Concept 50.5: The physical interaction of protein filaments is required for muscle function

- Muscle activity is a response to input from the nervous system
- The action of a muscle is always to contract

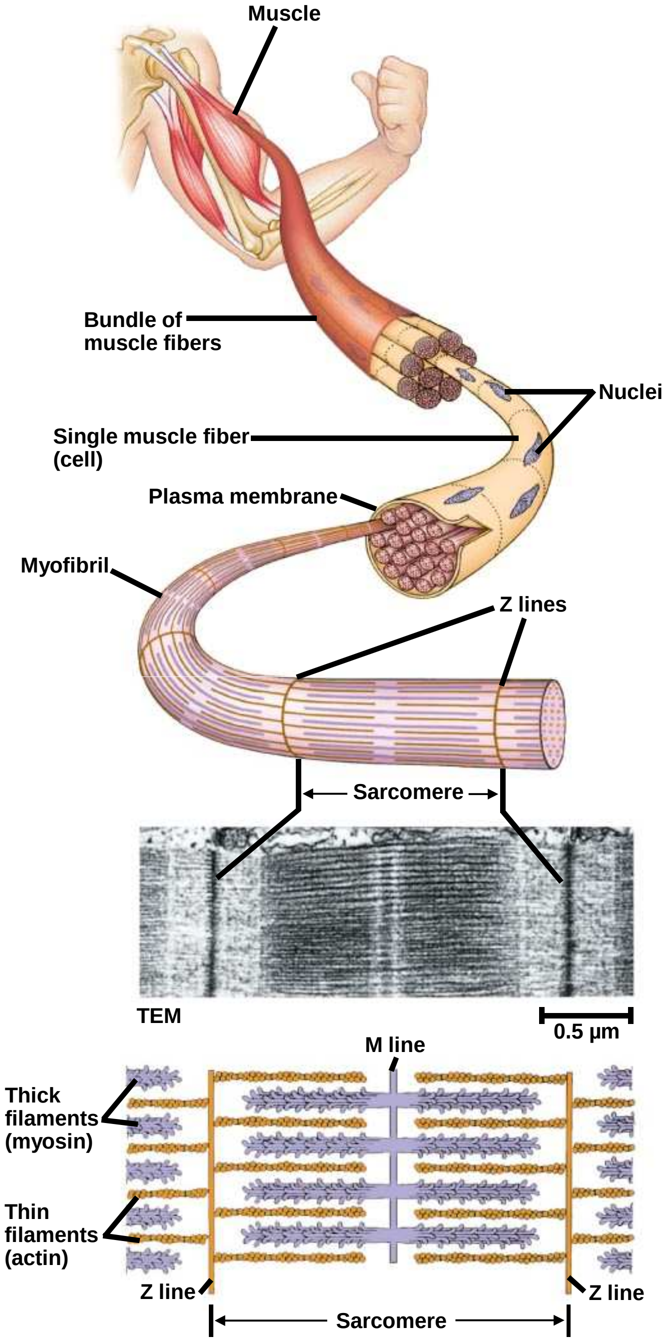
Vertebrate Skeletal Muscle

- Vertebrate **skeletal muscle** is characterized by a hierarchy of smaller and smaller units
- A skeletal muscle consists of a bundle of long fibers, each a single cell, running parallel to the length of the muscle
- Each muscle fiber is itself a bundle of smaller **myofibrils** arranged longitudinally

- The myofibrils are composed to two kinds of myofilaments:
  - **Thin filaments** consist of two strands of actin and one strand of regulatory protein
  - **Thick filaments** are staggered arrays of myosin molecules

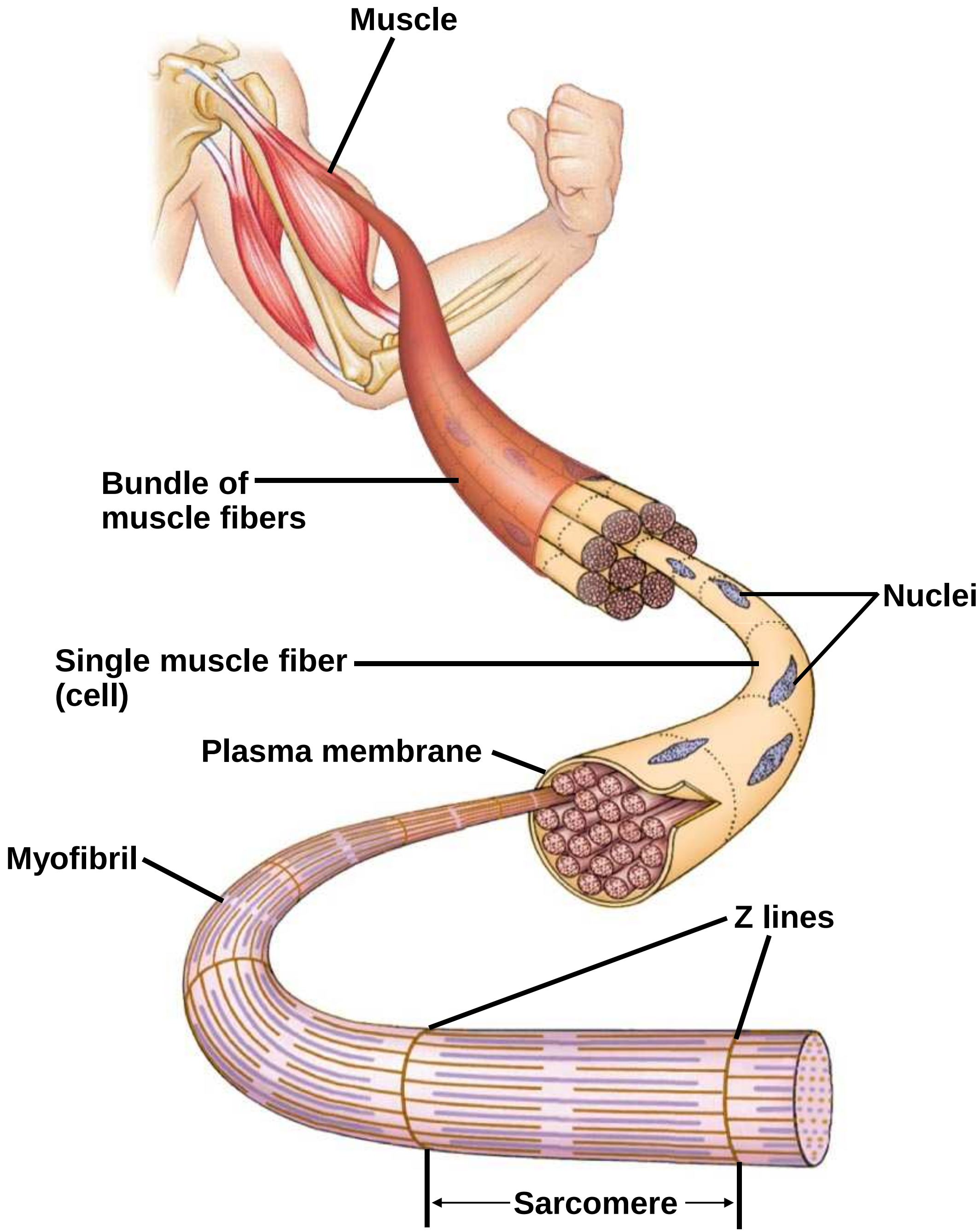
- Skeletal muscle is also called **striated muscle** because the regular arrangement of myofilaments creates a pattern of light and dark bands
- The functional unit of a muscle is called a **sarcomere**, and is bordered by Z lines

Fig. 50-25



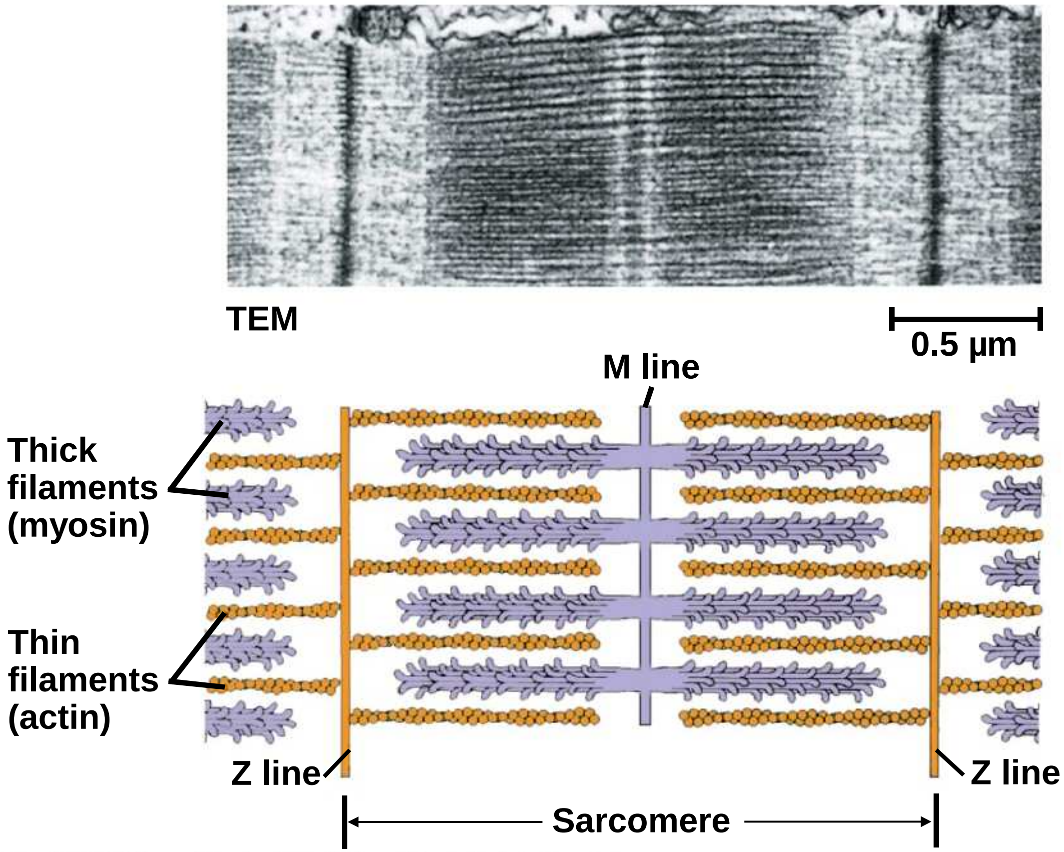
Muscle
Bundle of muscle fibers
Nuclei
Single muscle fiber (cell)
Plasma membrane
Myofibril
Z lines
Sarcomere
TEM
0.5 µm
M line
Thick filaments (myosin)
Thin filaments (actin)
Z line
Z line
Sarcomere

Fig. 50-25a



Muscle
Bundle of muscle fibers
Nuclei
Single muscle fiber (cell)
Plasma membrane
Myofibril
Z lines
Sarcomere

Fig. 50-25b

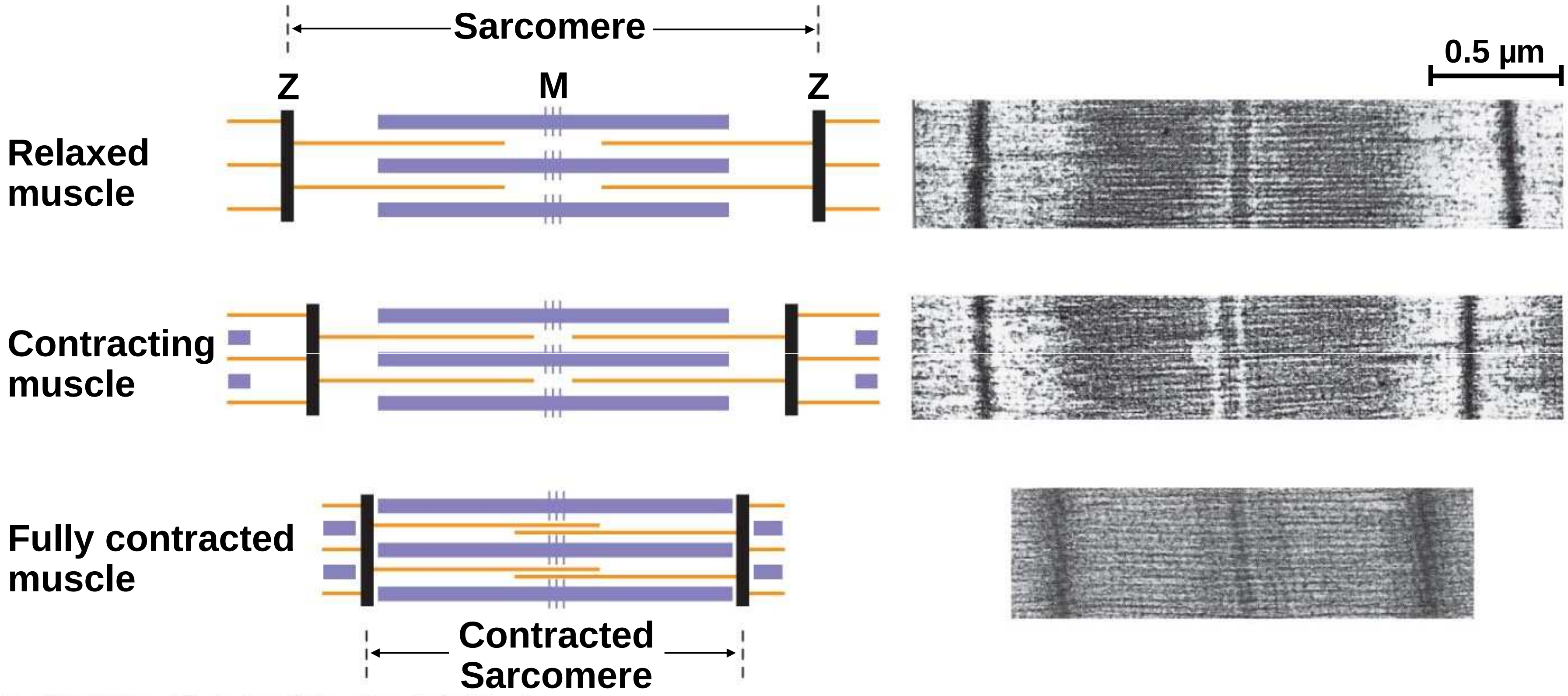


TEM
0.5 µm
M line
Thick
filaments
(myosin)
Thin
filaments
(actin)
Z line
Z line
Sarcomere

The Sliding-Filament Model of Muscle Contraction

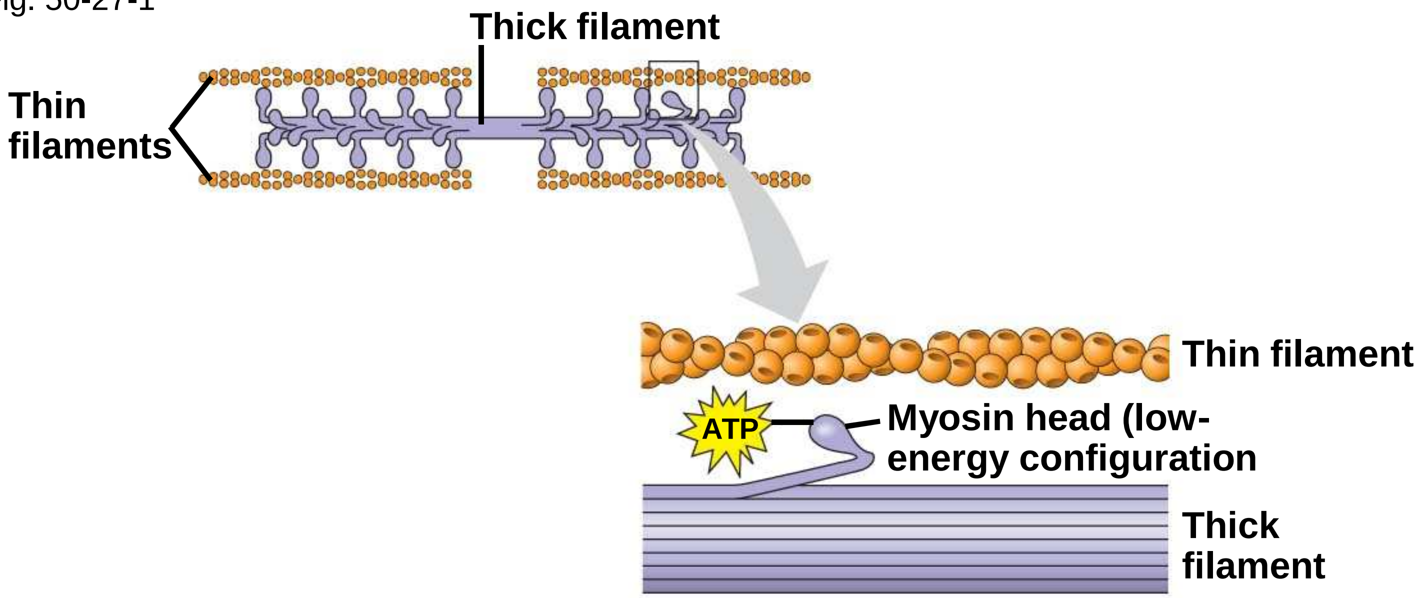
- According to the **sliding-filament model**, filaments slide past each other longitudinally, producing more overlap between thin and thick filaments

Fig. 50-26


Sarcomere
Z
M
Z
Relaxed muscle
Contracting muscle
Fully contracted muscle
Contracted Sarcomere
0.5 µm

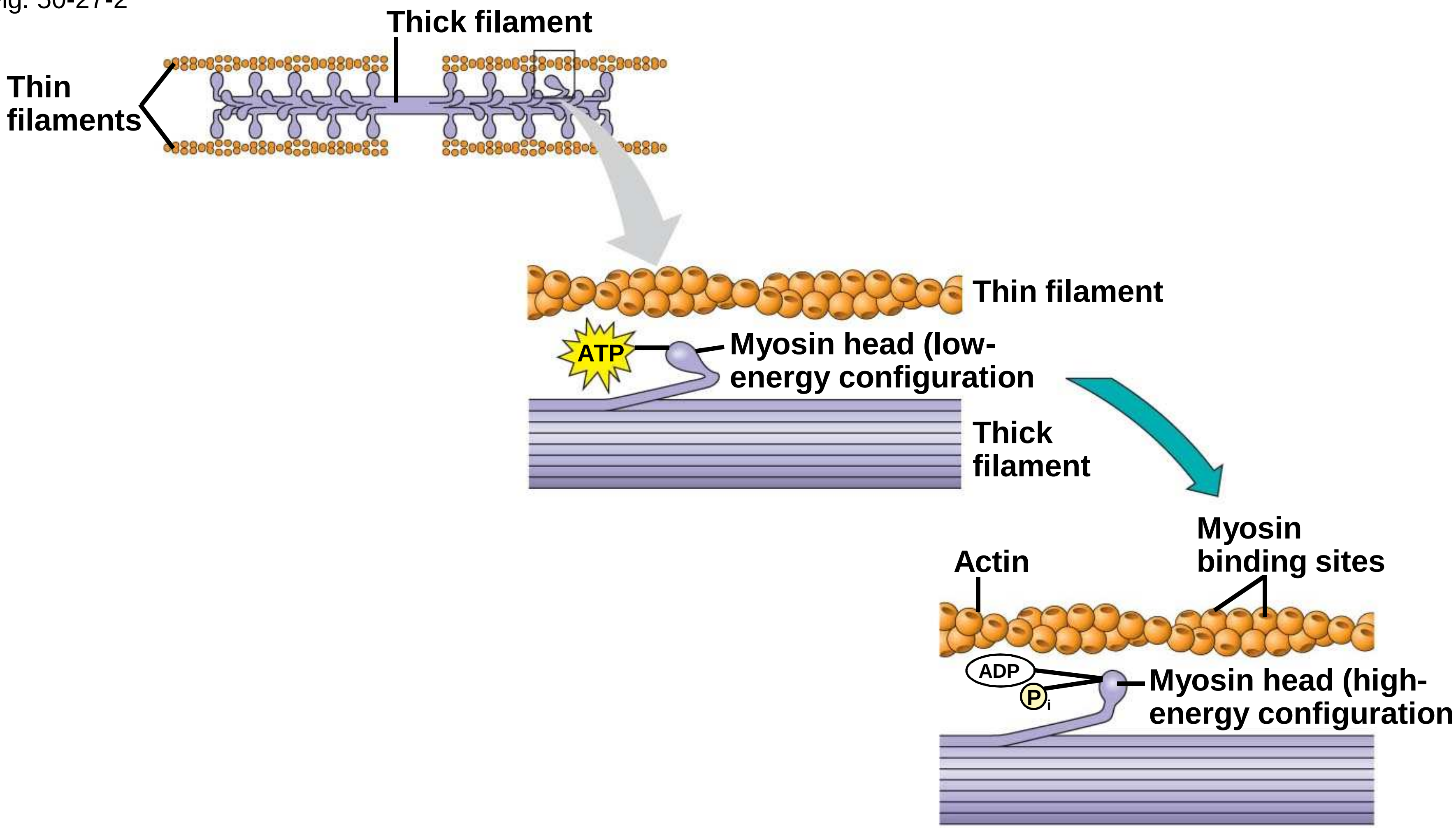
- The sliding of filaments is based on interaction between actin of the thin filaments and myosin of the thick filaments
- The “head” of a myosin molecule binds to an actin filament, forming a cross-bridge and pulling the thin filament toward the center of the sarcomere
- Glycolysis and aerobic respiration generate the ATP needed to sustain muscle contraction

Fig. 50-27-1



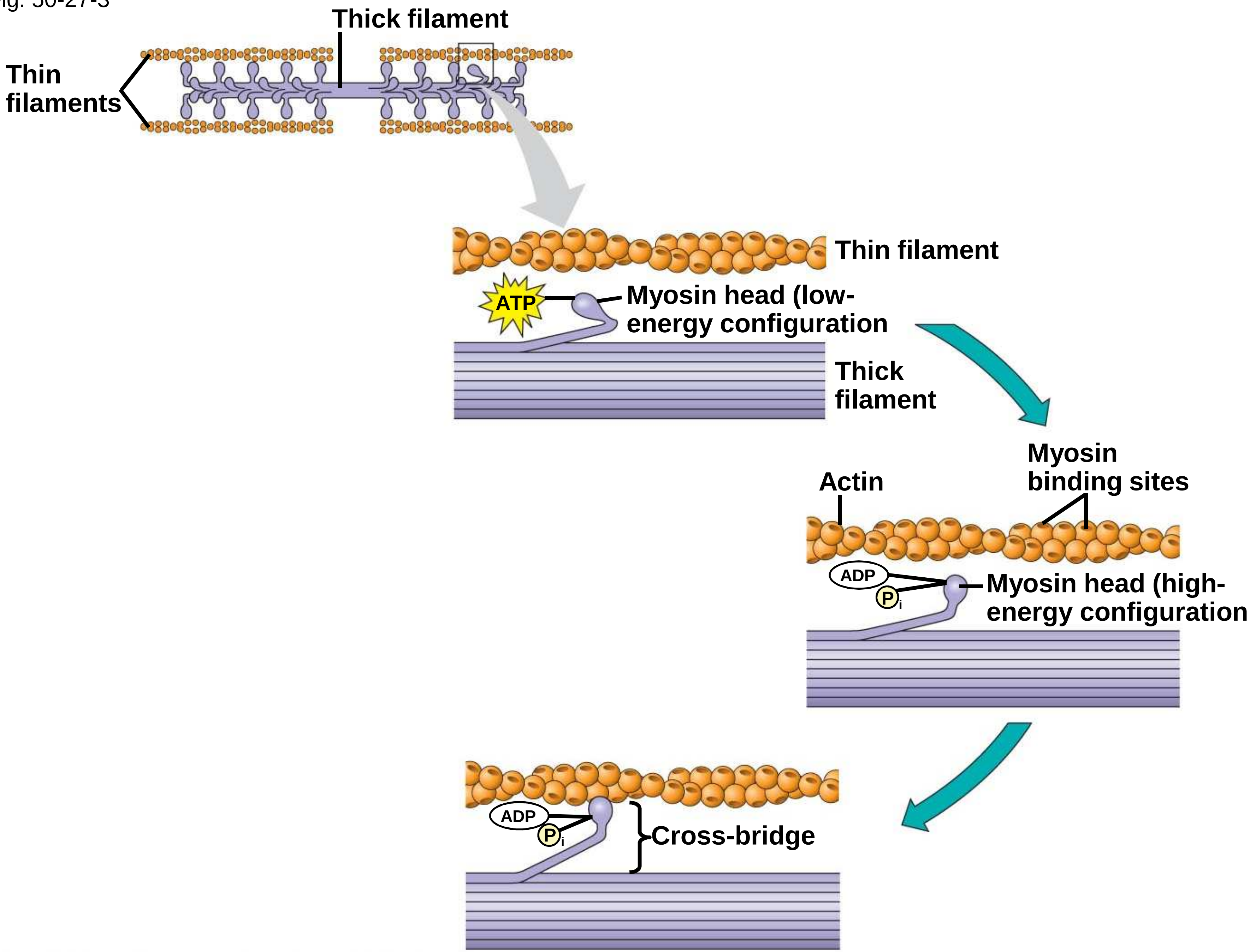
Thick filament
Thin
filaments
Thin filament
ATP
Myosin head (low-
energy configuration
Thick
filament

Fig. 50-27-2



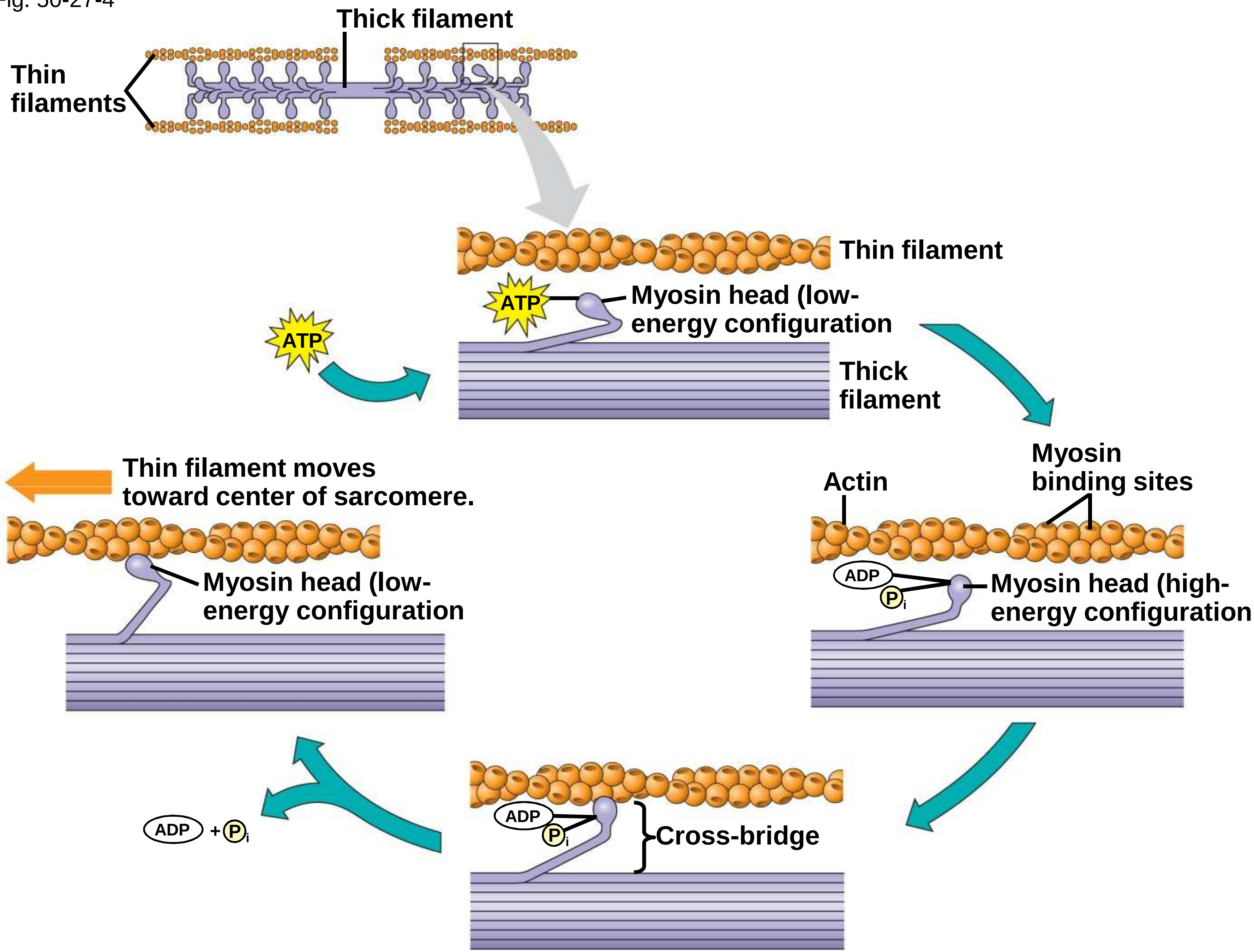
Thick filament
Thin filaments
Thin filament
ATP
Myosin head (low-energy configuration
Thick filament
Actin
Myosin binding sites
ADP
P_i
Myosin head (high-energy configuration

Fig. 50-27-3



Thick filament
Thin filaments
Thin filament
ATP
Myosin head (low-energy configuration
Thick filament
Actin
Myosin binding sites
ADP
P_i
Myosin head (high-energy configuration
ADP
P_i
Cross-bridge

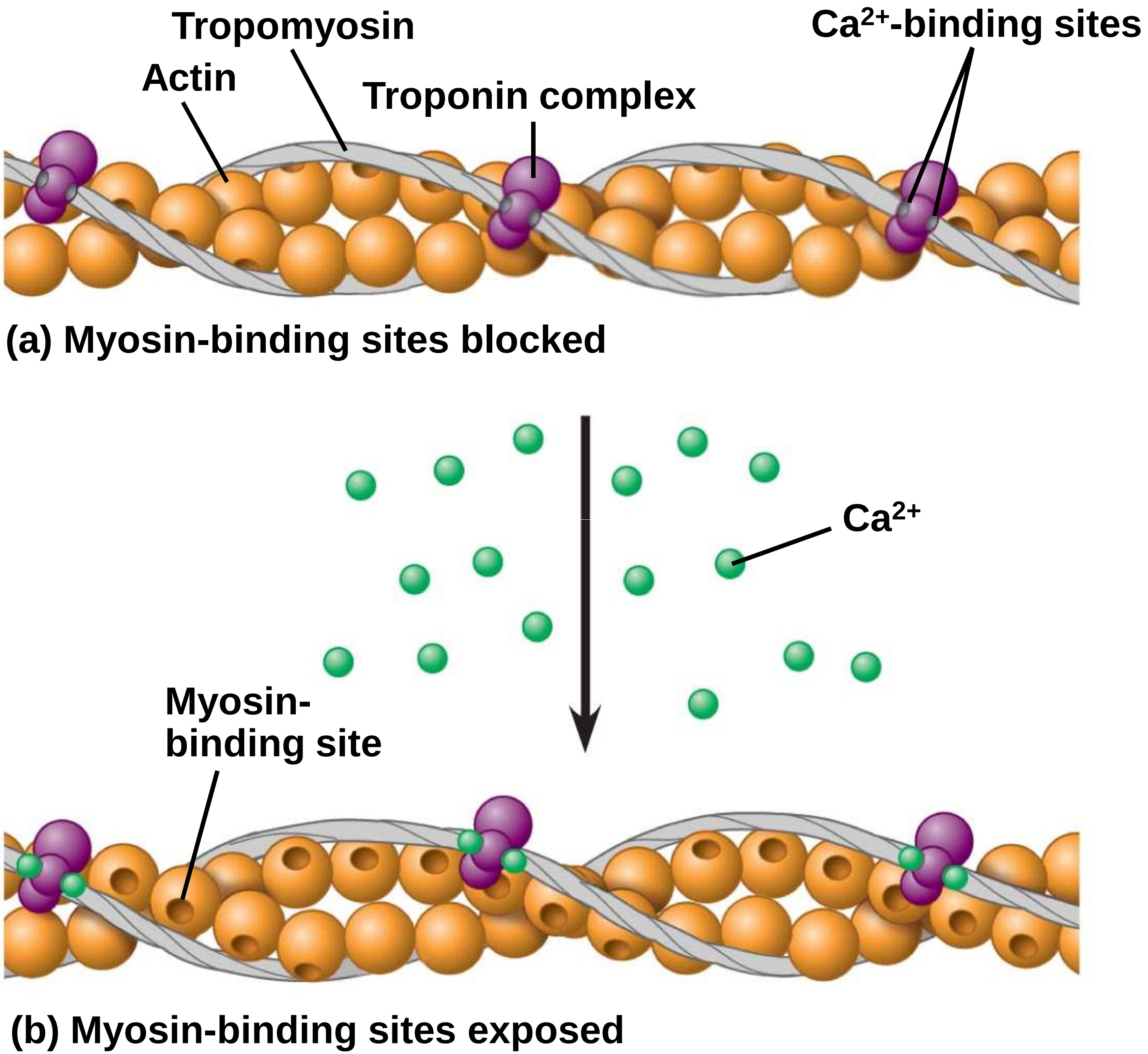
Fig. 50-27-4


Thick filament
Thin filaments
Thin filament
ATP
ATP
Myosin head (low-energy configuration
Thick filament
Actin
Myosin binding sites
ADP
P i
Myosin head (high-energy configuration
ADP
P i
Cross-bridge
ADP + P i
Thin filament moves toward center of sarcomere.
Myosin head (low-energy configuration

The Role of Calcium and Regulatory Proteins

- A skeletal muscle fiber contracts only when stimulated by a motor neuron
- When a muscle is at rest, myosin-binding sites on the thin filament are blocked by the regulatory protein **tropomyosin**

Fig. 50-28

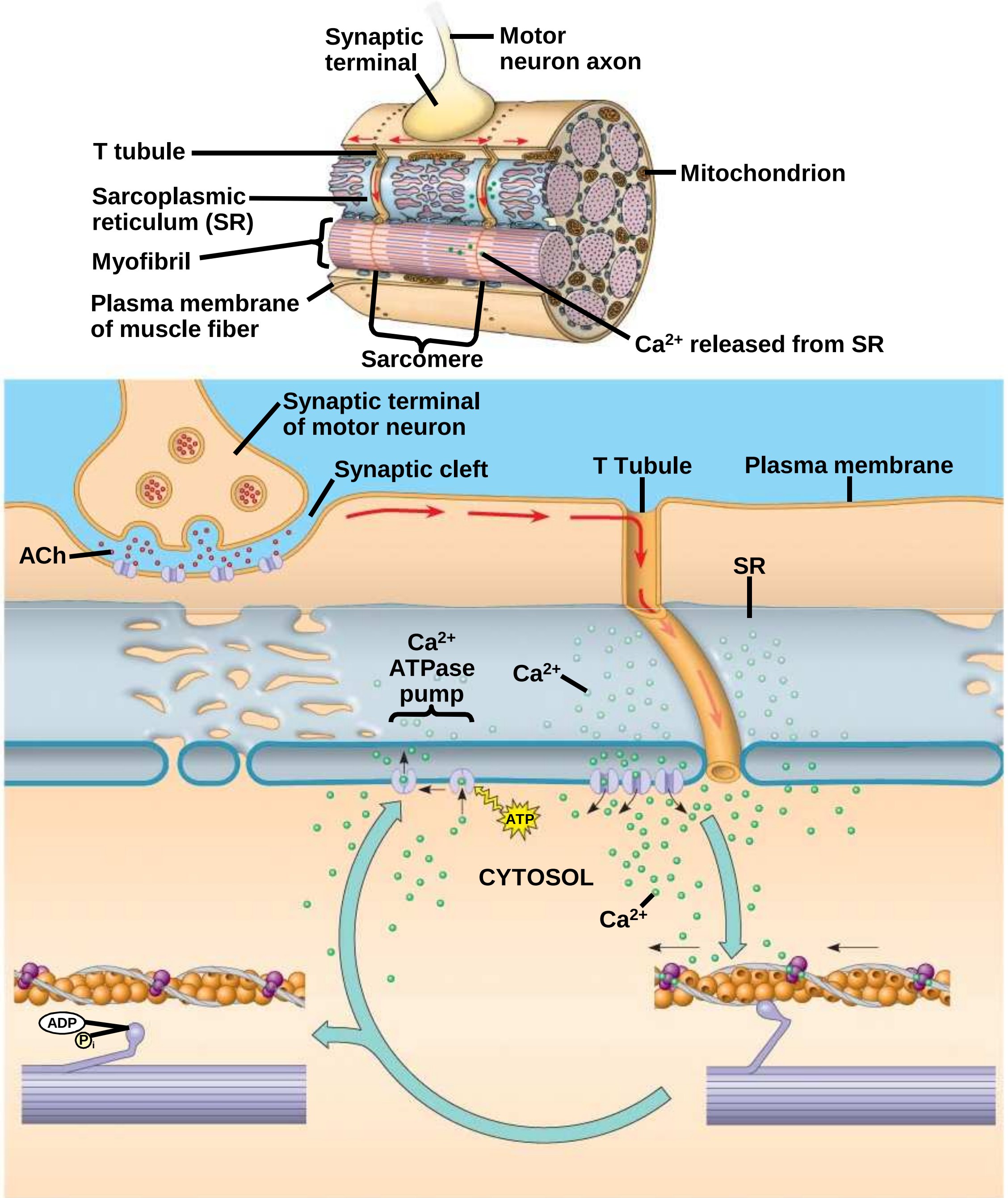


Tropomyosin
Actin
Troponin complex
Ca^{2+}-binding sites
(a) Myosin-binding sites blocked
Ca^{2+}
Myosin-
binding site
(b) Myosin-binding sites exposed

- For a muscle fiber to contract, myosin-binding sites must be uncovered
- This occurs when calcium ions (Ca^{2+}) bind to a set of regulatory proteins, the **troponin complex**
- Muscle fiber contracts when the concentration of Ca^{2+} is high; muscle fiber contraction stops when the concentration of Ca^{2+} is low

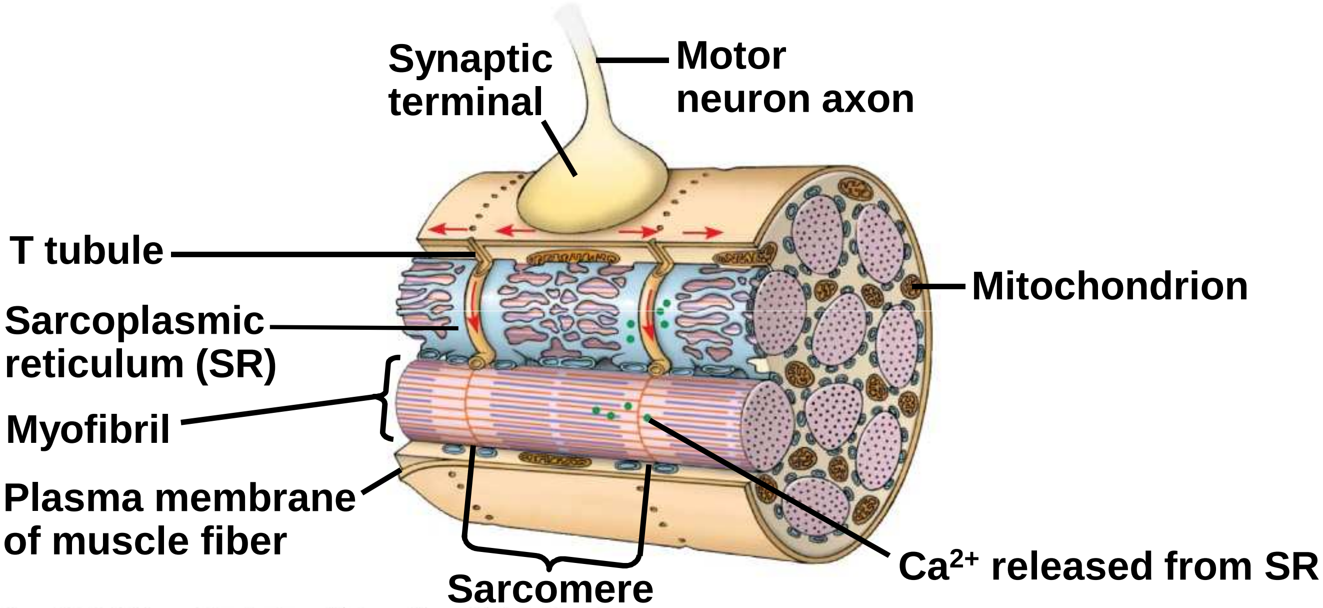
- The stimulus leading to contraction of a muscle fiber is an action potential in a motor neuron that makes a synapse with the muscle fiber

Fig. 50-29



Synaptic terminal
Motor neuron axon
T tubule
Sarcoplasmic reticulum (SR)
Mitochondrion
Myofibril
Plasma membrane of muscle fiber
Sarcomere
Ca^{2+} released from SR
Synaptic terminal of motor neuron
Synaptic cleft
T Tubule
Plasma membrane
ACh
SR
Ca^{2+} ATPase pump
Ca^{2+}
ATP
CYTOSOL
Ca^{2+}
ADP
P_i

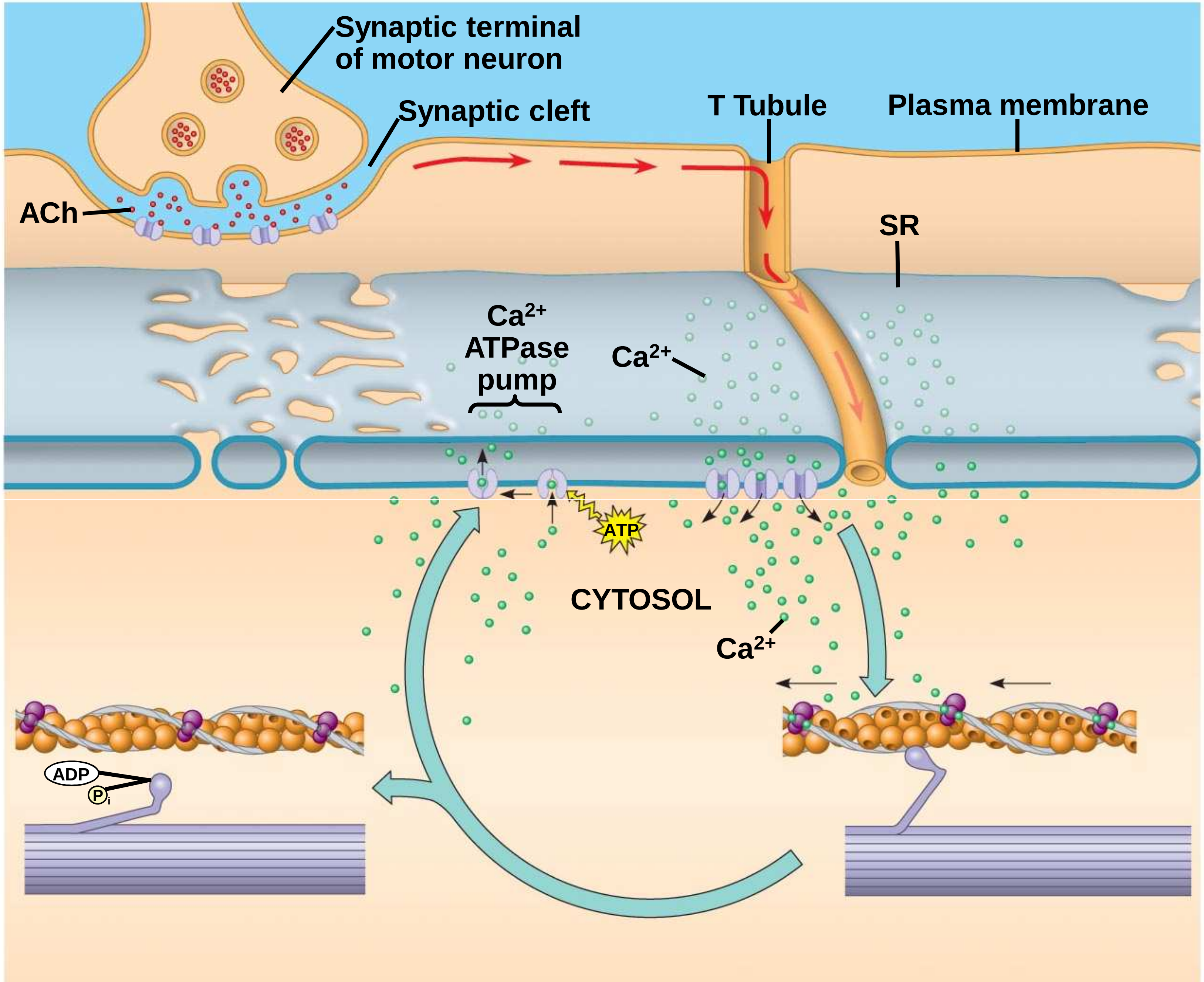
Fig. 50-29a



Synaptic terminal
Motor neuron axon
T tubule
Sarcoplasmic reticulum (SR)
Myofibril
Plasma membrane of muscle fiber
Sarcomere
Mitochondrion
Ca2+ released from SR

- The synaptic terminal of the motor neuron releases the neurotransmitter acetylcholine
- Acetylcholine depolarizes the muscle, causing it to produce an action potential

Fig. 50-29b



Synaptic terminal of motor neuron
Synaptic cleft
T Tubule
Plasma membrane
ACh
SR
Ca2+ ATPase pump
Ca2+
ATP
CYTOSOL
Ca2+
ADP
Pi

- Action potentials travel to the interior of the muscle fiber along **transverse (T) tubules**
- The action potential along T tubules causes the **sarcoplasmic reticulum (SR)** to release Ca^{2+}
- The Ca^{2+} binds to the troponin complex on the thin filaments
- This binding exposes myosin-binding sites and allows the cross-bridge cycle to proceed

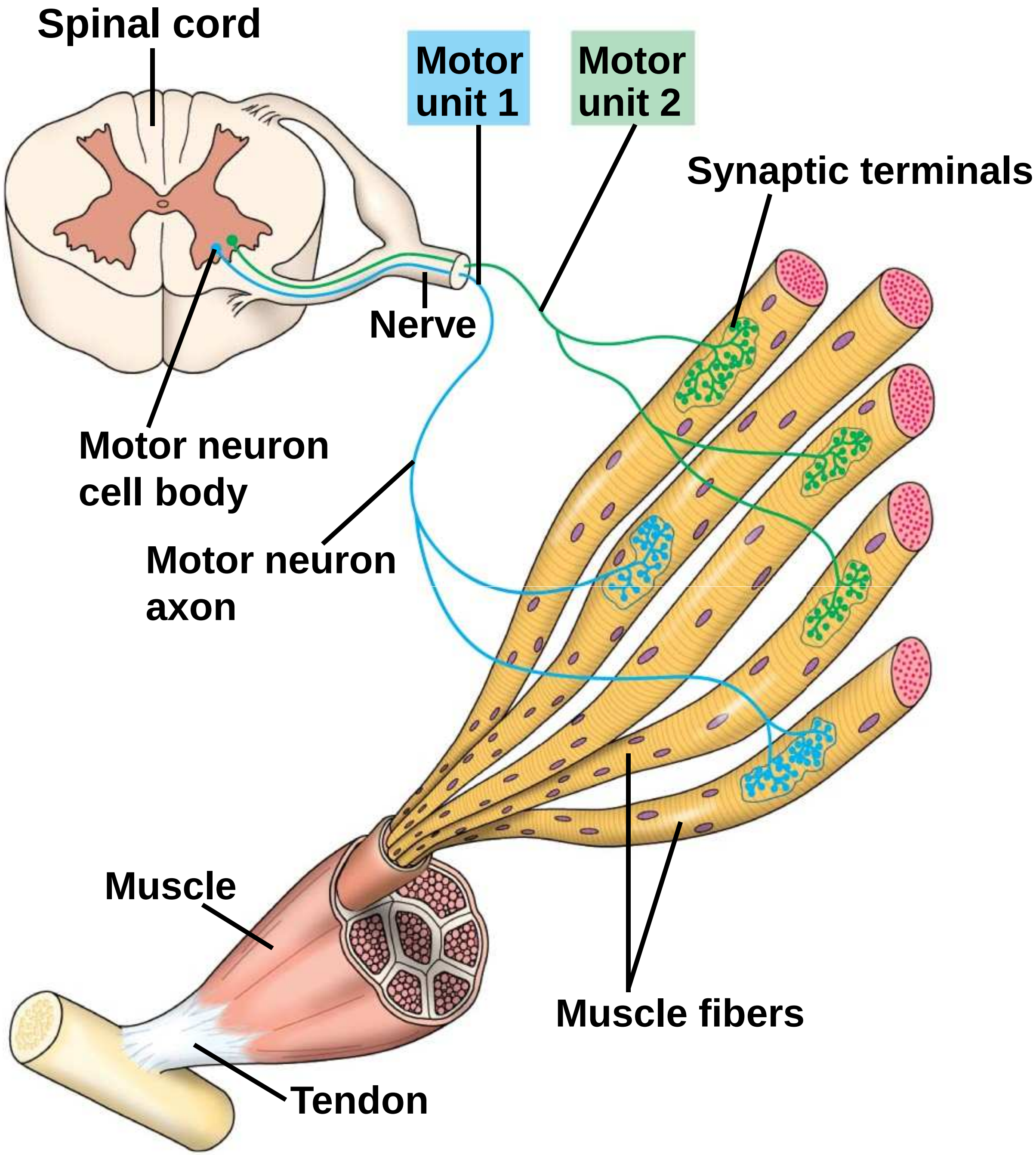
- Amyotrophic lateral sclerosis (ALS), formerly called Lou Gehrig's disease, interferes with the excitation of skeletal muscle fibers; this disease is usually fatal
- Myasthenia gravis is an autoimmune disease that attacks acetylcholine receptors on muscle fibers; treatments exist for this disease

Nervous Control of Muscle Tension

- Contraction of a whole muscle is graded, which means that the extent and strength of its contraction can be voluntarily altered
- There are two basic mechanisms by which the nervous system produces graded contractions:
  – Varying the number of fibers that contract
  – Varying the rate at which fibers are stimulated

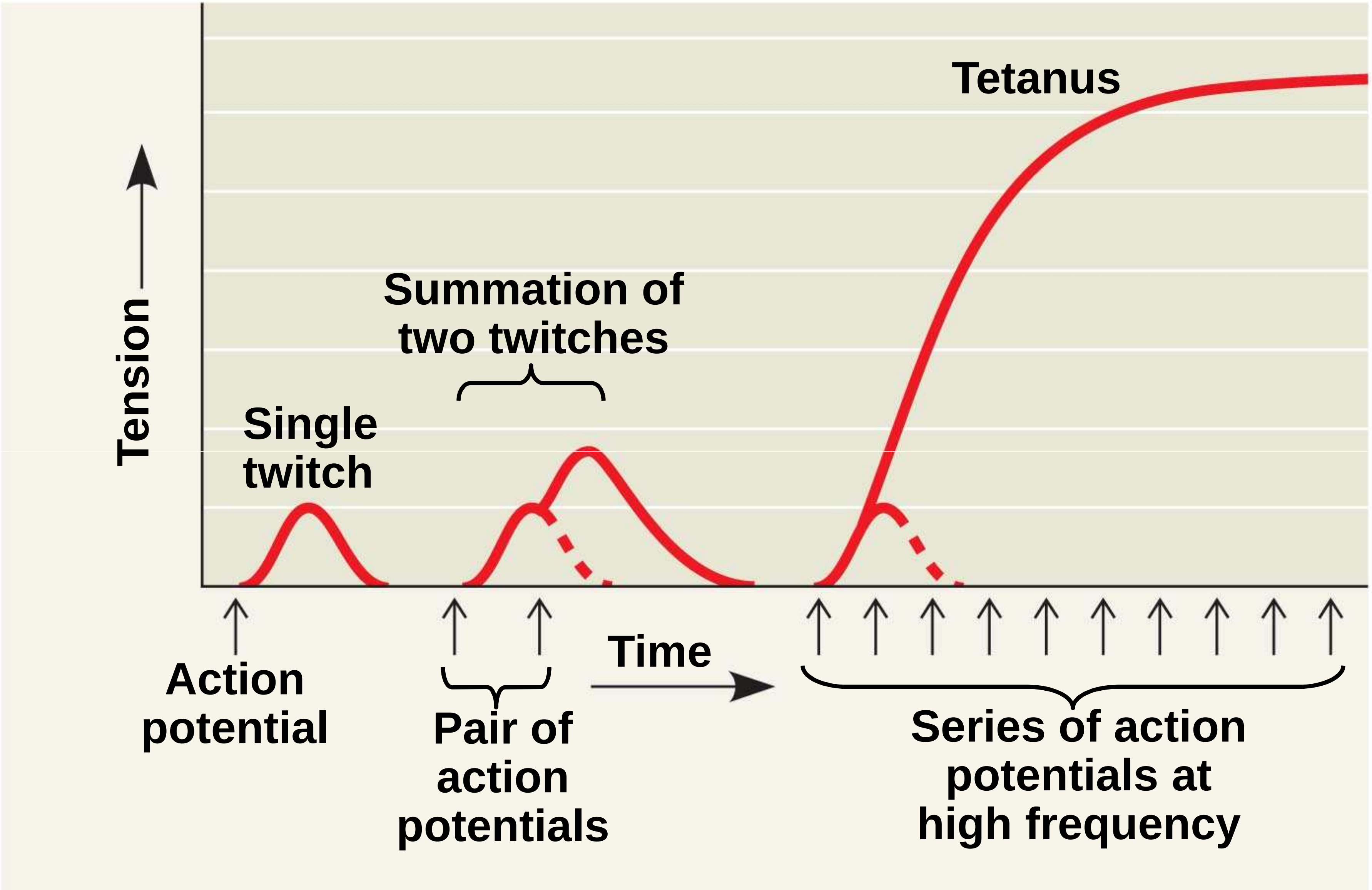
- In a vertebrate skeletal muscle, each branched muscle fiber is innervated by one motor neuron
- Each motor neuron may synapse with multiple muscle fibers
- A **motor unit** consists of a single motor neuron and all the muscle fibers it controls

Fig. 50-30


Spinal cord
Motor unit 1
Motor unit 2
Synaptic terminals
Nerve
Motor neuron cell body
Motor neuron axon
Muscle
Muscle fibers
Tendon

- **Recruitment** of multiple motor neurons results in stronger contractions
- A twitch results from a single action potential in a motor neuron
- More rapidly delivered action potentials produce a graded contraction by summation

Fig. 50-31


Tetanus
Summation of two twitches
Single twitch
Tension
Time
Action potential
Pair of action potentials
Series of action potentials at high frequency

- **Tetanus** is a state of smooth and sustained contraction produced when motor neurons deliver a volley of action potentials

Types of Skeletal Muscle Fibers

- Skeletal muscle fibers can be classified
  - As oxidative or glycolytic fibers, by the source of ATP
  - As fast-twitch or slow-twitch fibers, by the speed of muscle contraction

Oxidative and Glycolytic Fibers

- Oxidative fibers rely on aerobic respiration to generate ATP
- These fibers have many mitochondria, a rich blood supply, and much myoglobin
- **Myoglobin** is a protein that binds oxygen more tightly than hemoglobin does

- Glycolytic fibers use glycolysis as their primary source of ATP
- Glycolytic fibers have less myoglobin than oxidative fibers, and tire more easily
- In poultry and fish, light meat is composed of glycolytic fibers, while dark meat is composed of oxidative fibers

Fast-Twitch and Slow-Twitch Fibers

- **Slow-twitch fibers** contract more slowly, but sustain longer contractions
- All slow twitch fibers are oxidative
- **Fast-twitch fibers** contract more rapidly, but sustain shorter contractions
- Fast-twitch fibers can be either glycolytic or oxidative

- Most skeletal muscles contain both slow-twitch and fast-twitch muscles in varying ratios

Other Types of Muscle

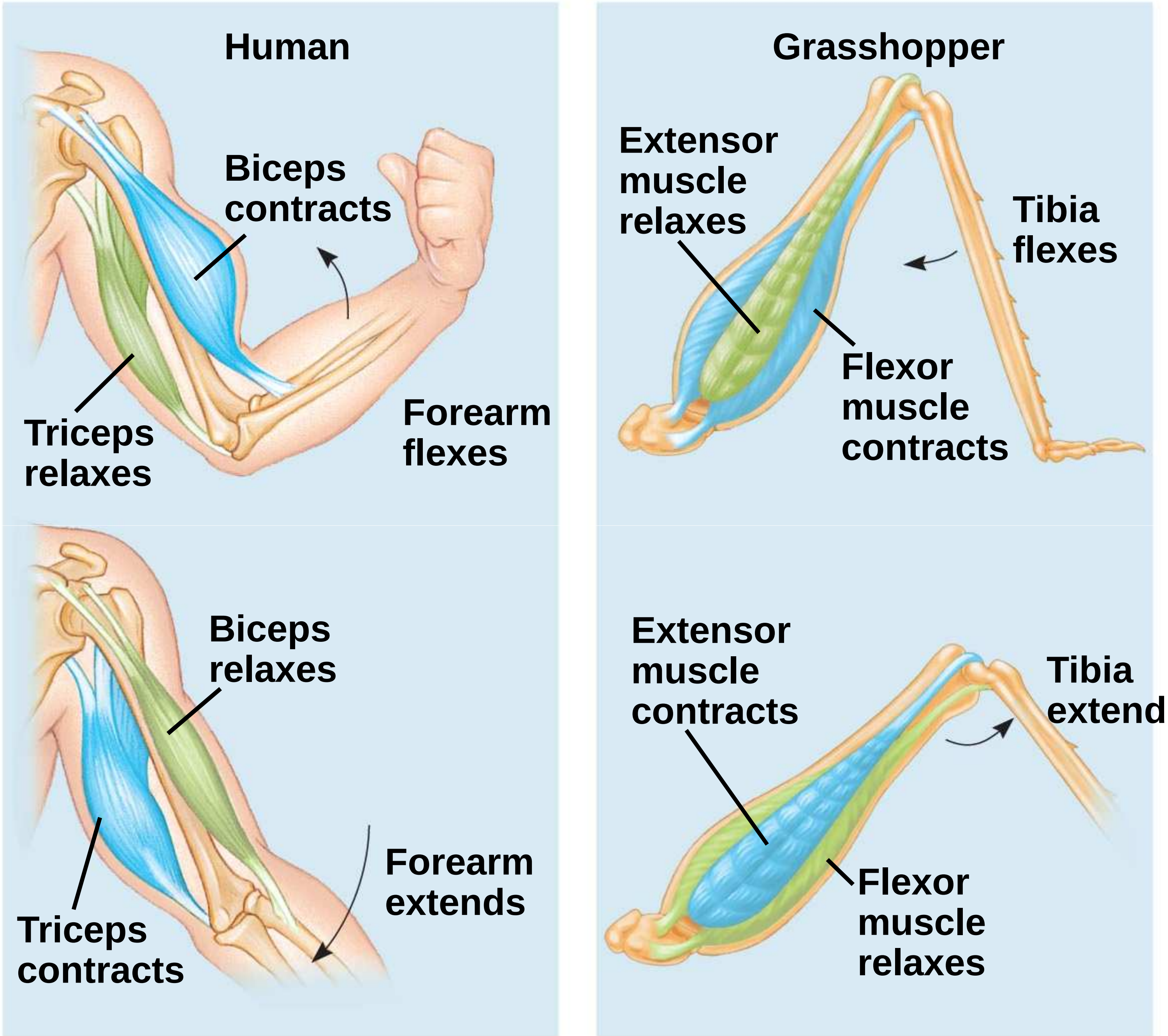
- In addition to skeletal muscle, vertebrates have cardiac muscle and smooth muscle
- **Cardiac muscle**, found only in the heart, consists of striated cells electrically connected by **intercalated disks**
- Cardiac muscle can generate action potentials without neural input

- In **smooth muscle**, found mainly in walls of hollow organs, contractions are relatively slow and may be initiated by the muscles themselves
- Contractions may also be caused by stimulation from neurons in the autonomic nervous system

Concept 50.6: Skeletal systems transform muscle contraction into locomotion

- Skeletal muscles are attached in antagonistic pairs, with each member of the pair working against the other
- The skeleton provides a rigid structure to which muscles attach
- Skeletons function in support, protection, and movement

Fig. 50-32



Human
Grasshopper
Biceps contracts
Triceps relaxes
Forearm flexes
Extensor muscle relaxes
Tibia flexes
Flexor muscle contracts
Biceps relaxes
Triceps contracts
Forearm extends
Extensor muscle contracts
Tibia extends
Flexor muscle relaxes