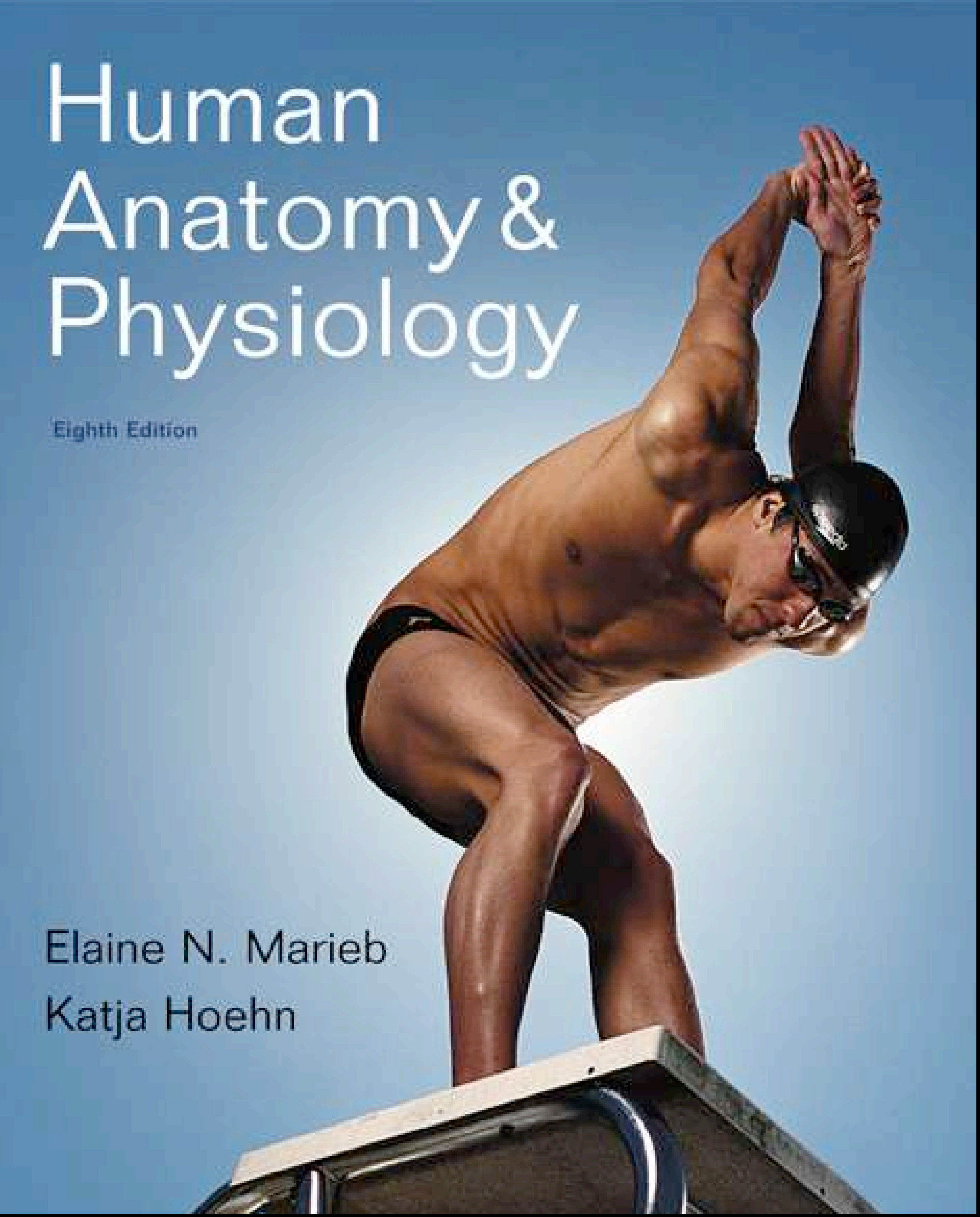

PowerPoint® Lecture Slides

prepared by
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Mount Royal College

CHAPTER 9

Muscles and Muscle Tissue: Part C

Force of Muscle Contraction

- The force of contraction is affected by:
  - Number of muscle fibers stimulated (recruitment)
  - Relative size of the fibers—hypertrophy of cells increases strength

Force of Muscle Contraction

- The force of contraction is affected by:
  - Frequency of stimulation—↑ frequency allows time for more effective transfer of tension to noncontractile components
  - Length-tension relationship—muscles contract most strongly when muscle fibers are 80–120% of their normal resting length

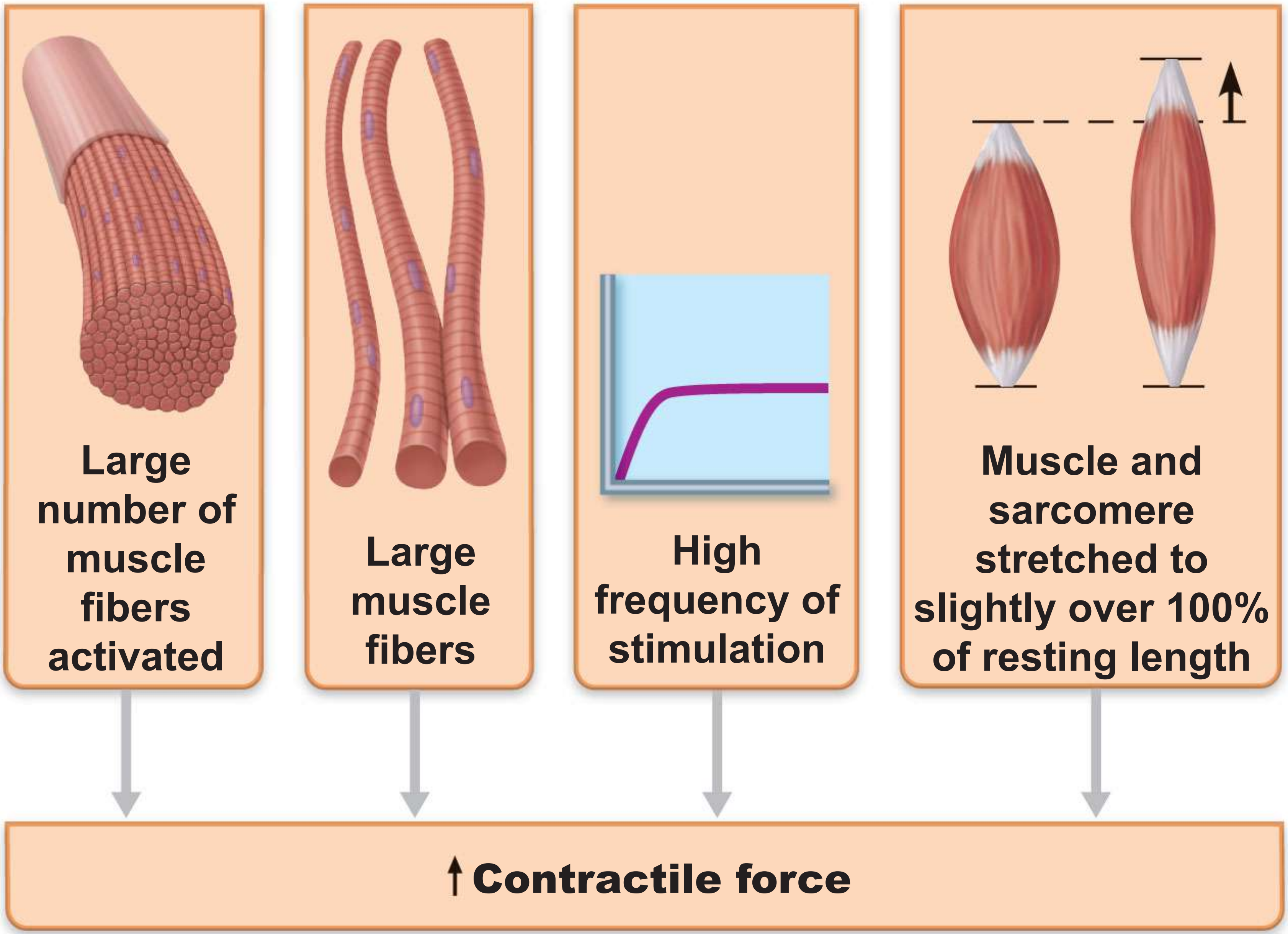
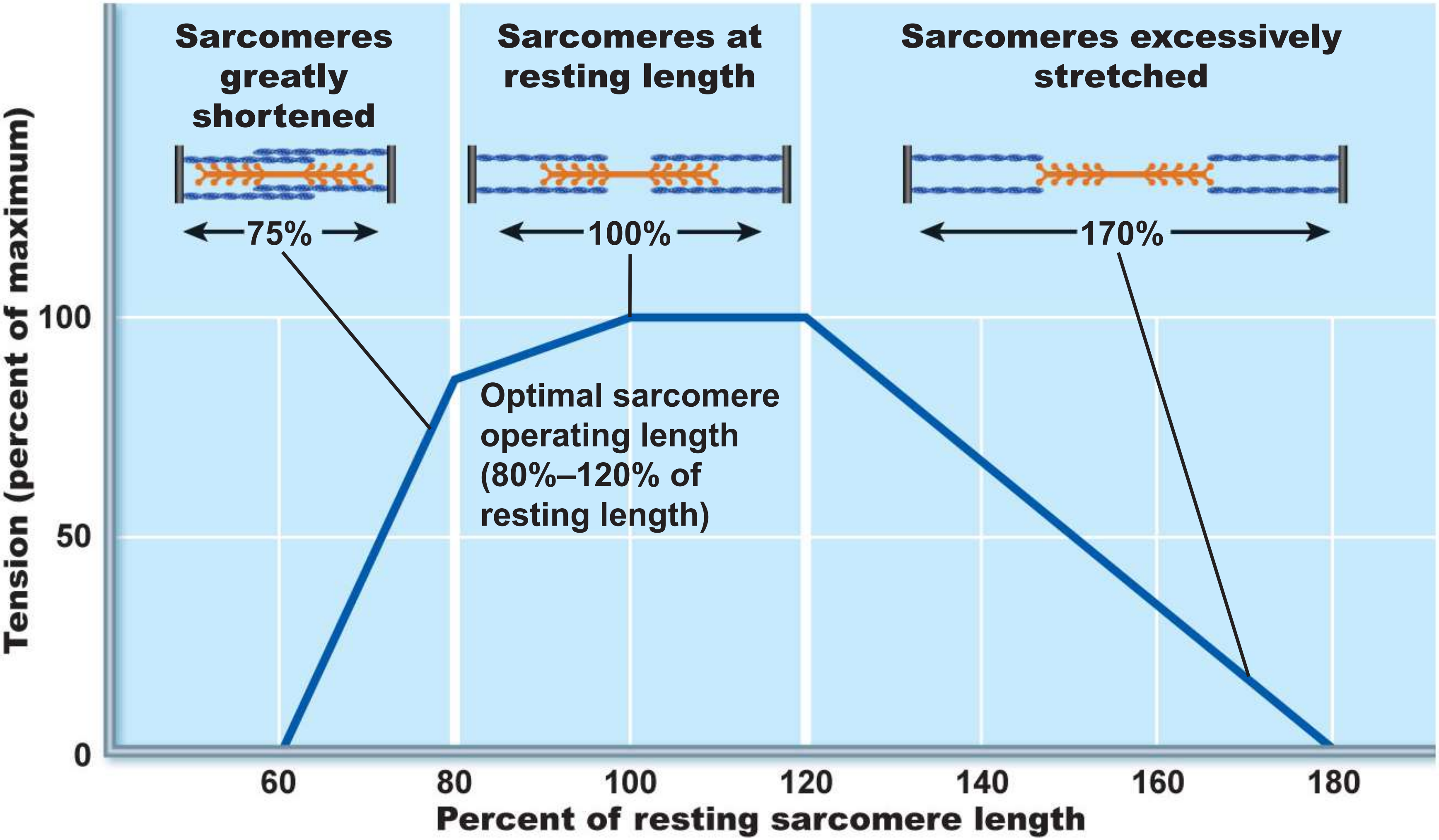

Large number of muscle fibers activated
Large muscle fibers
High frequency of stimulation
Muscle and sarcomere stretched to slightly over 100% of resting length
↑ Contractile force

Figure 9.21



Sarcomeres greatly shortened
Sarcomeres at resting length
Sarcomeres excessively stretched
75%
100%
170%
Optimal sarcomere operating length (80%–120% of resting length)
Tension (percent of maximum)
100
50
0
60
80
100
120
140
160
180
Percent of resting sarcomere length

Figure 9.22

Velocity and Duration of Contraction

Influenced by:

1. Muscle fiber type
2. Load
3. Recruitment

Muscle Fiber Type

Classified according to two characteristics:

1. Speed of contraction: slow or fast, according to:
   - Speed at which myosin ATPases split ATP
   - Pattern of electrical activity of the motor neurons
2. Metabolic pathways for ATP synthesis:
   - Oxidative fibers—use aerobic pathways
   - Glycolytic fibers—use anaerobic glycolysis

Muscle Fiber Type

Three types:

- Slow oxidative fibers (aerobic)
- Fast oxidative fibers (aerobic)
- Fast glycolytic fibers (anaerobic)

E 9.2	Structural and Functional Characteristics of the Three Types of Skeletal Muscle Fibers		
	SLOW OXIDATIVE FIBERS	FAST OXIDATIVE FIBERS	FAST GLYCOLYTIC FIBERS
bolic Characteristics			
d of contraction	Slow	Fast	Fast
in ATPase activity	Slow	Fast	Fast
ry pathway for ATP esis	Aerobic	Aerobic (some anaerobic glycolysis)	Anaerobic glycolysis
globin content	High	High	Low
gen stores	Low	Intermediate	High
itment order	First	Second	Third
of fatigue	Slow (fatigue-resistant)	Intermediate (moderately fatigue-resistant)	Fast (fatigable)
ities Best Suited For			
	Endurance-type activities—e.g., running a marathon; maintaining posture (antigravity muscles)	Sprinting, walking	Short-term intense or powe ful movements, e.g., hitting baseball
tural Characteristics			
	Red	Red to pink	White (pale)
diameter	Small	Intermediate	Large
chondria	Many	Many	Few
aries	Many	Many	Few

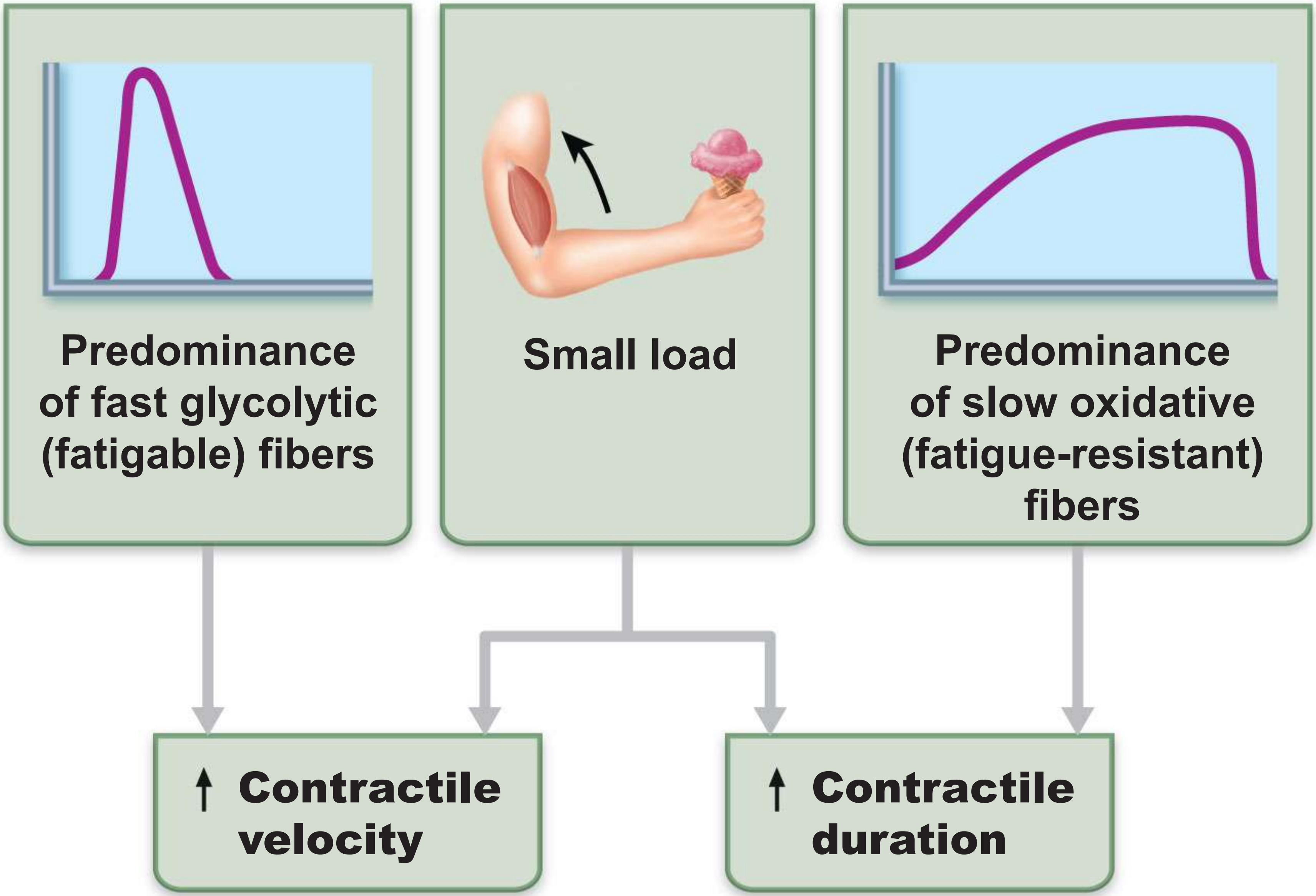

Predominance of fast glycolytic (fatigable) fibers
Small load
Predominance of slow oxidative (fatigue-resistant) fibers
↑ Contractile velocity
↑ Contractile duration

Figure 9.23

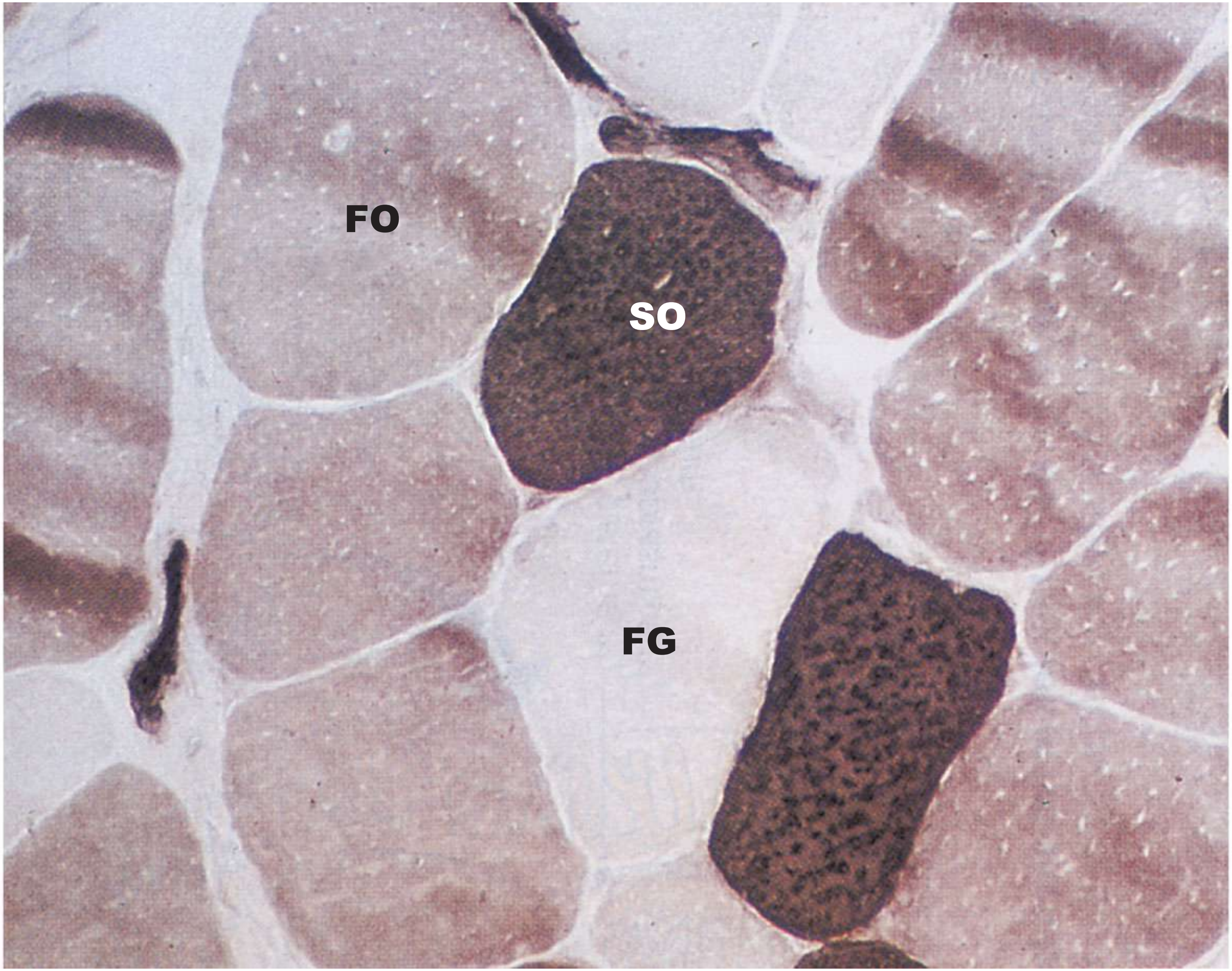
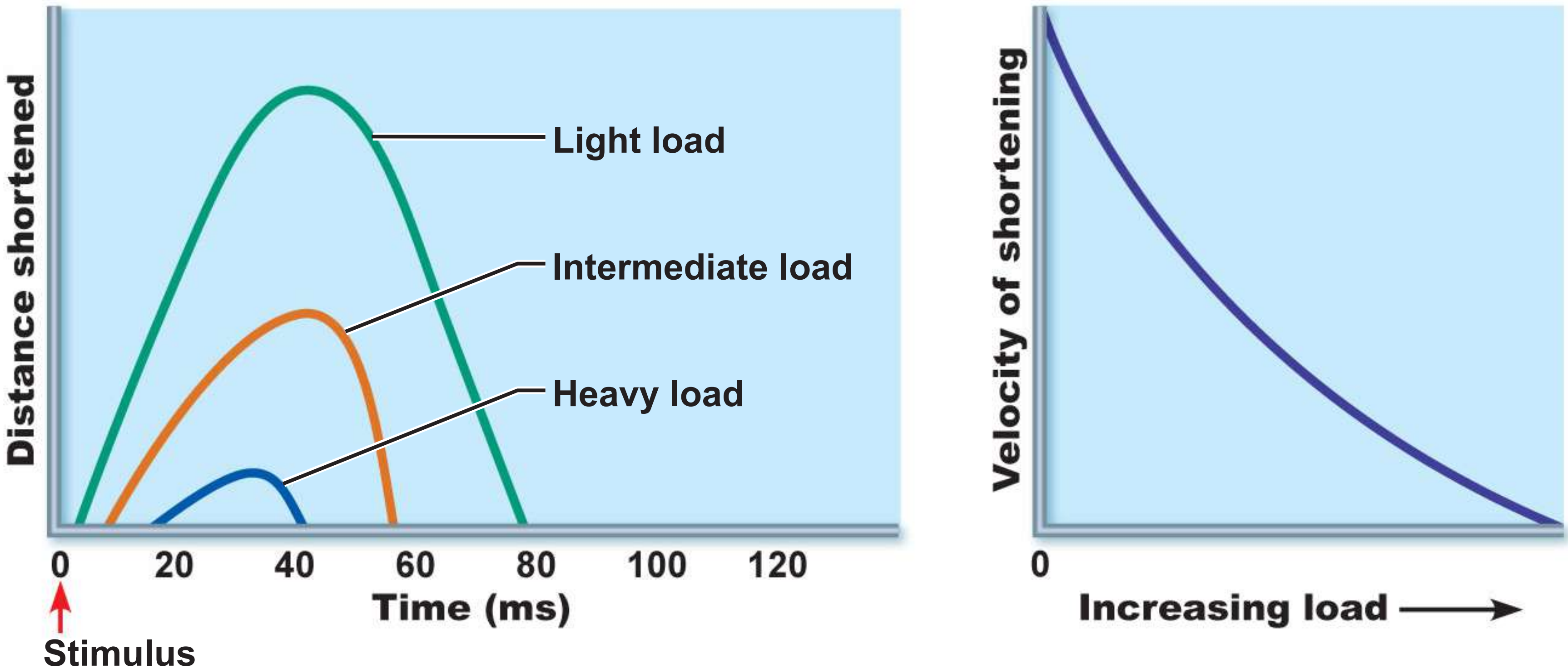


Figure 9.24

Influence of Load

↑ load → ↑ latent period, ↓ contraction, and ↓ duration of contraction



(a) The greater the load, the less the muscle shortens and the shorter the duration of contraction

(b) The greater the load, the slower the contraction

Figure 9.25

Influence of Recruitment

Recruitment → faster contraction and ↑ duration of contraction

Effects of Exercise

Aerobic (endurance) exercise:

- Leads to increased:
  - Muscle capillaries
  - Number of mitochondria
  - Myoglobin synthesis
- Results in greater endurance, strength (?), and resistance to fatigue
- May convert fast glycolytic fibers into fast oxidative fibers

Effects of Resistance Exercise

- Resistance exercise (typically anaerobic) results in:
  - Muscle hypertrophy, size (due to increase in fiber size)
  - Increased mitochondria, myofilaments, glycogen stores, and connective tissue
  - Increased strength

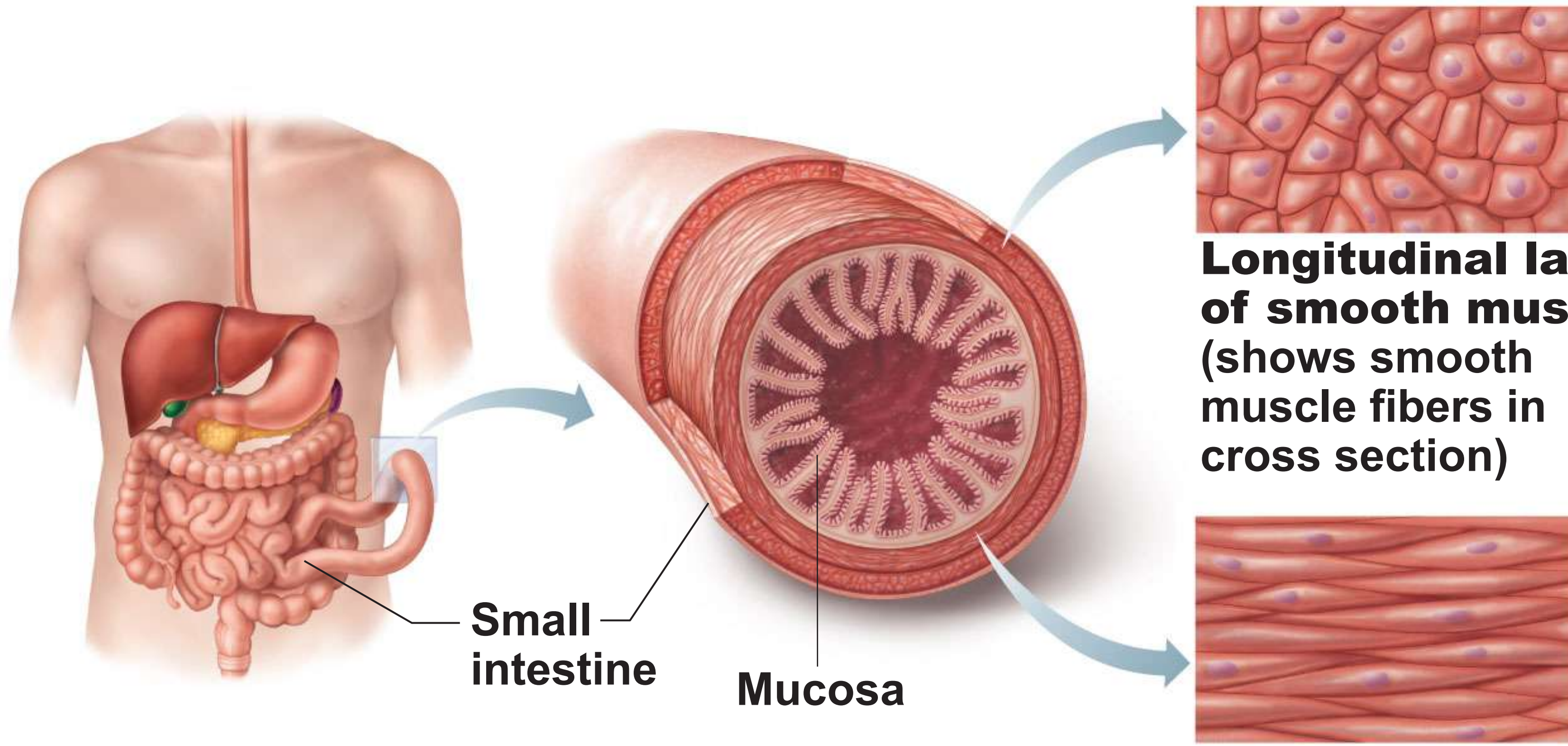
The Overload (bad word) Principle

- Forcing a muscle to work hard promotes increased muscle strength and endurance
- Two components –
  load (reps) & intensity (weight)
- Muscles must be stressed to produce gains
- Muscles adapt to increased demands
- Must vary load & intensity for muscles to continue to grow

Smooth Muscle

- Found in walls of most hollow organs (except heart)
- Usually in two layers –
-     - longitudinal (outer)

  - circular (inner)



Circular layer of smooth muscle (shows longitudinal views of smooth muscle fibers)

(a)

(b) Cross section of the intestine showing the smooth muscle layers (one circular and the other longitudinal) running at right angles to each other.

Figure 9.26

Peristalsis

- Alternating contractions and relaxations (in a wave-like manner) of smooth muscle layers that mix and squeeze substances through the lumen of hollow organs
  - Longitudinal layer contracts; organ dilates and shortens
  - Circular layer contracts; organ constricts and elongates

Microscopic Structure

- Spindle-shaped fibers: thin and short compared with skeletal muscle fibers
- Connective tissue: endomysium only
- SR: less developed than in skeletal muscle
- Pouchlike infoldings (caveolae) of sarcolemma sequester Ca^{2+}
- No sarcomeres, myofibrils, or T tubules

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

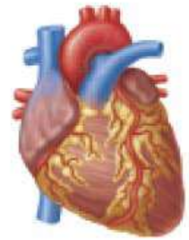
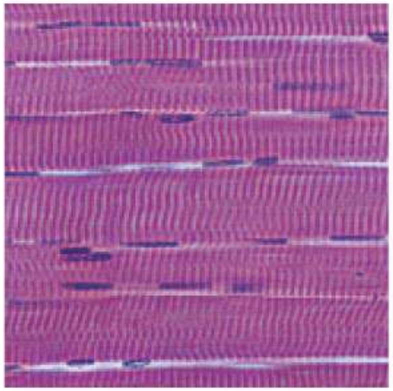
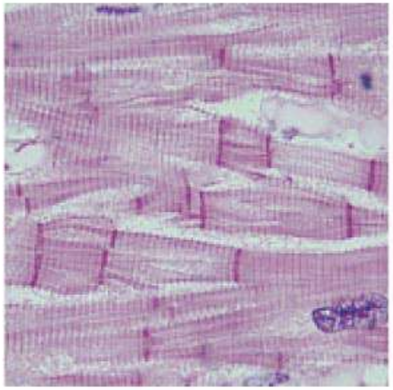
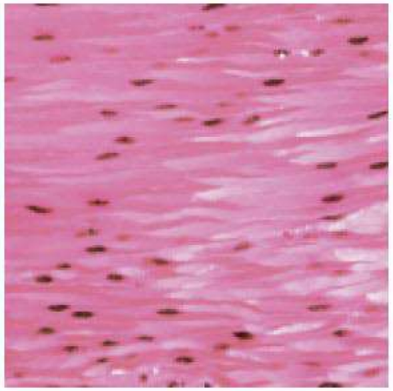
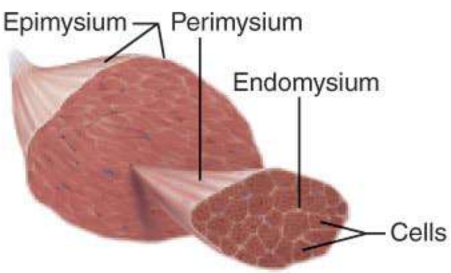
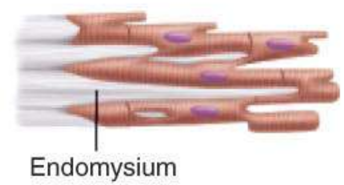
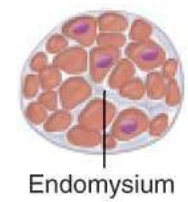
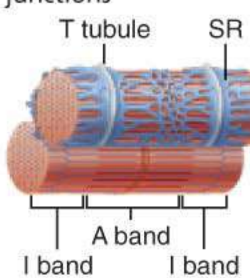
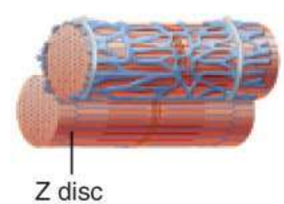
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Body location	Attached to bones or (some facial muscles) to skin 	Walls of the heart 	Single-unit muscle in walls of hollow visceral organs (other than the heart); multiunit muscle in intrinsic eye muscles, airways, large arteries 
Cell shape and appearance	Single, very long, cylindrical, multinucleate cells with obvious striations  	Branching chains of cells; uni- or binucleate; striations  	Single, fusiform, uninucleate; no striations  

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Connective tissue components	Epimysium, perimysium, and endomysium 	Endomysium attached to fibrous skeleton of heart 	Endomysium 
Presence of myofibrils composed of sarcomeres	Yes	Yes, but myofibrils are of irregular thickness	No, but actin and myosin filaments are present throughout; dense bodies anchor actin filaments
Presence of T tubules and site of invagination	Yes; two in each sarcomere at A-I junctions 	Yes; one in each sarcomere at Z disc; larger diameter than those of skeletal muscle 	No; only caveolae

Innervation of Smooth Muscle

- Autonomic nerve fibers innervate smooth muscle at diffuse junctions
- Varicosities (bulbous swellings) of nerve fibers store and release neurotransmitters

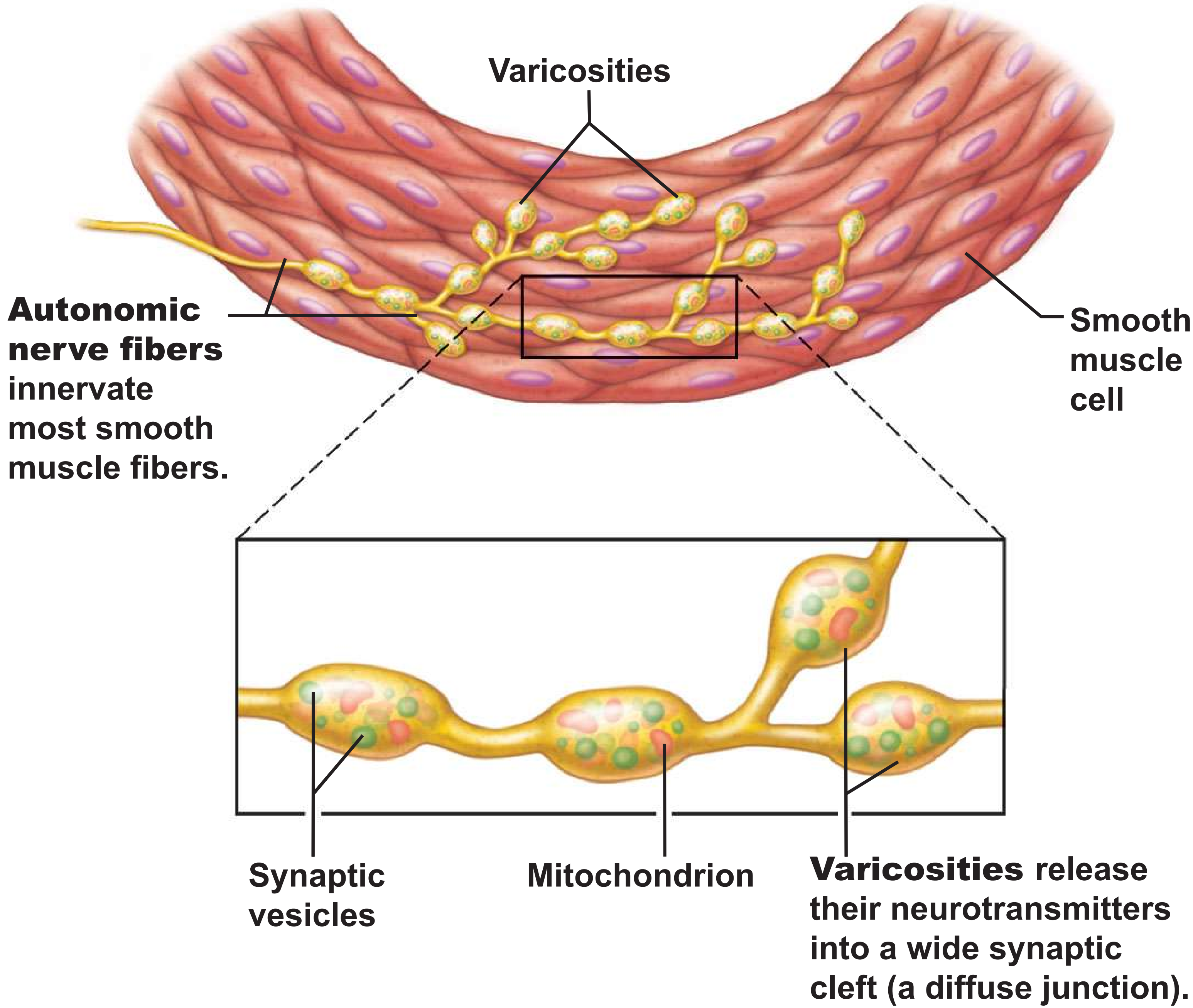

Varicosities
Autonomic nerve fibers innervate most smooth muscle fibers.
Smooth muscle cell
Synaptic vesicles
Mitochondrion
Varicosities release their neurotransmitters into a wide synaptic cleft (a diffuse junction).

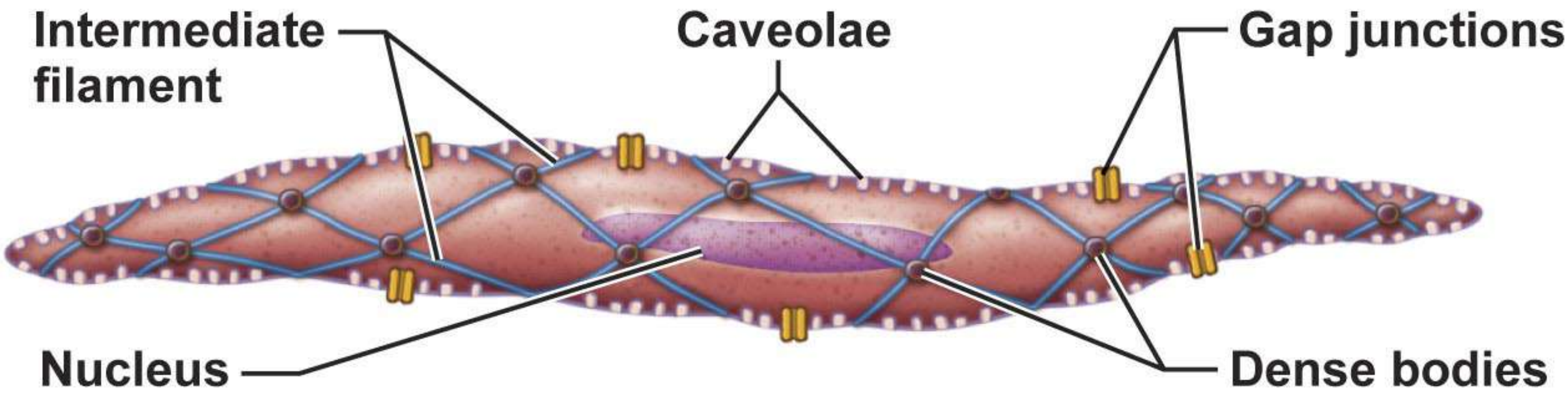
Figure 9.27

Myofilaments in Smooth Muscle

- Ratio of thick to thin filaments (1:13) is much lower than in skeletal muscle (1:2)
- Thick filaments have heads along their entire length
- No troponin complex; protein calmodulin binds Ca^{2+}

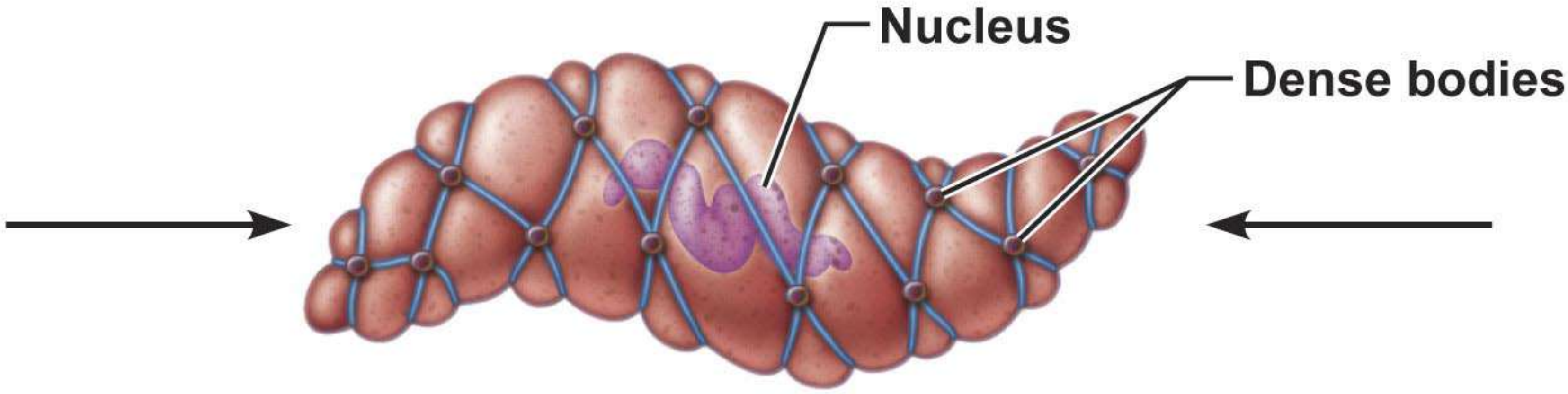
Myofilaments in Smooth Muscle

- Myofilaments are spirally arranged, causing smooth muscle to contract in a corkscrew manner
- Dense bodies: proteins that anchor noncontractile intermediate filaments to sarcolemma at regular intervals



(a) Relaxed smooth muscle fiber (note that adjacent fibers are connected by gap junctions)

Figure 9.28a



(b) Contracted smooth muscle fiber

Figure 9.28b

Contraction of Smooth Muscle

- Slow, synchronized contractions
- Cells are electrically coupled by gap junctions
- Some cells are self-excitatory (depolarize without external stimuli); act as pacemakers for sheets of muscle
- Rate and intensity of contraction may be modified by neural and chemical stimuli
- Sliding filament mechanism
- Final trigger is ↑ intracellular Ca^{2+}
- Ca^{2+} is obtained from the SR and extracellular space

Role of Calcium Ions

- Ca^{2+} binds to and activates calmodulin
- Activated calmodulin activates myosin (light chain) kinase
- Activated kinase phosphorylates and activates myosin
- Cross bridges interact with actin

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

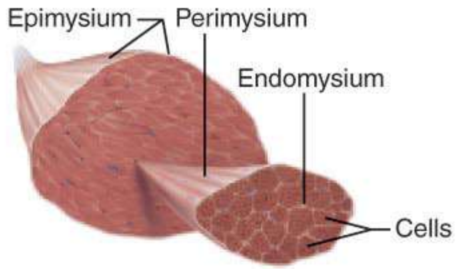
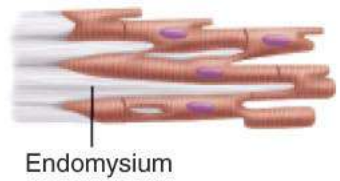
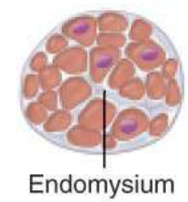
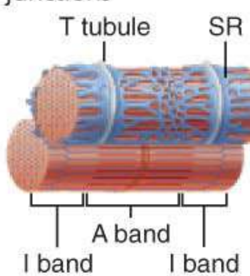
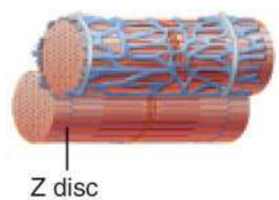
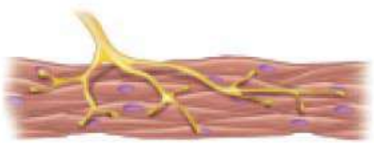
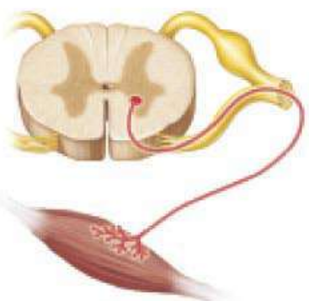
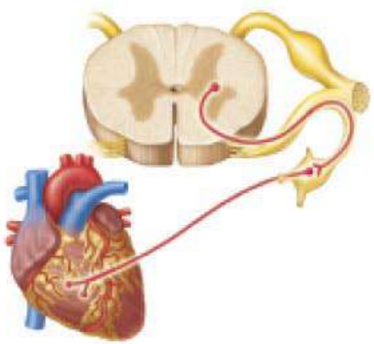
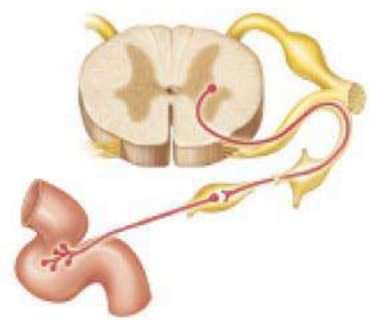
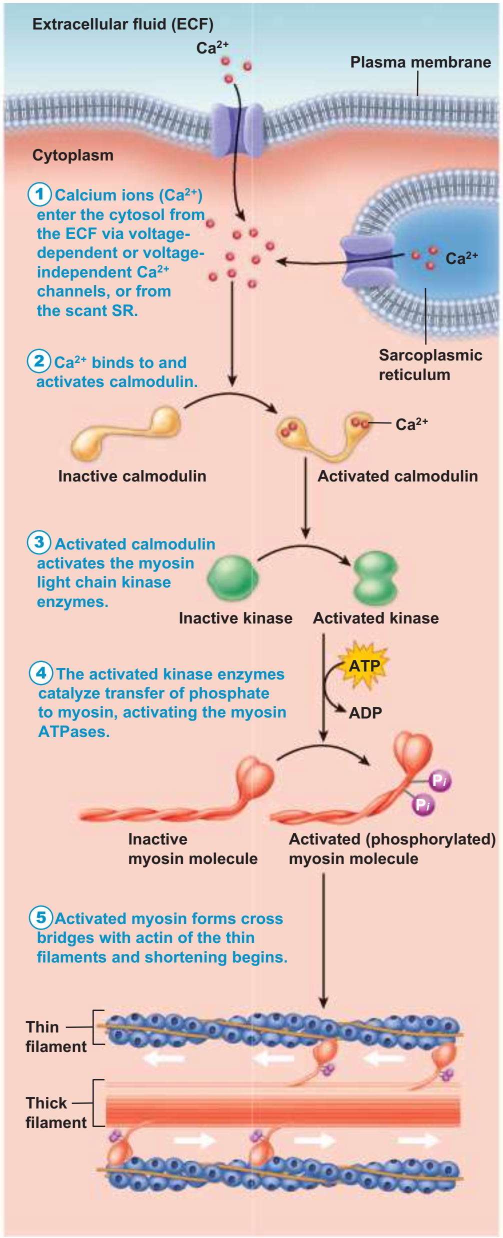
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Connective tissue components	Epimysium, perimysium, and endomysium 	Endomysium attached to fibrous skeleton of heart 	Endomysium 
Presence of myofibrils composed of sarcomeres	Yes	Yes, but myofibrils are of irregular thickness	No, but actin and myosin filaments are present throughout; dense bodies anchor actin filaments
Presence of T tubules and site of invagination	Yes; two in each sarcomere at A-I junctions 	Yes; one in each sarcomere at Z disc; larger diameter than those of skeletal muscle 	No; only caveolae

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle *(continued)*

CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Elaborate sarcoplasmic reticulum	Yes	Less than skeletal muscle (1–8% of cell volume); scant terminal cisternae	Equivalent to cardiac muscle (1–8% of cell volume); some SR contacts the sarcolemma
Presence of gap junctions	No	Yes; at intercalated discs	Yes; in single-unit muscle
Cells exhibit individual neuromuscular junctions	Yes 	No	Not in single-unit muscle; yes in multiunit muscle 
Regulation of contraction	Voluntary via axon terminals of the somatic nervous system 	Involuntary; intrinsic system regulation; also autonomic nervous system controls; hormones; stretch 	Involuntary; autonomic nerves, hormones, local chemicals; stretch 



Extracellular fluid (ECF)
Ca2+
Plasma membrane
Cytoplasm
1 Calcium ions (Ca2+) enter the cytosol from the ECF via voltage-dependent or voltage-independent Ca2+ channels, or from the scant SR.
Ca2+
Sarcoplasmic reticulum
2 Ca2+ binds to and activates calmodulin.
Ca2+
Inactive calmodulin
Activated calmodulin
3 Activated calmodulin activates the myosin light chain kinase enzymes.
Inactive kinase
Activated kinase
ATP
ADP
4 The activated kinase enzymes catalyze transfer of phosphate to myosin, activating the myosin ATPases.
Pi
Pi
Inactive myosin molecule
Activated (phosphorylated) myosin molecule
5 Activated myosin forms cross bridges with actin of the thin filaments and shortening begins.
Thin filament
Thick filament

Figure 9.29

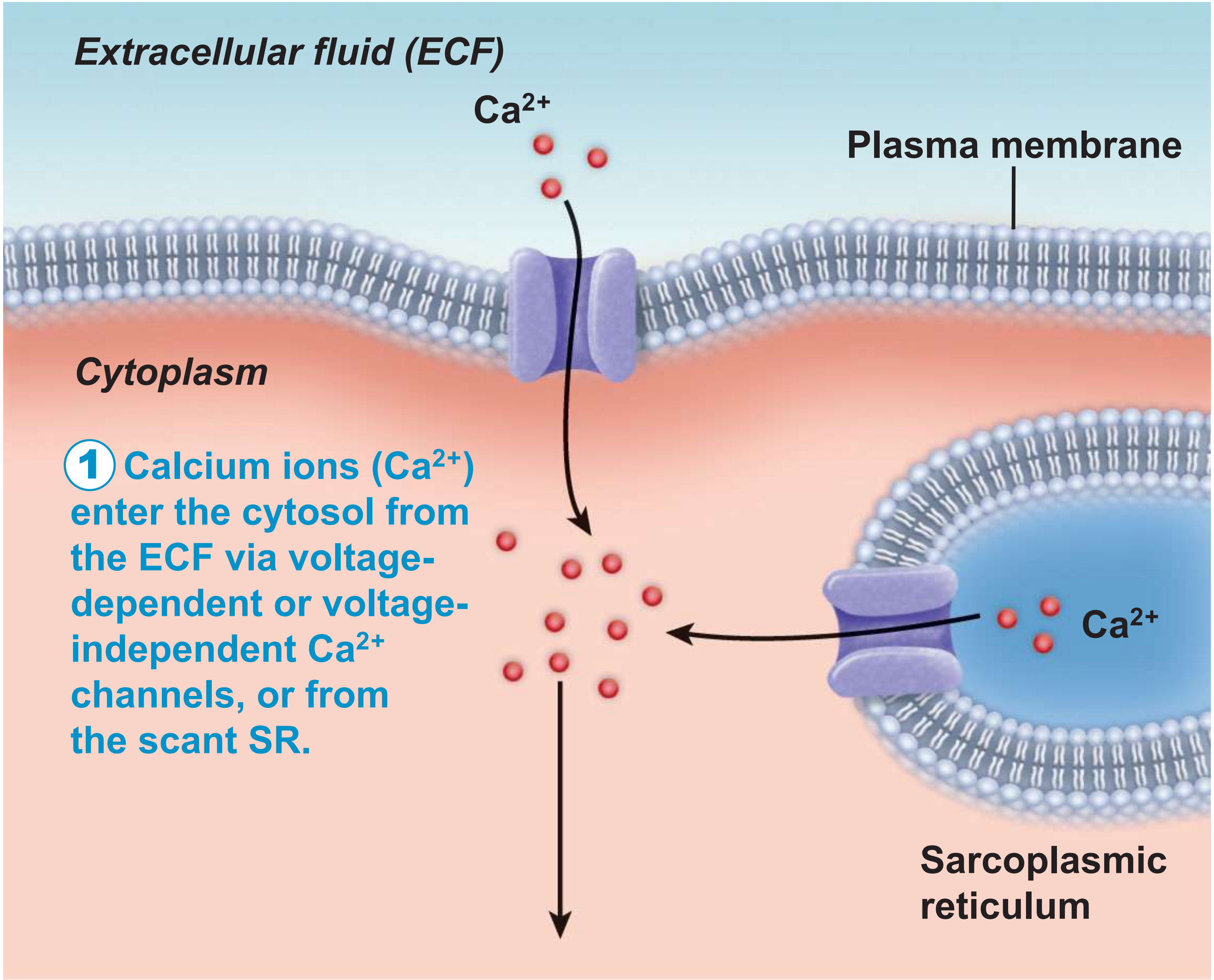


Figure 9.29, step 1

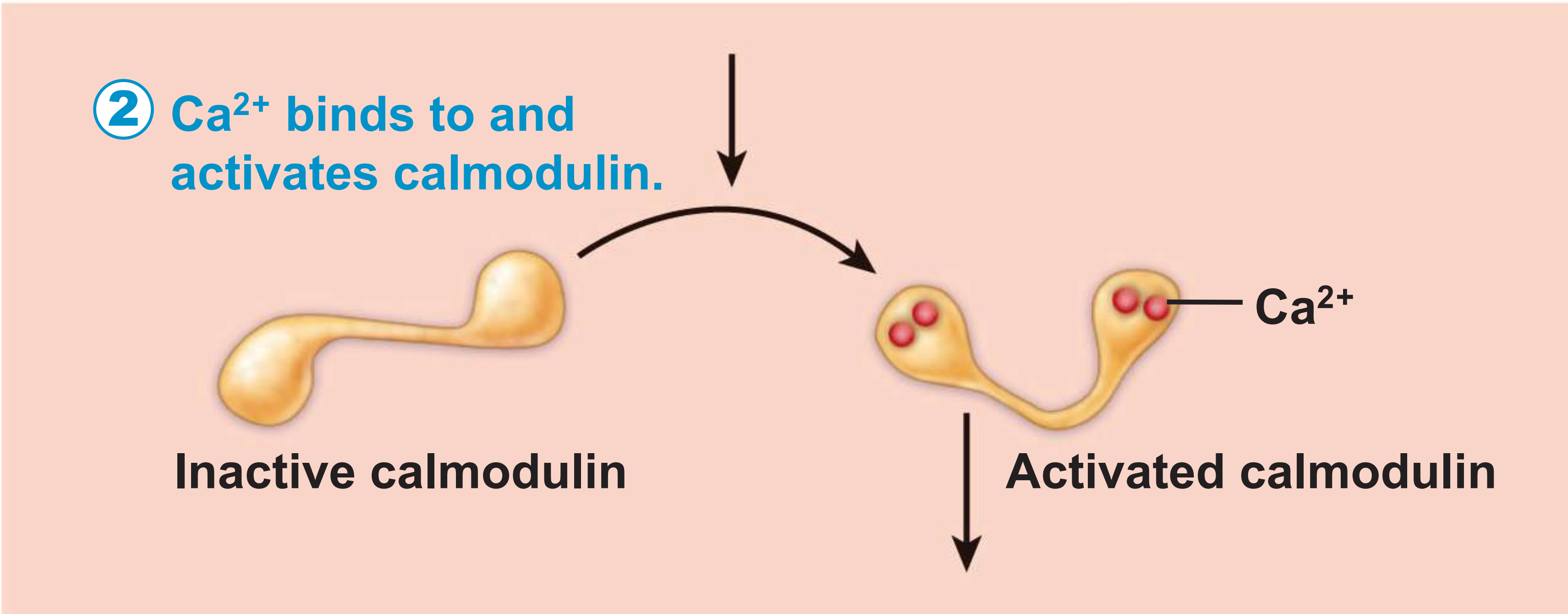


Figure 9.29, step 2

3 Activated calmodulin activates the myosin light chain kinase enzymes.

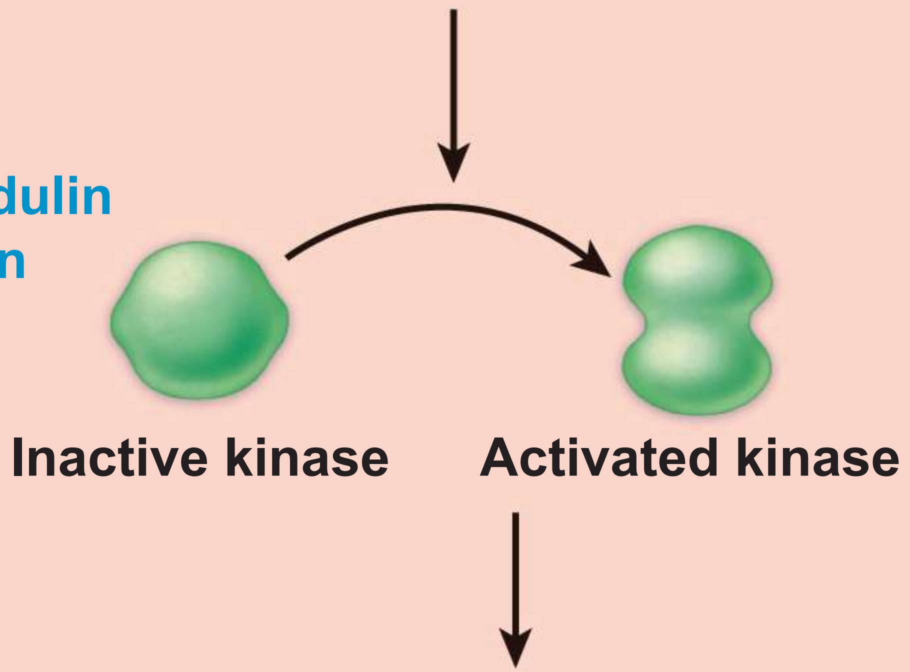


Figure 9.29, step 3

4 The activated kinase enzymes catalyze transfer of phosphate to myosin, activating the myosin ATPases.

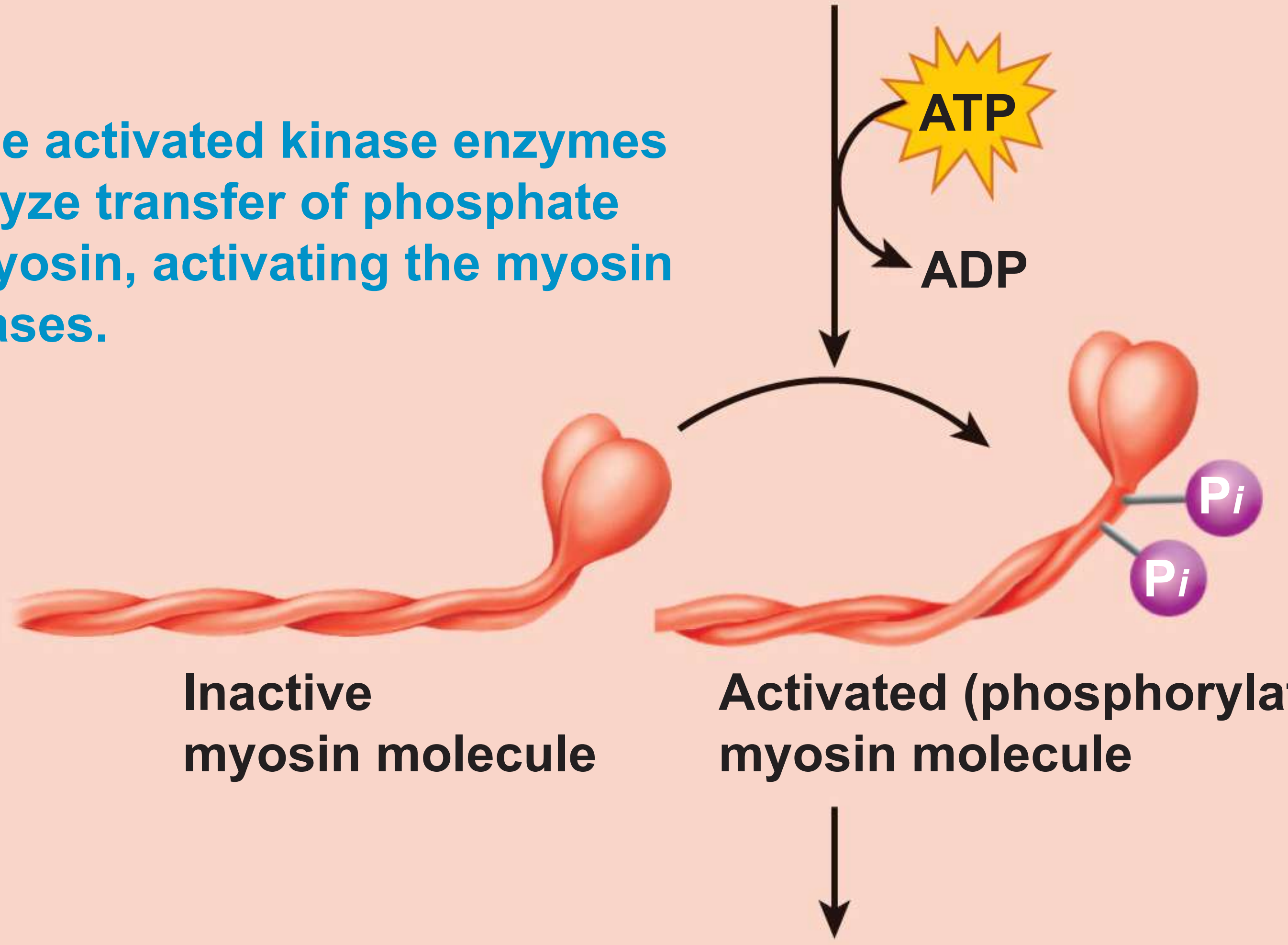


Figure 9.29, step 4

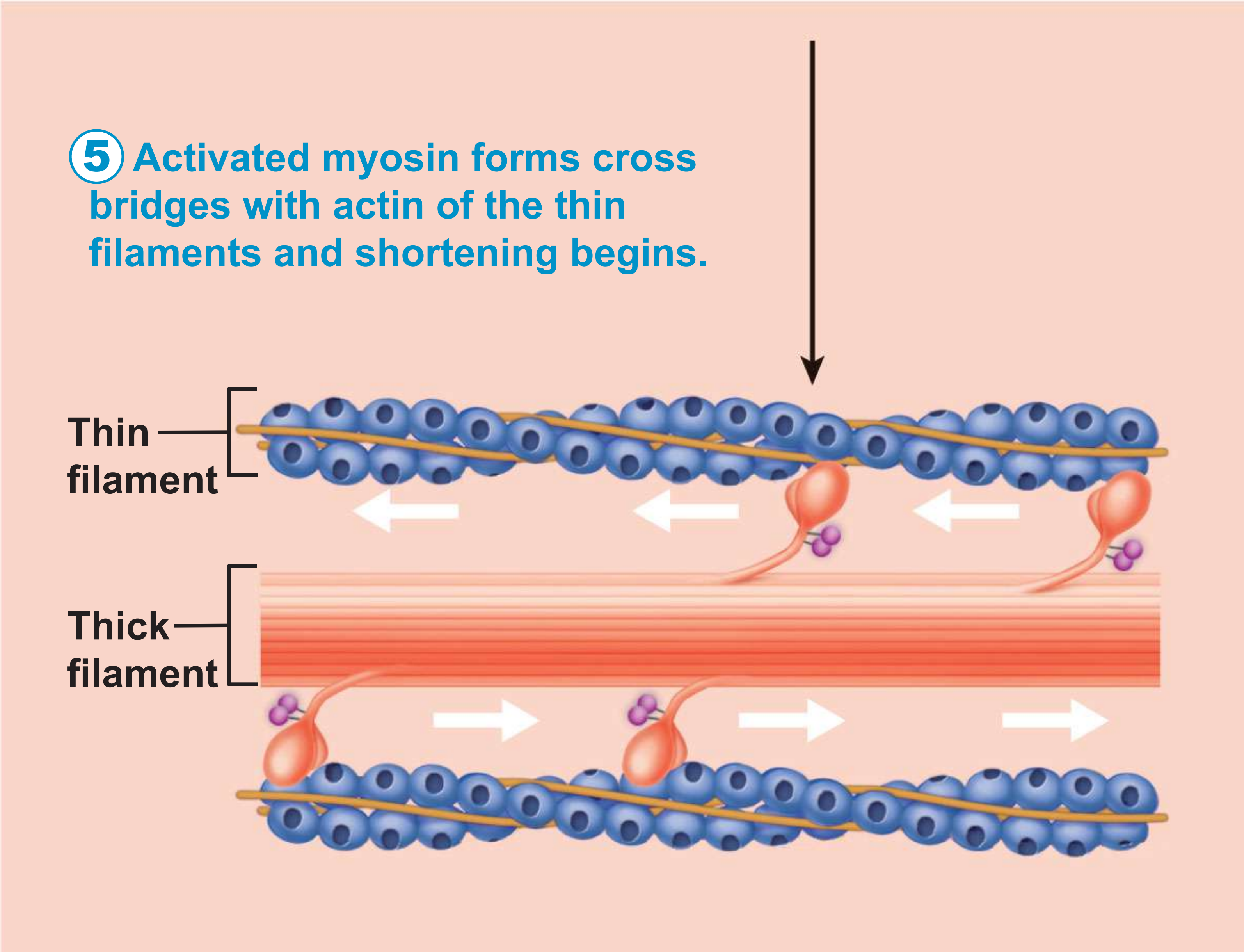
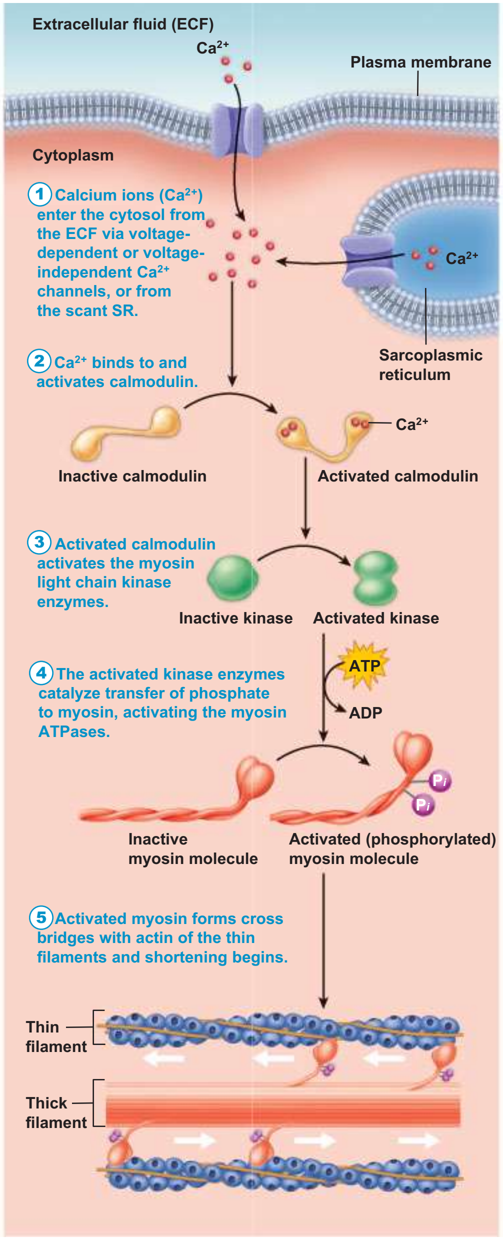


Figure 9.29, step 5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Cytoplasm
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Ca^{2+}
Sarcoplasmic reticulum
2 Ca^{2+} binds to and activates calmodulin.
Ca^{2+}
Inactive calmodulin
Activated calmodulin
3 Activated calmodulin activates the myosin light chain kinase enzymes.
Inactive kinase
Activated kinase
ATP
ADP
4 The activated kinase enzymes catalyze transfer of phosphate to myosin, activating the myosin ATPases.
P_i
P_i
Inactive myosin molecule
Activated (phosphorylated) myosin molecule
5 Activated myosin forms cross bridges with actin of the thin filaments and shortening begins.
Thin filament
Thick filament

Figure 9.29

Contraction of Smooth Muscle

- Very energy efficient (slow ATPases)
- Myofilaments may maintain a latch state for prolonged contractions

Relaxation requires:

- Ca^{2+} detachment from calmodulin
- Active transport of Ca^{2+} into SR and ECF
- Dephosphorylation of myosin to reduce myosin ATPase activity

Regulation of Contraction

Neural regulation:

- Neurotransmitter binding $\rightarrow \uparrow [Ca^{2+}]$ in sarcoplasm; either graded (local) potential or action potential
- Response depends on neurotransmitter released and type of receptor molecules

Regulation of Contraction

Hormones and local chemicals:

- May bind to G protein–linked receptors
- May either enhance or inhibit Ca^{2+} entry

Special Features of Smooth Muscle Contraction

Stress-relaxation response:

- Responds to stretch only briefly, then adapts to new length
- Retains ability to contract on demand
- Enables organs such as the stomach and bladder to temporarily store contents

Length and tension changes:

- Can contract when between half and twice its resting length

Special Features of Smooth Muscle Contraction

Hyperplasia:

- Smooth muscle cells can divide (mitosis) and increase their numbers
- Example:
  - estrogen effects on uterus at puberty and during pregnancy

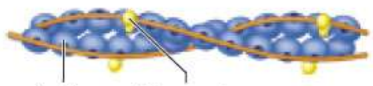
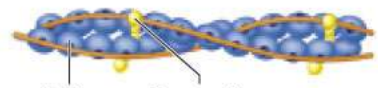
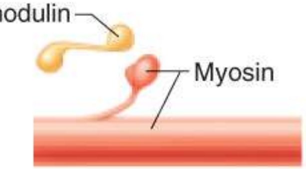
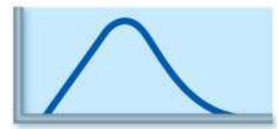
TABLE 9.3	Comparison of Skeletal, Cardiac, and Smooth Muscle *(continued)*		
CHARACTERISTIC	**SKELETAL**	**CARDIAC**	**SMOOTH**
Site of calcium regulation	Troponin on actin-containing thin filaments 	Troponin on actin-containing thin filaments 	Calmodulin in the cytosol 
Presence of pace-maker(s)	No	Yes	Yes (in single-unit muscle only)
Effect of nervous system stimulation	Excitation	Excitation or inhibition	Excitation or inhibition
Speed of con-traction	Slow to fast 	Slow 	Very slow 
Rhythmic con-traction	No	Yes	Yes in single-unit muscle
Response to stretch	Contractile strength increases with degree of stretch (to a point)	Contractile strength increases with degree of stretch	Stress-relaxation response
Respiration	Aerobic and anaerobic	Aerobic	Mainly aerobic

Table 9.3

Types of Smooth Muscle

Single-unit (visceral) smooth muscle:

- Sheets contract rhythmically as a unit (gap junctions)
- Often exhibit spontaneous action potentials
- Arranged in opposing sheets and exhibit stress-relaxation response

Types of Smooth Muscle: Multiunit

Multiunit smooth muscle:

- Located in large airways, large arteries, arrector pili muscles, and iris of eye
- Gap junctions are rare
- Arranged in motor units
- Graded contractions occur in response to neural stimuli

Developmental Aspects

- All muscle tissues develop from embryonic myoblasts
- Multinucleated skeletal muscle cells form by fusion
- Growth factor agrin stimulates clustering of ACh receptors at neuromuscular junctions
- Cardiac and smooth muscle myoblasts develop gap junctions

Developmental Aspects

- Cardiac and skeletal muscle become amitotic, but can lengthen and thicken
- Myoblast-like skeletal muscle satellite cells have limited regenerative ability
- Injured heart muscle is mostly replaced by connective tissue
- Smooth muscle regenerates throughout life

Developmental Aspects

- Muscular development reflects neuromuscular coordination
- Development occurs head to toe, and proximal to distal
- Peak natural neural control occurs by midadolescence
- Athletics and training can improve neuromuscular control

Developmental Aspects

- Female skeletal muscle makes up 36% of body mass
- Male skeletal muscle makes up 42% of body mass, primarily due to testosterone
- Body strength per unit muscle mass is the same in both sexes

Developmental Aspects

- With age, connective tissue increases and muscle fibers decrease
- By age 30, loss of muscle mass (sarcopenia) begins
- Regular exercise reverses sarcopenia
- Atherosclerosis may block distal arteries, leading to intermittent claudication and severe pain in leg muscles

Muscular Dystrophy

- Group of inherited muscle-destroying diseases
- Muscles enlarge due to fat and connective tissue deposits
- Muscle fibers atrophy

Muscular Dystrophy

Duchenne muscular dystrophy (DMD):

- Most common and severe type
- Inherited, sex-linked, carried by females and expressed in males (1/3500) as lack of dystrophin
- Victims become clumsy and fall frequently; usually die of respiratory failure in their 20s
- No cure, but viral gene therapy or infusion of stem cells with correct dystrophin genes show promise