal for myocardial contraction comes **NOT** from the nervous system but from specialized myocardial cells also called **pacemaker cells** (auto rhythmic cells).
- The cardiac muscle cells are striated and have several branching processes. The adjacent cells are joined end to end at **intercalated discs**. Within the intercalated discs are 2 types of membrane junctions

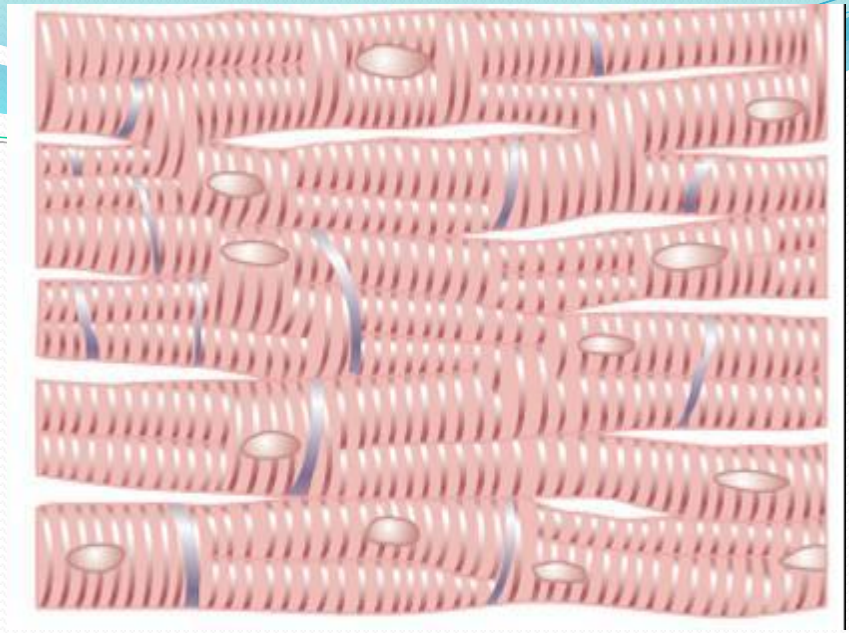
Type of membrane junction:

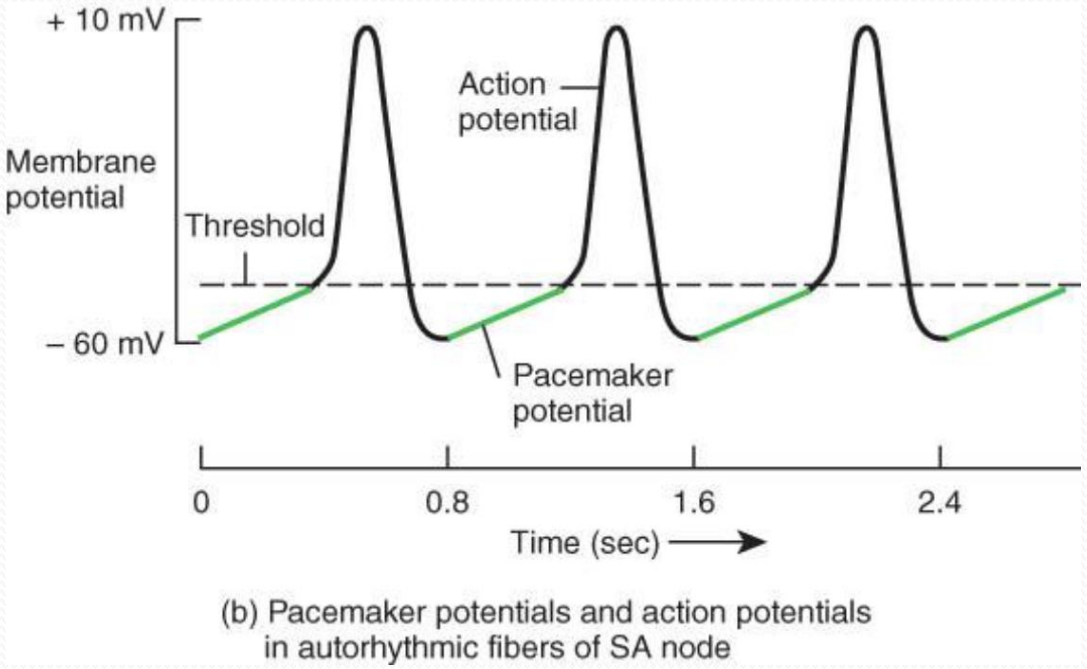
1- Desmosomes which hold the cells together and to which the myofilaments are attached.

2- Gap junctions which allow the spread of action potential from one cardiac muscle cell to another

Action Potential of the Sinoatrial node (SA node)(Autorrythmic) cardiac cells

- The SA node (auto rhythmic) cells **do not** have a stable resting membrane potential like the nerve and the skeletal muscles .
- Instead, they have an unstable membrane potential that starts at – 60mv and slowly drifts upwards towards the threshold .
- Because the membrane potential never rests at a constant value, it is called a **Pacemaker Potential rather** than a resting membrane potential.





(b) Pacemaker potentials and action potentials in autorhythmic fibers of SA node

IONIC BASIS OF ACTION POTENTIAL OF AUTORRYTHMIC CELLS

Phase 1: Pacemaker Potential:

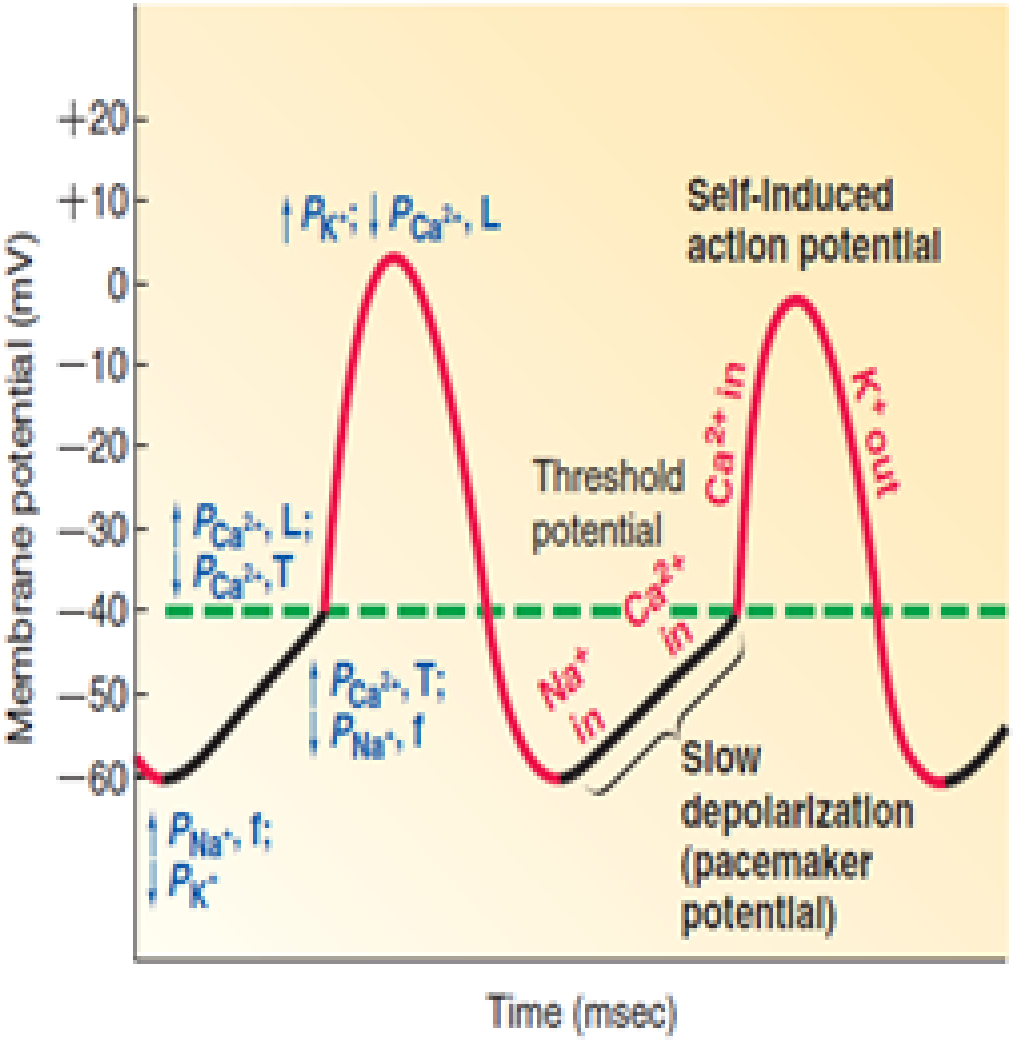
- Opening of voltage-gated Sodium channels called Funny channels (I_f or f channels).
- Closure of voltage-gated Potassium channels.
- Opening of Voltage-gated Transient-type Calcium (T-type Ca^{2+} channels) channels.

Phase 2: The Rising Phase or Depolarization:

- Opening of Long-lasting voltage-gated Calcium channels (L-type Ca^{2+} channels).
- Large influx of Calcium.

Phase 3: The Falling Phase or Repolarization:

- Opening of voltage-gated Potassium channels
- Closing of L-type Ca channels.
- Potassium Efflux.



KEY

f = Funny channels
T = Transient-type channels
L = Long-lasting channels

Pacemaker Potential:

The pacemaker tissue makes up the conduction system that spreads impulses throughout the heart. Pacemaker tissue is characterized by an unstable membrane potential

Ionic basis of the action potential of Sinoatrial node

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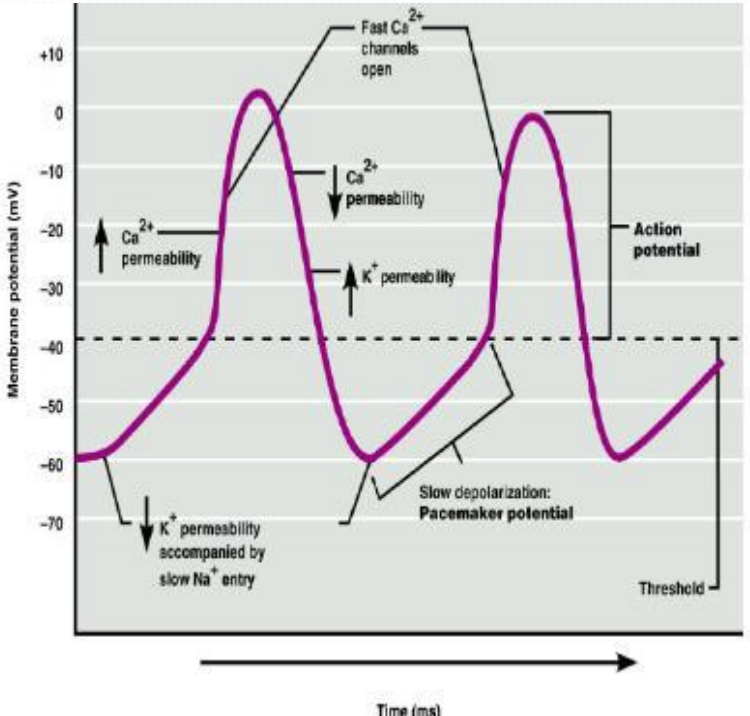
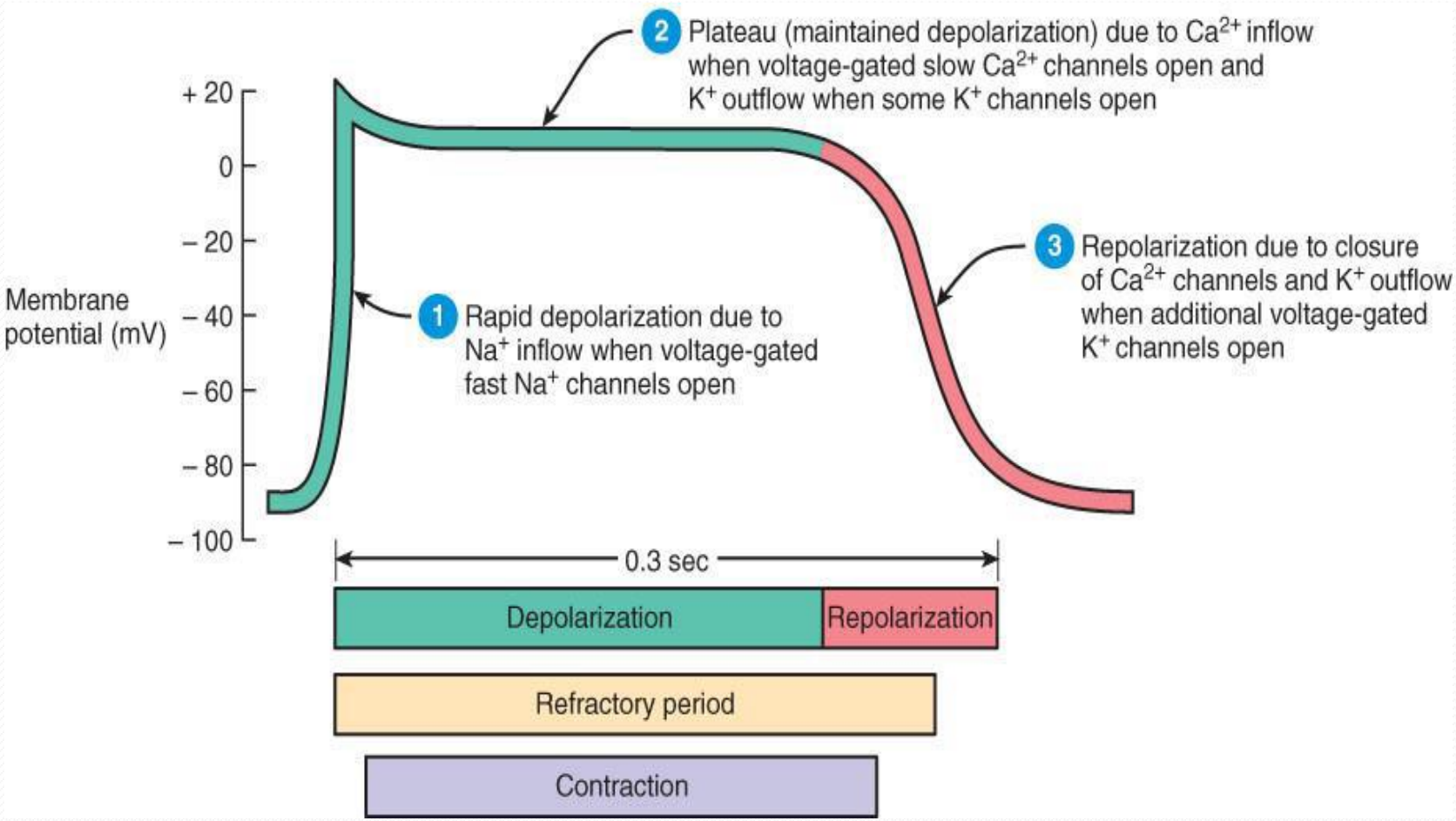


Action potential of a contractile myocardial cell: a typical ventricular

Unlike the membranes of the auto rhythmic cells, the membrane of the contractile cells remains essentially at rest at about -90mv until excited by electrical activity propagated by the pacemaker cells



Action potential of a contractile myocardial cell: a typical ventricular

1- Depolarization

- Opening of fast voltage-gated Na+ channels.
- Rapid Influx of Sodium ions leading to rapid depolarization.

2- Small Repolarization

- Opening of a subclass of Potassium channels which are fast channels.
- Rapid Potassium Efflux.

3- Plateau phase

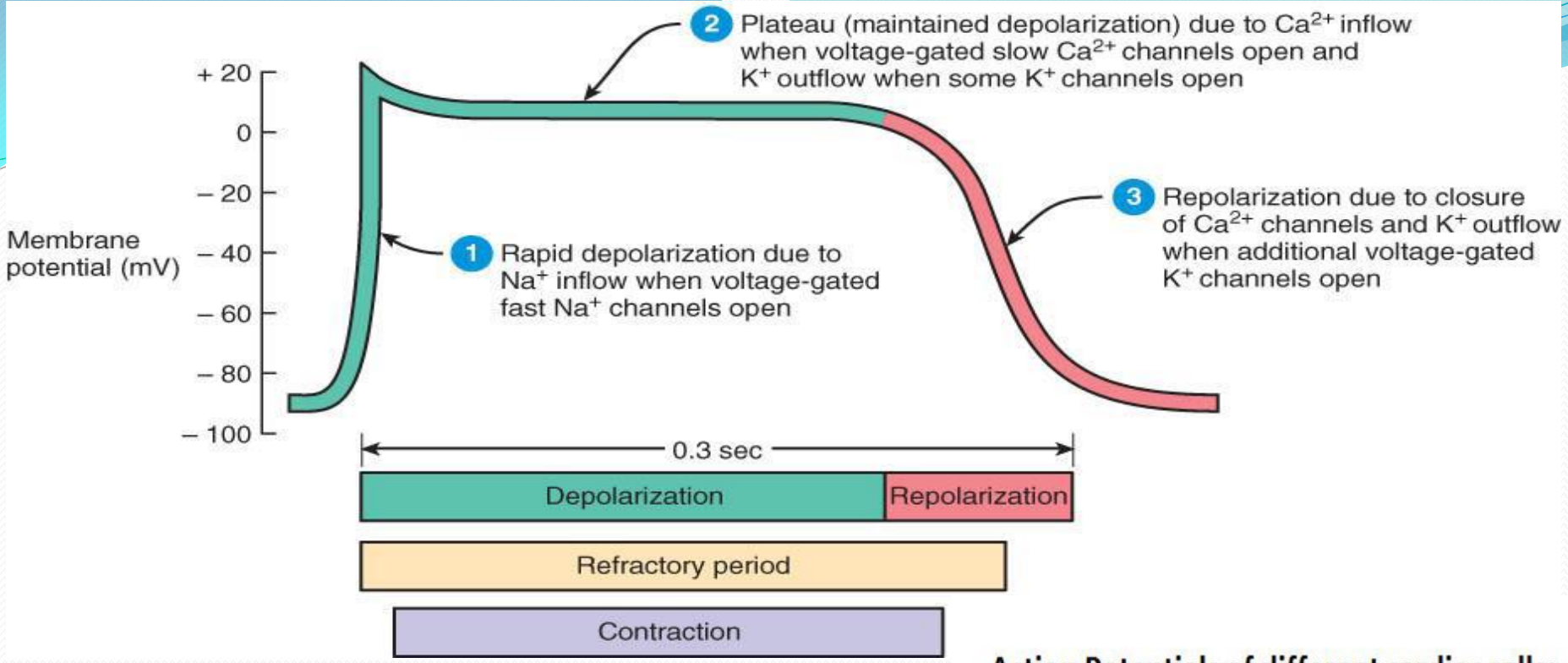
- 250 msec duration (while it is only 1msec in neuron (
- Opening of the voltage-gated slow Calcium channels & Closure of the Fast K+ channels.

• Large Calcium influx

- K+ Efflux is very small as K+ permeability decreases & only a few K channels are open.

4-Repolarization

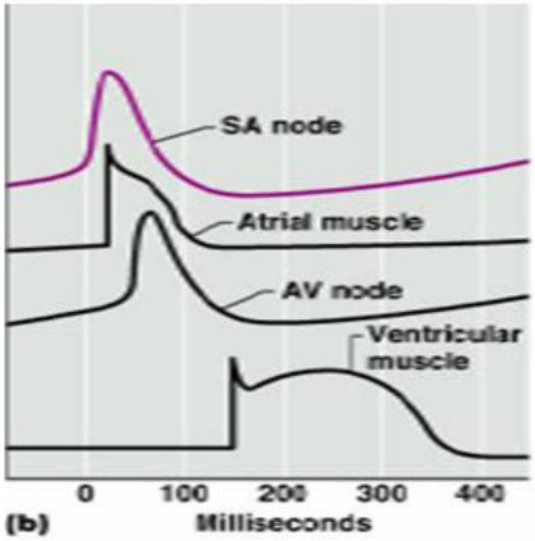
- Opening of the typical, slow, voltage-gated Potassium channels.
- Closure of the L-type, voltage-gated Calcium channels.



Summary of Action Potential of a Myocardial Contractile Cell

- **Depolarization**= Sodium Influx
- **Rapid Repolarization**= Potassium Efflux
- **Plateau**= Calcium Influx
- **Repolarization**= Potassium Efflux

Action Potentials of different cardiac cells:



➢ Physiology of Smooth muscle:

It lacks cross –striations. The sarcoplasmic reticulum is poorly developed. Smooth muscle contains actin, myosin and tropomyosin but does not contain troponin. It contains few mitochondria and depends to a large degree on glycolysis for their metabolic needs.

Type of smooth muscle

1- Visceral smooth muscle

2- Multi-unit smooth muscle

Visceral smooth muscle:

1-It found primarily in the walls of hollow viscera (e.g intestine, uterus).

2- It is characterized by the instability of its membrane potential

3- It shows continuous, irregular contractions that are independent of its nerve supply. This maintained state of partial contraction is called tonus or tone.

4- The membrane potential averages about -50 Mv .there are various types of waves superimposed on the membrane potential

a- **slow waves**

b- Spikes

5- There is pacemaker potential similar to those found in the cardiac pacemaker.
6- The excitation-contraction coupling in a very slow process
7- The myosin in smooth muscle must be phosphorylated for activation of myosin ATPase Ca+2 ion binds to calmodulin, and the resulting Ca+2 calmodulin complexes activate myosin light chain kinase (The enzyme that catalyzes the phosphorylation of myosin). Actin then slides on myosin, producing a contraction.
8- Visceral smooth **Muscle** contracts when starched.
Stretched is followed by:
a- A decline in membrane potential
b- An increase in the frequency of spikes
c- A general increase in tone

Multi-unite smooth muscle

1- The smooth muscle fibers of the ciliary muscle of the eye, the iris of the eye and the piloerector muscle are examples of multi-unit smooth muscle.
2- Multi-unit smooth muscle is composed of discrete smooth muscle fibers. Each fiber operates independently of the others.
3- The control of multi-unit smooth muscle fibers is exerted mainly by nerve signals.
4- Multi-unit smooth muscle fibers seldom exhibit spontaneous contractions.