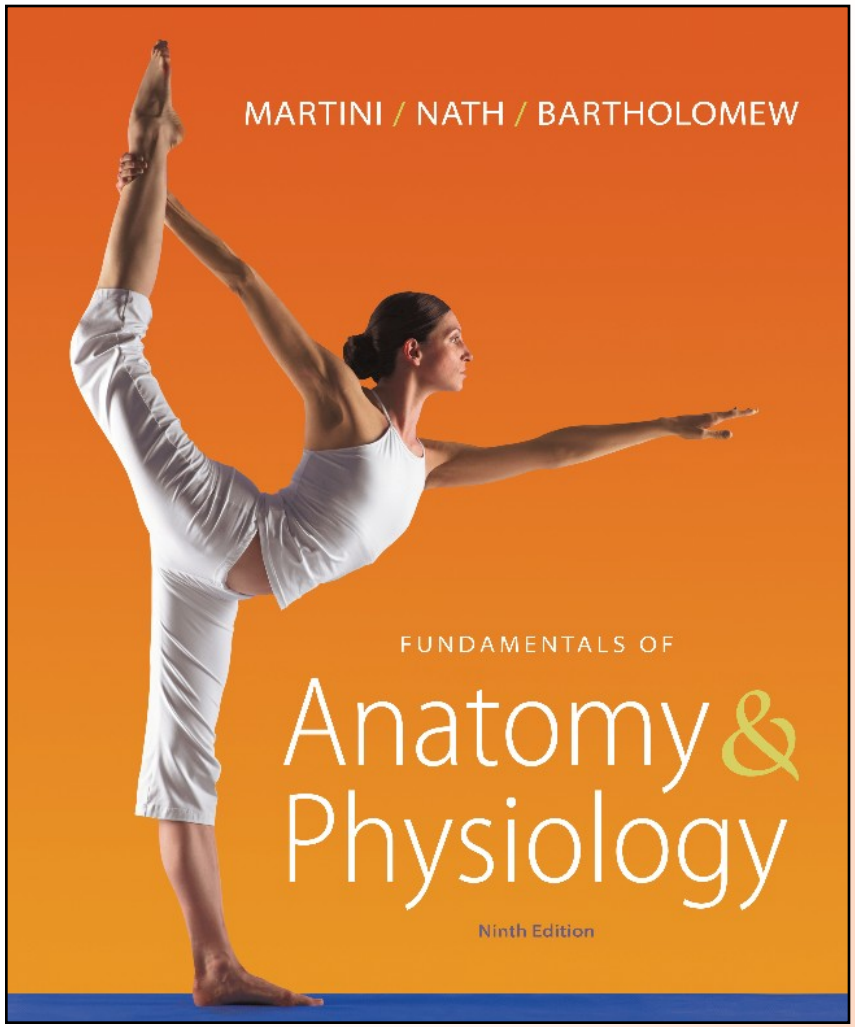


10

Muscle Tissue

PowerPoint® Lecture Presentations prepared by Jason LaPres

Lone Star College—North Harris

An Introduction to Muscle Tissue

- Muscle Tissue
  - A primary tissue type, divided into:
    - **Skeletal** muscle tissue
    - **Cardiac** muscle tissue
    - **Smooth** muscle tissue

10-2 Organization of Muscle

- Skeletal Muscle
  - Muscle tissue (muscle cells or fibers)
  - Connective tissues
  - Nerves
  - Blood vessels

10-2 Organization of Muscle

- Organization of Connective Tissues
  - Muscles have three layers of connective tissues
    1. **Epimysium**
    2. **Perimysium**
    3. **Endomysium**

10-2 Organization of Muscle

- **Epimysium**
  - Exterior collagen layer
  - Separates muscle from surrounding tissues

10-2 Organization of Muscle

- **Perimysium**
  - Surrounds muscle fiber bundles (fascicles)
  - Contains blood vessel and nerve supply to fascicles

10-2 Organization of Muscle

- **Endomysium**
  - Surrounds individual muscle cells (muscle fibers)
  - Contains capillaries and nerve fibers contacting muscle cells

Figure 10-1 The Organization of Skeletal Muscles

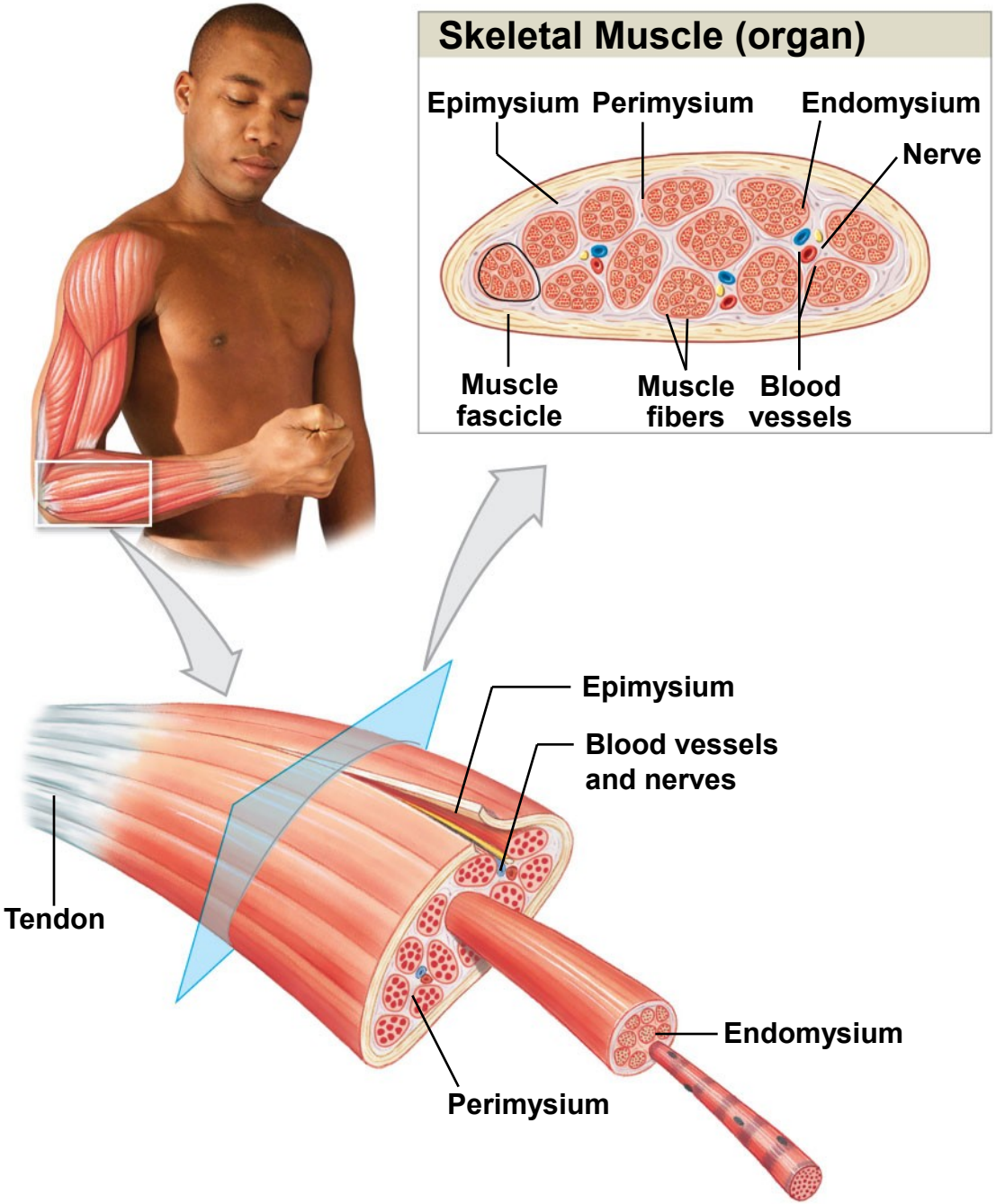


Figure 10-1 The Organization of Skeletal Muscles

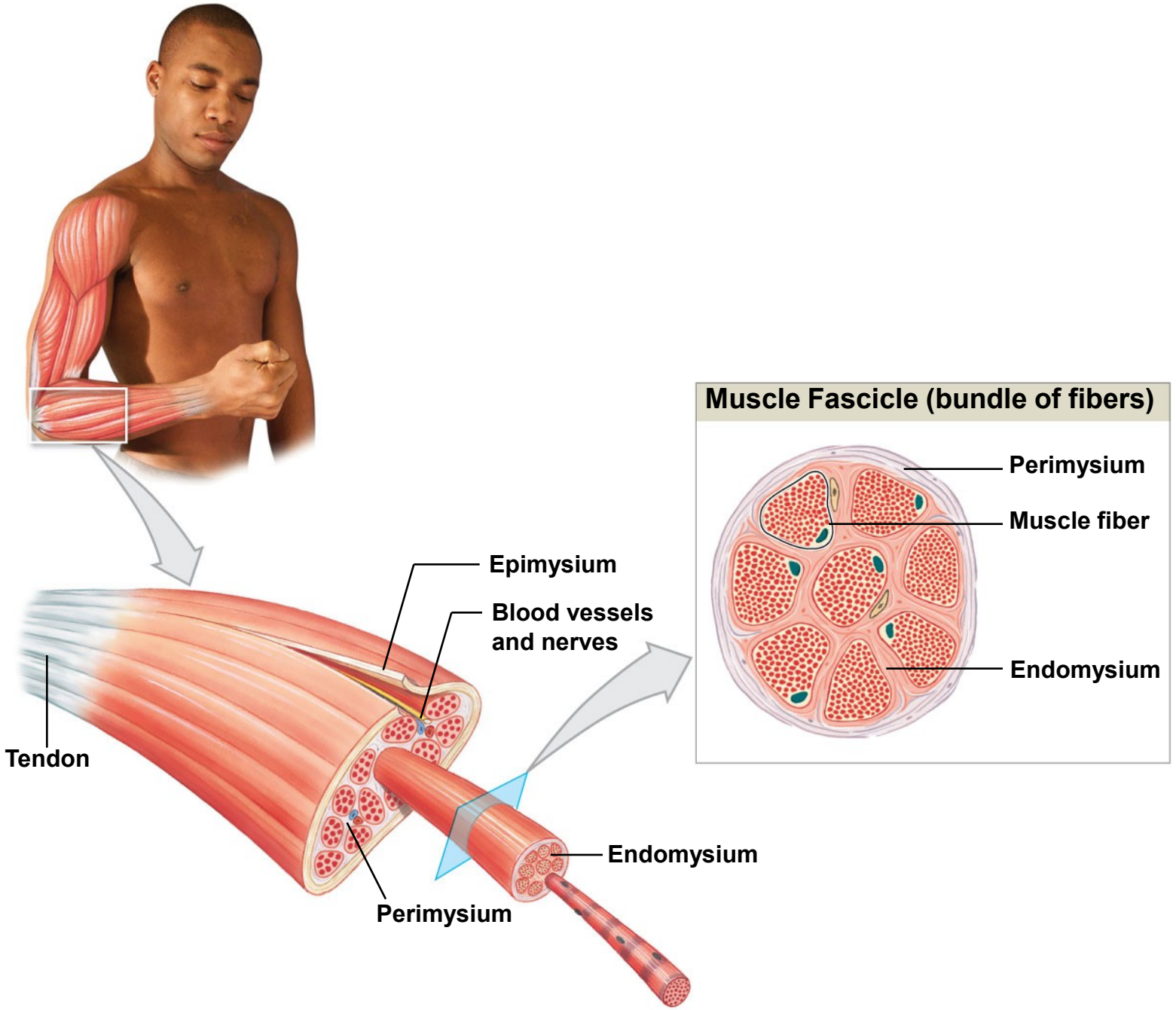
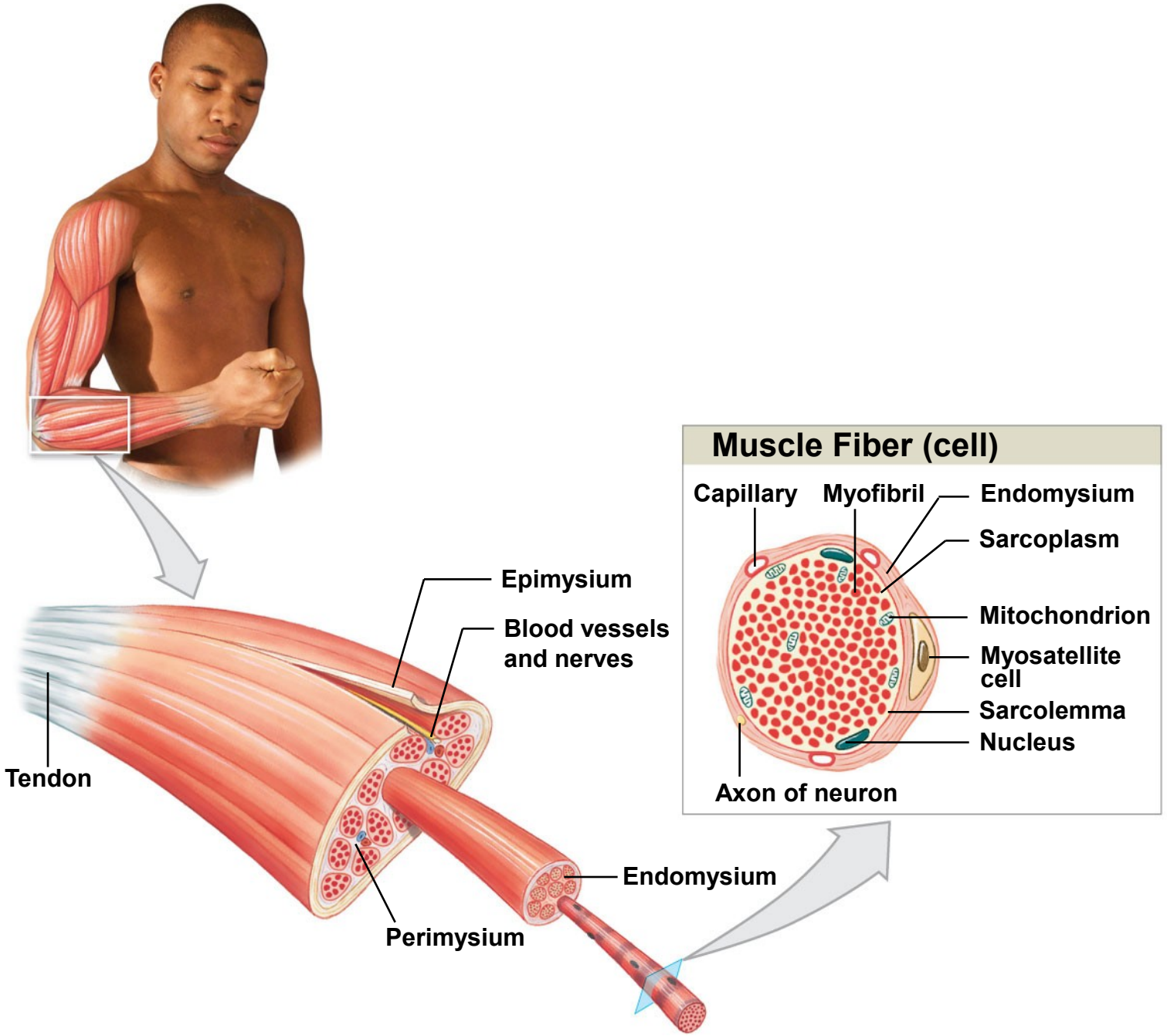


Figure 10-1 The Organization of Skeletal Muscles



10-2 Organization of Muscle

- Organization of Connective Tissues
  - Muscle Attachments
    - Endomysium, perimysium, and epimysium come together:
      - At ends of muscles
      - To form connective tissue attachment to bone matrix
      - I.e., **tendon** (bundle)

10-3 Characteristics of Skeletal Muscle Fibers

- Skeletal Muscle Cells
  - Are very long
  - Become very large
  - Contain hundreds of nuclei

10-3 Characteristics of Skeletal Muscle Fibers

- The Sarcolemma and Transverse Tubules
  - The **sarcolemma**
    - The cell membrane of a muscle fiber (cell)
    - Surrounds the **sarcoplasm** (cytoplasm of muscle fiber)
    - A change in transmembrane potential begins contractions

10-3 Characteristics of Skeletal Muscle Fibers

- The Sarcolemma and Transverse Tubules
  - **Transverse tubules (T tubules)**
    - Transmit **action potential** through cell
    - Allow entire muscle fiber to contract simultaneously
    - Have same properties as sarcolemma

10-3 Characteristics of Skeletal Muscle Fibers

- **Myofibrils**
  - Lengthwise subdivisions within muscle fiber
  - Made up of bundles of protein filaments (**myofilaments**)
  - Myofilaments are responsible for muscle contraction
  - Types of myofilaments:
    - **Thin filaments**
      - Made of the protein actin
    - **Thick filaments**
      - Made of the protein myosin

10-3 Characteristics of Skeletal Muscle Fibers

- The **Sarcoplasmic Reticulum (SR)**
  - A membranous structure surrounding each myofibril
  - Helps transmit action potential to myofibril
  - Similar in structure to smooth endoplasmic reticulum

Figure 10-3 The Structure of a Skeletal Muscle Fiber

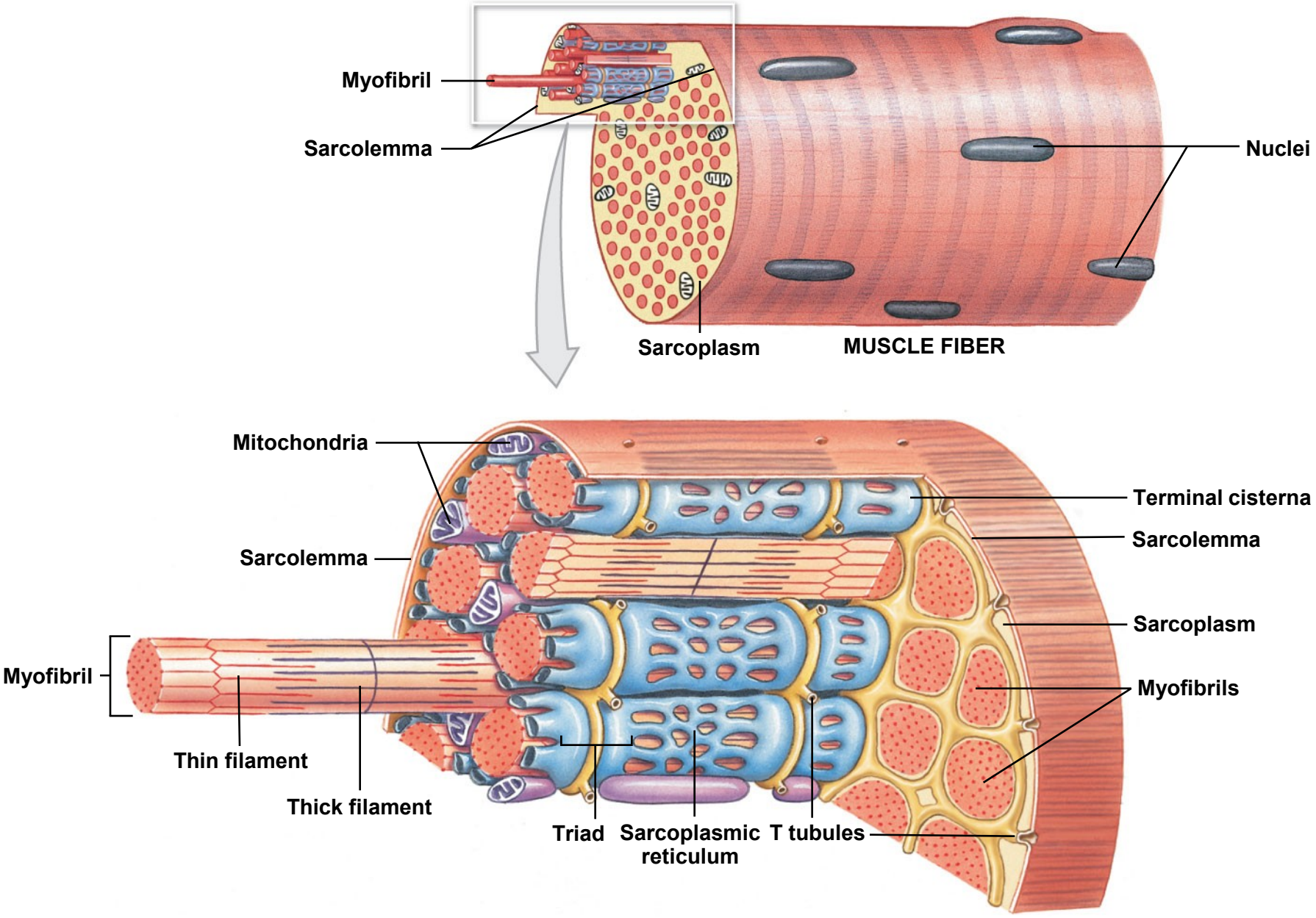


Figure 10-3 The Structure of a Skeletal Muscle Fiber

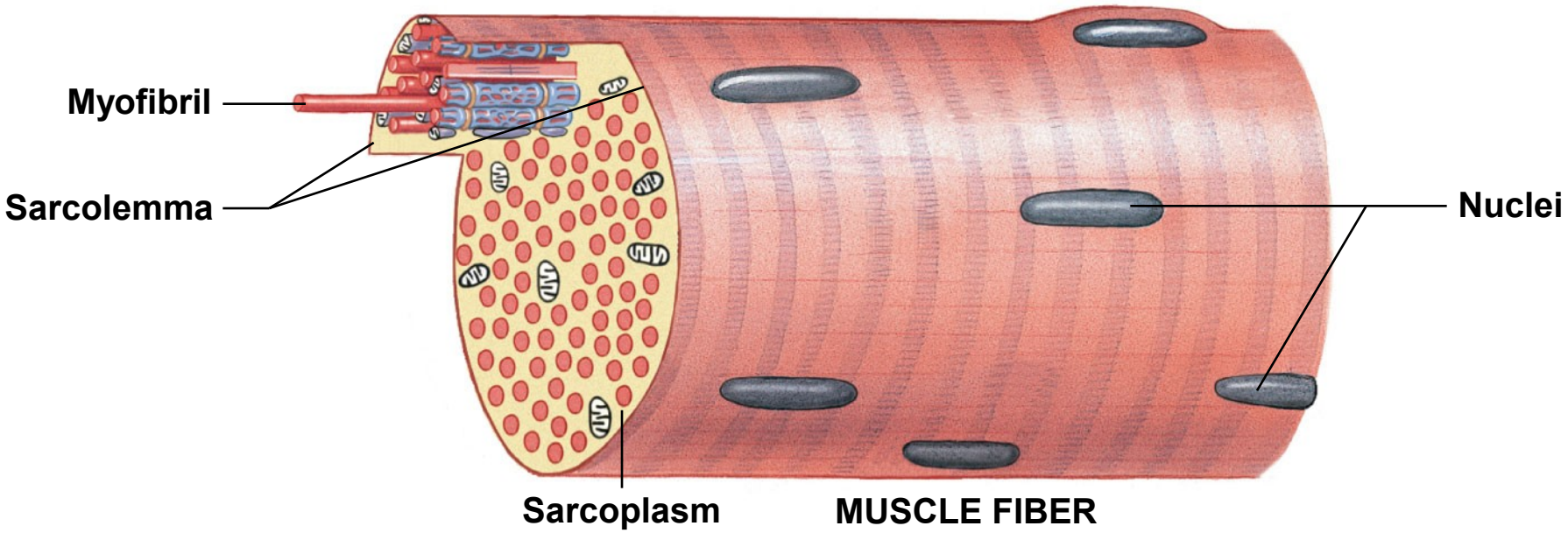


Figure 10-3 The Structure of a Skeletal Muscle Fiber

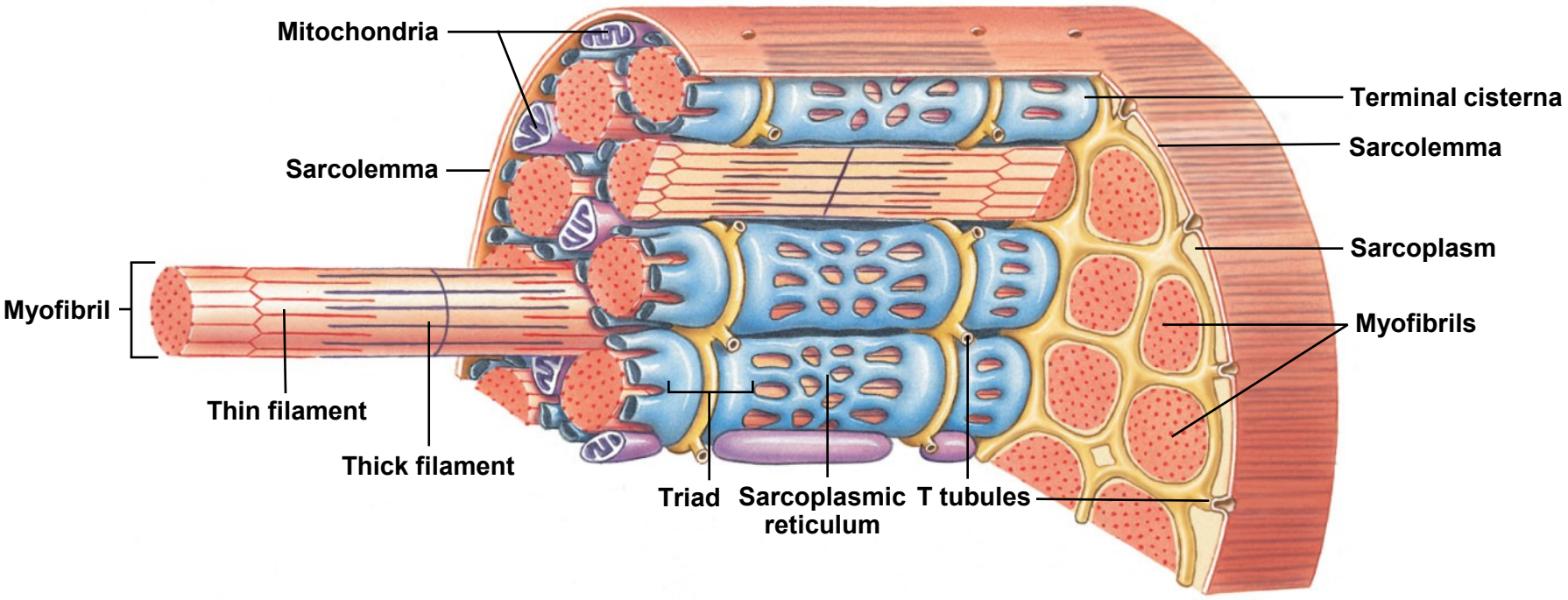


Figure 10-3 The Structure of a Skeletal Muscle Fiber

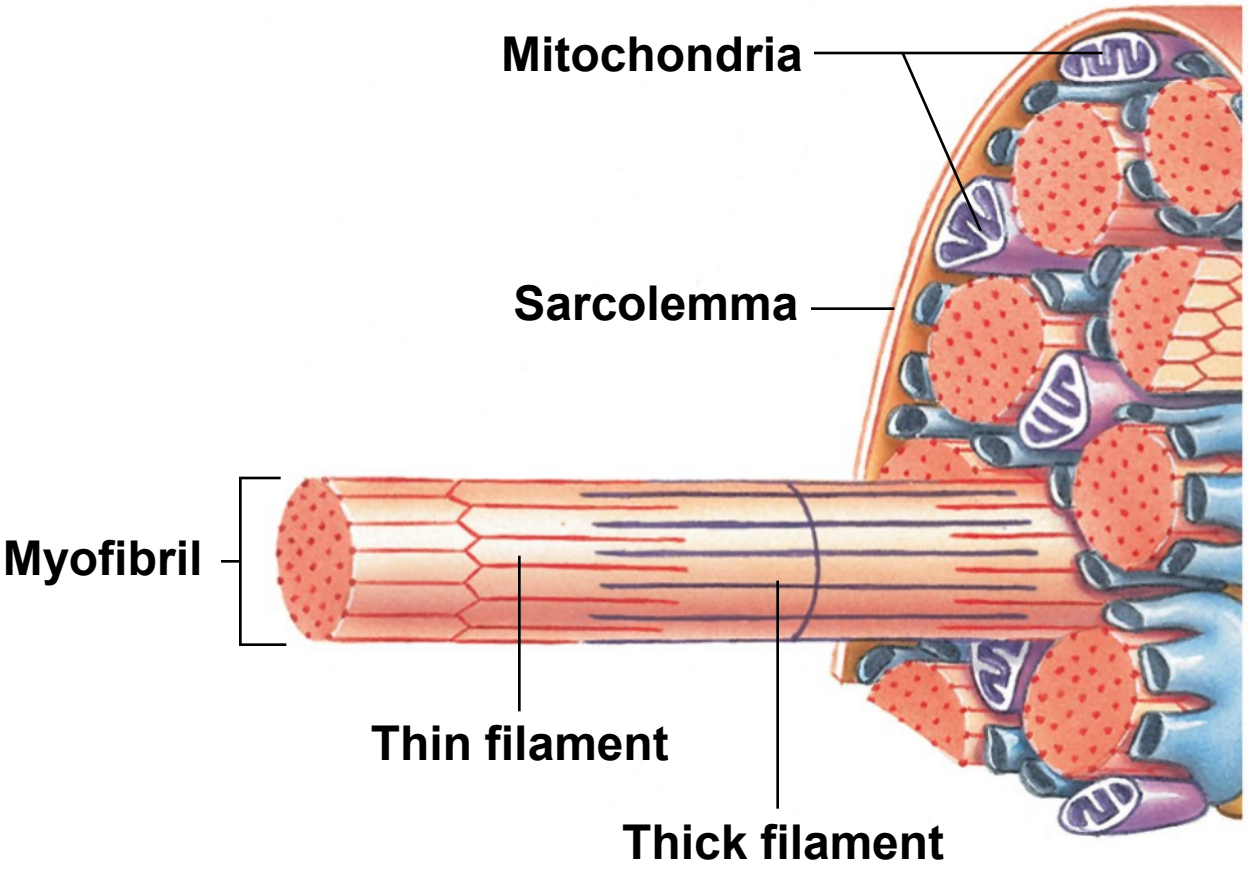
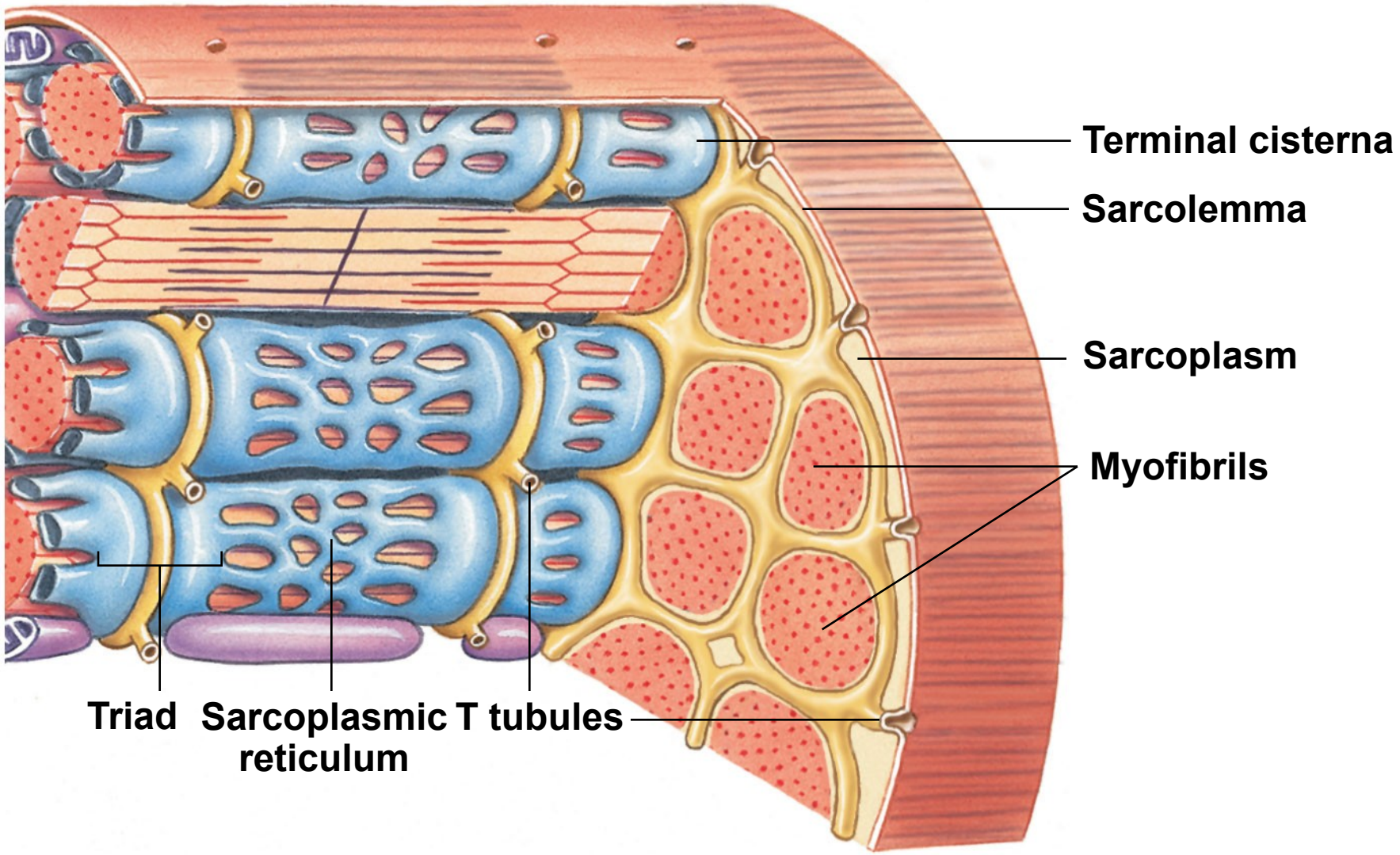


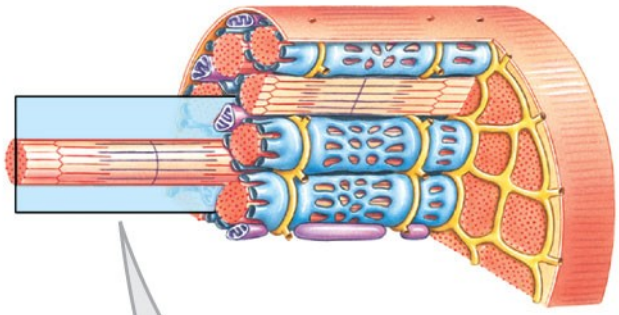
Figure 10-3 The Structure of a Skeletal Muscle Fiber

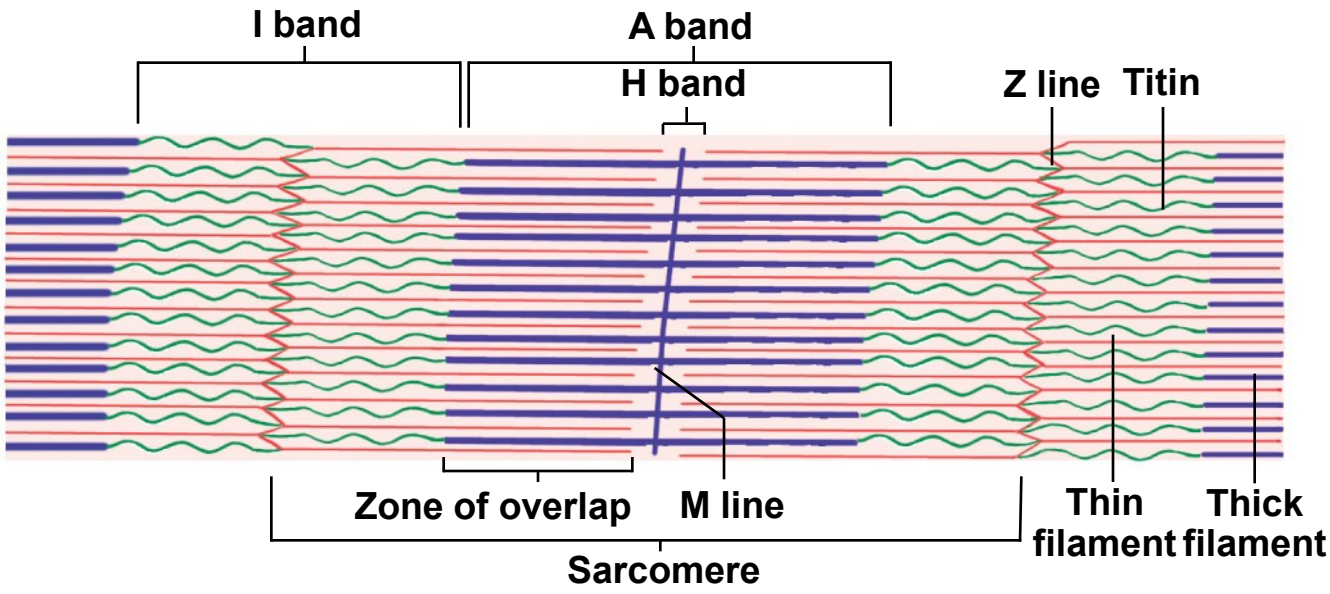


10-3 Structural Components of a Sarcomere

- Sarcomeres
  - The contractile units of muscle
  - Structural units of myofibrils
  - Form visible patterns within myofibrils
  - A striped or striated pattern within myofibrils
    - Alternating dark, thick filaments (**A bands**) and light, thin filaments (**I bands**)

Figure 10-4a Sarcomere Structure, Part I





a A longitudinal section of a sarcomere, showing bands

Figure 10-4b Sarcomere Structure, Part I

b **A corresponding view of a sarcomere in a myofibril from a muscle fiber in the gastrocnemius muscle of the calf**

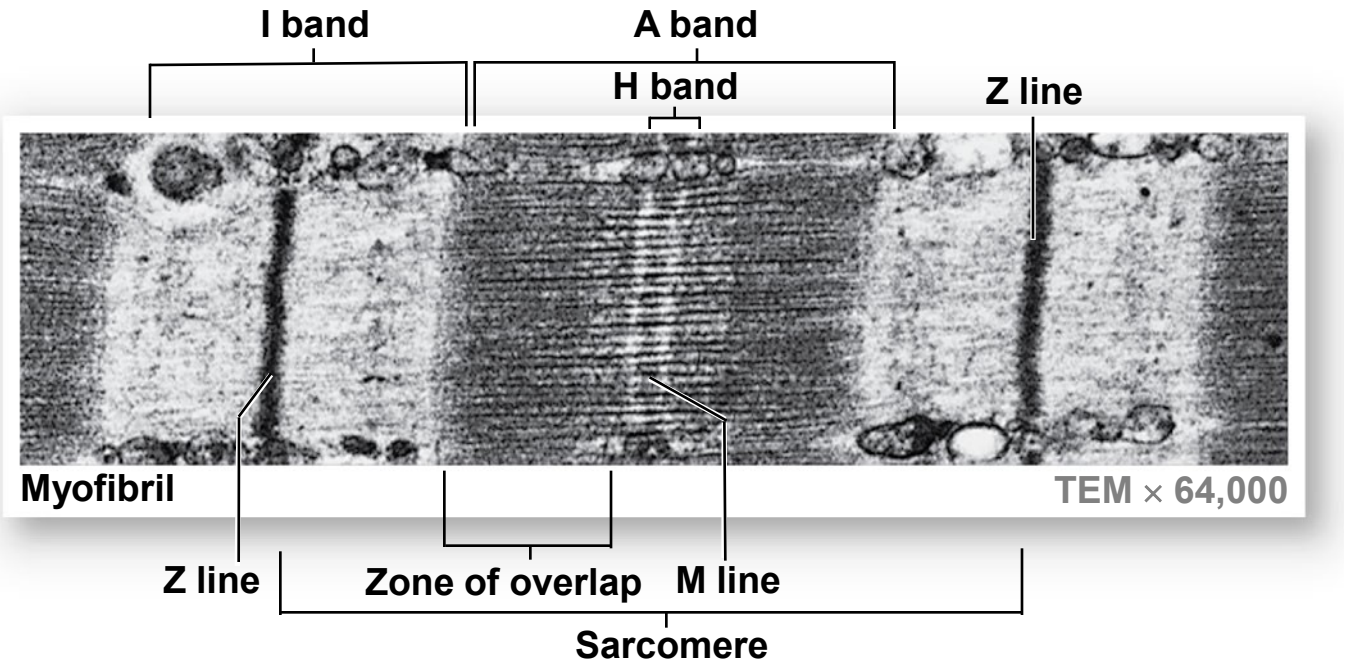


Figure 10-6 Levels of Functional Organization in a Skeletal Muscle

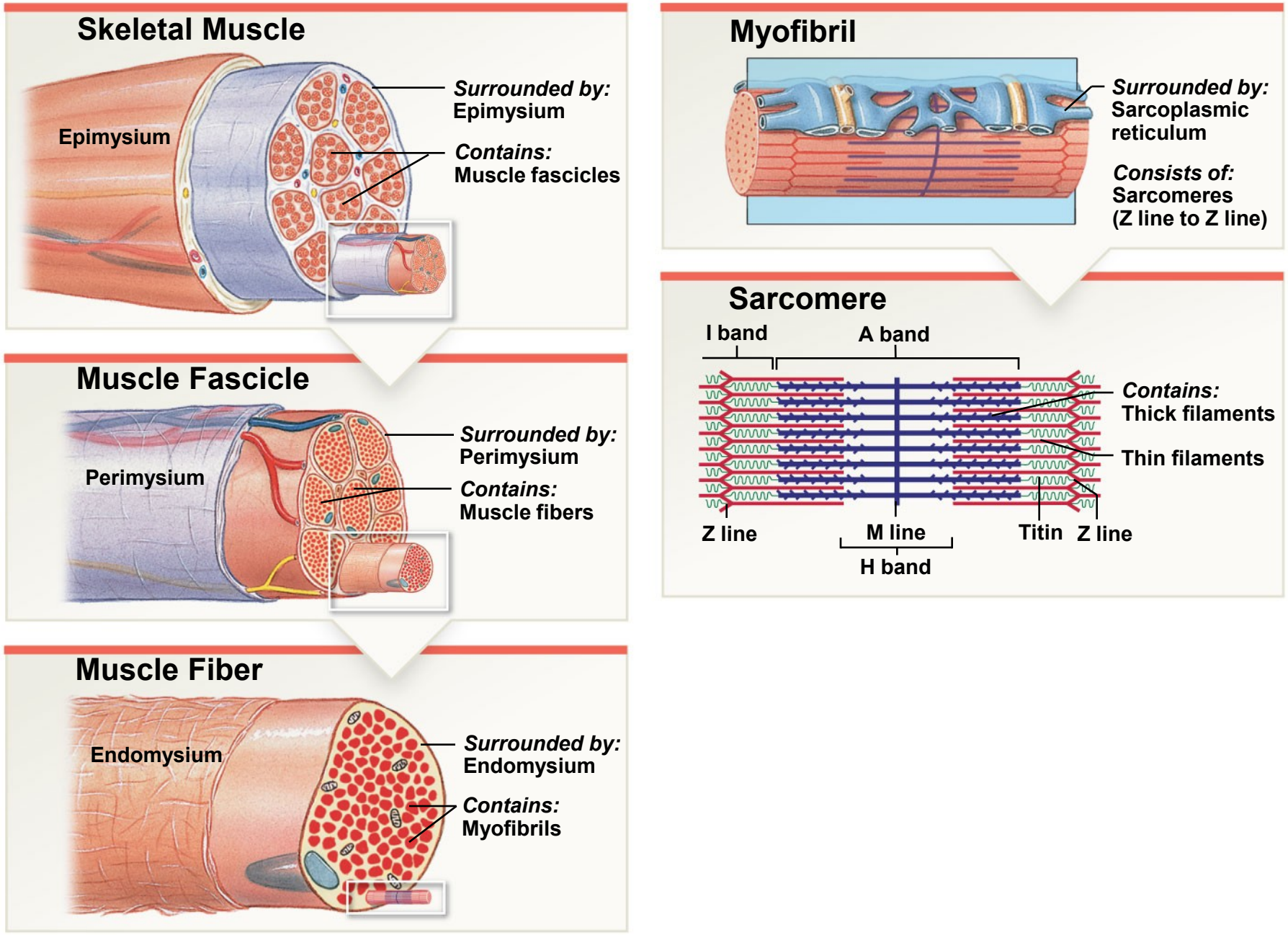


Figure 10-6 Levels of Functional Organization in a Skeletal Muscle

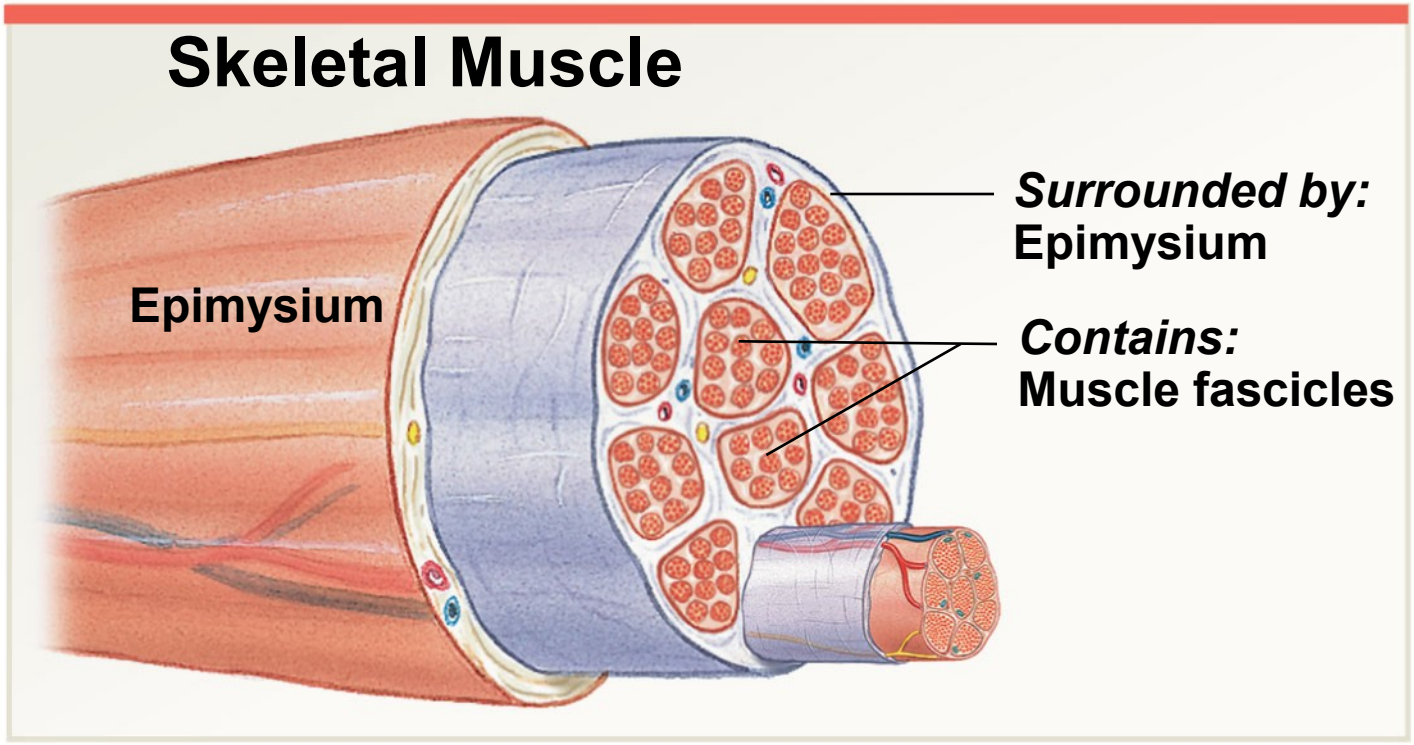


Figure 10-6 Levels of Functional Organization in a Skeletal Muscle

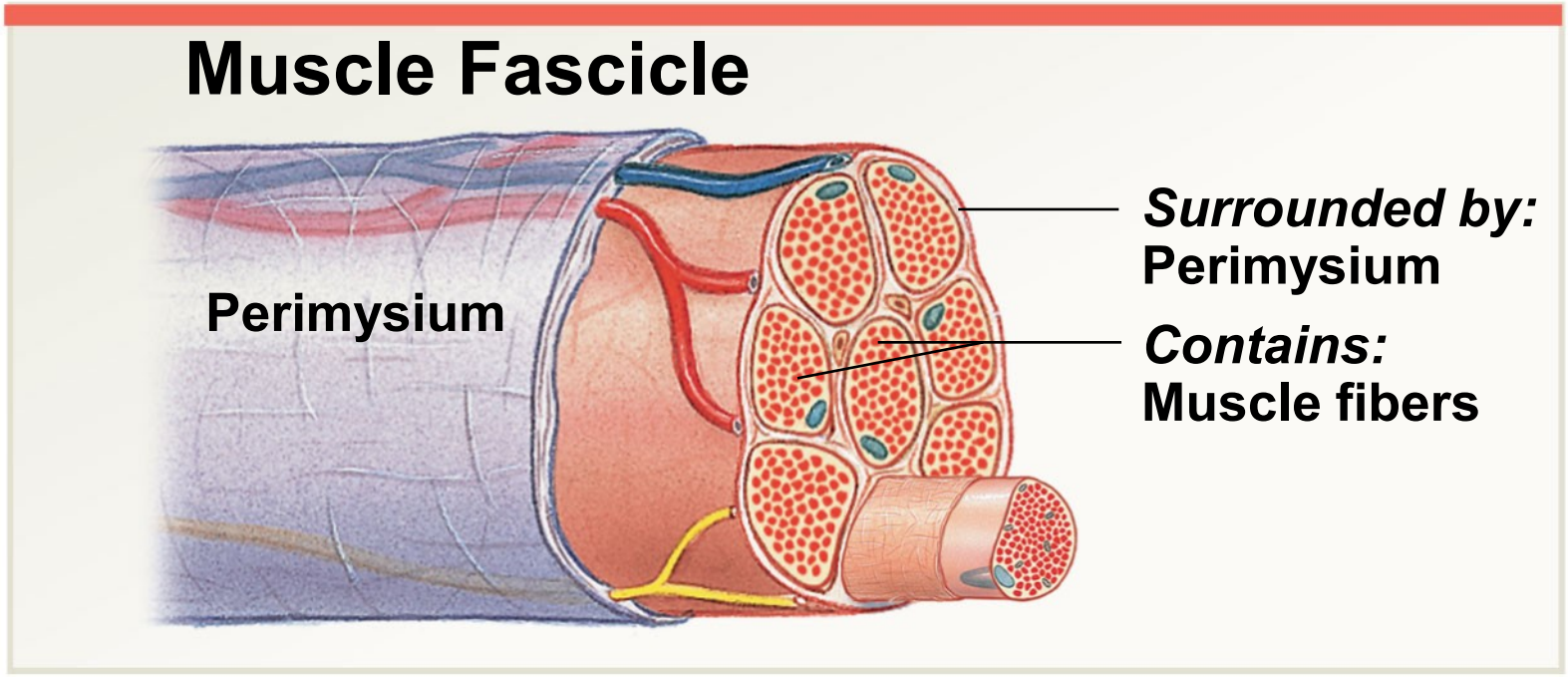


Figure 10-6 Levels of Functional Organization in a Skeletal Muscle

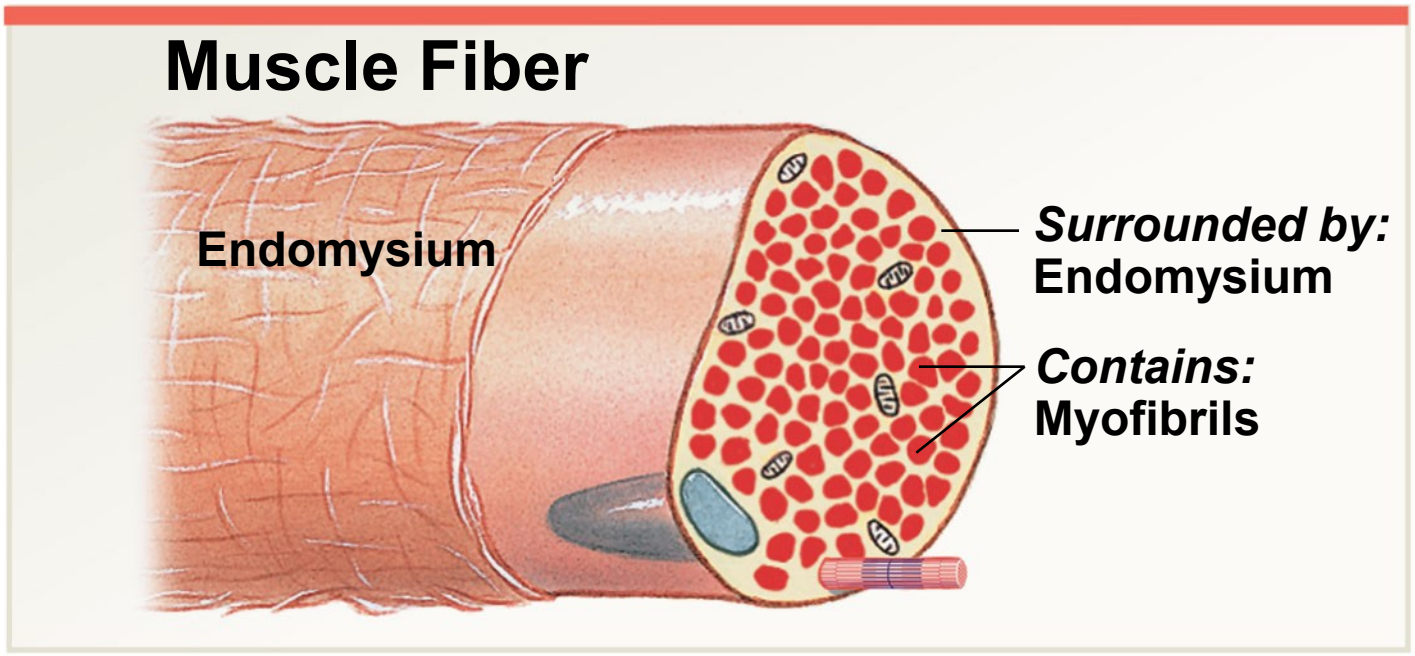


Figure 10-6 Levels of Functional Organization in a Skeletal Muscle

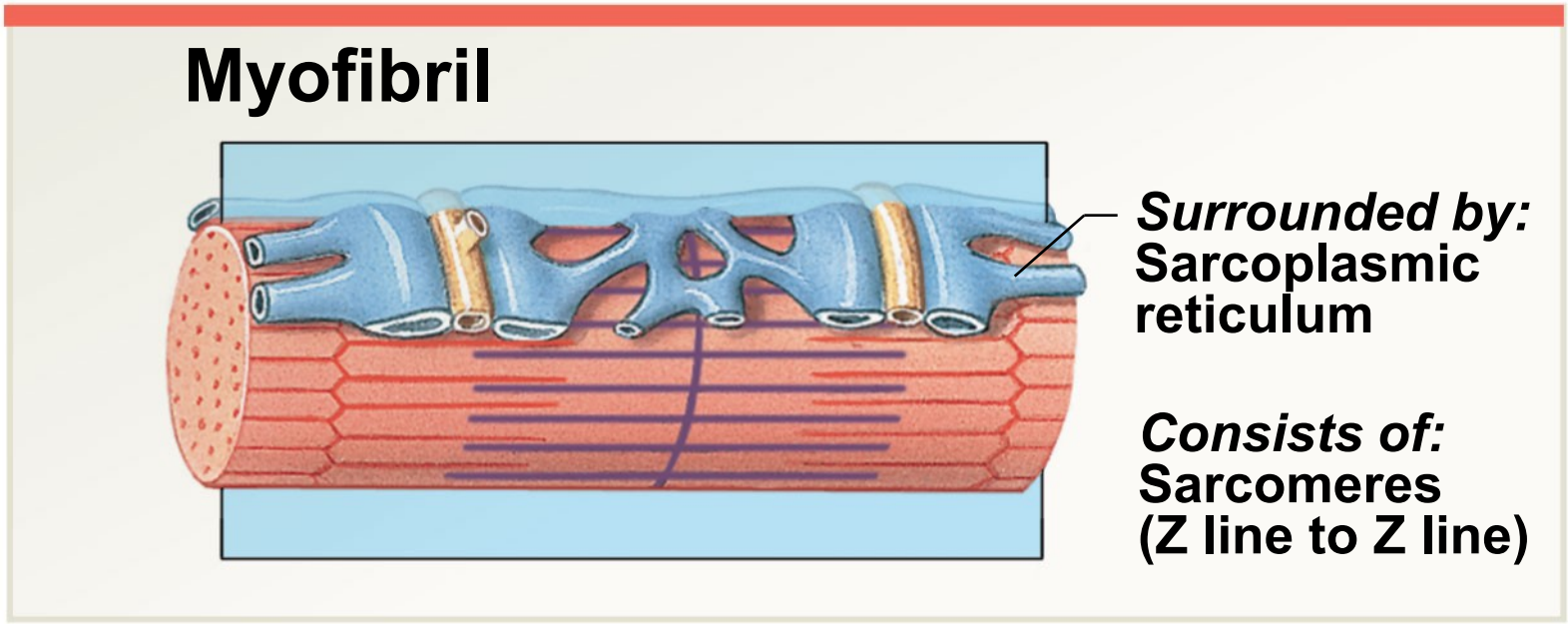
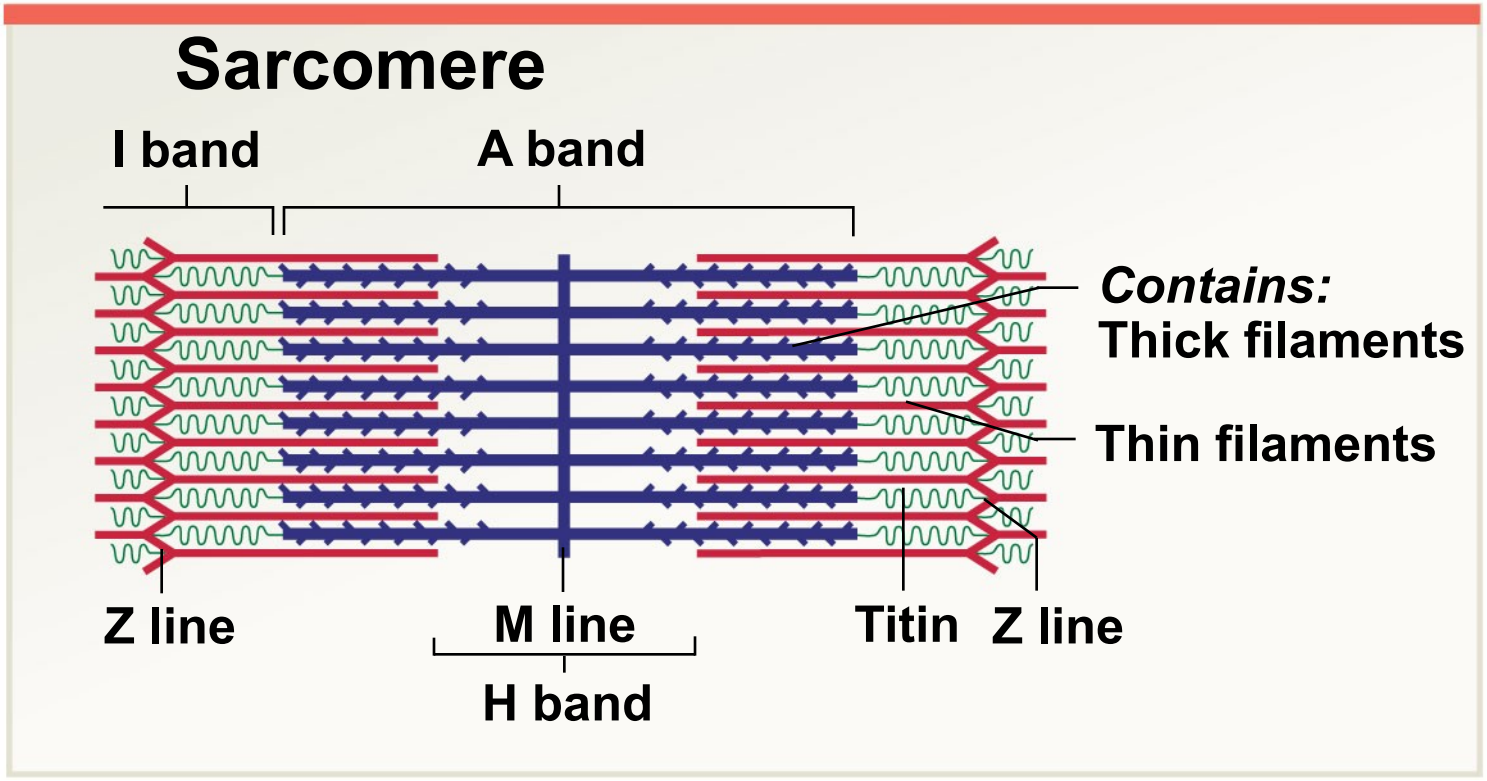


Figure 10-6 Levels of Functional Organization in a Skeletal Muscle



10-3 Structural Components of a Sarcomere

- Thin Filaments
  - **F-actin (filamentous actin)**
    - Is two twisted rows of globular G-actin
    - The active sites on G-actin strands bind to myosin

10-3 Structural Components of a Sarcomere

- Thin Filaments
  - **Tropomyosin**
    - Is a double strand
    - Prevents actin–myosin interaction
  - **Troponin**
    - A globular protein
    - Binds tropomyosin to G-actin
    - Controlled by Ca^{2+}

Figure 10-7ab Thick and Thin Filaments

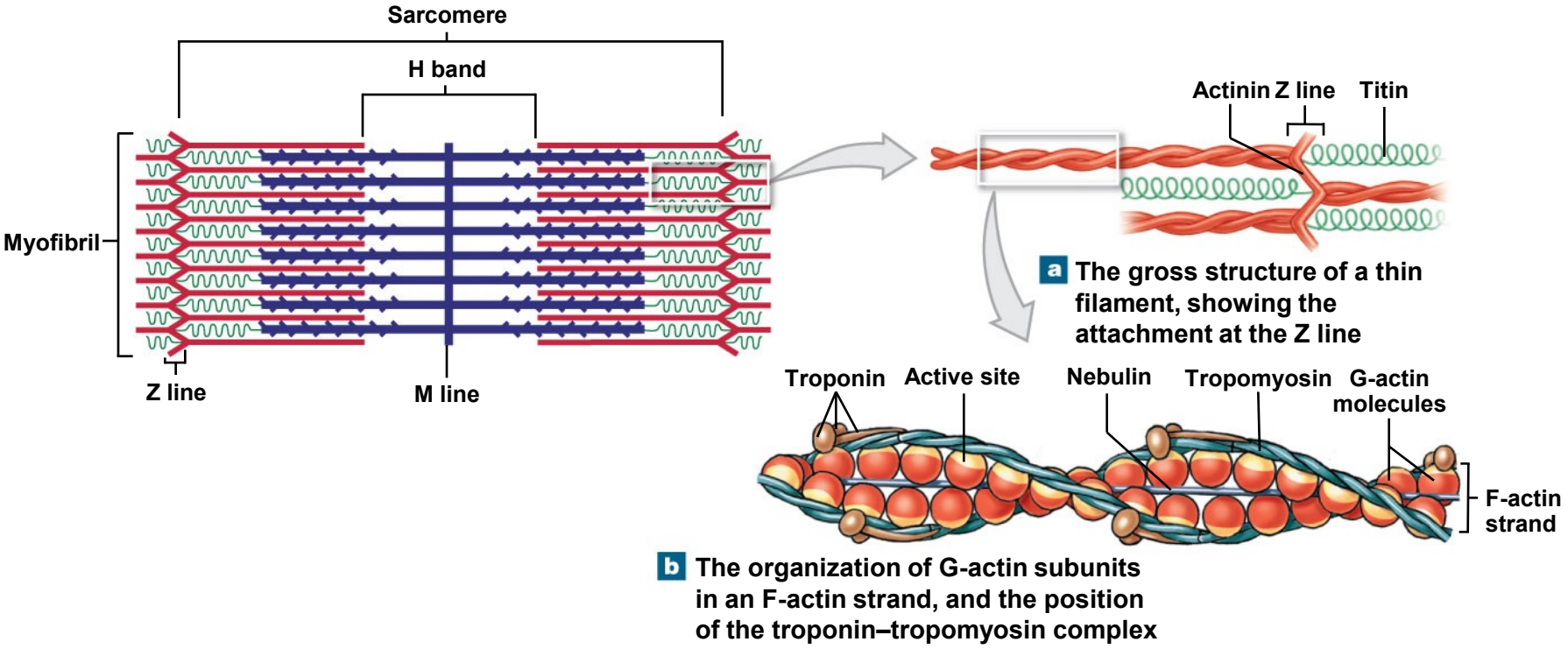
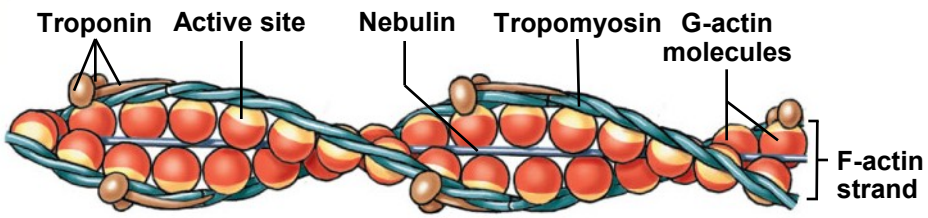


Figure 10-7b Thick and Thin Filaments



b The organization of G-actin subunits in an F-actin strand, and the position of the troponin–tropomyosin complex

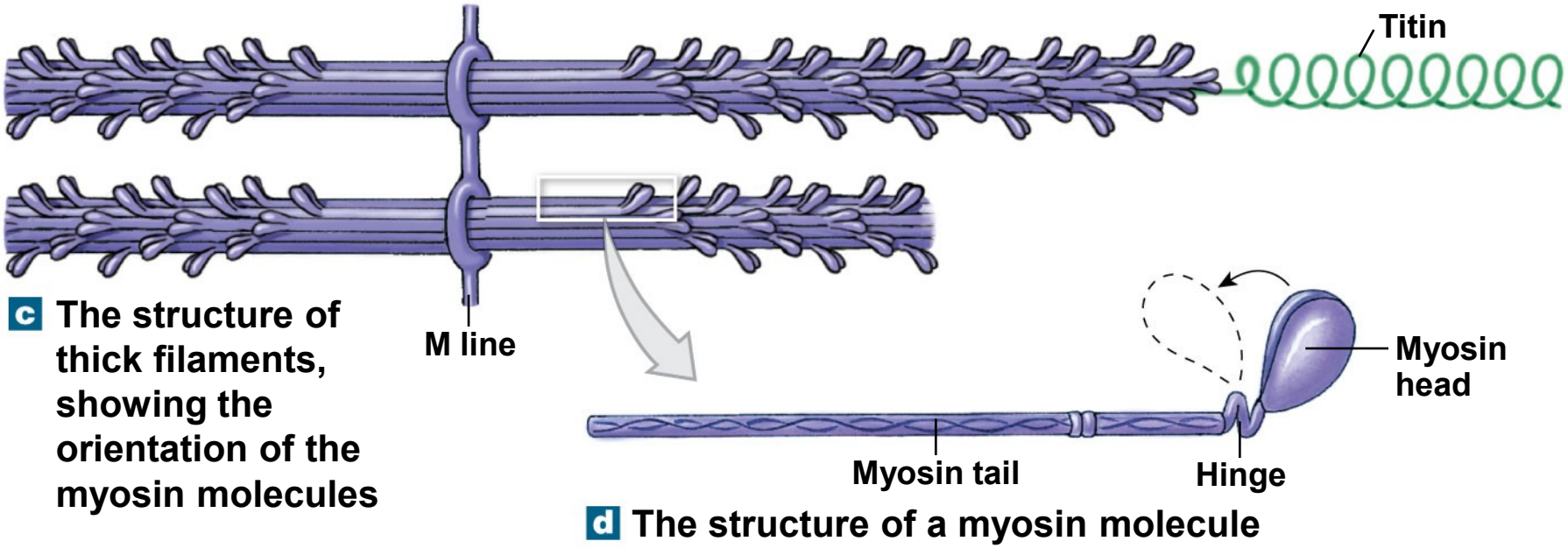
10-3 Structural Components of a Sarcomere

- Initiating Contraction
  - Ca^{2+} binds to receptor on **troponin** molecule
  - Troponin–tropomyosin complex changes
  - Exposes **active site** of **F-actin**

10-3 Structural Components of a Sarcomere

- Thick Filaments
  - Contain about 300 twisted **myosin** subunits
  - The mysosin molecule
    - Tail
      - Binds to other myosin molecules
    - Head
      - Made of two globular protein subunits
      - Reaches the nearest thin filament

Figure 10-7cd Thick and Thin Filaments



c The structure of thick filaments, showing the orientation of the myosin molecules

d The structure of a myosin molecule

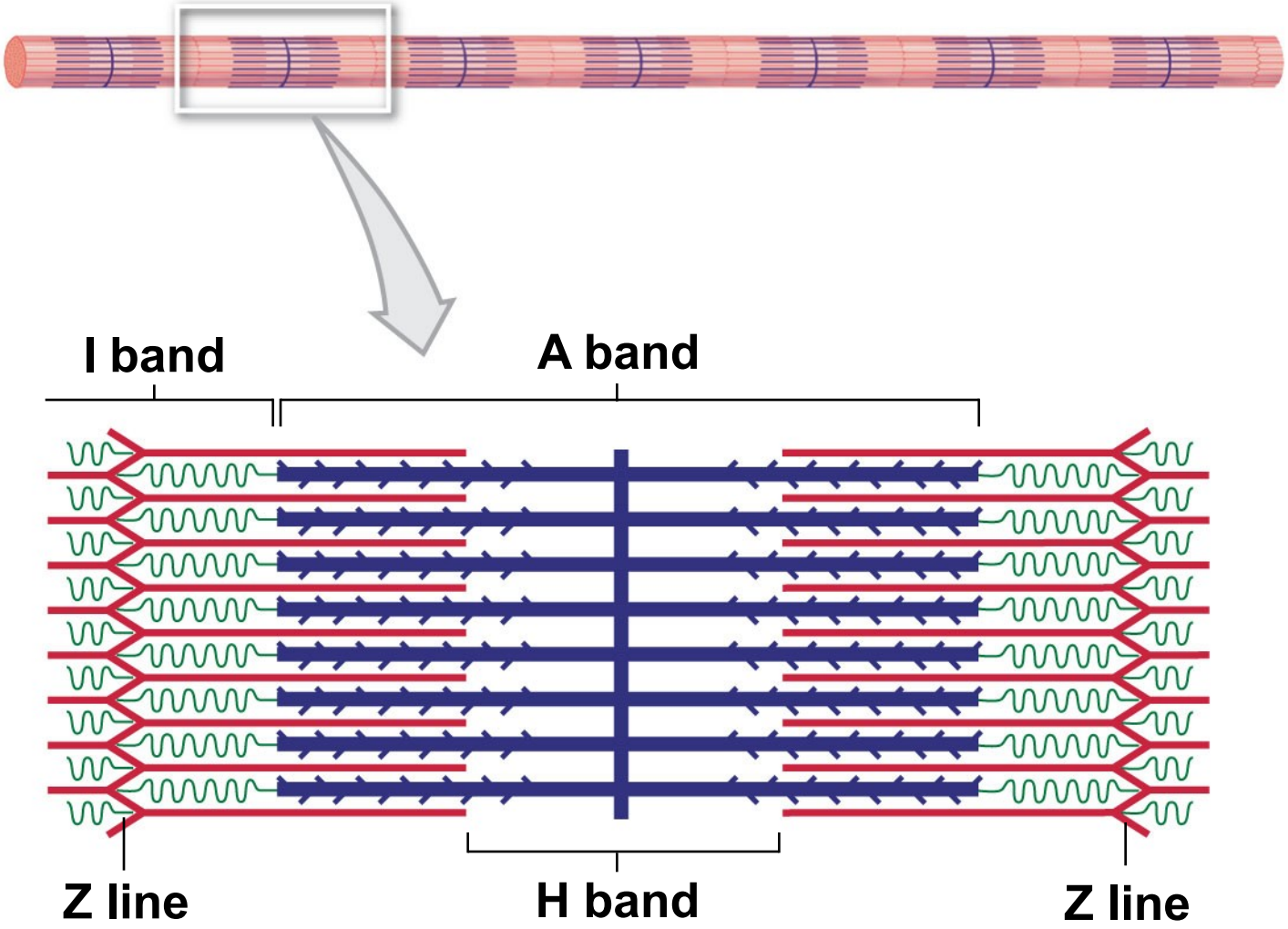
10-3 Structural Components of a Sarcomere

- Myosin Action
  - During contraction, myosin heads:
    - Interact with actin filaments, forming **cross-bridges**
    - Pivot, producing motion

10-3 Structural Components of a Sarcomere

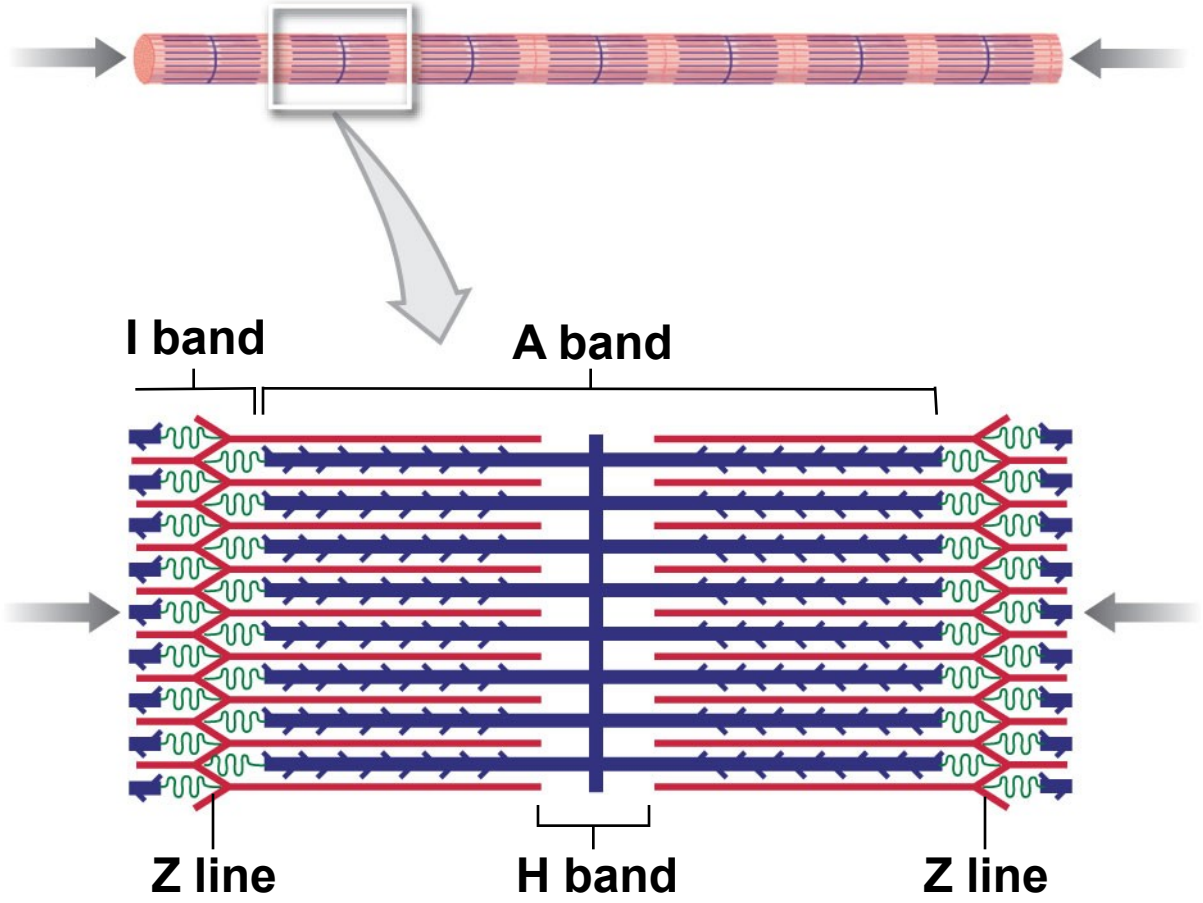
- Sliding Filaments and Muscle Contraction
  - **Sliding filament theory**
    - Thin filaments of sarcomere slide toward M line, alongside thick filaments
    - The width of A zone stays the same
    - Z lines move closer together

Figure 10-8a Changes in the Appearance of a Sarcomere during the Contraction of a Skeletal Muscle Fiber



a A relaxed sarcomere showing location of the A band, Z lines, and I band.

Figure 10-8b Changes in the Appearance of a Sarcomere during the Contraction of a Skeletal Muscle Fiber



b During a contraction, the A band stays the same width, but the Z lines move closer together and the I band gets smaller. When the ends of a myofibril are free to move, the sarcomeres shorten simultaneously and the ends of the myofibril are pulled toward its center.

10-3 Structural Components of a Sarcomere

- Skeletal Muscle Contraction
  - The process of contraction
    - Neural stimulation of sarcolemma
      - Causes **excitation–contraction coupling**
    - Muscle fiber contraction
      - Interaction of thick and thin filaments
    - Tension production

Figure 10-9 An Overview of Skeletal Muscle Contraction

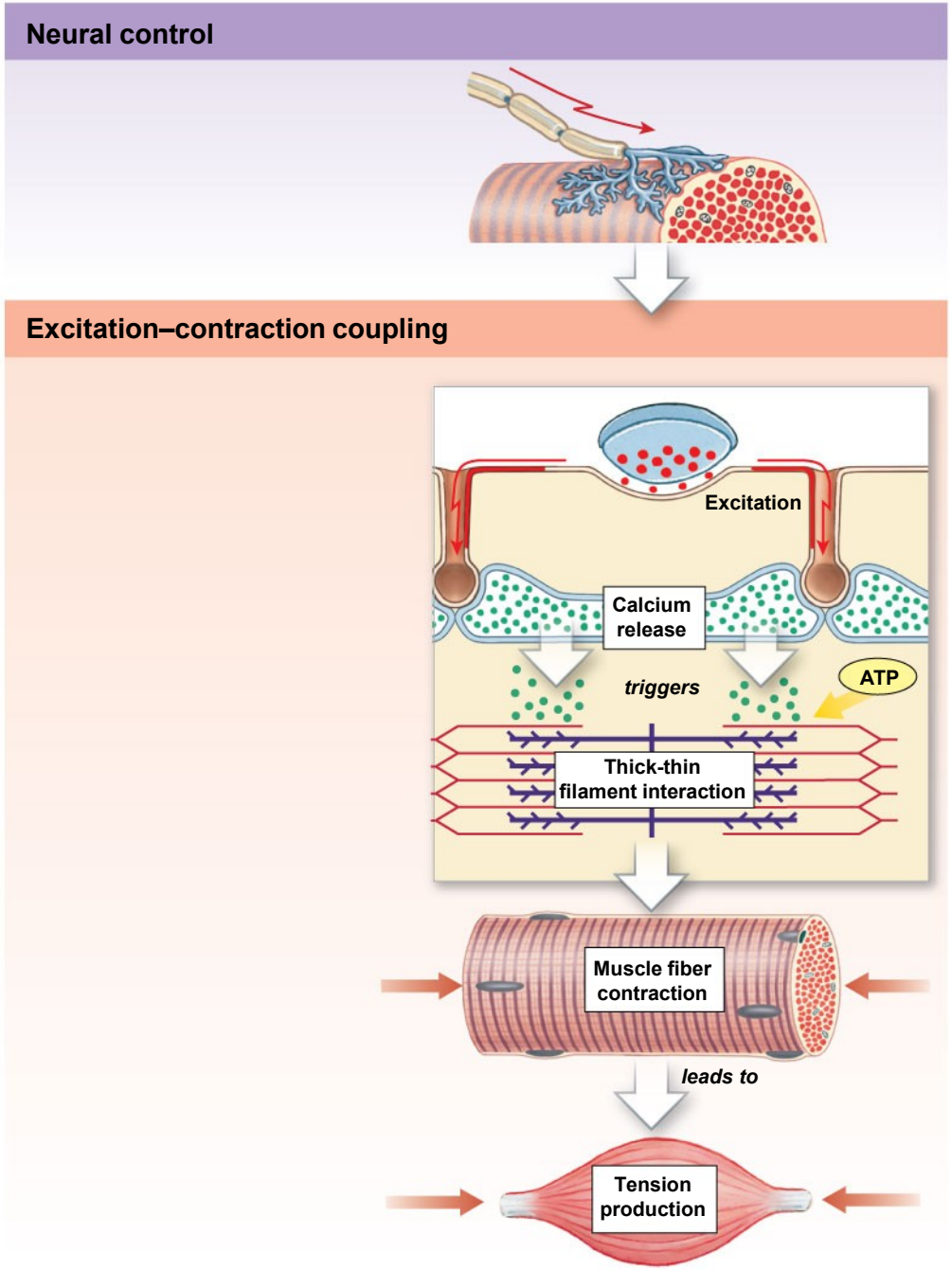


Figure 10-9 An Overview of Skeletal Muscle Contraction

Neural control

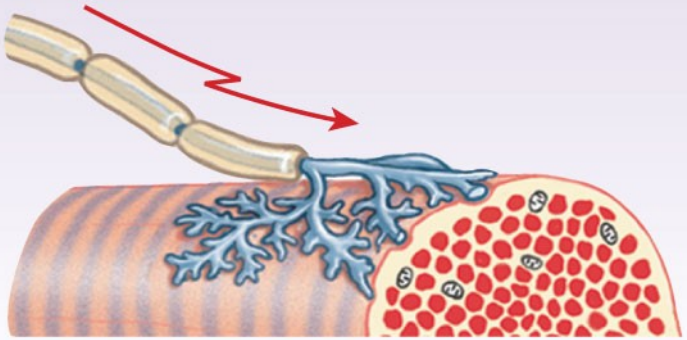


Figure 10-9 An Overview of Skeletal Muscle Contraction

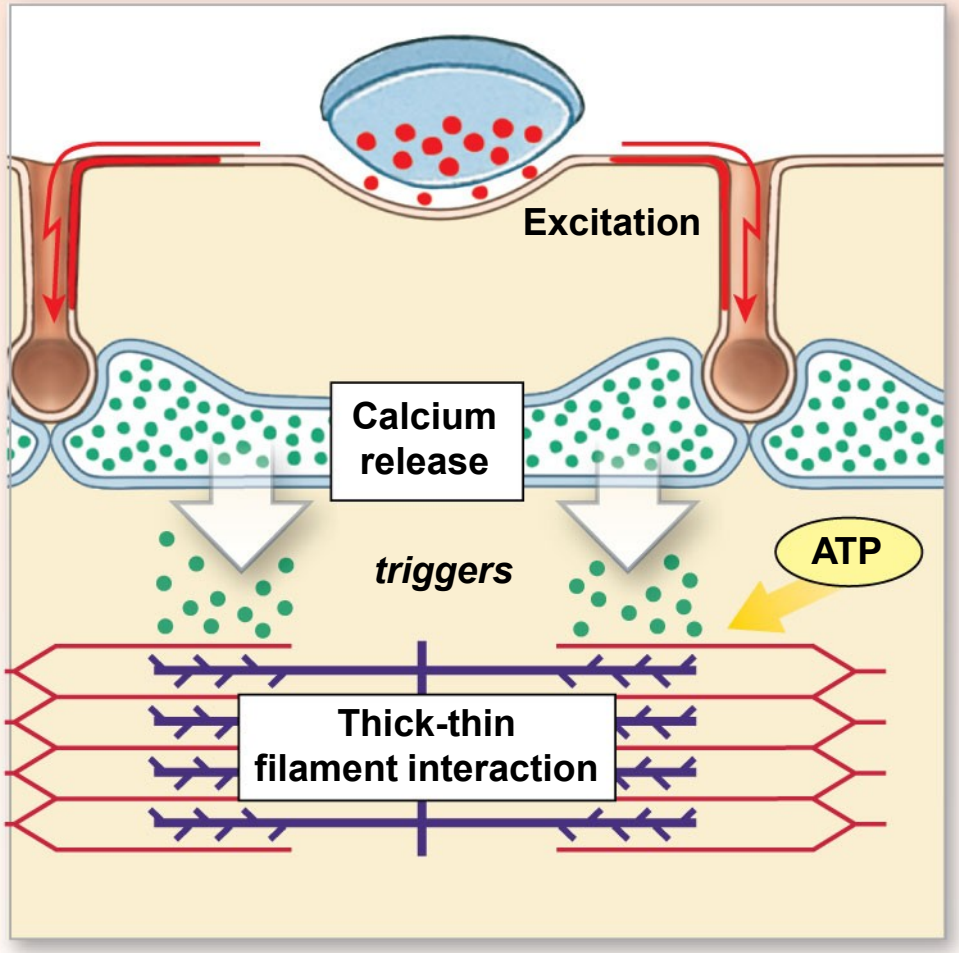
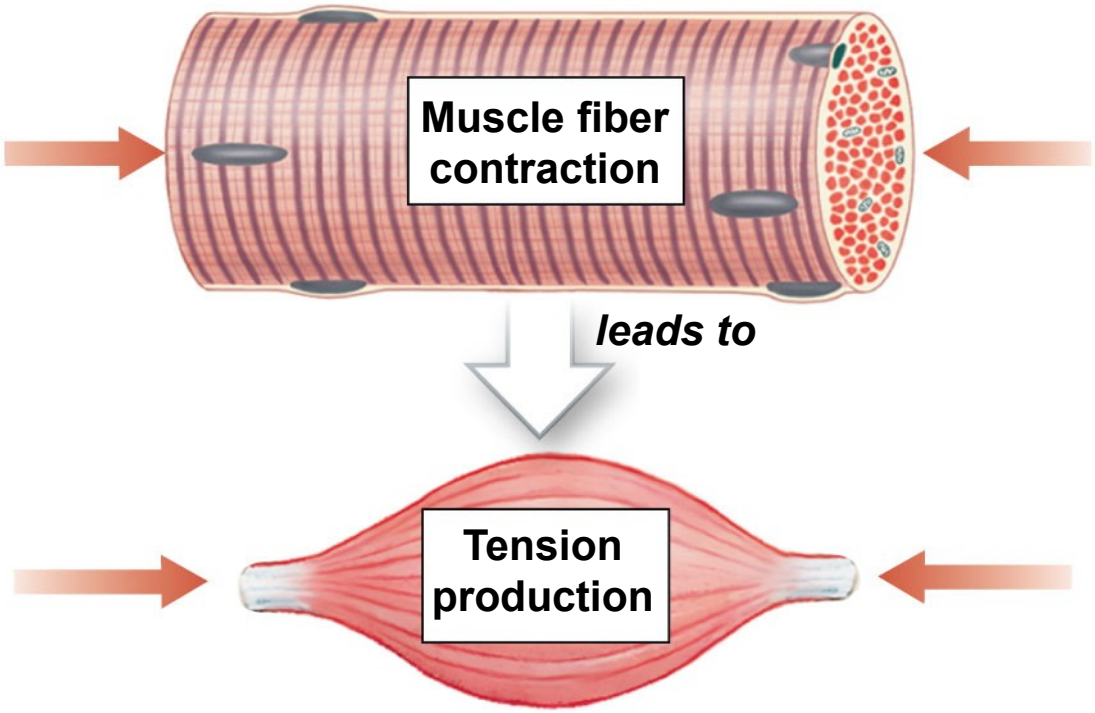


Figure 10-9 An Overview of Skeletal Muscle Contraction



10-4 Components of the Neuromuscular Junction

- The Control of Skeletal Muscle Activity
  - The **neuromuscular junction (NMJ)**
    - Special intercellular connection between the nervous system and skeletal muscle fiber
    - Controls calcium ion release into the sarcoplasm

Figure 10-11 Skeletal Muscle Innervation

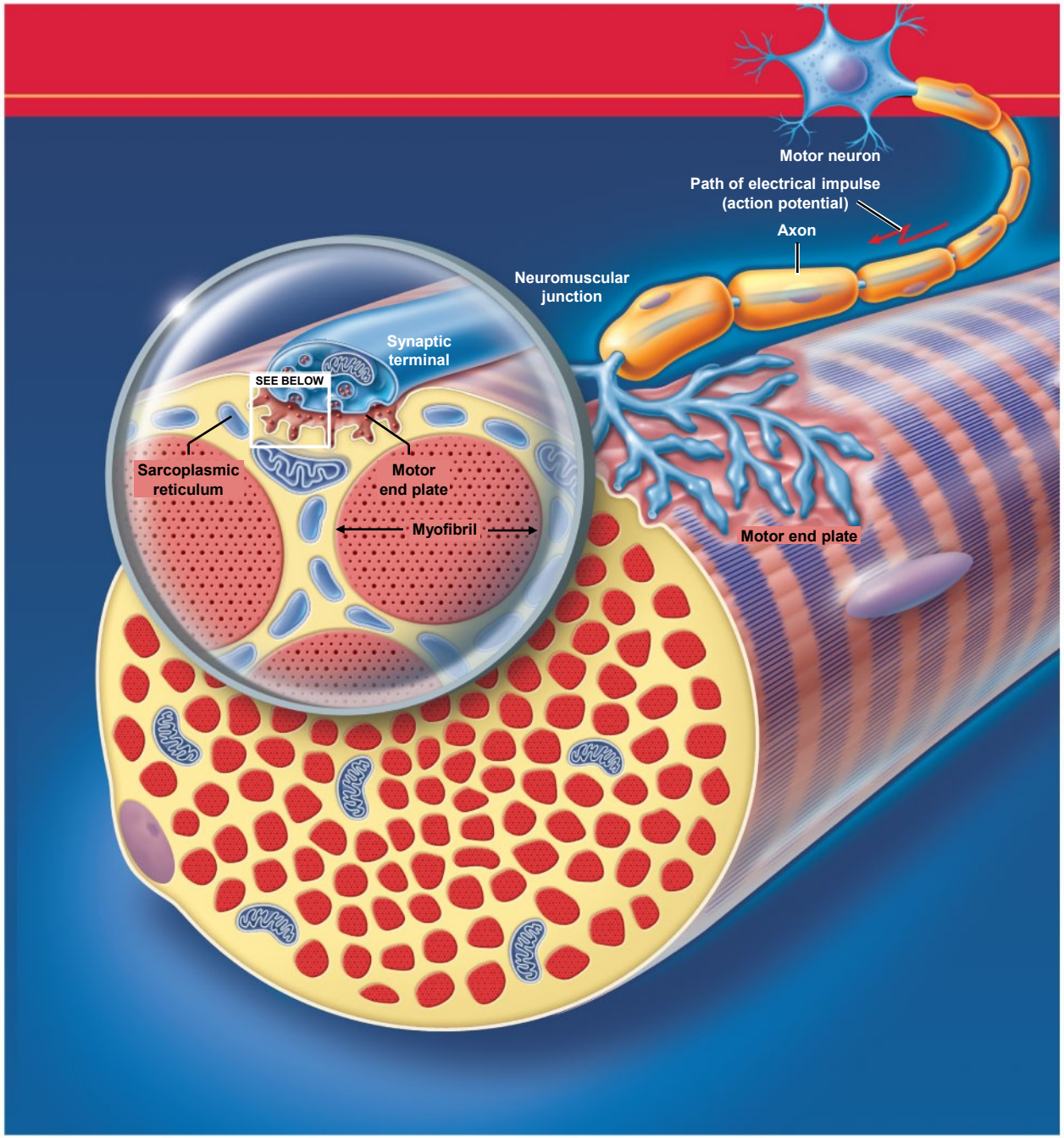


Figure 10-11 Skeletal Muscle Innervation

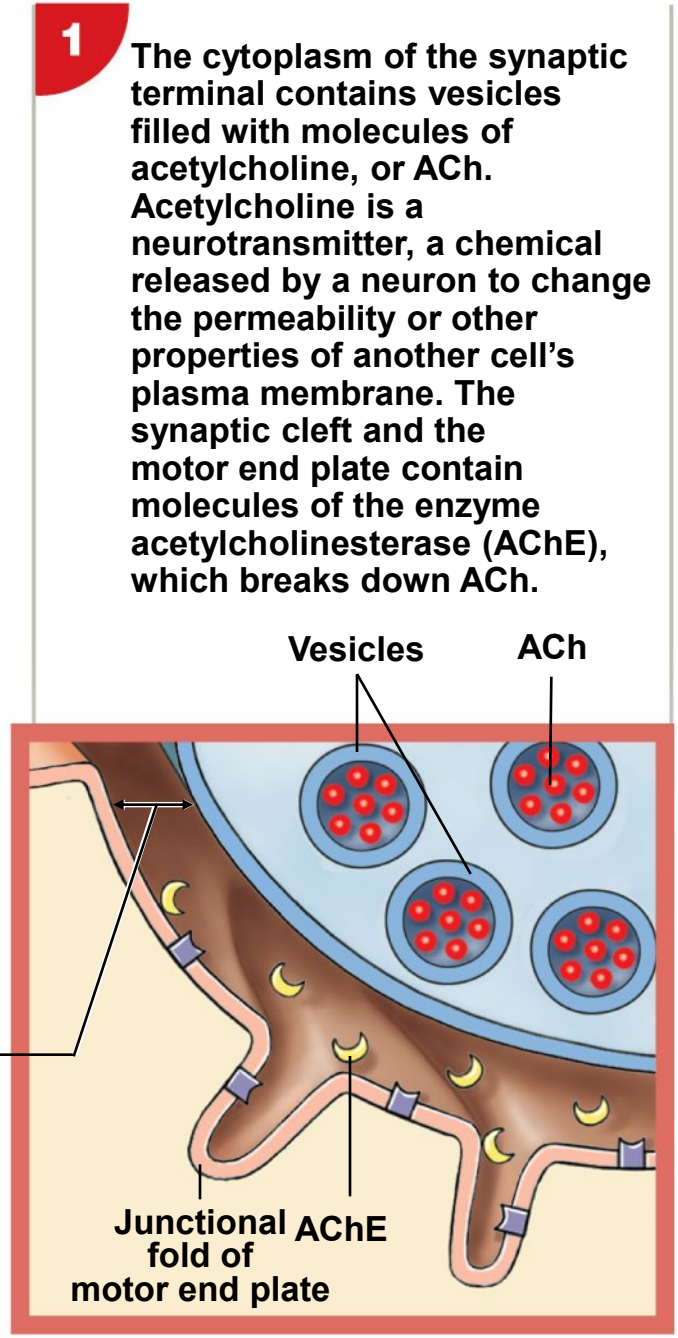


Figure 10-11 Skeletal Muscle Innervation

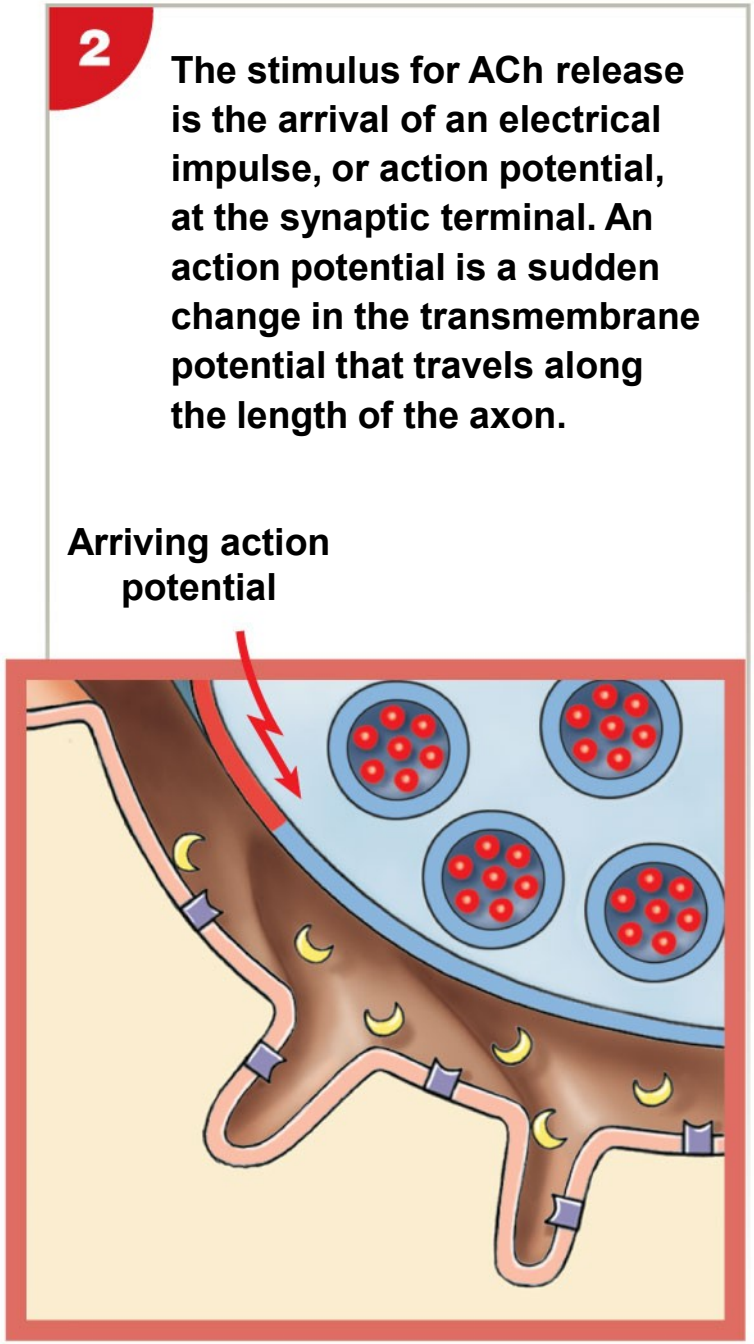


Figure 10-11 Skeletal Muscle Innervation

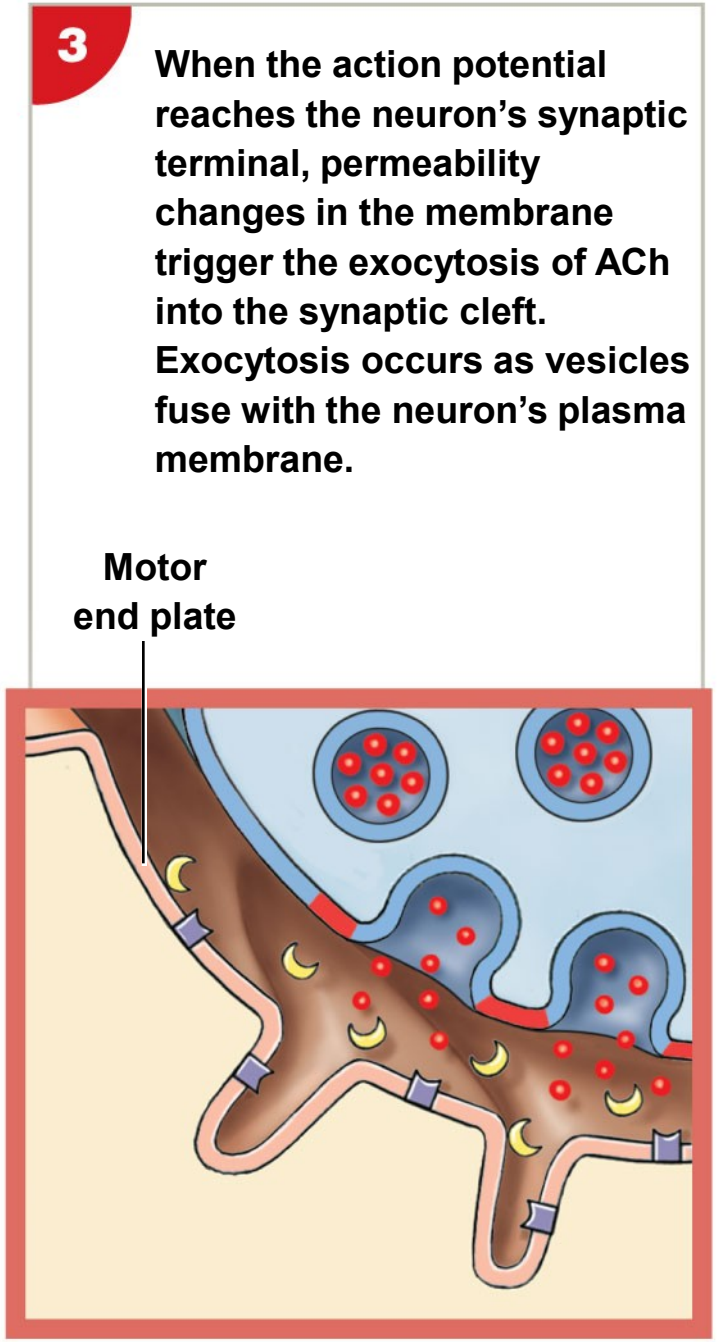


Figure 10-11 Skeletal Muscle Innervation

4

ACh molecules diffuse across the synatpic cleft and bind to ACh receptors on the surface of the motor end plate. ACh binding alters the membrane's permeability to sodium ions. Because the extracellular fluid contains a high concentration of sodium ions, and sodium ion concentration inside the cell is very low, sodium ions rush into the sarcoplasm.

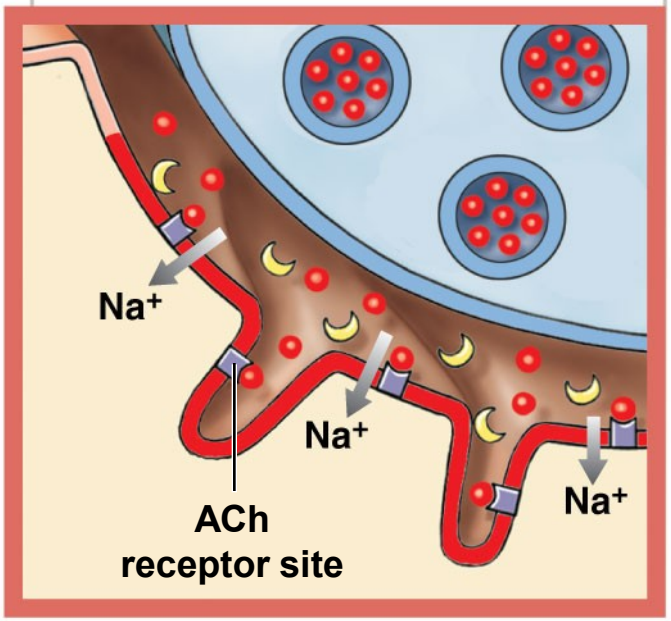


Figure 10-11 Skeletal Muscle Innervation

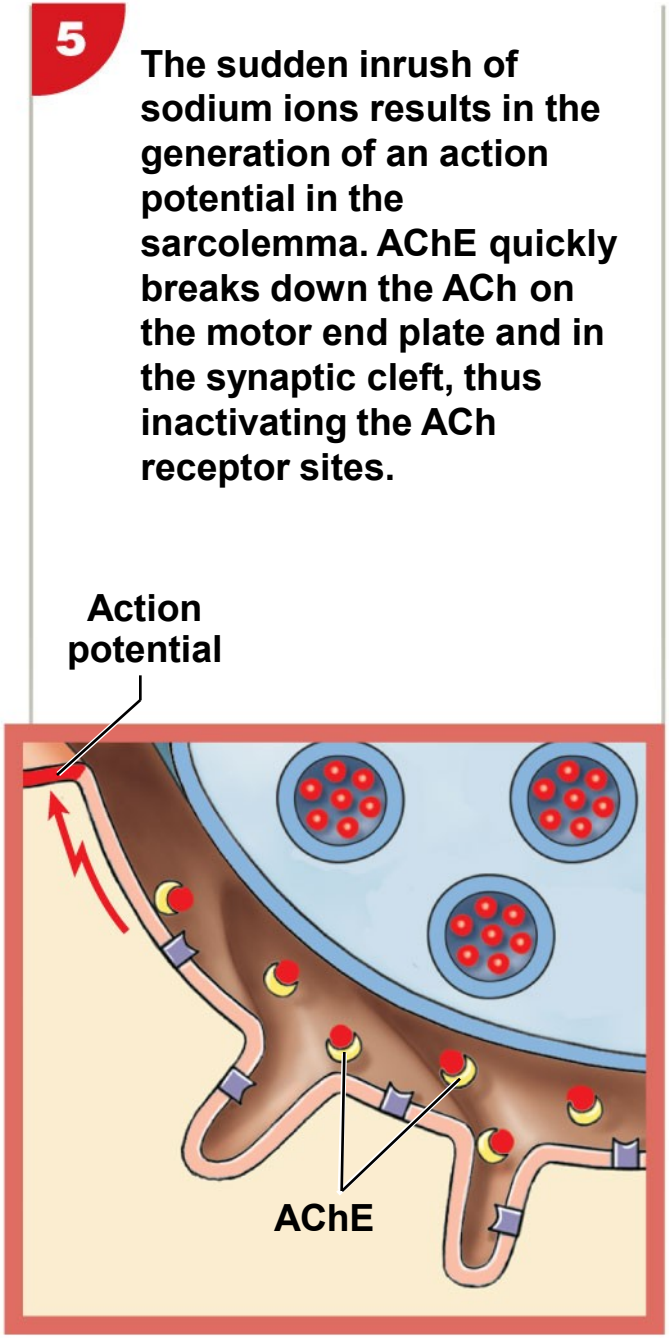
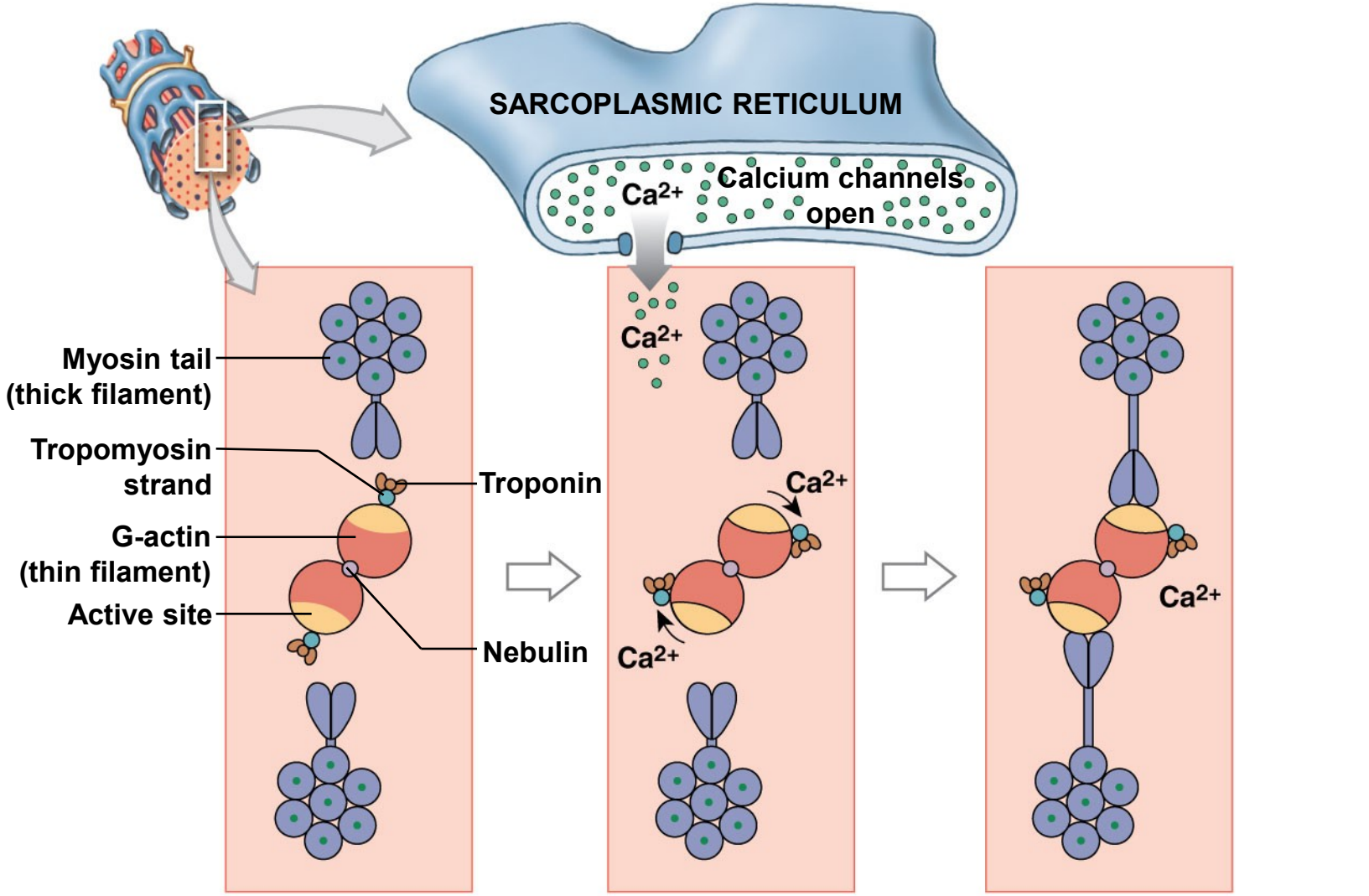


Figure 10-10 The Exposure of Active Sites



a In a resting sarcomere, the tropomyosin strands cover the active sites on the thin filaments, preventing cross-bridge formation.

b When calcium ions enter the sarcomere, they bind to troponin, which rotates and swings the tropomyosin away from the active sites.

c Cross-bridge formation then occurs, and the contraction cycle begins.

Figure 10-12 The Contraction Cycle

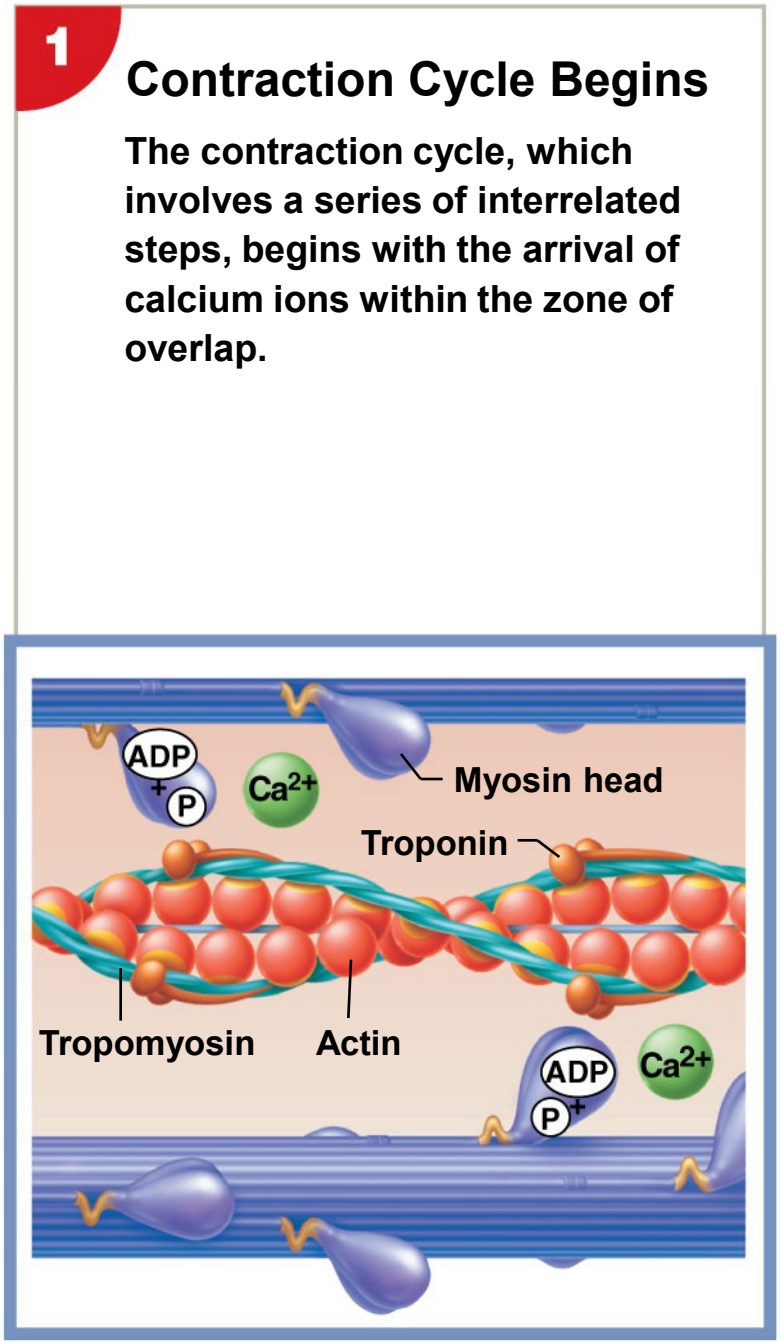


Figure 10-12 The Contraction Cycle

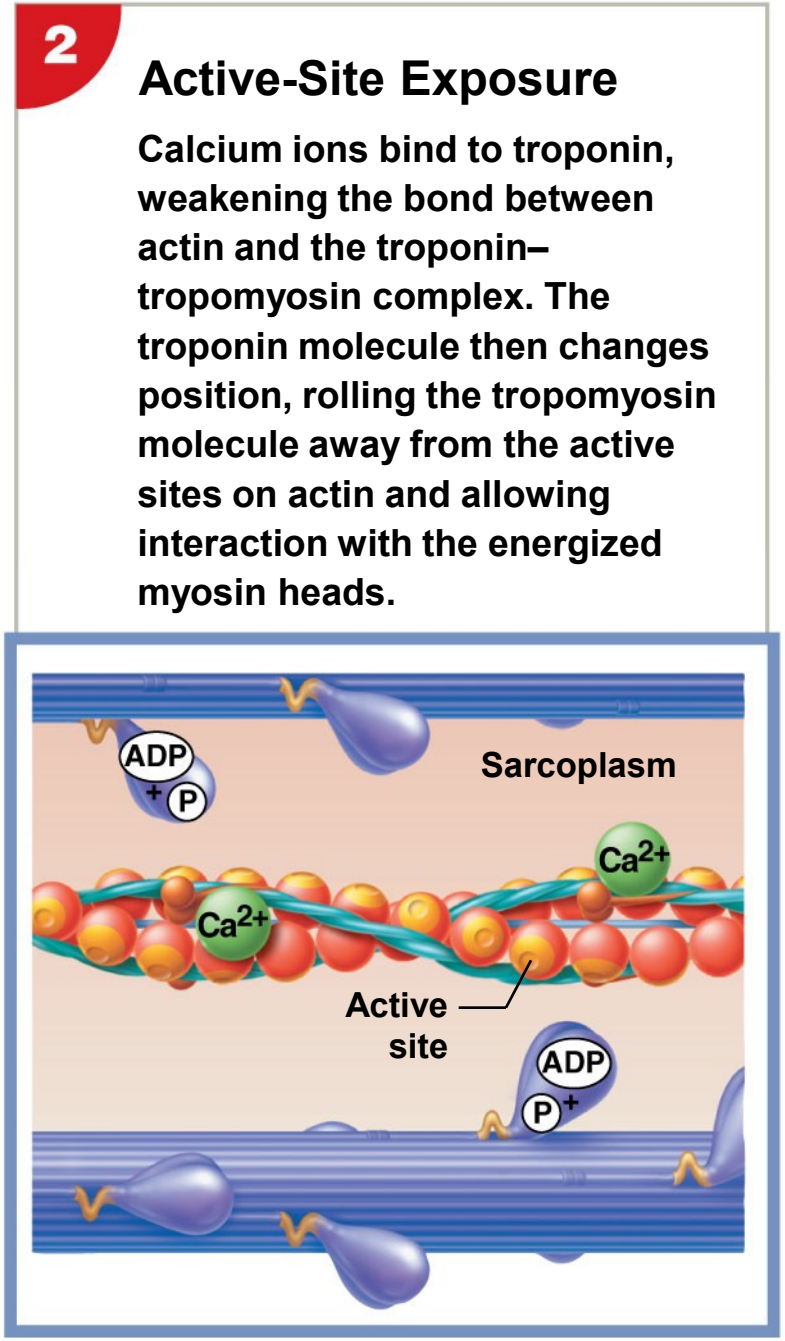


Figure 10-12 The Contraction Cycle

3

Cross-Bridge Formation

Once the active sites are exposed, the energized myosin heads bind to them, forming cross-bridges.

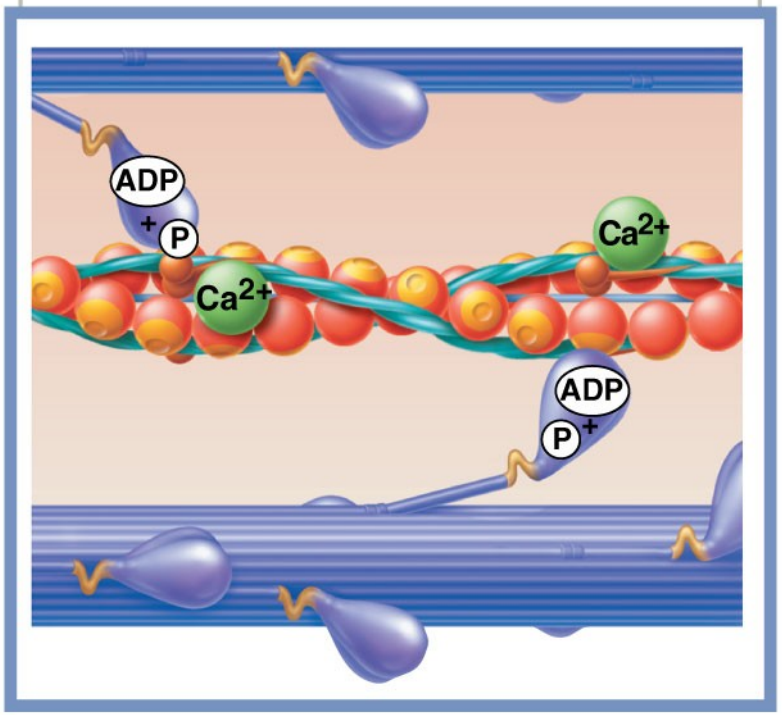


Figure 10-12 The Contraction Cycle

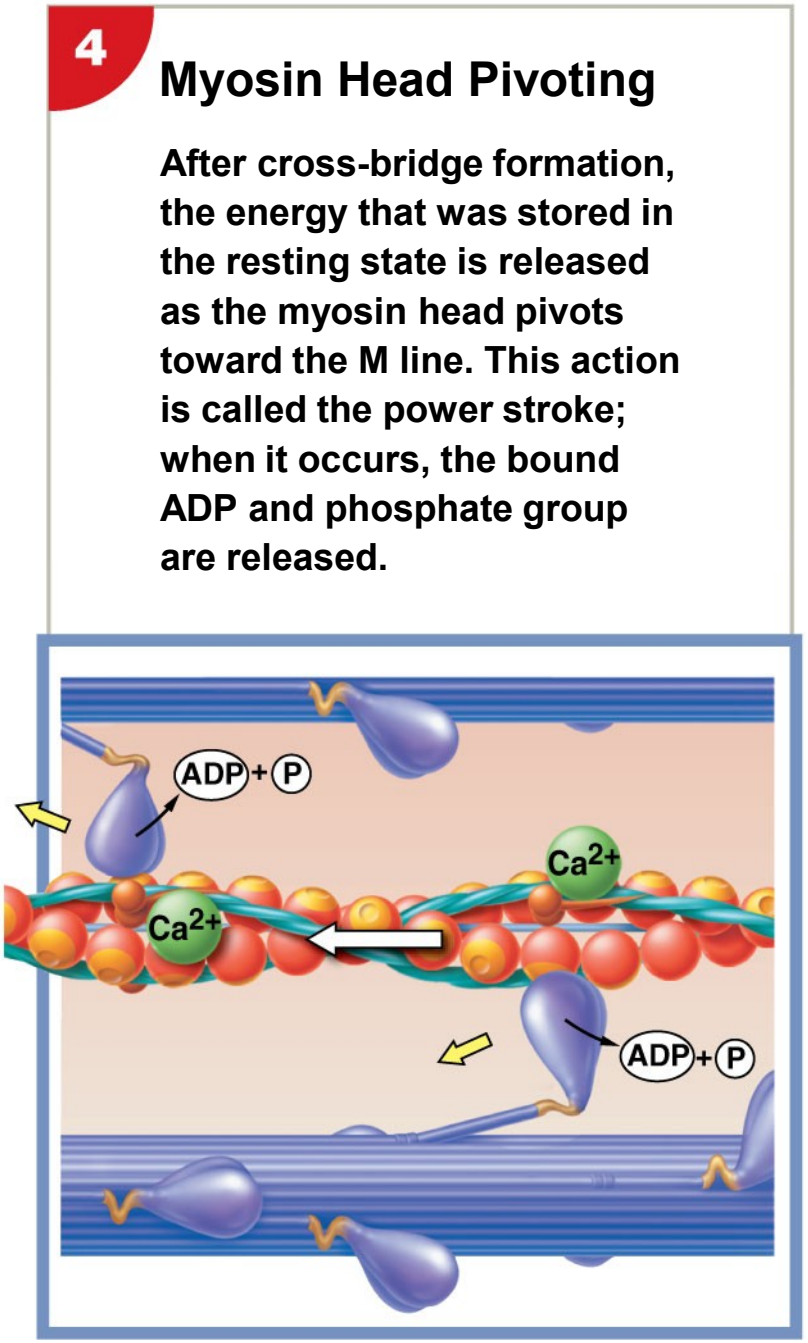


Figure 10-12 The Contraction Cycle

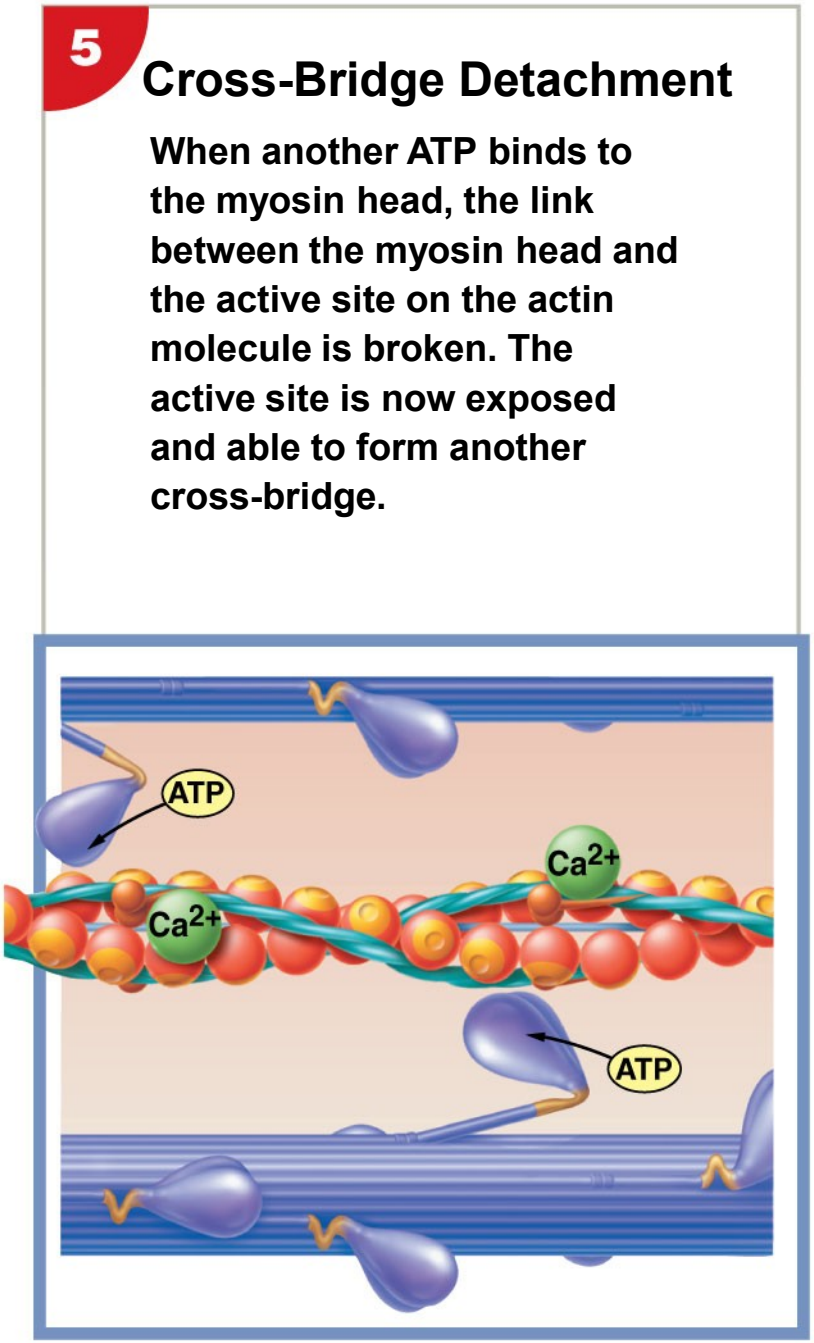


Figure 10-12 The Contraction Cycle

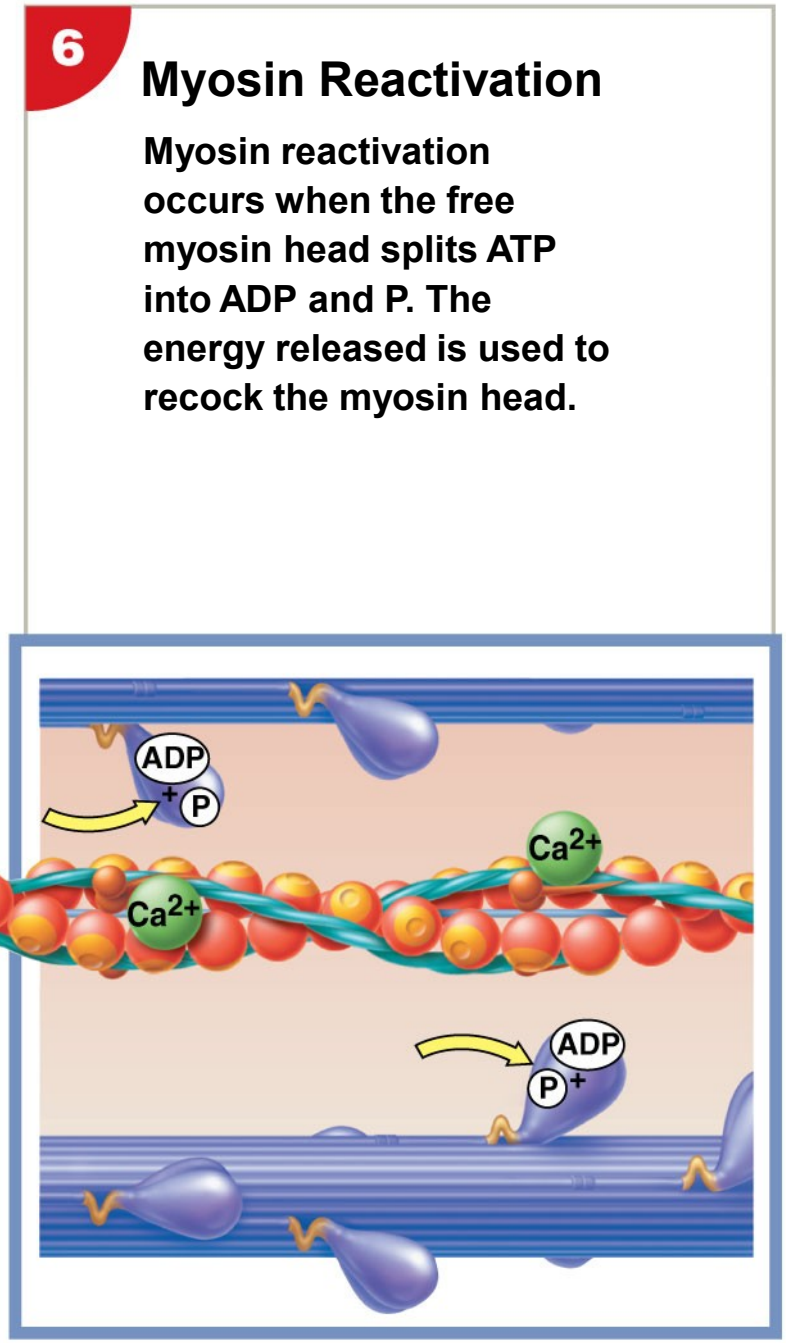


Figure 10-12 The Contraction Cycle

Resting Sarcomere

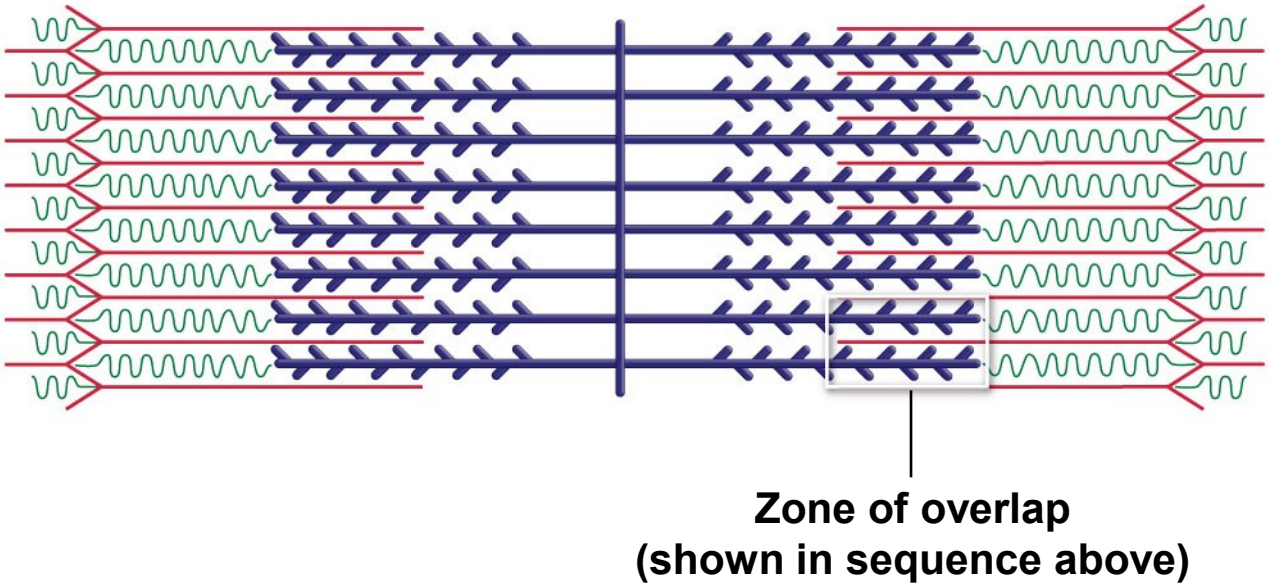
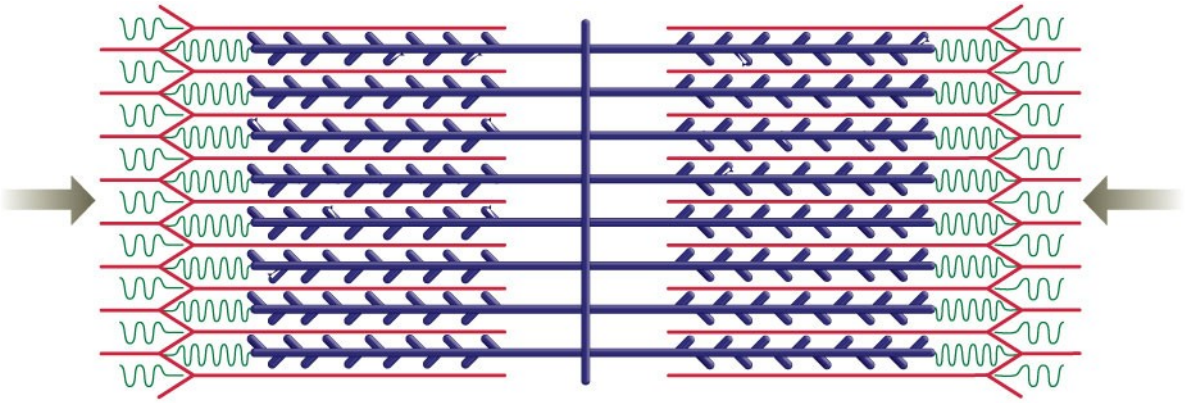


Figure 10-12 The Contraction Cycle



Contracted Sarcomere

10-4 Skeletal Muscle Contraction

- Fiber Shortening
  - As sarcomeres shorten, muscle pulls together, producing *tension*

10-4 Skeletal Muscle Relaxation

- Relaxation
  - Contraction Duration
    - Depends on:
      - Duration of neural stimulus
      - Number of free calcium ions in sarcoplasm
      - Availability of ATP

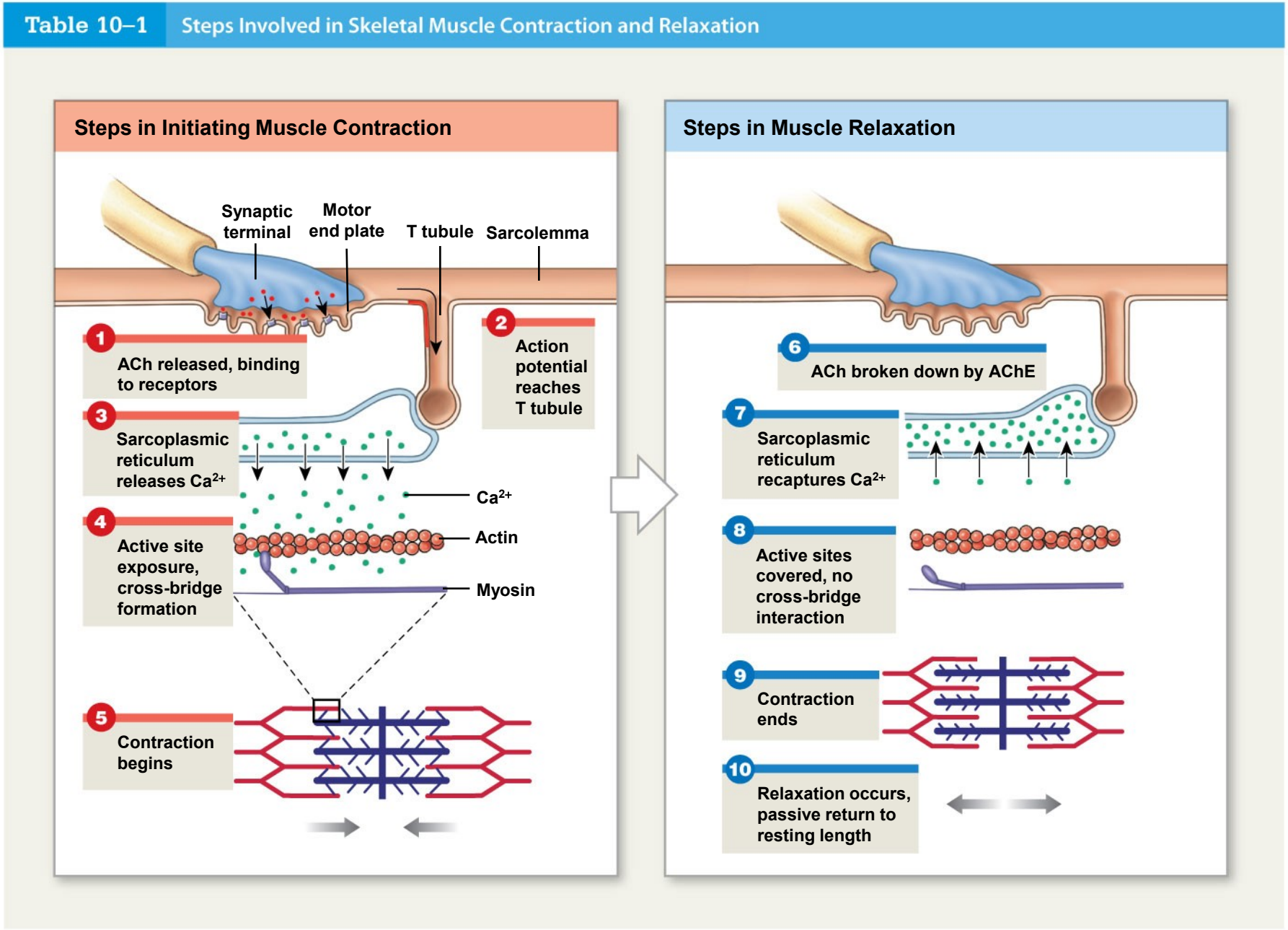
10-4 Skeletal Muscle Relaxation

- Relaxation
  - Ca^{2+} concentrations fall
  - Ca^{2+} detaches from troponin
  - Active sites are re-covered by tropomyosin

10-4 Skeletal Muscle Contraction and Relaxation

- Summary
  - Skeletal muscle fibers shorten as thin filaments slide between thick filaments
  - Free Ca^{2+} in the sarcoplasm triggers contraction
  - SR releases Ca^{2+} when a motor neuron stimulates the muscle fiber
  - Contraction is an active process
  - Relaxation and return to resting length are passive

Table 10-1 Steps Involved in Skeletal Muscle Contraction and Relaxation



10-6 Energy to Power Contractions

- ATP Provides Energy For Muscle Contraction
  - Sustained muscle contraction uses a lot of ATP energy
  - Muscles store enough energy to start contraction
  - Muscle fibers must manufacture more ATP as needed

10-6 Energy to Power Contractions

- ATP and CP Reserves
  - Adenosine triphosphate (ATP)
    - The active energy molecule
  - **Creatine phosphate (CP)**
    - The storage molecule for excess ATP energy in resting muscle
- Energy recharges ADP to ATP
  - Using the enzyme **creatine kinase (CK)**
  - When CP is used up, other mechanisms generate ATP

10-6 Energy to Power Contractions

- ATP Generation
  - Cells produce ATP in two ways
    1. **Aerobic metabolism** of fatty acids in the mitochondria
    2. **Anaerobic glycolysis** in the cytoplasm

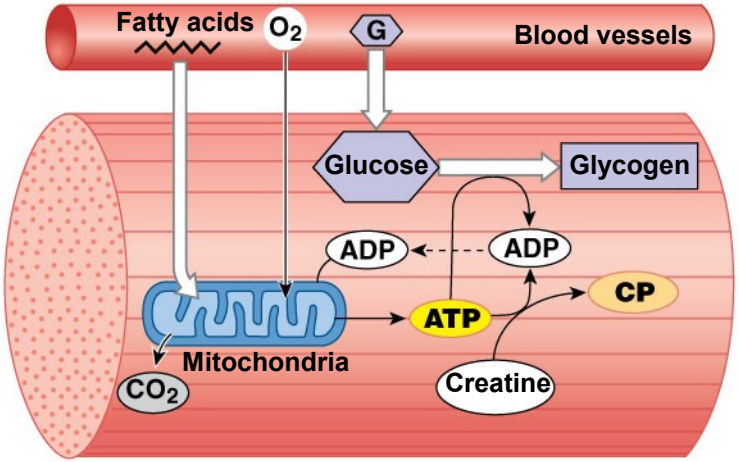
10-6 Energy to Power Contractions

- **Aerobic Metabolism**
  - Is the primary energy source of resting muscles
  - Breaks down fatty acids
  - Produces 34 ATP molecules per glucose molecule
- **Glycolysis**
  - Is the primary energy source for peak muscular activity
  - Produces two ATP molecules per molecule of glucose
  - Breaks down glucose from glycogen stored in skeletal muscles

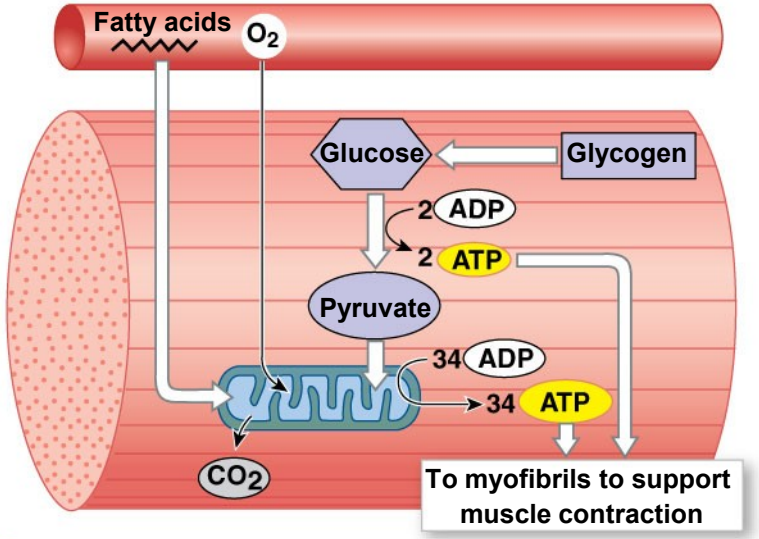
10-6 Energy to Power Contractions

- Energy Use and the Level of Muscular Activity
  - Skeletal muscles at rest metabolize fatty acids and store glycogen
  - During light activity, muscles generate ATP through anaerobic breakdown of carbohydrates, lipids, or amino acids
  - At peak activity, energy is provided by anaerobic reactions that generate **lactic acid** as a byproduct

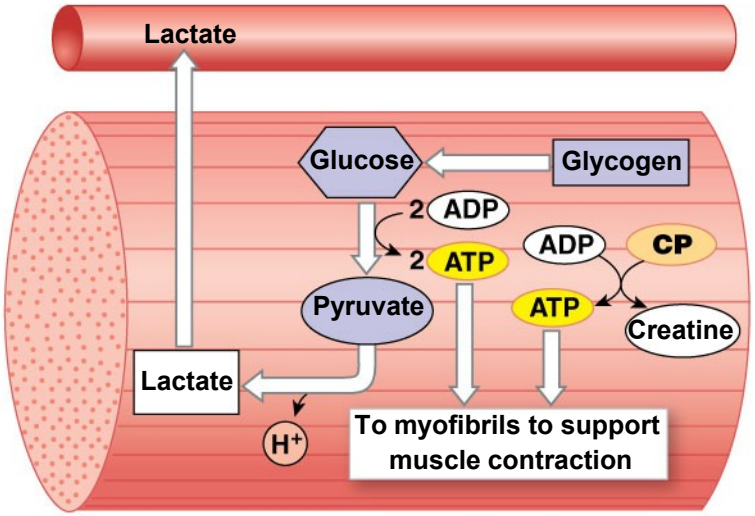
Figure 10-20 Muscle Metabolism



a Resting muscle: Fatty acids are catabolized; the ATP produced is used to build energy reserves of ATP, CP, and glycogen.

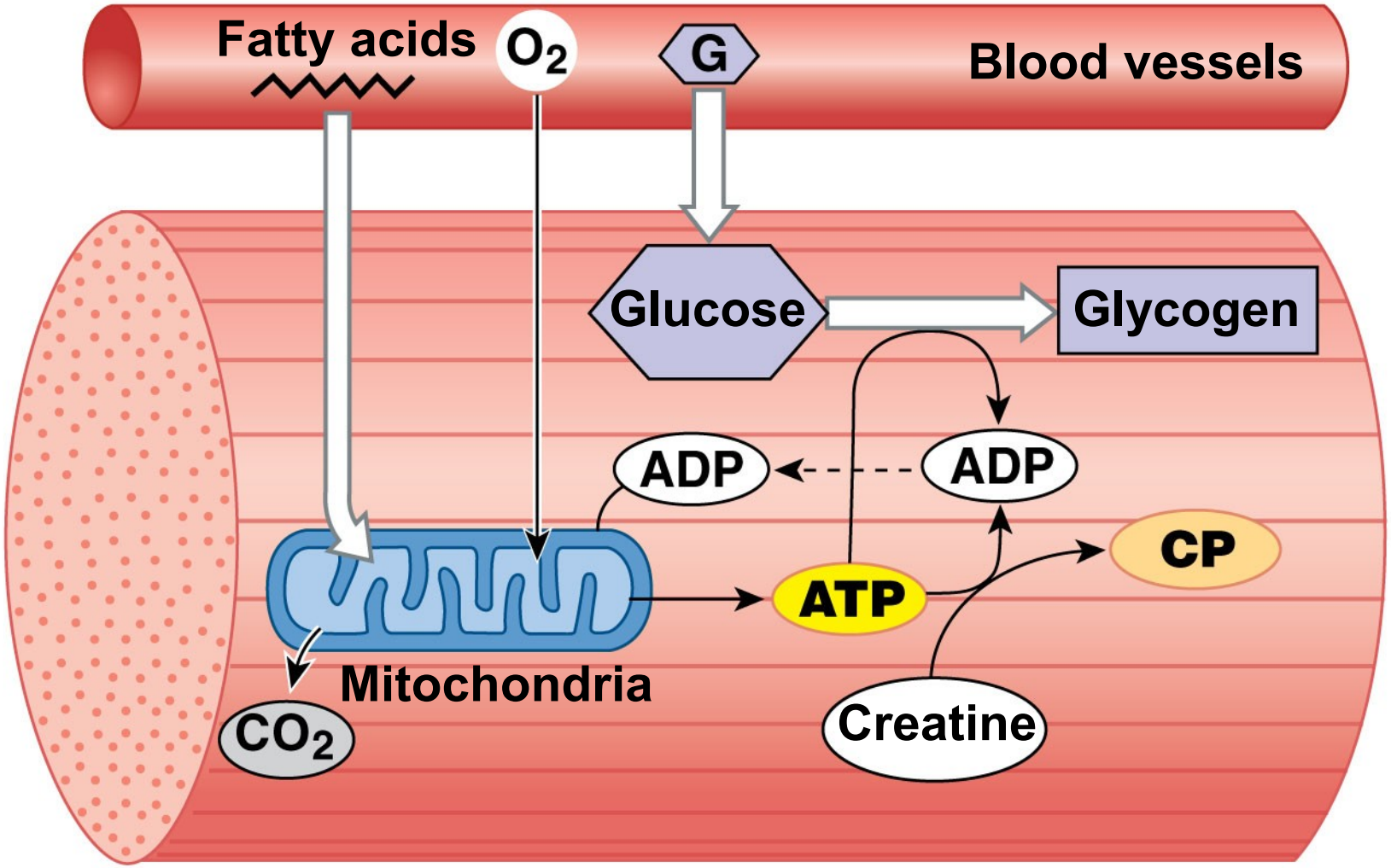


b Moderate activity: Glucose and fatty acids are catabolized; the ATP produced is used to power contraction.



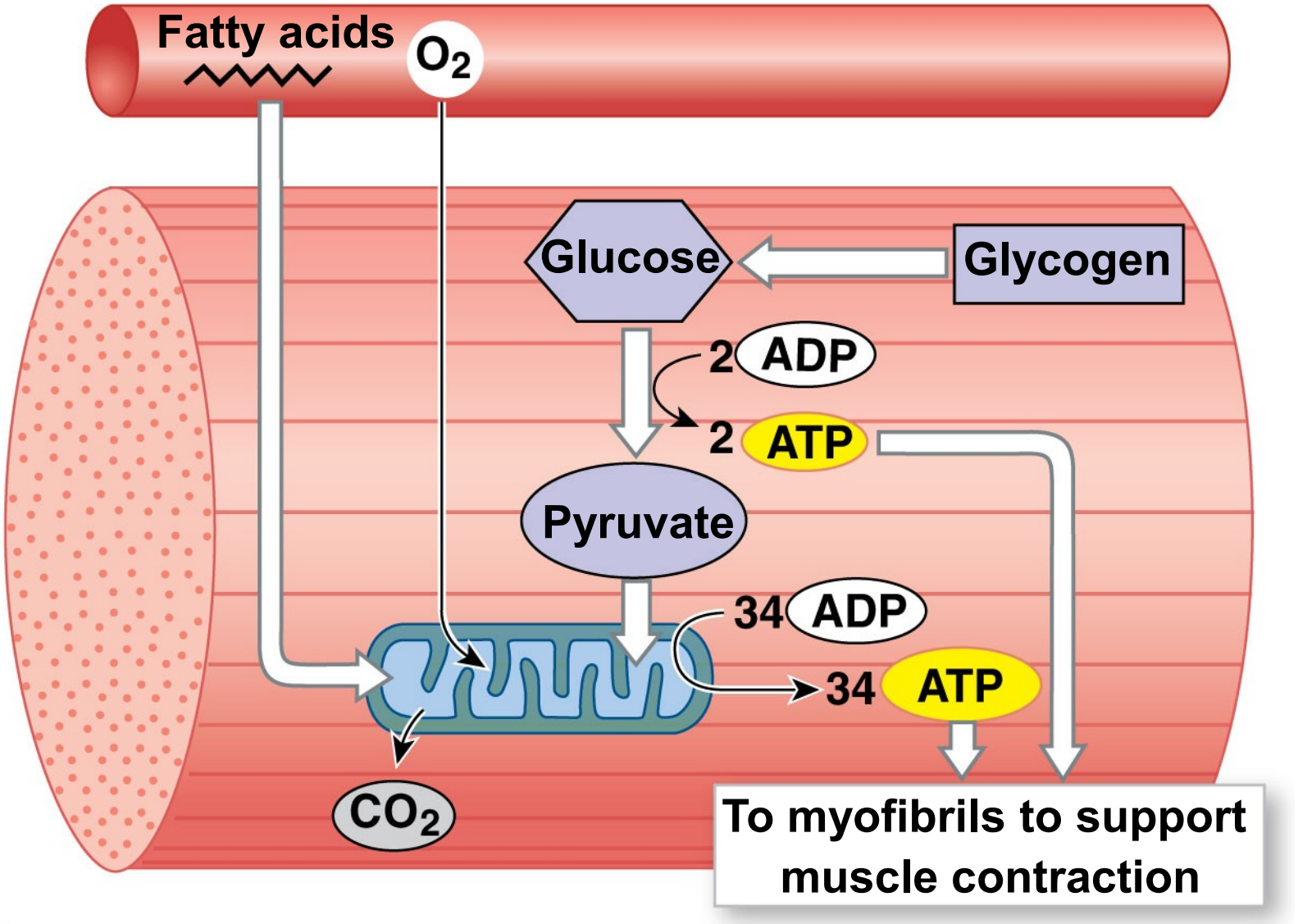
c Peak activity: Most ATP is produced through glycolysis, with lactate as a by-product. Mitochondrial activity (not shown) now provides only about one-third of the ATP consumed.

Figure 10-20a Muscle Metabolism



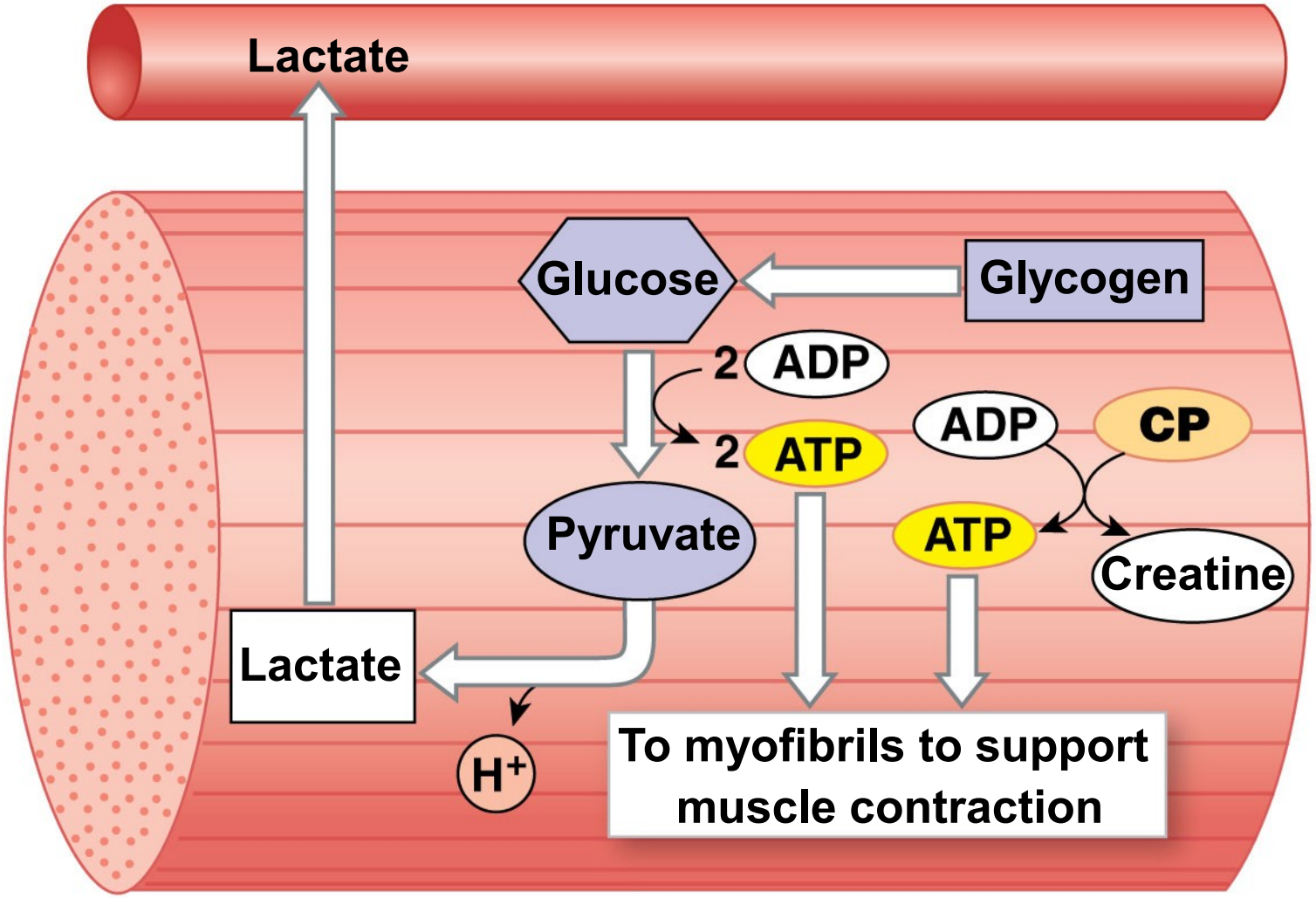
a **Resting muscle: Fatty acids are catabolized; the ATP produced is used to build energy reserves of ATP, CP, and glycogen.**

Figure 10-20b Muscle Metabolism



b **Moderate activity: Glucose and fatty acids are catabolized; the ATP produced is used to power contraction.**

Figure 10-20c Muscle Metabolism



c **Peak activity: Most ATP is produced through glycolysis, with lactate as a by-product. Mitochondrial activity (not shown) now provides only about one-third of the ATP consumed.**

10-6 Energy to Power Contractions

- Muscle Fatigue
  - When muscles can no longer perform a required activity, they are **fatigued**
- Results of Muscle Fatigue
  - Depletion of metabolic reserves
  - Damage to sarcolemma and sarcoplasmic reticulum
  - Low pH (lactic acid)
  - Muscle exhaustion and pain

10-6 Energy to Power Contractions

- The **Recovery Period**
  - The time required after exertion for muscles to return to normal
  - Oxygen becomes available
  - Mitochondrial activity resumes

10-6 Energy to Power Contractions

- Lactic Acid Removal and Recycling
  - The removal and recycling of lactic acid by the liver
  - Liver converts lactate to pyruvate
  - Glucose is released to recharge muscle glycogen reserves

10-6 Energy to Power Contractions

- Heat Production and Loss
  - Active muscles produce heat
  - Up to 70% of muscle energy can be lost as heat, raising body temperature

10-7 Types of Muscles Fibers and Endurance

- Three Major Types of Skeletal Muscle Fibers
  1. **Fast fibers**
  2. **Slow fibers**
  3. **Intermediate fibers**

10-7 Types of Muscles Fibers and Endurance

- **Fast Fibers**
  - Contract very quickly
  - Have large diameter, large glycogen reserves, few mitochondria
  - Have strong contractions, fatigue quickly

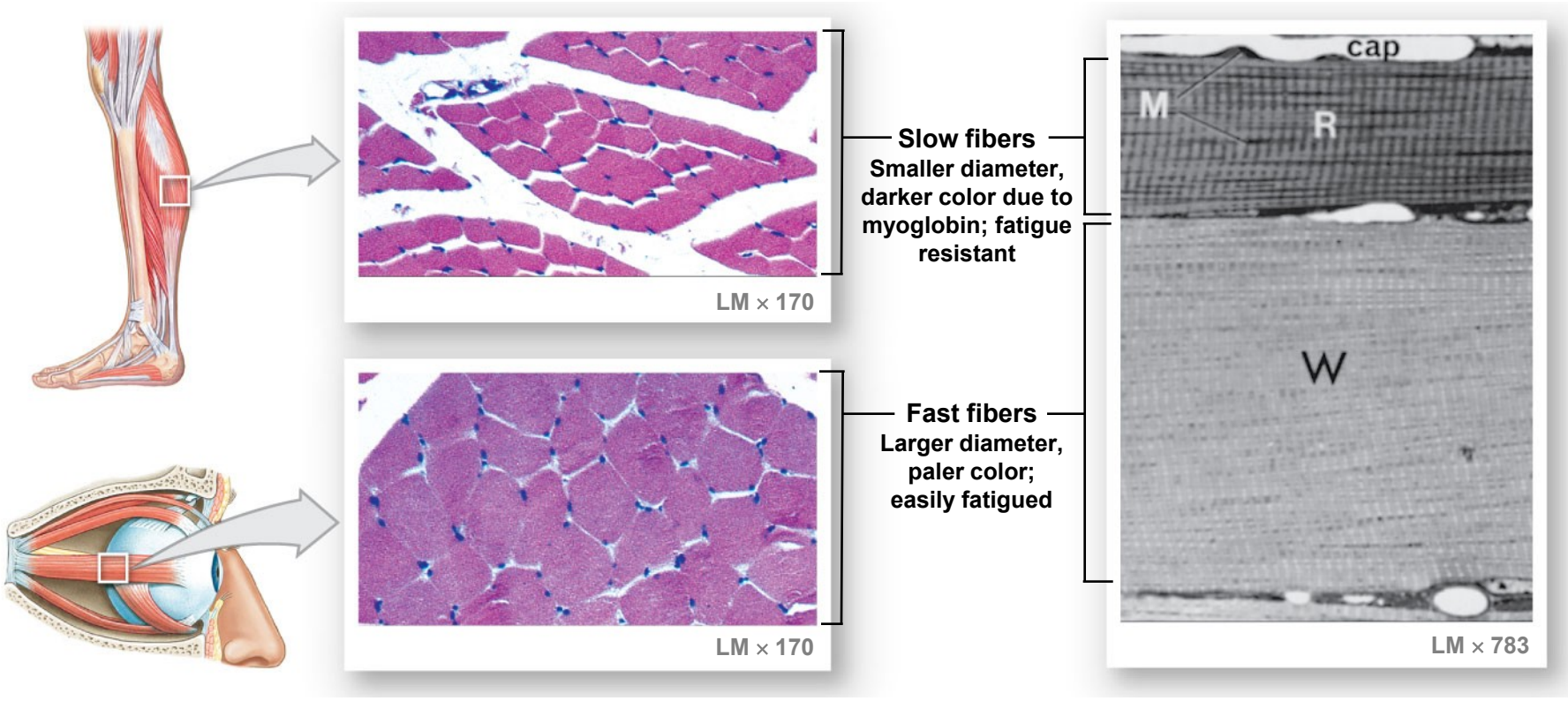
10-7 Types of Muscles Fibers and Endurance

- **Slow Fibers**
  - Are slow to contract, slow to fatigue
  - Have small diameter, more mitochondria
  - Have high oxygen supply
  - Contain **myoglobin** (red pigment, binds oxygen)

10-7 Types of Muscles Fibers and Endurance

- **Intermediate Fibers**
  - Are mid-sized
  - Have low myoglobin
  - Have more capillaries than fast fibers, slower to fatigue

Figure 10-21 Fast versus Slow Fibers



10-7 Types of Muscles Fibers and Endurance

- Muscle Performance and the Distribution of Muscle Fibers
  - **White muscles**
    - Mostly fast fibers
    - Pale (e.g., chicken breast)
  - **Red muscles**
    - Mostly slow fibers
    - Dark (e.g., chicken legs)
  - Most human muscles
    - Mixed fibers
    - Pink

10-7 Types of Muscles Fibers and Endurance

- Muscle **Hypertrophy**
  - Muscle growth from heavy training
    - Increases diameter of muscle fibers
    - Increases number of myofibrils
    - Increases mitochondria, glycogen reserves
- Muscle **Atrophy**
  - Lack of muscle activity
    - Reduces muscle size, tone, and power

10-7 Types of Muscles Fibers and Endurance

- Physical Conditioning
  - Improves both power and endurance
    - **Anaerobic activities** (e.g., 50-meter dash, weightlifting)
      - Use fast fibers
      - Fatigue quickly with strenuous activity
    - Improved by:
      - Frequent, brief, intensive workouts
    - Causes hypertrophy

10-7 Types of Muscles Fibers and Endurance

- Physical Conditioning
  - Improves both power and endurance
    - **Aerobic activities** (prolonged activity)
      - Supported by mitochondria
      - Require oxygen and nutrients
    - Improves:
      - Endurance by training fast fibers to be more like intermediate fibers
      - Cardiovascular performance

10-7 Types of Muscles Fibers and Endurance

- Importance of Exercise
  - What you don’t use, you lose
  - Muscles become flaccid when inactive for days or weeks
  - Muscle fibers break down proteins, become smaller and weaker
  - With prolonged inactivity, fibrous tissue may replace muscle fibers