BHARATHIDASAN UNIVERSITY

Tiruchirappalli- 620024,
Tamil Nadu, India

Programme: M.Sc., Biomedical science

Course Title : Human Anatomy & Physiology

Course Code : BM12C2

Unit-II

TOPIC: Muscle Physiology

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Muscular System Functions

- Body movement
- Maintenance of posture
- Respiration
- Production of body heat
- Communication
- Constriction of organs and vessels
- Heart beat

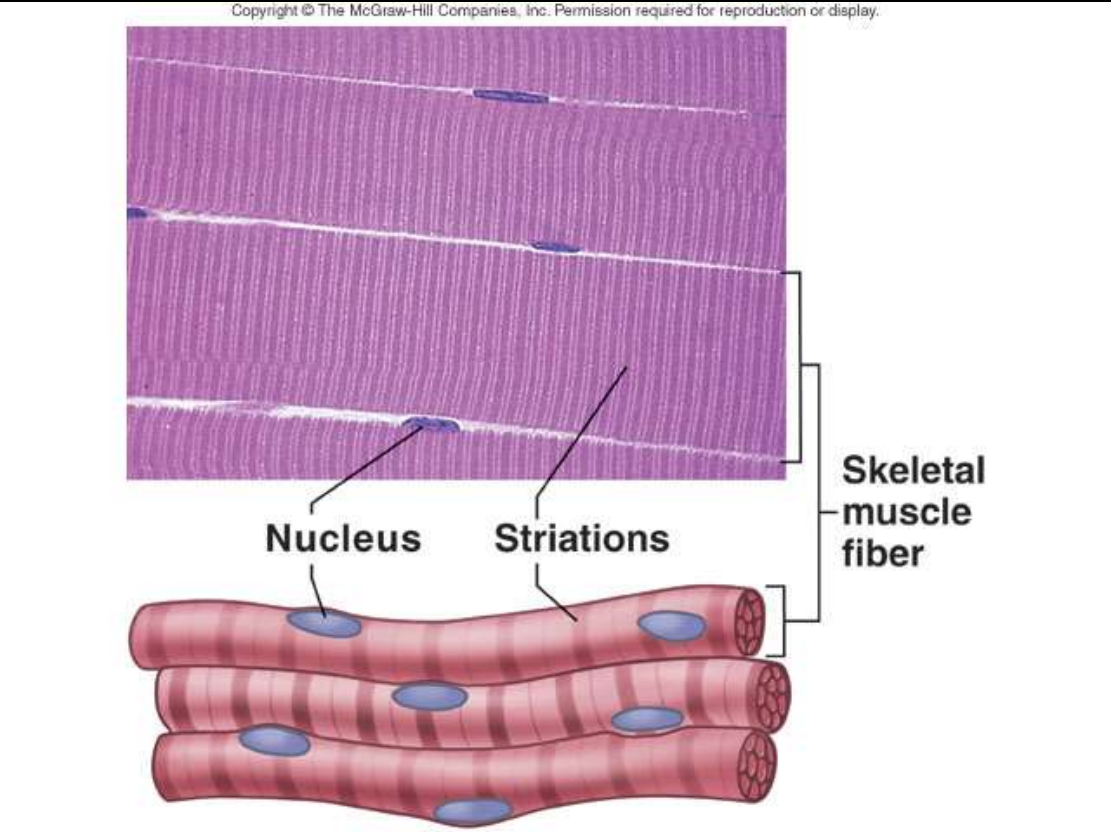
Properties of Muscle

- Contractility
  - Ability of a muscle to shorten with force
- Excitability
  - Capacity of muscle to respond to a stimulus
- Extensibility
  - Muscle can be stretched to its normal resting length and beyond to a limited degree
- Elasticity
  - Ability of muscle to recoil to original resting length after stretched

Muscle Tissue Types

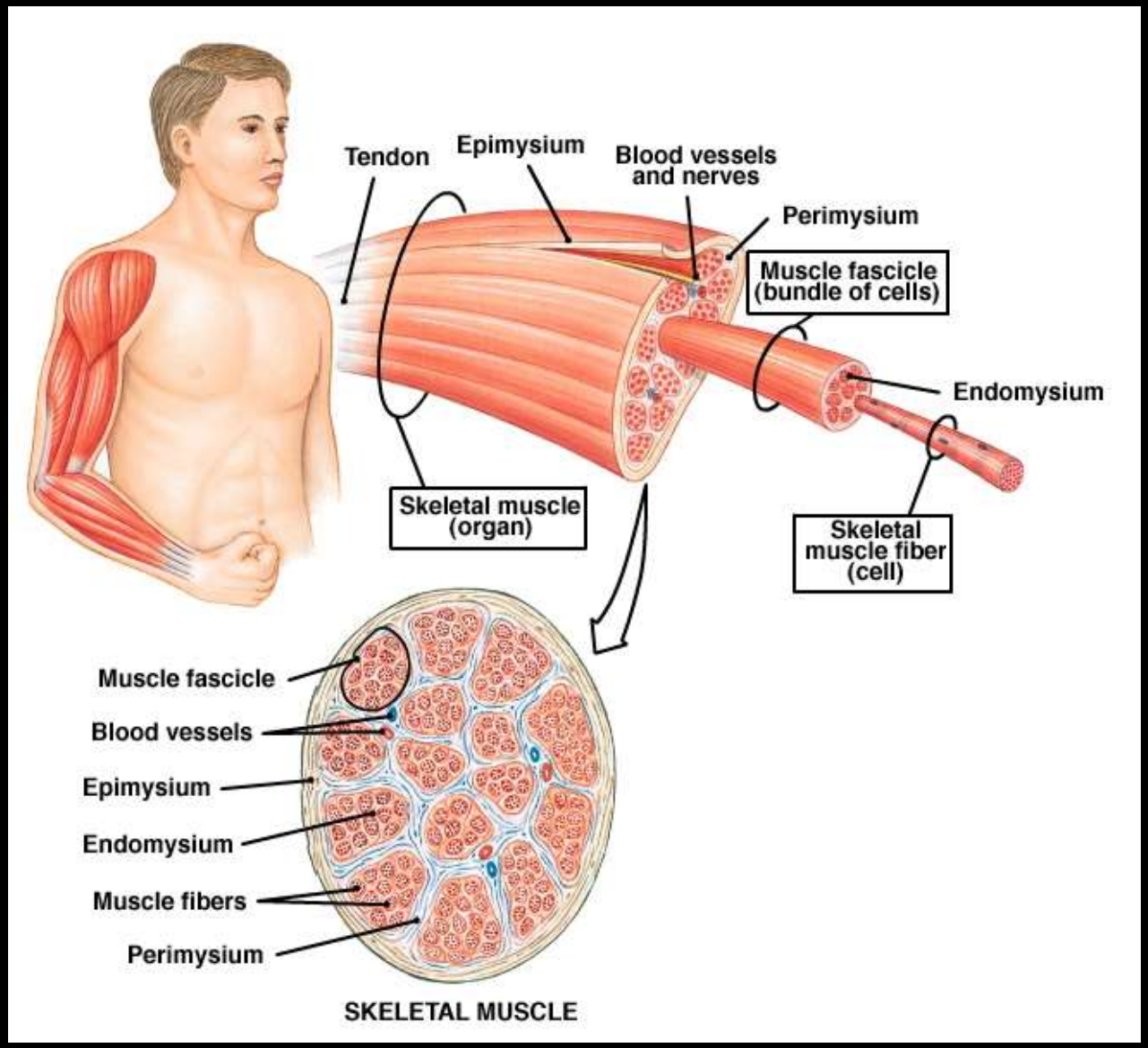
- Skeletal
  - Attached to bones
  - Nuclei multiple and peripherally located
  - Striated, Voluntary and involuntary (reflexes)
- Smooth
  - Walls of hollow organs, blood vessels, eye, glands, skin
  - Single nucleus centrally located
  - Not striated, involuntary, gap junctions in visceral smooth
- Cardiac
  - Heart
  - Single nucleus centrally located
  - Striations, involuntary, intercalated disks

Skeletal Muscle Structure

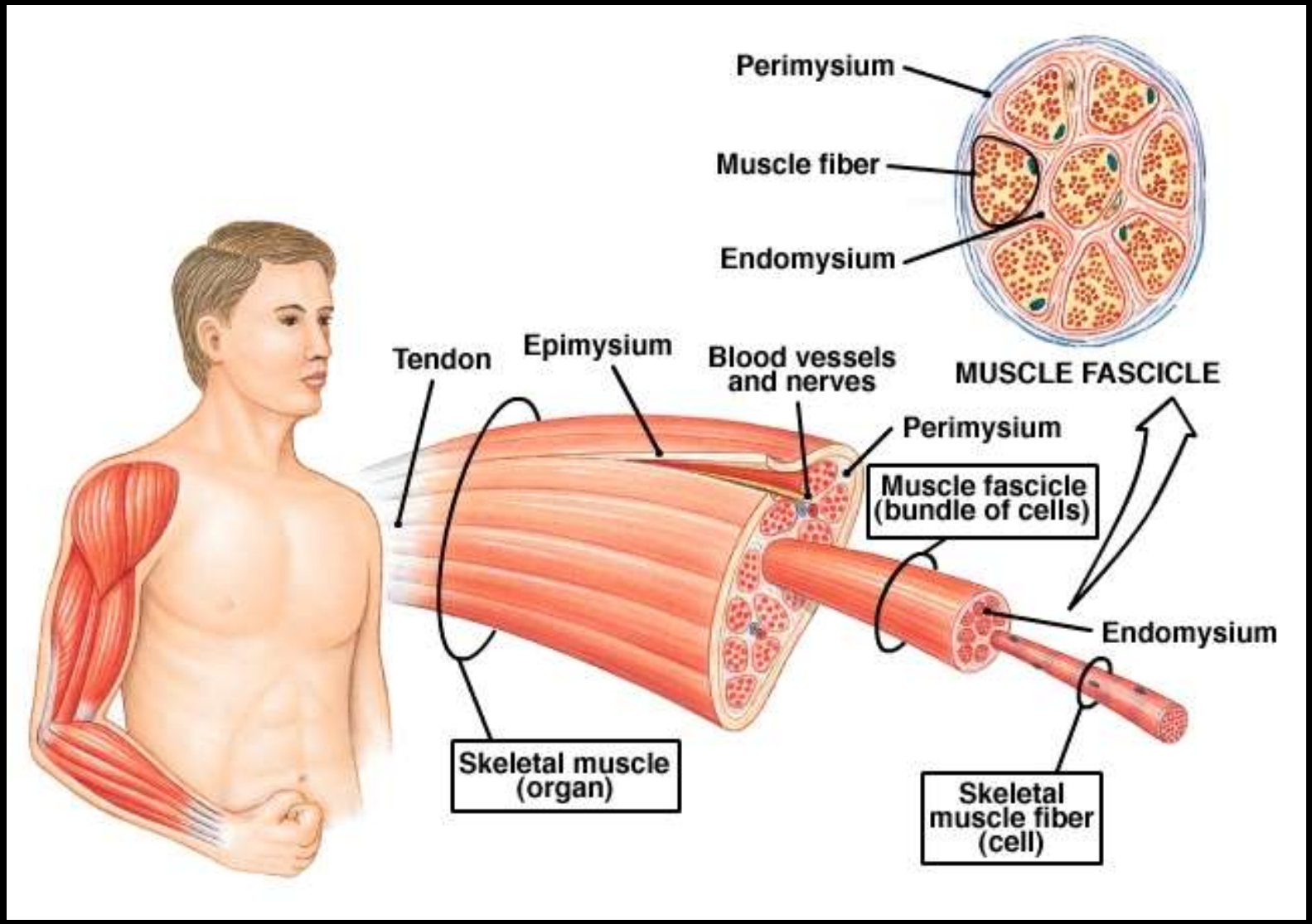


- Muscle fibers or cells
  - Develop from myoblasts
  - Numbers remain constant
- Connective tissue
- Nerve and blood vessels

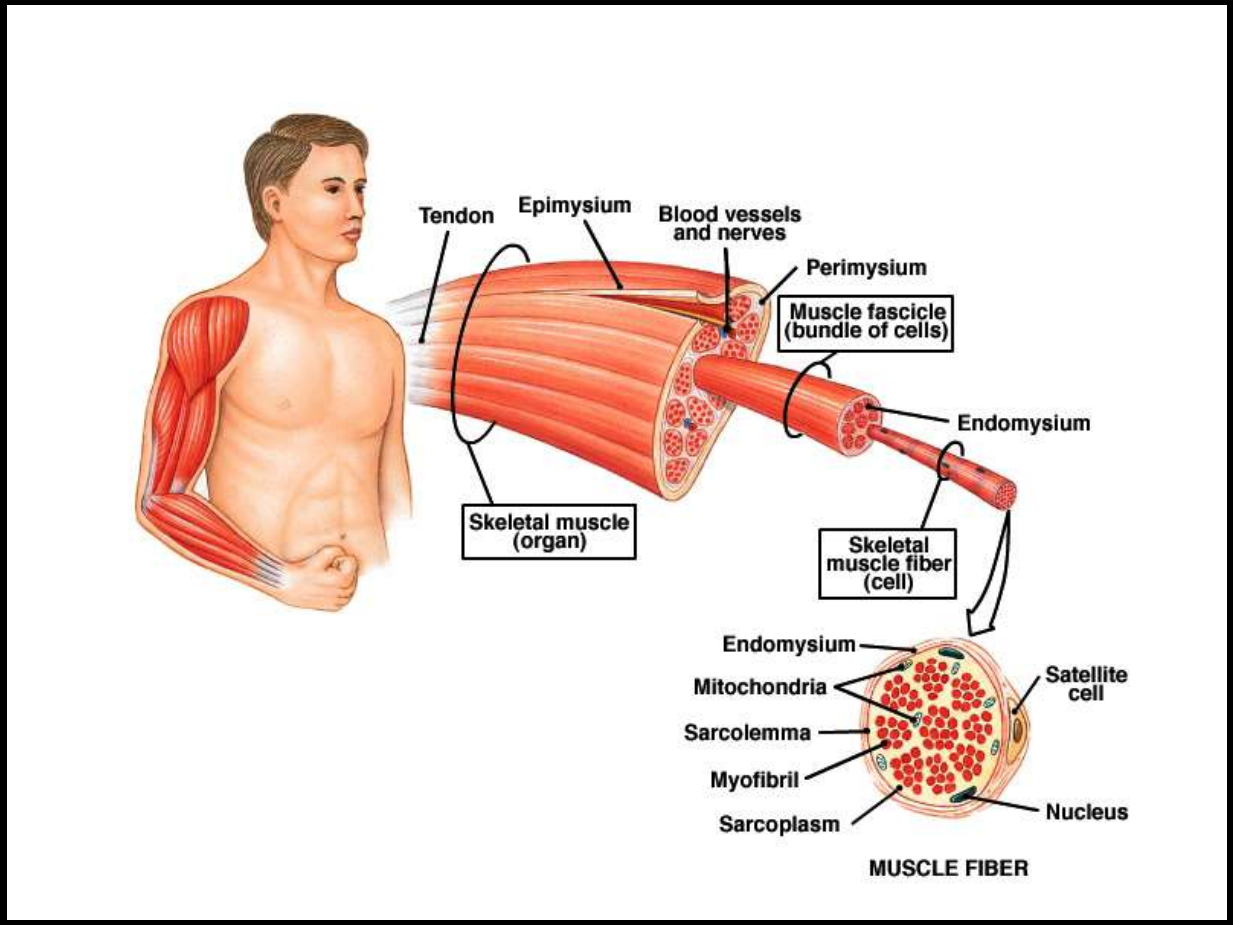
Organization I:



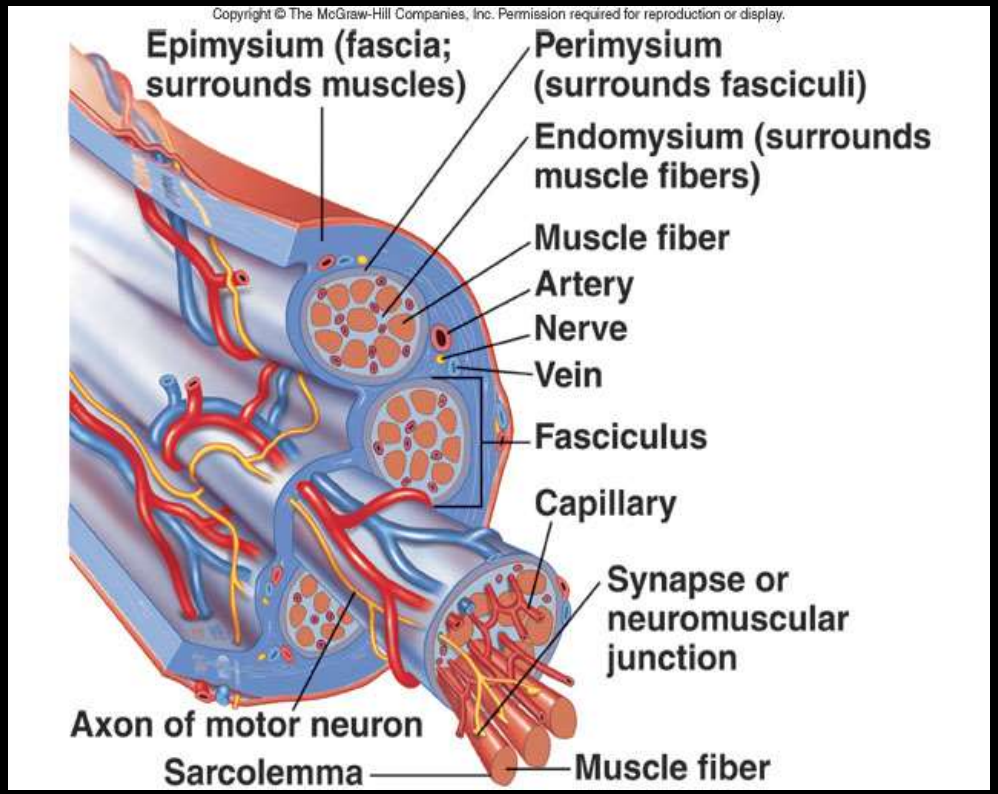
Organization II:



Organization III:

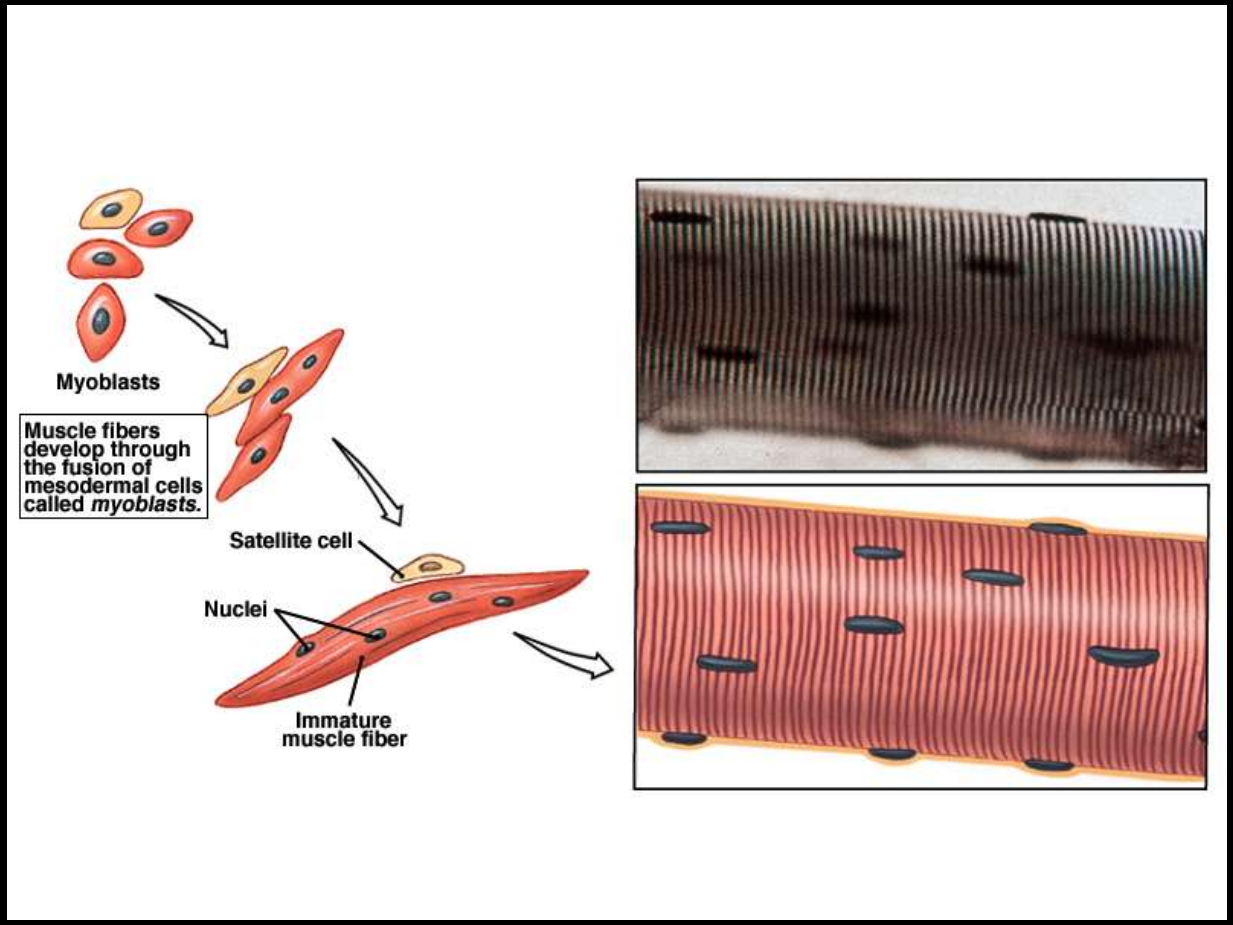


Connective Tissue, Nerve, Blood Vessels

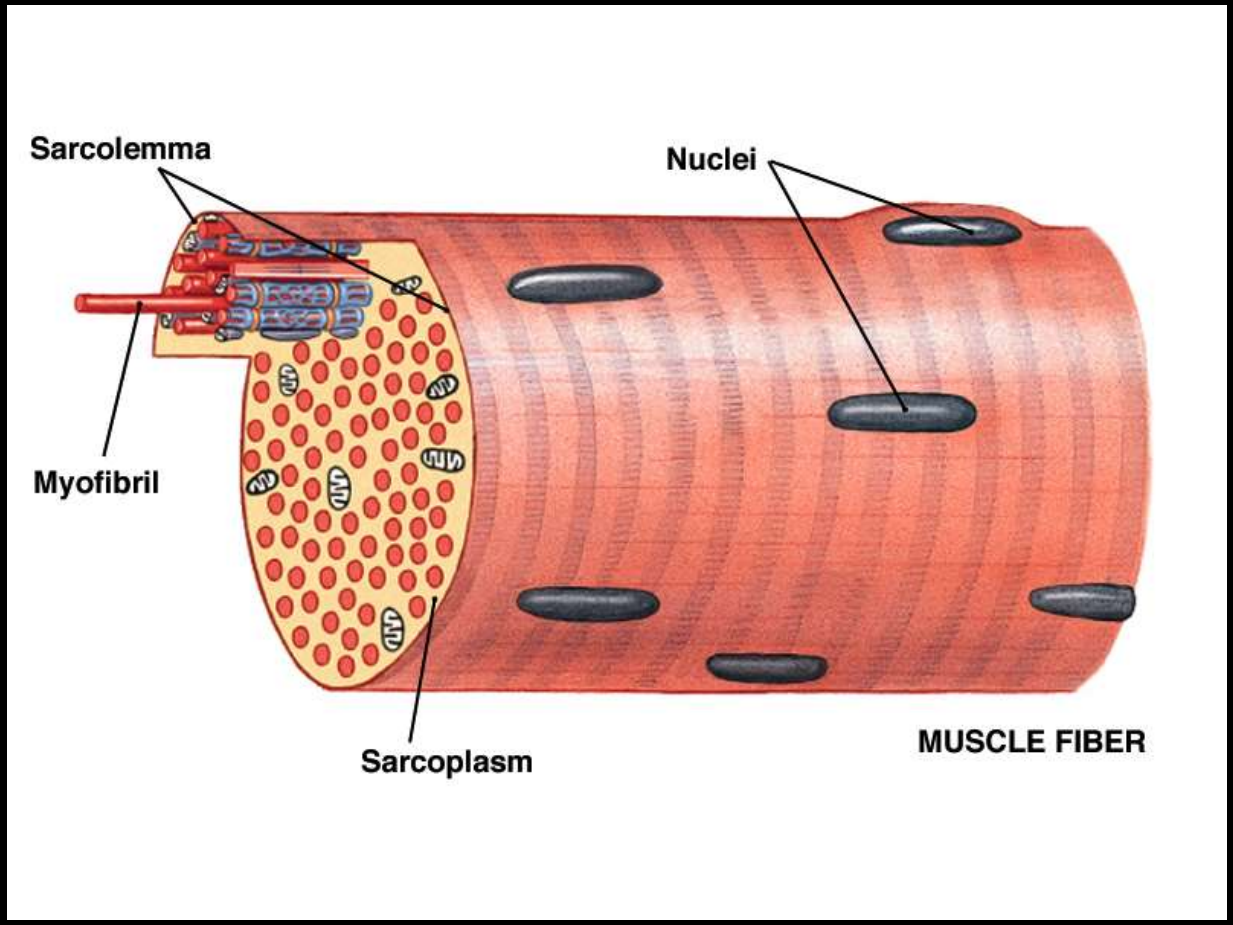


- Connective tissue
  - External lamina
  - Endomysium
  - Perimysium
  - Fasciculus
  - Epimysium
- Fascia
- Nerve and blood vessels
  - Abundant

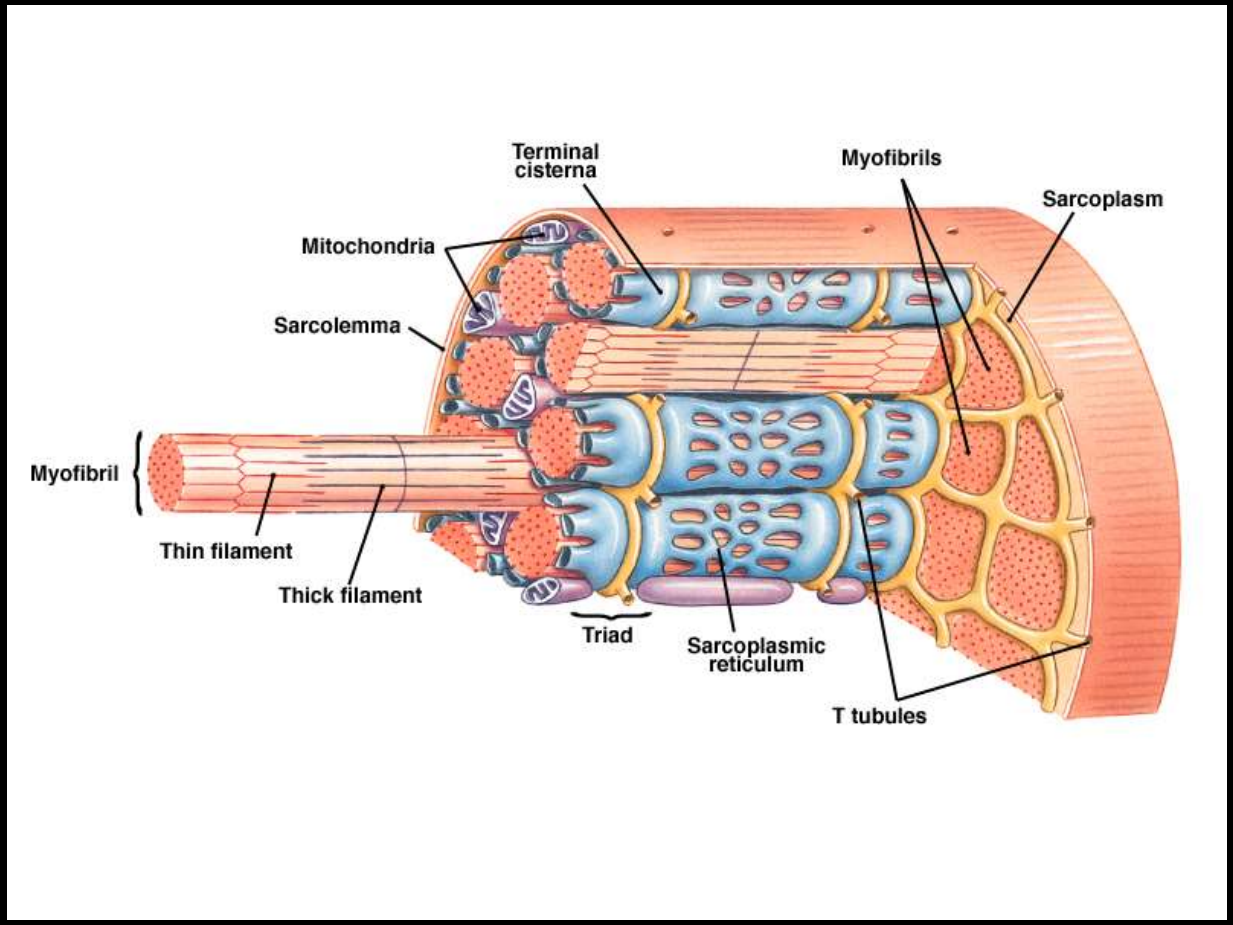
Embryologic origin:



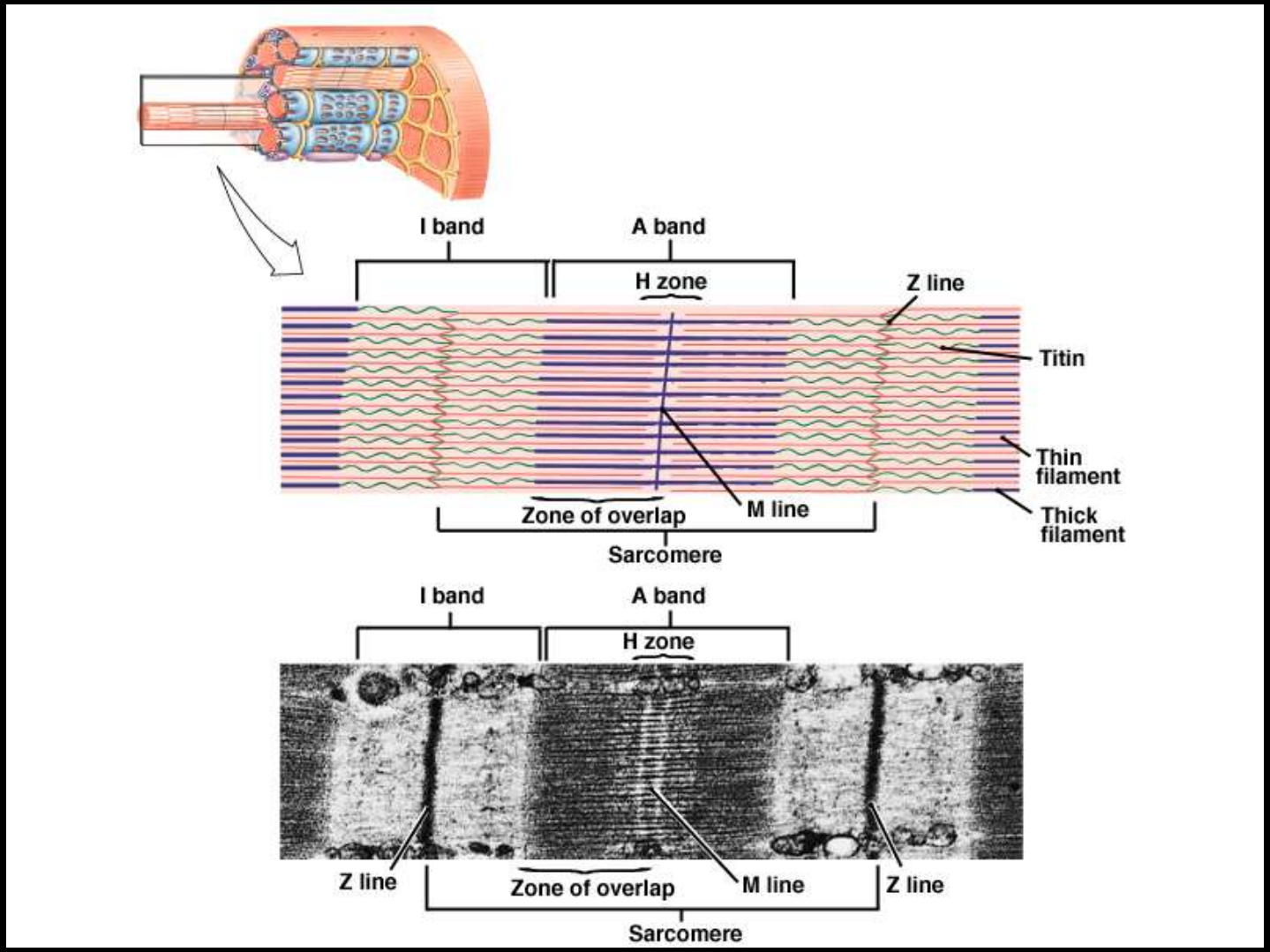
Muscle fibre:



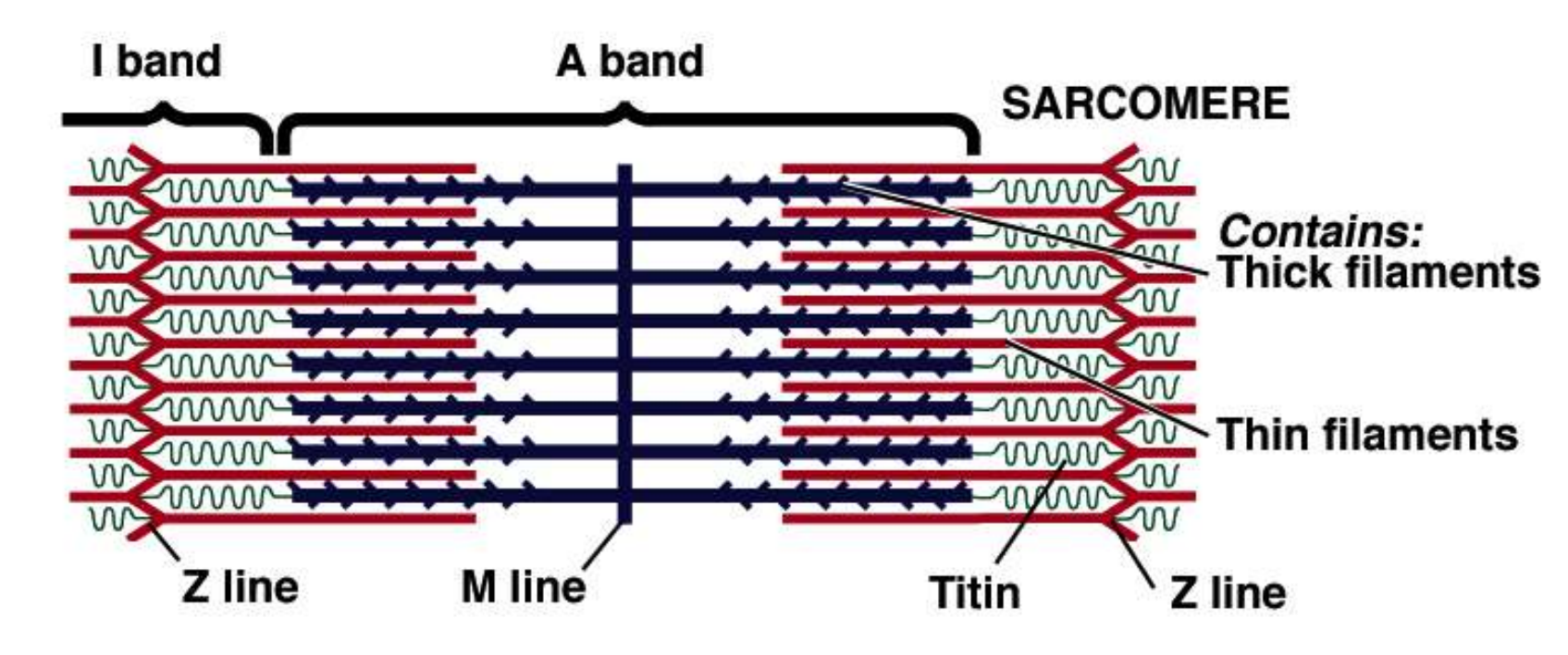
Internal organization:



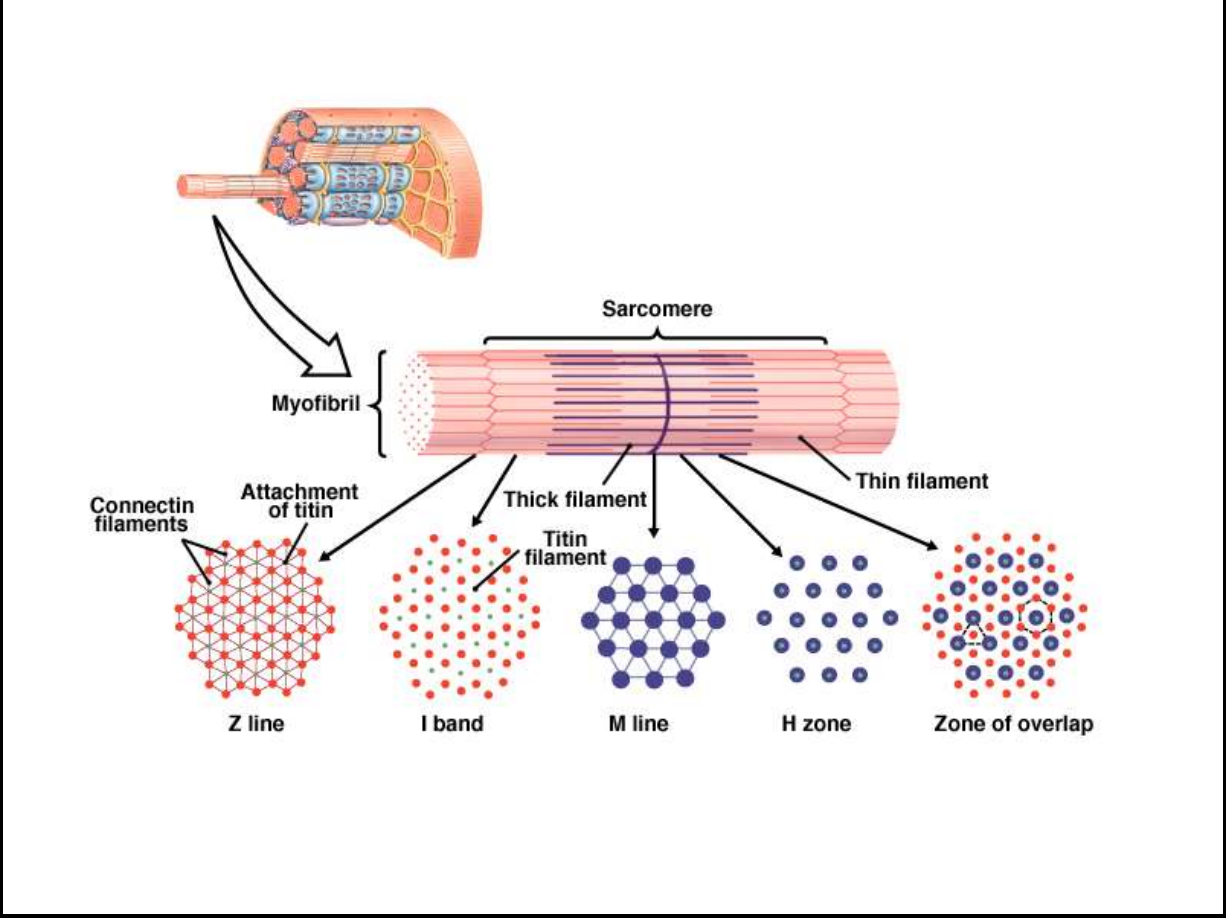
Striations:


I band
A band
H zone
Z line
Titin
Thin filament
Thick filament
M line
Zone of overlap
Sarcomere
I band
A band
H zone
Z line
Zone of overlap
M line
Z line
Sarcomere

Organization of myofilaments I:



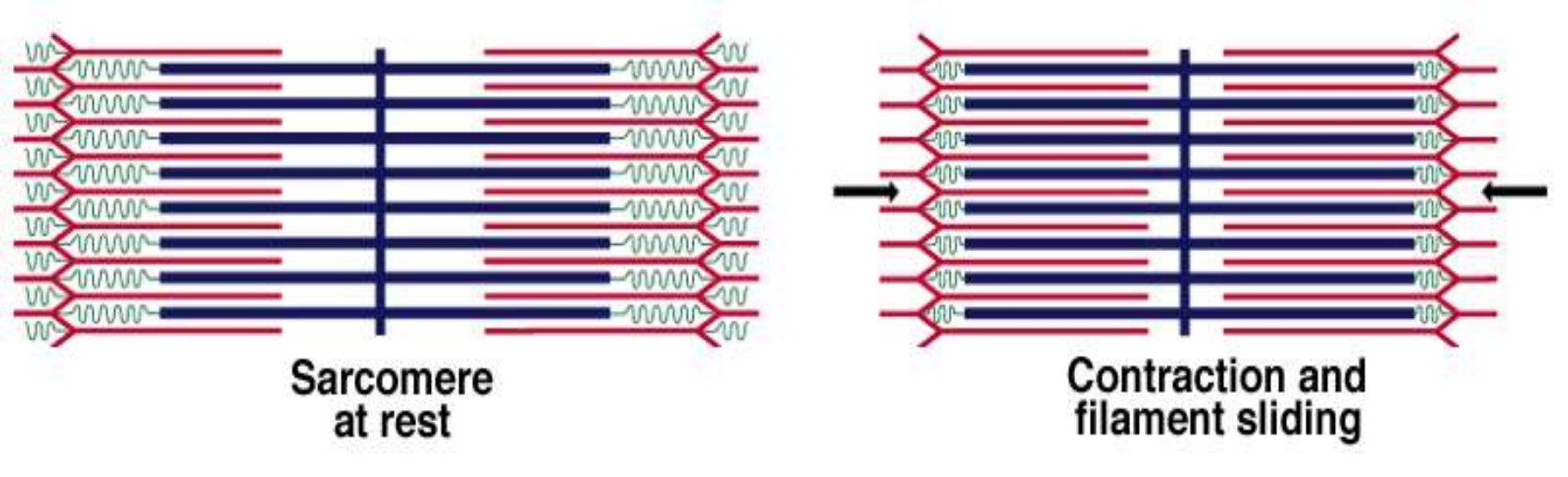
Organization of myofilaments II:



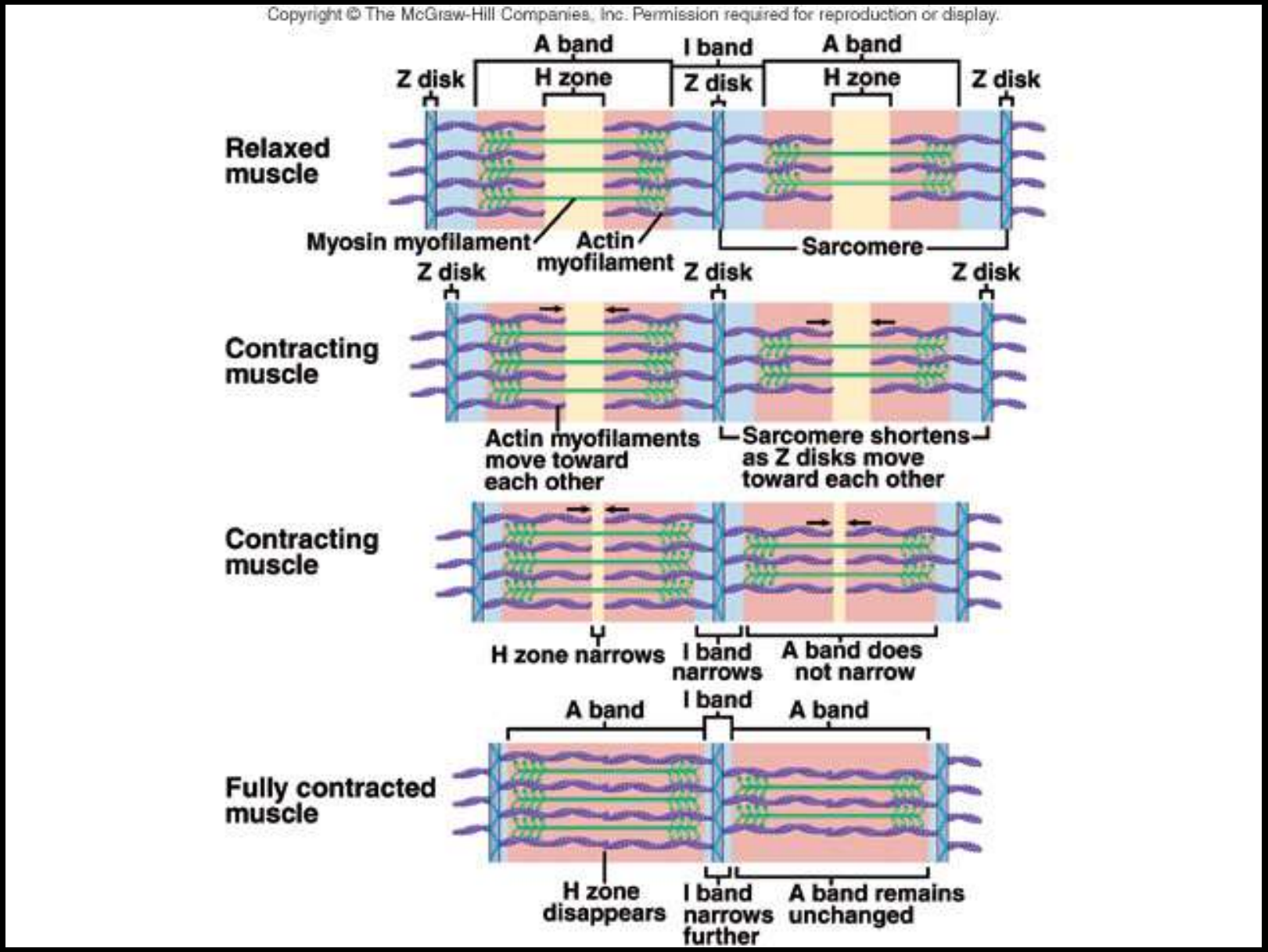
Sliding Filament Model I:

- Actin myofilaments sliding over myosin to shorten sarcomeres
  - Actin and myosin do not change length
  - Shortening sarcomeres responsible for skeletal muscle contraction
- During relaxation, sarcomeres lengthen

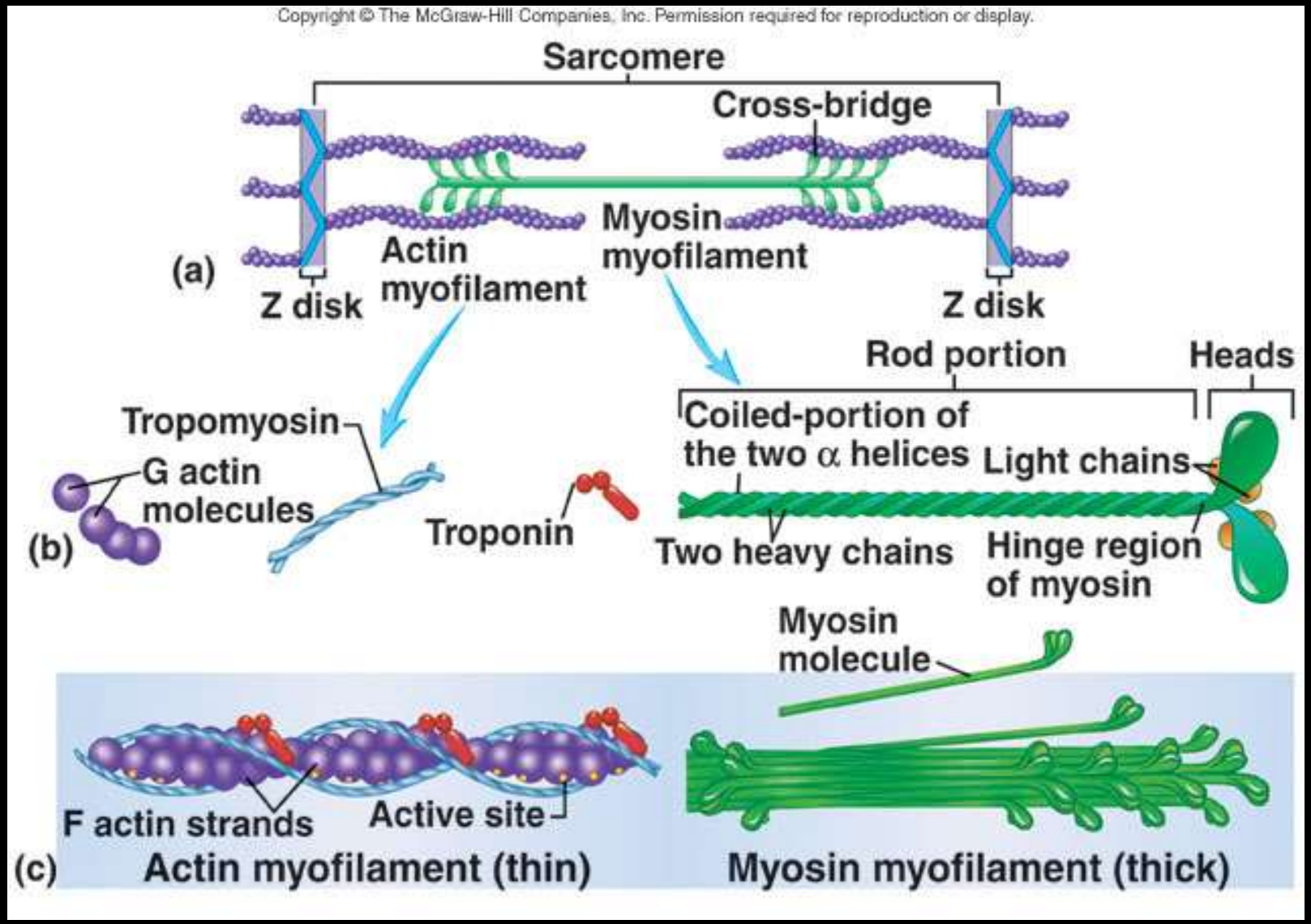
Sliding filament model II:



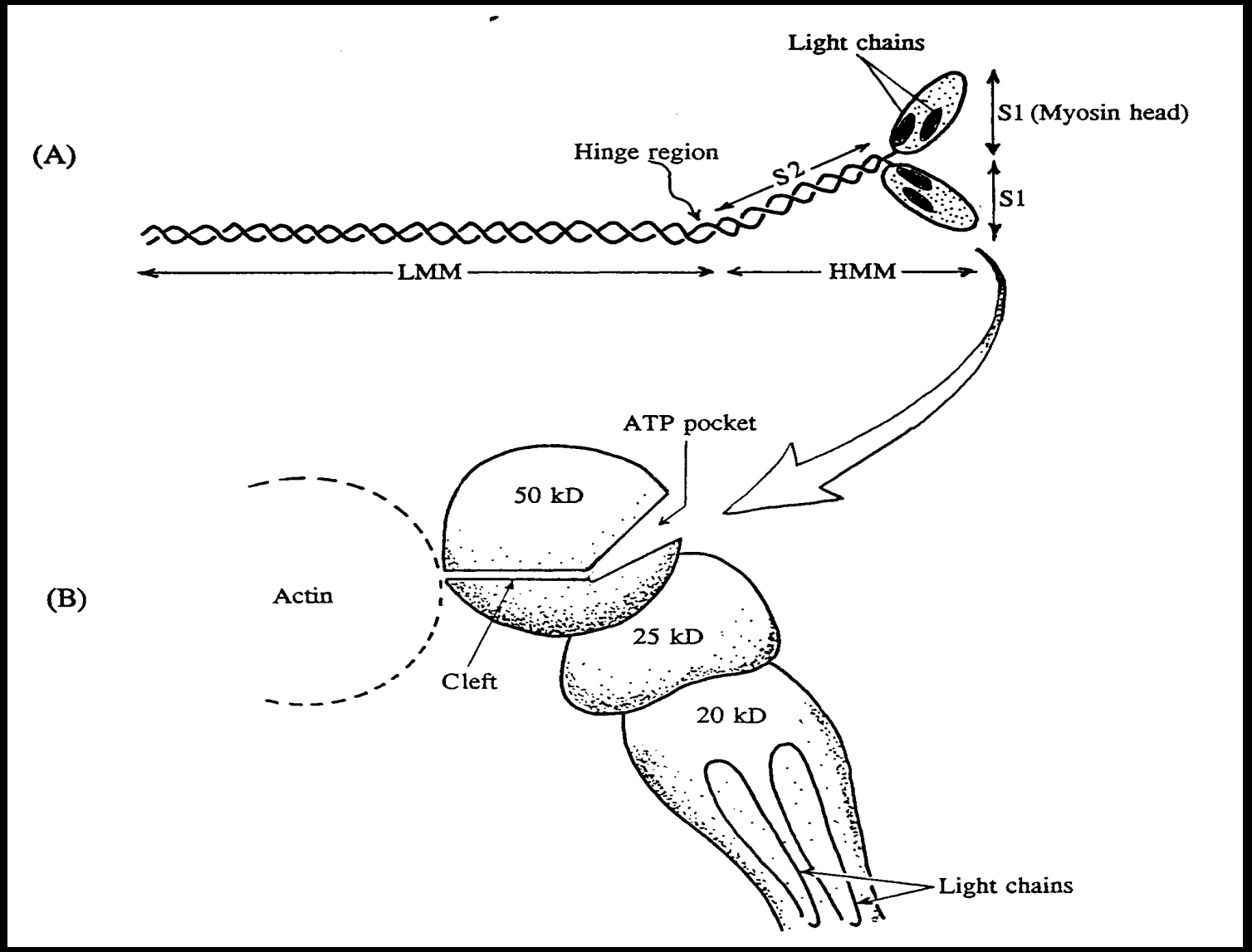
Sarcomere Shortening



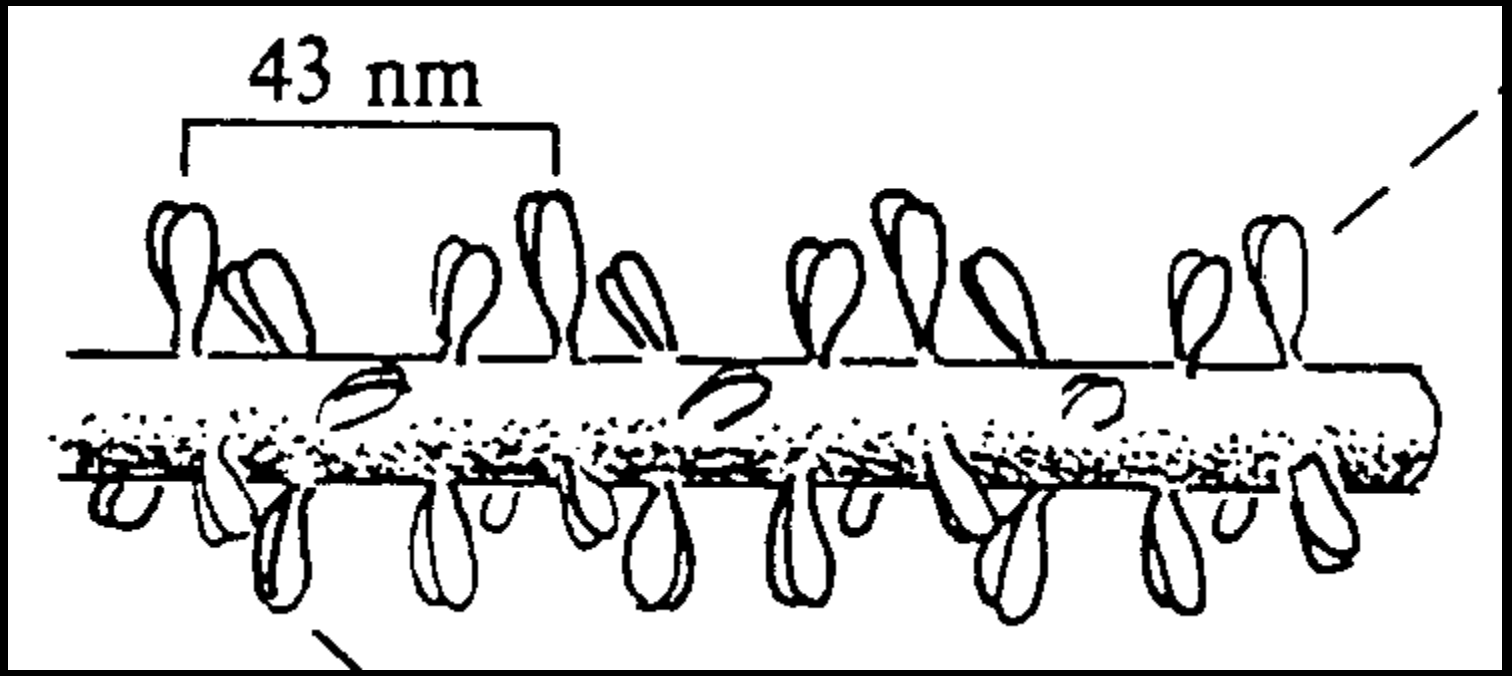
Structure of Actin and Myosin



Myosin structure:



Thick filament structure:



Structure of the M-line:

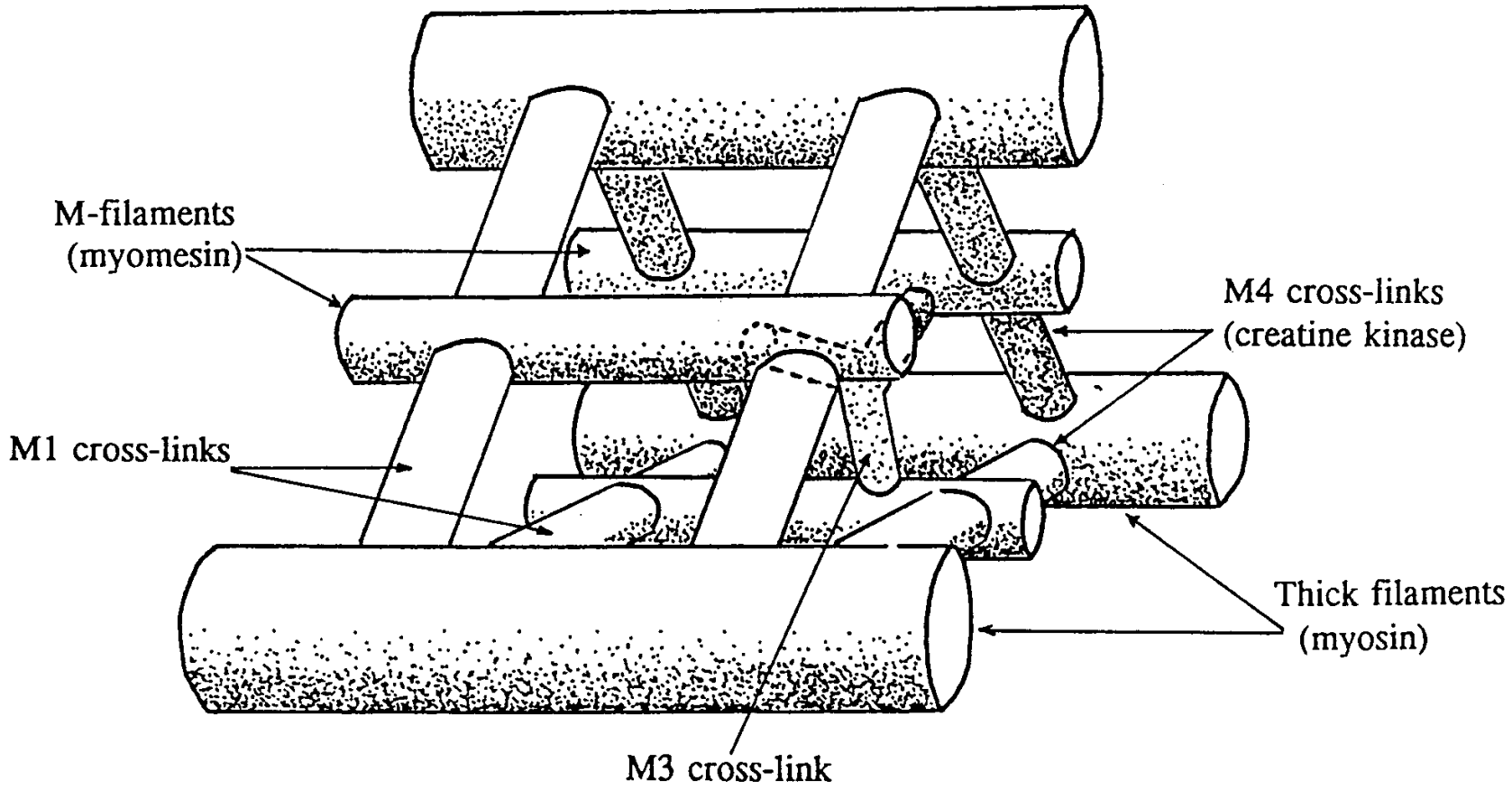
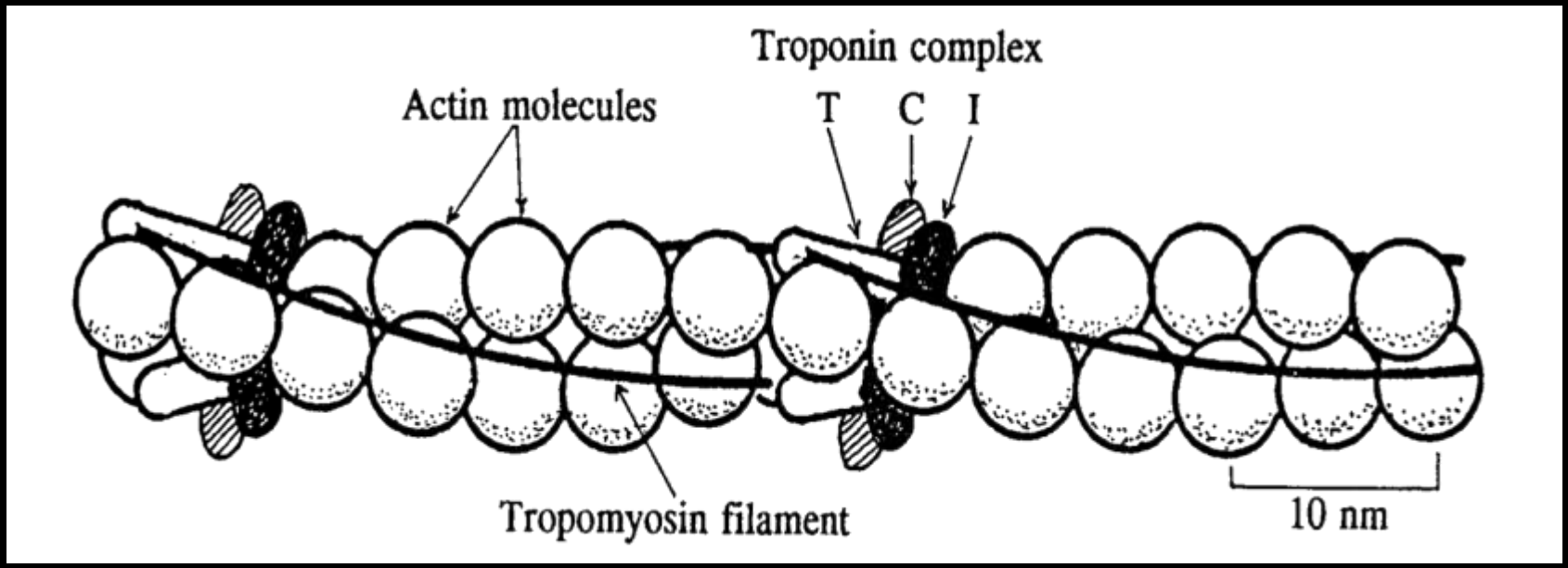
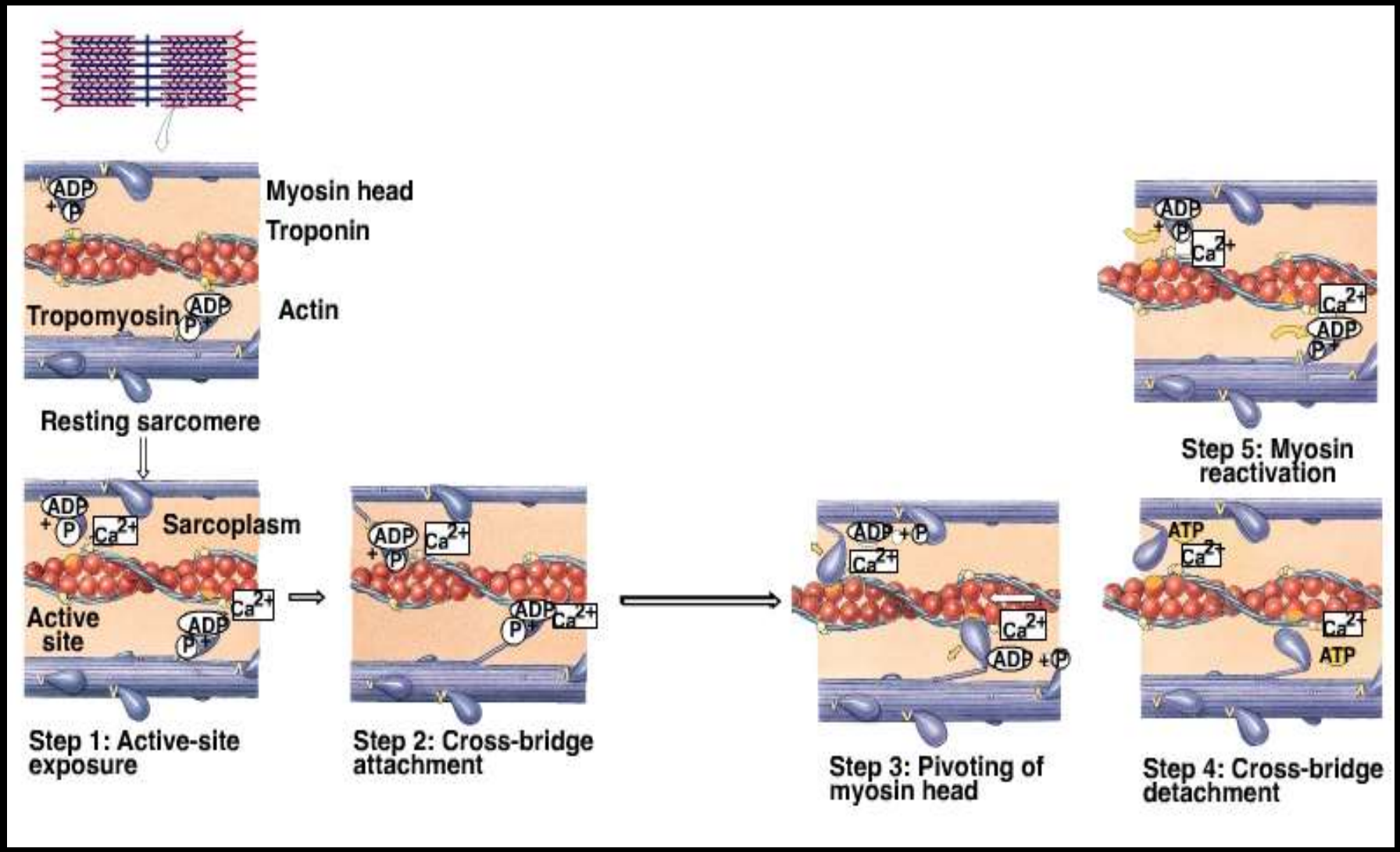


Figure 1.8 Model of the M-region, showing the thick (myosin) filaments and the M-filaments, together with the cross-links holding them in position. Adapted from Luther and Squire (1978, p. 322) and Strehler, Carlsson, Eppenberger, and Thornell (1983, p. 154).

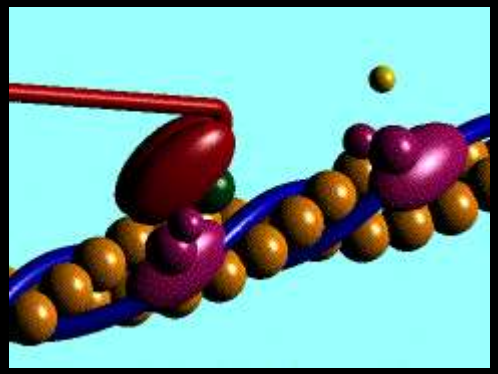
Structure of thin filament:

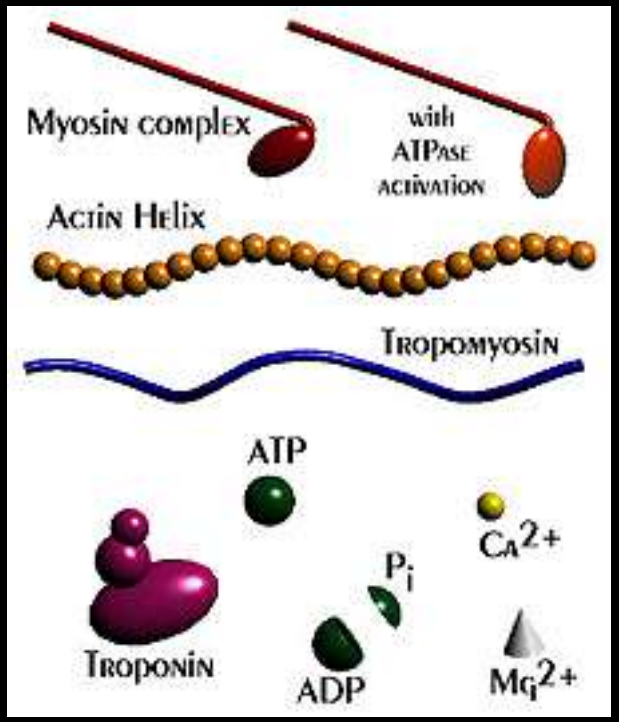


Cross-bridge formation:

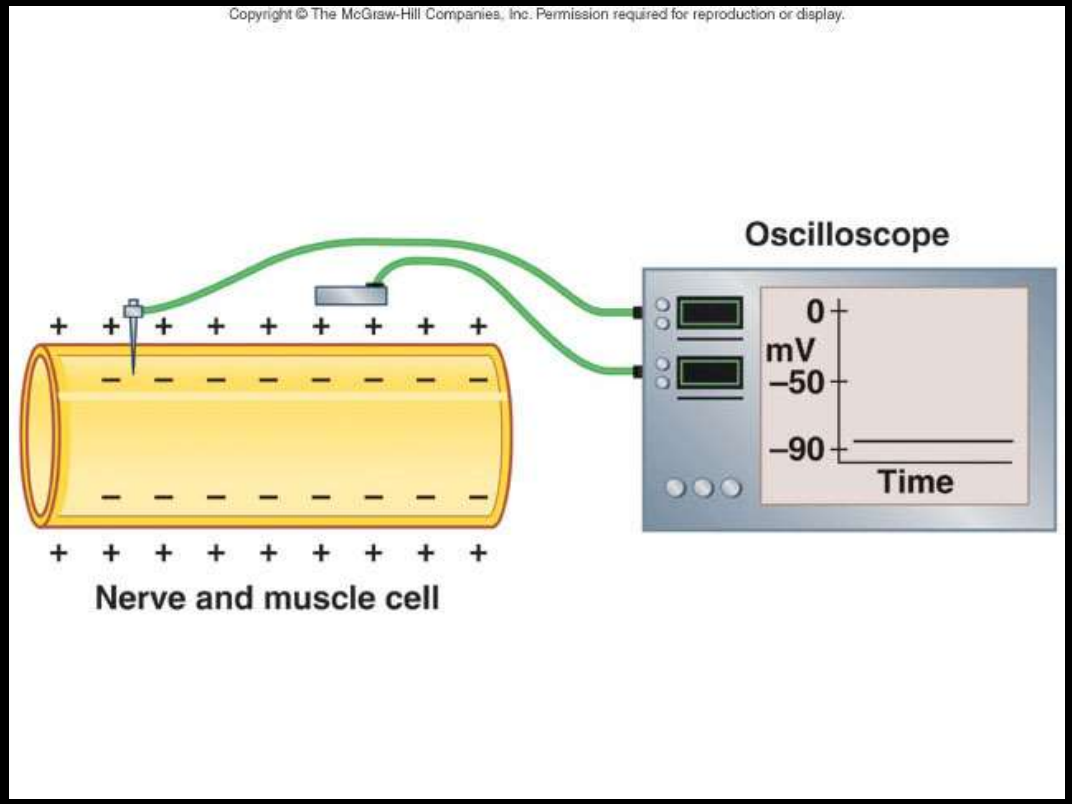


Mechanism of muscle contraction



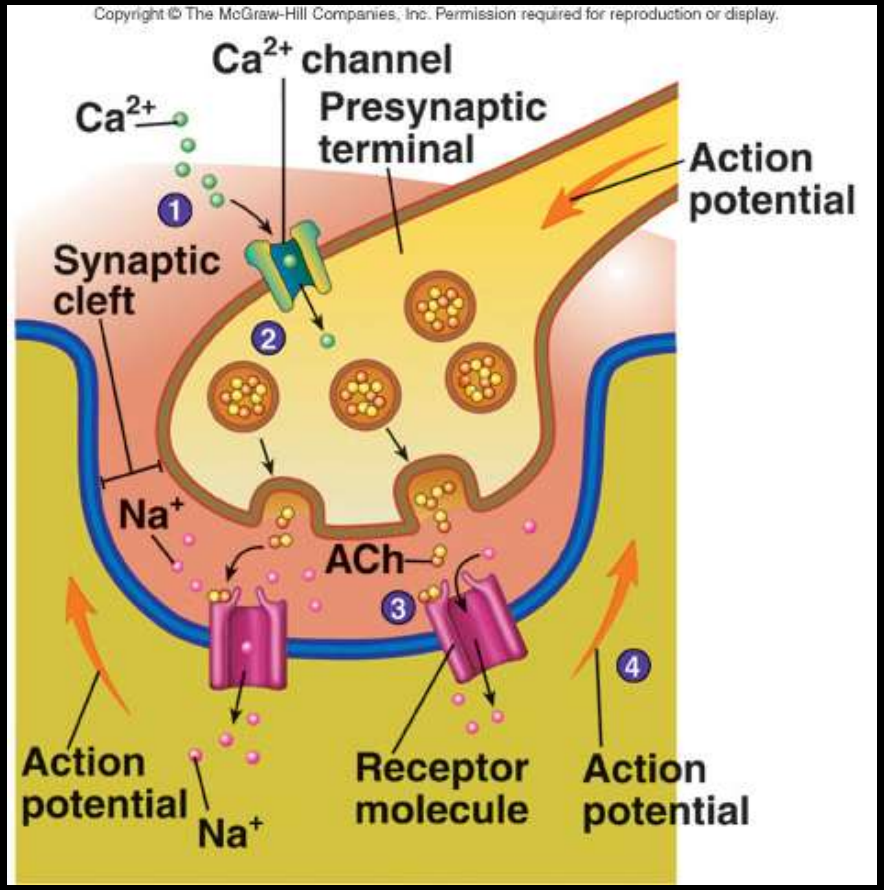


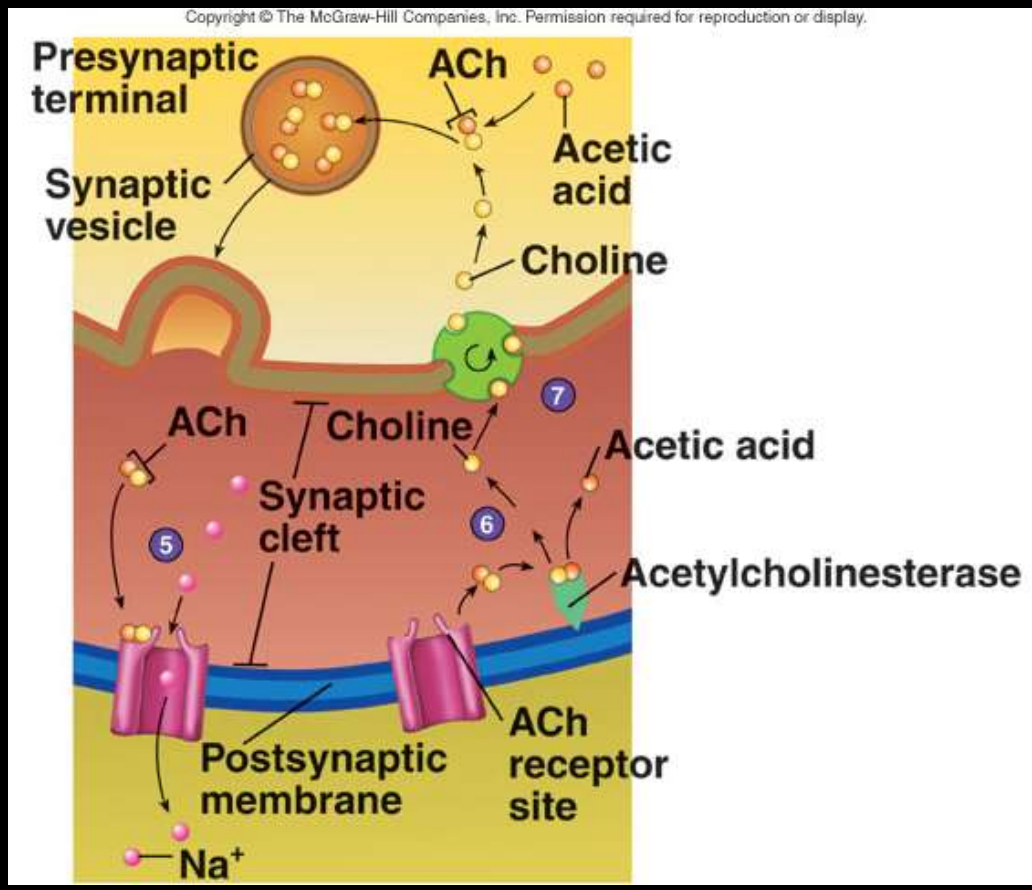
Physiology of Skeletal Muscle



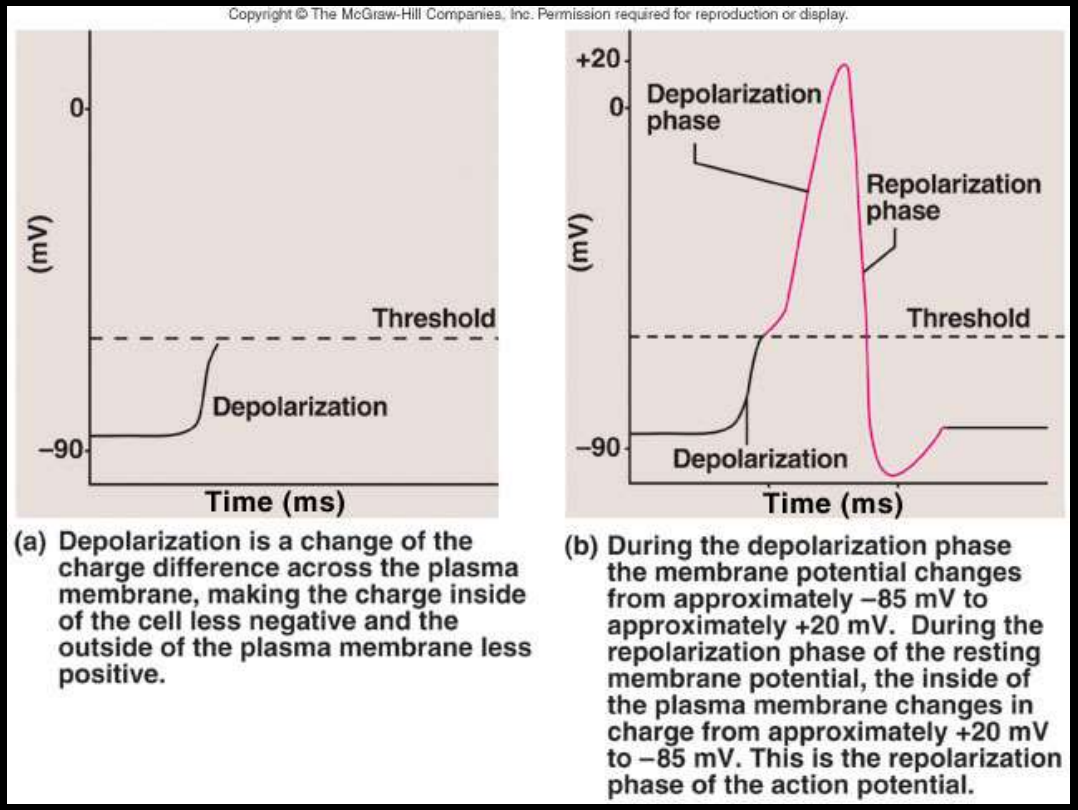
- Nervous system
  - Controls muscle contractions through action potentials
- Resting membrane potentials
  - Membrane voltage difference across membranes (polarized)
    - Inside cell more negative and more K^+
    - Outside cell more positive and more Na^+
  - Must exist for action potential to occur

Function of Neuromuscular Junction





Action Potentials

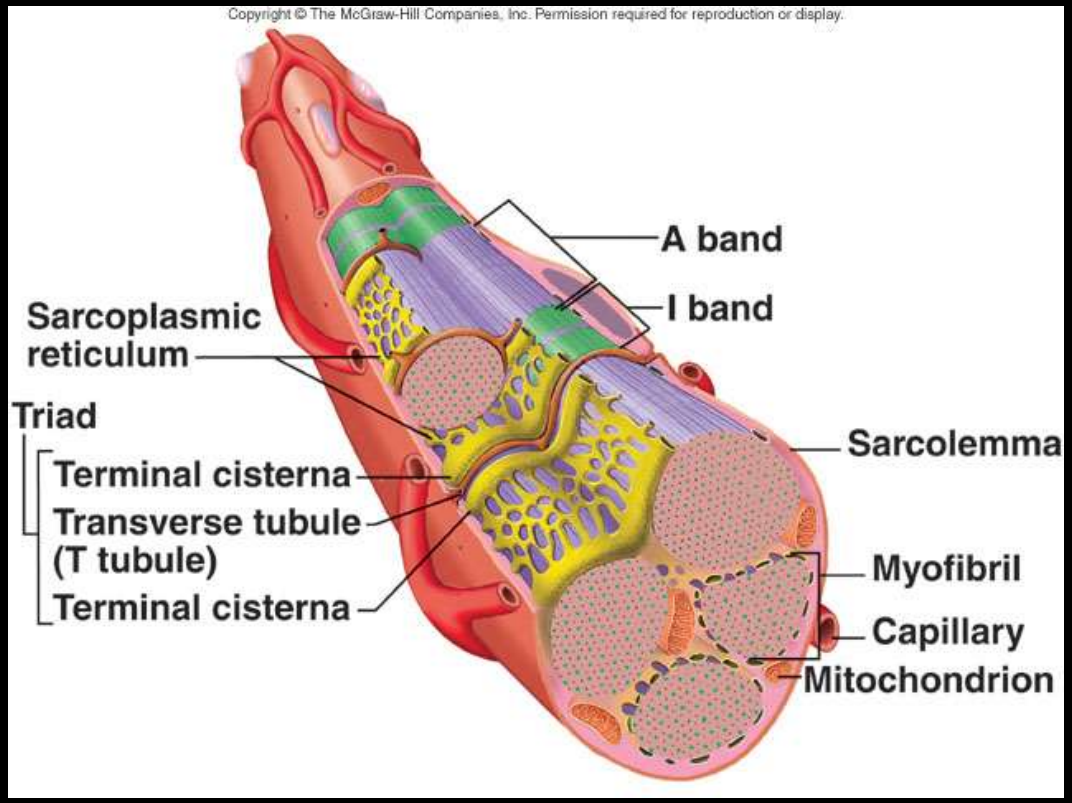


(a) Depolarization is a change of the charge difference across the plasma membrane, making the charge inside of the cell less negative and the outside of the plasma membrane less positive.

(b) During the depolarization phase the membrane potential changes from approximately −85 mV to approximately +20 mV. During the repolarization phase of the resting membrane potential, the inside of the plasma membrane changes in charge from approximately +20 mV to −85 mV. This is the repolarization phase of the action potential.

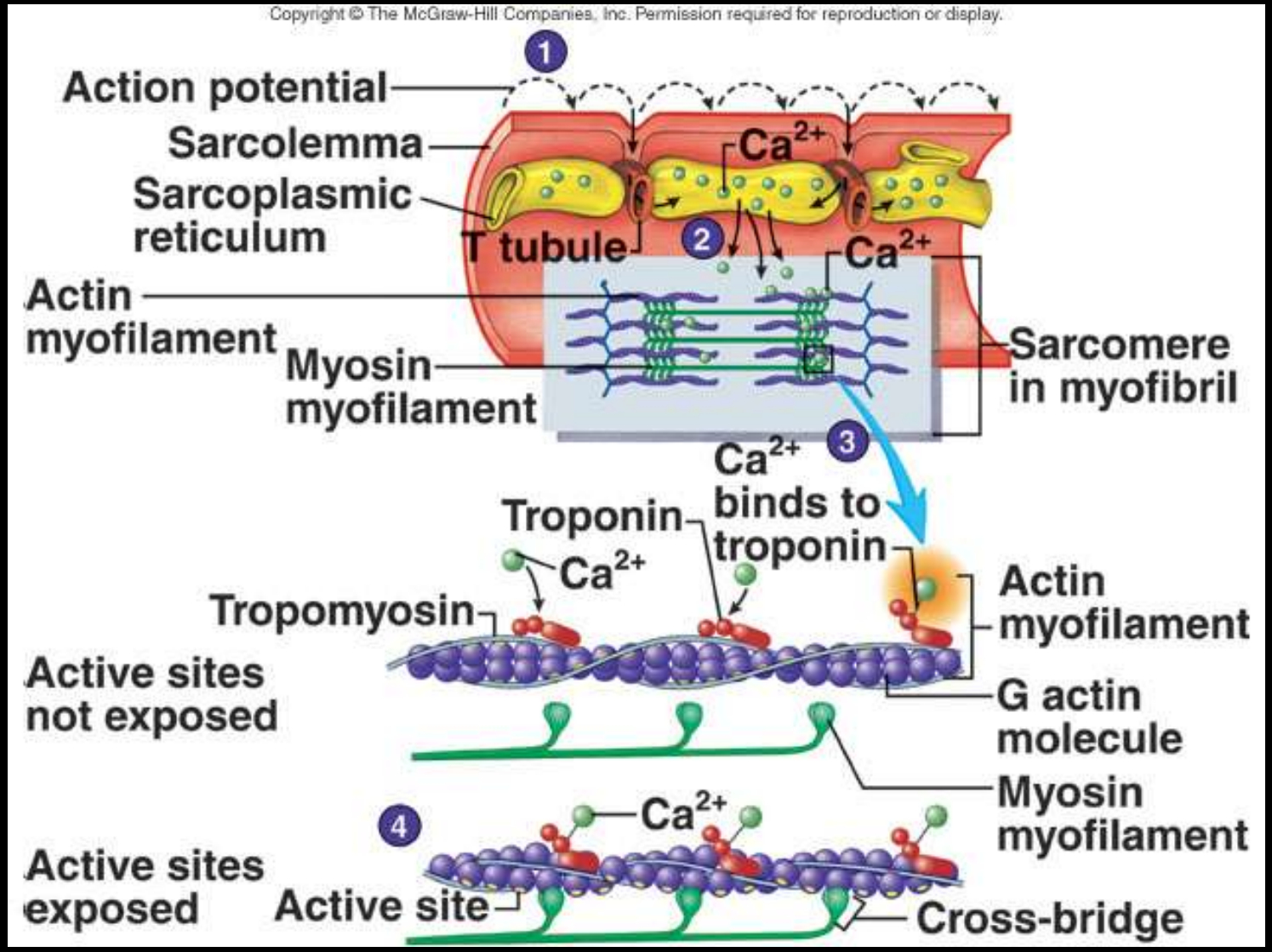
- Phases
  - Depolarization
    - Inside plasma membrane becomes less negative
  - Repolarization
    - Return of resting membrane potential
- All-or-none principle
  - Like camera flash system
- Propagate
  - Spread from one location to another
- Frequency
  - Number of action potential produced per unit of time

Excitation-Contraction Coupling

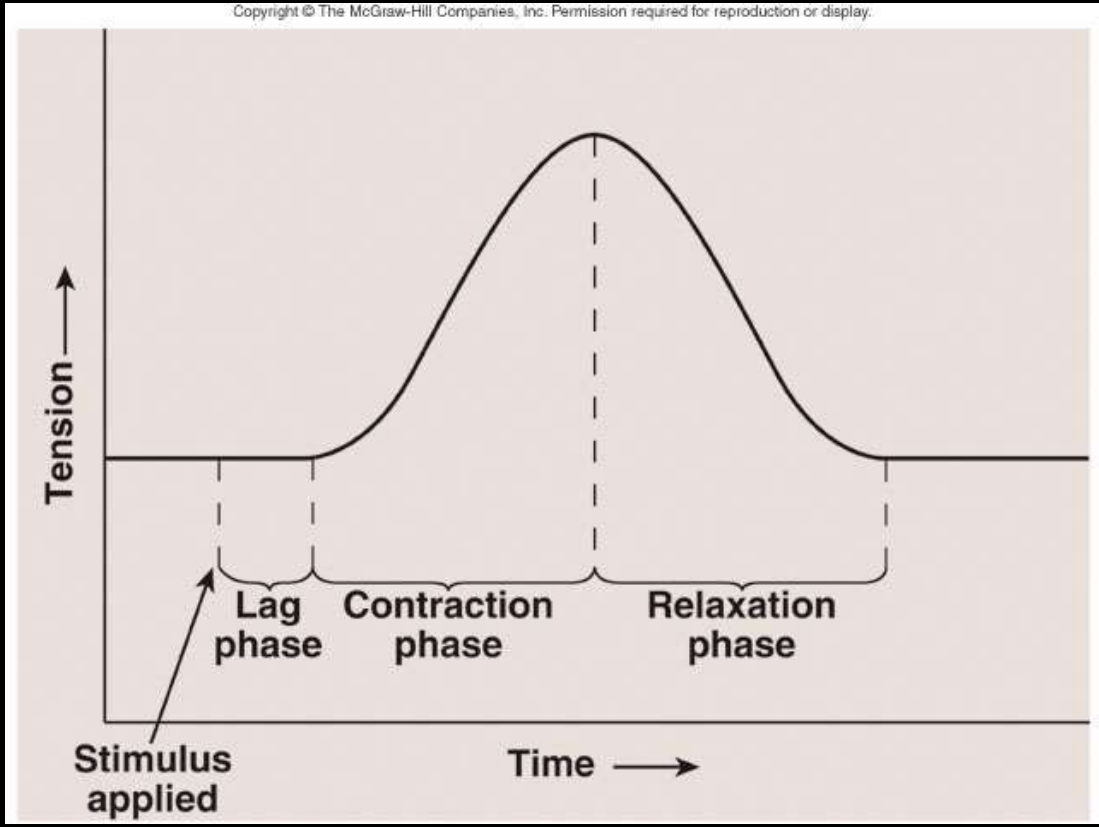


- Mechanism where an action potential causes muscle fiber contraction
- Involves
  - Sarcolemma
  - Transverse or T tubules
  - Terminal cisternae
  - Sarcoplasmic reticulum
  - Ca^{2+}
  - Troponin

Action Potentials and Muscle Contraction

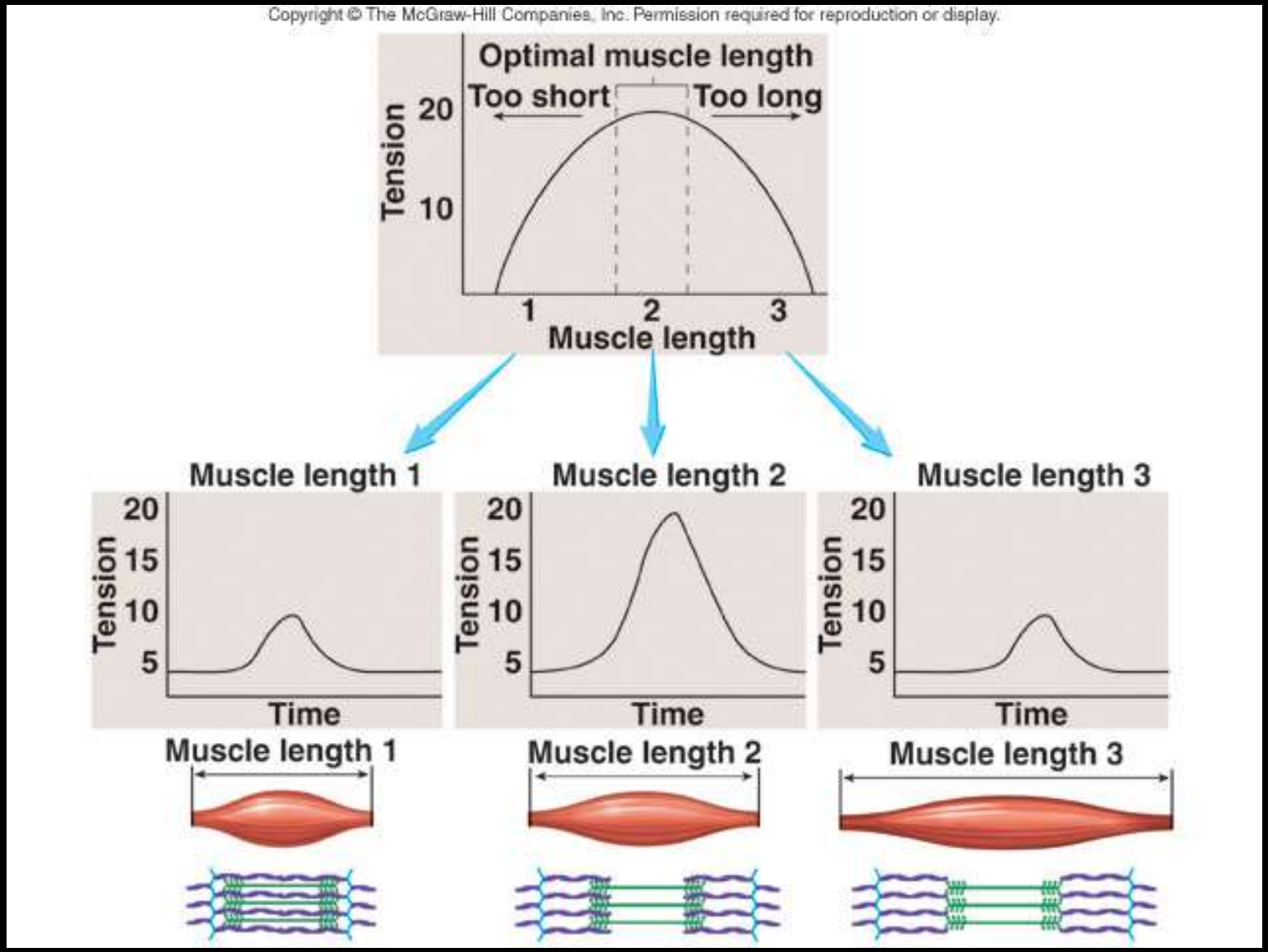


Muscle Twitch

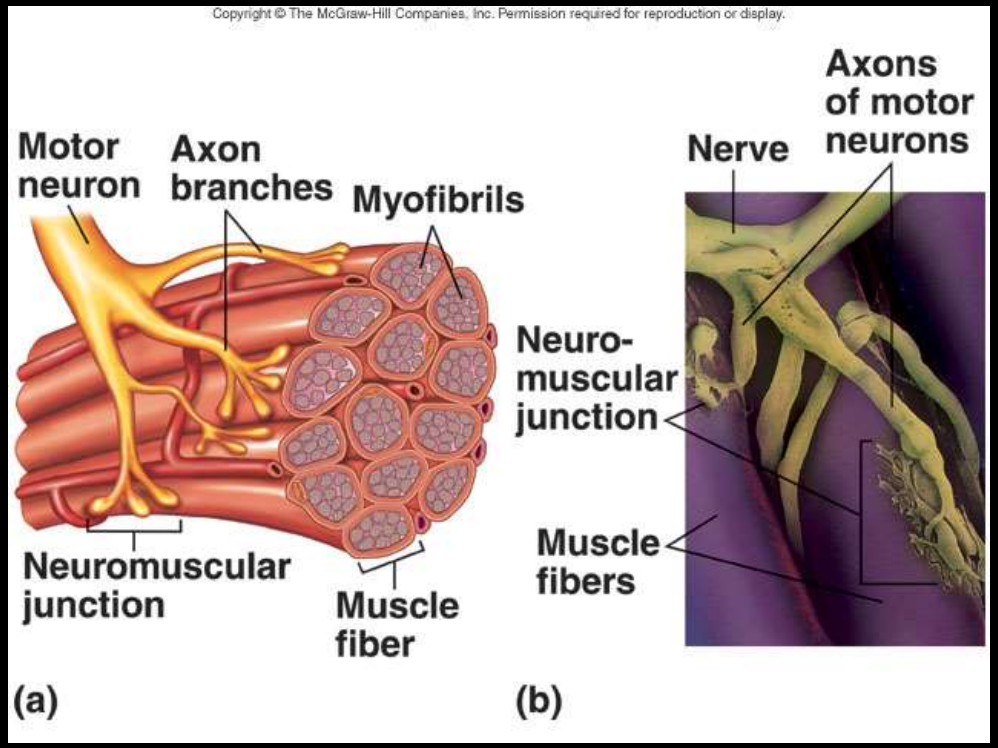


- Muscle contraction in response to a stimulus that causes action potential in one or more muscle fibers
- Phases
  - Lag or latent
  - Contraction
  - Relaxation

Muscle Length and Tension



Stimulus Strength and Muscle Contraction

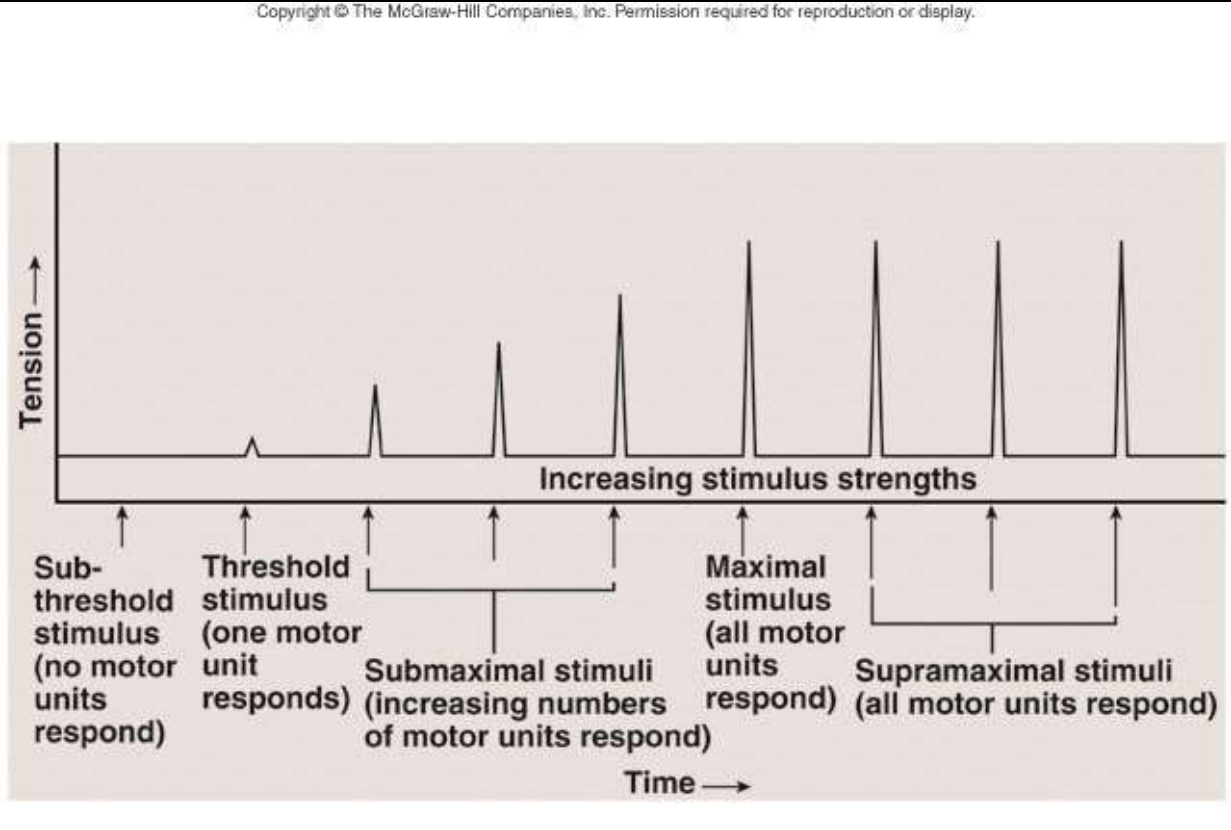


- All-or-none law for muscle fibers
  - Contraction of equal force in response to each action potential
    - Sub-threshold stimulus
    - Threshold stimulus
    - Stronger than threshold
- Motor units
  - Single motor neuron and all muscle fibers innervated
- Graded for whole muscles
  - Strength of contractions range from weak to strong depending on stimulus strength

Types of Muscle Contractions

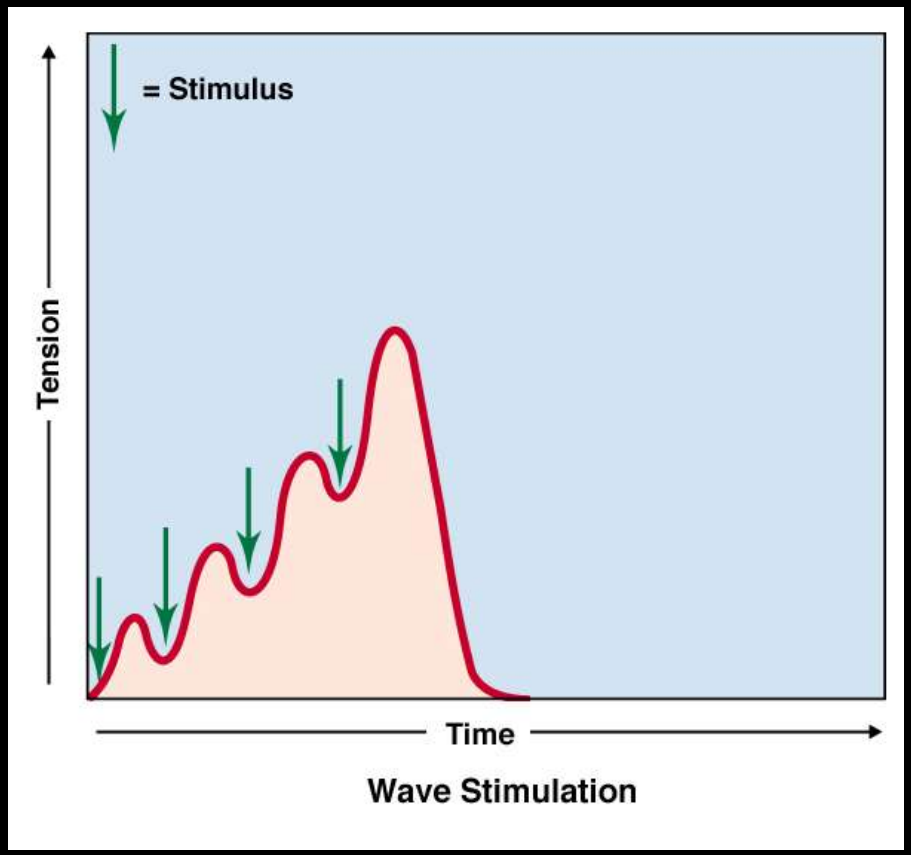
- Isometric: No change in length but tension increases
  - Postural muscles of body
- Isotonic: Change in length but tension constant
  - Concentric: Overcomes opposing resistance and muscle shortens
  - Eccentric: Tension maintained but muscle lengthens
- Muscle tone: Constant tension by muscles for long periods of time

Multiple Motor Unit Summation

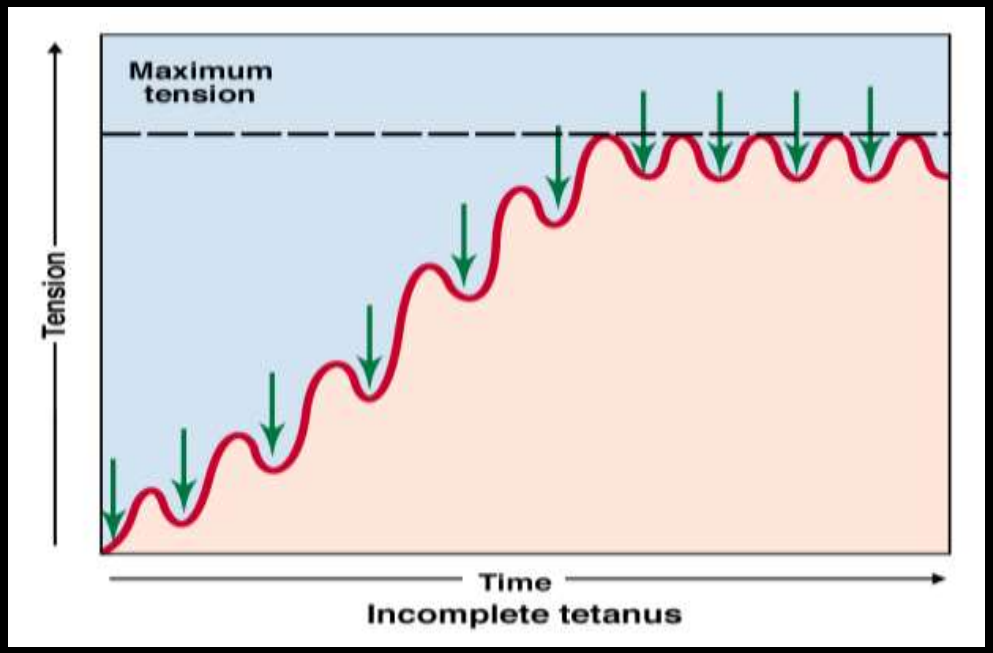


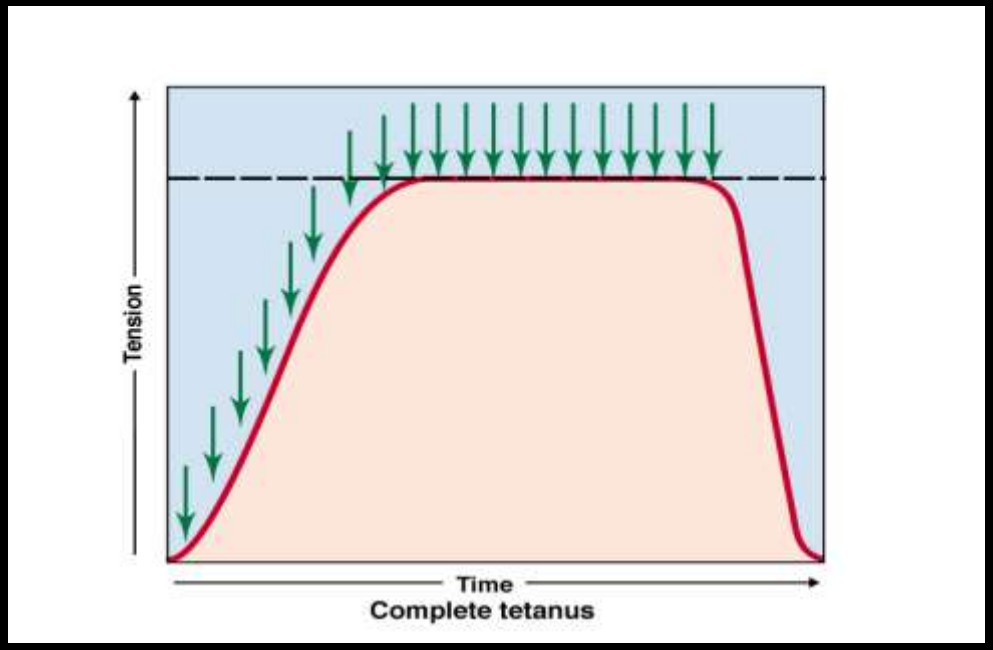
- A whole muscle contracts with a small or large force depending on number of motor units stimulated to contract

Multiple-Wave Summation



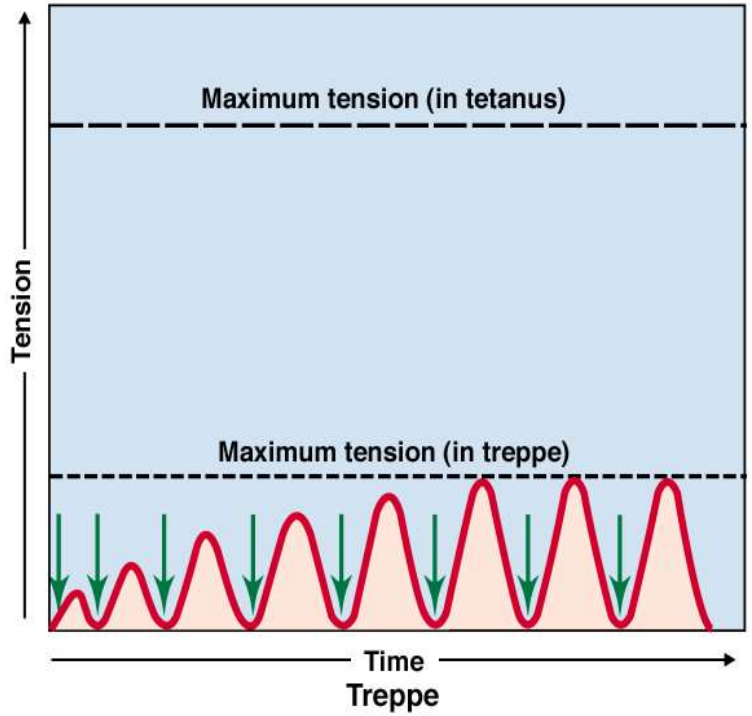
- As frequency of action potentials increase, frequency of contraction increases
- Action potentials come close enough together so that the muscle does not have time to completely relax between contractions.





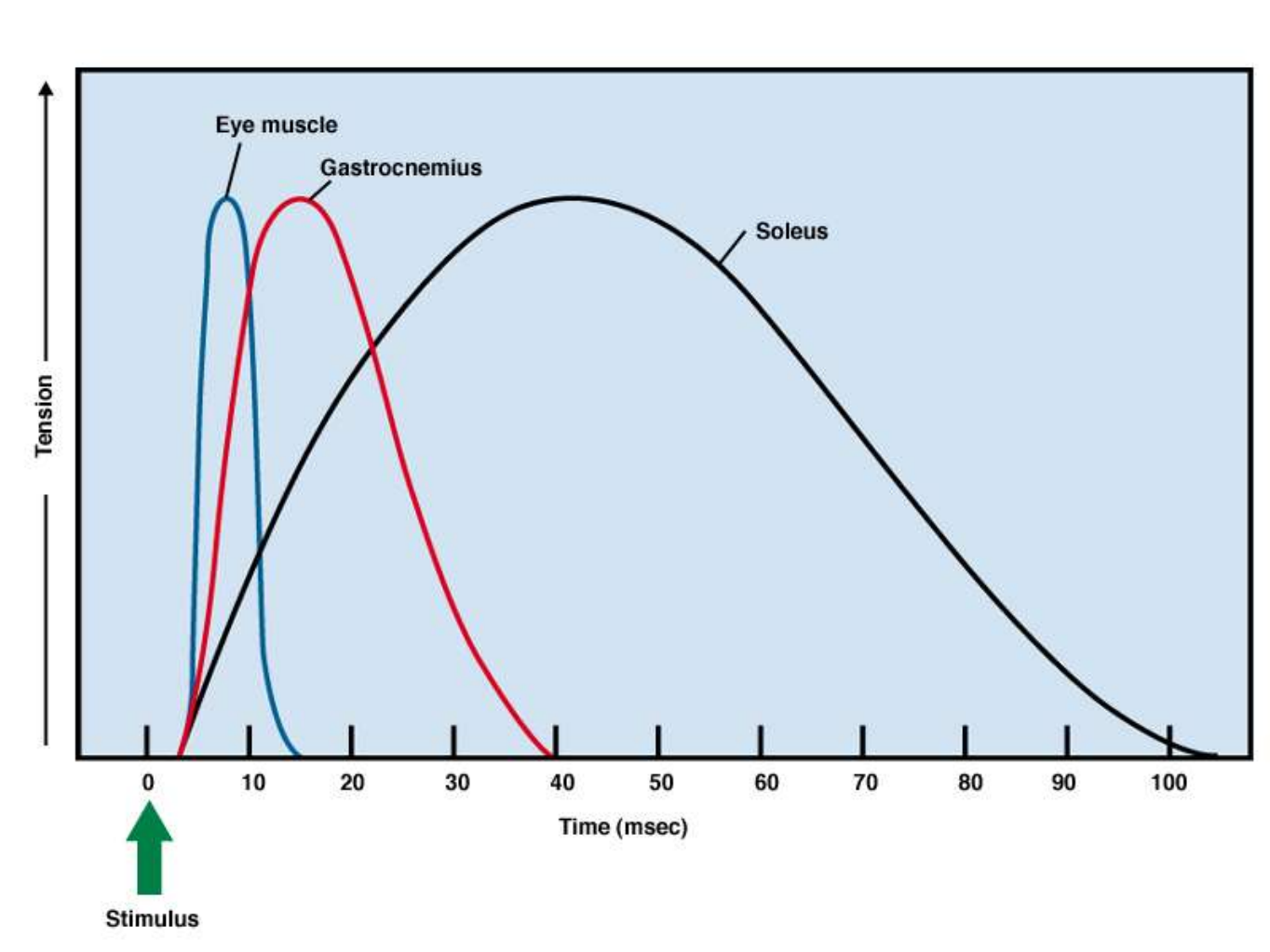
- Incomplete tetanus
  - Muscle fibers partially relax between contraction
  - There is time for Ca^{2+} to be recycled through the SR between action potentials
- Complete tetanus
  - No relaxation between contractions
  - Action potentials come sp close together that Ca^{2+} does not get re-sequestered in the SR

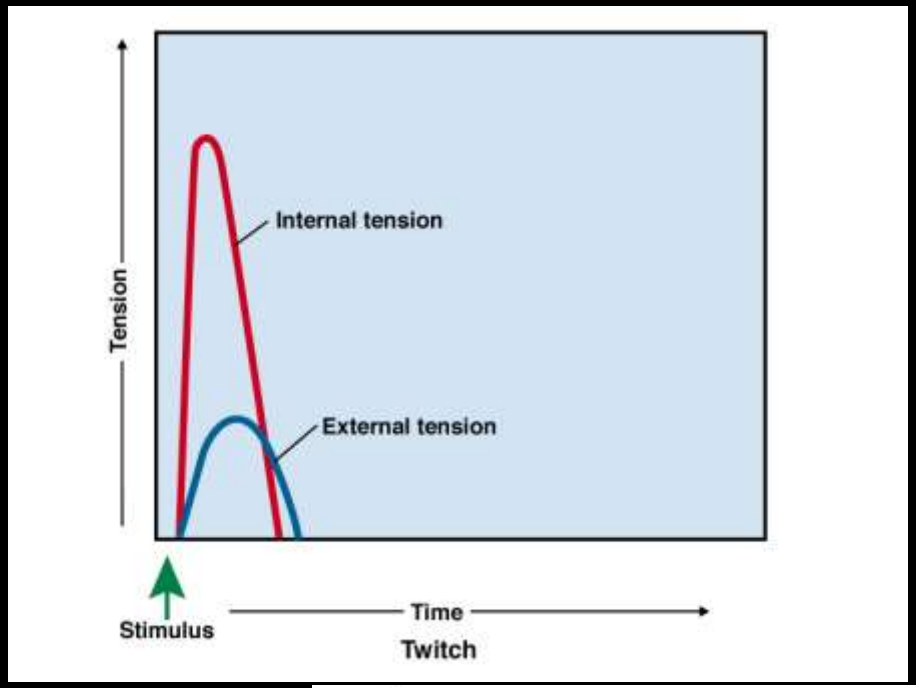
Treppe

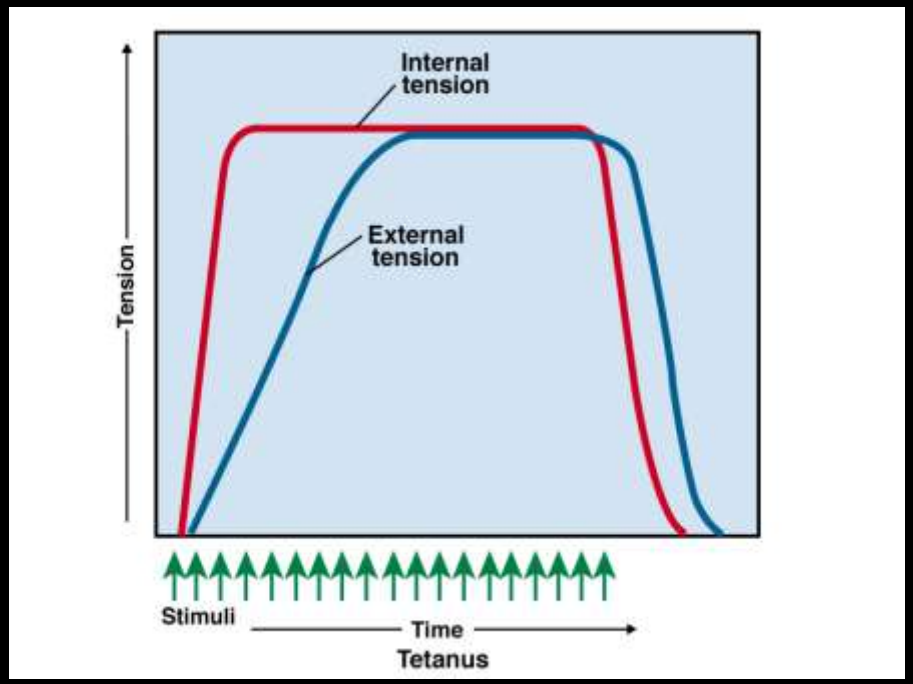


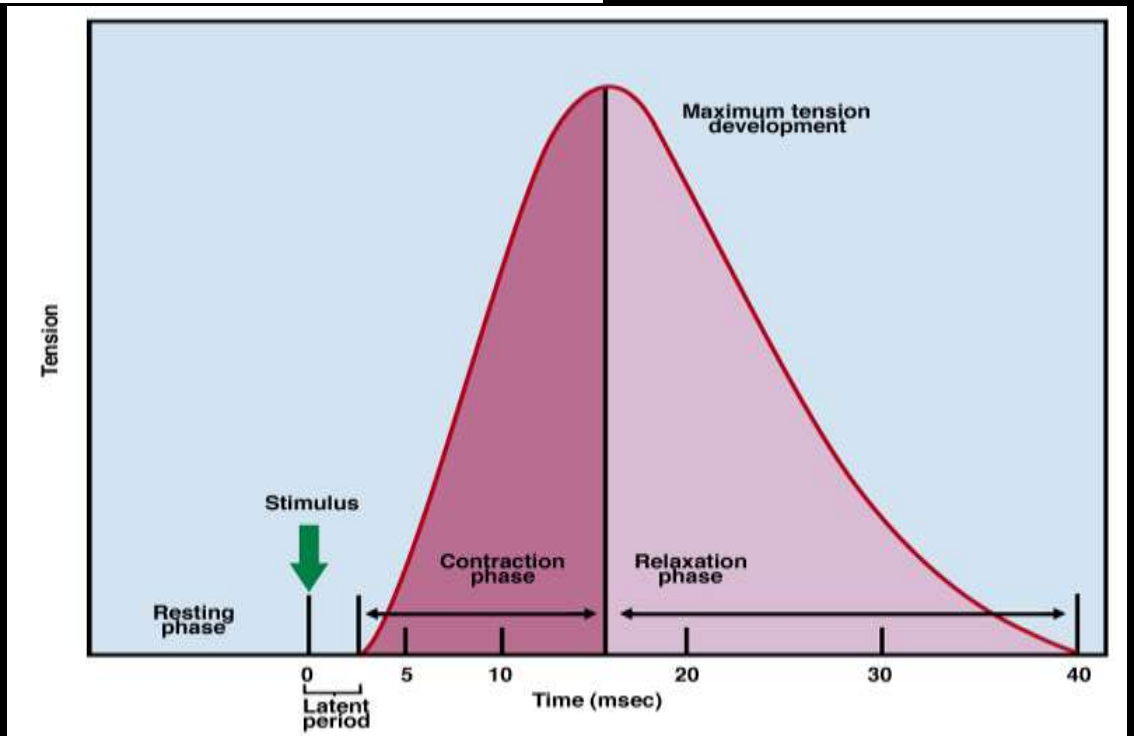
- Graded response
- Occurs in muscle rested for prolonged period
- Each subsequent contraction is stronger than previous until all equal after few stimuli

Speed of contraction:

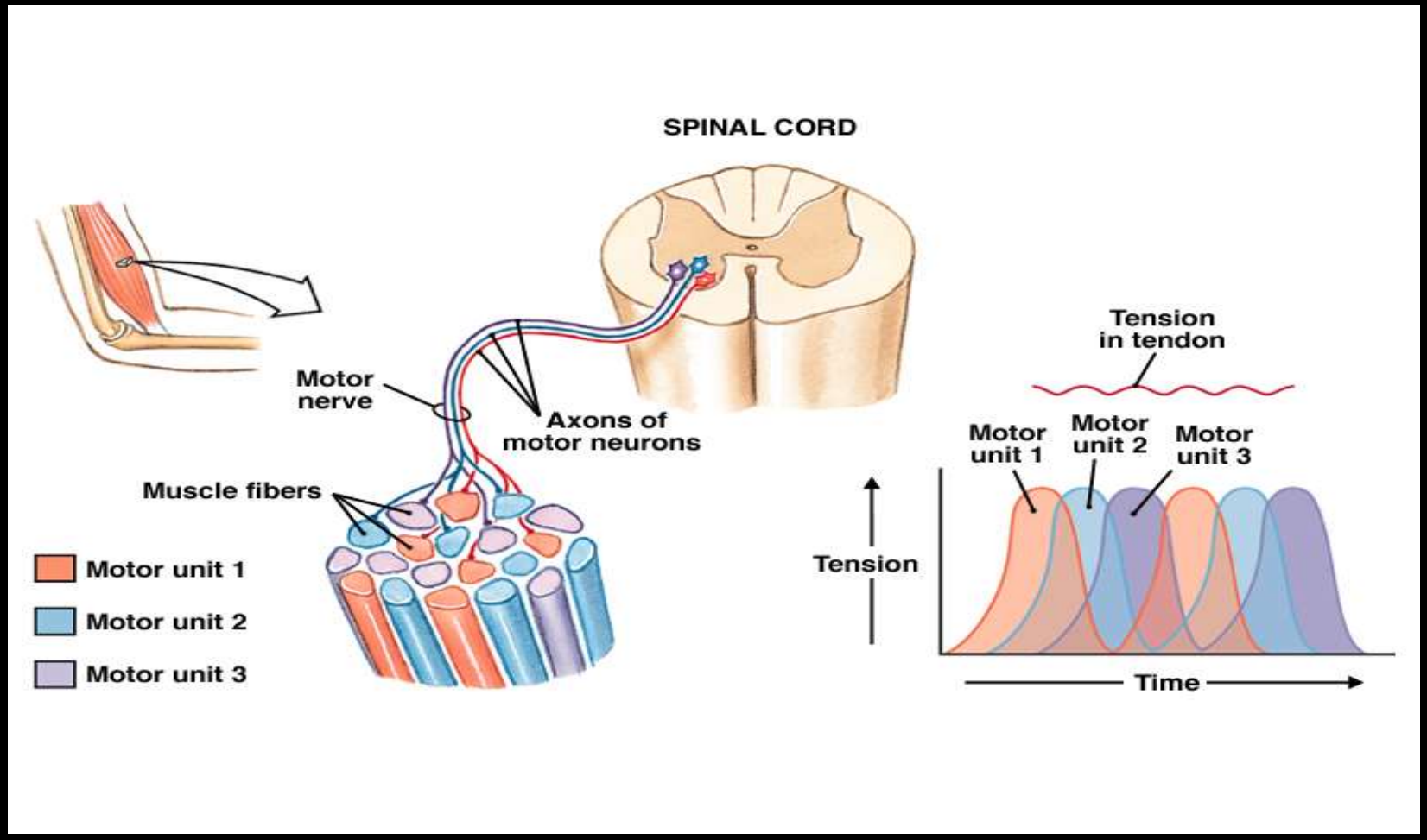


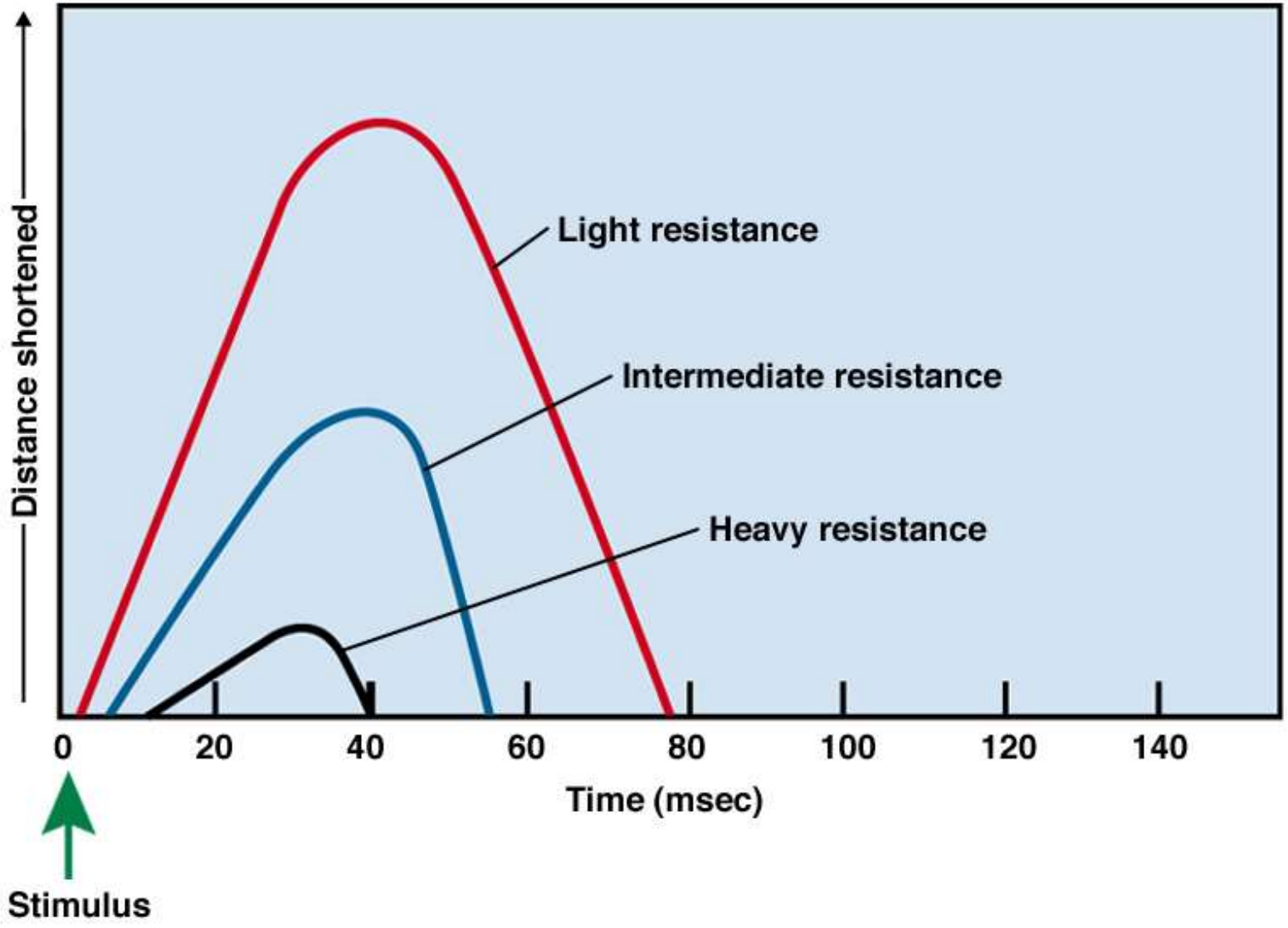

Tension
Internal tension
External tension
Stimulus
Time
Twitch

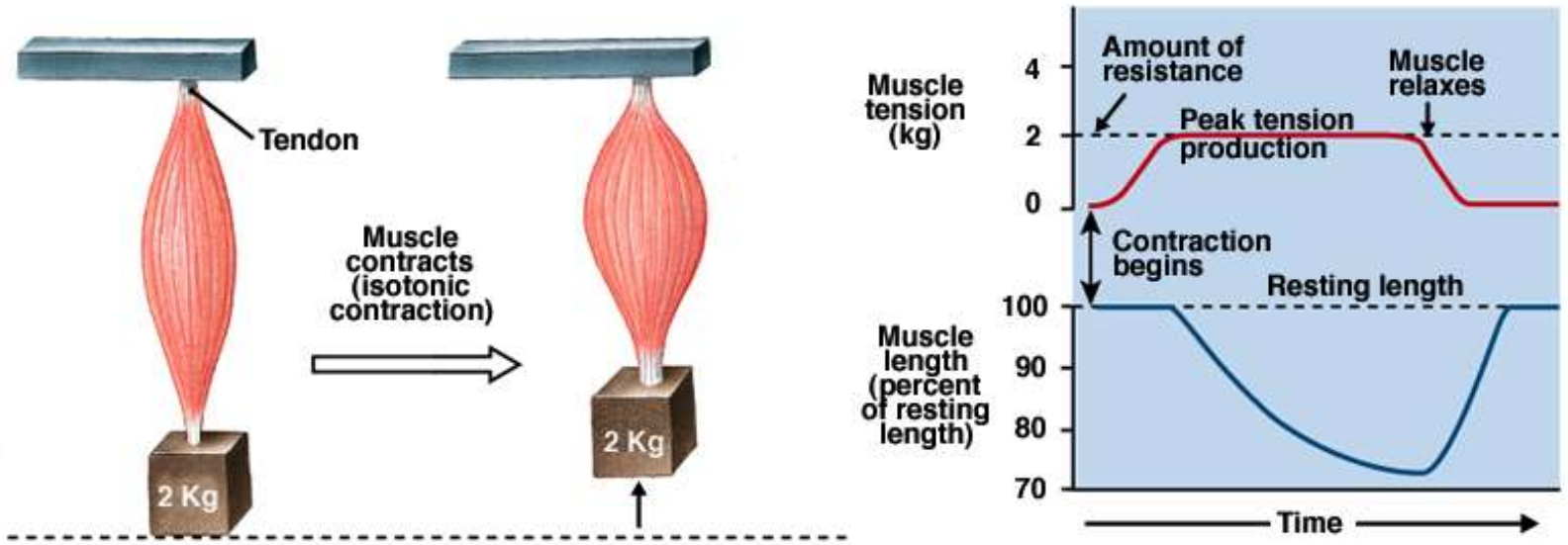

Tension
Internal tension
External tension
Stimuli
Time
Tetanus

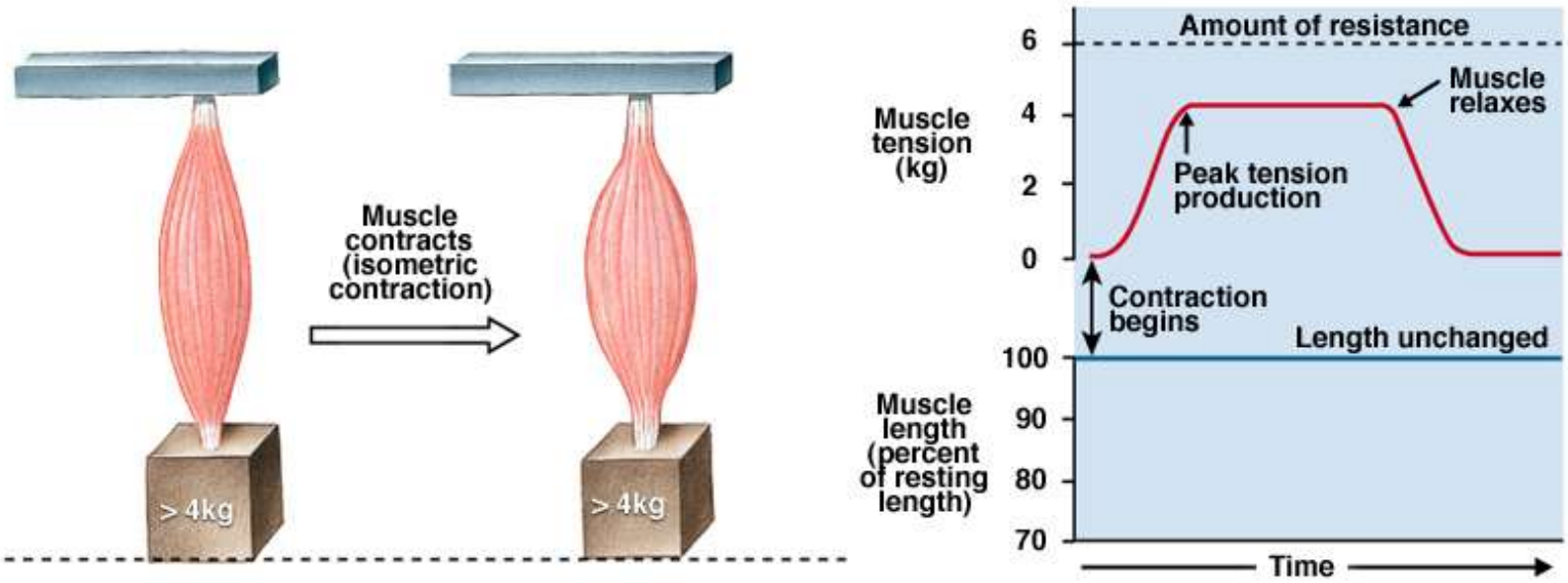

Tension
Maximum tension development
Stimulus
Contraction phase
Relaxation phase
Resting phase
0
Latent period
5
10
20
30
40
Time (msec)

Sustained sub-maximal tension:



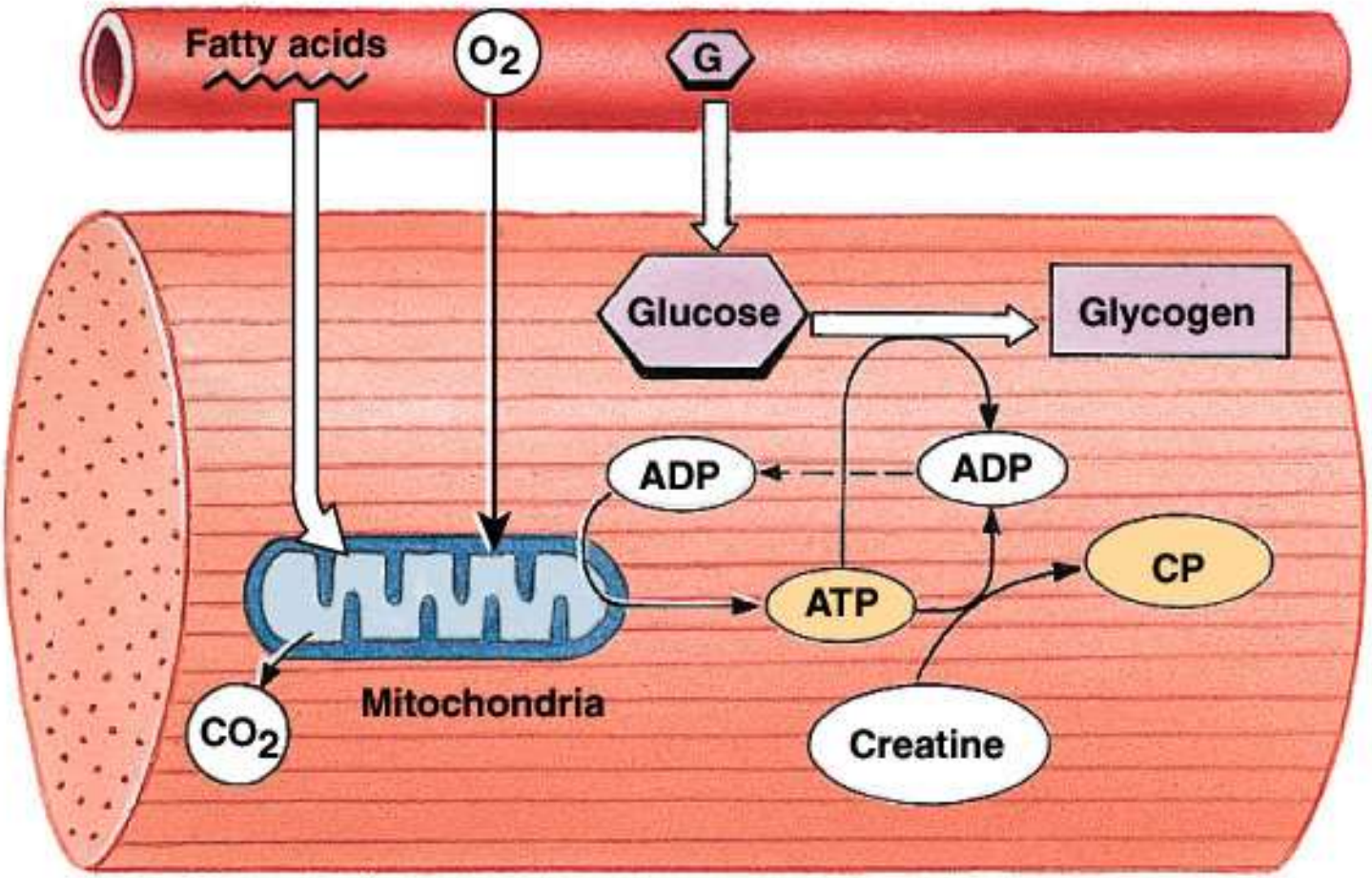

Distance shortened
Light resistance
Intermediate resistance
Heavy resistance
0
20
40
60
80
100
120
140
Time (msec)
Stimulus

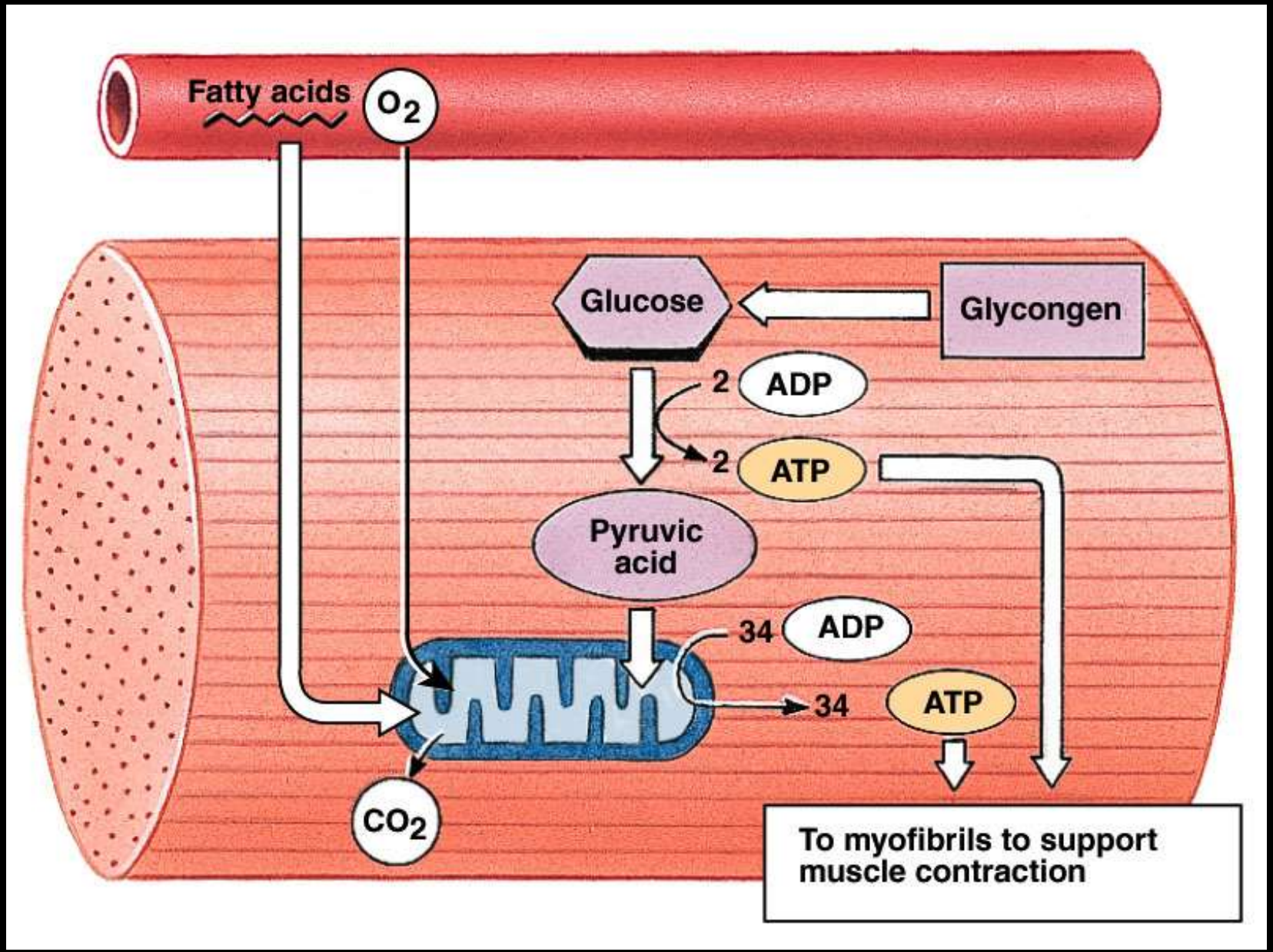

Tendon
2 Kg
Muscle contracts (isotonic contraction)
2 Kg
Muscle tension (kg)
4
2
0
Amount of resistance
Muscle relaxes
Peak tension production
Contraction begins
Resting length
Muscle length (percent of resting length)
100
90
80
70
Time

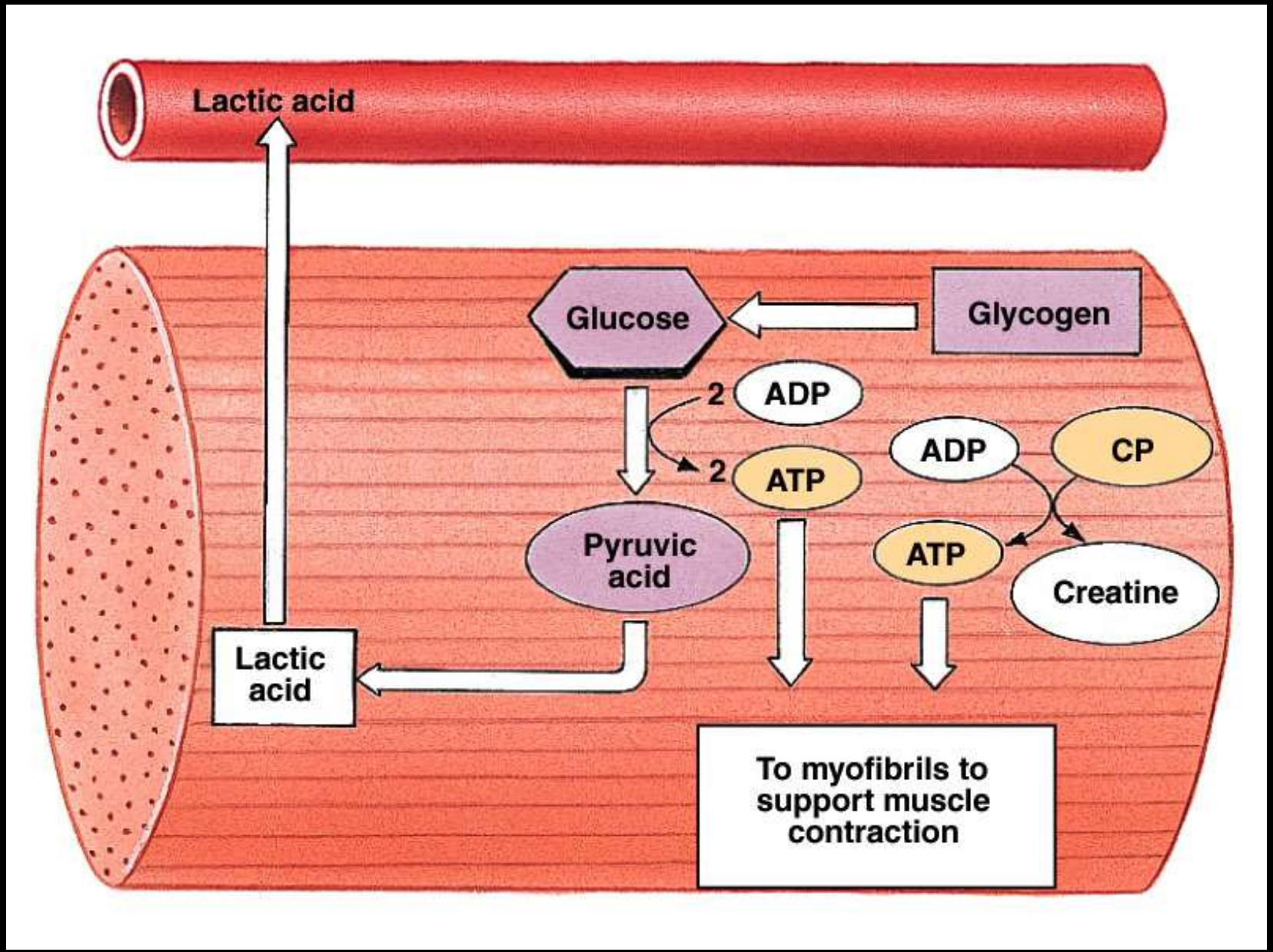

> 4kg
Muscle contracts (isometric contraction)
> 4kg
Amount of resistance
6
4
2
0
Muscle tension (kg)
Muscle relaxes
Peak tension production
Contraction begins
Length unchanged
100
90
80
70
Muscle length (percent of resting length)
Time

Energy Sources

- ATP provides immediate energy for muscle contractions from 3 sources
  - Creatine phosphate
    - During resting conditions stores energy to synthesize ATP
  - Anaerobic respiration
    - Occurs in absence of oxygen and results in breakdown of glucose to yield ATP and lactic acid
  - Aerobic respiration
    - Requires oxygen and breaks down glucose to produce ATP, carbon dioxide and water
    - More efficient than anaerobic

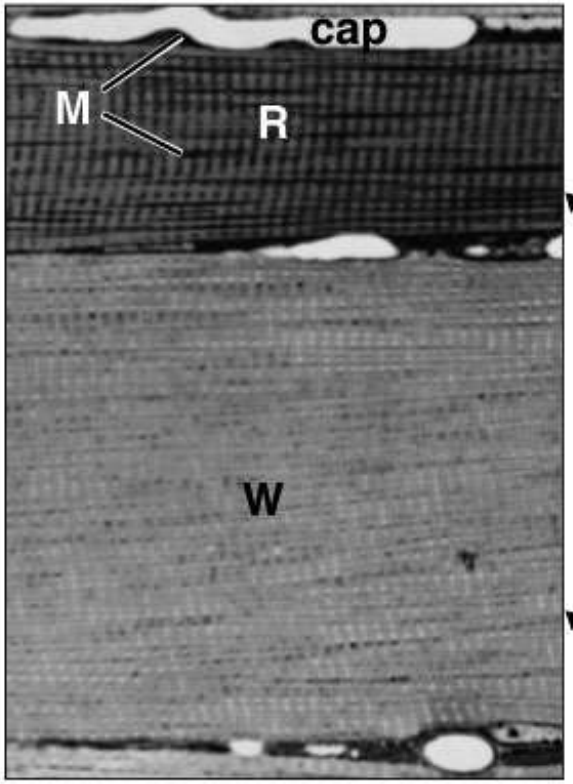

Fatty acids
O_2
G
Glucose
Glycogen
ADP
ADP
ATP
CP
Mitochondria
CO_2
Creatine


Fatty acids
O_2
Glucose
Glycongen
2
ADP
2
ATP
Pyruvic acid
34
ADP
34
ATP
CO_2
To myofibrils to support muscle contraction

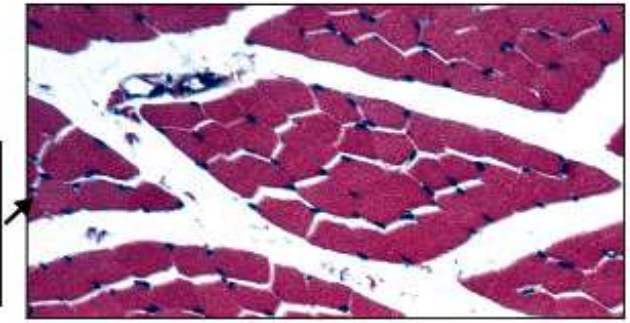

Lactic acid
Glucose
Glycogen
2
ADP
2
ATP
ADP
CP
ATP
Creatine
Pyruvic acid
Lactic acid
To myofibrils to support muscle contraction

Slow and Fast Fibers

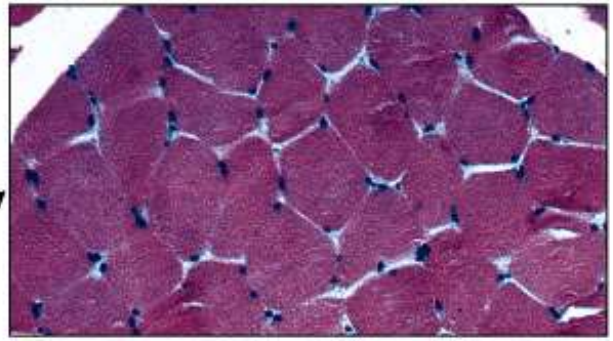
- Slow-twitch or high-oxidative
  - Contract more slowly, smaller in diameter, better blood supply, more mitochondria, more fatigue-resistant than fast-twitch
- Fast-twitch or low-oxidative
  - Respond rapidly to nervous stimulation, contain myosin to break down ATP more rapidly, less blood supply, fewer and smaller mitochondria than slow-twitch
- Distribution of fast-twitch and slow twitch
  - Most muscles have both but varies for each muscle
- Effects of exercise
  - Hypertrophies: Increases in muscle size
  - Atrophies: Decreases in muscle size



Slow fibers
Smaller diameter, darker color due to myoglobin; fatigue-resistant



Fast fibers
Larger diameter, paler color; easily fatigued



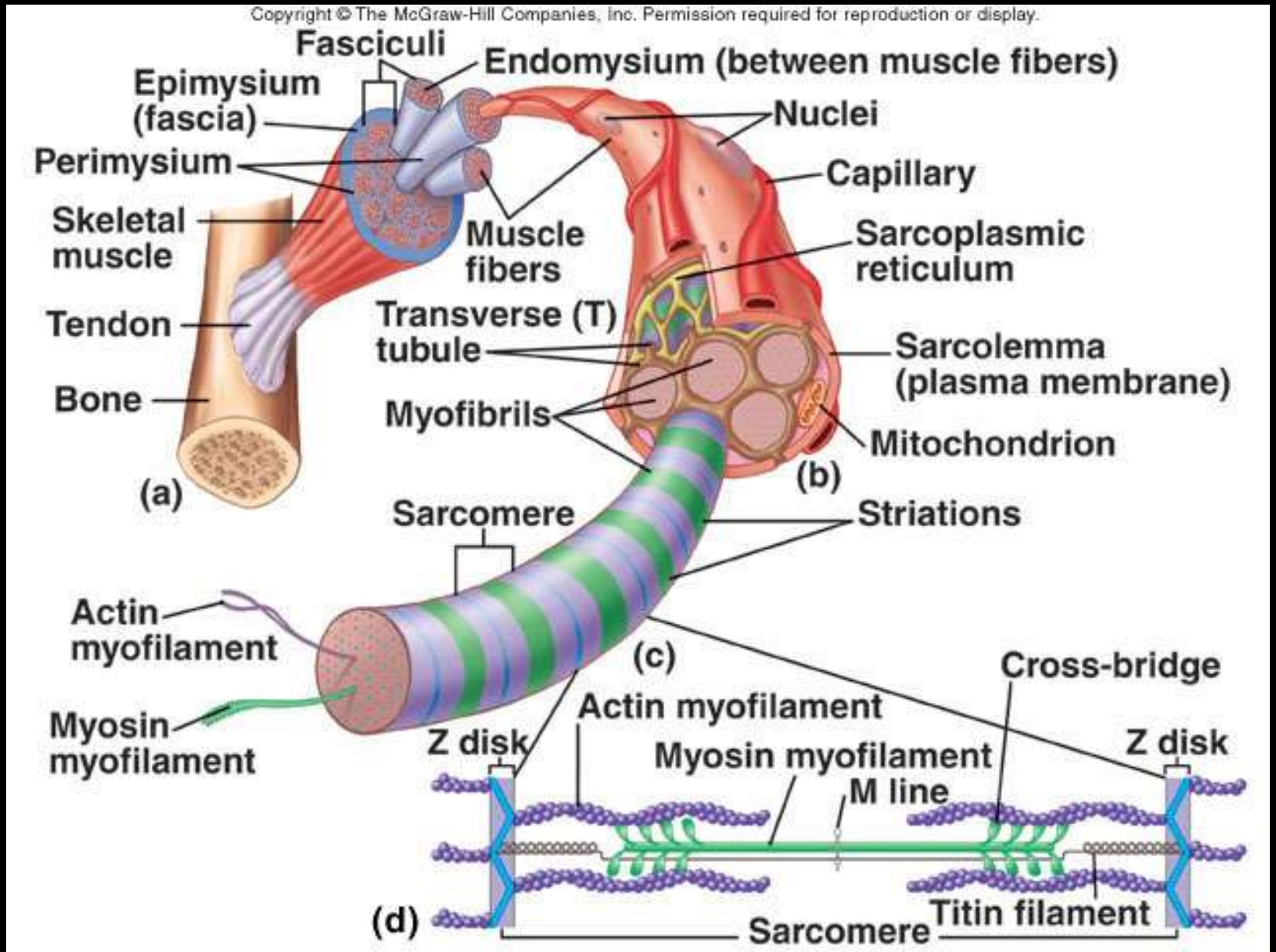
Fatigue

- Decreased capacity to work and reduced efficiency of performance
- Types:
  - Psychological
    - Depends on emotional state of individual
  - Muscular
    - Results from ATP depletion
  - Synaptic
    - Occurs in neuromuscular junction due to lack of acetylcholine

Effects of Aging on Skeletal Muscle

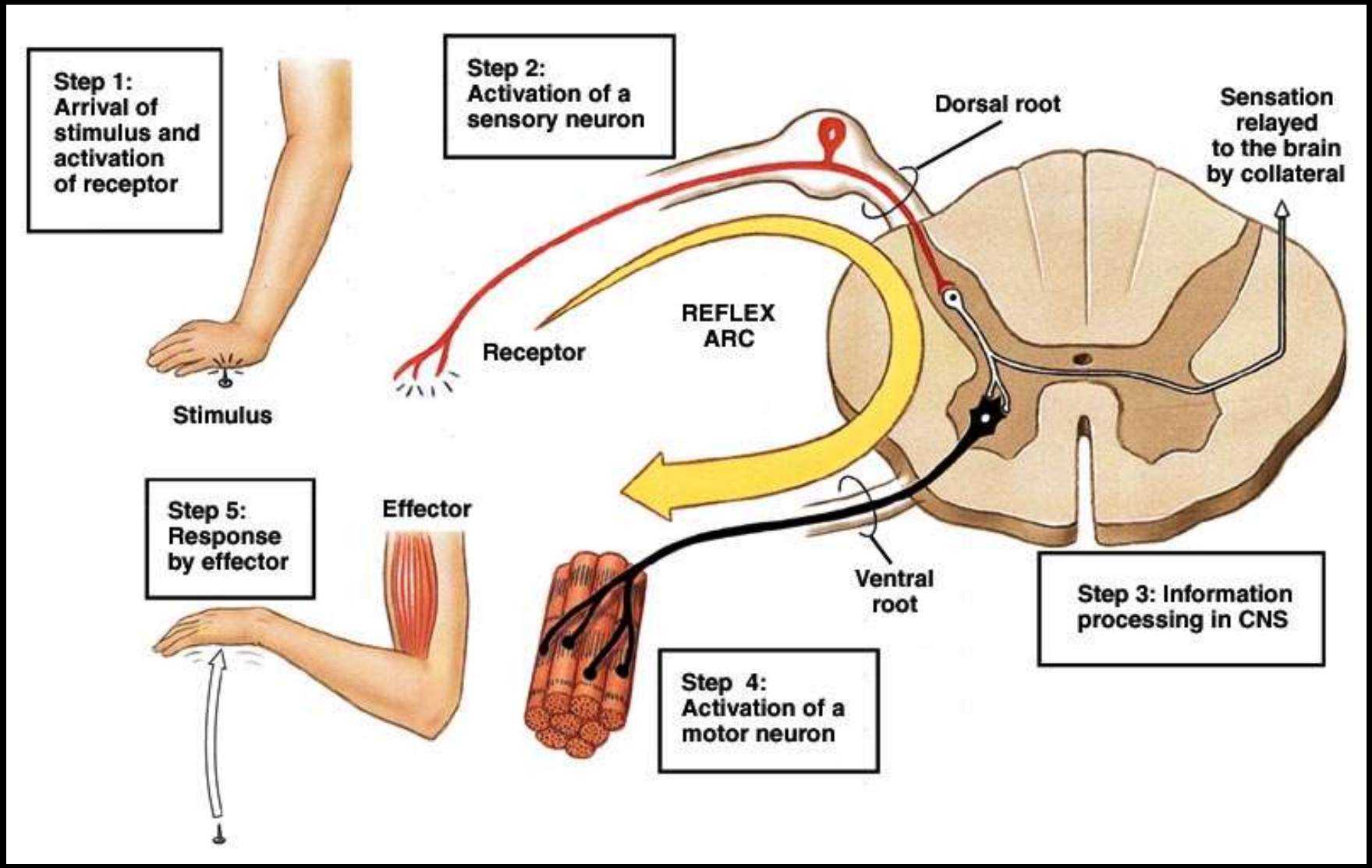
- Reduced muscle mass
- Increased time for muscle to contract in response to nervous stimuli
- Reduced stamina
- Increased recovery time
- Loss of muscle fibers
- Decreased density of capillaries in muscle

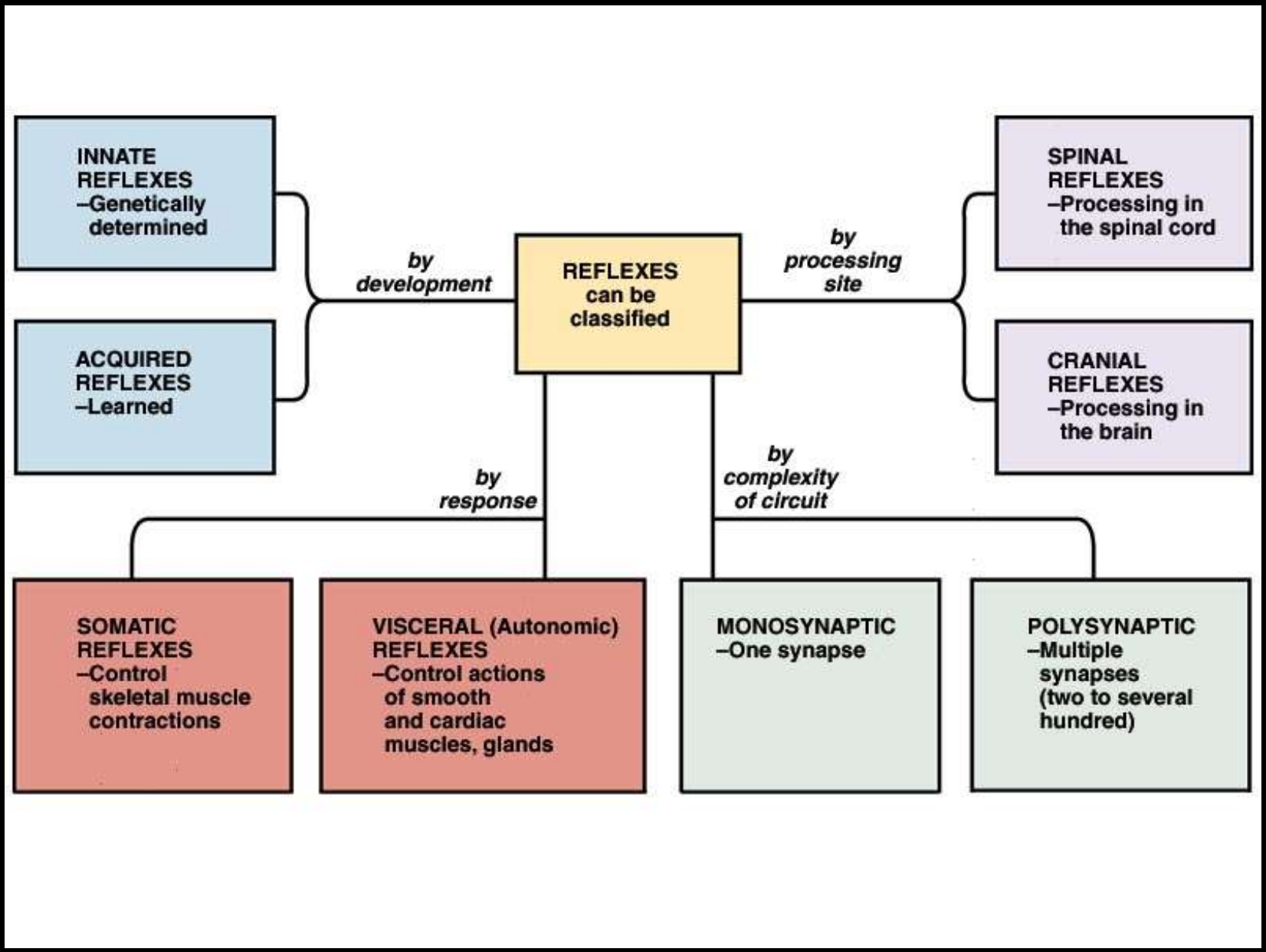
Parts of a Muscle

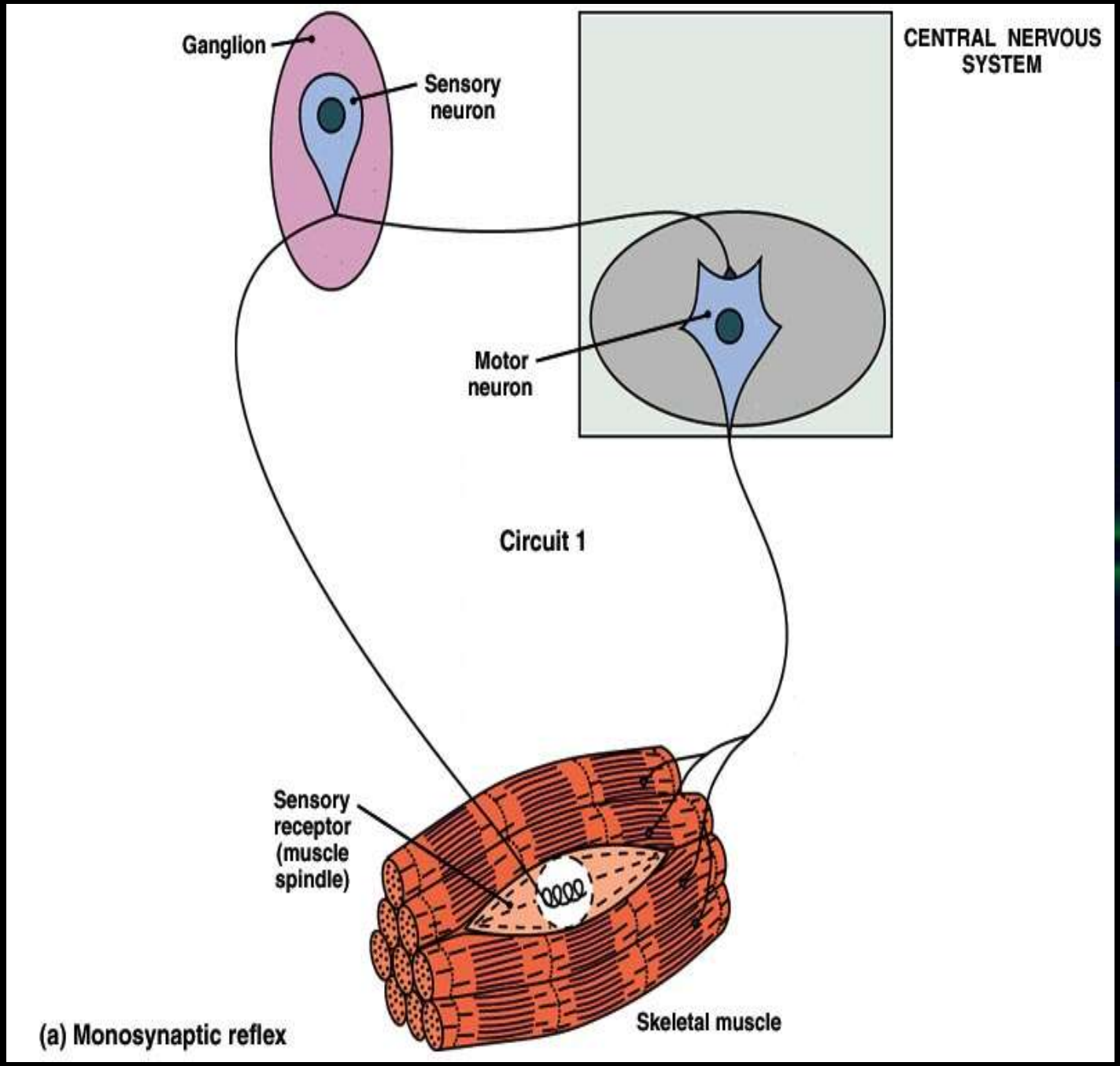


Reflexes:

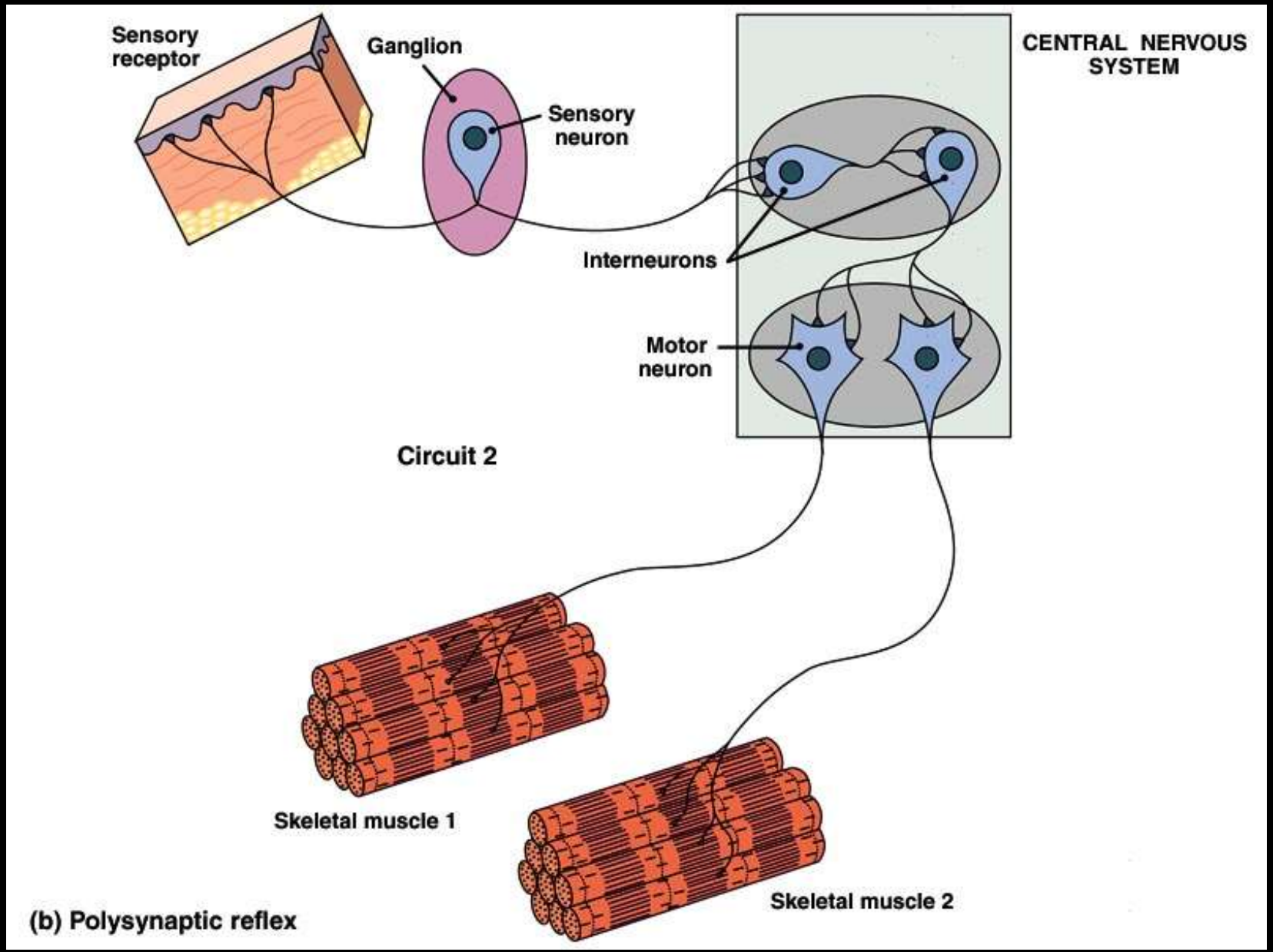
Muscle reflexes:

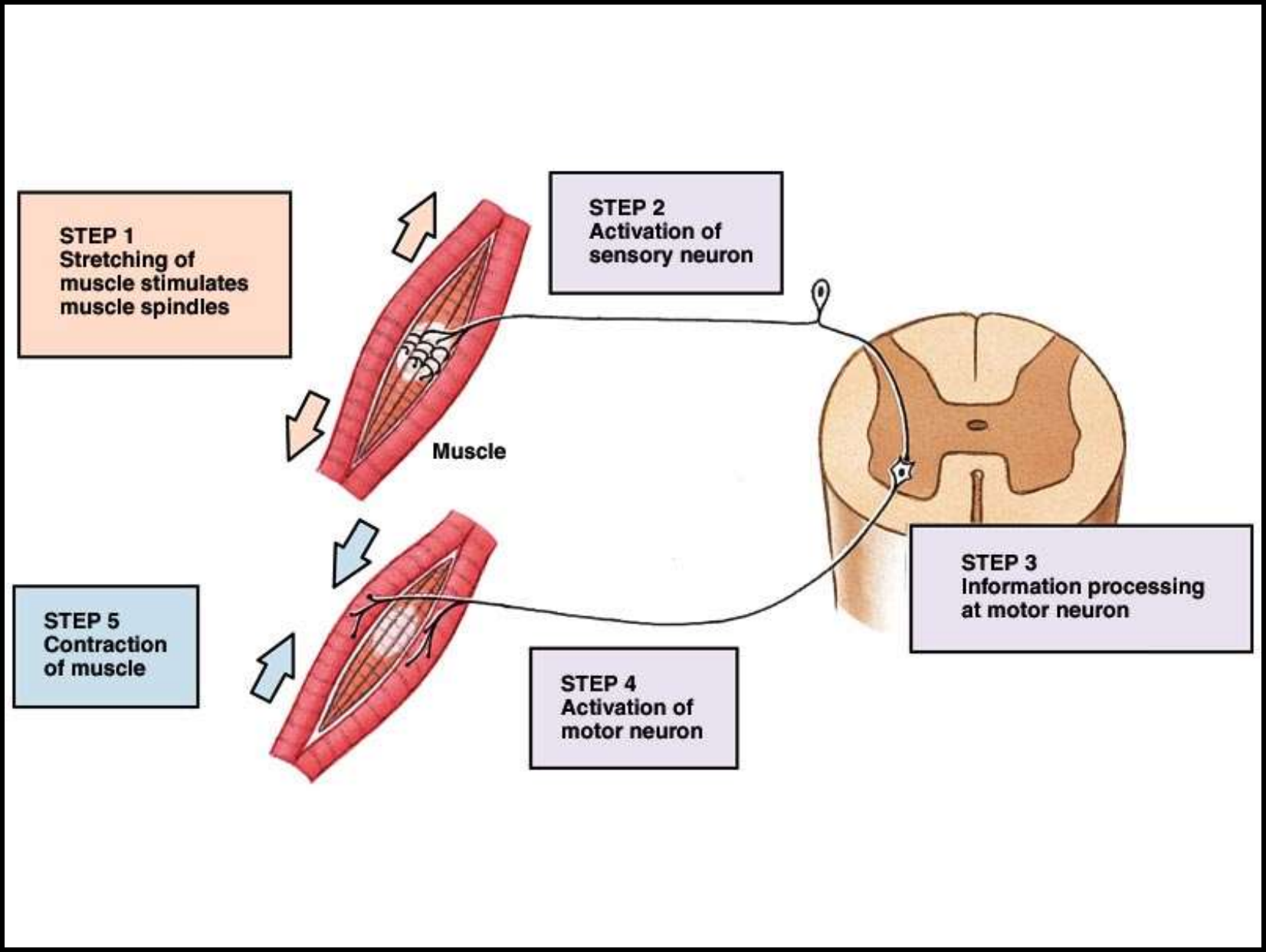


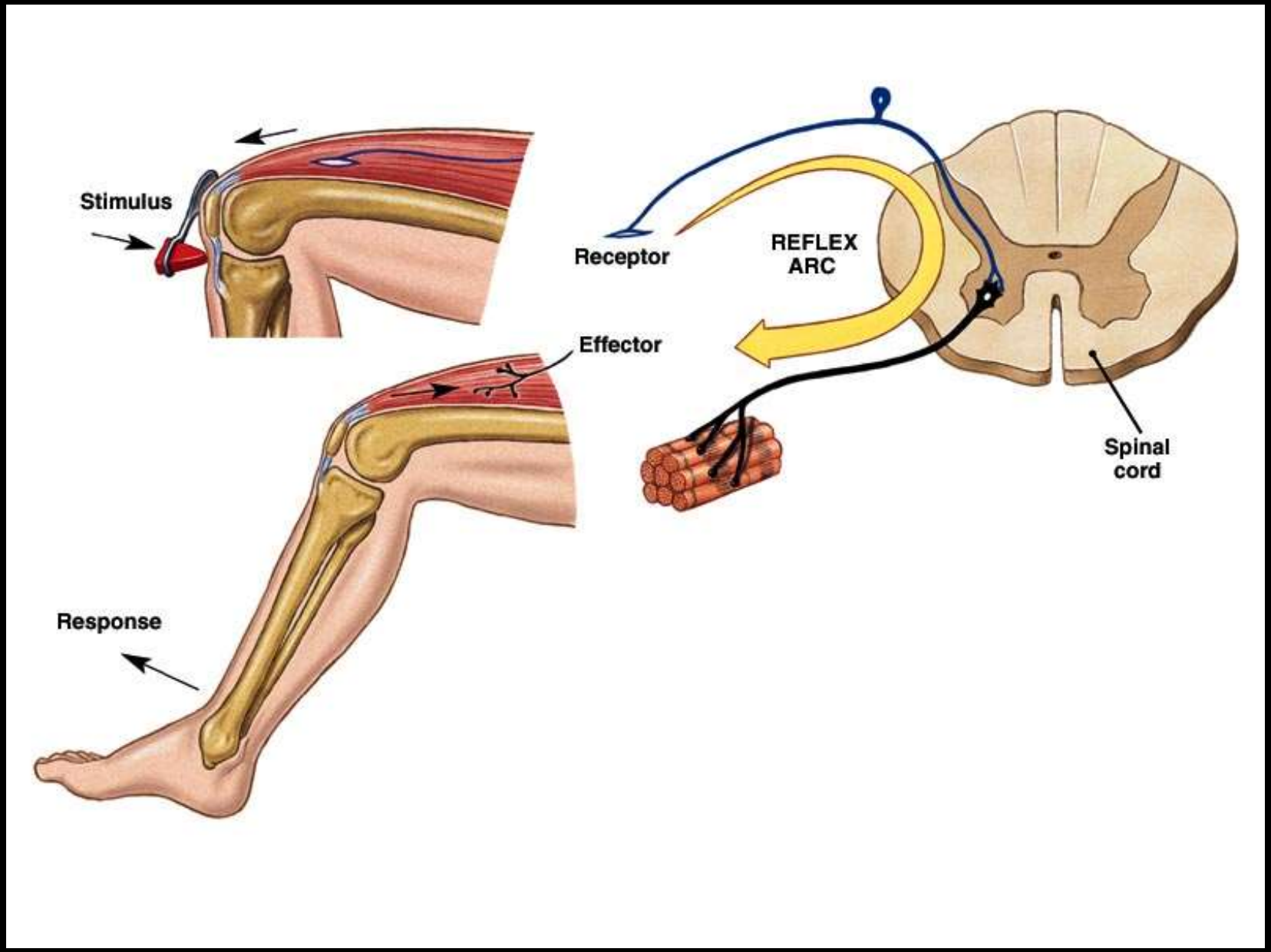

INNATE REFLEXES –Genetically determined
ACQUIRED REFLEXES –Learned
by development
REFLEXES can be classified
by processing site
SPINAL REFLEXES –Processing in the spinal cord
CRANIAL REFLEXES –Processing in the brain
by response
by complexity of circuit
SOMATIC REFLEXES –Control skeletal muscle contractions
VISCERAL (Autonomic) REFLEXES –Control actions of smooth and cardiac muscles, glands
MONOSYNAPTIC –One synapse
POLYSYNAPTIC –Multiple synapses (two to several hundred)

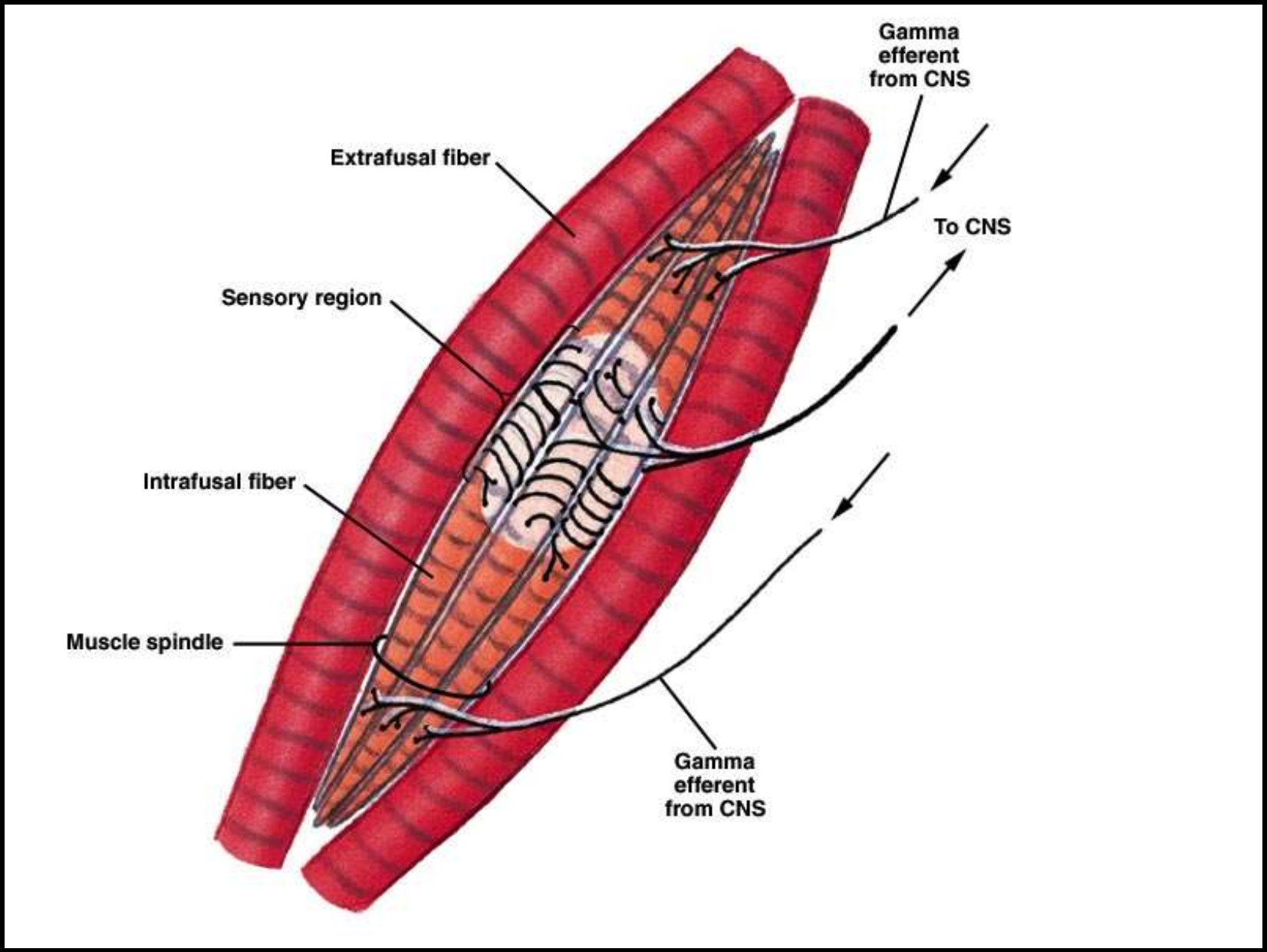

Ganglion
Sensory neuron
CENTRAL NERVOUS SYSTEM
Motor neuron
Circuit 1
Sensory receptor (muscle spindle)
Skeletal muscle
(a) Monosynaptic reflex

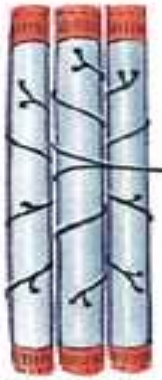

GFP PHOTO

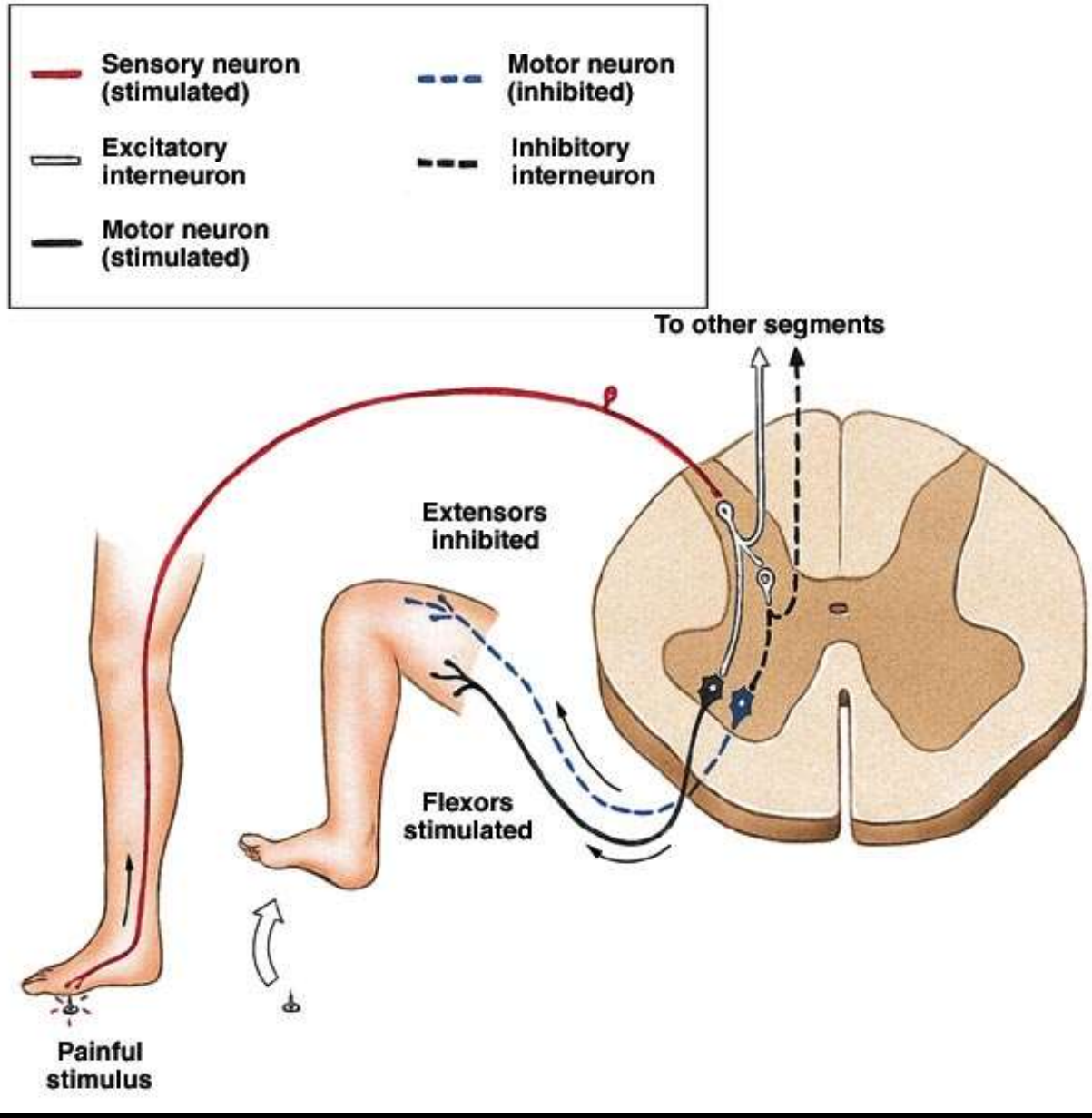

Sensory receptor
Ganglion
Sensory neuron
CENTRAL NERVOUS SYSTEM
Interneurons
Motor neuron
Circuit 2
Skeletal muscle 1
Skeletal muscle 2
(b) Polysynaptic reflex

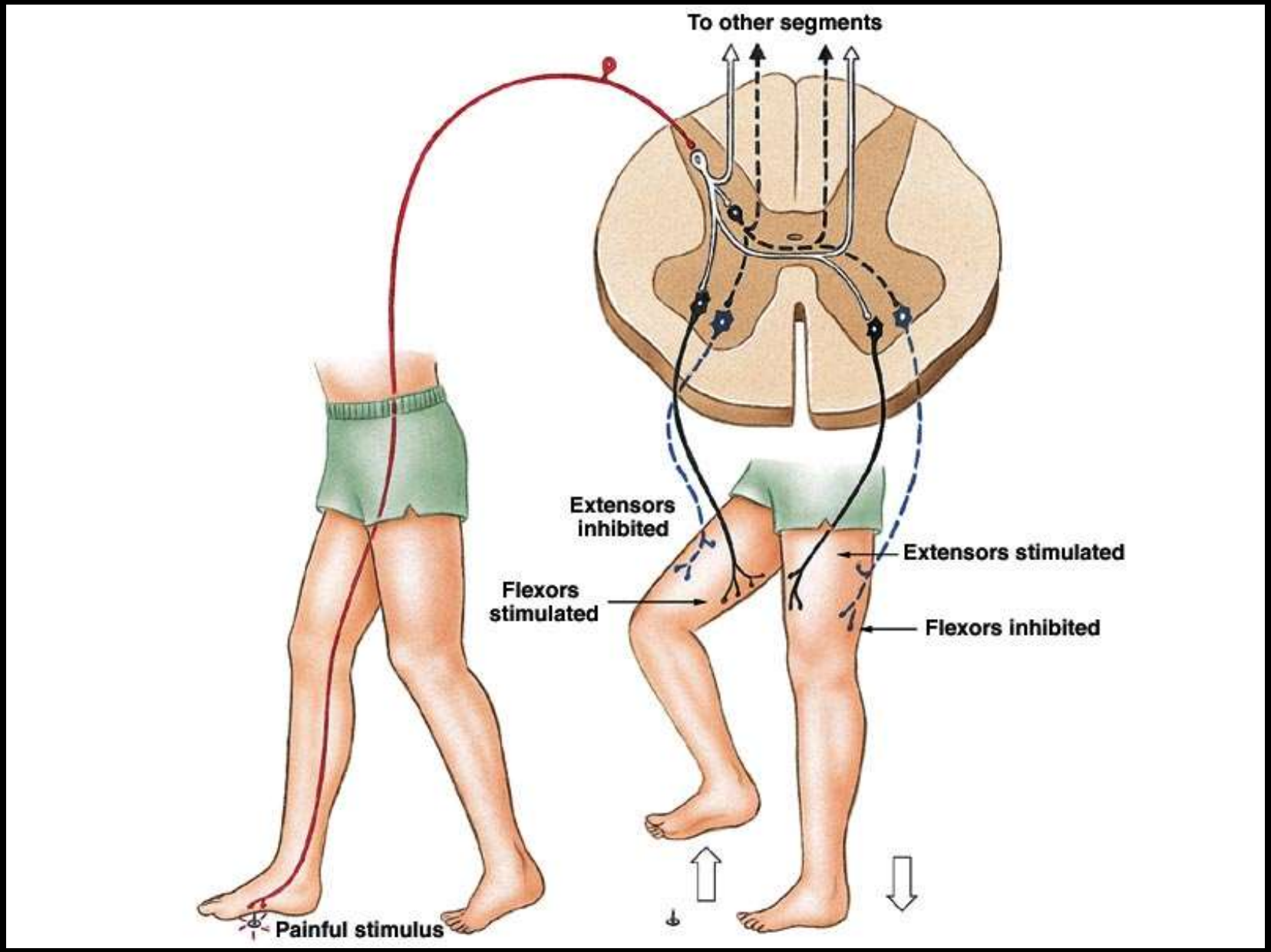

STEP 1
Stretching of muscle stimulates muscle spindles
STEP 2
Activation of sensory neuron
Muscle
STEP 3
Information processing at motor neuron
STEP 4
Activation of motor neuron
STEP 5
Contraction of muscle

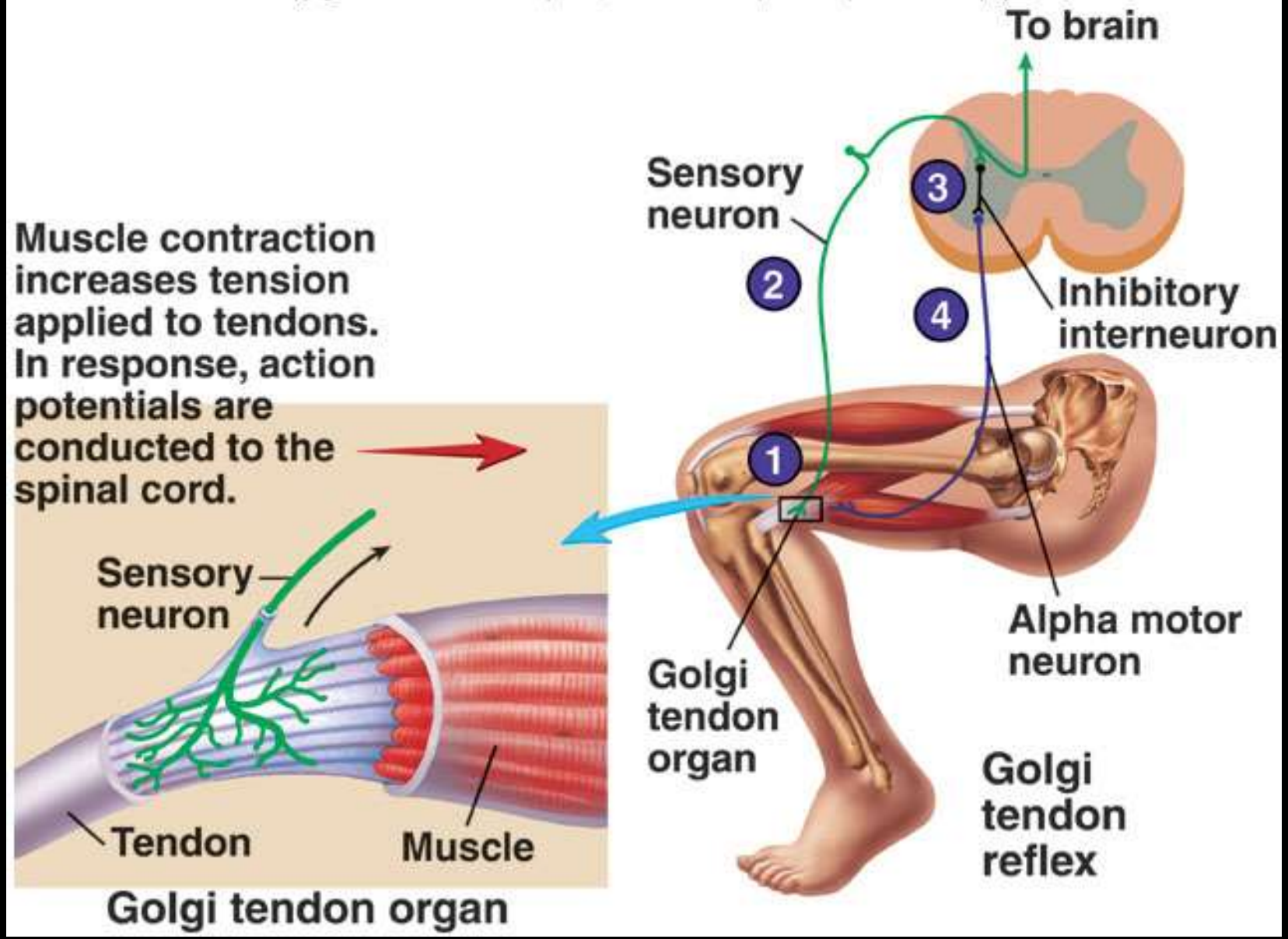

Stimulus
Receptor
REFLEX
ARC
Effector
Spinal
cord
Response

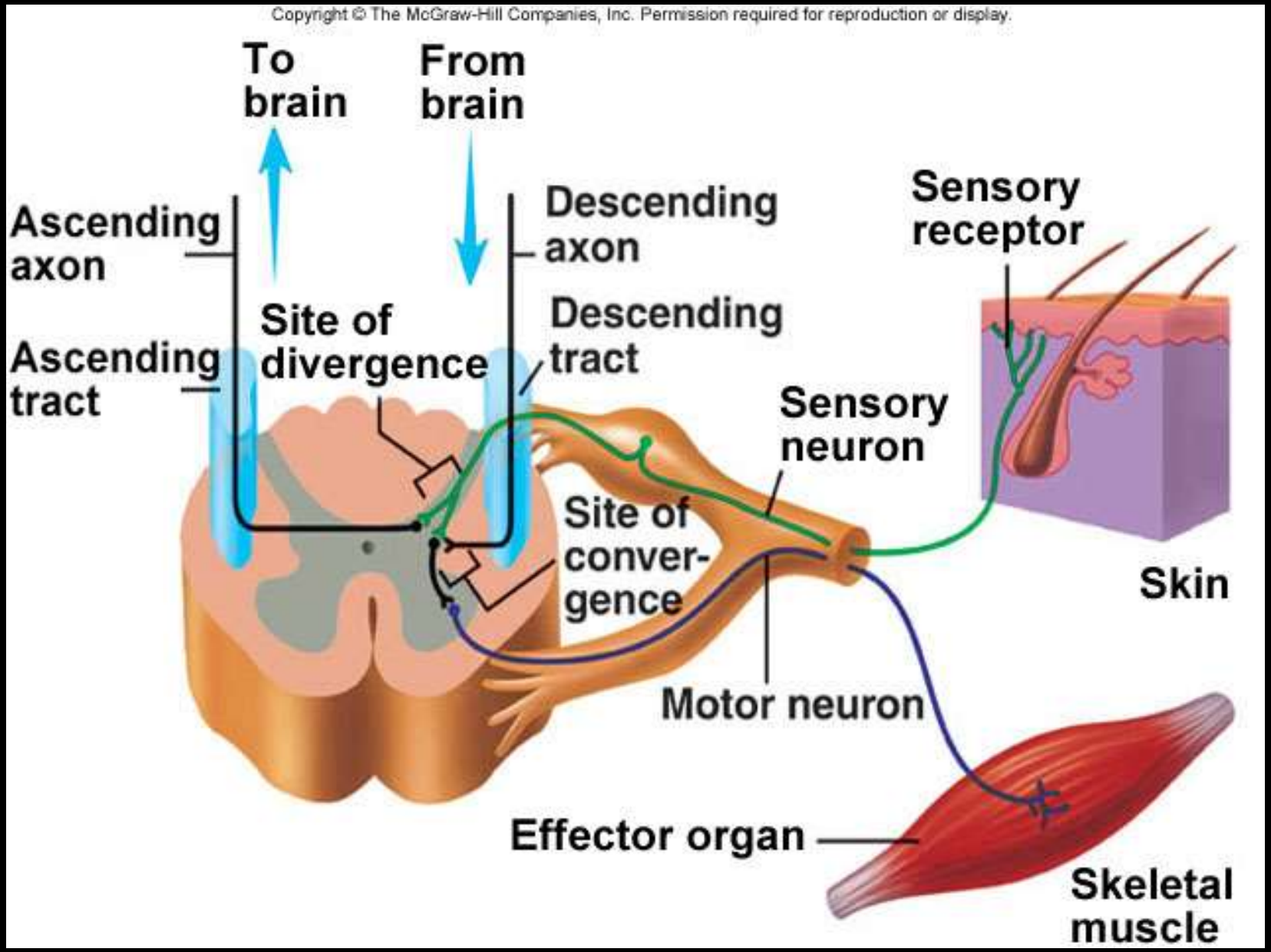

Gamma efferent from CNS
Extrafusal fiber
To CNS
Sensory region
Intrafusal fiber
Muscle spindle
Gamma efferent from CNS

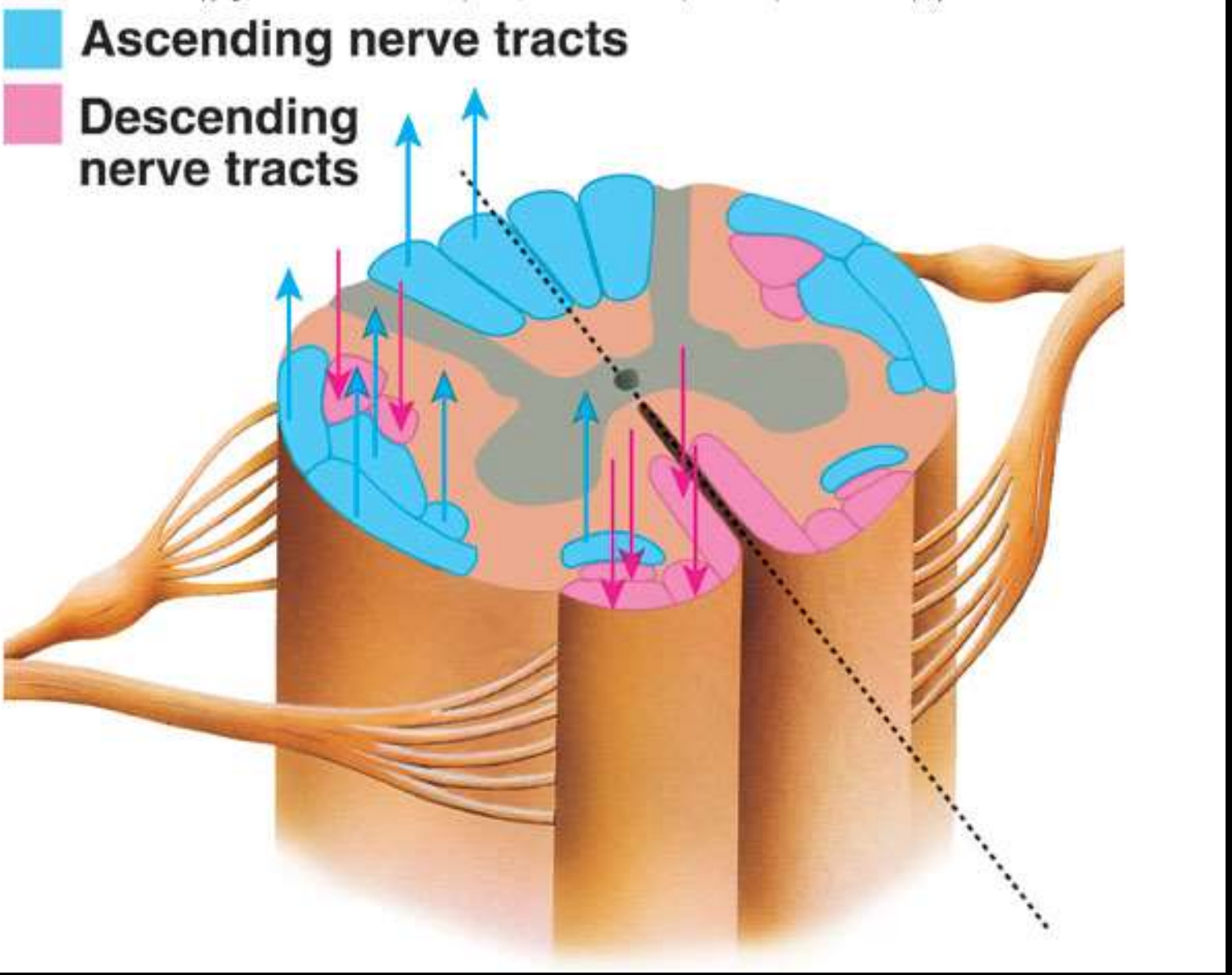
Sensory Region	Action Potential in Sensory Neuron	Effect on Extrafusal Fibers
 Resting length		Normal muscle tone
 Stretched		Muscle tone increases
 Compressed		Muscle tone decreases


Sensory neuron (stimulated)
Motor neuron (inhibited)
Excitatory interneuron
Inhibitory interneuron
Motor neuron (stimulated)
To other segments
Extensors inhibited
Flexors stimulated
Painful stimulus

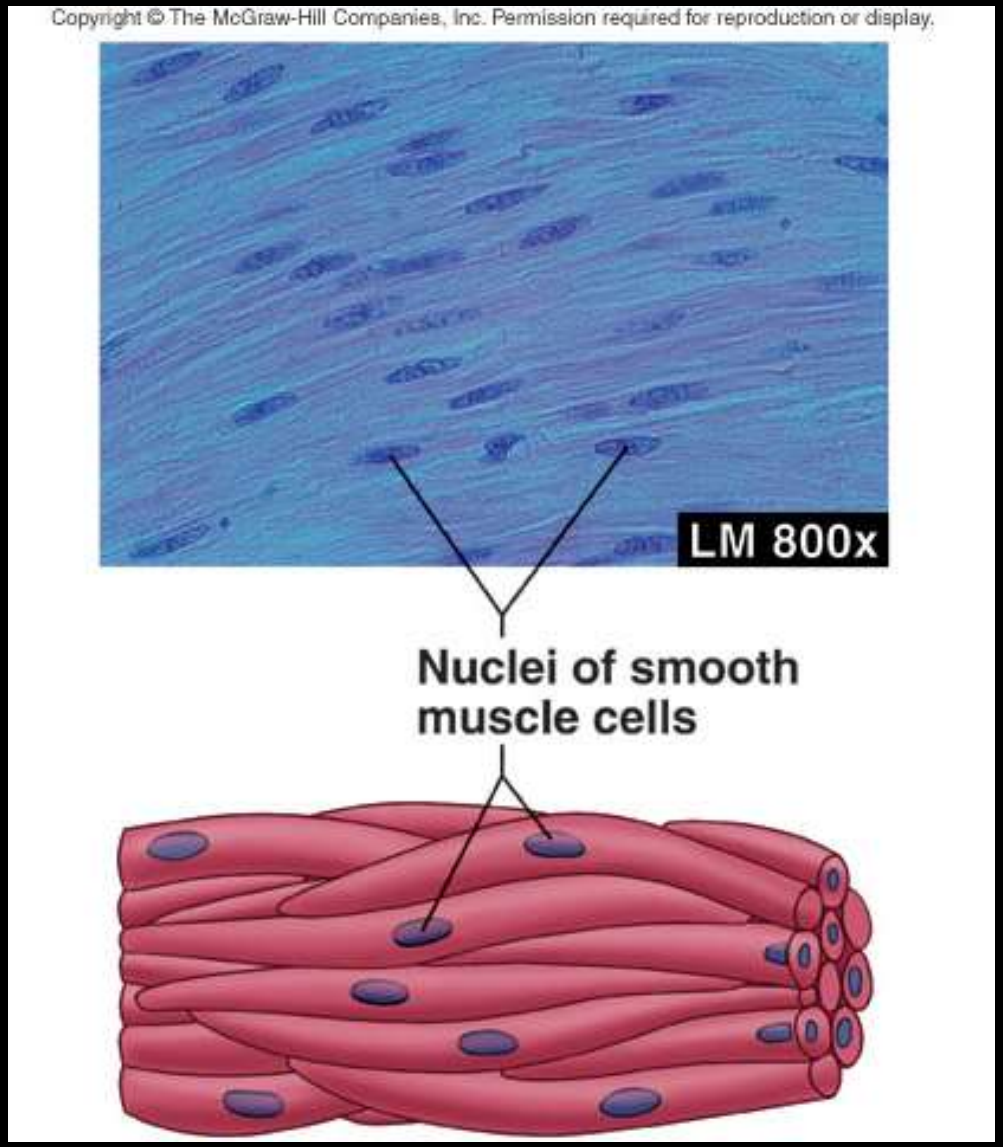

To other segments
Extensors inhibited
Extensors stimulated
Flexors stimulated
Flexors inhibited
Painful stimulus



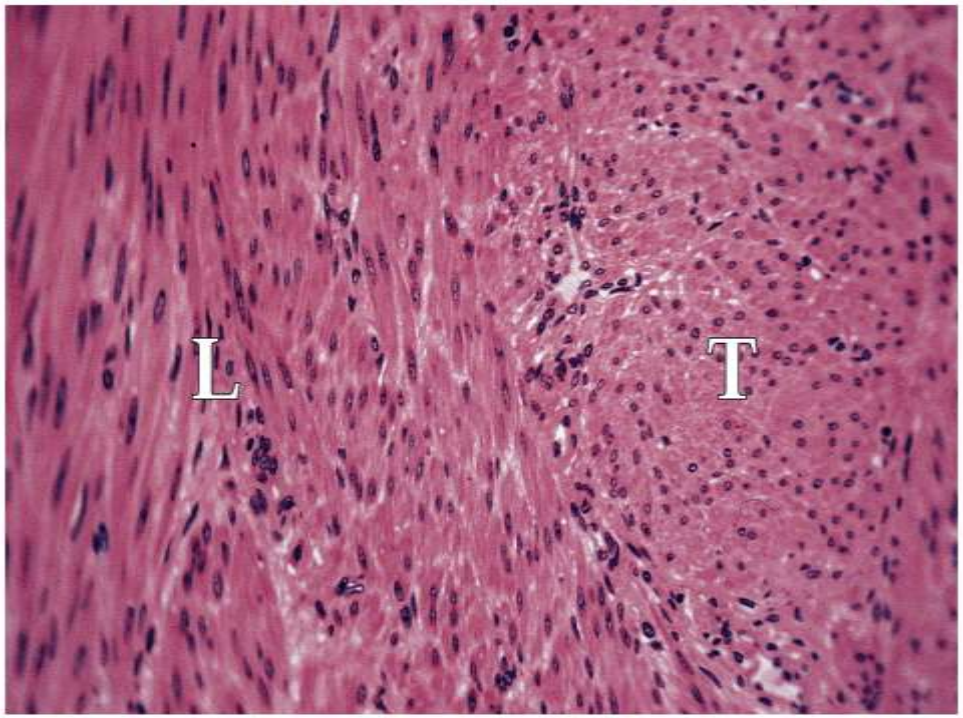




Smooth Muscle



- Characteristics
  - Not striated
  - Dense bodies instead of Z disks as in skeletal muscle
    - Have noncontractile intermediate filaments
  - Ca^{2+} required to initiate contractions
- Types
  - Visceral or unitary
    - Function as a unit
  - Multiunit
    - Cells or groups of cells act as independent units


L
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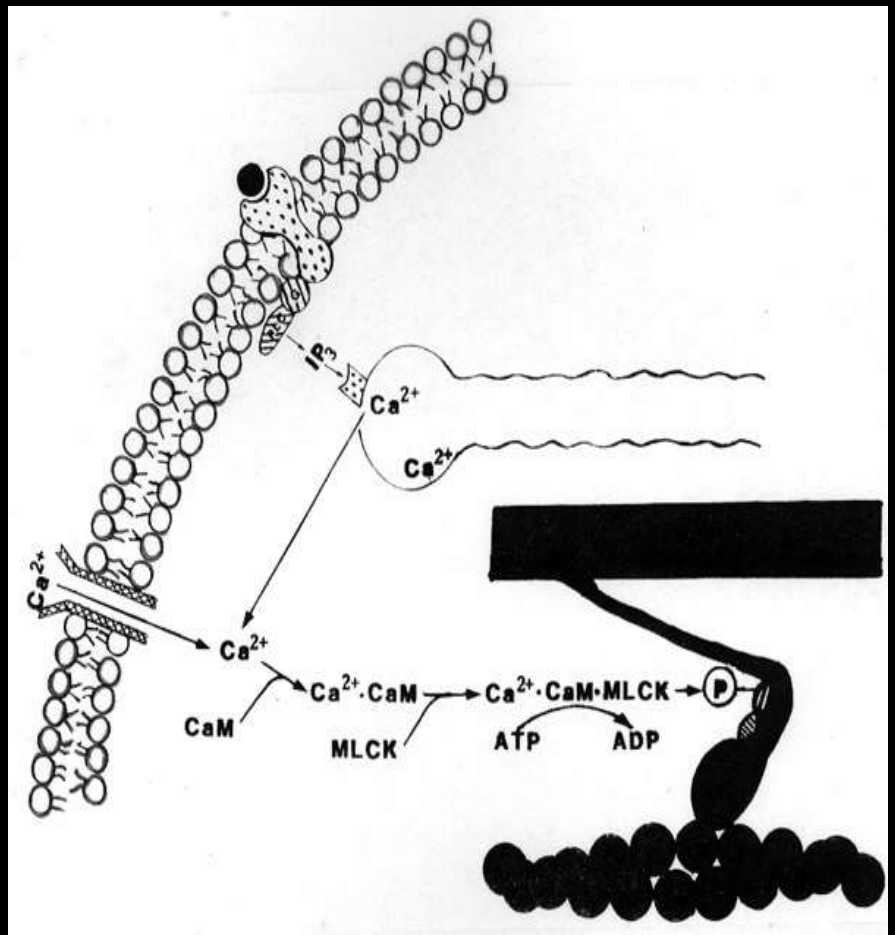
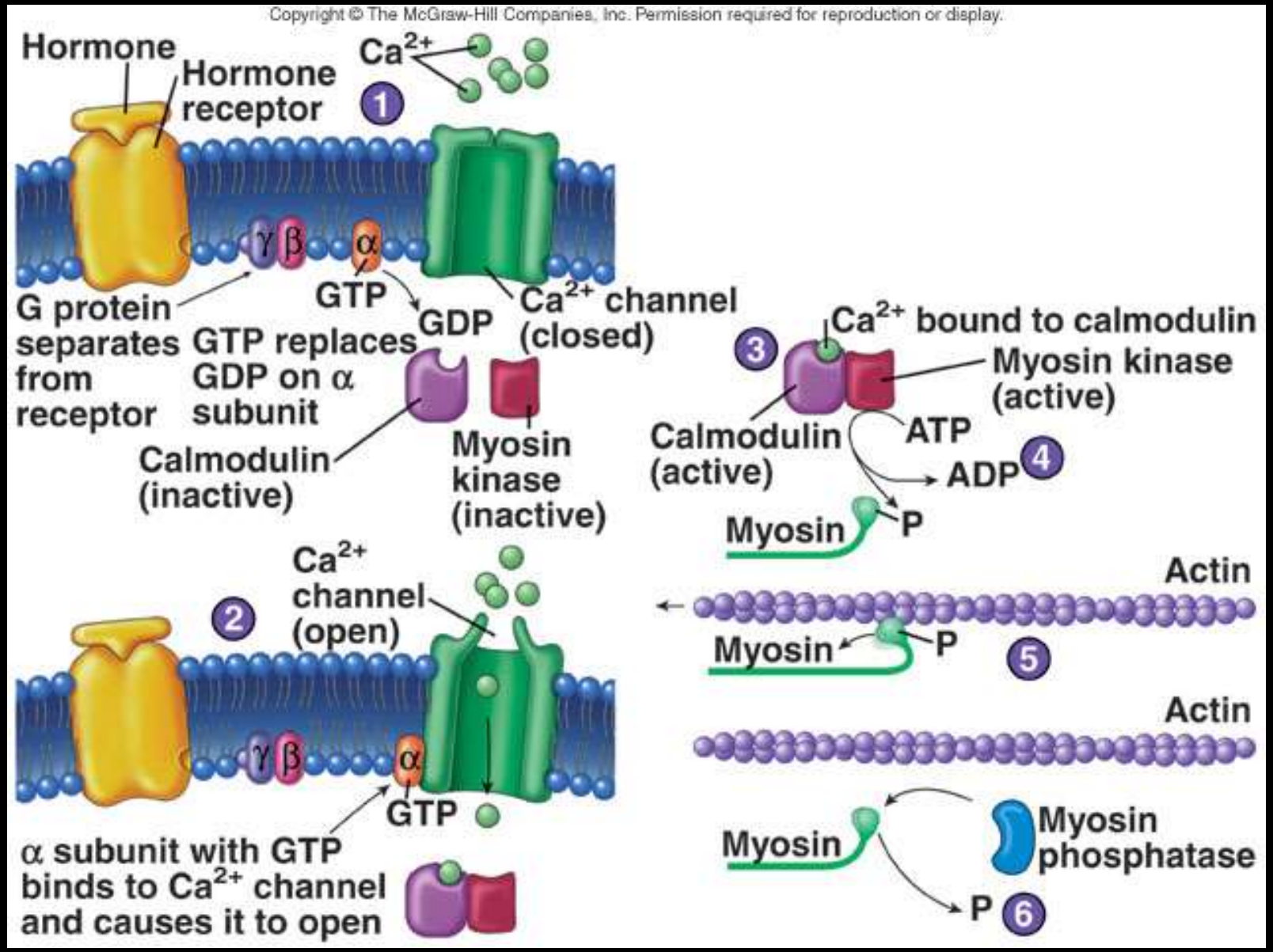
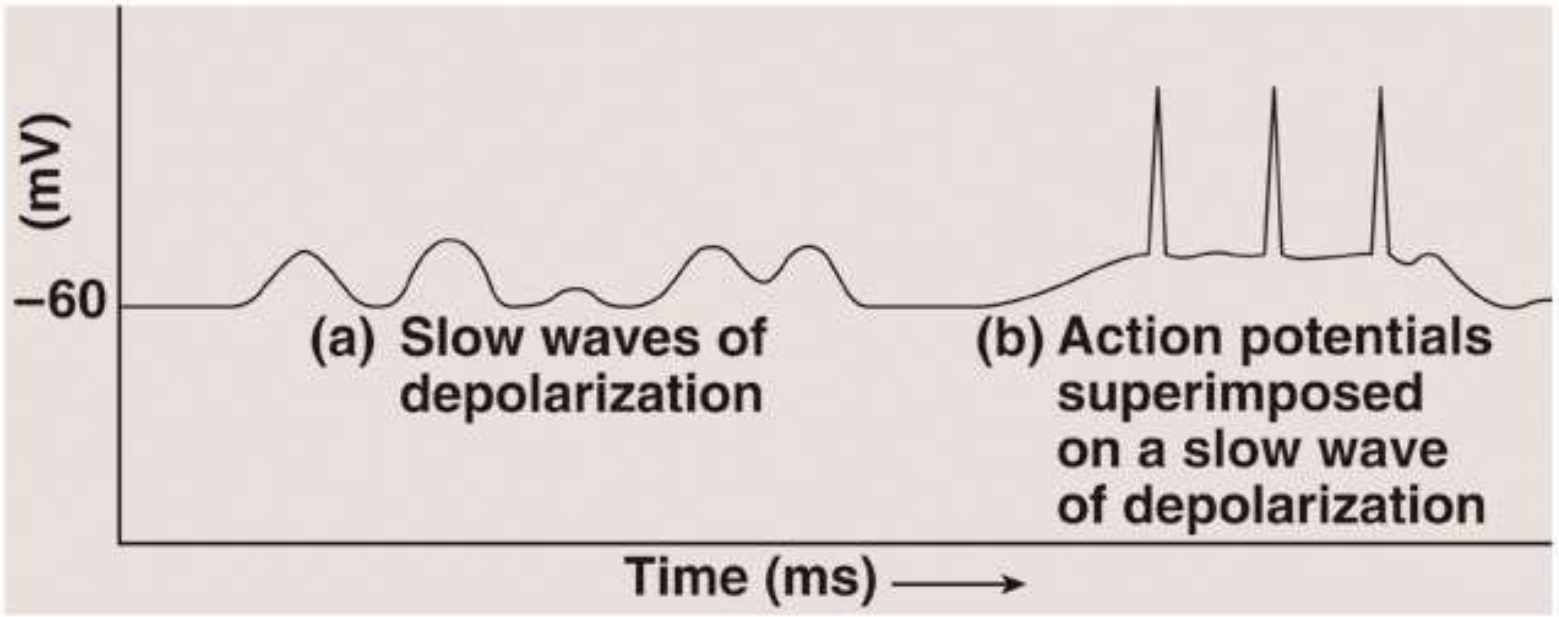

IP3
Ca2+
Ca2+
Ca2+
Ca2+
Ca2+·CaM
Ca2+·CaM·MLCK
P
CaM
MLCK
ATP
ADP

Smooth Muscle Contraction



Electrical Properties of Smooth Muscle

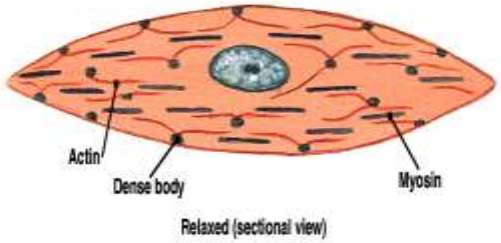


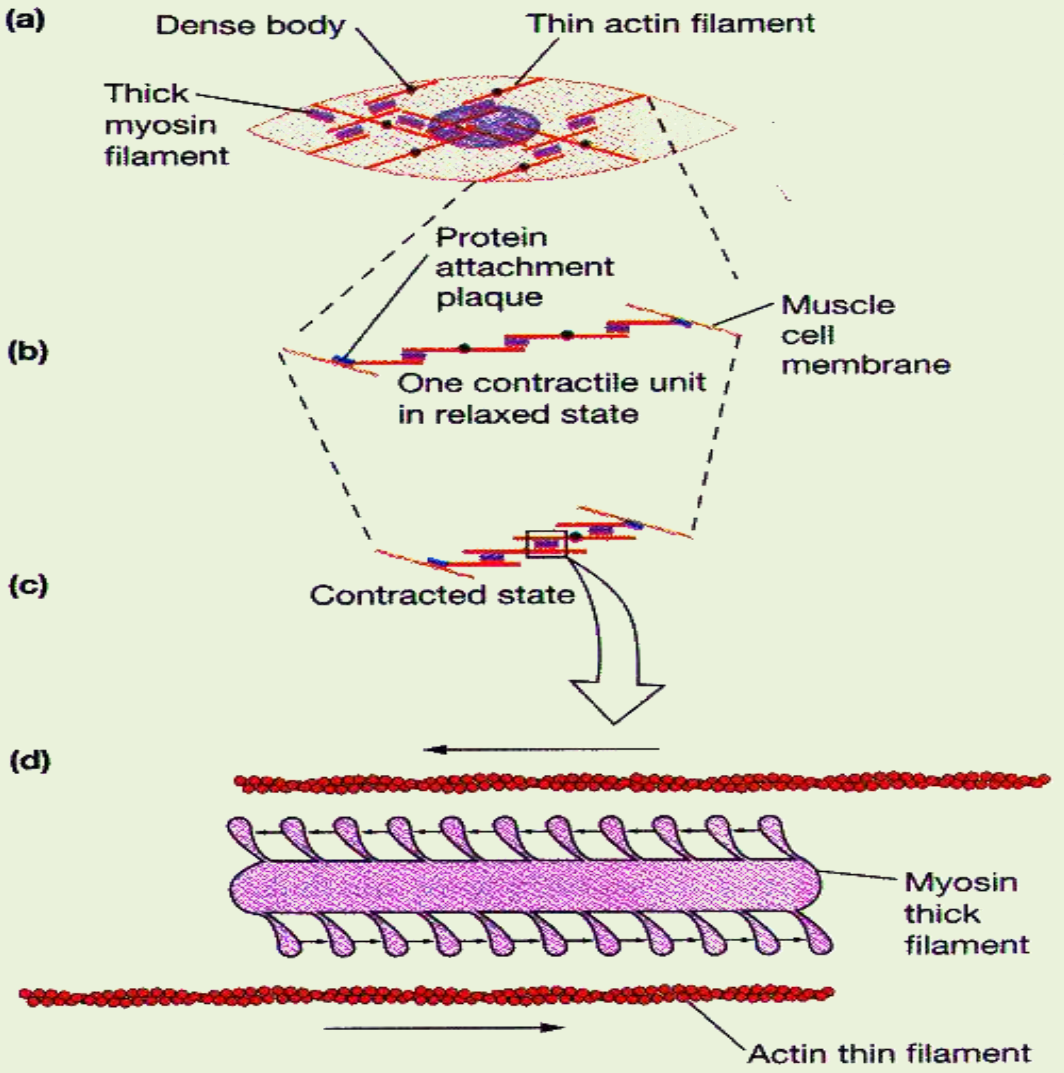
Functional Properties of Smooth Muscle

- Some visceral muscle exhibits autorhythmic contractions
- Tends to contract in response to sudden stretch but no to slow increase in length
- Exhibits relatively constant tension: Smooth muscle tone
- Amplitude of contraction remains constant although muscle length varies

Smooth Muscle Regulation

- Innervated by autonomic nervous system
- Neurotransmitter are acetylcholine and norepinephrine
- Hormones important as epinephrine and oxytocin
- Receptors present on plasma membrane which neurotransmitters or hormones bind determines response





■ **Figure 12-23** **Sliding filaments in smooth muscle** (a) The actin and myosin filaments of smooth muscle are longer than in skeletal muscle. (b) The long actin filaments attach to dense bodies in the cytoplasm and terminate at protein plaques in the cell membrane. (c) Myosin can slide along actin for long distances without encountering the end of a sarcomere. (d) Smooth muscle myosin has hinged heads all along its length, in contrast to skeletal muscle myosin, which has no heads in the center of each filament.

Acknowledgement

- The presentation is being used for educational and non-commercial purposes.
- Thanks are due to all the original contributors and entities whose pictures were used in the creation of this presentation.