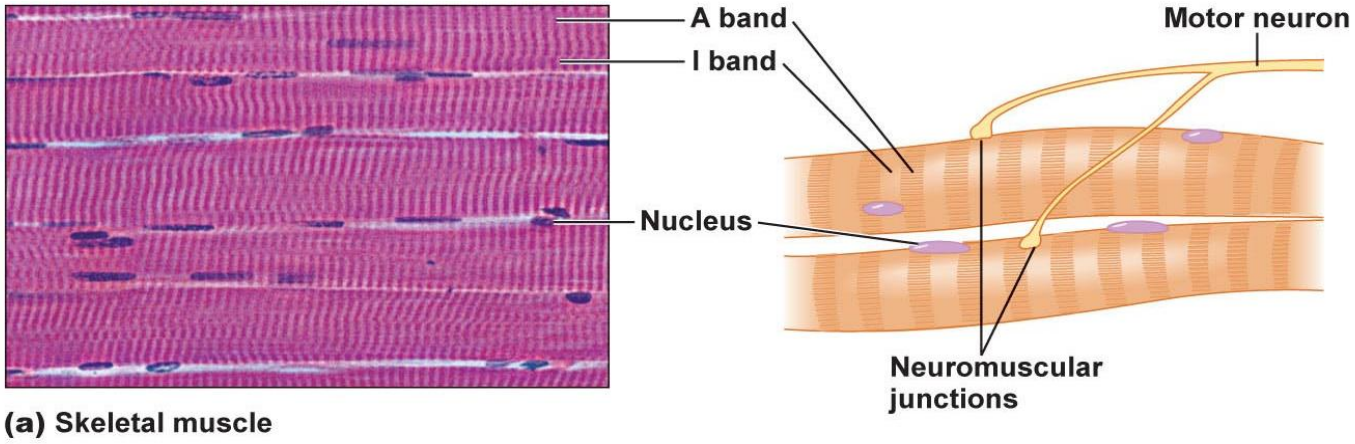
Chapter 9 肌肉

9-1　骨骼肌(p.260-274)

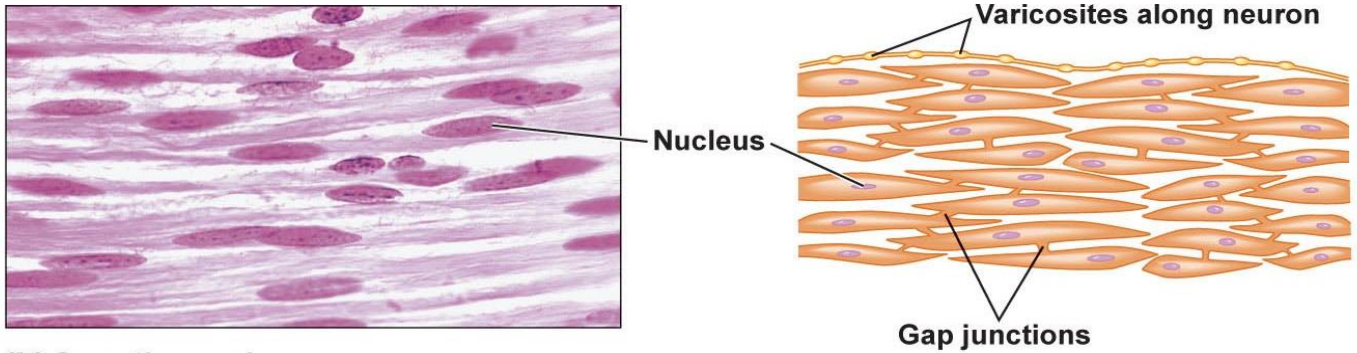
9-2　心　肌(p.278-280)

9-3　平滑肌(p.280-285)

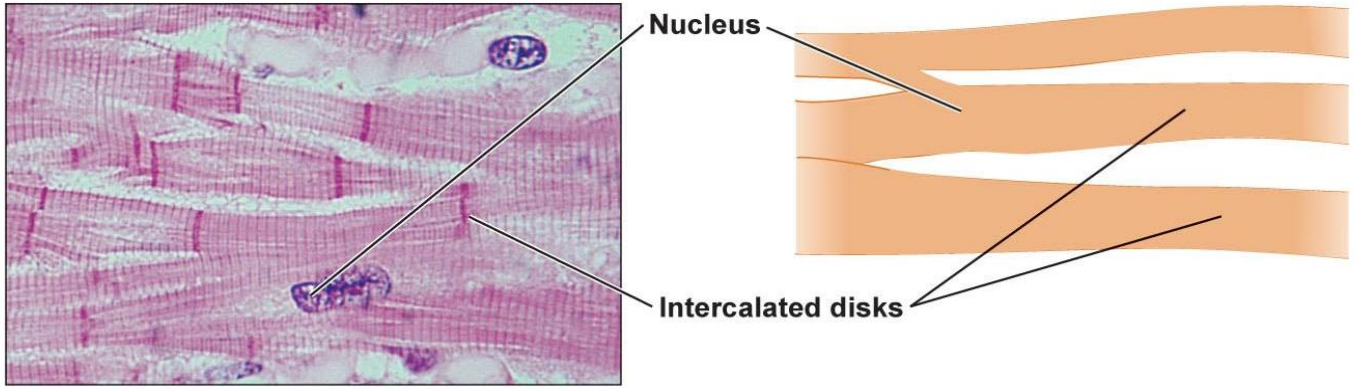
Types of Muscle Tissue



(a) Skeletal muscle



(b) Smooth muscle



(c) Cardiac muscle

Types of Muscle Tissue

- **Skeletal Muscle Tissue**
  - So named because most skeletal muscles move bones
  - Skeletal muscle tissue is striated:
    - Alternating light and dark bands (striations) as seen when examined with a microscope
  - Skeletal muscle tissue works mainly in a voluntary manner (somatic motor sys.)
    - Its activity can be consciously controlled
  - Most skeletal muscles also are controlled subconsciously to some extent
    - Ex: the diaphragm alternately contracts and relaxes without conscious control

Types of Muscle Tissue

- **Cardiac Muscle Tissue**
  - Found only in the walls of the heart
  - Striated like skeletal muscle
  - Action is involuntary (autonomic nervous sys.)
    - Contraction and relaxation of the heart is not consciously controlled
    - Contraction of the heart is initiated by a node of tissue called the "pacemaker"
- **Smooth Muscle Tissue**
  - Located in the walls of hollow internal structures
    - Blood vessels, airways, and many organs
  - Lacks the striations of skeletal and cardiac muscle tissue
  - Usually involuntary (autonomic nervous sys.)

Properties of Muscle Tissue

- **Excitability**
  - Ability to respond to stimuli
- **Conductivity**
  - Ability to propagate electrical signals over membrane
- **Contractility**
  - Ability to shorten and generate force
- **Extensibility**
  - Ability to be stretched without damaging the tissue
- **Elasticity**
  - Ability to return to original shape after being stretched

Functions of Muscle Tissue

- **Producing body movements**
  - Walking and running (600 muscles)
- **Stabilizing body positions**
- **Regulating organ volumes**
- **Movement of substances within the body**
  - Heart muscle pumping blood
  - Moving substances in the digestive tract
- **Producing heat**
  - Contracting muscle produces heat
  - Shivering increases heat production

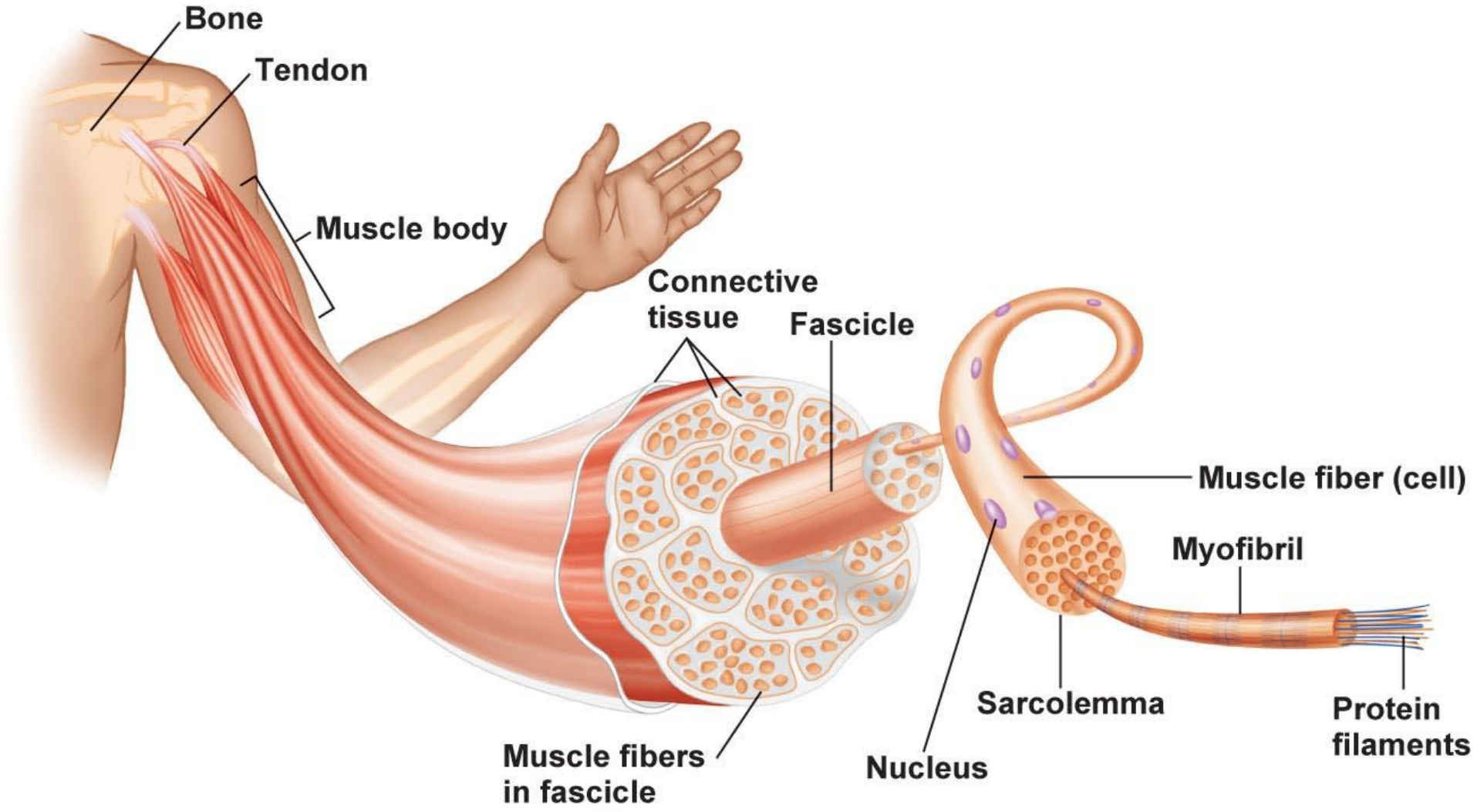
Skeletal Muscle Tissue

- 每塊骨骼肌外覆的結締組織稱為**肌外膜(epimysium)**。
- 肌外膜向內延伸形成**肌束膜(perimysium)**，連同血管和神經的分支，將肌肉分隔為個別的**肌束(fascicle)**。
- 每一個肌束是數千條平行排列而成的肌細胞=**肌纖維(muscle fiber)**所組成，肌纖維之間又以**肌內膜(endomysium)**相隔。
- 肌細胞的寬度大約是10~100 μm，長度依部位而定大約1~40 mm，肌細胞裡有更小的單位叫作—**肌原纖維(myofibril)**，寬度大約是1~2 μm，長度跟肌纖維相近。
- 由顯微鏡所看的排列方式，肌纖維表面的膜叫作**肌漿膜(sarcolemma)**，細胞質就稱為**肌漿(sarcoplasma)**。
- 肌漿內有**肌漿質網(sarcoplasmic reticulum, SR)**，可以儲存大量的**鈣離子**，跟一般細胞的sER相近。

Skeletal Muscle Tissue

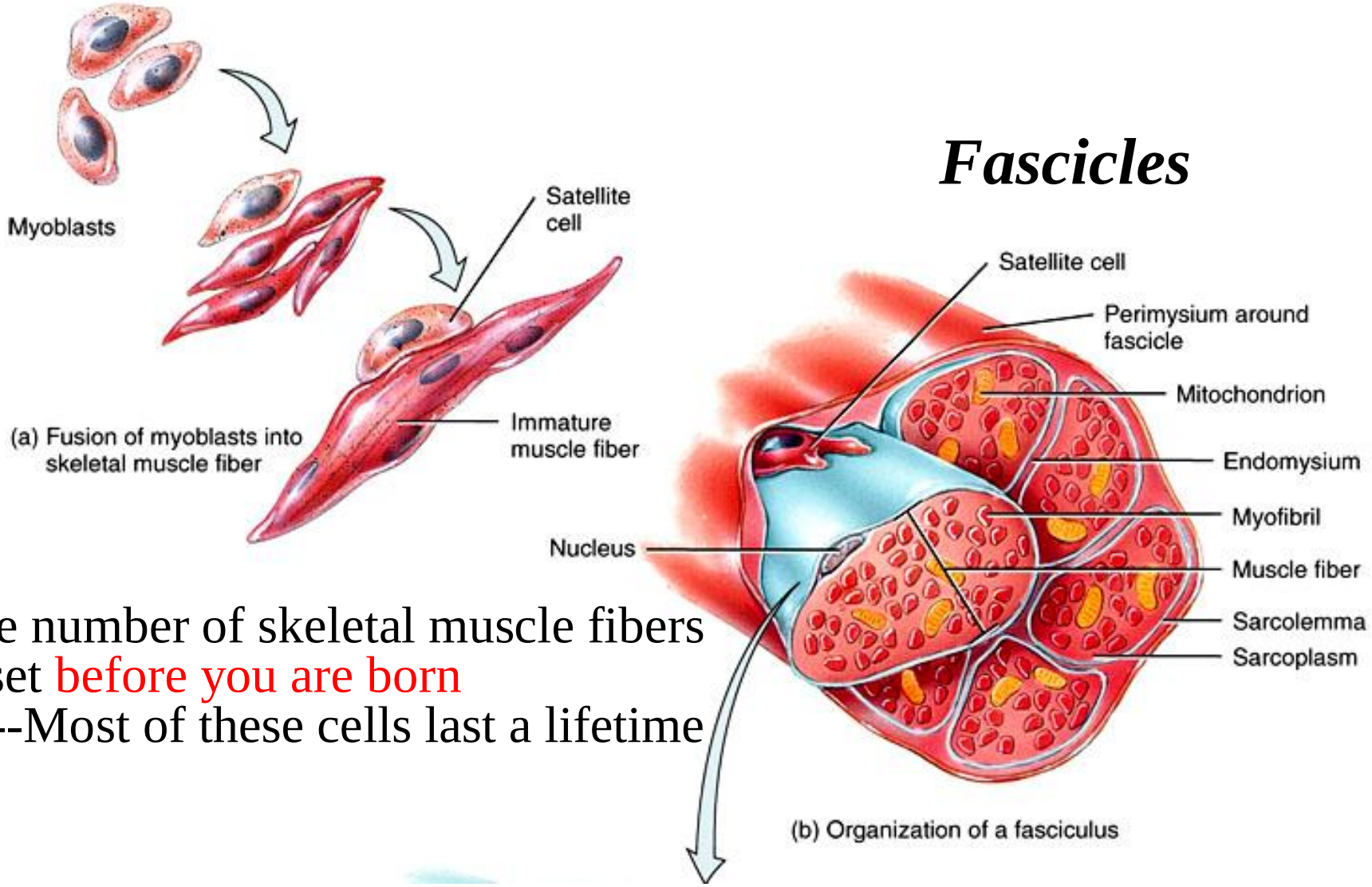
- 骨骼肌纖維是**多核細胞**，一條肌纖維內含有幾十個甚至幾百個細胞核，細胞核呈扁橢圓形，位於肌漿膜下方。
- 肌原纖維內有著和收縮非常有關的蛋白質叫作肌絲蛋白質(filaments)，分為兩種：**粗肌絲及細肌絲**。當收縮時，透過肌漿質網被活化之後，釋出大量的鈣離子，來引發肌肉收縮。
- T小管(橫小管)由肌漿膜衍生而來，每兩個T小管間就會有肌漿質網，所以T小管的兩側就有肌漿質網的**側囊(lateral sacs=terminal cisternae)**結構，此為儲存鈣離子的主要部位。

Structure of Skeletal Muscle



- Muscle = group of fascicles

Fascicles

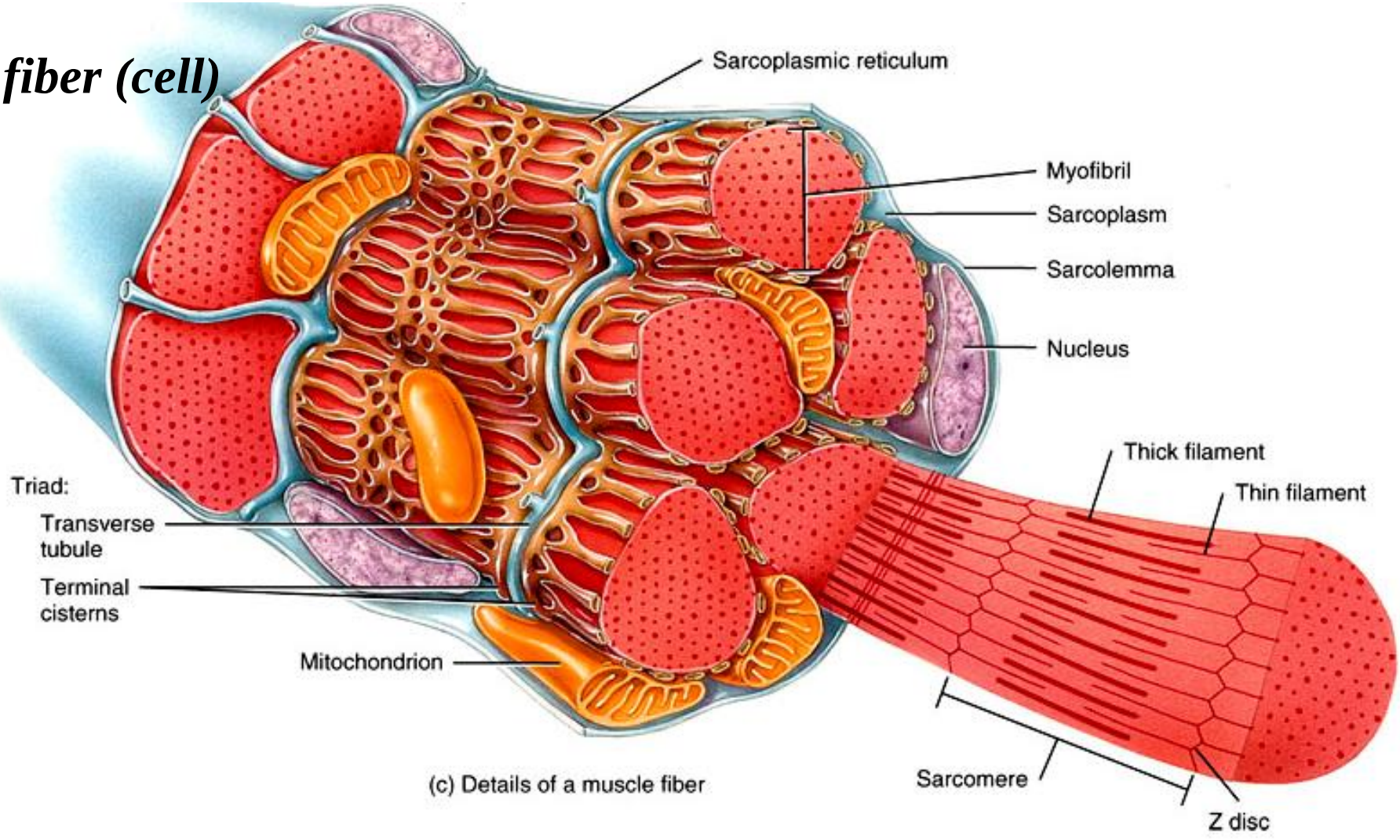


- The number of skeletal muscle fibers is set before you are born
  --Most of these cells last a lifetime

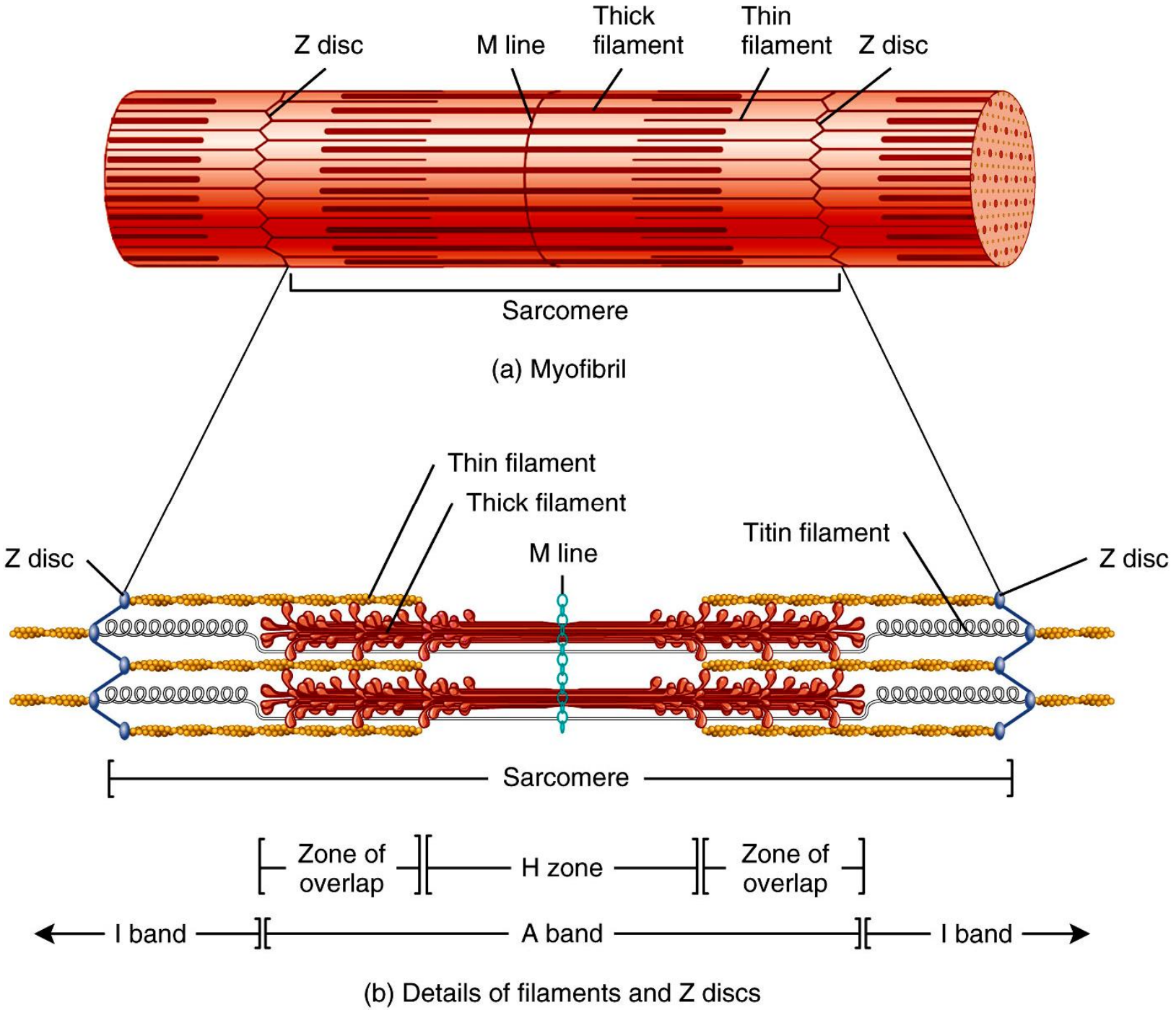
- Muscle growth occurs by hypertrophy
  --An enlargement of existing muscle fibers
- Testosterone and human growth hormone stimulate hypertrophy
- Satellite cells retain the capacity to regenerate damaged muscle fibers

Structure of Skeletal Muscle

Muscle fiber (cell)



Structure at the Molecular Level



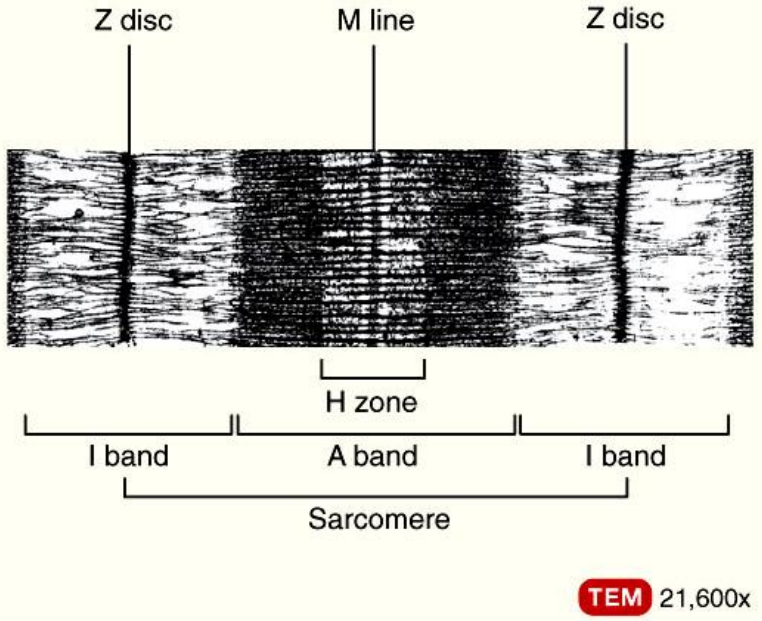
Structure at the Molecular Level

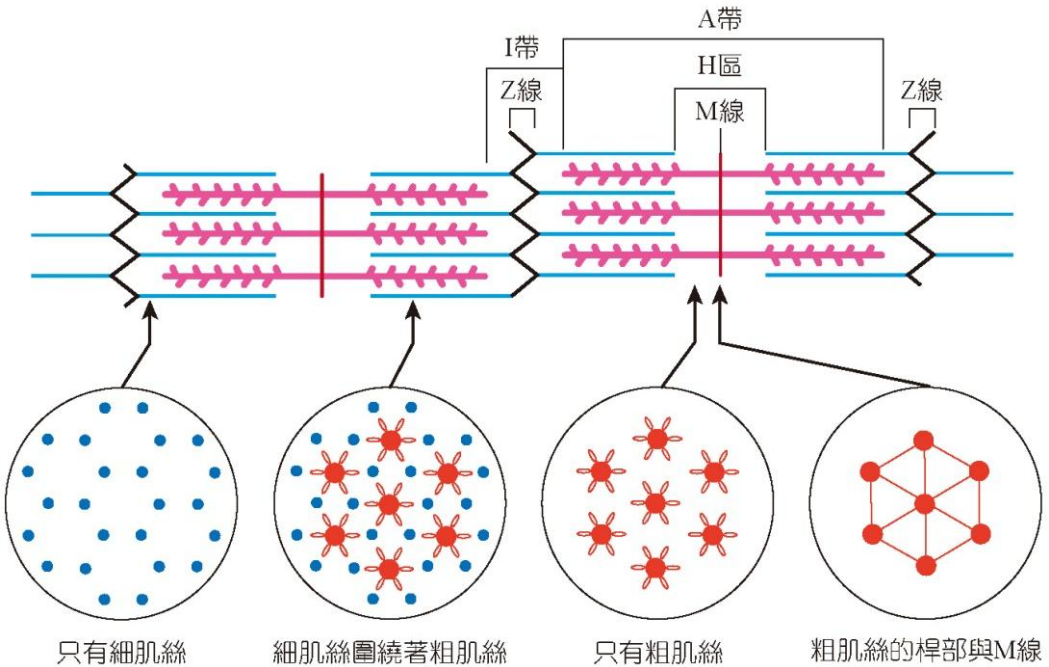
- **Striations produced by thick and thin filaments**
  - **--I bands** contain only thin filaments.
  - **--A bands** contain all of the thick filament with some thin filament overlap.
  - **--H bands** are the center of the A band with no thin filament overlap
  - **--Z lines** are found in the center of each I band
  - **--M lines** are found in the center of each A band and help hold down thick filaments
  - **--Sarcomere**: area from one Z line to the next (Functional unit)

Structure at the Molecular Level

Components of the Sarcomere

COMPONENT	DESCRIPTION
Z discs	Narrow, plate-shaped regions of dense material that separate one sarcomere from the next.
A band	The dark, middle part of the sarcomere that extends the entire length of the thick filaments and also includes those parts of the thin filaments that overlap with the thick filaments.
I band	The lighter, less dense area of the sarcomere that contains the rest of the thin filaments but no thick filaments. A Z disc passes through the center of each I band.
H zone	A narrow region in the center of each A band that contains thick filaments but no thin filaments.
M line	A region in the center of the H zone that contains proteins that hold the thick filaments together at the center of the sarcomere.





Skeletal Muscle Fiber Protein

- Myofibrils are built from three kinds of proteins

1) Contractile proteins

--Generate force during contraction

--Myosin and Actin

2) Regulatory proteins

--Switch the contraction process on and off

--Troponin and tropomyosin

3) Structural proteins

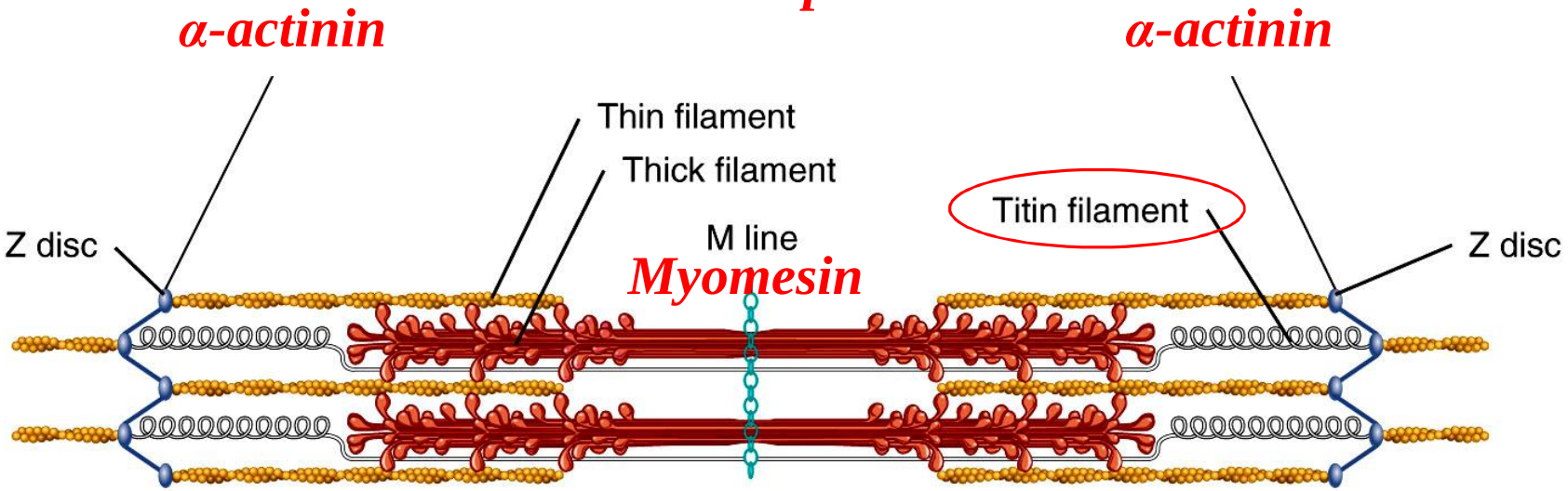
--Align the thick and thin filaments properly

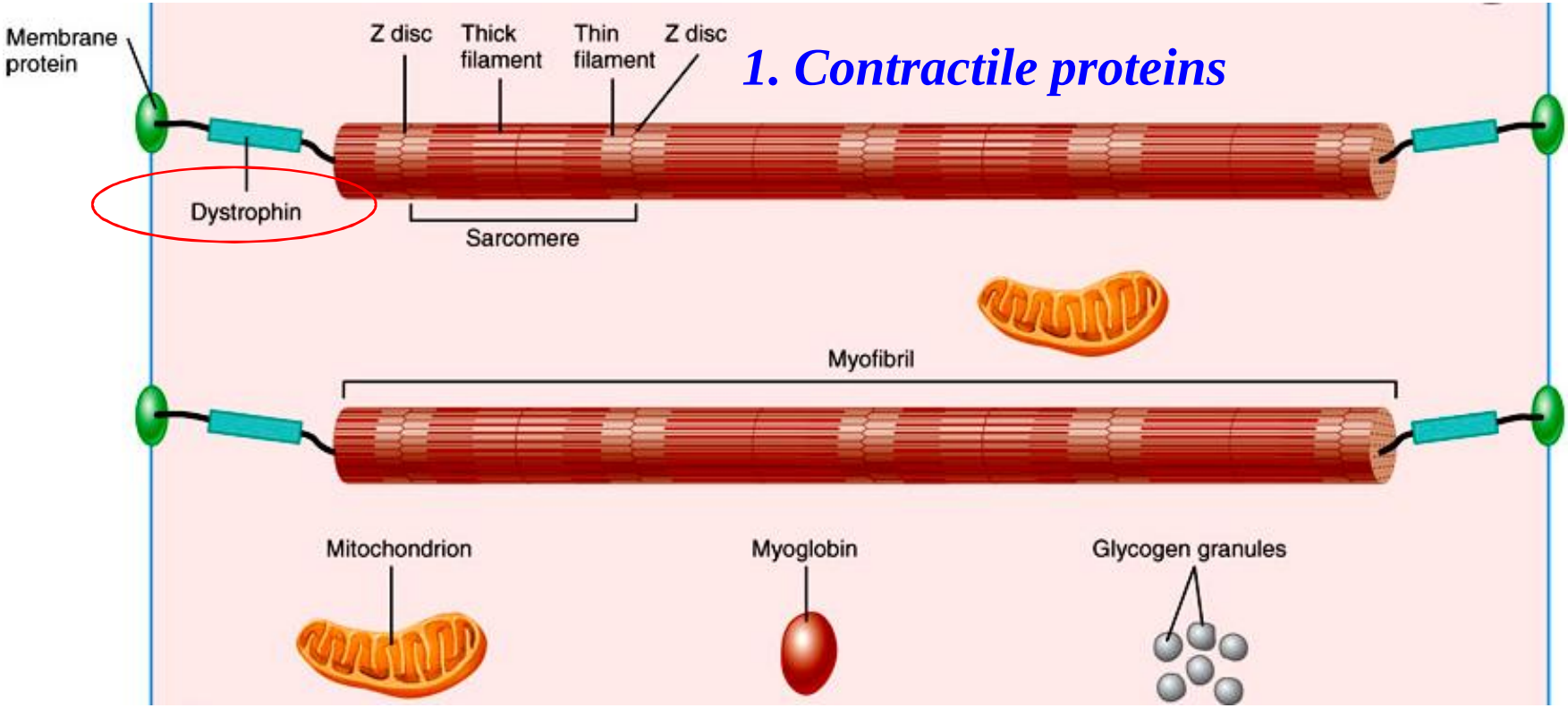
--Provide elasticity and extensibility

--Link the myofibrils to the sarcolemma

--Titin, myomesin, actinin, nebulin and dystrophin

3. Structural proteins





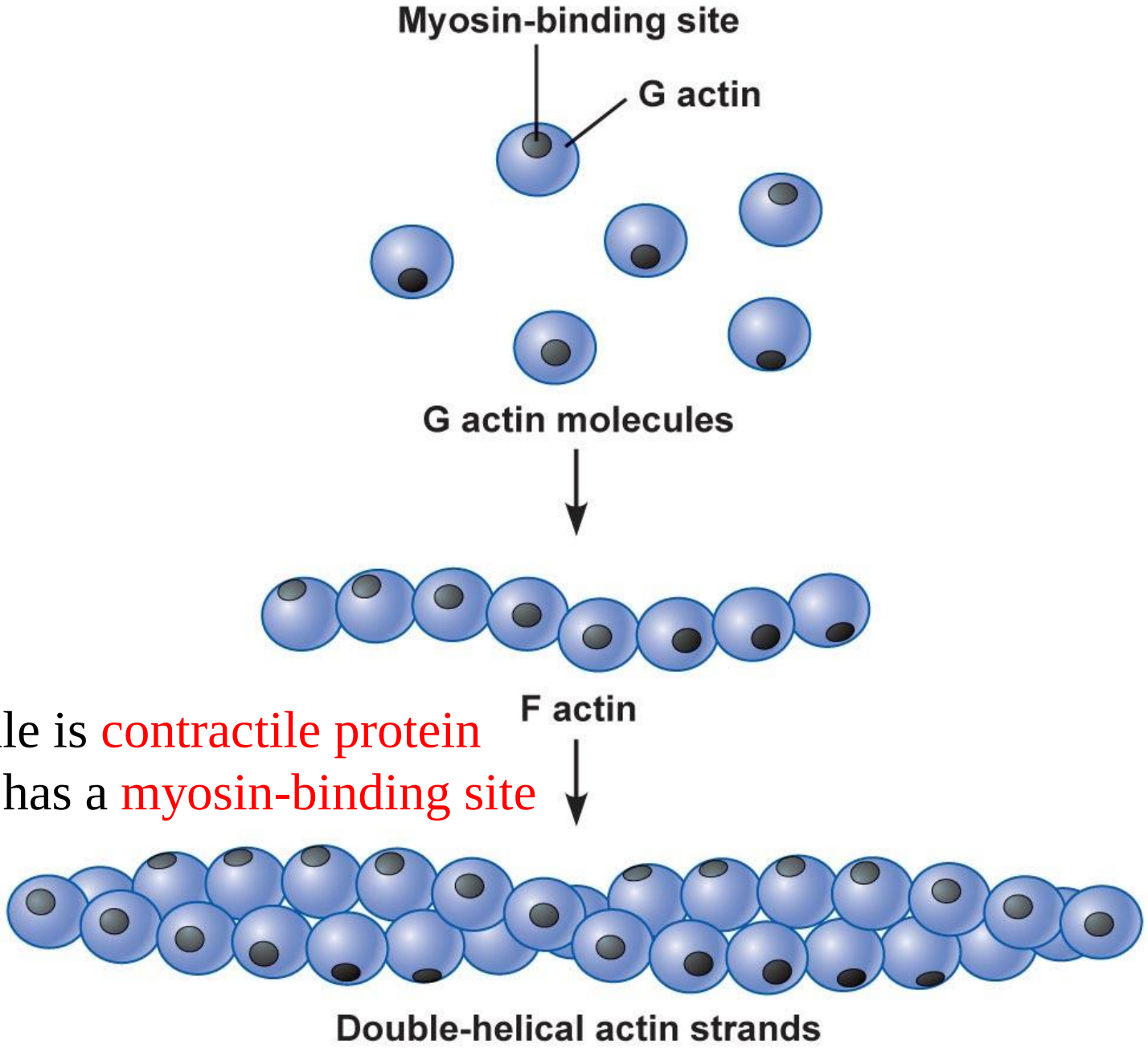
Skeletal Muscle Fiber Protein

蛋白質類型	描述
一、收縮性蛋白(contractile proteins)	**提供肌肉收縮時的力量。**
肌凝蛋白(myosin)	形成粗肌絲，由尾端和兩個頭端構成，肌肉收縮時頭端可和細肌絲的肌動蛋白結合。
肌動蛋白(actin)	形成細肌絲，每一個肌動蛋白在肌肉收縮時會與粗肌絲頭端的肌凝蛋白結合位置結合。
二、調節性蛋白(regulatory proteins)	**可以幫助肌肉收縮或放鬆。**
旋轉肌球素(tropomyosin)	是細肌絲的組成之一，當骨骼肌纖維放鬆時，旋轉肌球素覆蓋肌動蛋白的橫橋結合位置，避免肌凝蛋白與肌動蛋白結合。
旋轉素(troponin)	細肌絲的組成之一，當鈣離子與旋轉素結合時，結構改變會移開旋轉肌球素在肌動蛋白的橫橋結合位置，然後肌凝蛋白和肌動蛋白開始結合促使肌肉收縮。
三、結構性蛋白(structural proteins)	**維持粗肌絲和細肌絲成一直線排列，給予彈性和強韌性，並連結肌纖維至肌漿膜和胞外基質。**
Titin	連結肌節從Z 線和M 線，穩定粗肌絲。當沒有受張力時可以伸直和彈回，並穩定粗肌絲所需的彈性和延展性。
α-actinin	在Z線上，可以連結肌動蛋白及titin。
Myomesin	形成肌節的M線，連結肌原纖維和鄰近的粗肌絲到另一個。
Nebulin	纏繞細肌絲，幫助繫住細肌絲到Z線上，還可以協助細肌絲在肌肉內的排列。
Dystrophin	跟肌肉萎縮症有關，主要強化肌漿膜的結構和穩定度，可以協助將收縮的力量傳送到肌腱的地方。

Thin Filament & Thick Filament

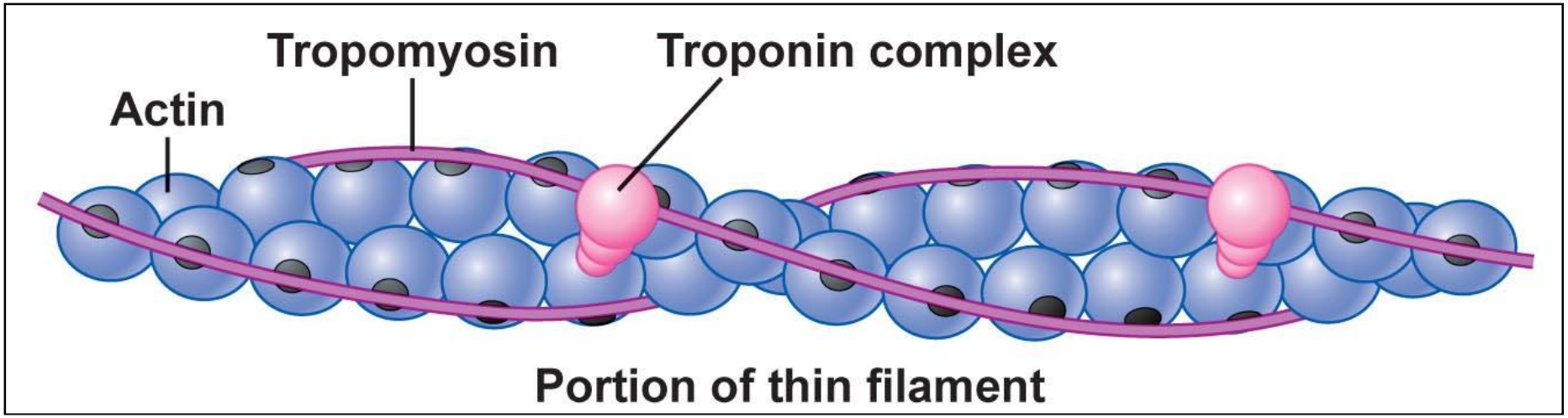
特性	粗肌絲	細肌絲
主要成分	肌凝蛋白(myosin)	肌動蛋白(actin)
直徑	約12~18 nm	5~8 nm
長度	約1.6 μm是A帶長度	約1 μm是一端連於Z帶上，一端游離
排列	外圍會有六條細肌絲形成六角型排列	外圍會有三條粗肌絲形成三角形排列

Molecular Structure of Thin Filament



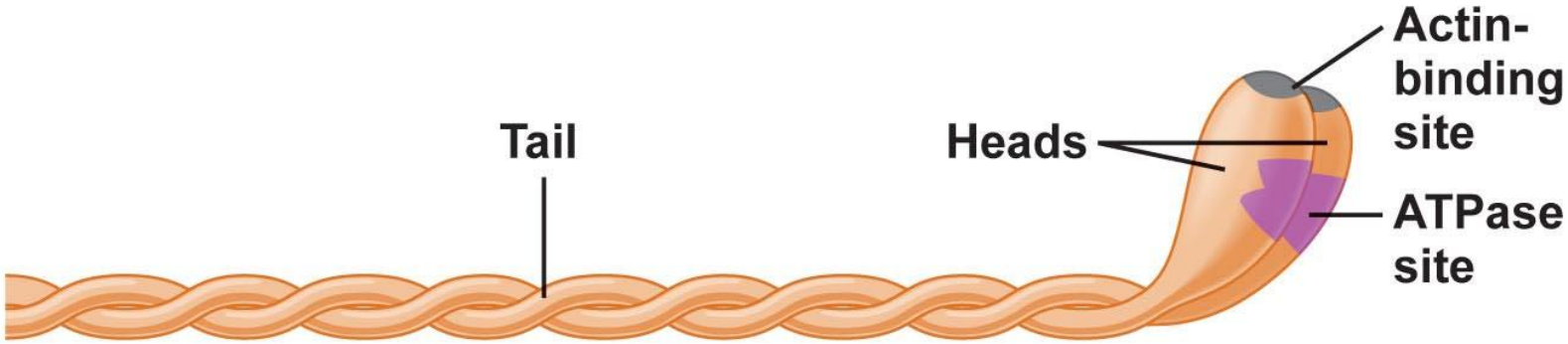
- Actin molecule is contractile protein
- Each G actin has a myosin-binding site

- **Tropomyosin (Tm)**
  - Regulatory protein
  - Overlaps myosin-binding site



- **Troponin (Tn)**
  - Regulatory protein
  - Complex of three proteins
    - --Attaches to actin, inhibits binding of myosin (TnI)
    - --Attaches to tropomyosin (TnT)
    - --Binds calcium (TnC)
  - Calcium binding to troponin regulates skeletal muscle contraction

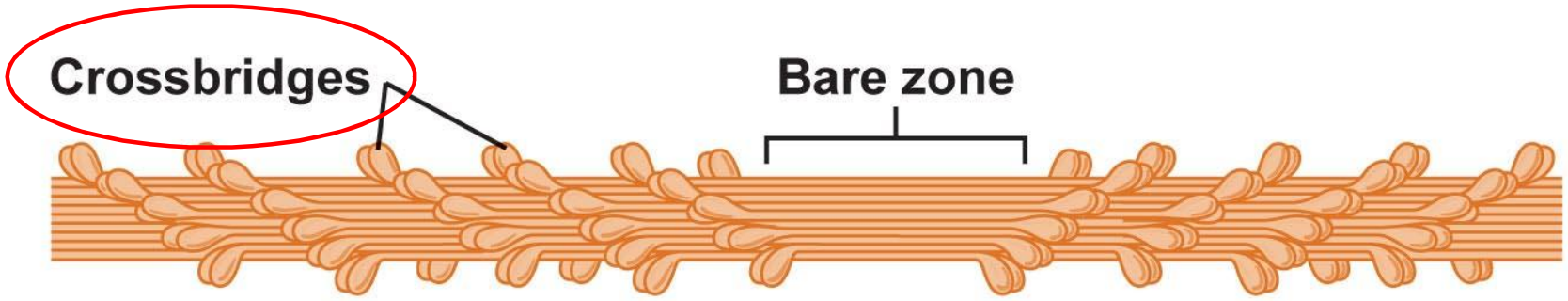
Molecular Structure of Thick Filament



(a) Myosin molecule

➢Myosin head binding sites (Actin & ATP)

(b) Two myosin molecules bound at their tail ends



(c) Portion of thick filament

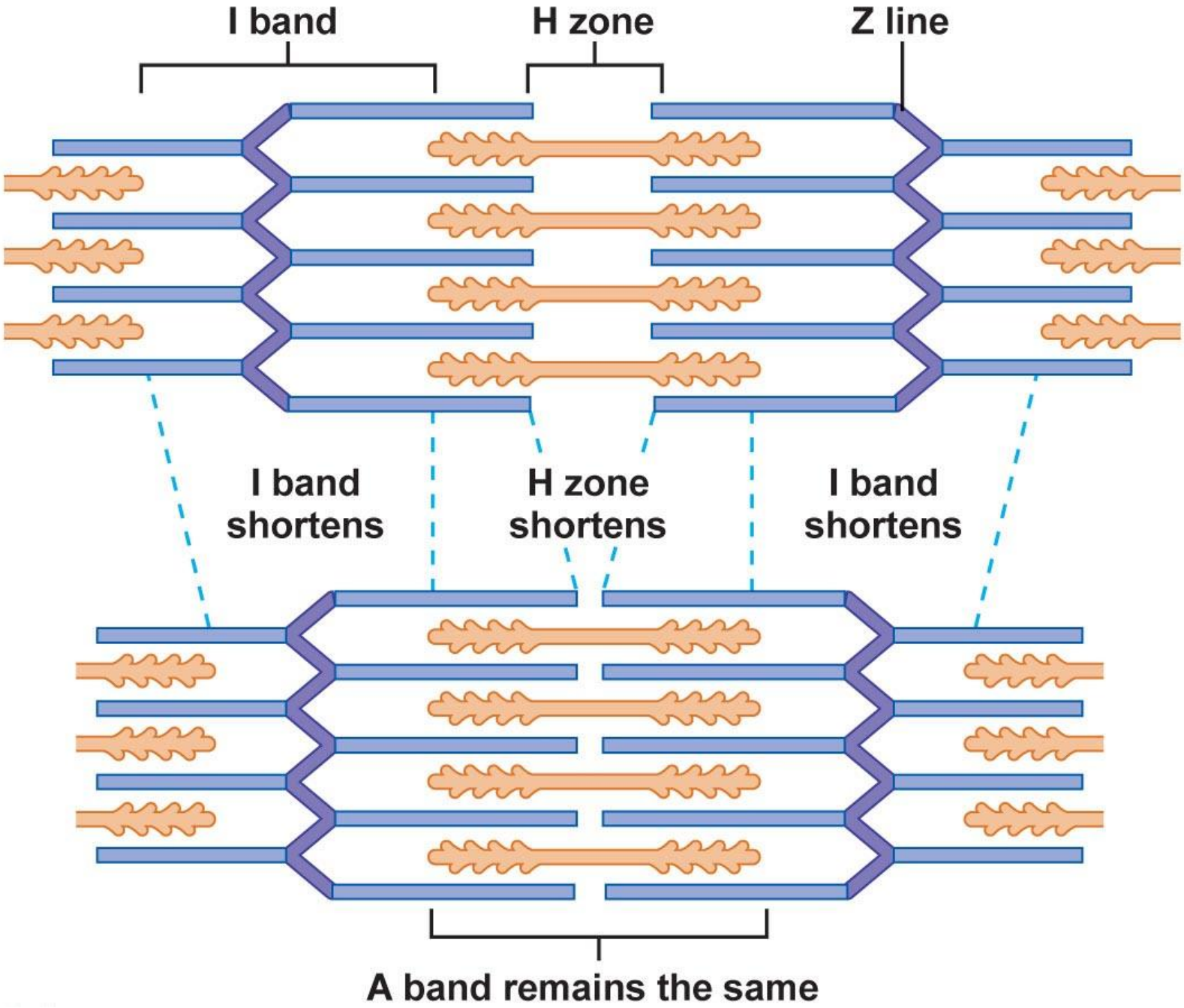
➢Myosin tail is toward M line

➢Myosin head is toward I band

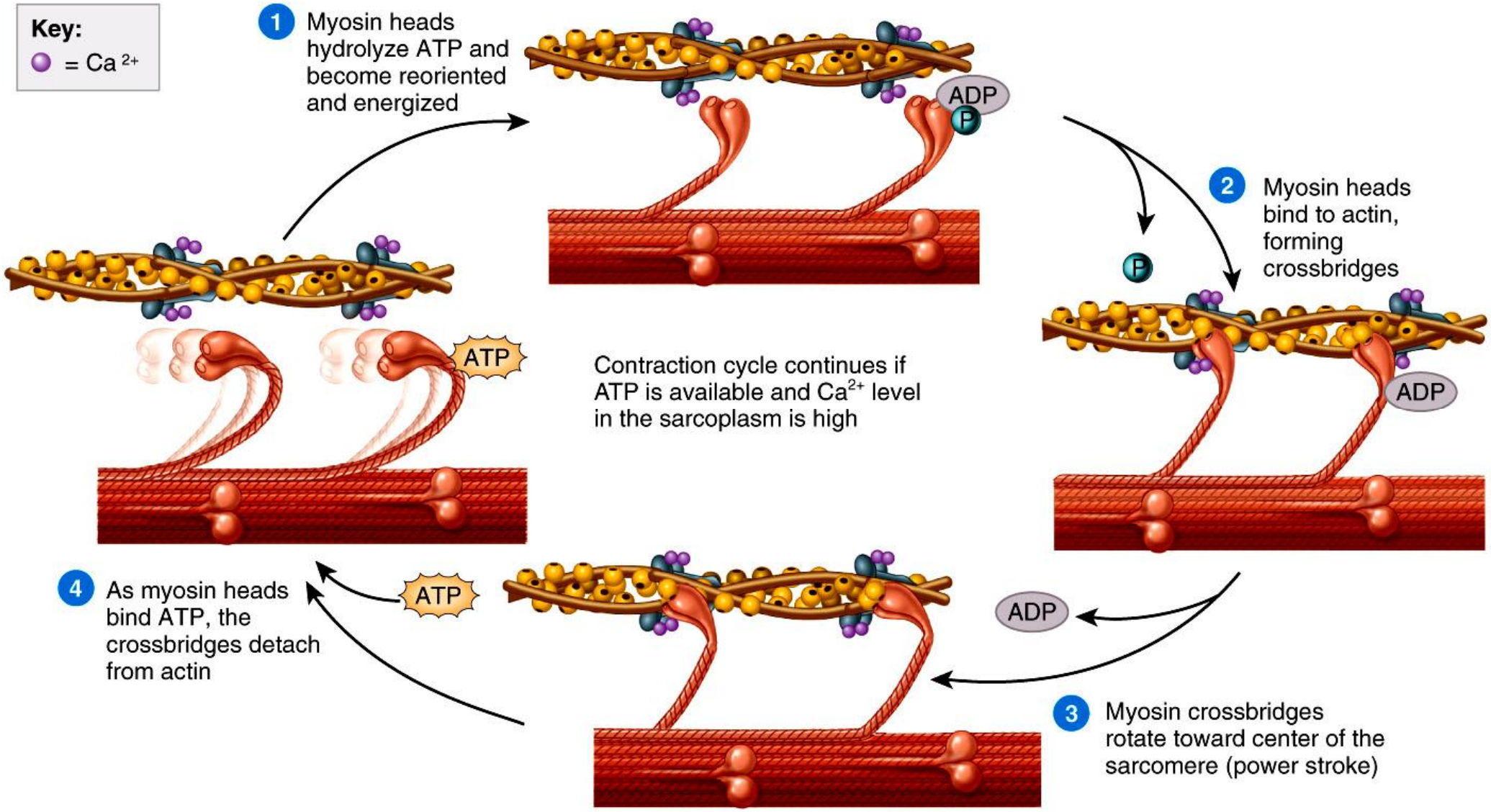
The Mechanism of Force Generation in Muscle

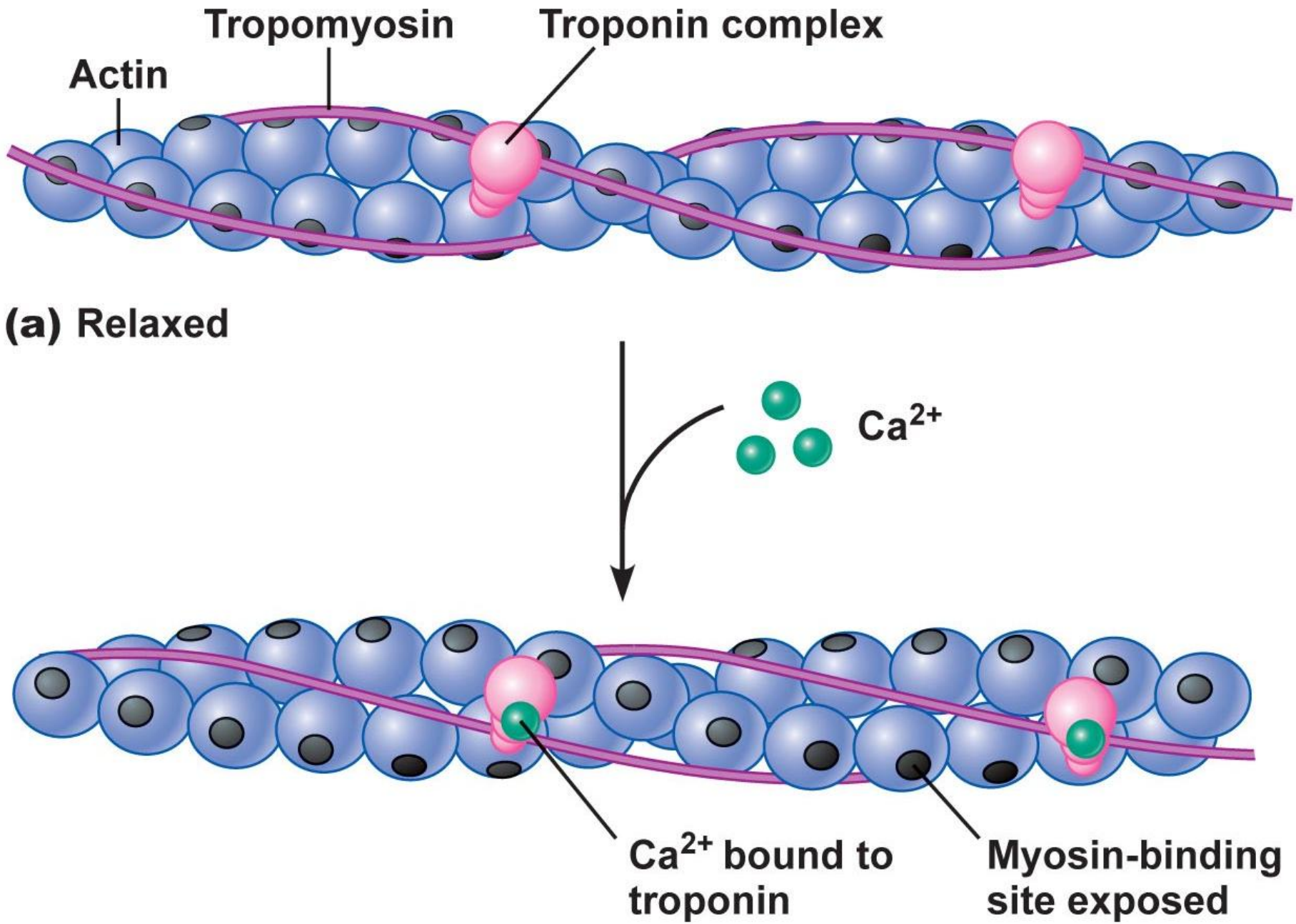
- The **sliding filament model**
- The **crossbridge cycle**: How muscles generate force
- The **excitation-contraction coupling**: How muscle contractions are turned on and off
- Muscle cell **metabolism**: How muscle cells provide ATP to drive the crossbridge cycle

Sliding Filament Theory

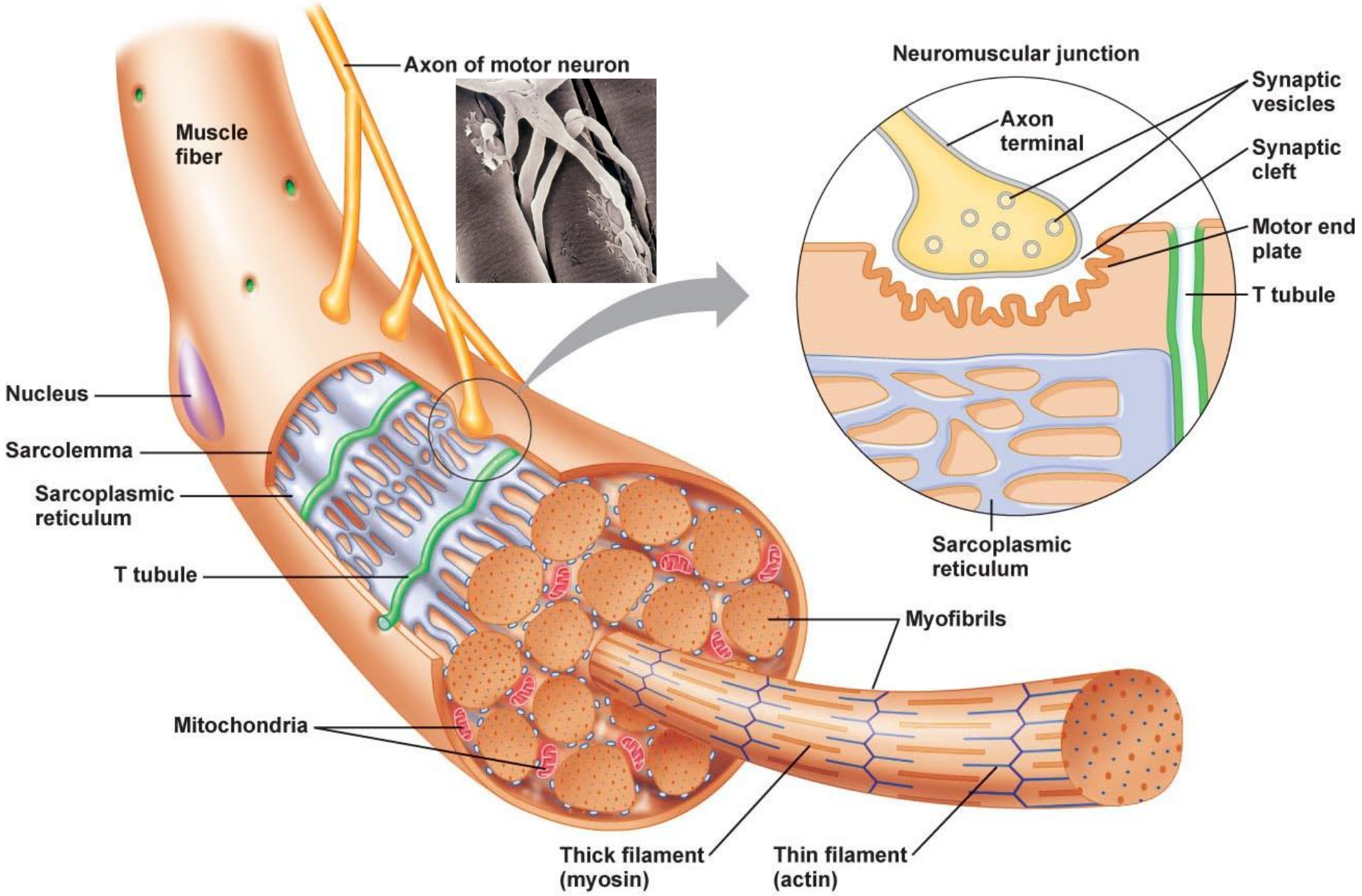


Cross-Bridge Cycle




Tropomyosin
Troponin complex
Actin
(a) Relaxed
Ca^{2+}
Ca^{2+} bound to troponin
Myosin-binding site exposed
(b) Contracting

Neuromuscular Junction (NMJ)



- **Motor unit**
  --A motor neuron have a threadlike axon that extends from the brain or spinal cord to a group of muscle fibers
- **Neuromuscular junction (NMJ)**
  --Action potentials arise at the interface of the motor neuron and muscle fiber
- **Synapse**
  --Where communication occurs between a somatic motor neuron and a muscle fiber
- **Synaptic cleft**
  --Gap that separates the two cells
- **Neurotransmitter**
  --Chemical released by the initial cell communicating with the second cell
- **Synaptic vesicles**
  --Sacs suspended within the synaptic end bulb containing molecules of the neurotransmitter **acetylcholine (ACh)**
- **Motor end plate**
  --The region of the muscle cell membrane opposite the synaptic end bulbs
  --Contain acetylcholine **nicotinic** receptors

- **Nerve impulses elicit a muscle action potential in the following way**

1) Release of acetylcholine

--Nerve impulse arriving at the synaptic end bulbs causes many synaptic vesicles to release ACh into the synaptic cleft

2) Activation of ACh receptors

--Binding of ACh to the nicotinic receptor on the motor end plate opens an ion channel (ligand-gated ion channels)

--Allows flow of Na^+ to the inside of the muscle cell

3) Production of muscle action potential

--The inflow of Na^+ makes the inside of the muscle fiber more positively charged triggering a muscle action potential

--The muscle action potential then propagates to the SR to release its stored Ca^{++}

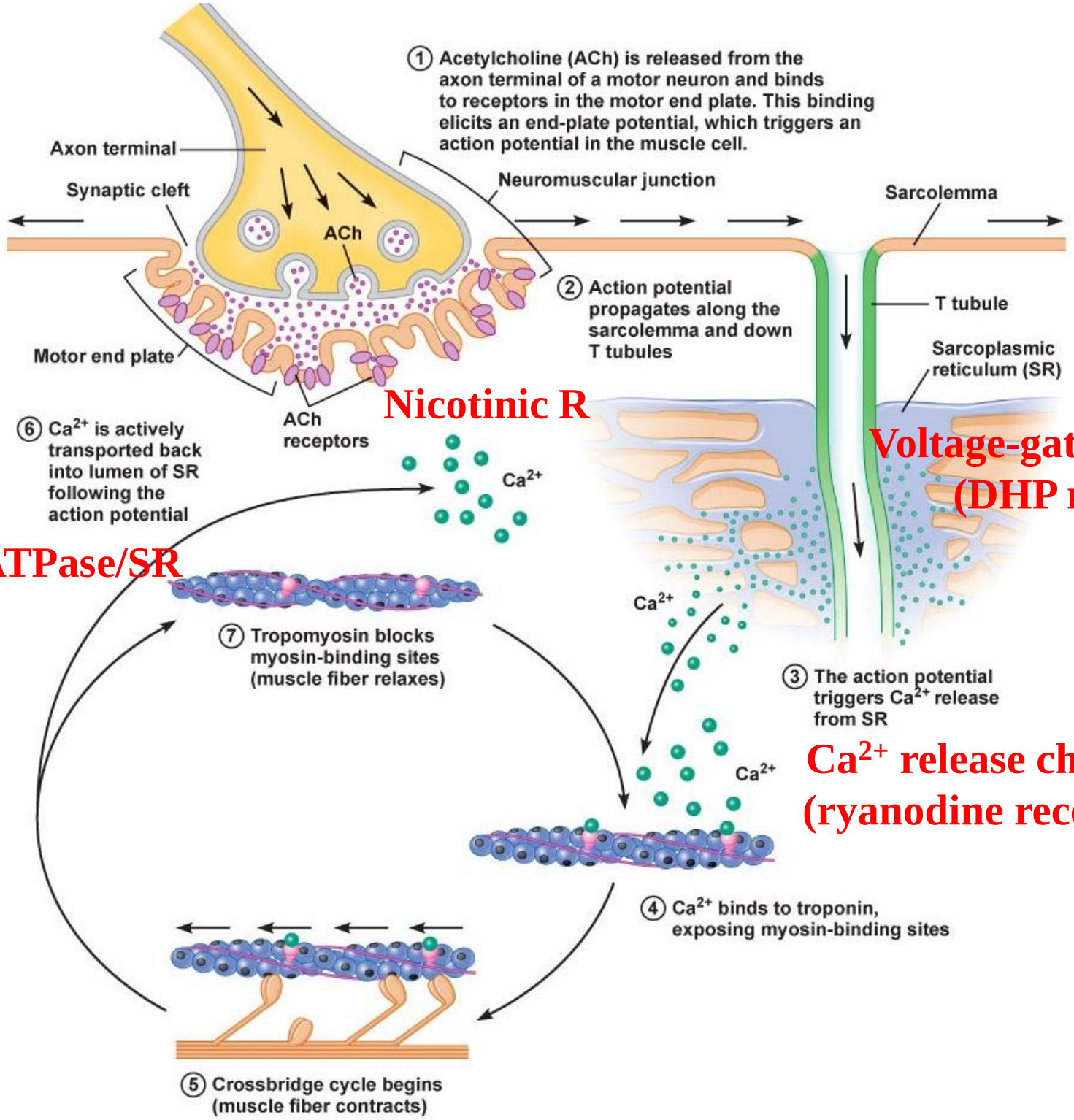
4) Termination of ACh activity

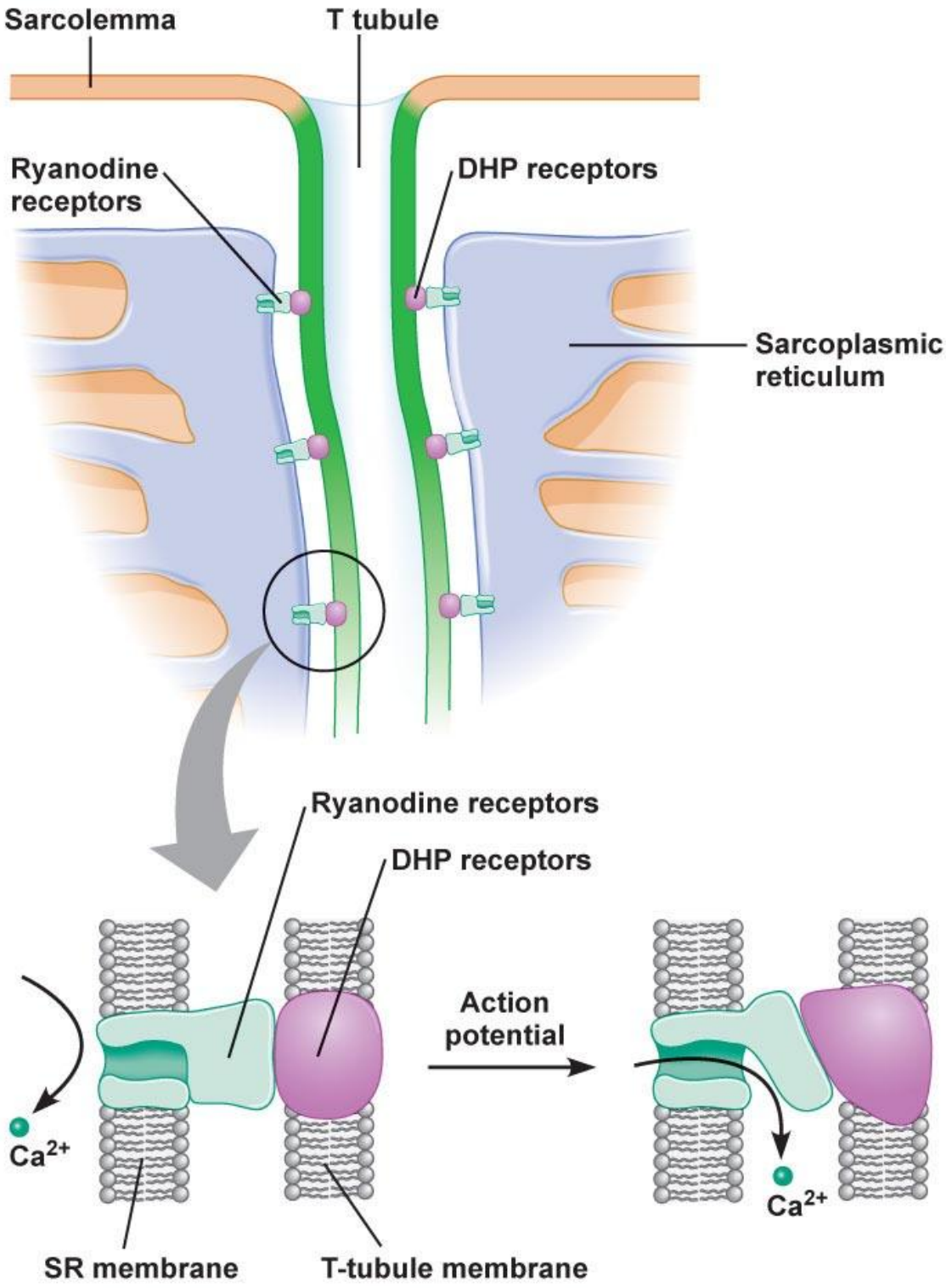
--ACh effects last only briefly because it is rapidly broken down by **acetylcholinesterase (AChE)**

Excitation-Contraction Coupling

Sequence of events whereby an action potential in the sarcolemma causes contraction

1. Action potential in sarcolemma
2. Action potential down T tubules
3. DHP (dihydropyridine) receptors=voltage-gated Ca channel of T tubules open Ca^{2+} release channels (ryanodine receptors) in lateral sacs of SR
4. Calcium increases in cytosol ($>1\times10^{-5}$ M)
5. Calcium binds to troponin shifting tropomyosin
6. Crossbridge cycling occurs


1 Acetylcholine (ACh) is released from the axon terminal of a motor neuron and binds to receptors in the motor end plate. This binding elicits an end-plate potential, which triggers an action potential in the muscle cell.
Axon terminal
Synaptic cleft
ACh
Neuromuscular junction
Sarcolemma
2 Action potential propagates along the sarcolemma and down T tubules
T tubule
Sarcoplasmic reticulum (SR)
Motor end plate
ACh receptors
Nicotinic R
6 Ca2+ is actively transported back into lumen of SR following the action potential
Ca2+
Voltage-gated Ca channel (DHP receptors)
Ca2+ ATPase/SR
Ca2+
7 Tropomyosin blocks myosin-binding sites (muscle fiber relaxes)
3 The action potential triggers Ca2+ release from SR
Ca2+
Ca2+ release channels (ryanodine receptors)
4 Ca2+ binds to troponin, exposing myosin-binding sites
5 Crossbridge cycle begins (muscle fiber contracts)


Sarcolemma
T tubule
Ryanodine receptors
DHP receptors
Sarcoplasmic reticulum
Ryanodine receptors
DHP receptors
Action potential
Ca^{2+}
Ca^{2+}
SR membrane
T-tubule membrane

Pharmacology of the NMJ

- **Botulinum toxin**
  - ➢Blocks release of ACh from synaptic vesicles
  - ➢May be found in improperly canned foods
    - --A tiny amount can cause death by paralyzing respiratory muscles
  - ➢Used as a medicine (Botox®)
    - --Strabismus (crossed eyes)
    - --Blepharospasm (uncontrollable blinking)
    - --Spasms of the vocal cords that interfere with speech
    - --Cosmetic treatment to relax muscles that cause facial wrinkles
    - --Alleviate chronic back pain due to muscle spasms in the lumbar region

Pharmacology of the NMJ

- **Curare**
  - A plant poison used by South American Indians on arrows and blowgun darts
  - Causes muscle paralysis by blocking ACh N-receptors inhibiting Na^+ ion channels
  - Derivatives of curare are used during surgery to relax skeletal muscles
- **Anticholinesterase**
  - Slow actions of acetylcholinesterase (AChE) and removal of ACh
  - Can strengthen weak muscle contractions
    - Ex: **Neostigmine**
      - Treatment for myasthenia gravis (MG)
      - Antidote for curare poisoning
      - Terminate the effects of curare after surgery

Clinical Application: Myasthenia Gravis

- Progressive **autoimmune** disorder that blocks the **ACh N-receptors** at the neuromuscular junction
- The more receptors are damaged the weaker the muscle
- More common in women 20 to 40 with possible line to **thymus gland tumors**
- Begins with double vision & swallowing difficulties & progresses to paralysis of respiratory muscles
- Treatment includes **steroids** that reduce antibodies that bind to ACh receptors and **inhibitors of acetylcholinesterase (AChE inhibitor)**

Where Muscles Get Their Energy

- At rest and for mild exercise: from fatty acids, ketone body, glucose
- For moderate exercise: from glycogen stores
- For heavy exercise: from blood glucose

  --As exercise intensity and duration increase, GLUT4 channels are inserted into the sarcolemma to allow more glucose into cells

Muscle Metabolism

- **Production of ATP in Muscle Fibers**

  --A huge amount of ATP is needed to:

  - Power the crossbridge cycle (contraction)
  - Pump Ca^{++} into the SR (relaxation)

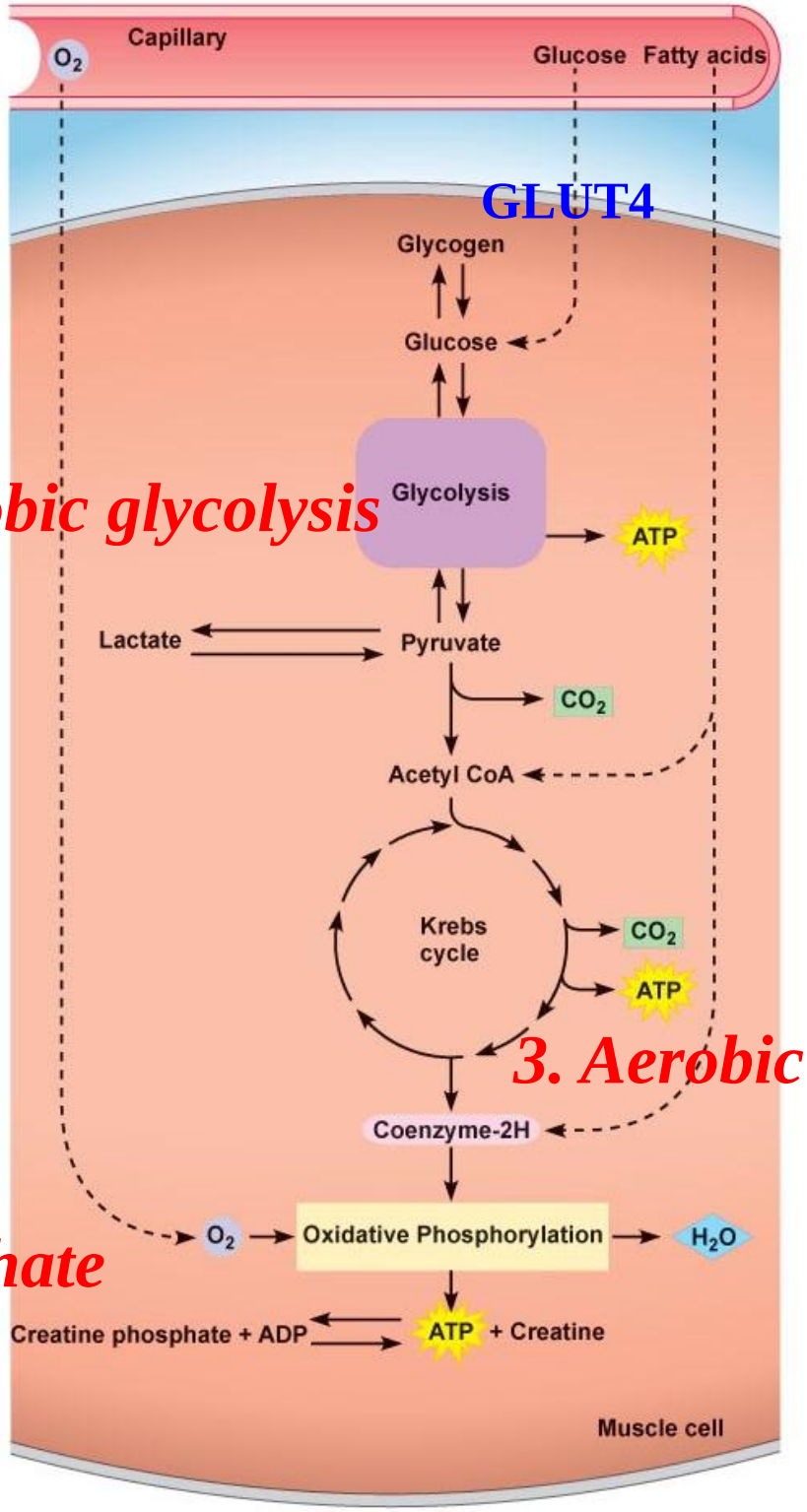
  --The ATP inside muscle fibers will power contraction for only a few seconds

  --ATP must be produced by the muscle fiber after reserves are used up

  --Muscle fibers have three ways to produce ATP

  1) From creatine phosphate (CP)
  2) By anaerobic cellular respiration
  3) By aerobic cellular respiration

名稱	特性	舉例
磷酸肌酸 (creatine phosphate)	1.肌肉收縮時，磷酸肌酸會和ADP產生作用而形成ATP與肌胺酸(creatine)。 2.肌肉放鬆時，ATP會和肌胺酸產生作用而形成磷酸肌酸與ADP。	1.反應快速，不需要氧氣，作為重度體力勞動最初的能量供應 2.持續時間短，約15秒。
無氧性醣解作用 (anaerobic glycolysis)	1.當肌肉活動超過15秒時，磷酸肌酸的供應就會耗盡，便會透過無氧性醣解作用。 2.醣解作用產生出2~3個ATP，可以提供30~40秒肌肉收縮。	400公尺賽跑最後的300公尺，若時間太久可能會形成乳酸(lactic acid)進入到血液中。
有氧性細胞呼吸 (aerobic cellular respiration)	1.主要發生在粒腺體中，需要一連串的氧化磷酸化來產生36個ATP。 2.提供持續超過10分鐘的活動 3.有氧代謝不產生疲勞物質—乳酸。	1.反應較緩慢，主要能量來源有葡萄糖、脂肪酸及胺基酸。 2.慢跑、游泳及散步等，所以有氧呼吸可以提供大部分的ATP。

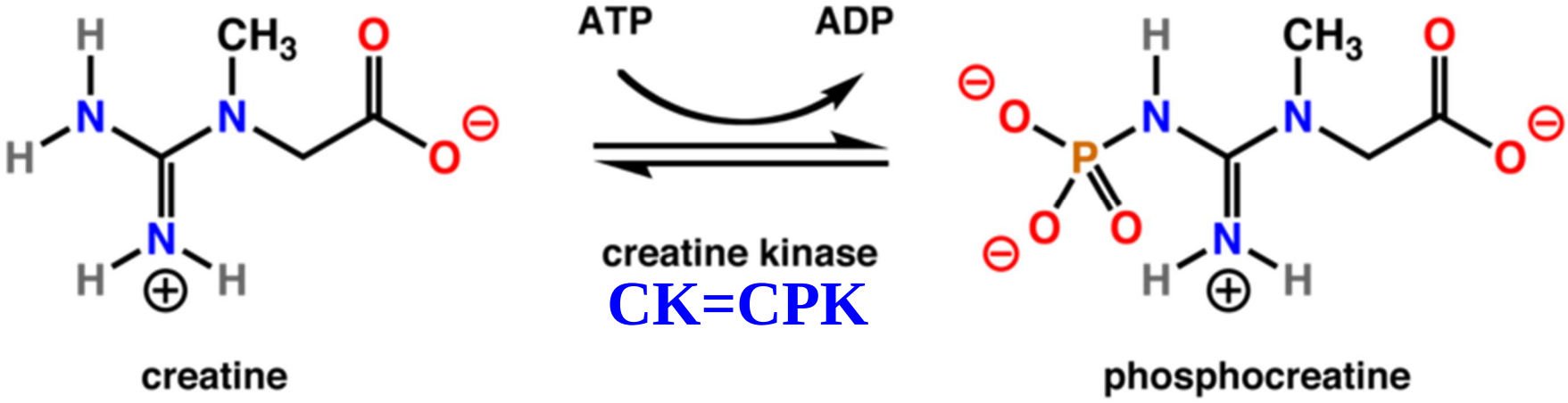


2. Anaerobic glycolysis

3. Aerobic cellular respiration

1. Creatine phosphate

Clinical Application: CK=CPK

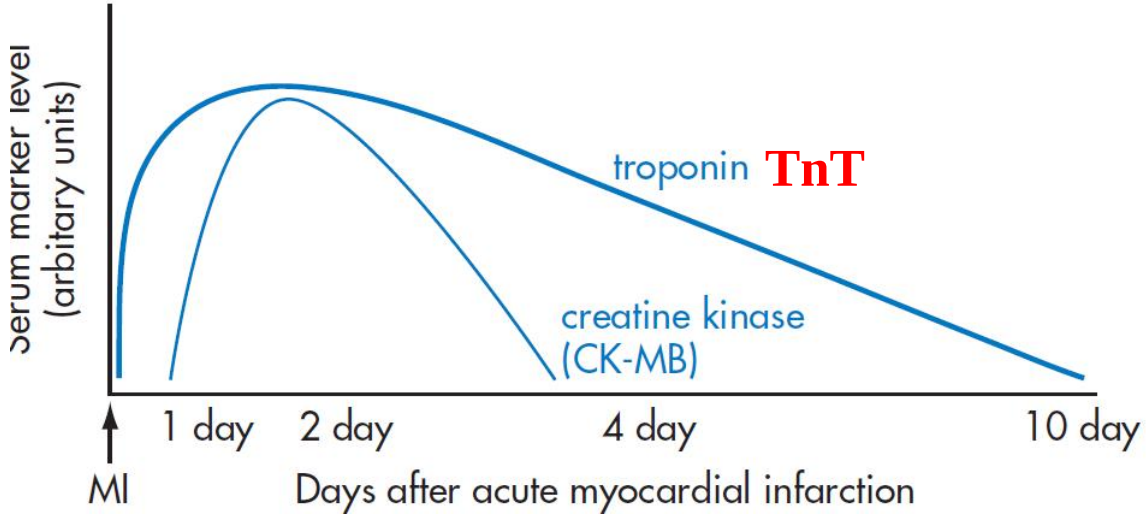


- In the cells, the "cytosolic" CK enzymes consist of two subunits, which can be either ***B* (brain type)** or ***M* (muscle type)**. There are, therefore, three different isoenzymes: **CK-MM (muscle), CK-BB (brain) and CK-MB (heart)**
- Clinically, creatine kinase is assayed in blood tests as a marker of **myocardial infarction** (heart attack), **rhabdomyolysis** (severe muscle breakdown), and **muscular dystrophy**

Enzyme	Diseases Associated with Abnormal Plasma Enzyme Concentrations
Alkaline phosphatase	Obstructive jaundice, Paget's disease (osteitis deformans), carcinoma of bone
Acid phosphatase	Benign hypertrophy of prostate, cancer of prostate
Amylase	Pancreatitis, perforated peptic ulcer
Aldolase	Muscular dystrophy
Creatine kinase (or creatine phosphokinase-CPK)	Muscular dystrophy, myocardial infarction
Lactate dehydrogenase (LDH)	Myocardial infarction, liver disease, renal disease, pernicious anemia
Transaminases (AST and ALT)	Myocardial infarction, hepatitis, muscular dystrophy

CK-MM **CK-MB**

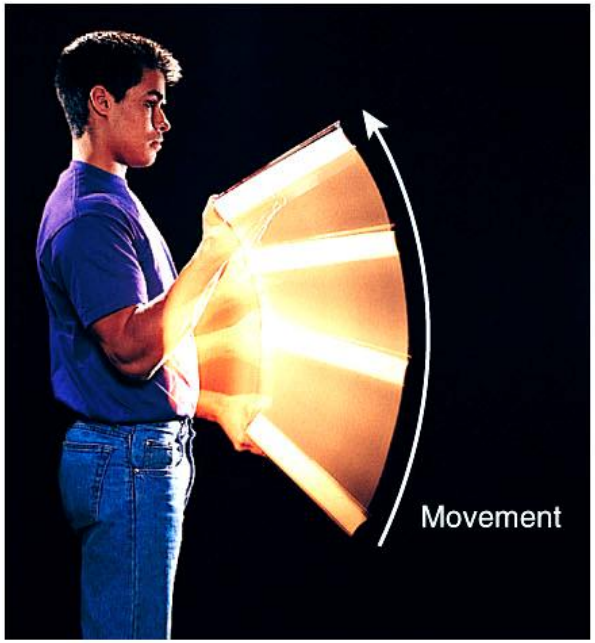
Rhabdomyolysis



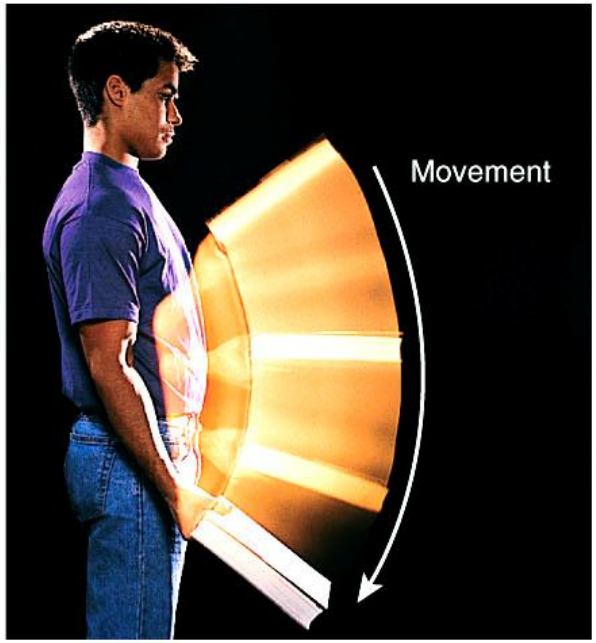
Control of Muscle Tension

- **The tension or force of muscle cell contraction varies**
- **Maximum Tension (force) is dependent on**
  - --The rate at which nerve impulses arrive (frequency of stimulation)
  - --The number of fibers recruited to contract
  - --The nutrient and oxygen availability
  - --Fiber diameter (thicker= ↑number of crossbridges/sarcomere and filaments = stronger)
  - --The size of the motor unit
  - --Initial length of the fiber at rest

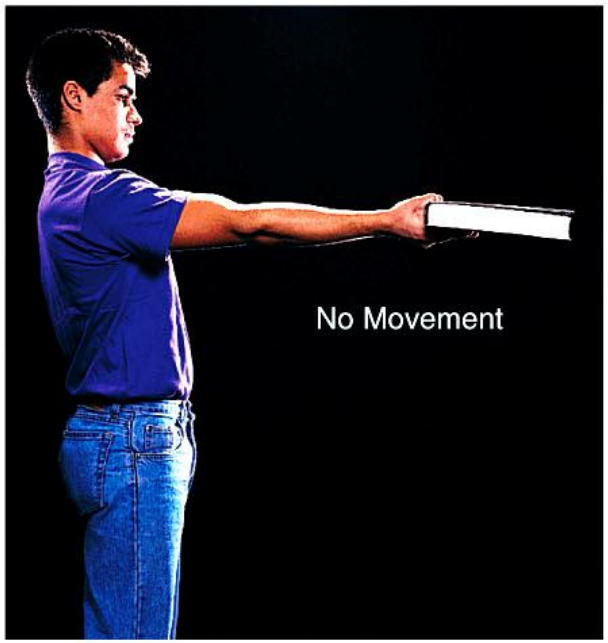
Types of Muscle Contractions



(a) Concentric contraction while picking up a book



(b) Eccentric contraction while lowering a book



(c) Isometric contraction while holding a book steady

- **Isotonic contractions = a load is moved (tension > load)**

  --**Concentric contraction** = a muscle shortens to produce force and movement ex.上樓梯

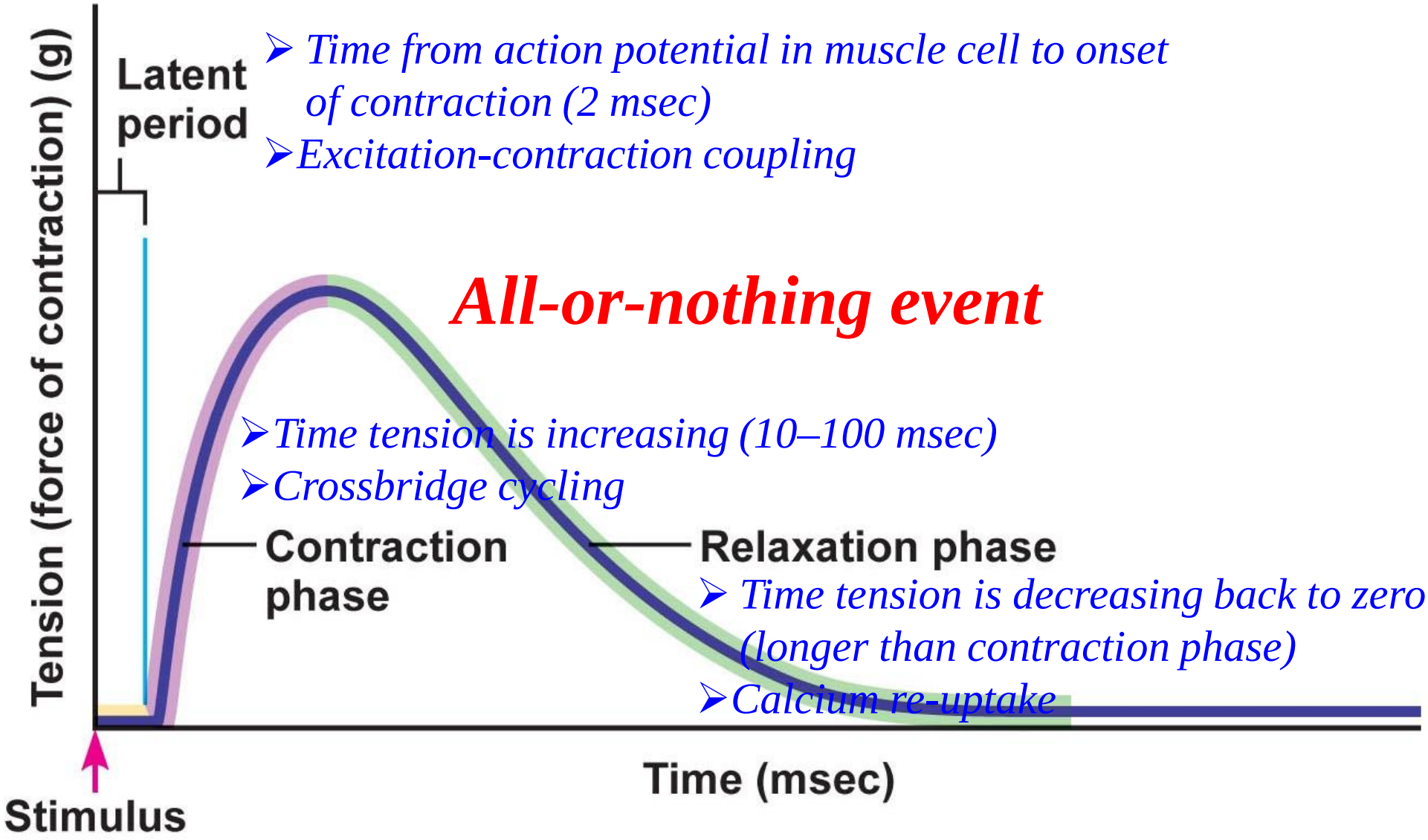
  --**Eccentric contractions** = a muscle lengthens while maintaining force and movement ex.下樓梯

- **Isometric contraction = no movement occurs (load > tension)**

  --tension is generated without muscle shortening

  --maintaining posture & supports objects in a fixed position

Twitch Contraction

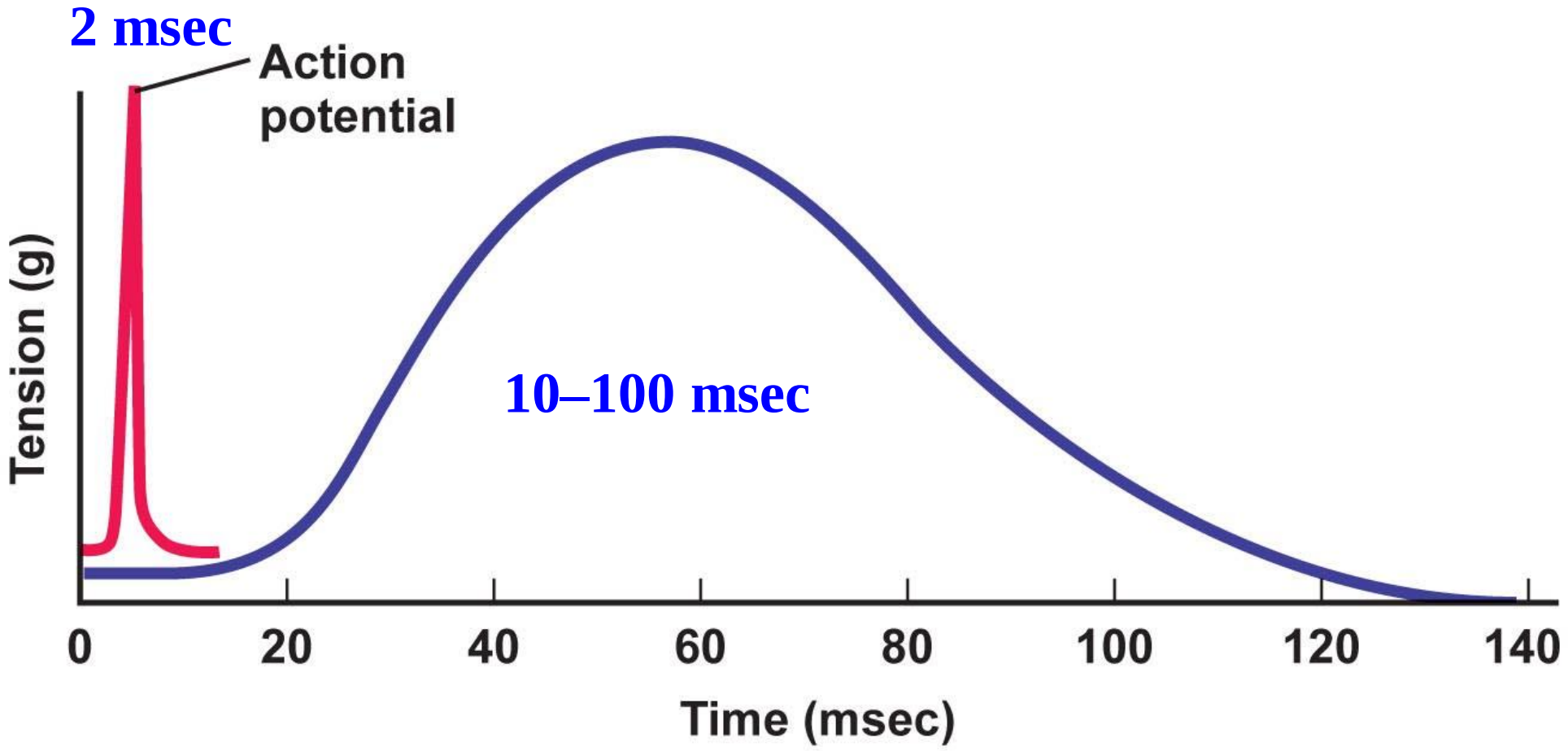


- *Time from action potential in muscle cell to onset of contraction (2 msec)*
- *Excitation-contraction coupling*

All-or-nothing event

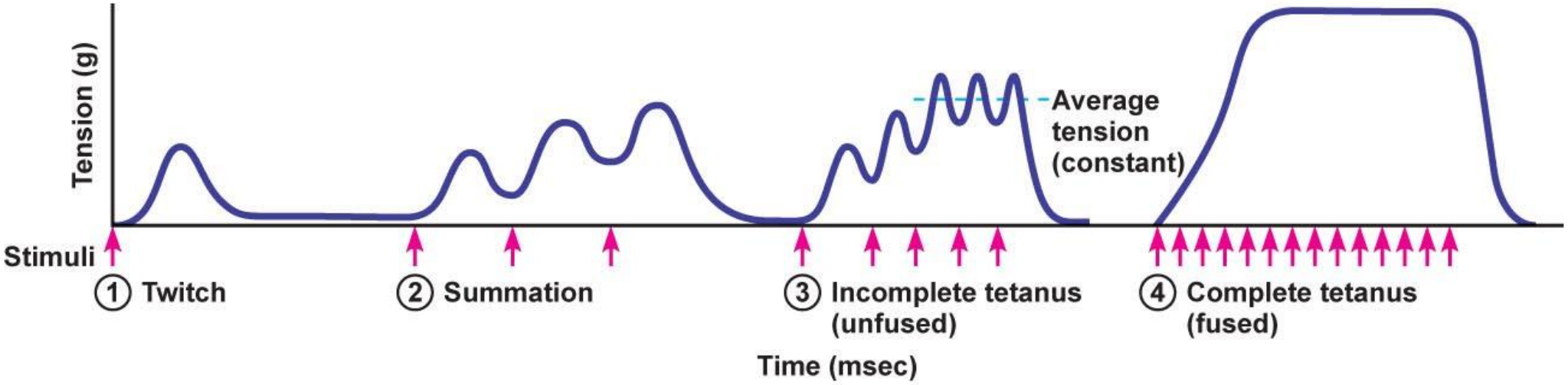
- *Time tension is increasing (10–100 msec)*
- *Crossbridge cycling*
- *Time tension is decreasing back to zero (longer than contraction phase)*
- *Calcium re-uptake*

Isometric Twitch Duration



Contractions can overlap and sum

Summation of Contraction & Tetanic Contraction



- Amount of tension developed depends on amount of calcium bound to troponin
- At high frequencies, release > re-uptake

Types of Skeletal Muscle Fibers

- **Differences in the speed of contraction:**

  --Slow- (type I) and **Fast-**twitch fibers (type II)

- **Differences in the content of myoglobin:**

  --Red muscle fibers and **White** muscle fibers

- **Differences in the primary mode of ATP production:**

  --Glycolytic fibers and **Oxidative** fibers

  1) Slow oxidative fibers (SO=Red fibers)

  2) Fast oxidative glycolytic fibers (FOG)

  3) Fast glycolytic fibers (FG=White fibers)

特性	有氧慢肌(紅肌)	有氧快肌	無氧快肌(白肌)
一、結構特徵			
纖維直徑	小	中	大
肌紅素濃度	多	多	少
粒腺體	多	多	少
微血管	多	多	少
顏色	紅	粉紅	白或灰白
二、功能特徵			
產生ATP數量和方式	高，藉由有氧細胞呼吸	中，藉由有氧和無氧細胞呼吸	少，無氧細胞呼吸(醣解作用)
肌凝蛋白ATP水解速率	慢	快	快
收縮速率	慢	快	快
疲勞抵抗程度	高	中	低
肌酸激酶	最少	中	最多
肝醣儲存	低	中	高
豐富部位	頸部、背部	下肢	上臂、肩膀
纖維主要功能	維持姿勢、有氧持久運動	走路、短跑衝刺	快速運動，重量訓練者，長期短跑

Adaptation to Aerobic Exercise

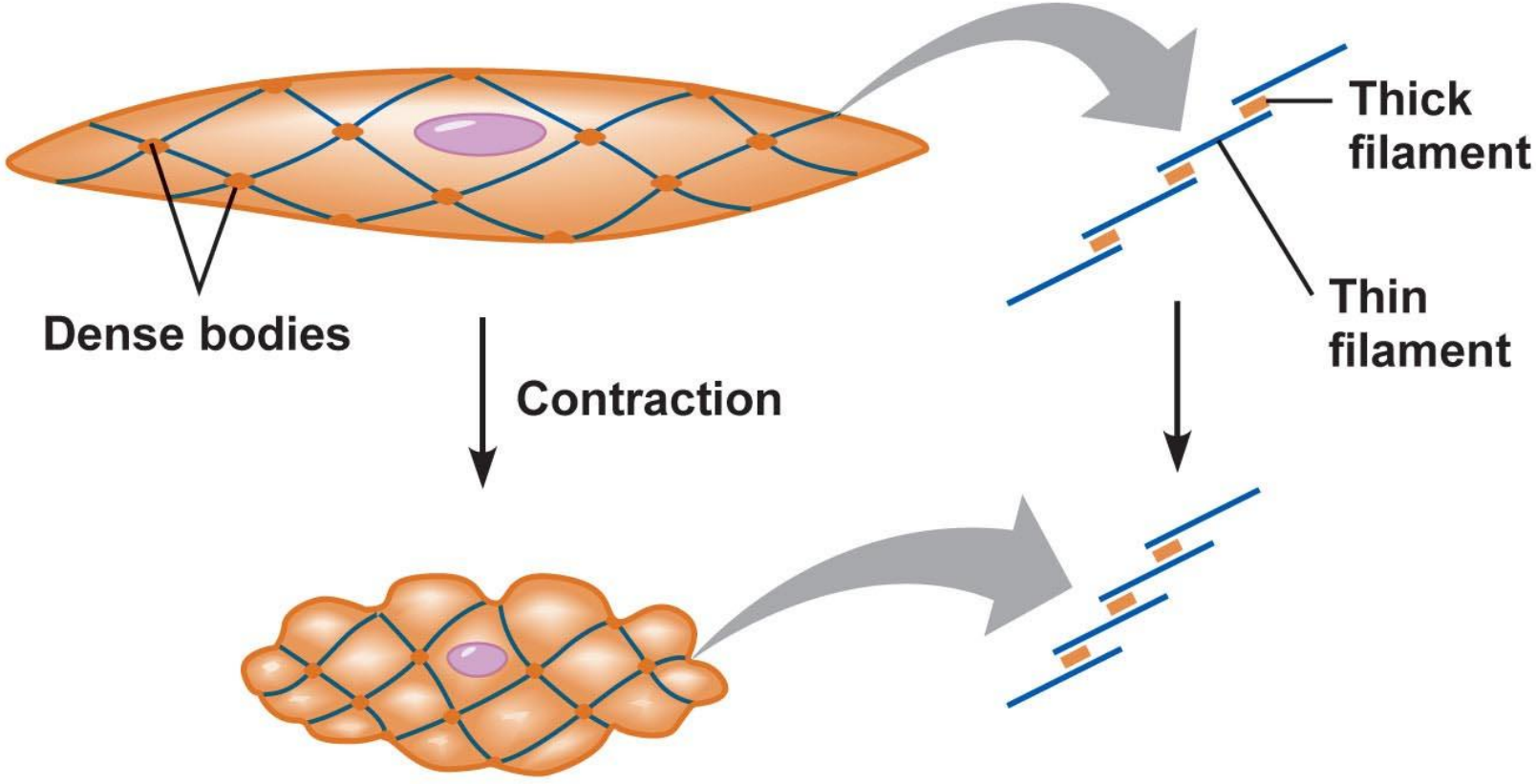
- **Endurance exercises = aerobic exercises**
  - --Low to moderate intensity can be sustained
- **Increases oxidative capacity of muscle**
  - --More mitochondria
  - --Increase blood supply (capillaries)
  - --Decrease in diameter

Adaptation to Anaerobic Exercise

- **High-intensity exercise**
  --Cannot be sustained
- **Increases ability of muscle to generate more tension (strength)**
  --Increases amount of actin and myosin
  --Increases number of myofibrils
  --Increases diameter of muscle fiber
  --Increases glycolytic enzymes
  --Decreases oxidative capacity

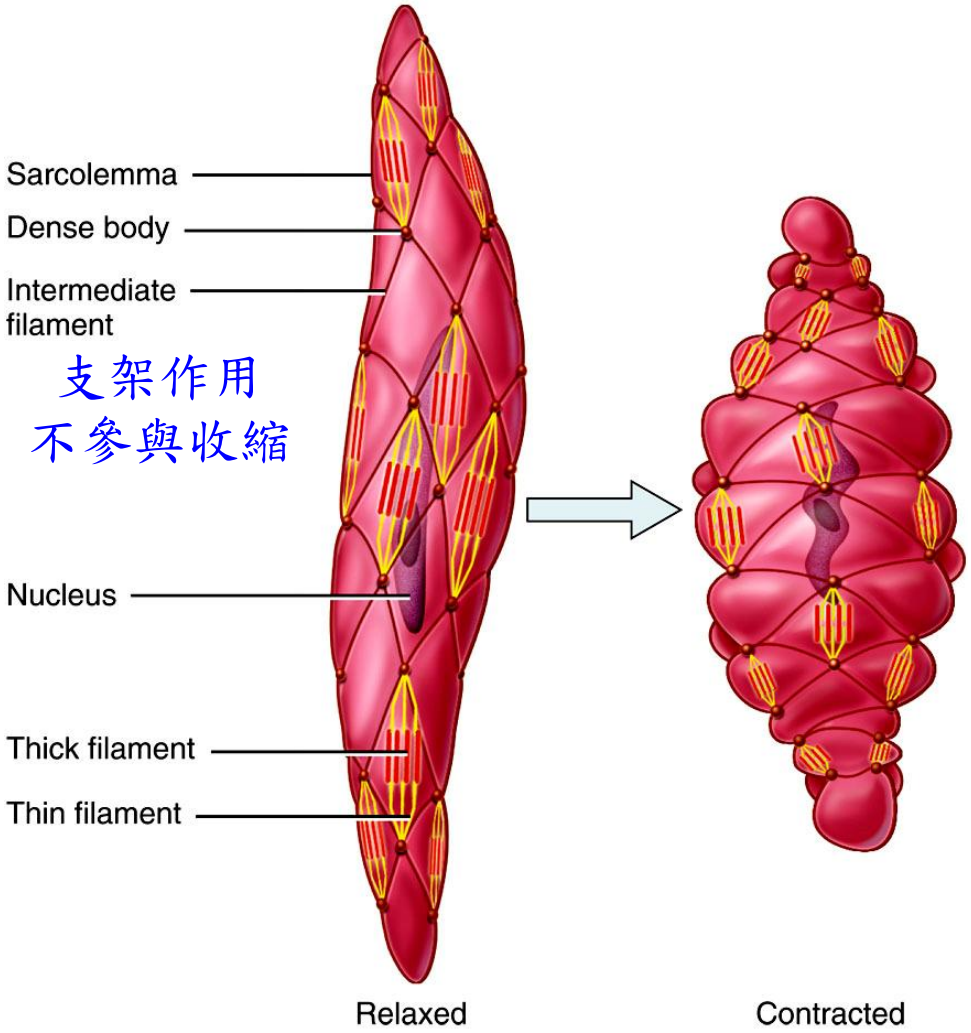
Properties of Smooth Muscle

- Spindle-shaped
- Small, approximately 1/10 skeletal
- No striations
- Contains actin and myosin

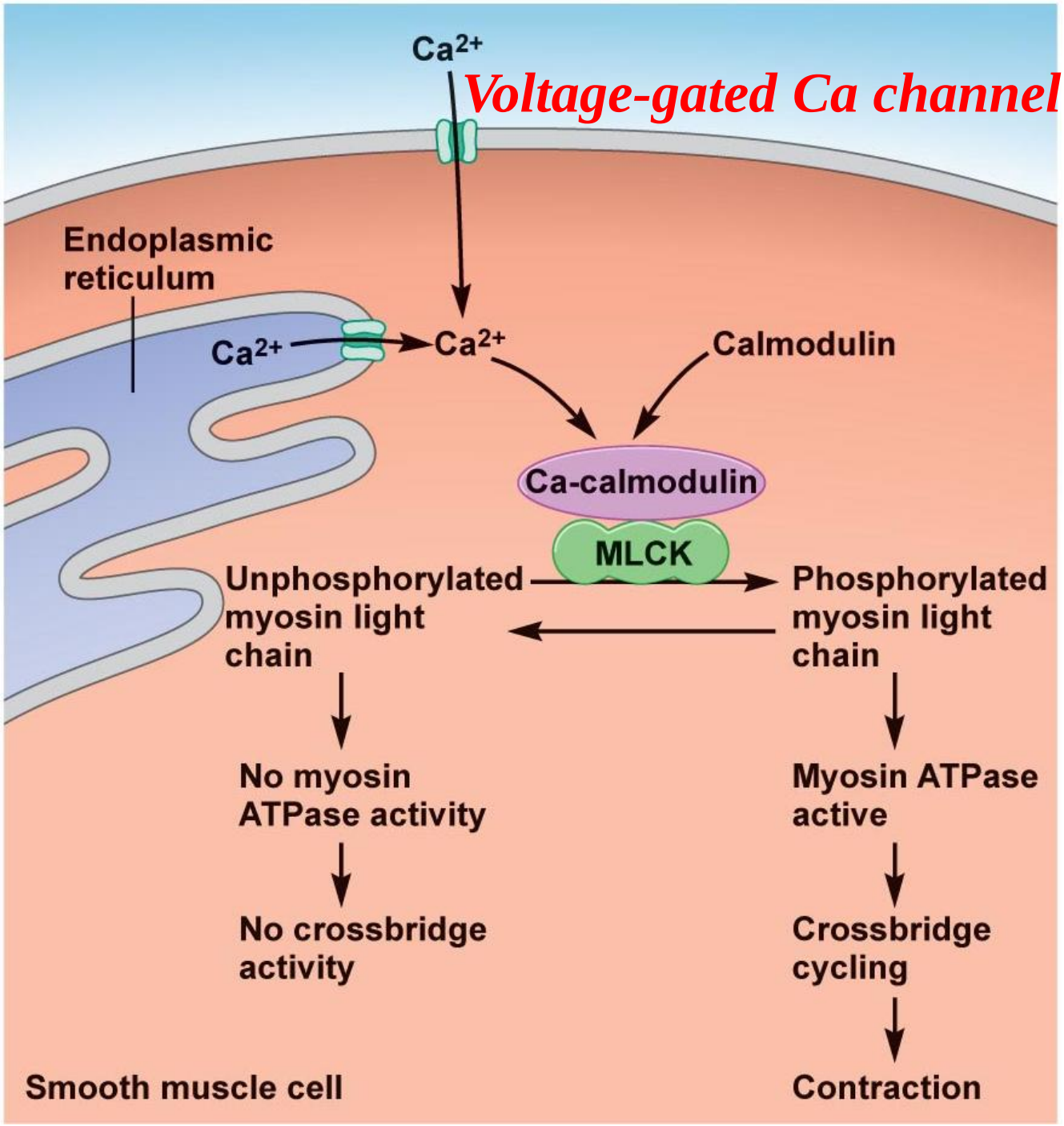


Properties of Smooth Muscle

- No sarcomeres
- Higher actin:myosin ratio
- Actin and myosin much longer
- Myosin heads over entire length
- Arranged diagonally
- One nucleus per fiber (cell)
- Tropomyosin
- No troponin
- Dense bodies analogous to Z line
- Slow myosin ATPase activity
- Myosin has light chains
- Little sarcoplasmic reticulum



Excitation-Contraction Coupling



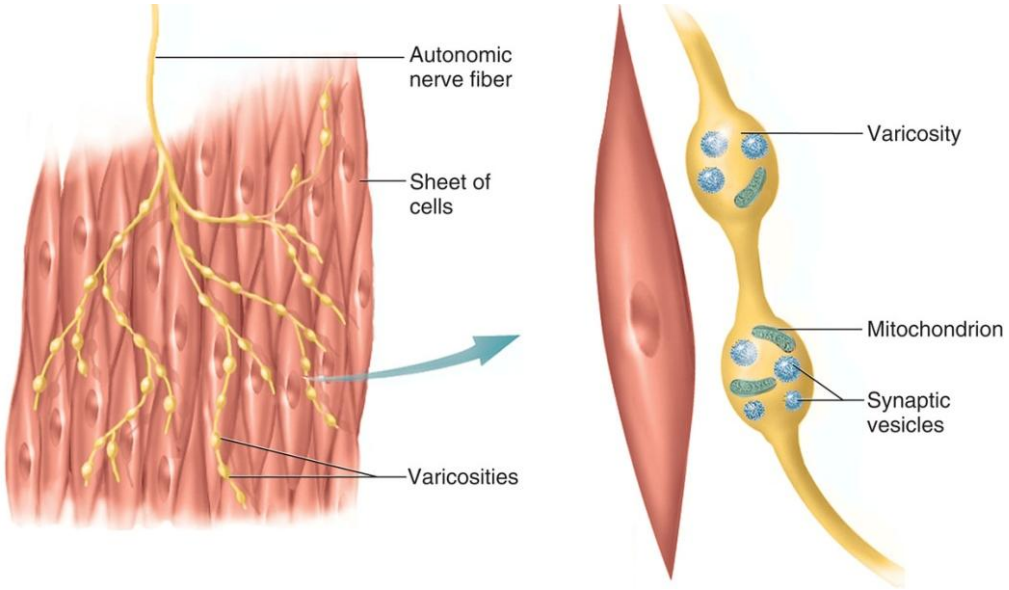
骨骼肌的興奮收縮偶合	平滑肌的興奮收縮偶合
1. 運動神經興奮會使肌漿質網側囊把鈣離子釋放至肌漿質內。 2. 鈣離子與細肌絲上的Tn結合Tn的形狀改變，因而牽動Tm，使得肌動蛋白上的橫橋接合位置裸露出，粗肌絲的橫橋即可接合到細肌絲上 3. ATP水解所釋放的能量會造成橫橋的強移，使得粗肌絲兩端的細肌絲滑向肌絲的中央，肌節就會縮短。 4. 若肌肉要繼續收縮下去，就要持續不斷產生橫橋週期。	1. 自主神經興奮會使肌漿質網側囊鈣離子釋放及細胞間液的鈣離子流入(主要)。 2. 肌漿質內鈣離子和攜鈣素(calmodulin)結合，形成複合體。 3. 複合體會和肌凝蛋白輕鏈激酶(myosin light-chain kinase)結合並活化。 4. 該激酶利用肌漿質內的ATP磷酸化粗肌絲肌凝蛋白的橫橋。 5. 磷酸化的橫橋則會結合至細肌絲肌動蛋白上進行橫橋週期而讓肌肉縮短。

Smooth Muscle Relaxation

- Calcium is pumped out using **calcium ATPase active transport pumps (Ca pump)**
- Calmodulin **dissociates** from myosin light chain kinase (MLCK)
- Phosphate groups are stripped from the myosin by **myosin phosphatase (de-P)**

Neural Regulation of Smooth Muscle Contraction

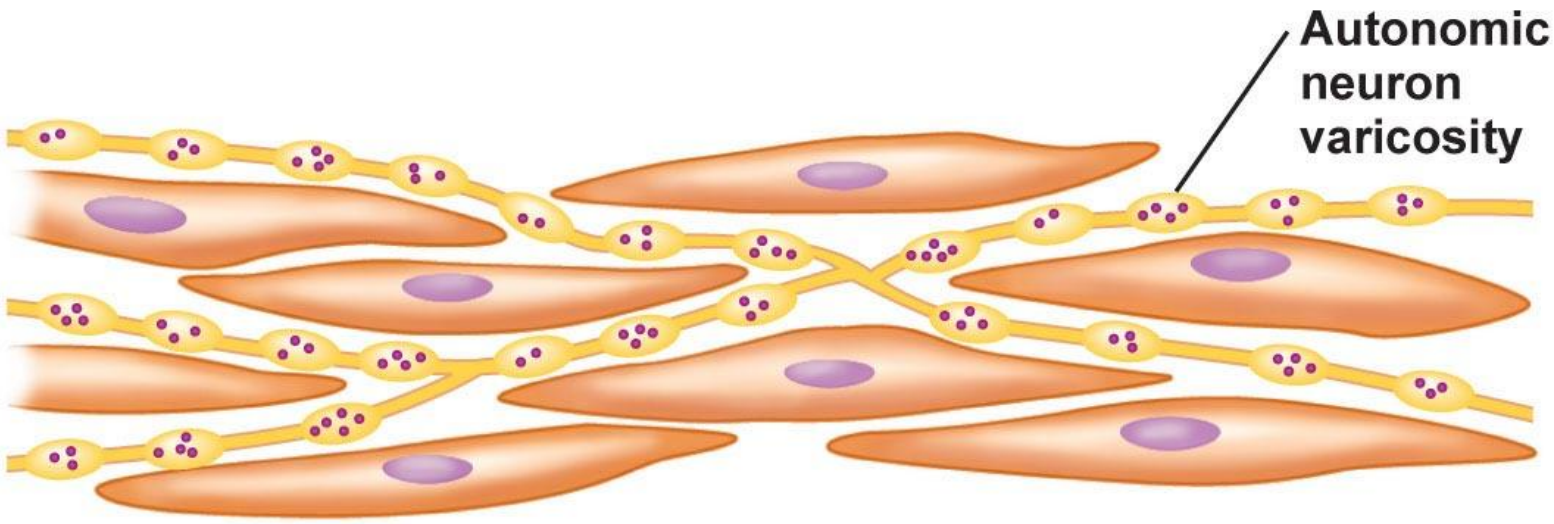
- Innervated by **autonomic nervous system**
  --Sympathetic and/or parasympathetic
- May be **excitatory or inhibitory**
- Target cell response depends on **receptor type**
- Neurotransmitter released from varicosities
- Diffuse binding of neurotransmitter to receptors
- Action potentials in smooth muscle are **calcium-mediated**
  --Slower
  --Longer duration
  --Lower strength



Non-Neural Regulation of Contraction

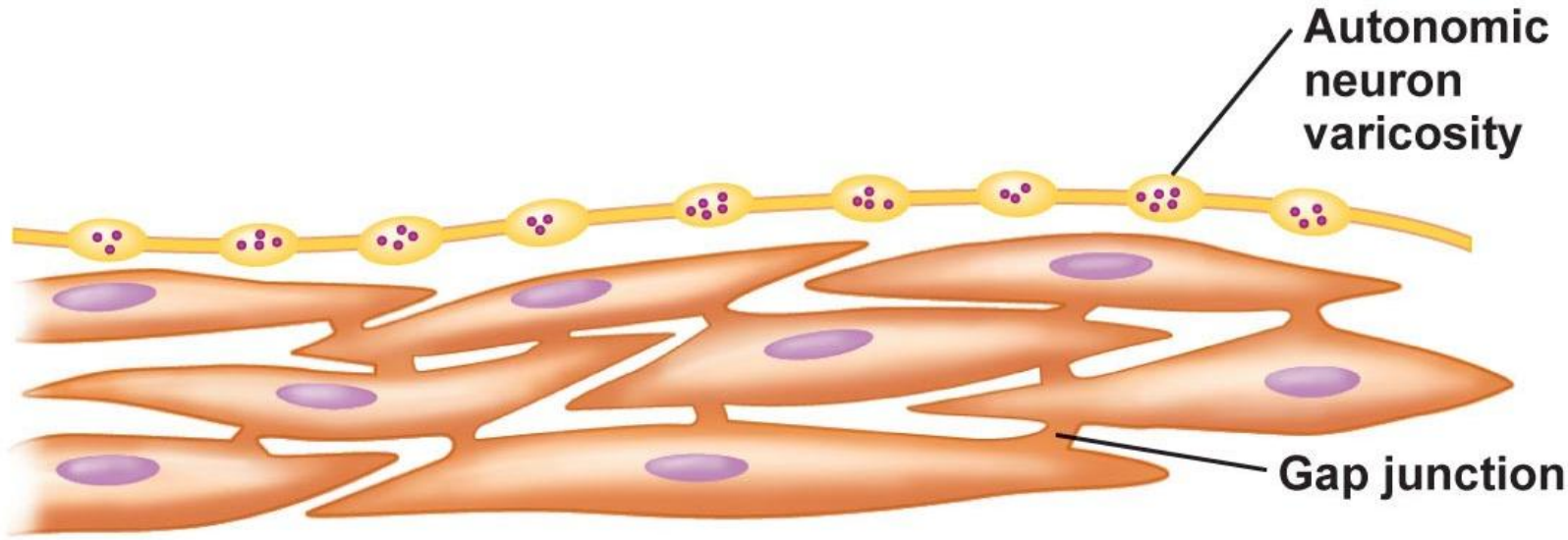
- **Intracellular [Ca]** determines tension (spontaneous electrical activity)
- Intracellular [Ca] influenced by
  - --Neural control—autonomic nervous system
  - --Hormonal control (ex. epinephrine)
  - --Paracrines (local controls ex. PG, O_2)
  - --Stretch

Classification of Smooth Muscle



神經性

(a) Multi-unit smooth muscle

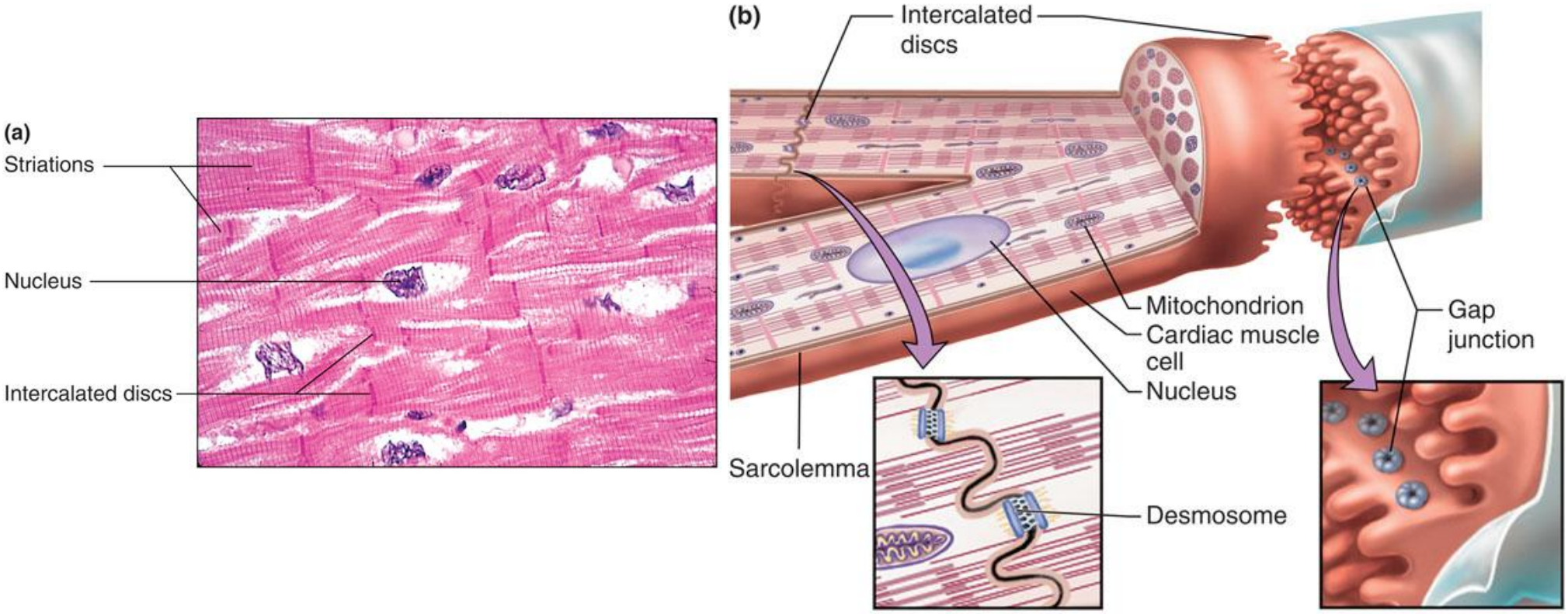


內臟性=功能性

(b) Single-unit smooth muscle

名稱	特性
Single-unit smooth muscles	1. Most common type 2. Pacemaker cells (has tone) --with spontaneous depolarizations (pacemaker potentials) 3. **Location:** GI tract, small blood vessels, respiratory tract, uterus, ureter and bladder 4. Innervation to few cells 5. Muscle fibers activated synchronously --Fibers connected by gap junctions --Contract together as a single unit
Multi-unit smooth muscles	1. **Location:** large airways and arteries, eye (ciliary muscle and iris), vas deferens and arrector pili muscles in skin 2. Few if any gap junctions 3. Each fiber acts individually 4. Receives own innervation 5. No tone

Cardiac Muscle



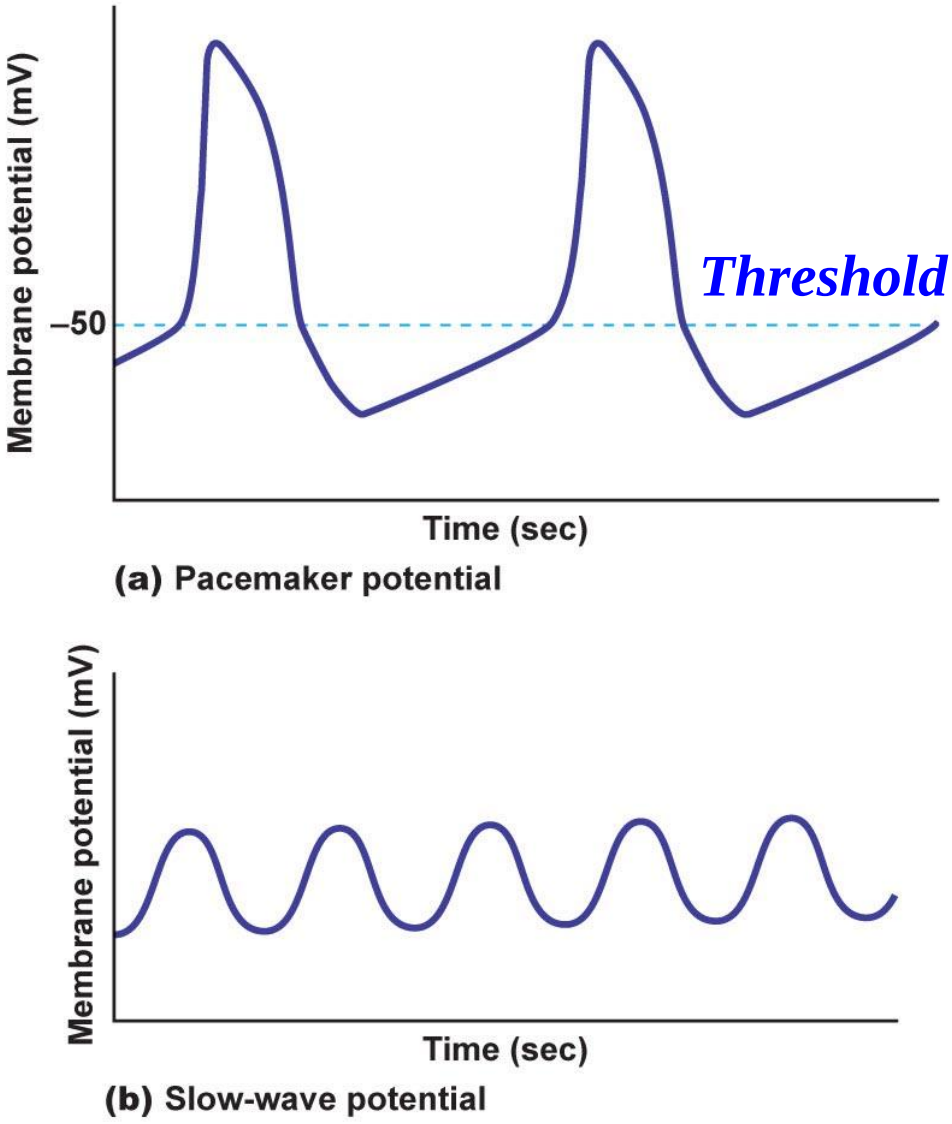
- Striated , short, quadrangular-shaped, branching fibers
- Single centrally located nucleus
- Cells connected by intercalated discs with gap junctions
- Same arrangement of thick & thin filaments as skeletal

Cardiac Muscle

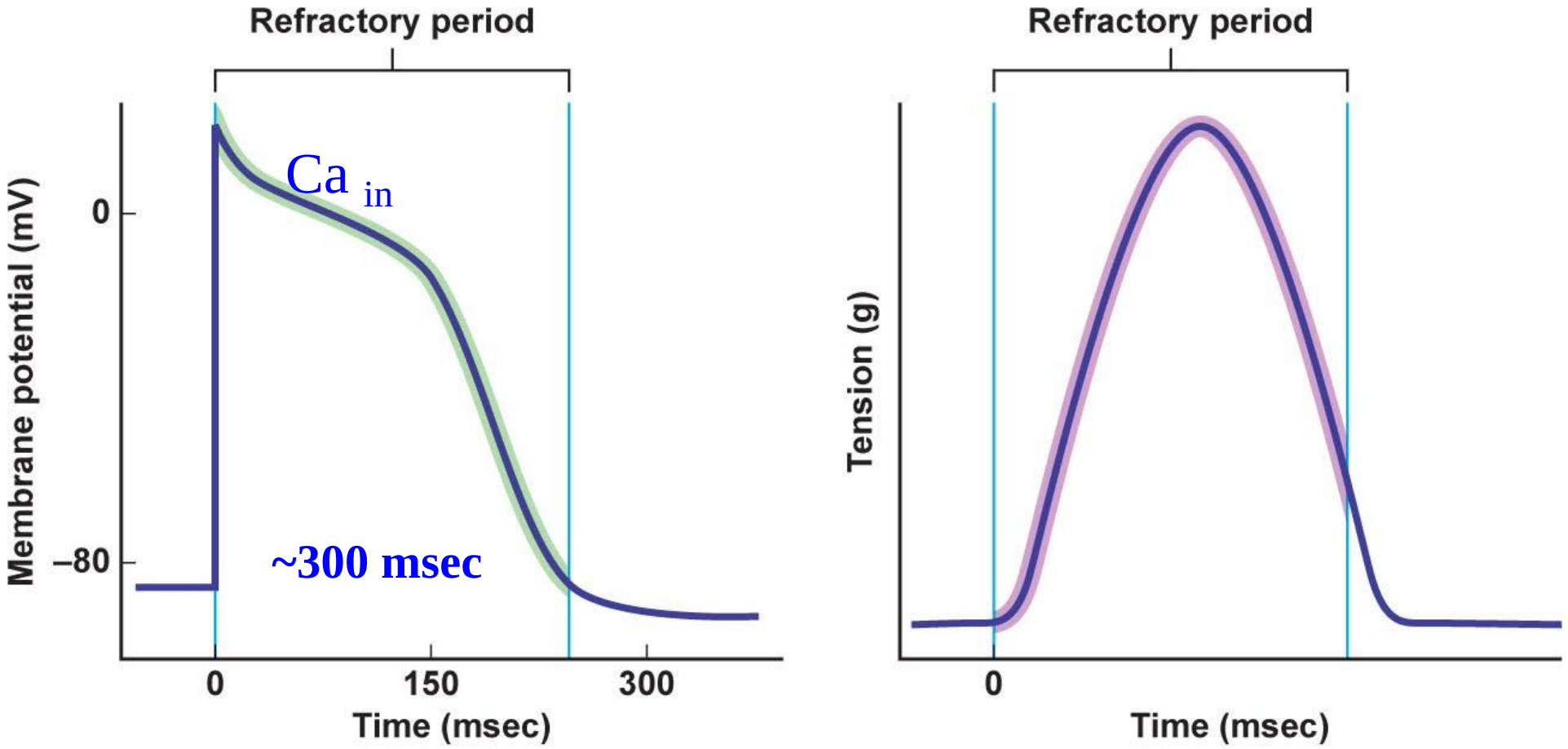
- **Similarities with Skeletal Muscle**
  - --Striated
    - Sarcomeres
  - --Troponin AND tropomyosin regulation
  - --T tubules
  - --Sarcoplasmic reticulum, but not as well developed
  - --Similar to slow oxidative fibers
    - Myoglobin
    - Mitochondria
    - Slow to fatigue

Cardiac Muscle

- **Similarities with Smooth Muscle**
  - --Gap junctions (within intercalated disks)
  - --Pacemaker (rhythmic) cells
  - --Innervated by autonomic nervous systems
  - --Influenced by hormones, paracrines
  - --Calcium comes from extracellular fluid and sarcoplasmic reticulum

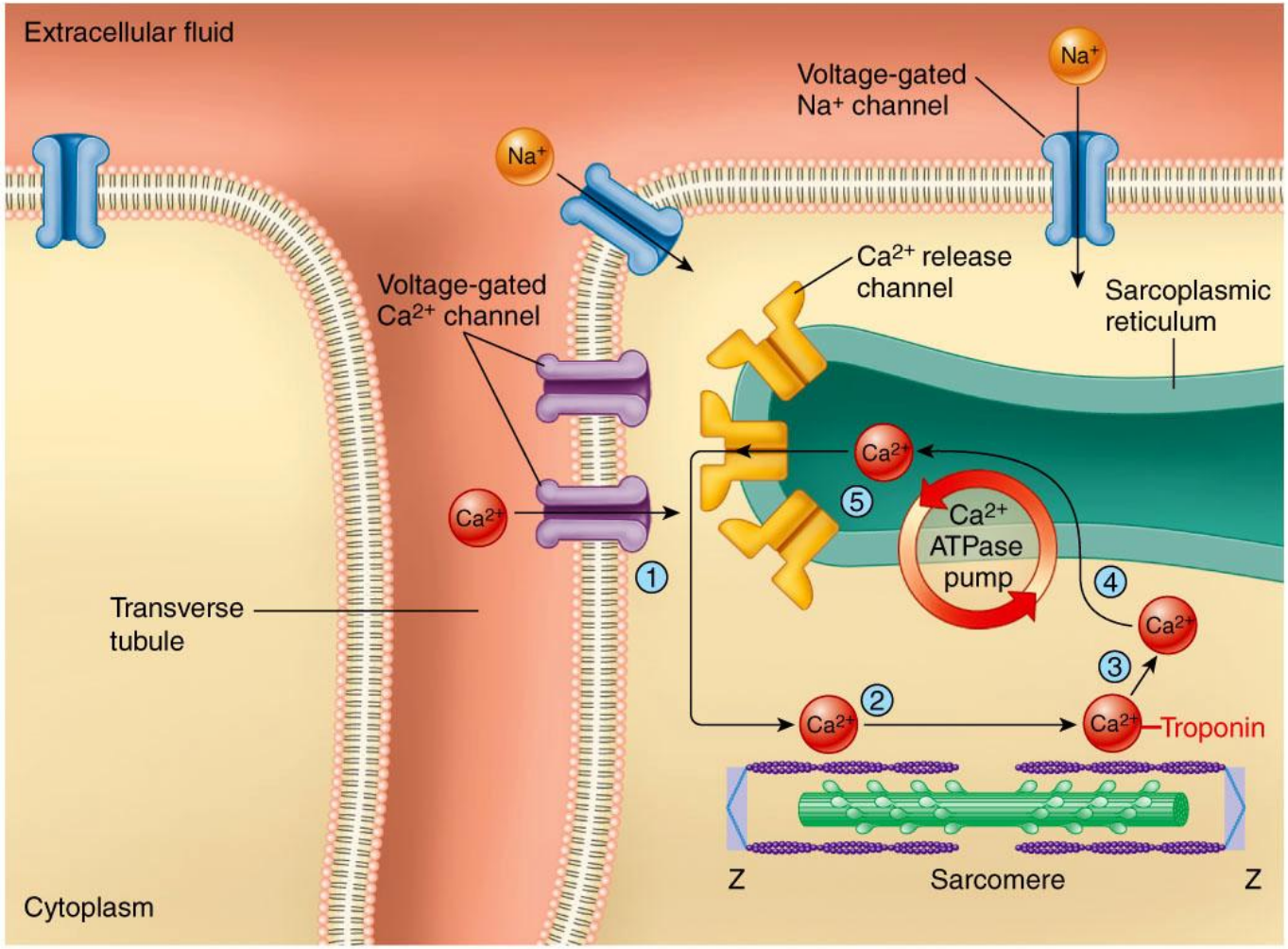


Cardiac Muscle



- Action potential lasts almost as **long** as tension
- **No summation** due to long refractory period

ECC in Cardiac Muscle



- Unlike skeletal muscle, the voltage-gated Ca channels are not directly connected to Ca channels on the SR(ryanodine receptor)
  - --Instead, calcium acts as a second messenger to open SR channels
  - --Called **calcium-induced calcium release**
  - --Excitation-contraction coupling is slower

特性	骨骼肌（skeletal）	心肌（cardiac）	平滑肌（smooth）
主要位置	骨骼上的肌肉	心臟臟壁	中空內臟腔壁如呼吸道、血管等
主要功能	支撐運動有關	心臟搏動促成循環	通常屬於內臟肌形成消化及內臟運動
結構特徵	周圍佈滿細胞核(多核)的長圓柱型，有條紋(橫紋肌)	中央位置有細胞核(單核)的分支長圓柱型，鄰近之間有肌間盤(intercalated discs)，有條紋(橫紋肌)	成梭狀中間較厚，中央位置有細胞核(單核)，無條紋(非橫紋肌)
纖維直徑	大(10~100 μm)	中(10~20 μm)	小(3~8 μm)
纖維長度	100 μm ~30 cm	50~100 μm	30~200 μm
肌節	有	有	無
肌漿質網	豐富	一些	很少
T小管	有，排列在每個A-I 帶處	有，排列在每個Z盤處	無
纖維間接合	無	肌間盤內有間隙接合和胞橋體	間隙接合在內臟的平滑肌；在多單位平滑肌中沒有
自主性收縮	無	有	有，在內臟平滑肌
提供收縮的鈣離子來源	肌漿質網	肌漿質網&組織間液	肌漿質網&組織間液
收縮調節蛋白	旋轉肌球素與旋轉素	旋轉肌球素與旋轉素	攜鈣素與肌凝蛋白輕鏈激酶(myosin light-chain kinase)
收縮速度	快	中	慢
神經控制	隨意（運動神經）	不隨意(自主神經)	不隨意(自主神經)
藉由何物調節收縮	由運動神經釋放乙醯膽鹼	乙醯膽鹼以及自主神經釋放正腎上腺素及少數荷爾蒙	乙醯膽鹼以及自主神經釋放正腎上腺素、少數荷爾蒙及化學媒介物
再生能力	有限(衛星細胞)	有極限(某些條件)	可以