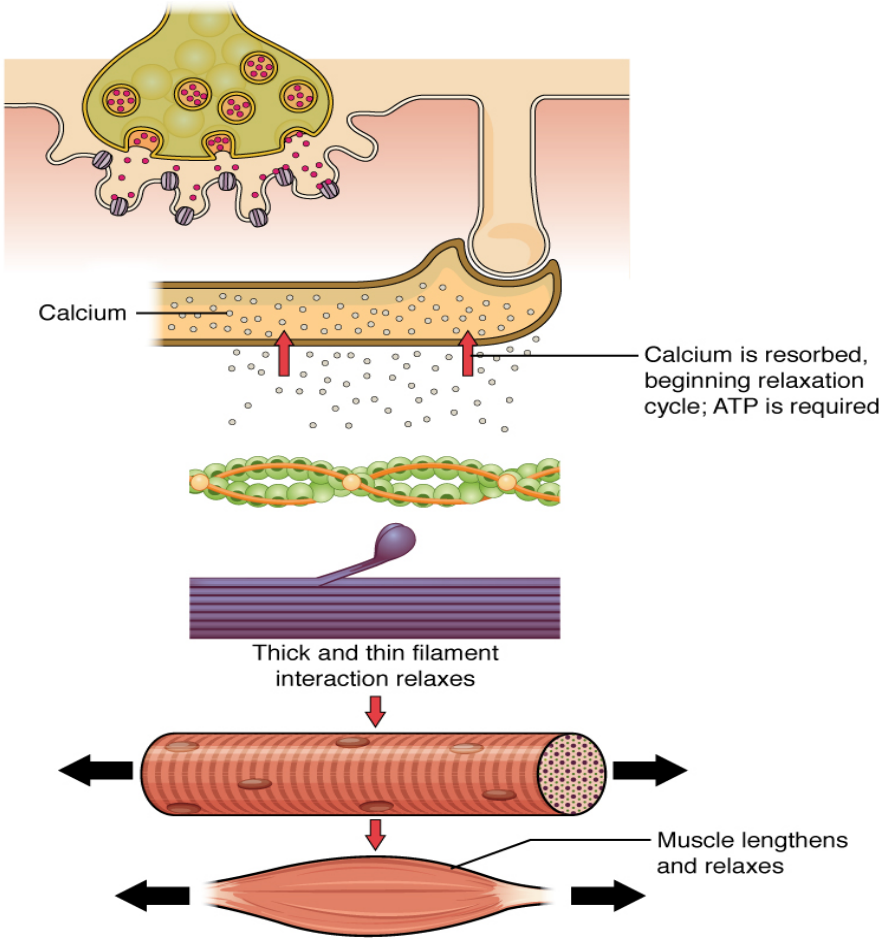
BIOLOGY 1103/1109
Human Anatomy and Physiology I

UNIT 16

Muscle Physiology

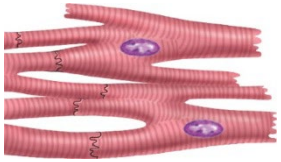


Movement

MOVEMENT ENVOLVES ***MUSCLE***

THERE ARE 3 TYPES OF MUSCLE:

CARDIAC

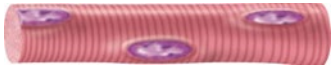


INVOLUNTARY
HEART

SMOOTH

INVOLUNTARY
INTESTINES
BLOOD VESSELS
BLADDER
EYE (inside the eye)
UTERUS etc.

SKELETAL



VOLUNTARY
MUSCLES ATTACHED TO BONES

*IT IS THE **SKELETAL MUSCLES,** TOGETHER WITH THE **BONES & JOINTS,** THAT ACCOMPLISHES **MOVEMENT***

Skeletal muscle physiology

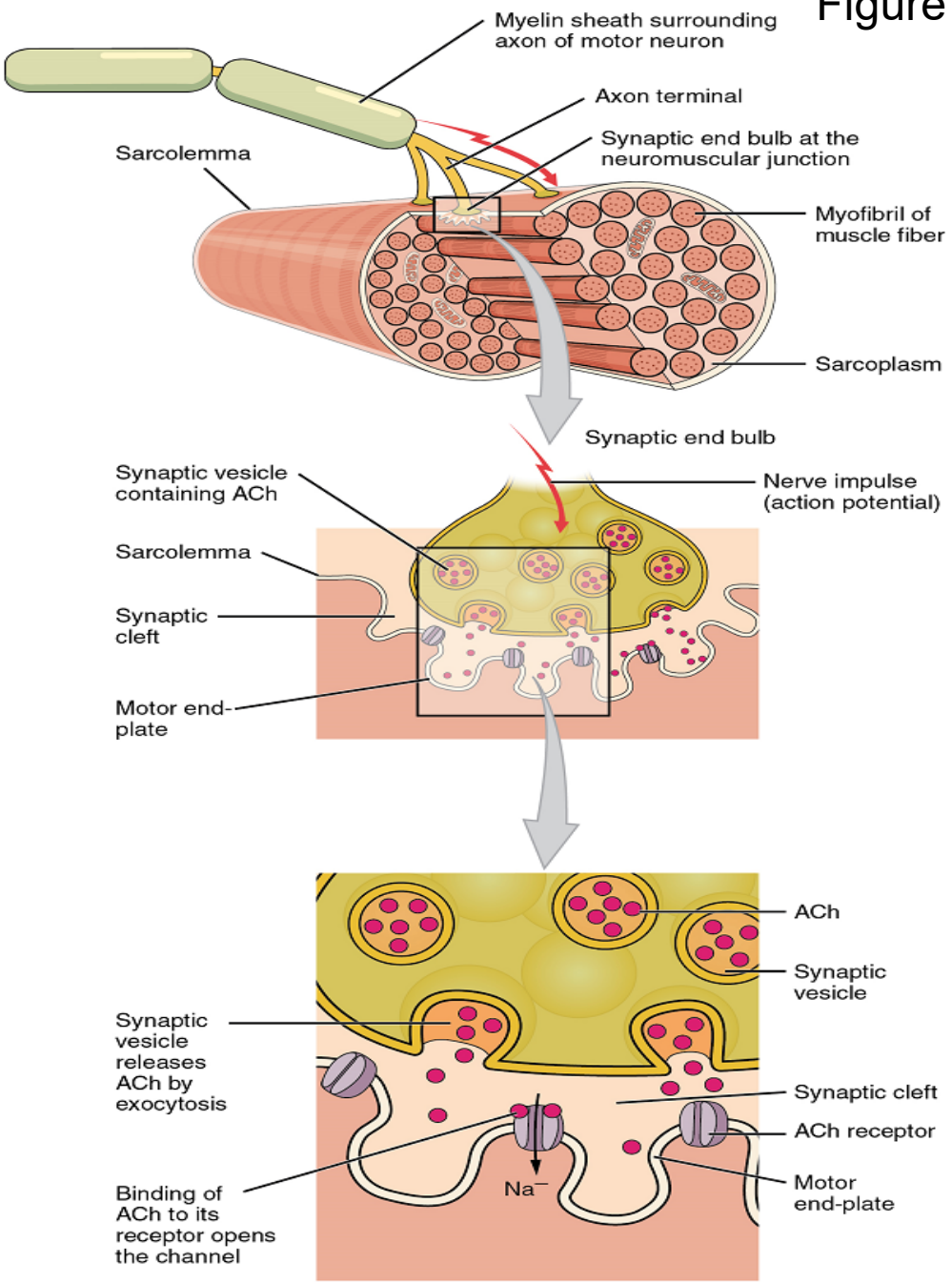
Objectives

1. Describe the anatomy of a neuromuscular junction.
2. Describe the process of muscle contraction
3. Describe the physiology of muscle relaxation.
4. Describe the concept of muscle tone as it pertains to skeletal muscles.
5. Define the following terms: paralysis, muscular dystrophy, muscular atrophy, muscular hypertrophy.

Anatomy of the neuromuscular junction

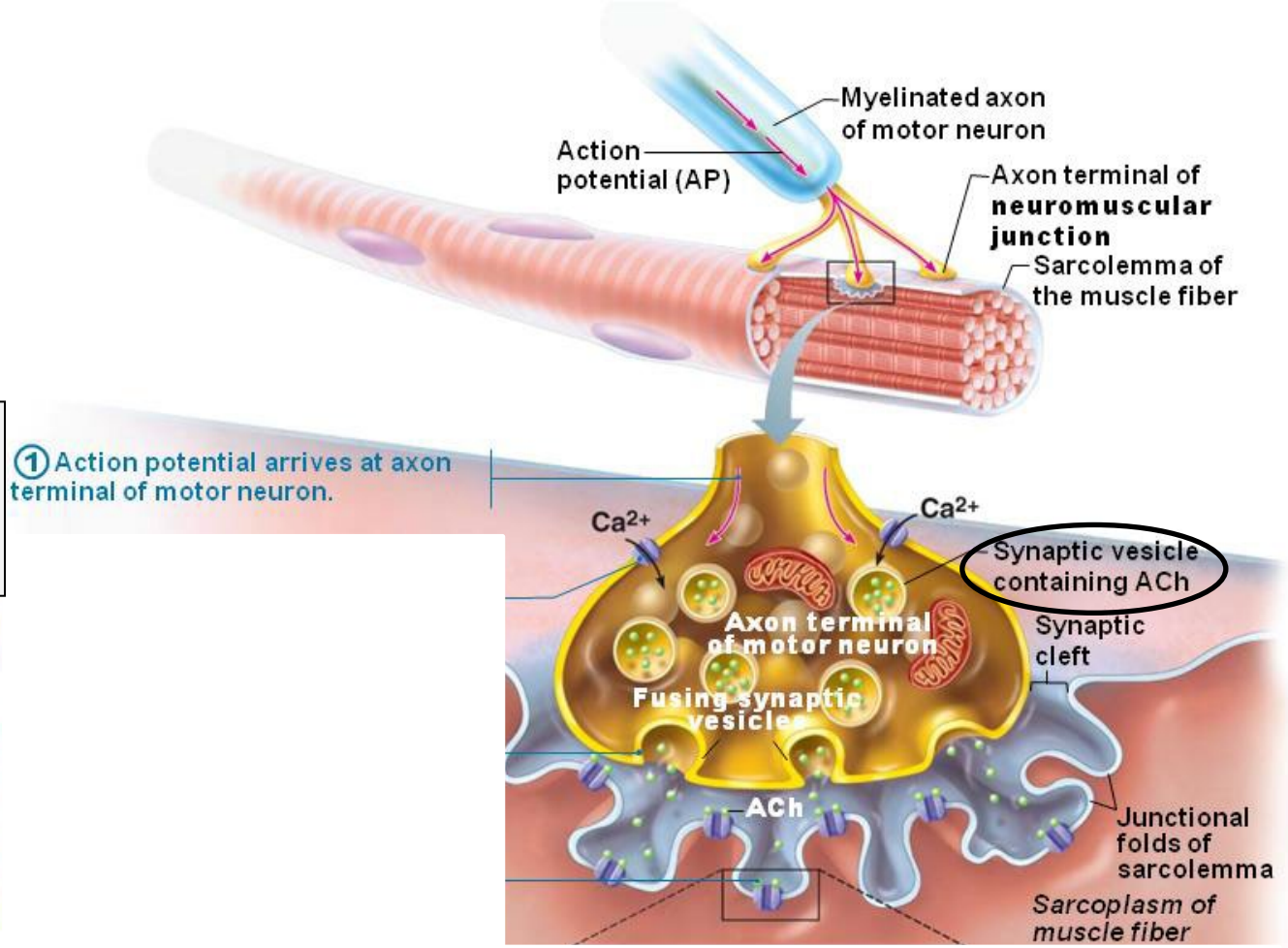
Nerve axon divides into swollen ending called synaptic end bulbs that do not touch the sarcolemma of the muscle cell. This gap is called the synaptic cleft and is part of the neuromuscular junction

Figure 1



1. Nerve impulse spreads to axon terminals

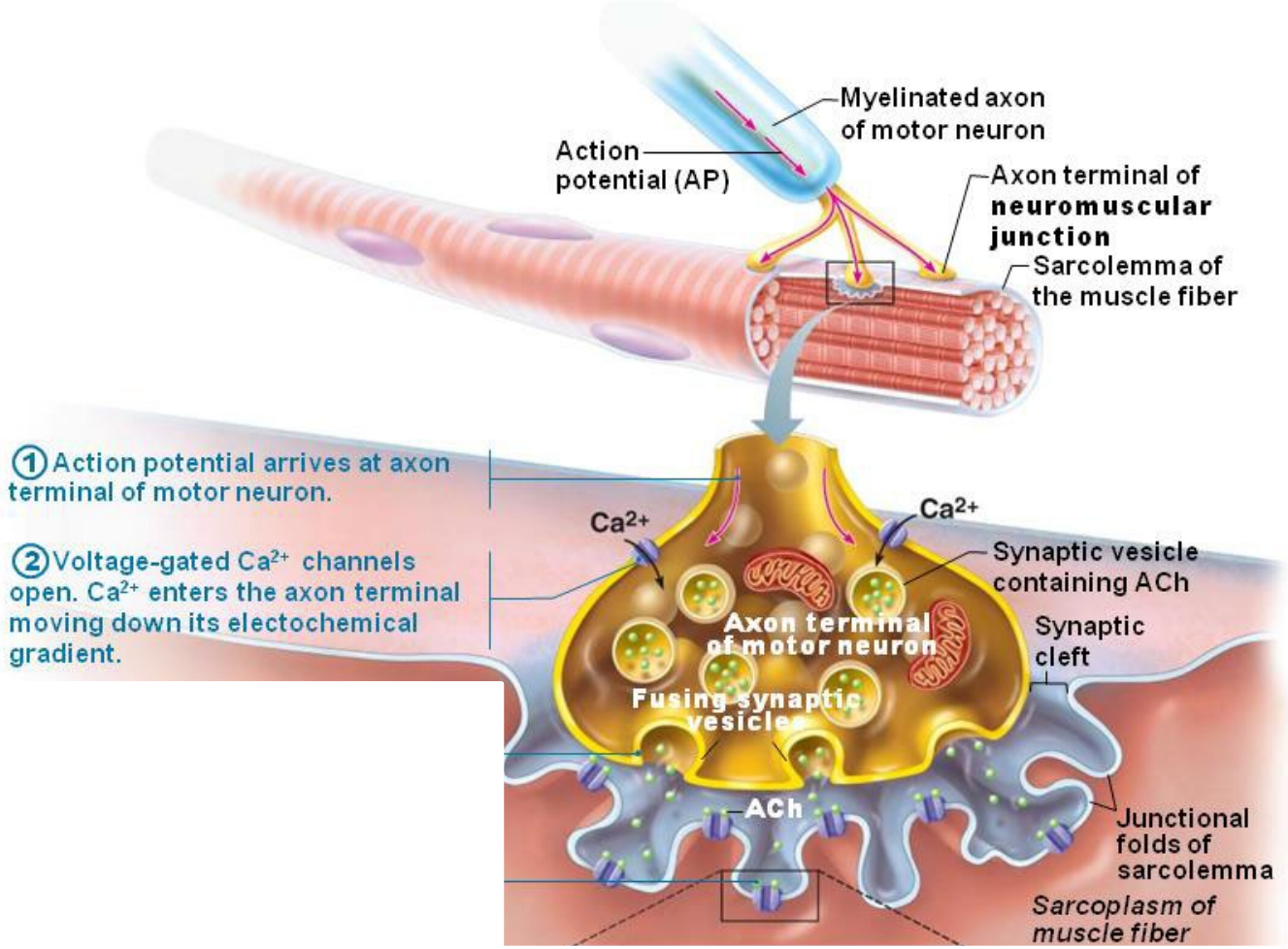
ACh = acetylcholine
Which is a chemical messenger



Marieb, Focus figure 9.1

ACh = acetylcholine
Which is a chemical messenger

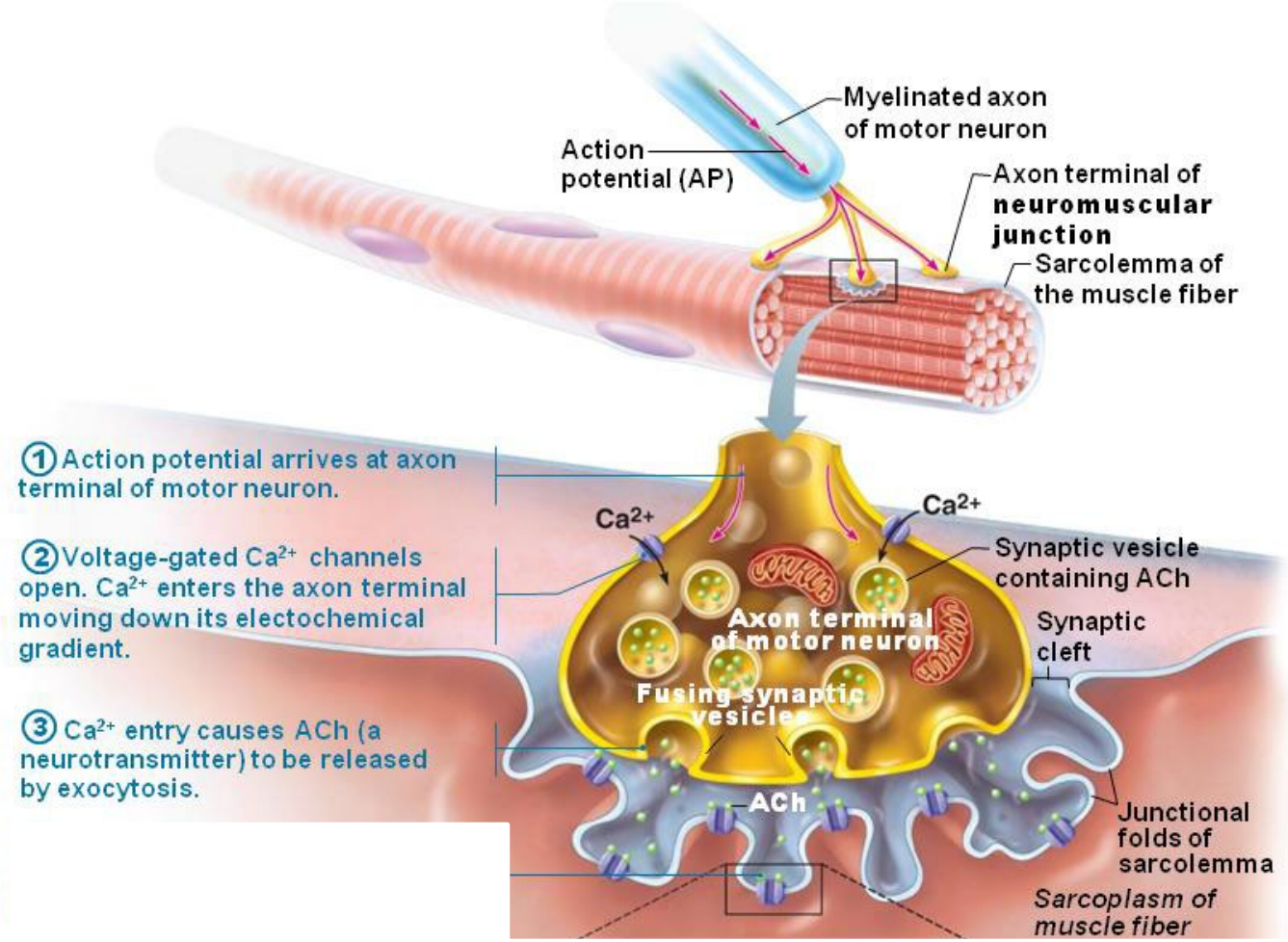
2. Voltage-gated Ca^{2+} channels open, Ca2+ enters the cell



Marieb, Focus figure 9.1

ACh = acetylcholine
Which is a chemical messenger

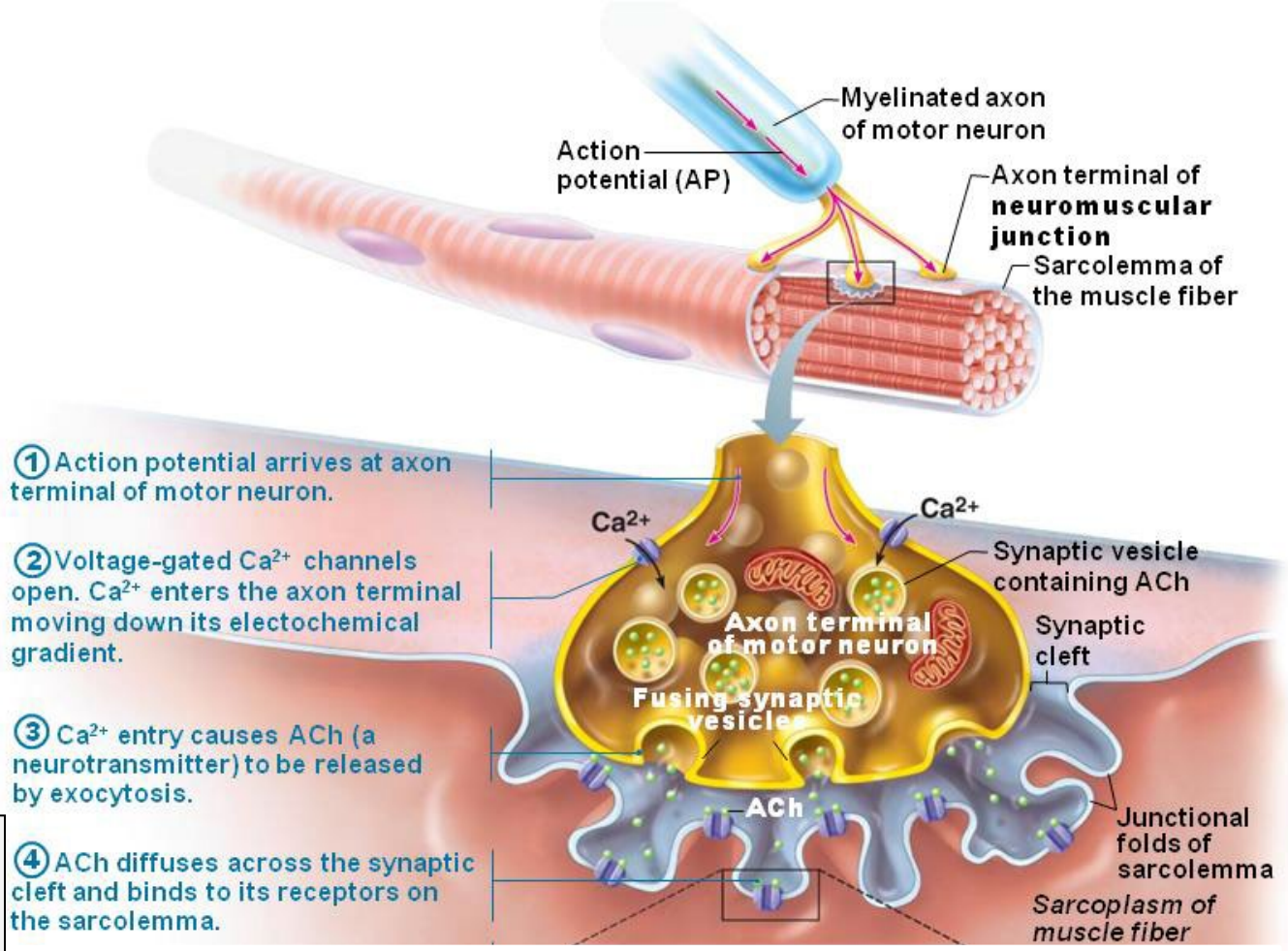
3. Synaptic vesicles fuse with synaptic membrane



Marieb, Focus figure 9.1

ACh = acetylcholine
Which is a chemical messenger

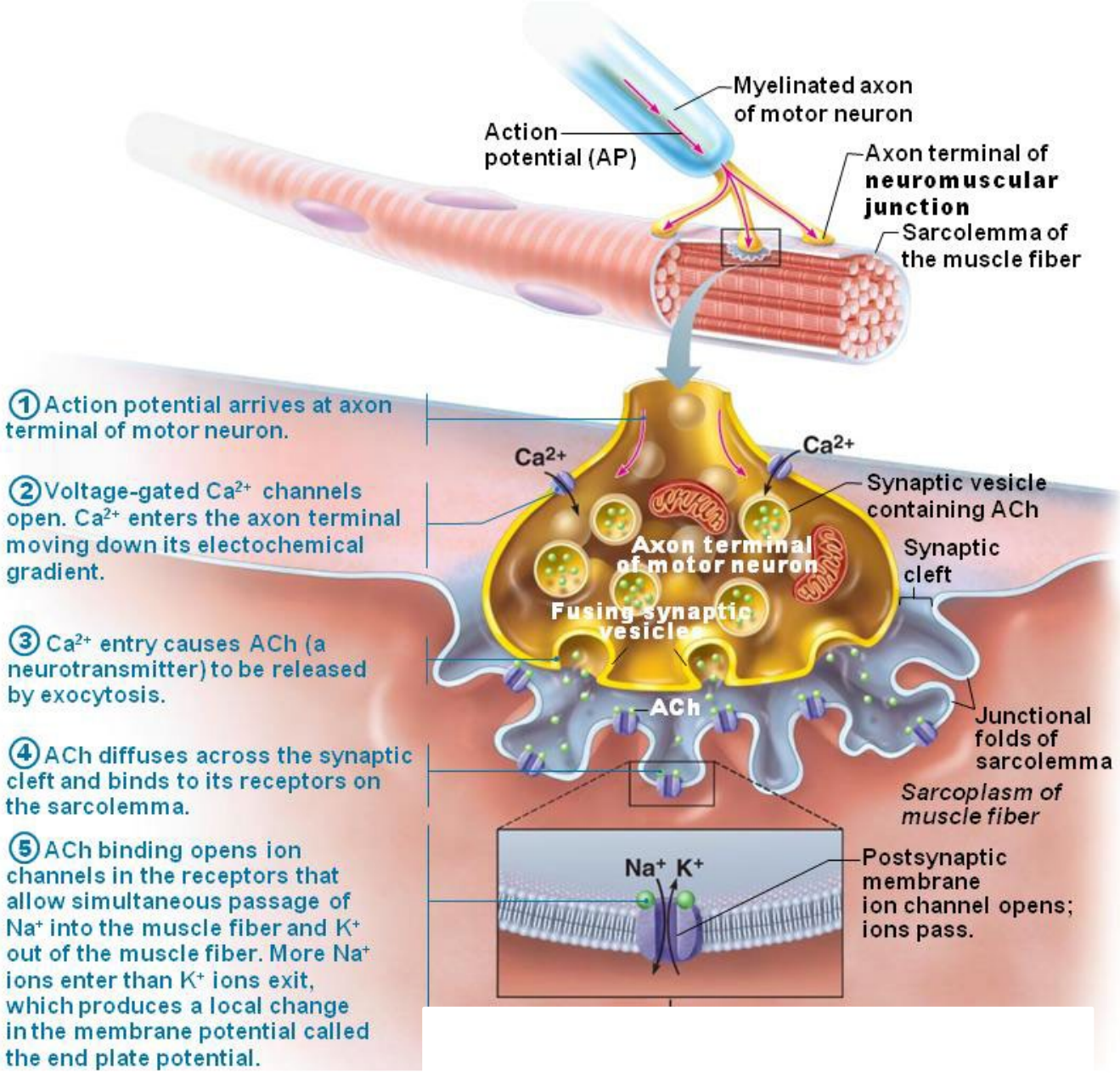
4. ACh diffuse across cleft & bind to receptors in junctional folds



Marieb, Focus figure 9.1

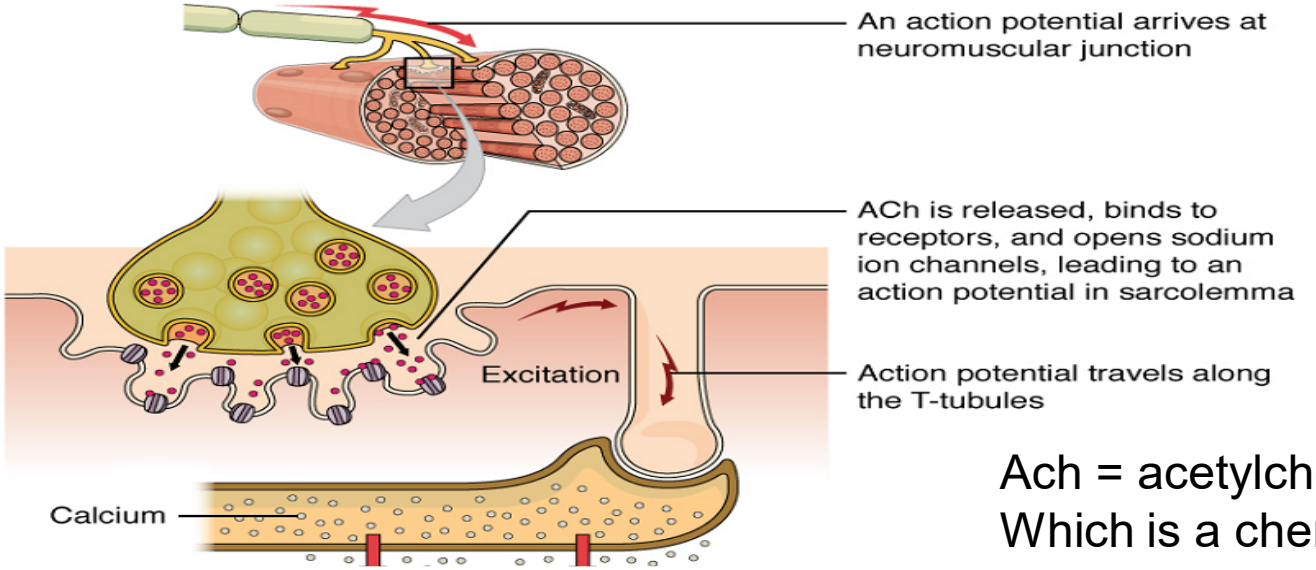
ACh = acetylcholine
Which is a chemical messenger

5. Receptors are ion channels which open & allow Na+ into sarcoplasm



Marieb, Focus figure 9.1

7. Depolarization spreads along sarcolemma



Ach = acetylcholine
Which is a chemical messenger

AChE = acetylcholinesterase, is an enzyme that breaks down Ach

6. Na^+ inflow causes local depolarization (change in membrane potential)

End plate potential generated at the neuromuscular junction propagates as an action potential across the sarcolemma

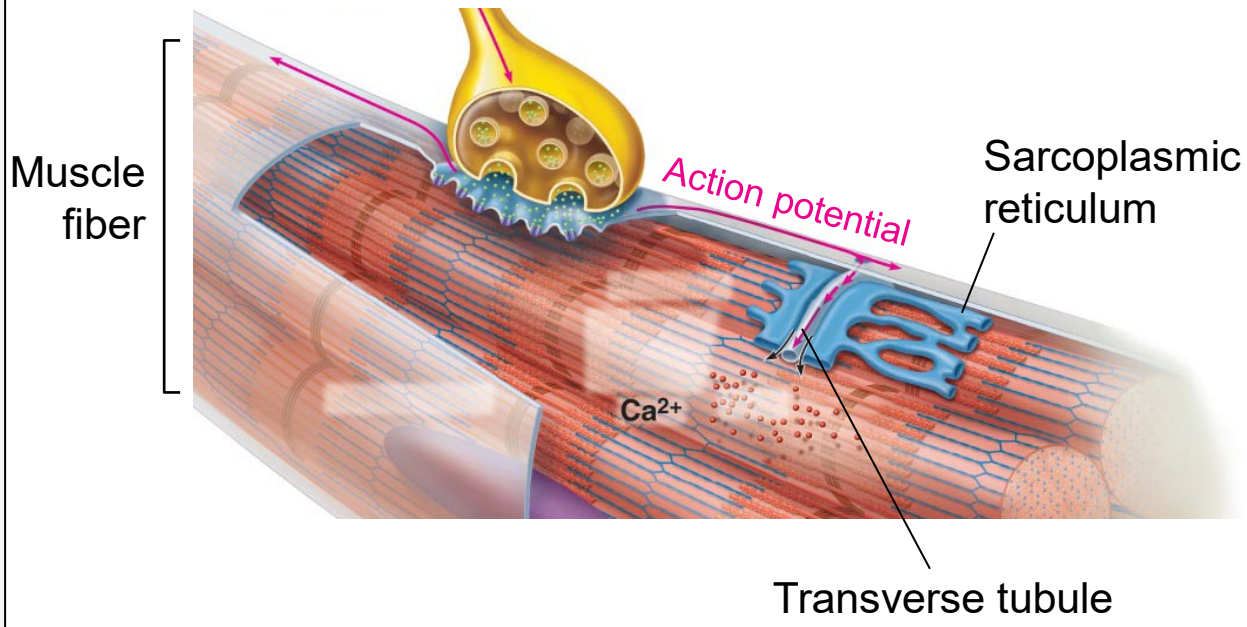
8. ACh broken down by enzyme to terminate stimulus

Excitation-contraction coupling

1. Wave of depolarization spreads to adjacent areas of sarcolemma

2.Generation of action potential via opening & closing of voltage-gated channels

3. Action potential (AP) spreads along sarcolemma and down the T tubules



Marieb, Focus figure 9.2

Excitation-contraction coupling

3. AP travels across the sarcolemma and down the T tubules

4. This AP causes voltage sensitive receptors on the SR to change shape and open, releasing Ca^{2+} into the sarcoplasm

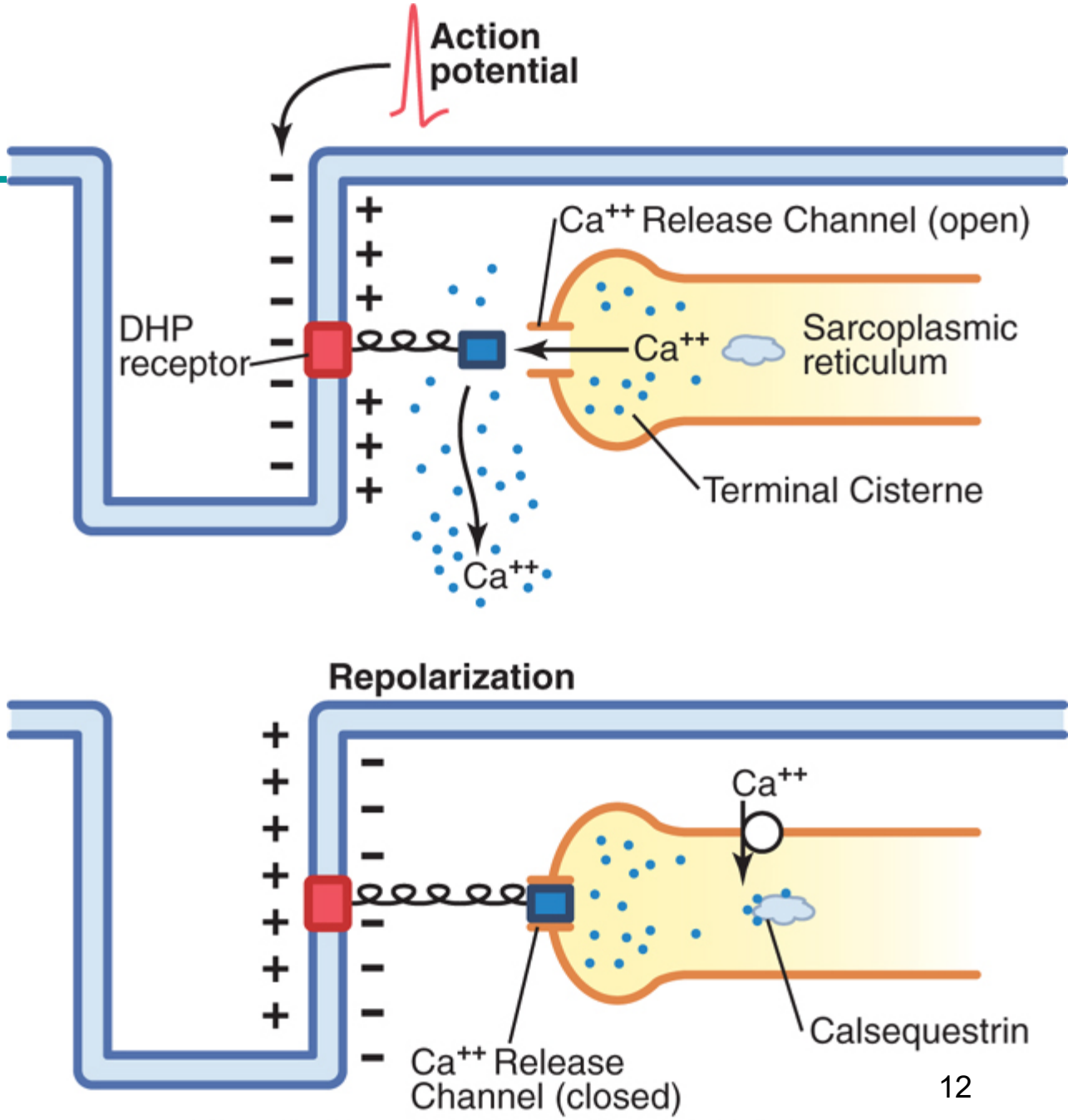
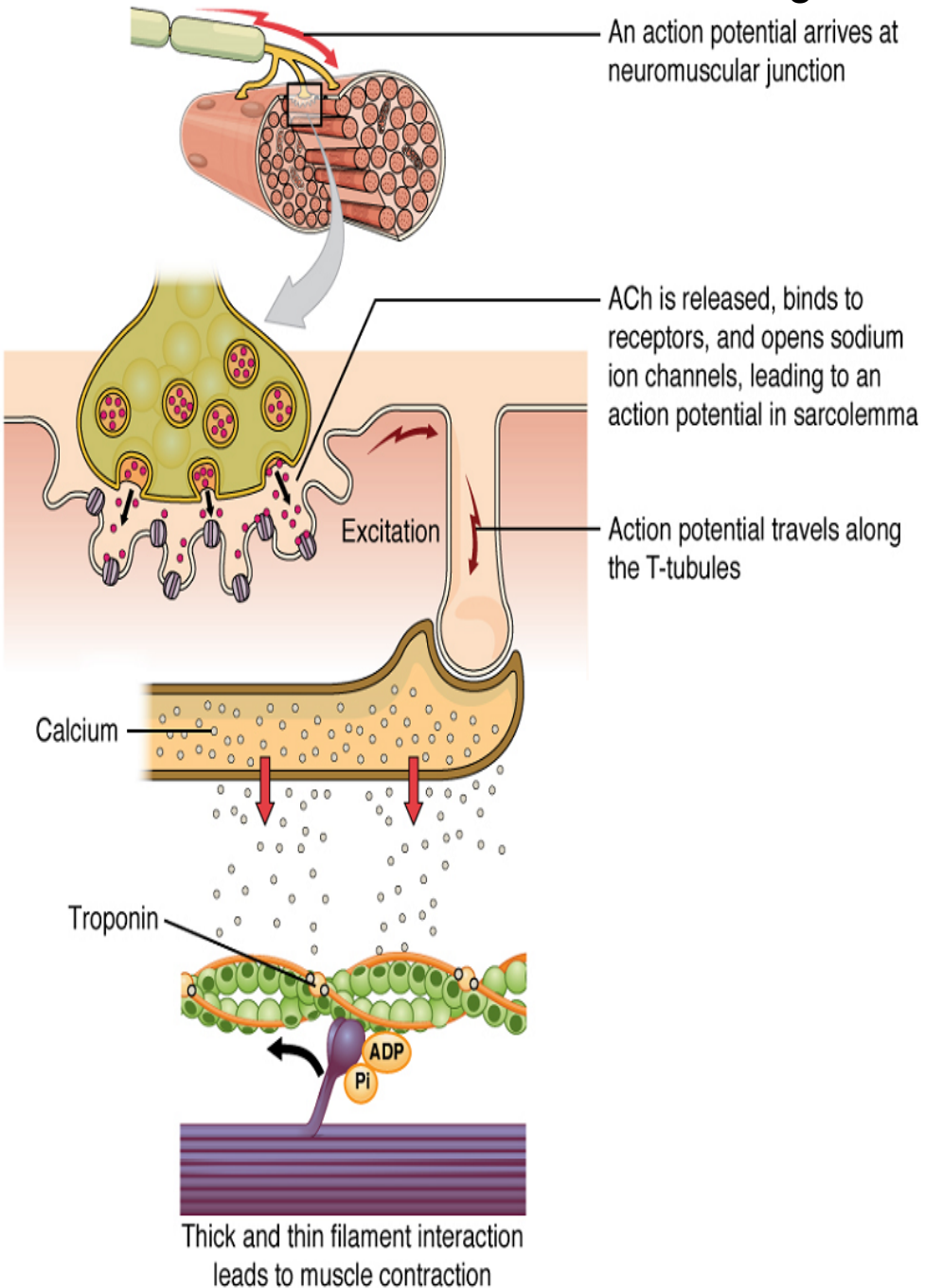


Figure 3

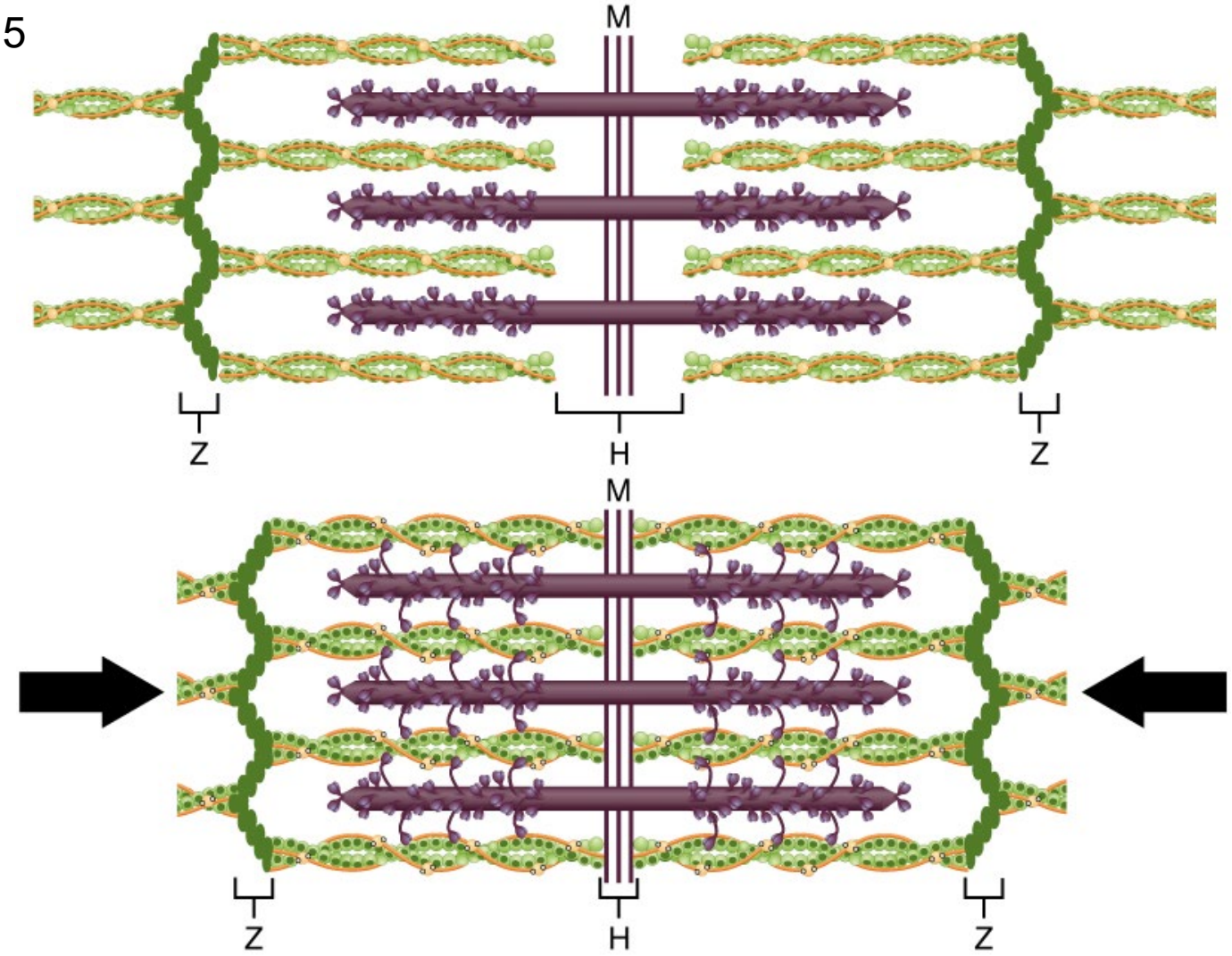


3 and 4. Spread of AP along transverse tubules causes sarcoplasmic reticulum to release Ca^{2+} into sarcoplasm.

5. Ca^{2+} bind to troponin causing the troponin-tropomyosin complex to change shape, which then uncovers myosin-binding sites on actin.

6. This change allows myosin heads to bind to actin forming a cross bridge.

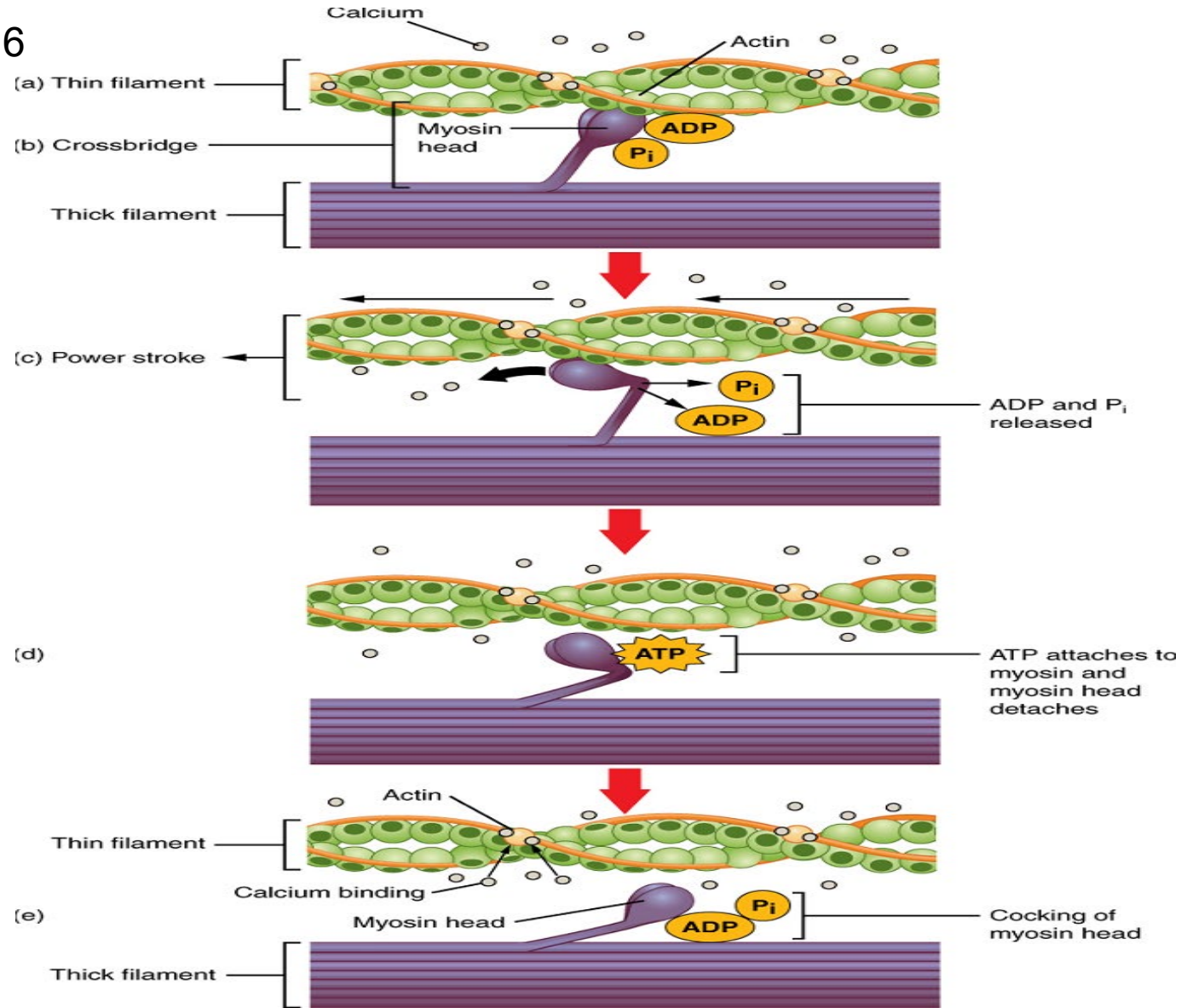
Figure 5



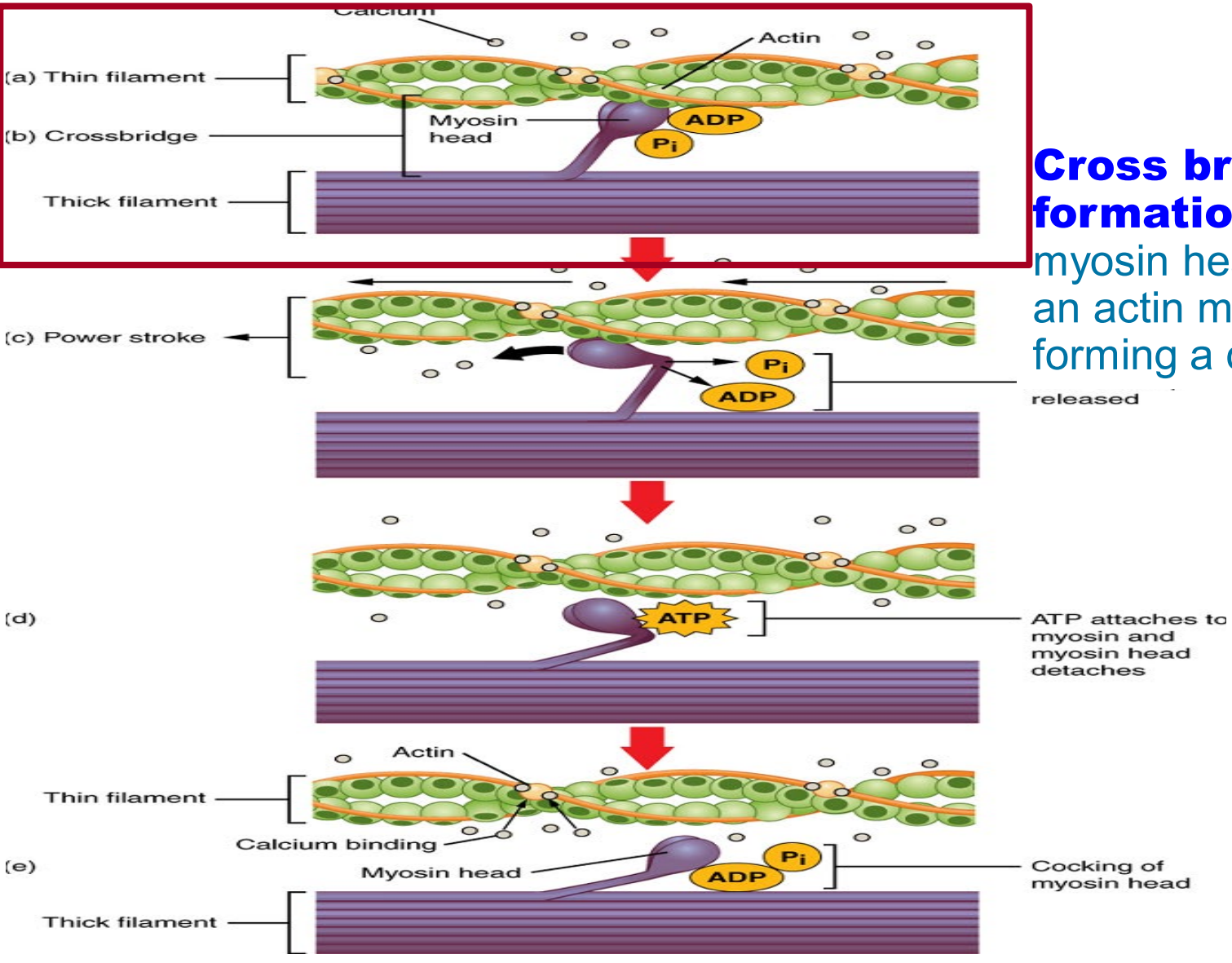
Sliding filament model of muscle contractions

Physiology of muscle contraction

Figure 6

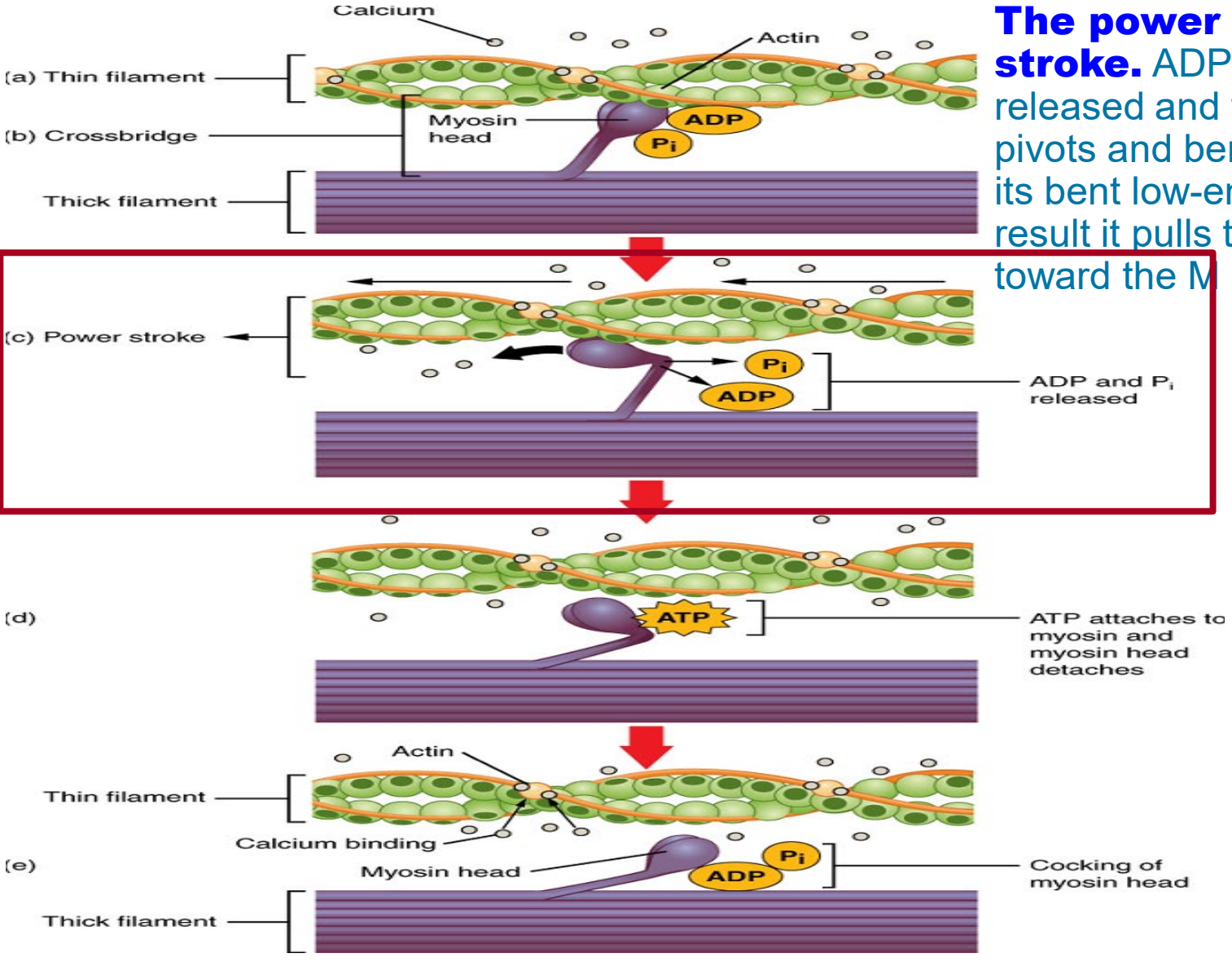


Step 1. Cross -bridge formation



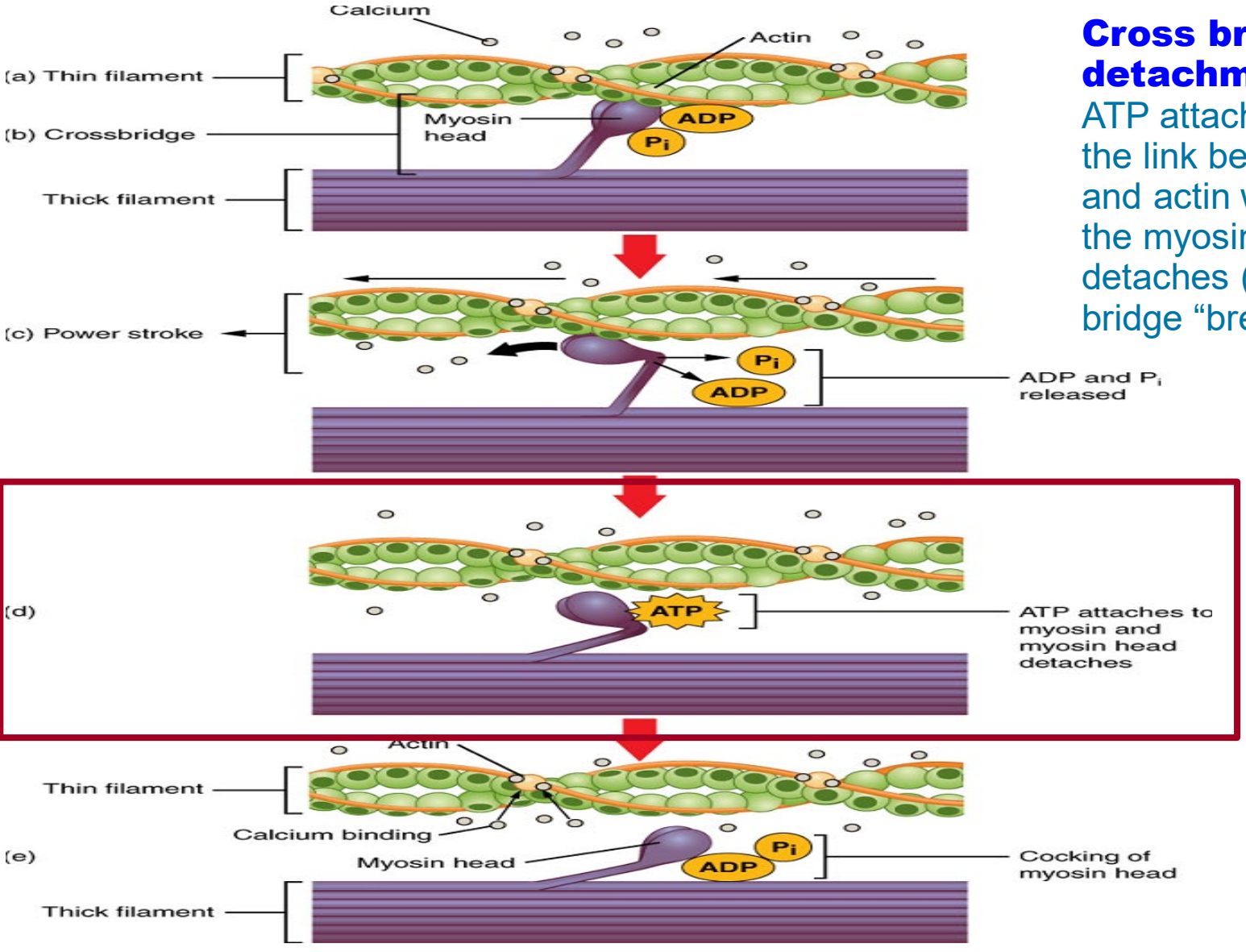
Cross bridge formation. Energized myosin head attaches to an actin myofilament, forming a cross bridge.

Step 2. The power stroke



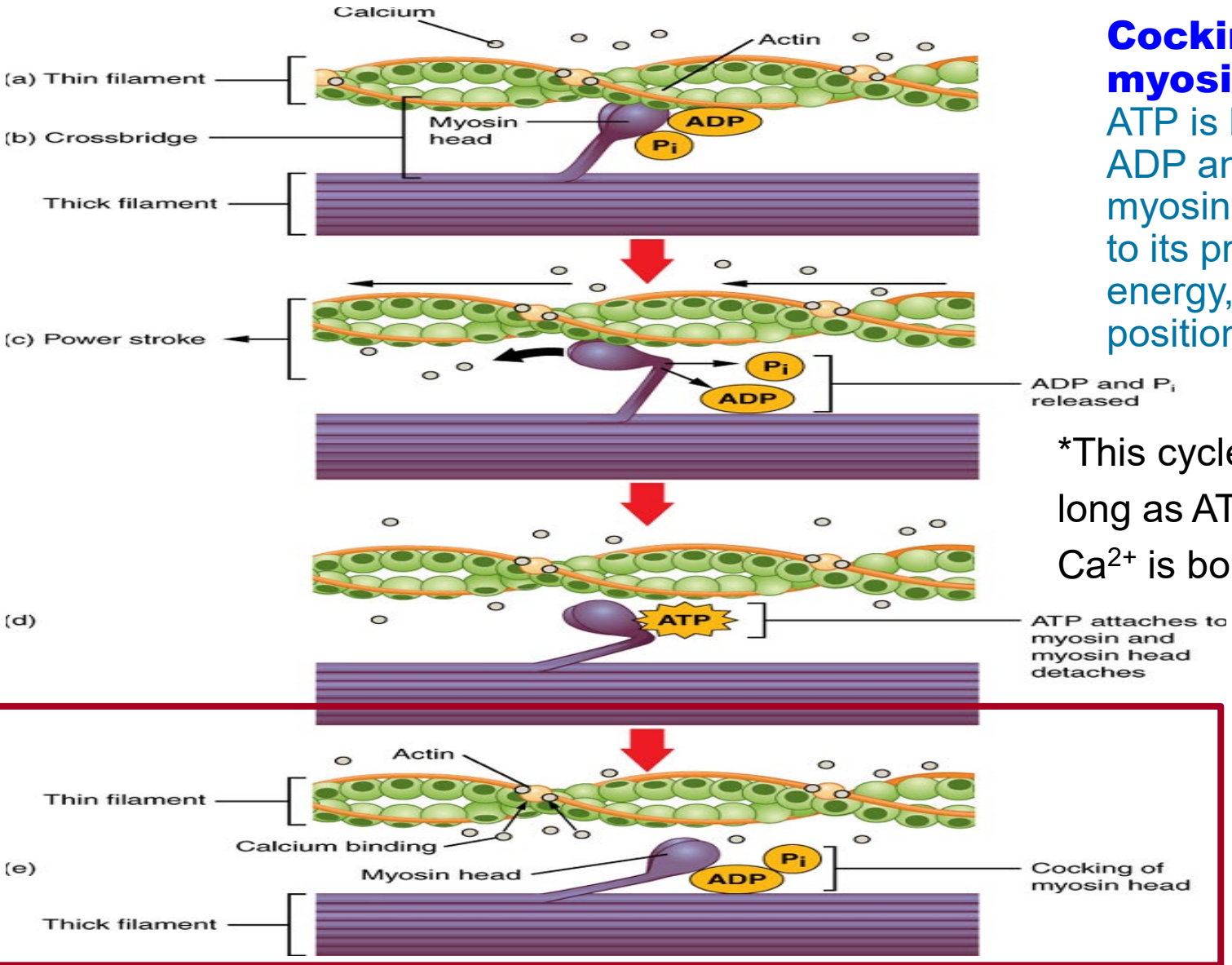
The power (working) stroke. ADP and P_i are released and the myosin head pivots and bends, changing to its bent low-energy state. As a result it pulls the actin filament toward the M line.

Step 3. Cross-bridge detachment



Cross bridge detachment. After ATP attaches to myosin, the link between myosin and actin weakens, and the myosin head detaches (the cross bridge "breaks").

Step 4. Myosin activation



Cocking of the myosin head. As ATP is hydrolyzed to ADP and P_i , the myosin head returns to its prestroke high-energy, or "cocked," position.*

*This cycle will continue as long as ATP is available and Ca^{2+} is bound to troponin.

Physiology of muscle contraction

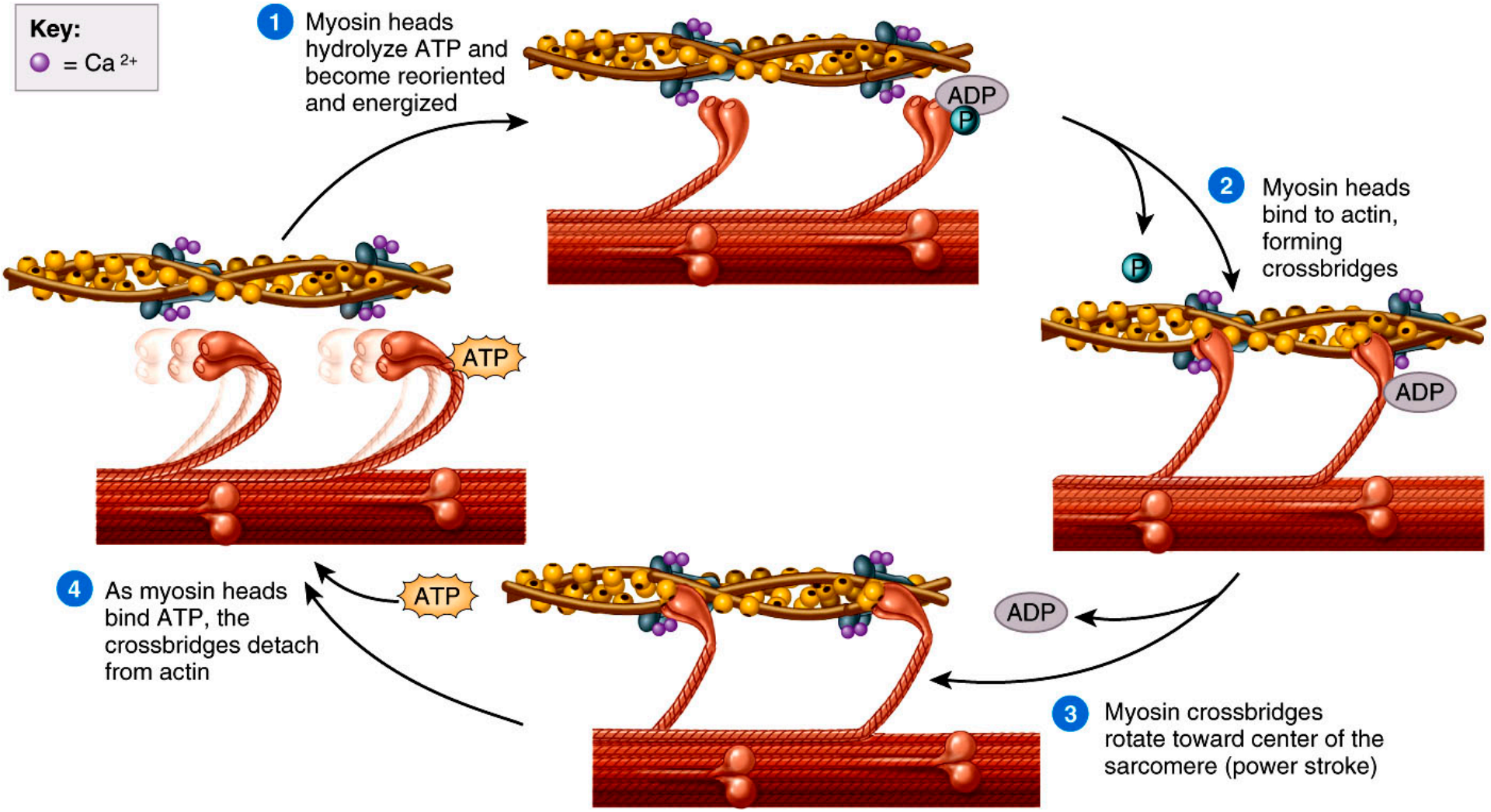


Figure 10.07 Tortora - PAP 12/e

Muscle contraction

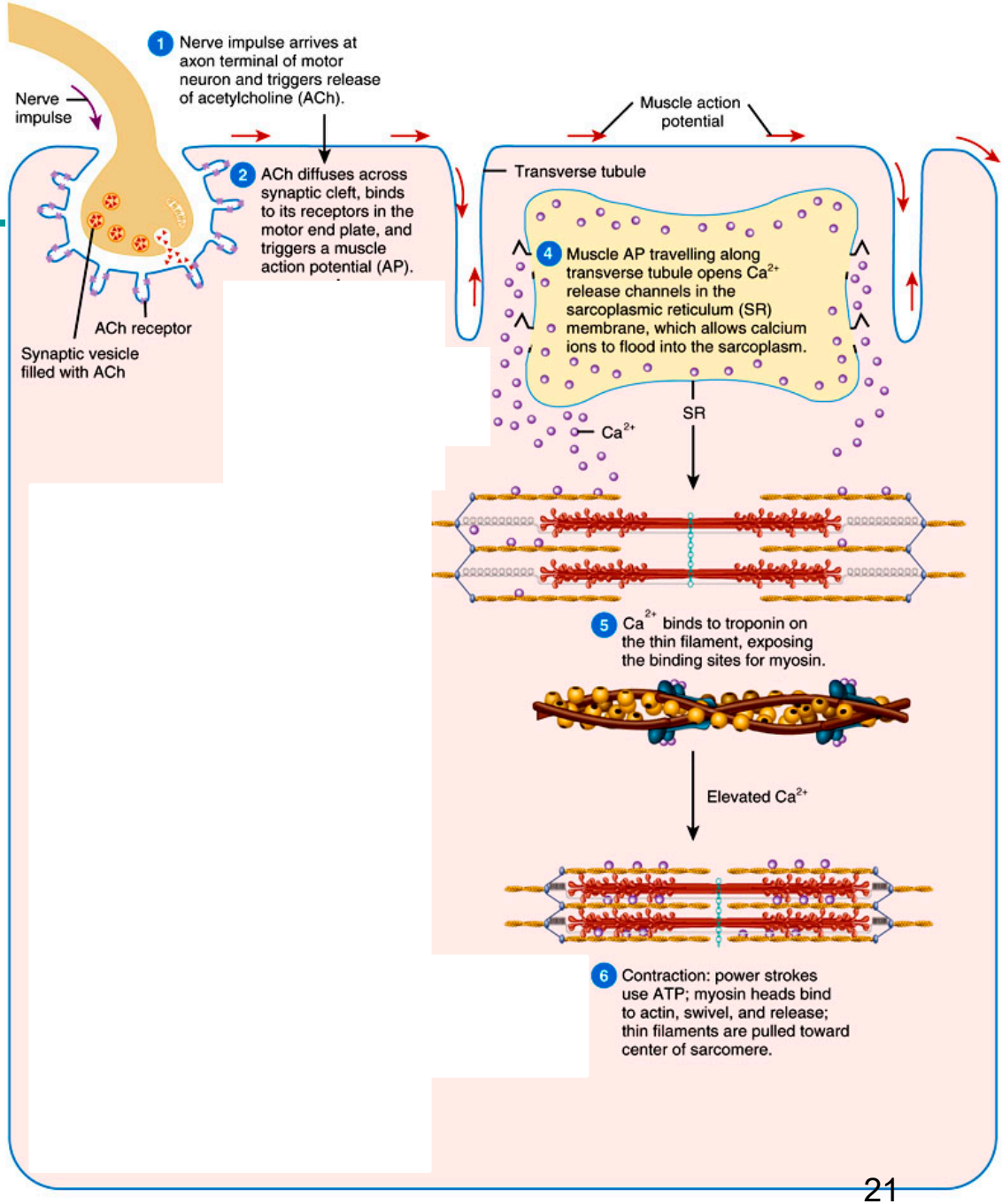
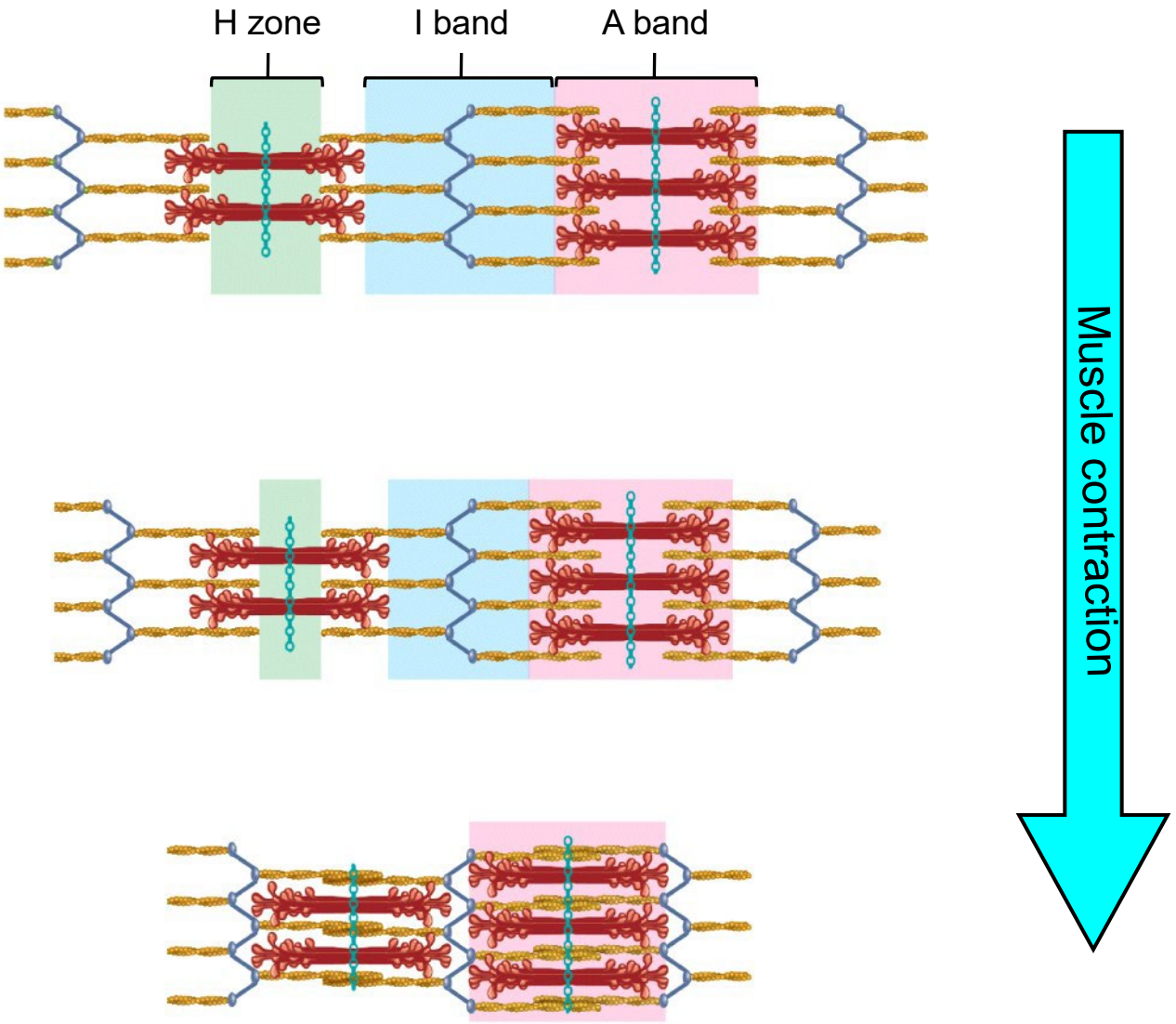


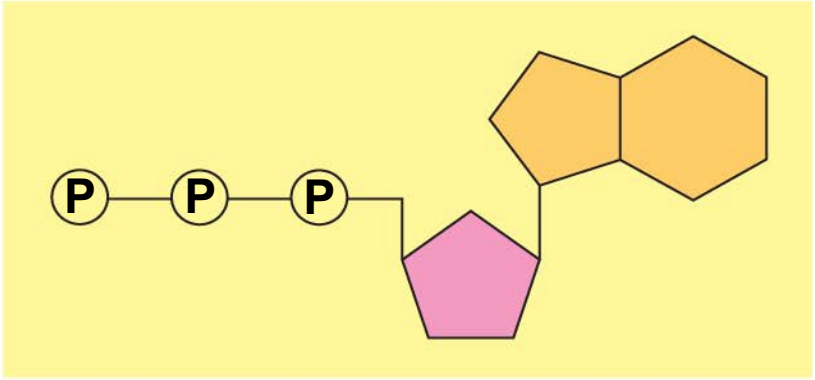
Figure 10.11 Tortora - PAP 12/e

Shortening of muscle fiber



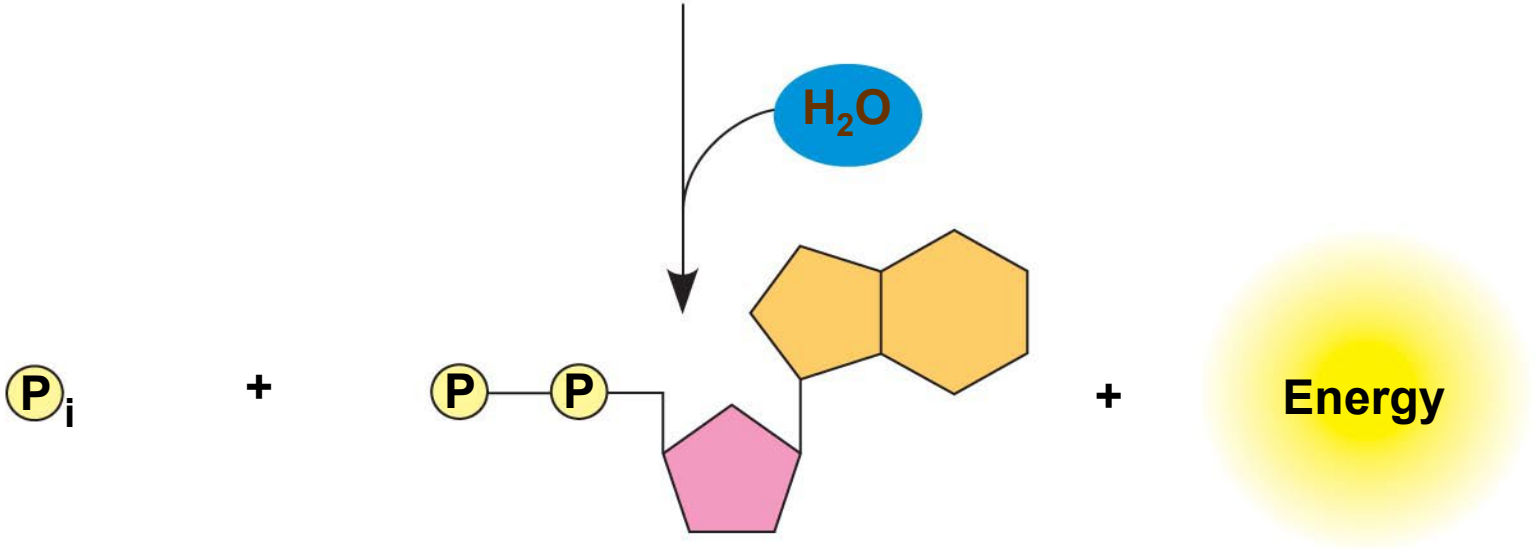
Sources of ATP for muscle contraction

ATP in the muscle itself



Adenosine triphosphate (ATP)

There is only enough ATP in a muscle for about 5 seconds of muscle activity

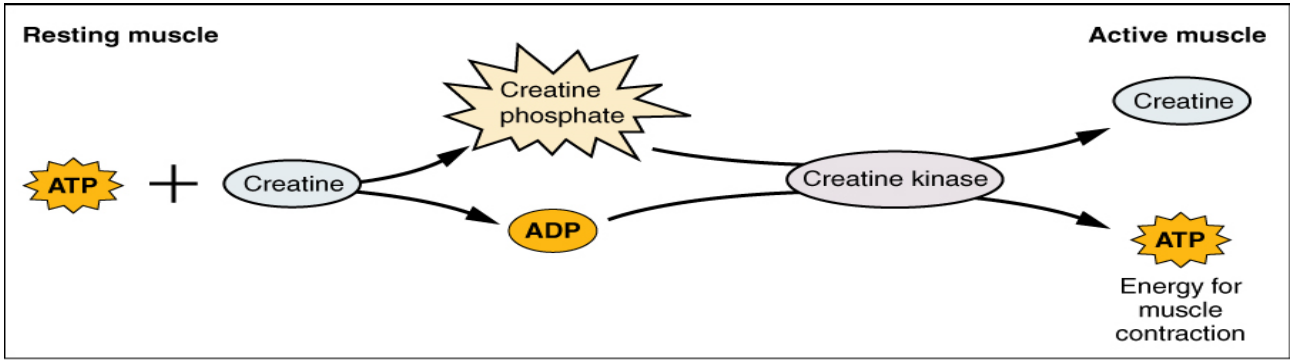


Inorganic phosphate **Adenosine diphosphate (ADP)**

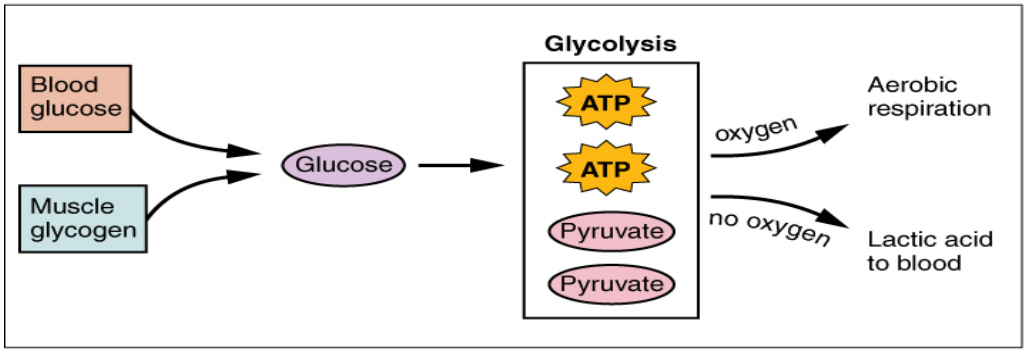
Sources of ATP for muscle contraction

1. creatine phosphate

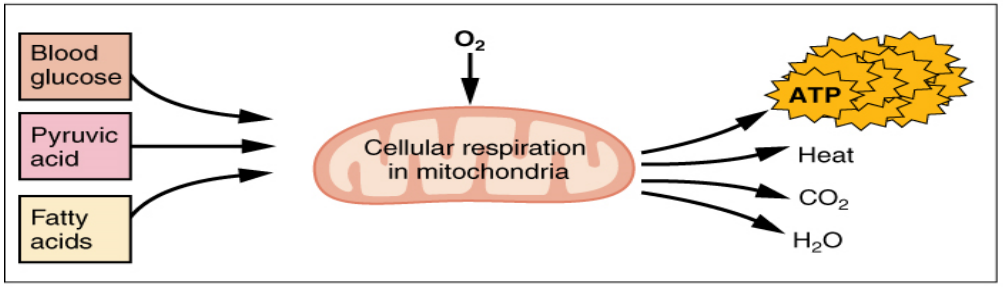
Figure 7



(a)



(b)

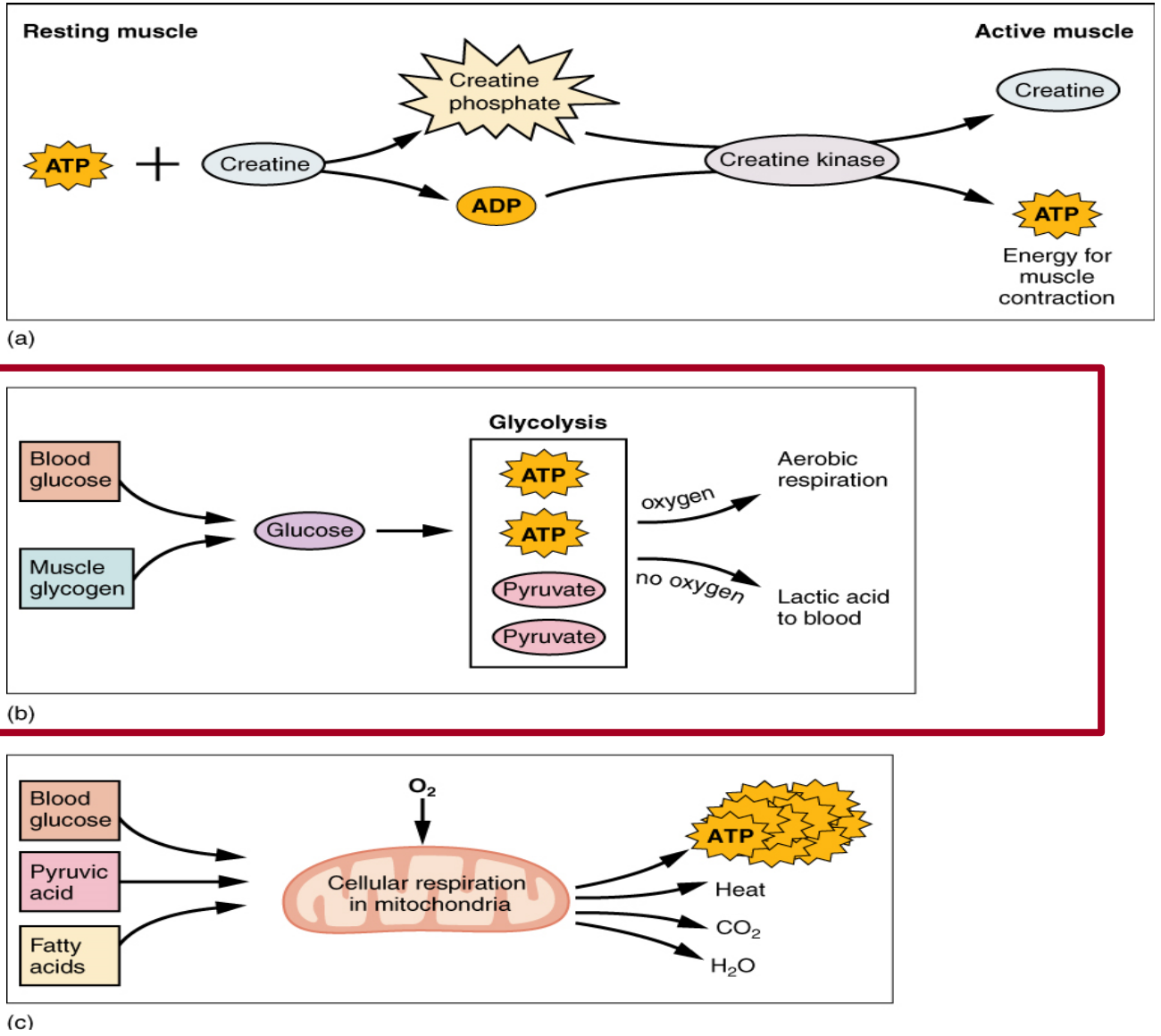


(c)

Sources of ATP for muscle contraction

2. anaerobic cellular respiration

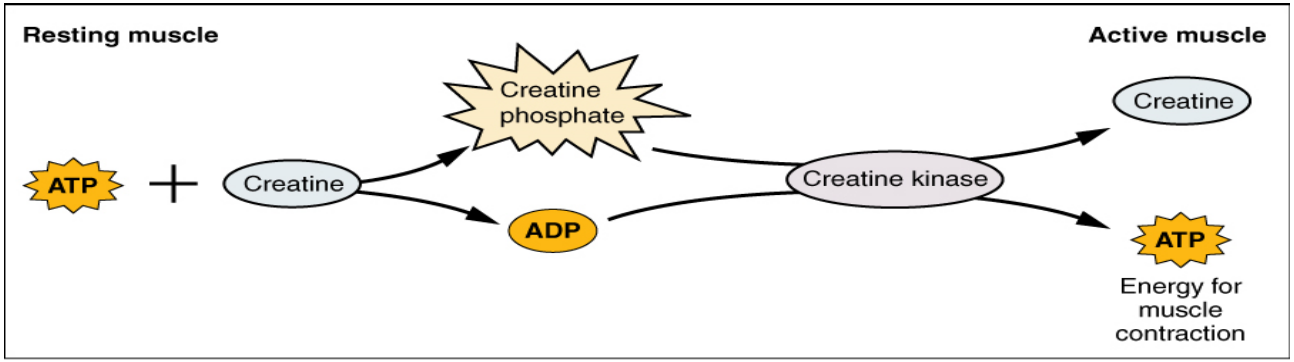
Figure 7



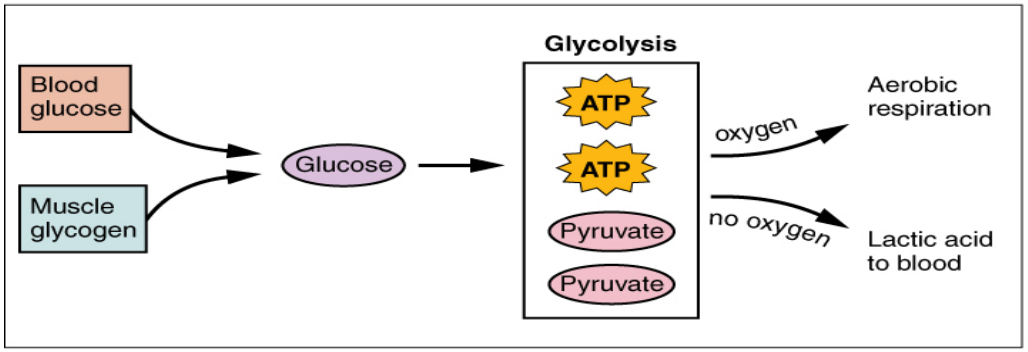
Sources of ATP for muscle contraction

3. aerobic cellular respiration

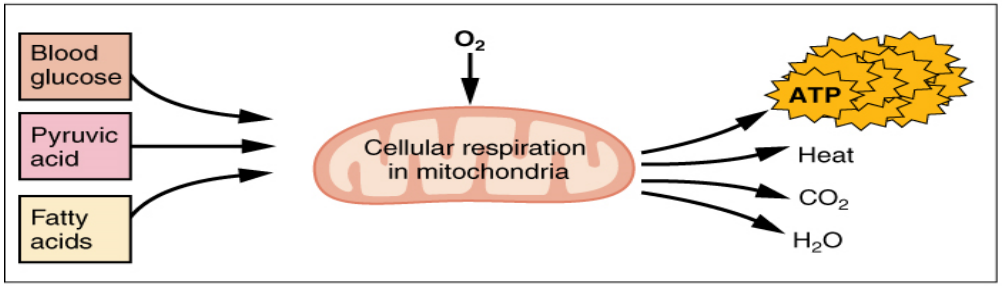
Figure 7



(a)



(b)



(c)

Oxygen required for aerobic cellular respiration from the blood and from an oxygen binding protein called myoglobin.

Myoglobin is only found in muscle cells.

Muscle relaxation

Key Events in Relaxation

I. Breakdown of acetylcholine by acetylcholinesterase

II. Pumping of calcium to the sarcoplasmic reticulum

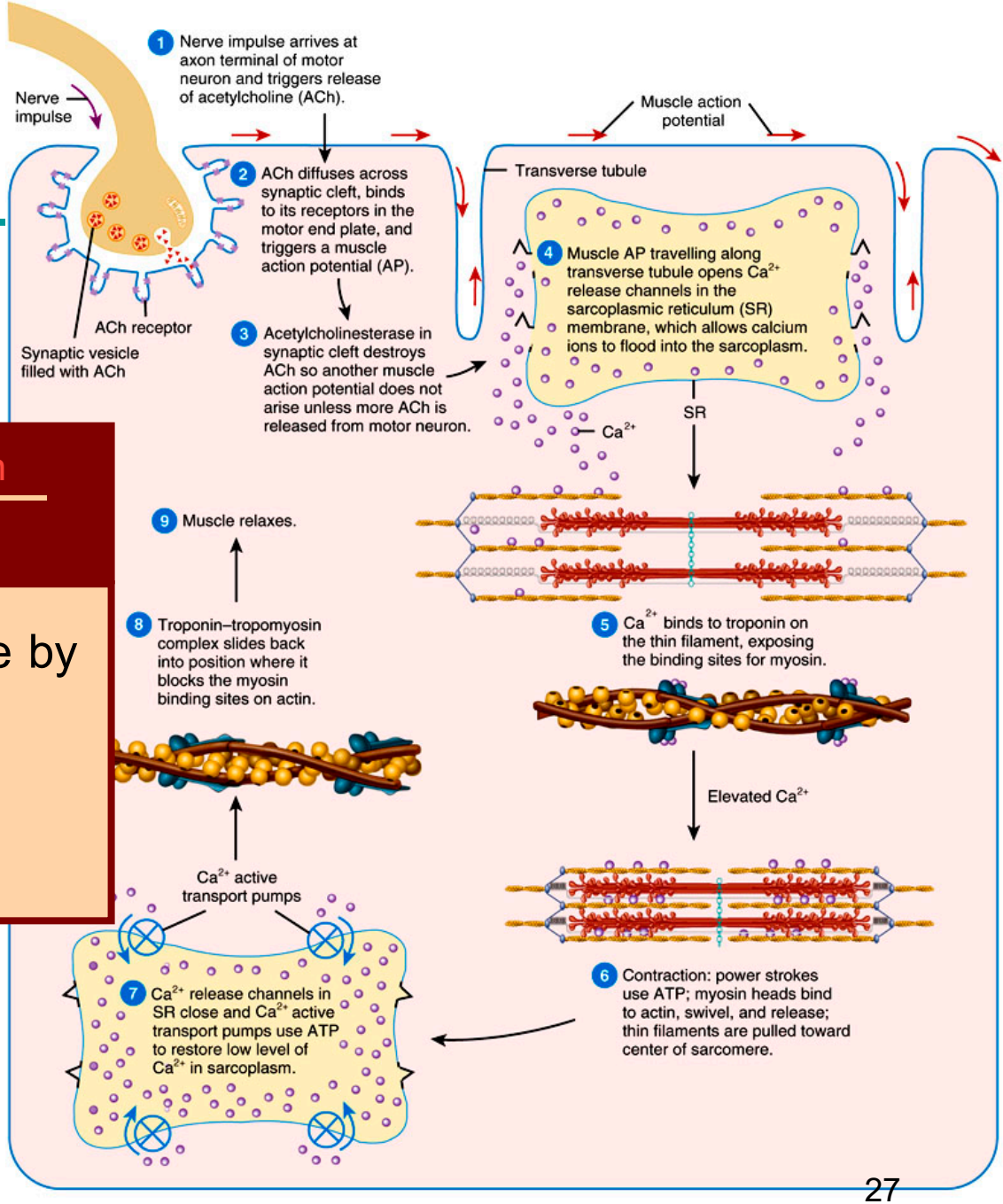


Figure 10.11 Tortora - PAP 12/e

Muscle relaxation

Major events

-Muscle action potential stops

Breakdown of acetylcholine by acetylcholinesterase

- Drop in concentration of Ca^{2+} in sarcoplasm

On membrane of sarcoplasmic reticulum: Ca^{2+} channels close & Ca^{2+} pumps actively reclaim Ca^{2+} from sarcoplasm

-Troponin-tropomyosin complex assumes original shape

- Tropomyosin covers myosin-binding sites on actin

Muscle tone

Term	Description
Muscle tone	- Sustained partial contraction of muscle, even at rest - Keeps muscle firm - Examples: Maintain posture, keep head up, maintain constant pressure within digestive tract
Paralysis	- Loss or impairment of motor functions - Possible causes: Lesion of neuron(s) or muscle(s) due to trauma, stroke or other conditions

Special conditions of the muscles

Muscular atrophy	**Muscular hypertrophy**	**Muscular dystrophy**
- Decrease in size of muscle cells & tissue - Wasting away of muscle tissue - Possible causes: Diseases, poor health, muscle disuse	- Increase in size of muscle tissue - Due to enlargement of cells, not cell division	- Group of inherited diseases - Progressive degeneration of skeletal muscle fibers - Often due to mutations - Leads to muscle atrophy - Examples: Duchenne muscular dystrophy, Becker's muscular dystrophy

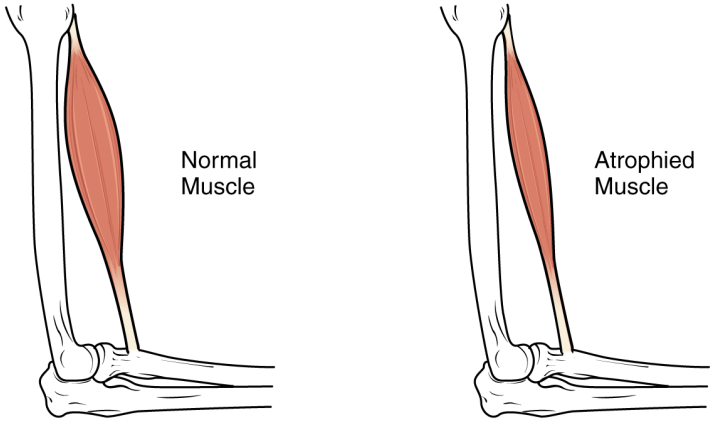


Figure 8

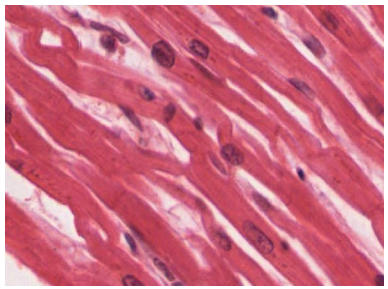
Skeletal muscle physiology

Objectives

1. Describe the anatomy of a neuromuscular junction.
2. Describe the process of muscle contraction
3. Describe the physiology of muscle relaxation.
4. Describe the concept of muscle tone as it pertains to skeletal muscles.
5. Define the following terms: paralysis, muscular dystrophy, muscular atrophy, muscular hypertrophy.

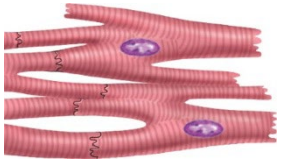
Movement

MOVEMENT ENVOLVES ***MUSCLE***



THERE ARE 3 TYPES OF MUSCLE:

CARDIAC

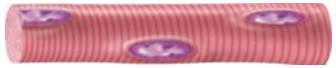


INVOLUNTARY
HEART

SMOOTH

INVOLUNTARY
INTESTINES
BLOOD VESSELS
BLADDER
EYE (inside the eye)
UTERUS etc.

SKELETAL



VOLUNTARY
MUSCLES ATTACHED TO BONES

*IT IS THE **SKELETAL MUSCLES,** TOGETHER WITH THE **BONES & JOINTS,** THAT ACCOMPLISHES **MOVEMENT***

Cardiac muscle physiology

Objectives

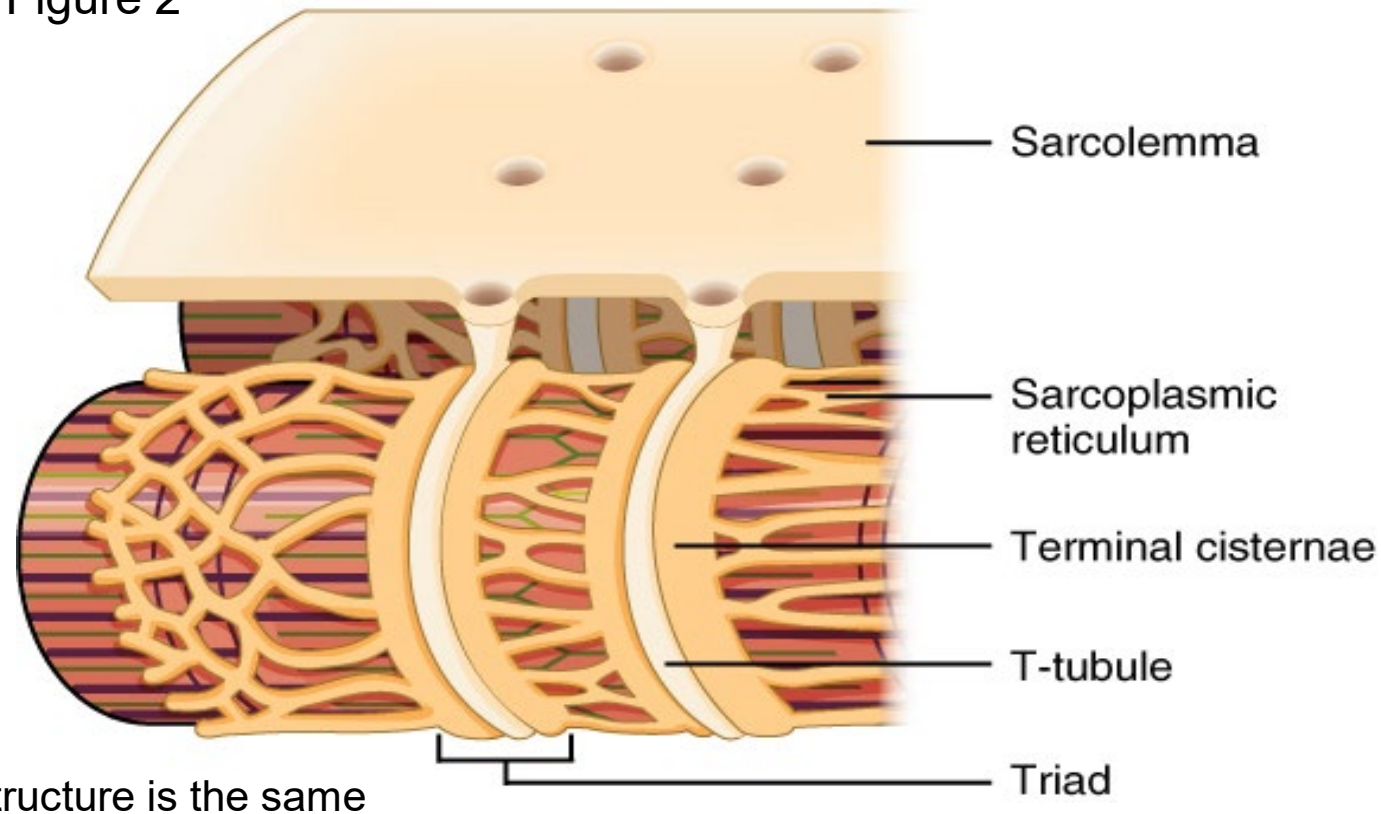
6. Describe the microscopic anatomy of cardiac muscle cells.

7. Describe the mechanism of contraction in cardiac muscle. Describe in detail how a cardiac muscle contracts by describing the events that occur within the cardiac muscle starting from the depolarization of the plasma membrane of a cardiac muscle cell and ending with cross-bridge formation..

8. Describe the functional significance of self-excitatory cardiac muscle cells.

Cardiac muscle structure

Figure 2



The basic structure is the same as skeletal muscle and the mechanism of contraction is the same as described for skeletal muscle

BUT THERE ARE SOME IMPORTANT DIFFERENCES

Cardiac muscle structure

Unique cardiac muscle structure

- Cardiac muscles have to contract synchronously (virtually simultaneously) to ensure normal heart function so if it cell contracts, it stimulates surrounding cells to contract
- To ensure simultaneous contractions
  1. Cardiac muscles cells are branched
  2. Branches connect to surrounding cells
- Cardiac cells are not connected to bone, but pull against one another during contraction
- Cells are connected to ensure that the impulse for contraction gets to the adjoining cells
- The connections are strong enough so cells don't pull apart during contraction

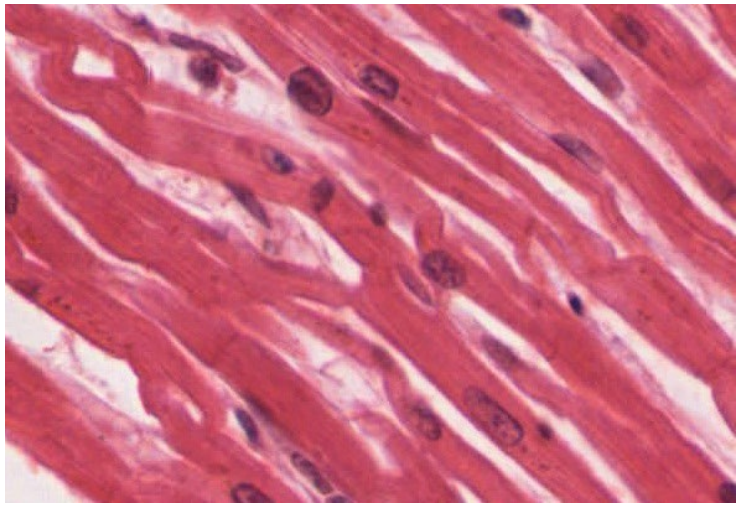


Figure 9

Connections between cardiac muscle cells

1. Gap junctions

- Channels formed by proteins in the membranes of adjoining cells that allow for ions, and impulses to pass directly from one cell to the next uninterrupted
- Fast transfer ensures the heart contracts synchronously

CHANNELS (GAPS) FORMED BY SPECIFIC INTEGRAL TRANS MEMBRANE PROTEINS CALLED CONNEXONS

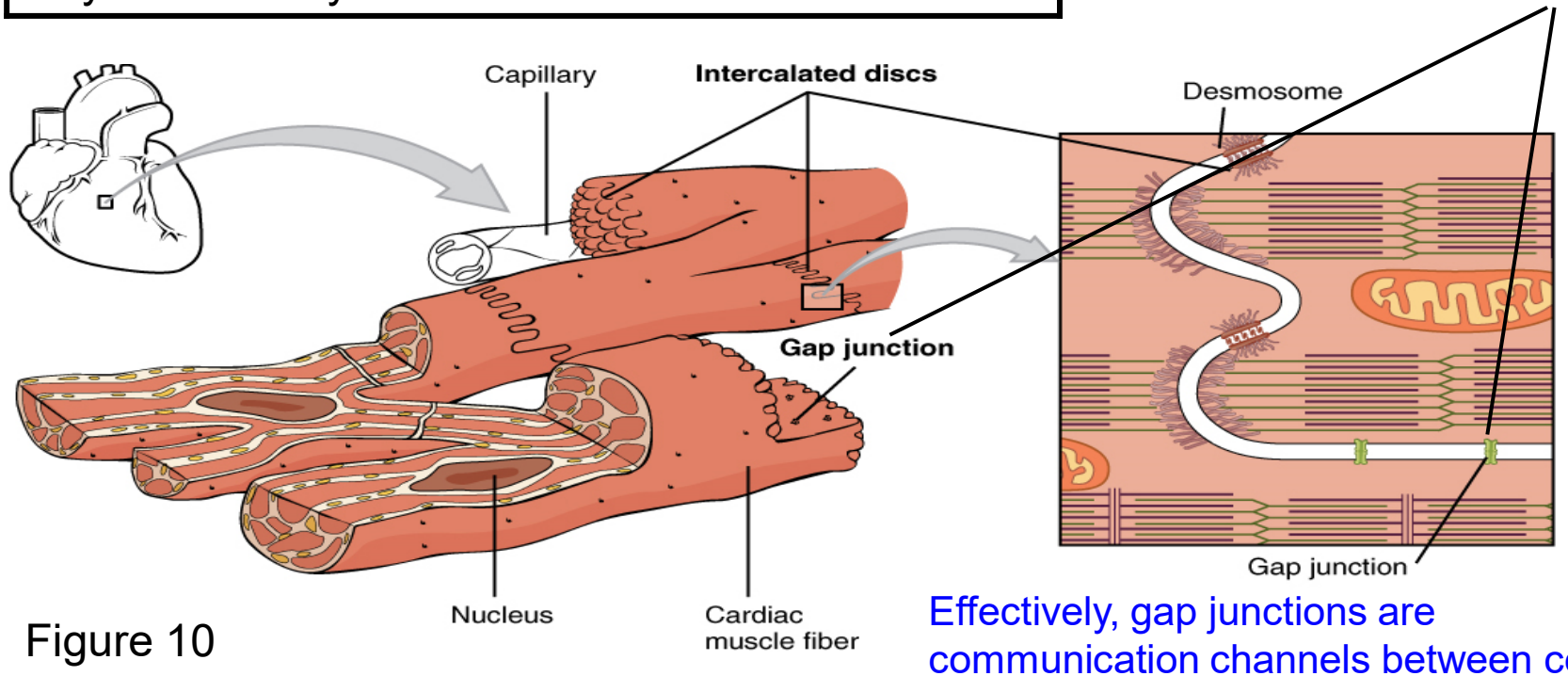


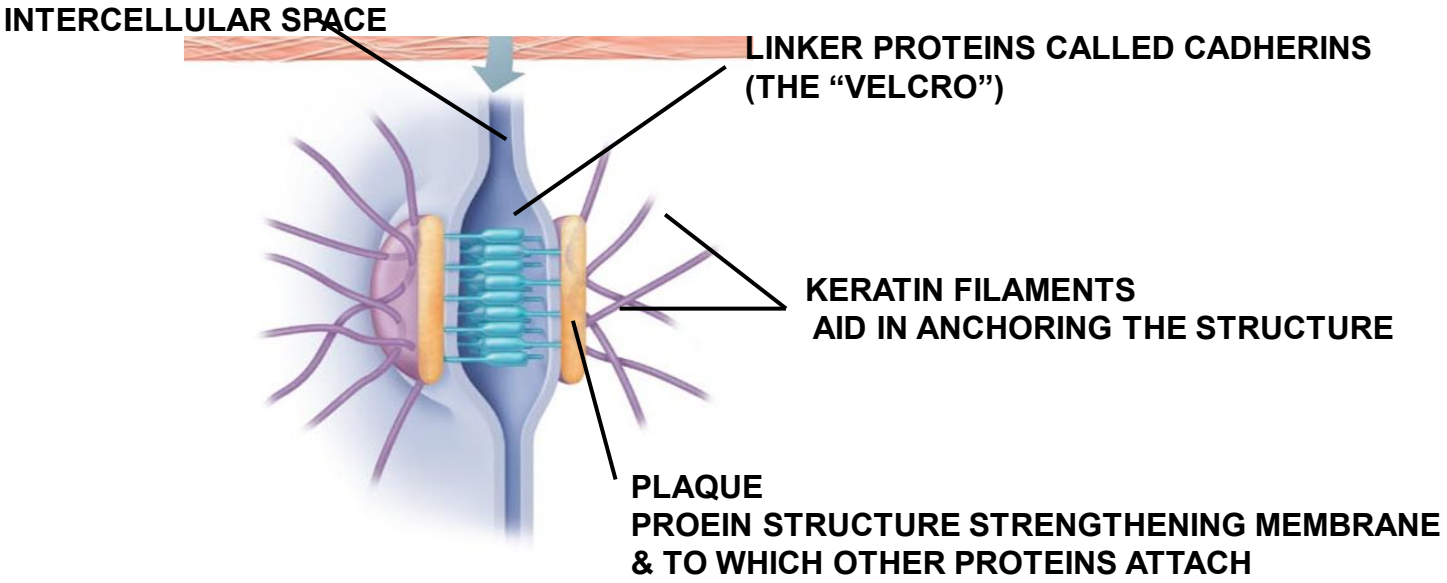
Figure 10

Effectively, gap junctions are communication channels between cells

Connections between cardiac muscle cells

2 Desmosomes

- Strong anchoring junctions between adjacent cells which prevents them from separating
- They are “Velcro spots” spanning the cell membrane that connect cells together



Intercalated discs

- Gap junctions and desmosomes are found at the ends of cardiac muscle branches
- These junctions, together with a folding of the cell membranes form a structure called an intercalated disc

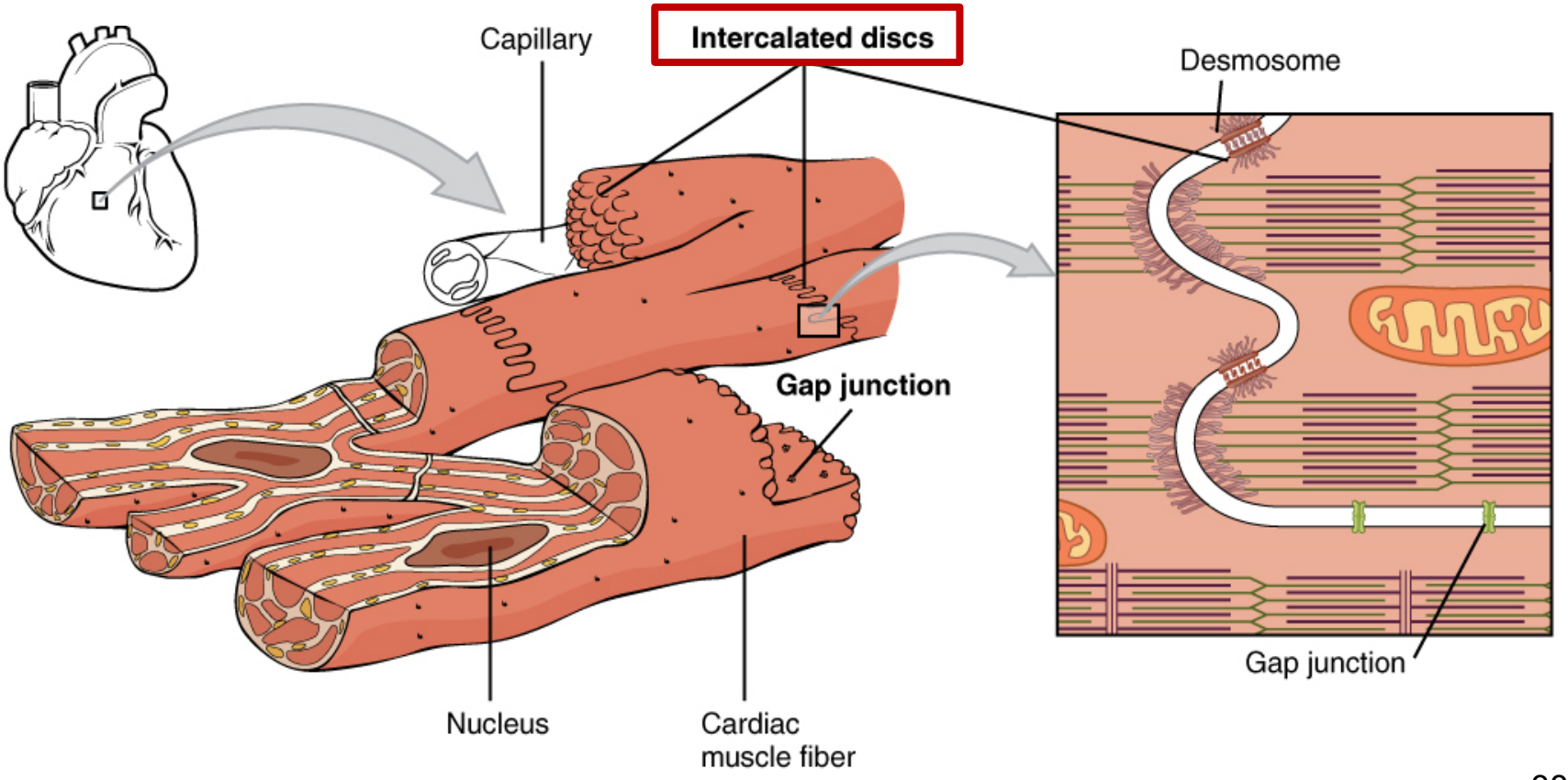
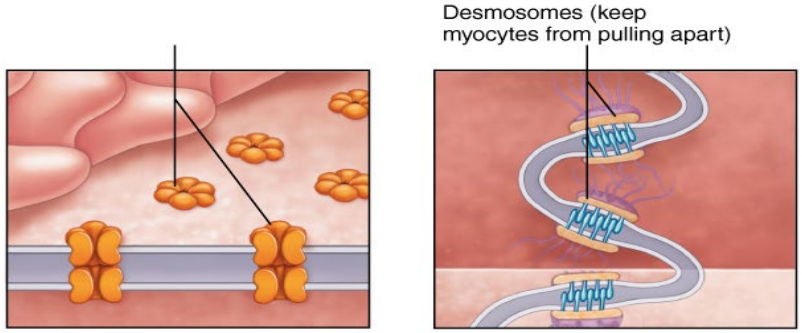
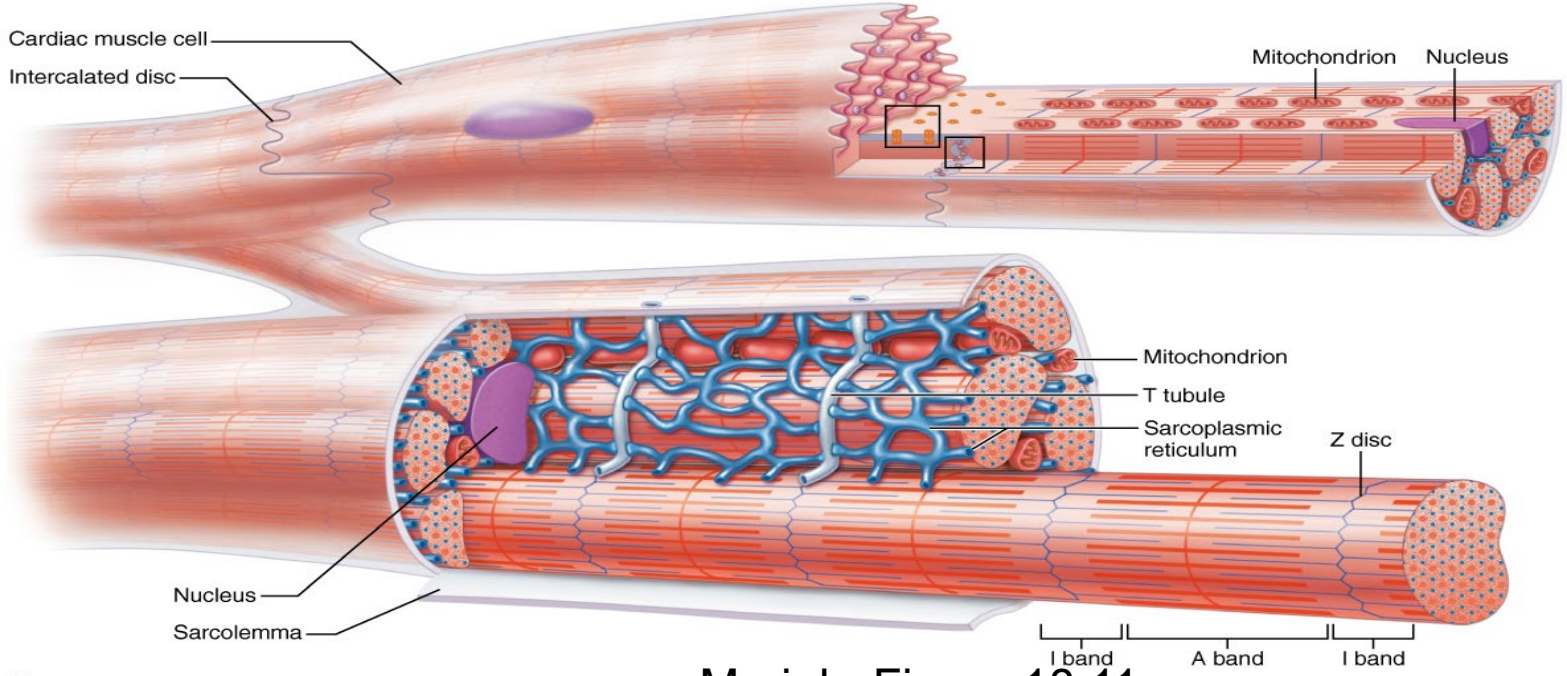


Figure 10

Cardiac muscle structure

- Sarcomeres with one T tubule next to the sarcoplasmic reticulum
- T tubule and SR alter intracellular calcium concentrations





Marieb, Figure 18.11

Cardiac contraction

Cardiac muscle contractions

- Similar to skeletal muscle contractions BUT
- Depolarization causes special calcium channels on plasma membrane to open and allow extracellular calcium to enter the sarcoplasm
- This calcium accounts for some of the calcium required for muscle contraction (some from the SR)
- Calcium binds to troponin and initiates the cross bridge formation and contraction via the sliding filament model
- Energy is provided by aerobic respiration

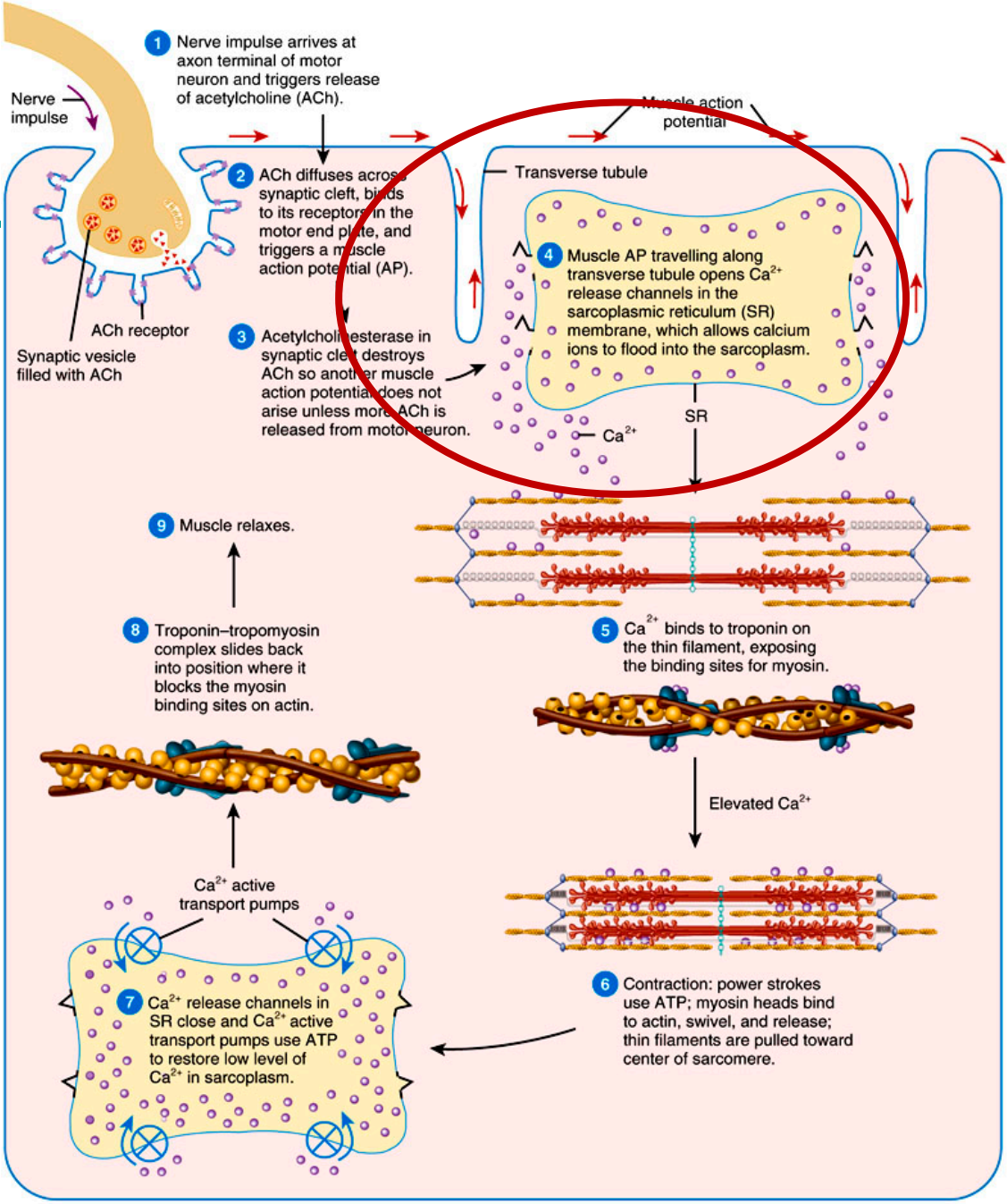
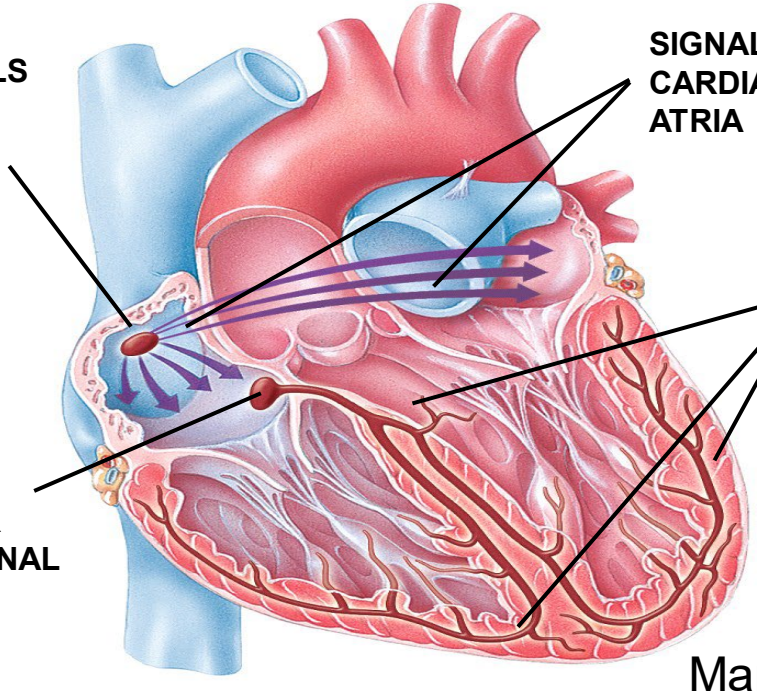


Figure 10.11 Tortora - PAP 12/e

Cardiac muscle are self excitable

- Some cardiac muscle cells are self-excitatory and can produce spontaneous depolarization that spreads quickly through gap junctions
- This ensures that the whole heart contracts at one time (called a heart beat)
- The pacemaker (sino atrial node) is one structure that helps regulate heart beat by producing regular depolarizations

PACE MAKER
SENDS OUT REGULAR SIGNALS CAUSING DEPOLARIZATION



SIGNALS SPREAD THROUGH CARDIAC MUSCLE OF BOTH ATRIA

SERIES OF NERVE FIBRES
AID IN DELIVERING SIGNAL TO CARDIAC MUSCLE OF BOTH VENTRICLES

ATRIO VENTRICULAR NODE
STIMULATED BY PACE MAKER DELAYS AND TRANSFERS SIGNAL TO VENTRICLE MUSCLE

Marieb, Figure 18.13

Cardiac muscle physiology

Objectives

6. Describe the microscopic anatomy of cardiac muscle cells.

7. Describe the mechanism of contraction in cardiac muscle. Describe in detail how a cardiac muscle contracts by describing the events that occur within the cardiac muscle starting from the depolarization of the plasma membrane of a cardiac muscle cell and ending with cross-bridge formation..

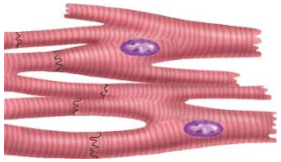
8. Describe the functional significance of self-excitatory cardiac muscle cells.

Movement

MOVEMENT ENVOLVES ***MUSCLE***

THERE ARE 3 TYPES OF MUSCLE:

CARDIAC

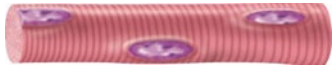


INVOLUNTARY
HEART

SMOOTH

INVOLUNTARY
INTESTINES
BLOOD VESSELS
BLADDER
EYE (inside the eye)
UTERUS etc.

SKELETAL



VOLUNTARY
MUSCLES ATTACHED TO BONES

*IT IS THE **SKELETAL MUSCLES**, TOGETHER WITH THE **BONES & JOINTS**, THAT ACCOMPLISHES **MOVEMENT***

Smooth muscle physiology

Objectives

9. Describe the microscopic anatomy of a smooth muscle.

10. Outline the mechanism of contraction and relaxation in smooth muscle.

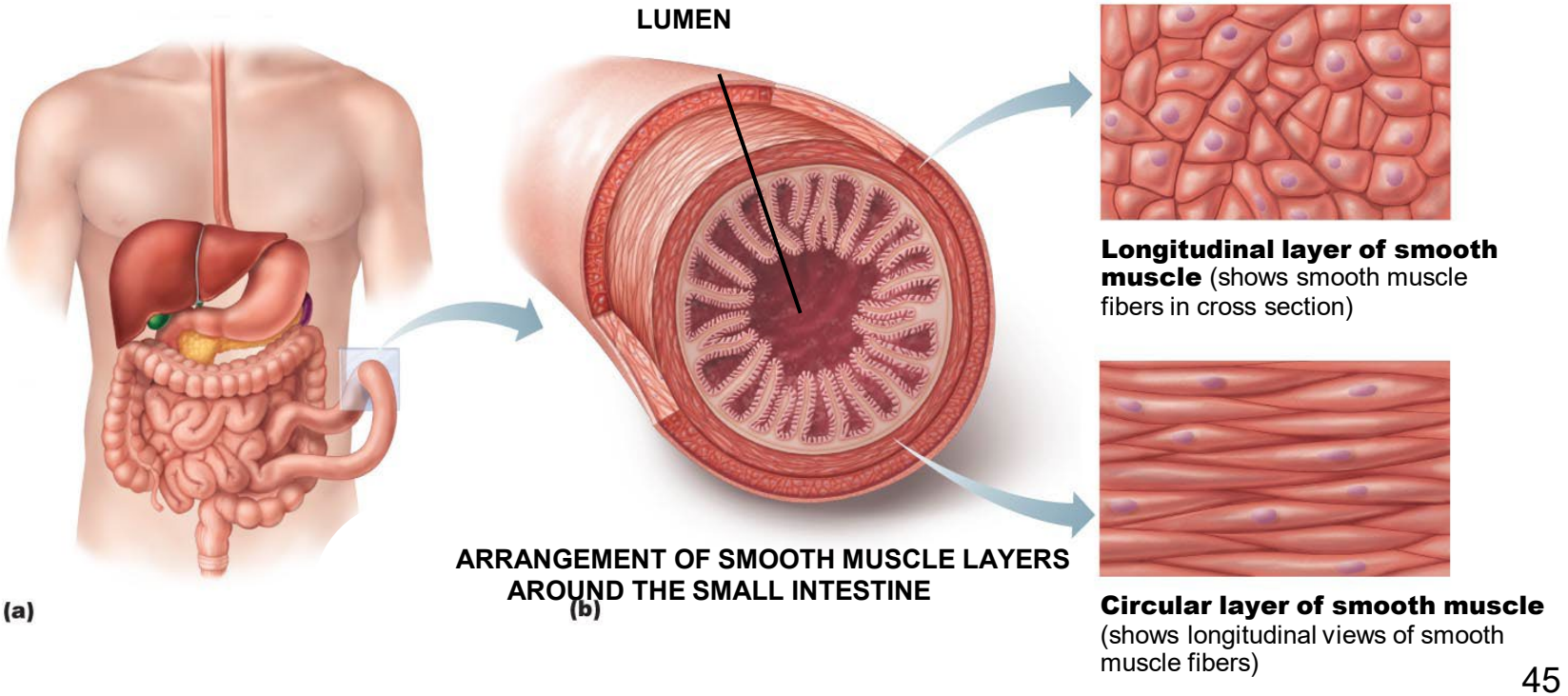
11. Describe the neural, hormonal and chemical factors that regulate contraction of smooth muscle.

12. Define the process and anatomical basis of peristalsis.

Smooth muscle tissue

Tissue Structure

- Organized into sheets forming layers of muscles
- Two sheets in most cases, oriented at different angles
- Found in walls of hallow organs (intestines, blood vessels, etc.)

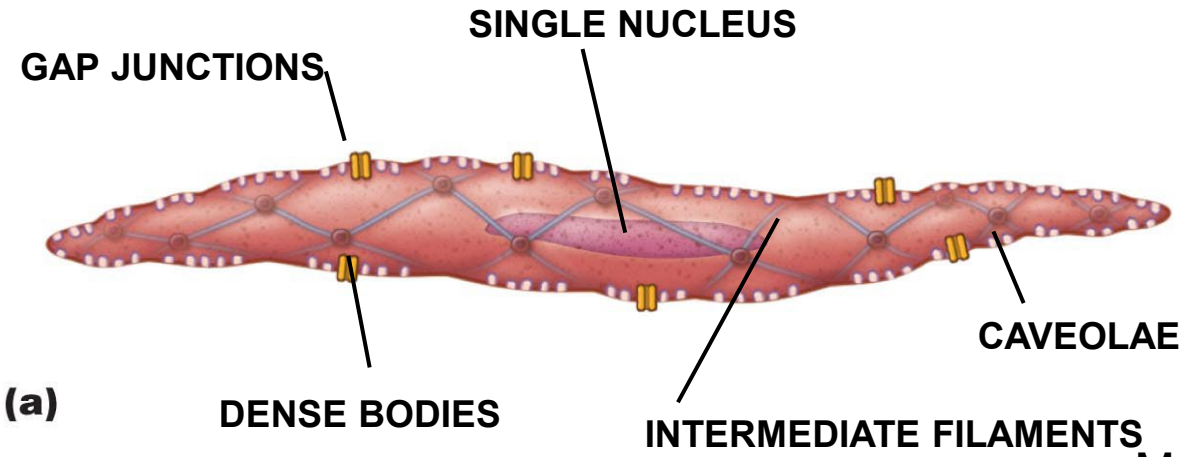


Marieb, Figure 9.22

Smooth muscle cell structure

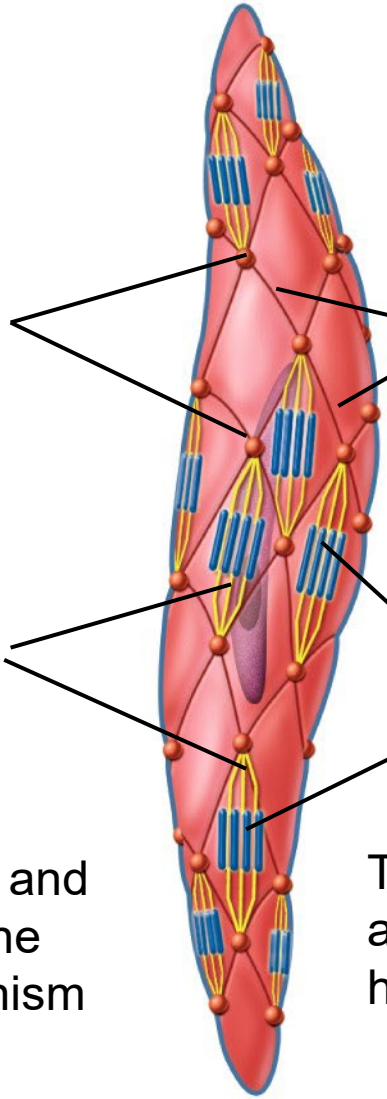
Cell structure

- Not striated and Actin and Myosin are not arranged as sarcomeres
- Single nucleus
- Caveolae = Infoldings of the sarcolemma which contain many calcium channels
- Gap junctions allow for communication between cells
- Myofilments crisscross the cells and corkscrew down the length of the cell
- Intermediate filaments are a lattice-like network of non contractile proteins which are attached to dense bodies
- Dense bodies are in turn attached to sarcolemma and the extracellular connective tissue



Marieb, Figure 9.25

Arrangement of actin and myosin



DENSE BODIES (ACT AS ATTACHMENT POINTS FOR ACTIN)

INTERMEDIATE FILAMENTS

ACTIN (THIN FILAMENT)

MYOSIN (THICK FILAMENT)

Actin & myosin interact and contraction occurs by the sliding filament mechanism

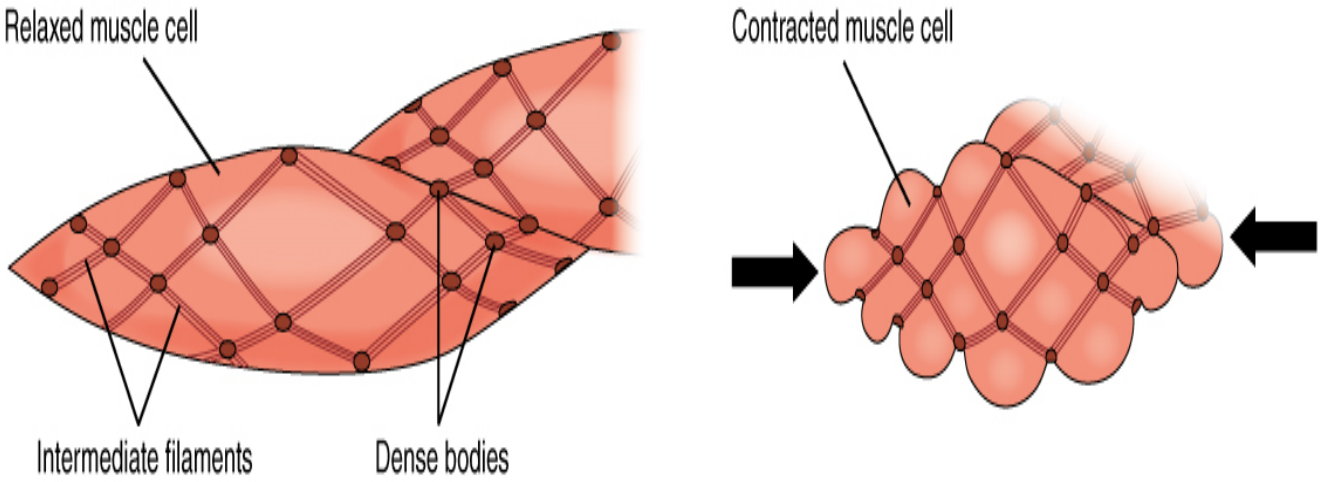
There is no troponin and myosin in smooth muscle contain heads along its entire length.

Smooth muscle contraction

Actin / myosin complex contract by the sliding filament mechanism

Sliding of the actin & myosin pulls on the dense bodies

Figure 12



Contraction

- Contraction pulls dense bodies closer together so shortening the cell as contraction continues, the sarcolemma bulges out between the intermediate filaments (gives it a puffy appearance) and the cell also spiral slightly (due to the arrangement of the intermediate filaments and of the myofilaments)
- All cells contract at the same time due gap junctions and dense bodies
- Energy for contraction comes from aerobic respiration

Smooth muscle mechanisms of contraction

- The autonomic nerves to smooth muscle have numerous bulb-like swellings called varicosites from which the neurotransmitter is released in the *general area* of the smooth muscle.
- Neurotransmitter then diffuses across a wide area and stimulates a number of cells to contract
- This type of neuromuscluar junction are called diffuse junctions

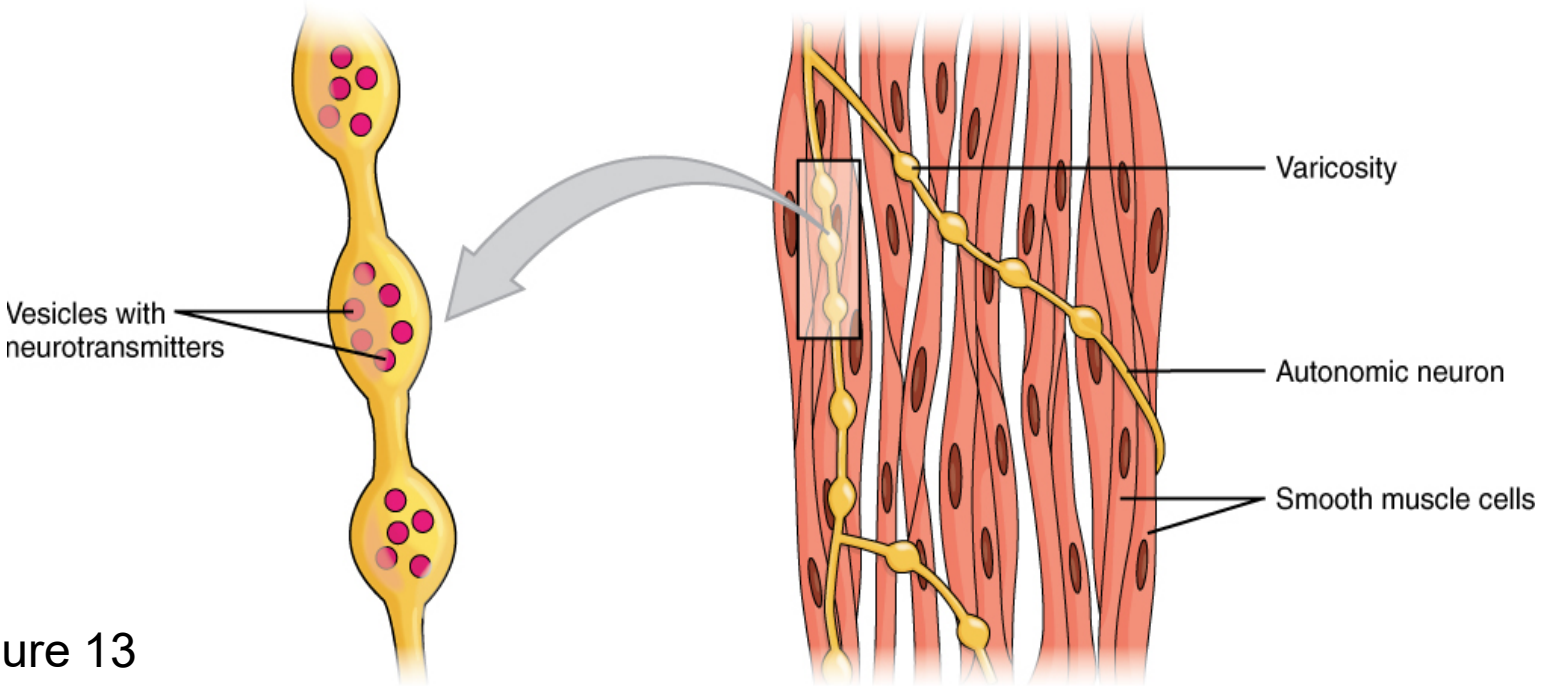


Figure 13

1. Smooth muscle cells do *not have t-tubules* and *very little sarcoplasmic reticulum*

2. Ca^{++} influx occurs via channels in the *caveoli* in the cells membrane. Most of the ca^{++} comes from the ECF some calcium comes from the reduced SR

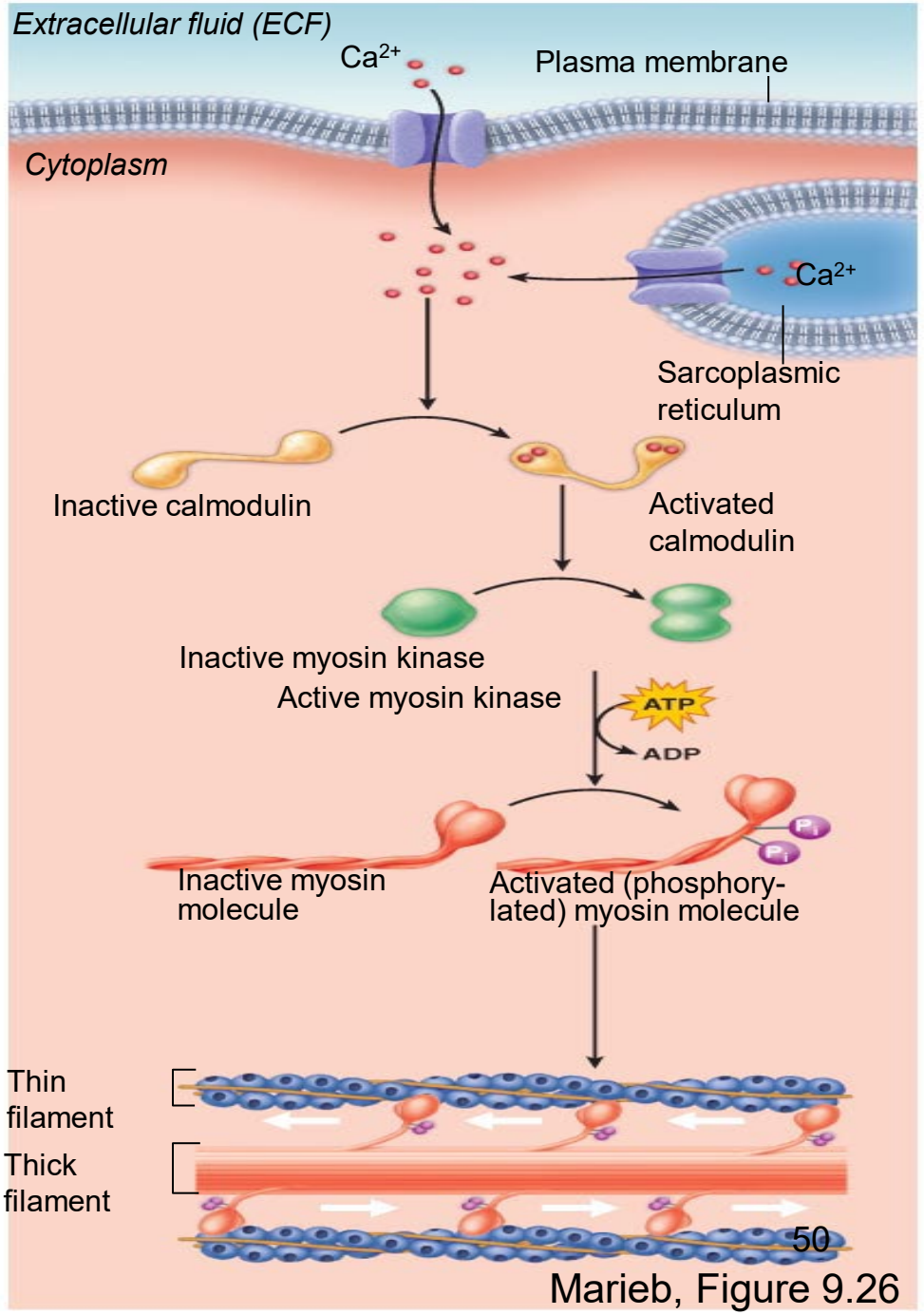
3. There is *no troponin* in the thin filament complex Ca^{++} binds instead to a regulatory protein in the cytoplasm called *calmodulin*

4. Activated cadmodulin in turn activates an enzyme called *myosin kinase.*

5. Activated myosin kinase *phosphorylates the myosin head, so activating it.*

6. Once activated the *myosin head can interact with the actin* and the contraction cycle begins.

As in skeletal & cardiac muscles, contraction is by the *sliding filament mechanism.*

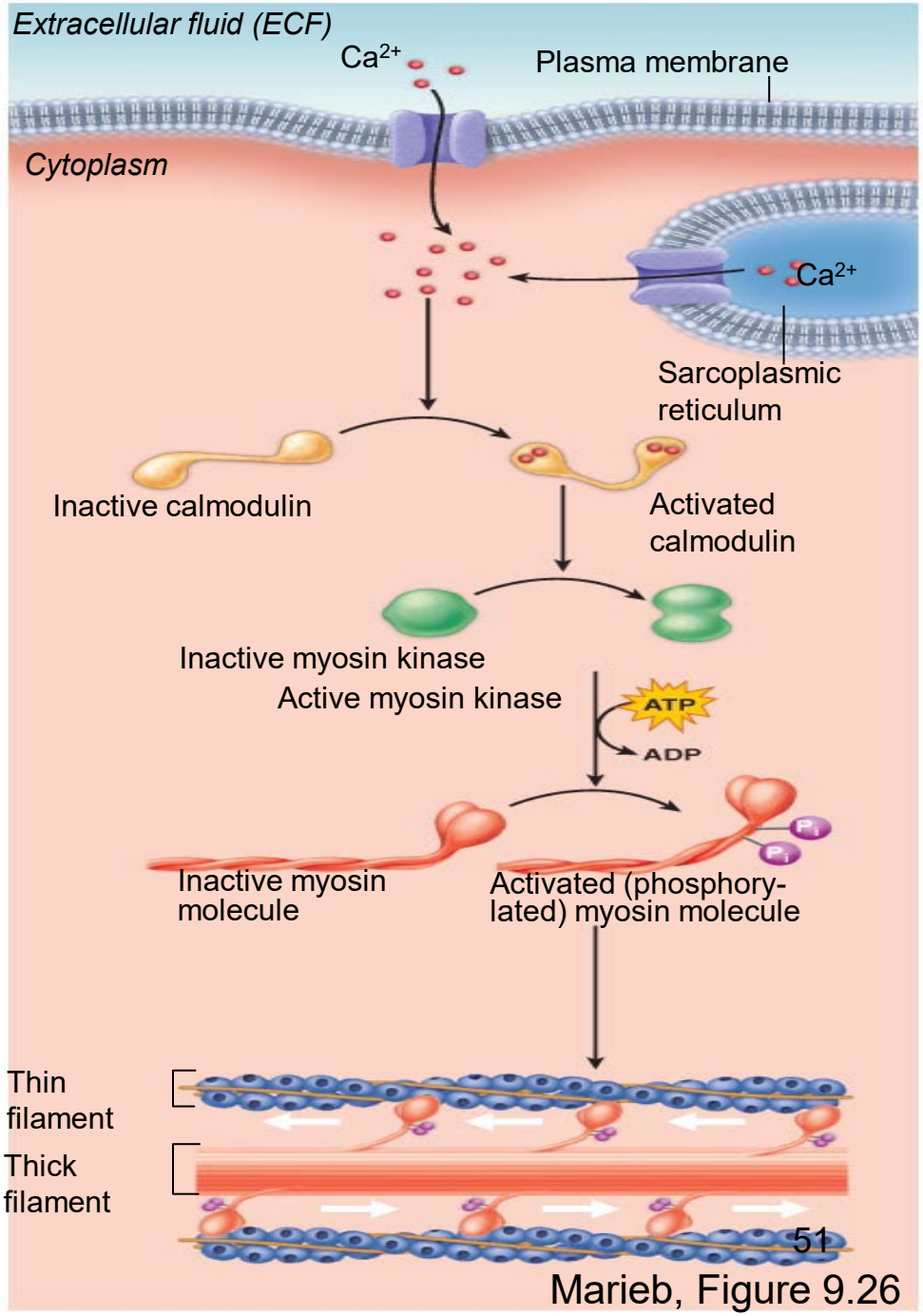


Marieb, Figure 9.26

Smooth muscle relaxation

Involves removal of Ca^{++} from the cytoplasm back into the SR and ECF by active transport via Ca^{++} pumps

Calmodulin is deactivated, dephosphorylation of myosin heads



Marieb, Figure 9.26

Factors that regular contraction in smooth muscles

Neurotransmitters

- From nervous system and generate an action potential
- Examples: Acetycholine, Norepinephrine (causes relaxation of some smooth muscles and contraction of others)

Chemicals

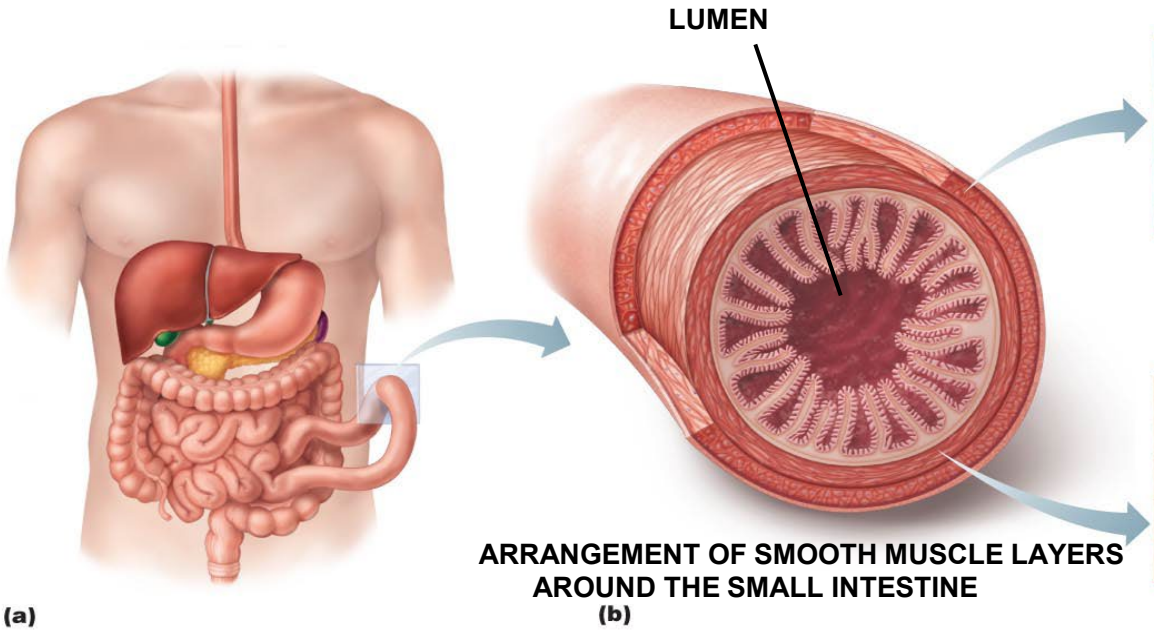
- Chemical can stimulate contractions WITHOUT generating an action potential by cause the movement of calcium into the cells
- Examples: histamine, high levels of CO_2, low pH, low levels of O_2

Hormones

- From endocrine system and can affect the activity of smooth muscles
- Examples: cholecystokinin, gastrin, oxytocin

Peristalsis

- Alternation contraction and relaxation of two or three layers of smooth muscle found surrounding some structures with lumens.
- Layers oriented differently (parallel or wrapped along the lumen)
- Causes mixing and/or unidirectional propulsion of material through the lumen
- Occurs in uterus, bladder, esophagus, stomach and intestines



Marieb, Figure 9.22

Smooth muscle physiology

Objectives

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