Department of Veterinary Physiology

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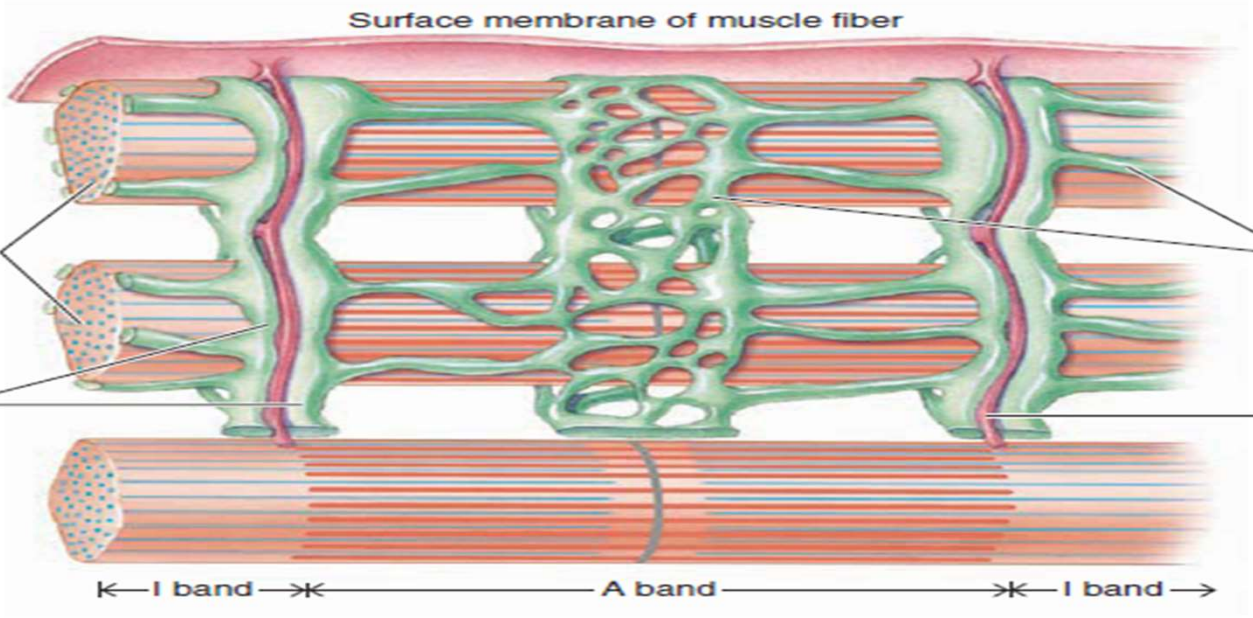
B.V.Sc. & A.H.
1st Year (2023-24)

पशुधनं नित्यं सर्वलोकोपकारकम्।

Muscle physiology-1



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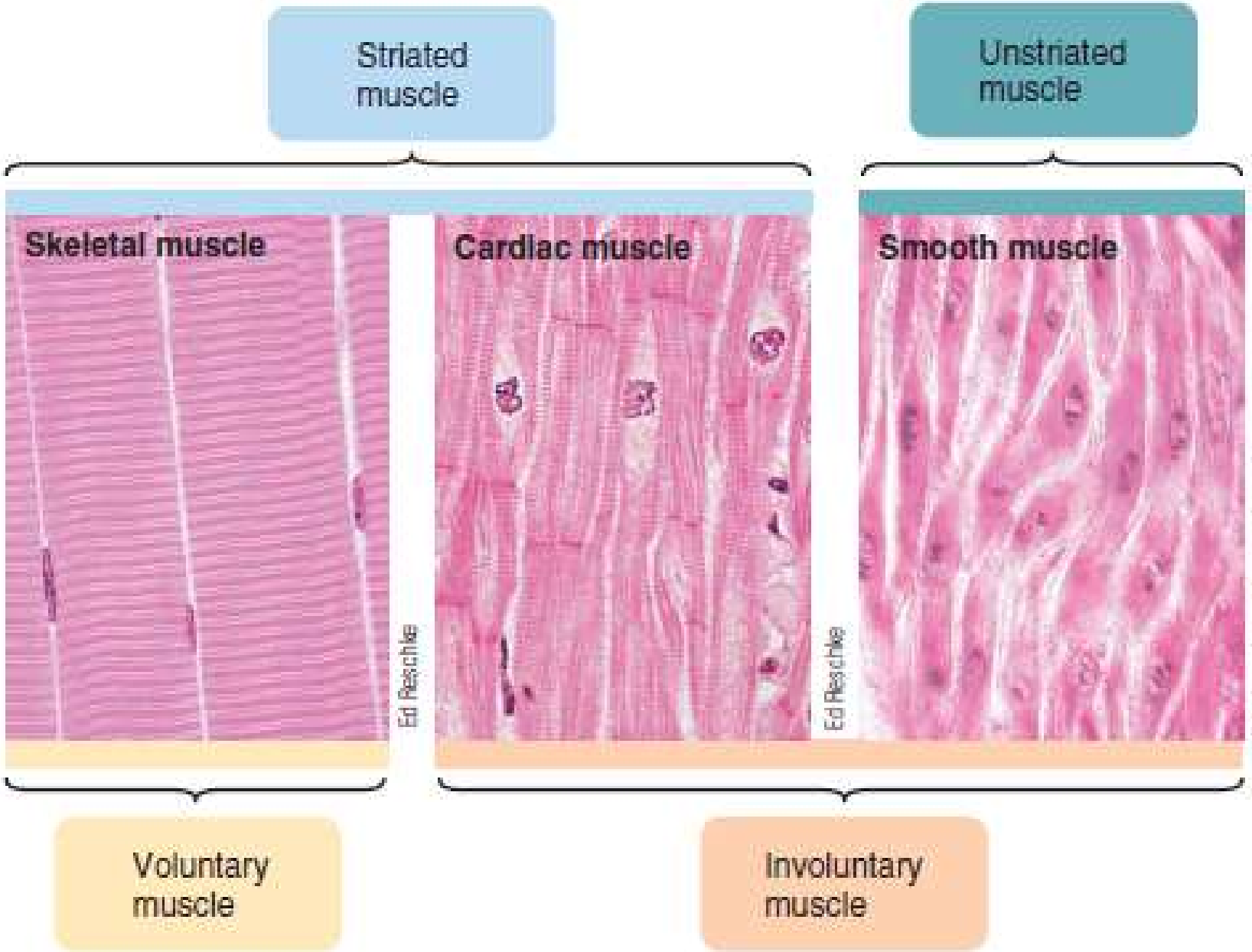

Striated muscle
Unstriated muscle
Skeletal muscle
Cardiac muscle
Smooth muscle
Ed Reschke
Ed Reschke
Biophoto/Photo Researchers, Inc.
Voluntary muscle
Involuntary muscle

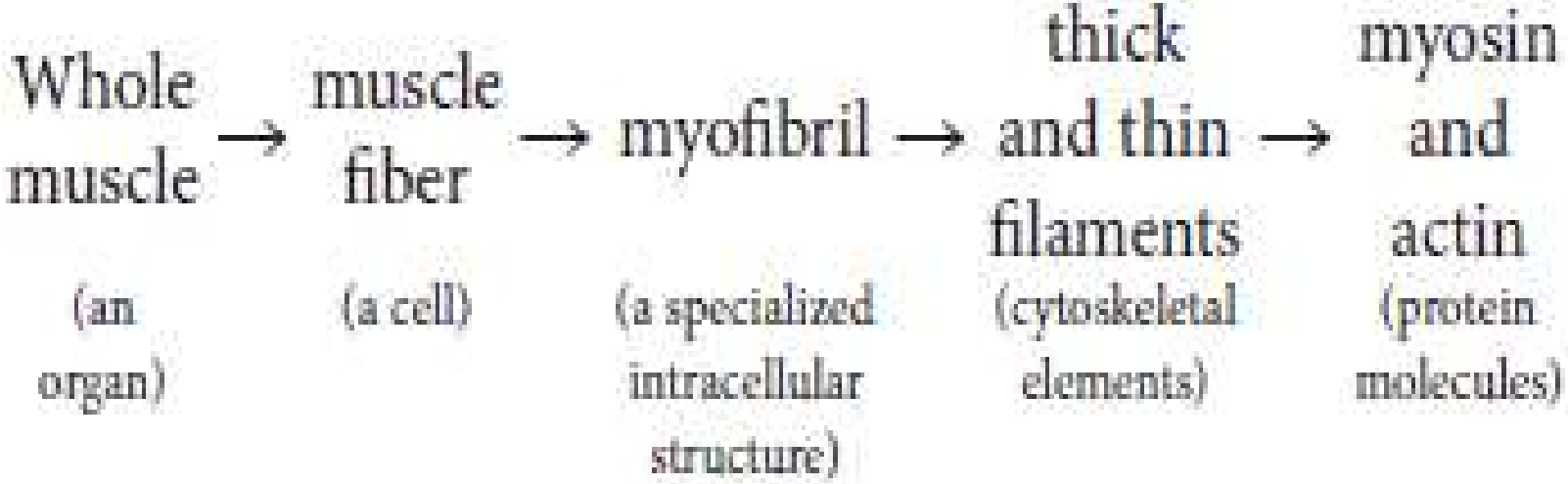
Skeletal muscle fibers are striated by a highly organized internal arrangement

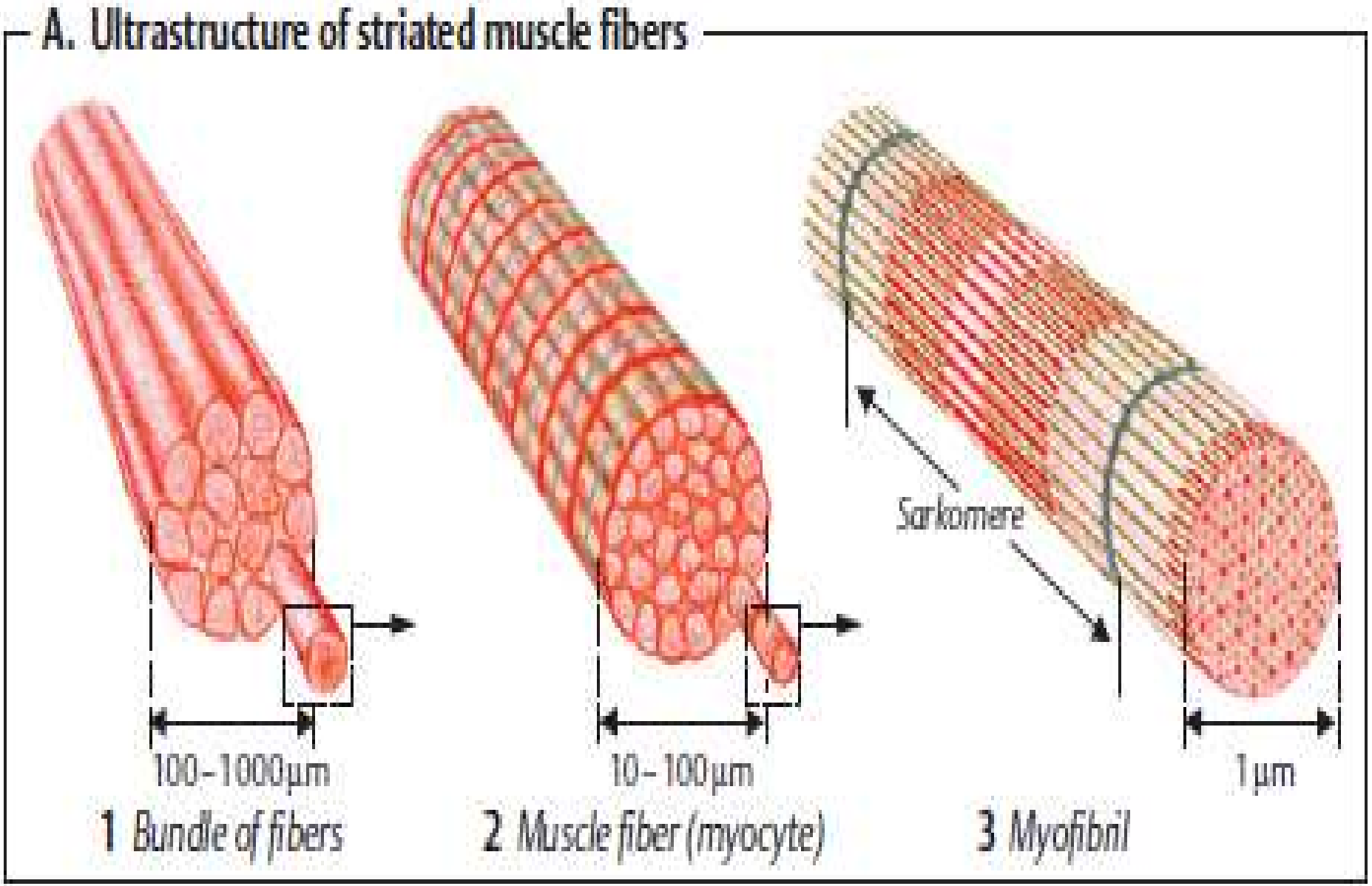
A single skeletal muscle cell, known as a ***muscle fiber.***

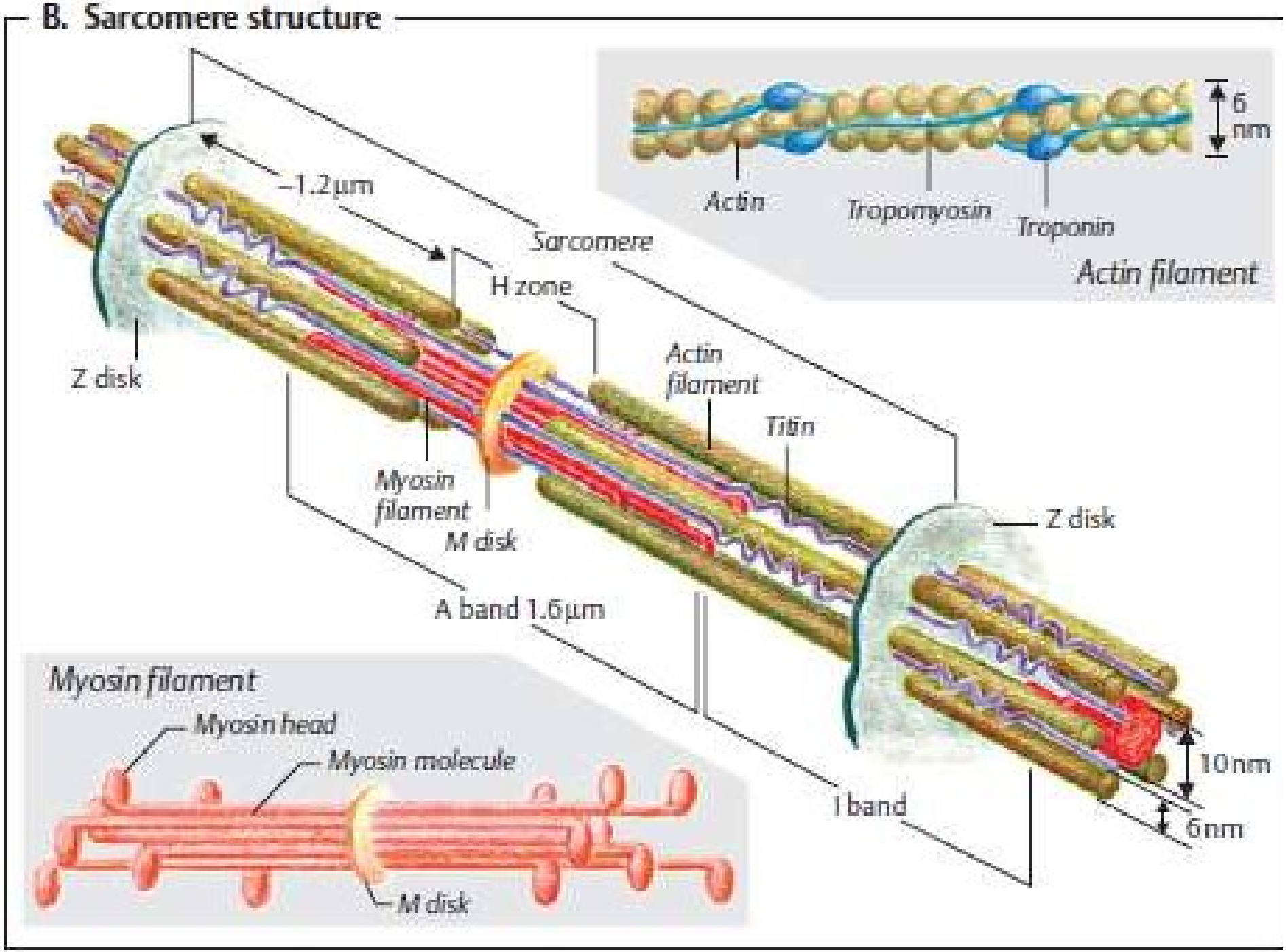
A skeletal muscle consists of a number of muscle fibers lying parallel to one another and bundled together by connective tissue.

The predominant structural feature of a skeletal muscle fiber is numerous ***myofibrils****.*

These specialized contractile elements, which constitute 80% of the volume of the muscle fiber, are cylindrical intracellular structures 1 mm in diameter that extend the entire length of the muscle fiber.


Whole muscle
(an organ)
muscle fiber
(a cell)
myofibril
(a specialized intracellular structure)
thick and thin filaments
(cytoskeletal elements)
myosin and actin
(protein molecules)


A. Ultrastructure of striated muscle fibers
Sarkomere
100–1000µm
10–100µm
1µm
1 Bundle of fibers
2 Muscle fiber (myocyte)
3 Myofibril


B. Sarcomere structure
~1.2 µm
Sarcomere
H zone
Z disk
Actin filament
Titin
Myosin filament
M disk
A band 1.6µm
I band
Z disk
10 nm
6 nm
6 nm
Actin
Tropomyosin
Troponin
Actin filament
Myosin filament
Myosin head
Myosin molecule
M disk

A AND I BANDS

Viewed with an electron microscope, a myofibril

displays alternating dark bands (the A bands) and light bands (the I bands)

*An **A band** is made up of a stacked set of thick filaments along with the portions of the thin filaments that overlap on both ends of the thick filaments.*

The thick filaments lie only within the A band and extend its entire width; that is, the two ends of the thick filaments within a stack define the outer limits of a given A band.

The lighter area within the middle of the A band, where the thin filaments do not reach, is the ***H zone****.*

Only the central portions of the thick filaments are found in this region.

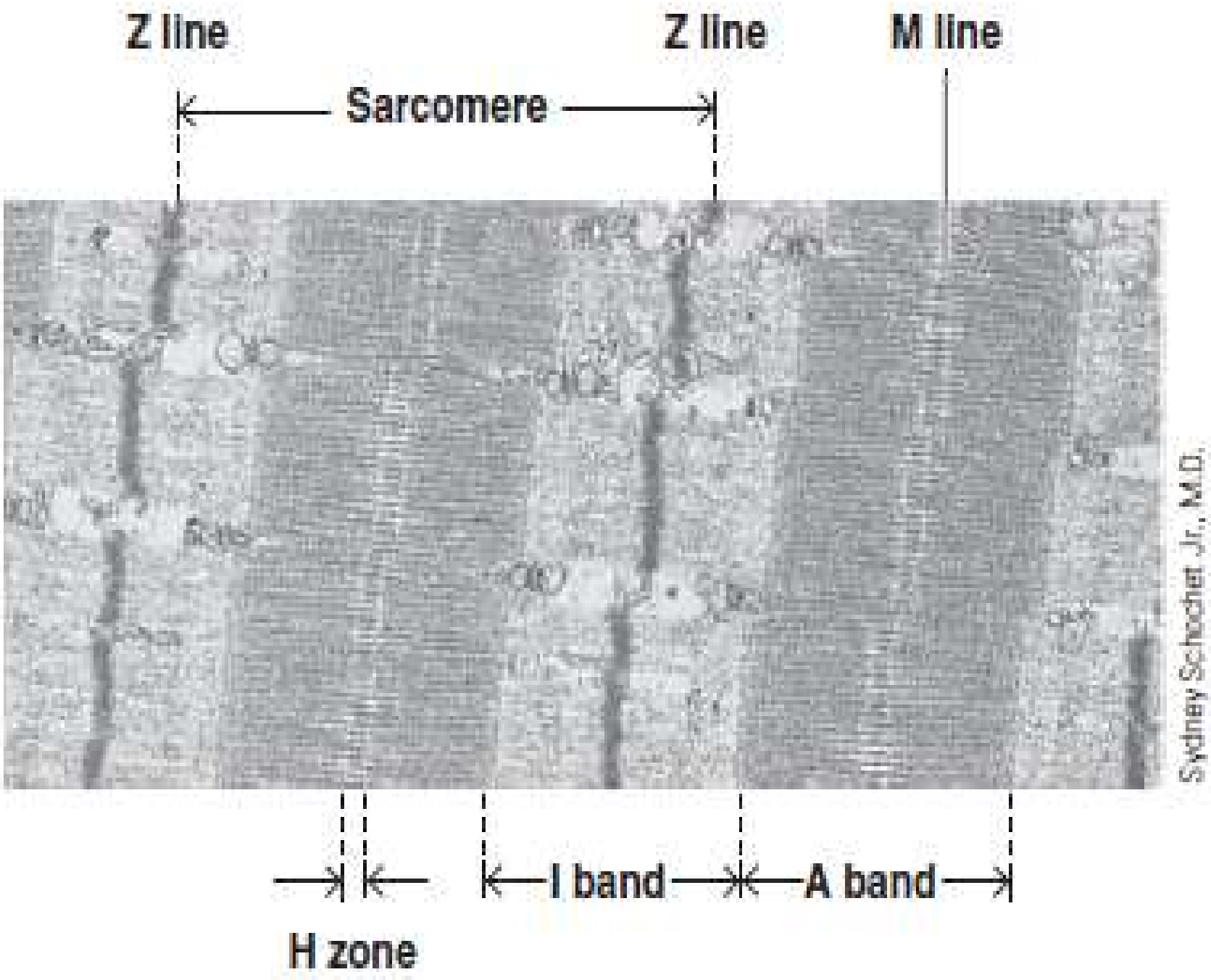
A system of supporting proteins holds the thick filaments together vertically within each stack.

*These proteins can be seen as the **M line**, which extends vertically down the middle of the A band within the center of the H zone.*

*An **I band** consists of the remaining portion of the thin filaments that do not project into the A band.*

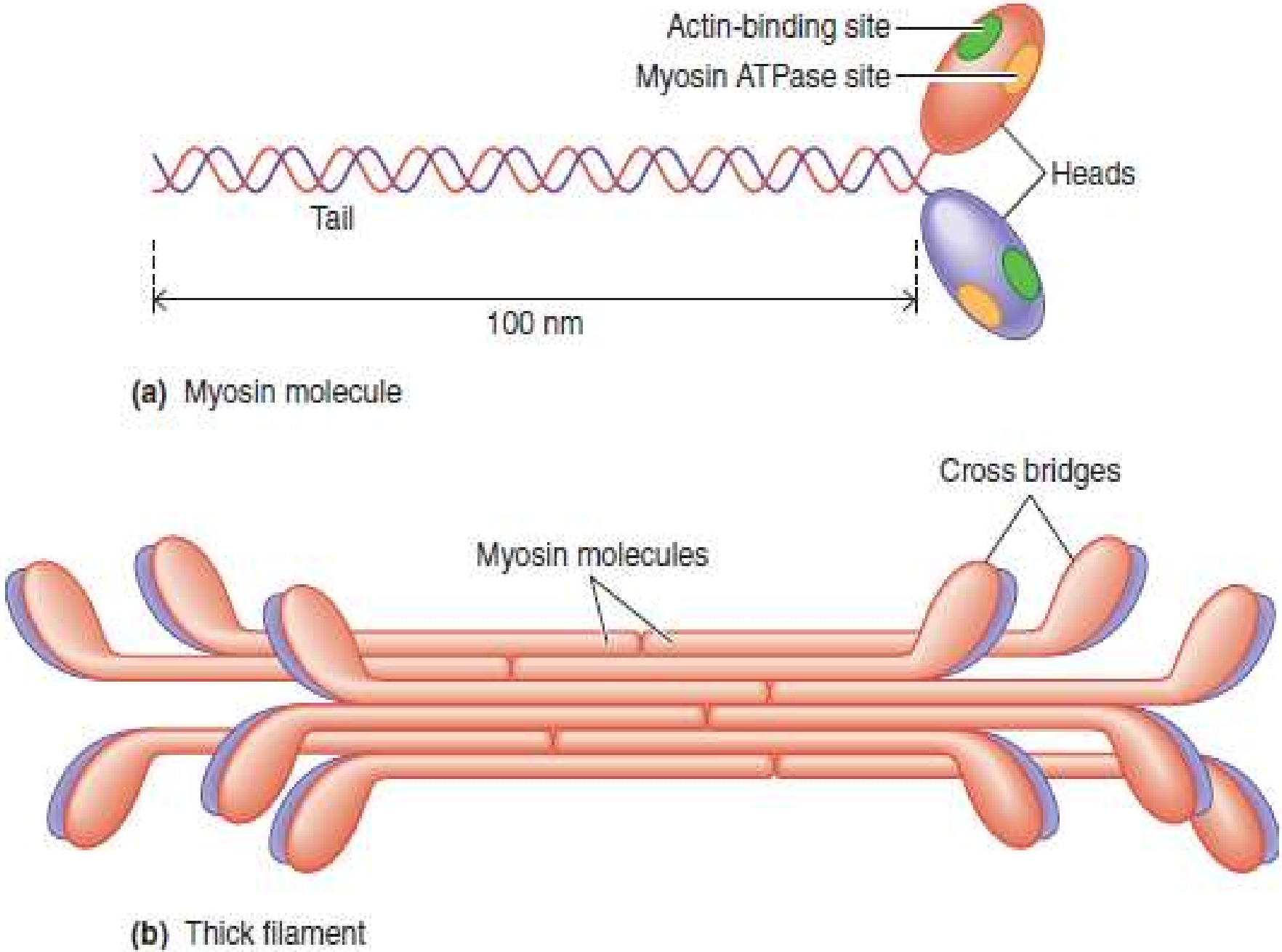
*Visible in the middle of each I band is a dense, vertical **Z line**.*

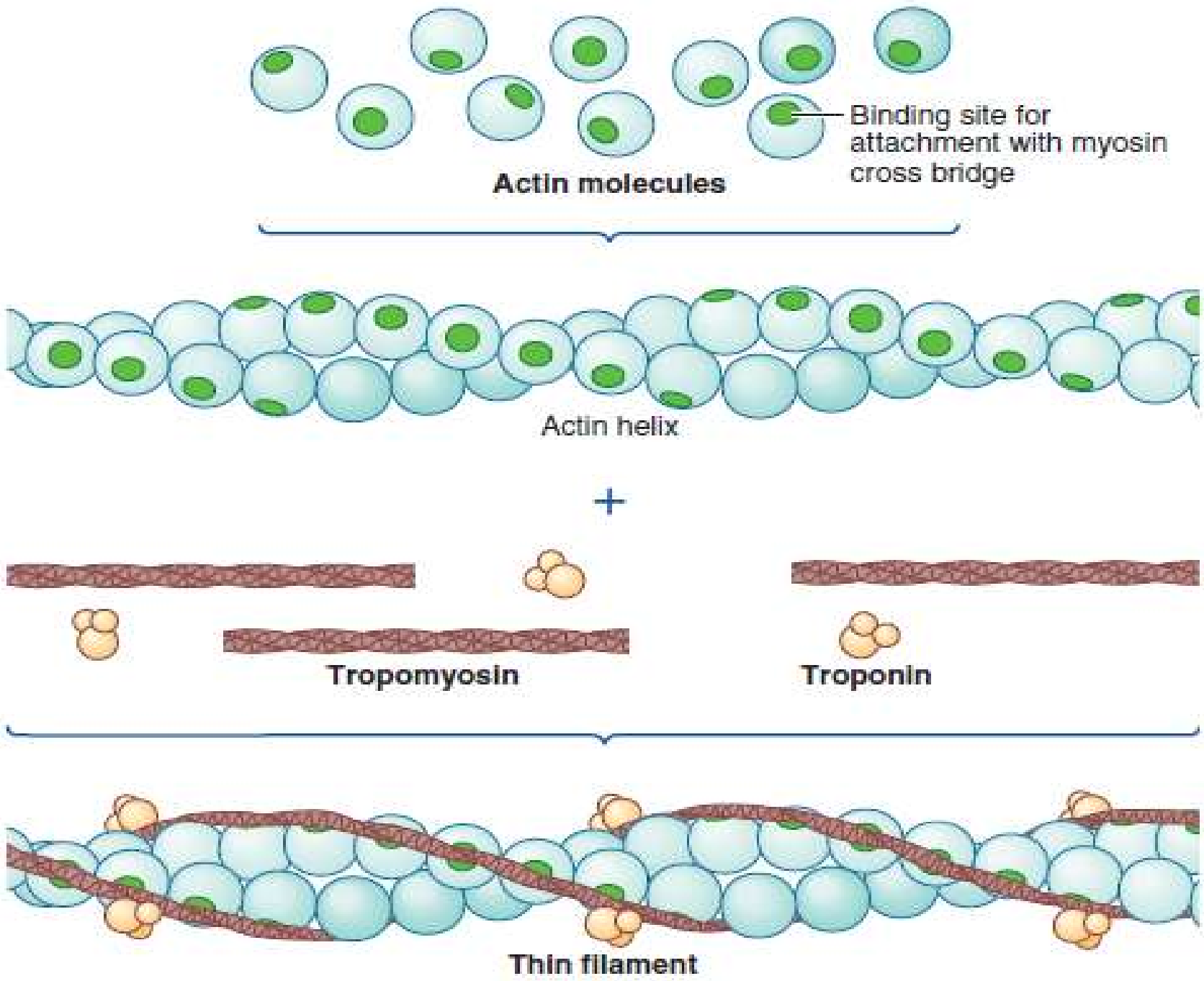
*The area between two Z lines is called a **sarcomere**, which is the functional unit of skeletal muscle.*


Z line
Z line
M line
Sarcomere
I band
A band
H zone
Sydney Schachet Jr., M.D.

Molecular Basis of Skeletal Muscle Contraction

Cross-bridge interaction between actin and myosin brings about muscle contraction by means of the sliding filament mechanism.


Actin-binding site
Myosin ATPase site
Heads
Tail
100 nm
(a) Myosin molecule
Cross bridges
Myosin molecules
(b) Thick filament


Binding site for attachment with myosin cross bridge
Actin molecules
Actin helix
+
Tropomyosin
Troponin
Thin filament

SLIDING FILAMENT MECHANISM

The thin filaments on each side of a sarcomere slide inward over the stationary thick filaments toward the A band's center during contraction.

As they slide inward, the thin filaments pull the Z lines to which they are attached closer together, so the sarcomere shortens.

As all the sarcomeres throughout the muscle fiber's length shorten simultaneously, the entire fiber shortens.

This is the ***sliding filament mechanism of muscle contraction*****.**

POWER STROKE

The myosin heads or cross bridges "walk" along an actin filament to pull it inward relative to

the stationary thick filament.

The two myosin heads of each myosin molecule act independently, with only one head attaching to actin at a given time.

When myosin and actin make contact at a cross bridge, the bridge changes shape, bending

45 inward as if it were on a hinge, “stroking” toward the center of the sarcomere.

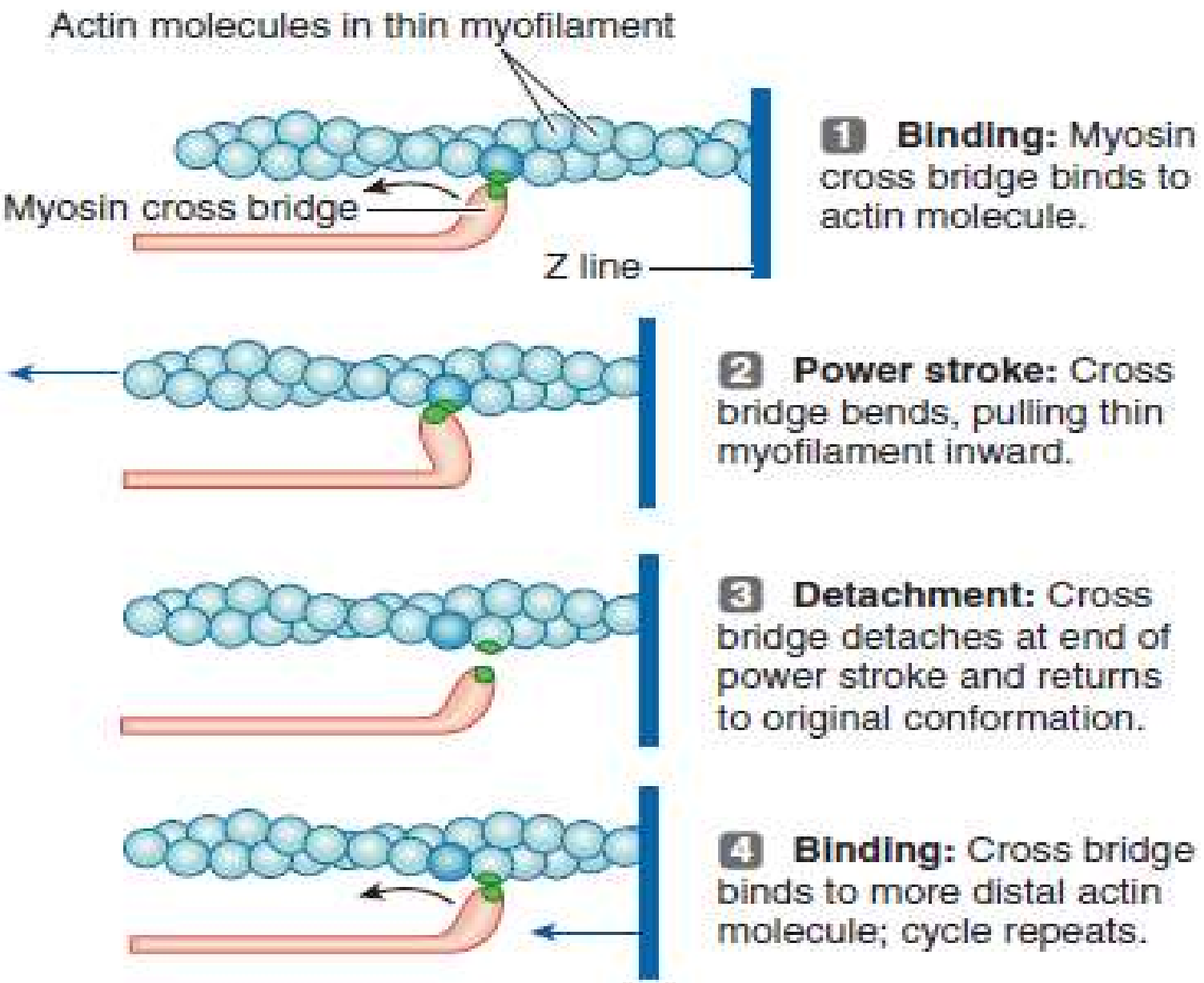
This so-called ***power stroke of a cross***

bridge *pulls inward the thin filament to which it is*

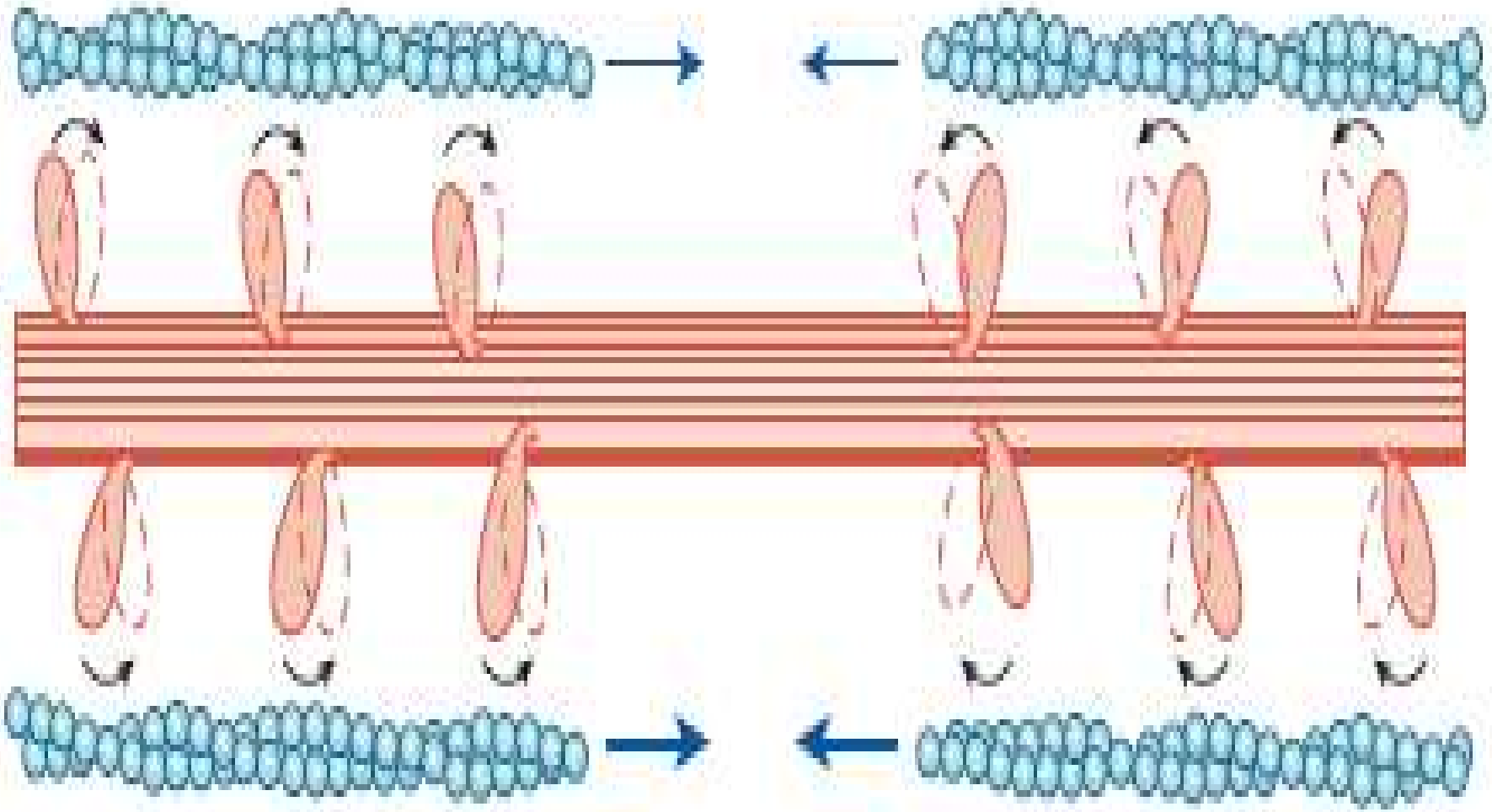
attached.

A single power stroke pulls the thin filament inward only a small percentage of the total shortening distance.

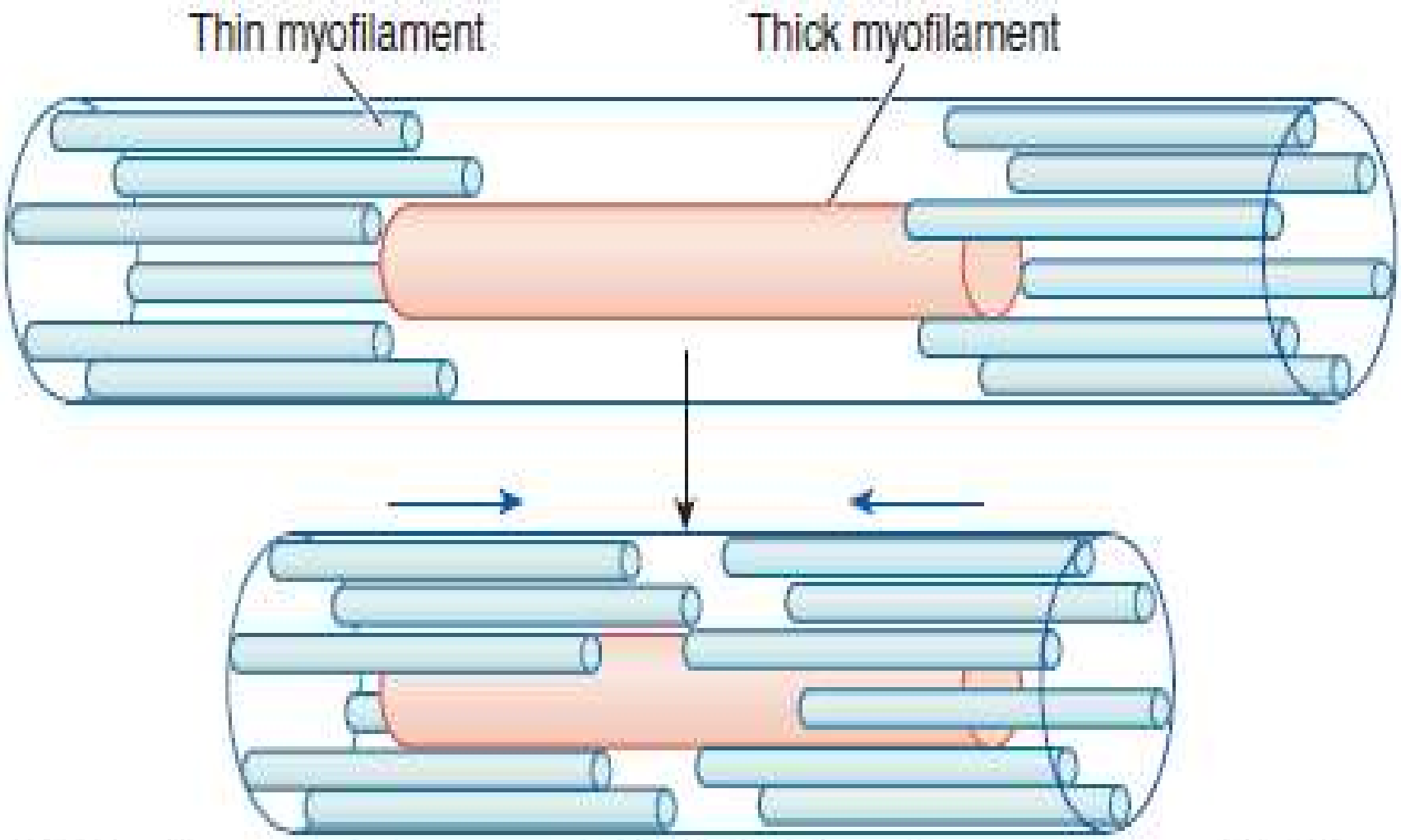
Repeated cycles of cross-bridge binding and bending complete the shortening.



(a) Single cross-bridge cycle



(b) All cross-bridge stroking directed toward center of thick filament



(c) Simultaneous pulling inward of all six thin filaments surrounding a thick filament

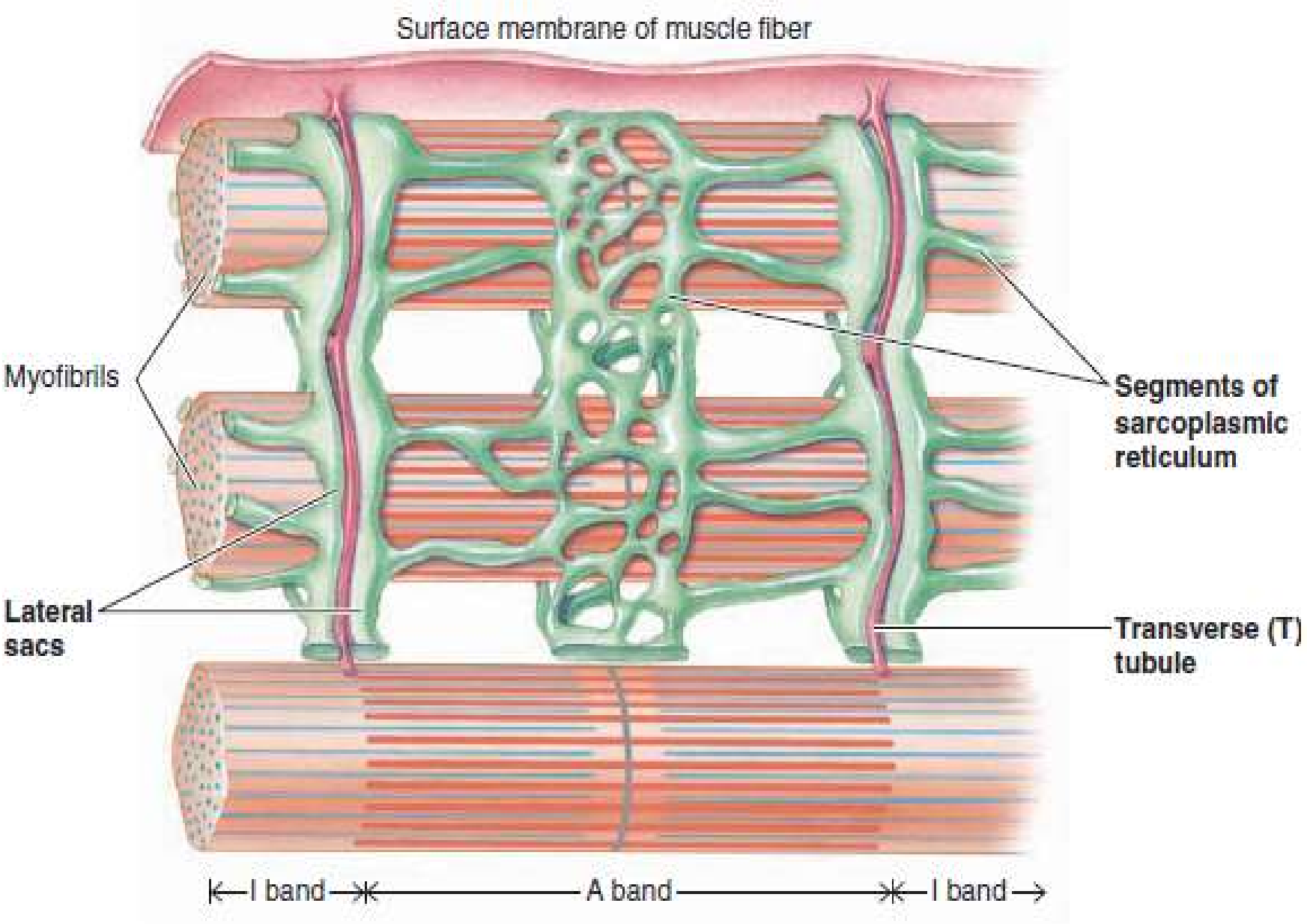
*The term **excitation–contraction coupling refers to** the series of events linking muscle excitation (the presence of an action potential in a muscle fiber) to muscle contraction (crossbridge activity that causes the thin filaments to slide closer together to produce sarcomere shortening).*

Calcium is the link between excitation and contraction

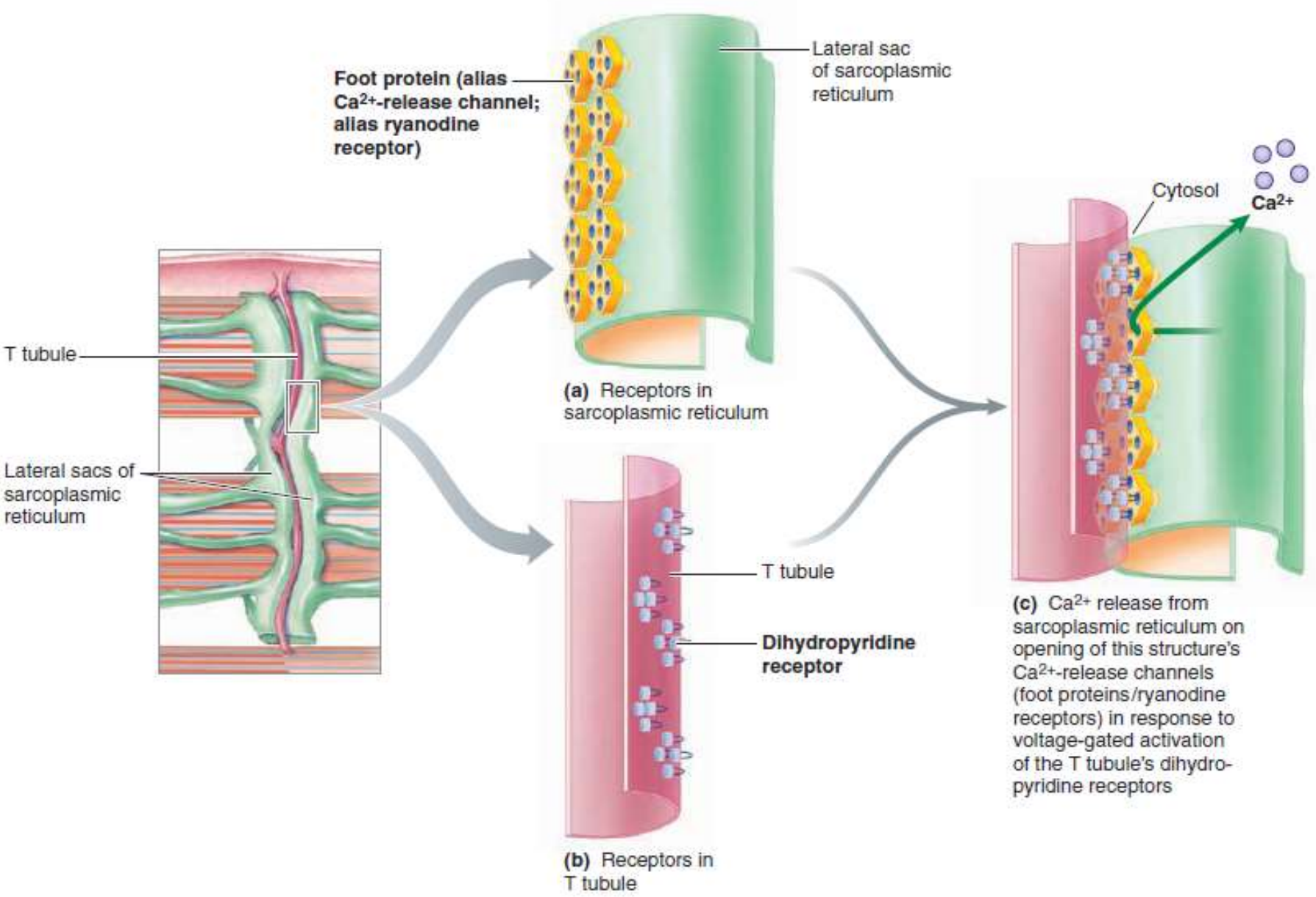
Skeletal muscles are stimulated to contract by release of acetylcholine (ACh) at neuromuscular junctions between motor neuron terminal buttons and muscle fibers.

Recall that binding of ACh with the motor end plate of a muscle fiber brings about permeability changes in the muscle fiber, resulting in an action potential that is conducted over the entire surface of the muscle cell membrane .

Two membranous structures within the muscle fiber play an important role in linking this excitation to contraction ***transverse tubules*** *and the* ***sarcoplasmic reticulum****.*


Surface membrane of muscle fiber
Myofibrils
Lateral sacs
Segments of sarcoplasmic reticulum
Transverse (T) tubule
I band
A band
I band

RELEASE OF CALCIUM FROM THE SARCOPLASMIC RETICULUM



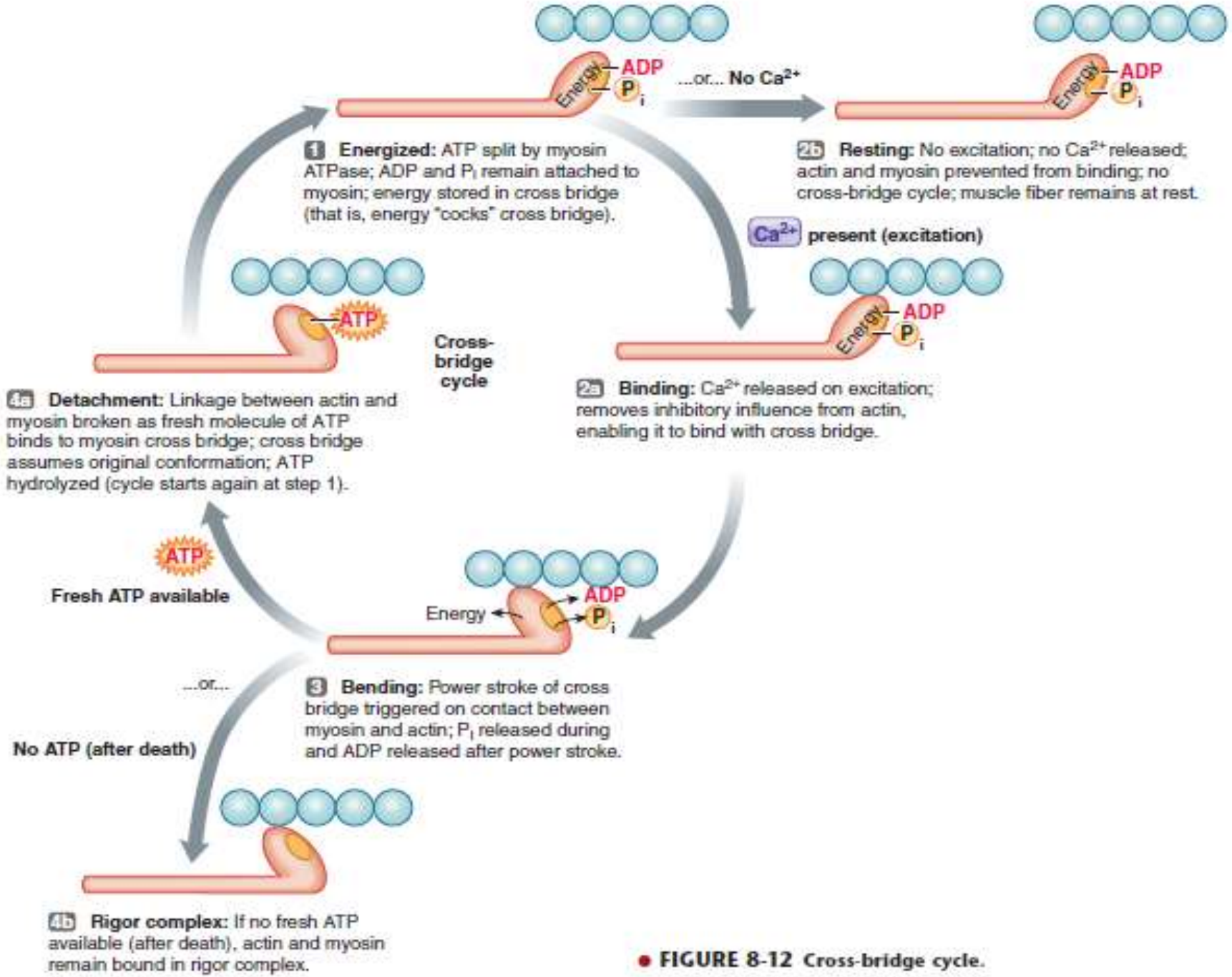
ATP-POWERED CROSS-BRIDGE CYCLING

The myosin cross bridge has two special sites, an actin-binding site and an ATPase site.

The latter is an enzymatic site that can bind the energy carrier adenosine triphosphate (ATP) and split it into adenosine diphosphate (ADP) and inorganic phosphate (Pi), yielding energy in the process.

The breakdown of ATP occurs on the myosin cross bridge before the bridge ever links with an actin molecule.

The ADP and Pi remain tightly bound to the myosin, and the generated energy is stored within the cross bridge to produce a high energy form of myosin.



● **FIGURE 8-12** Cross-bridge cycle.

Skeletal Muscle Mechanics

Each muscle is sheathed by connective tissue that penetrates from the surface into the muscle to envelop each individual fiber and divide the muscle into columns or bundles.

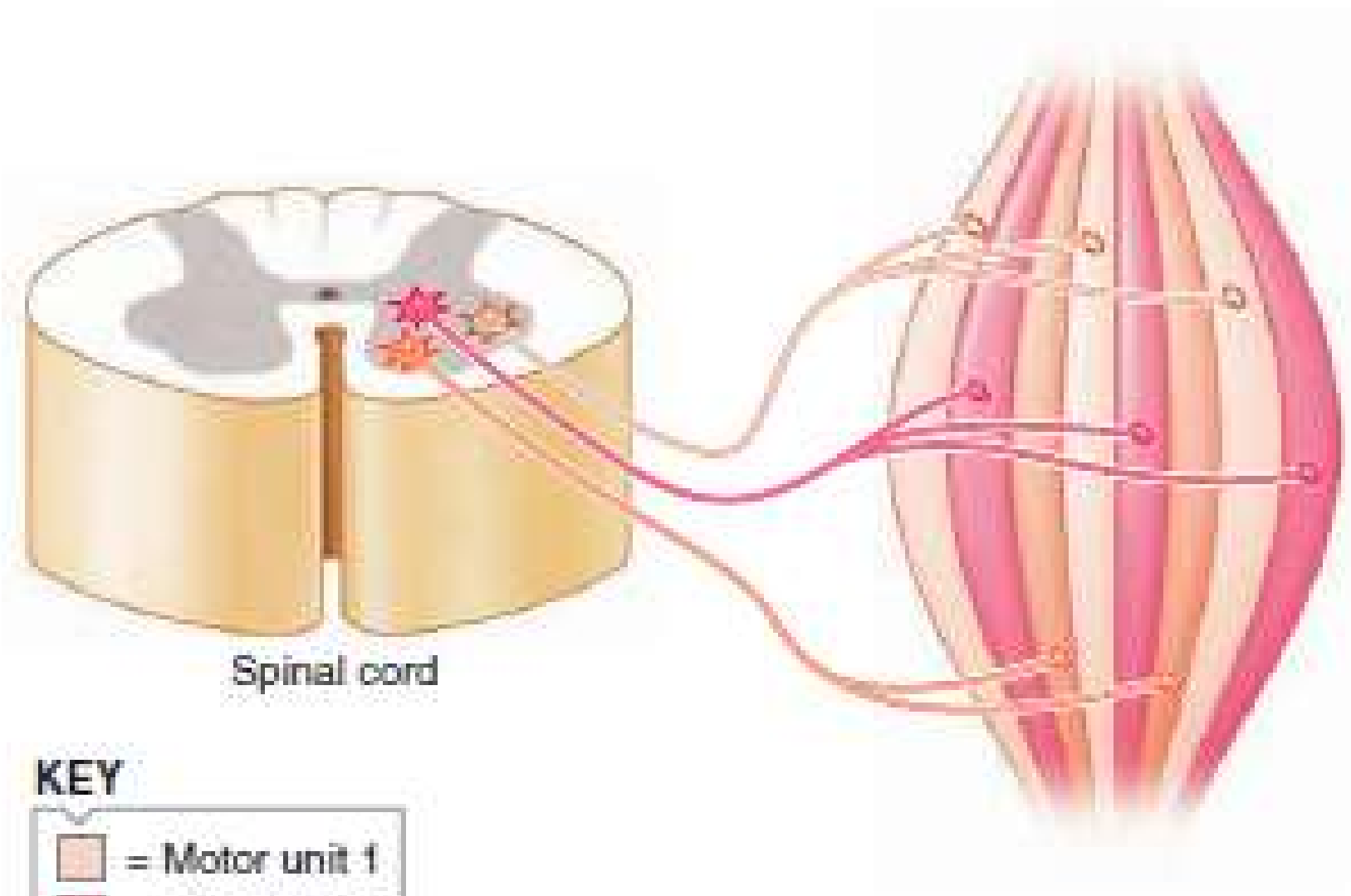
The connective tissue extends beyond the ends of the muscle to form tough, collagenous ***tendons*** *that attach the muscle to bones.*


Skeletal muscle
Afferent fiber
Golgi tendon organ
Collagen
Tendon
Bone

One motor neuron innervates a number of muscle fibers, but each muscle fiber is supplied by only one motor neuron.

When a motor neuron is activated, all the muscle fibers it supplies are stimulated to contract simultaneously.

This team of concurrently activated components—one motor neuron plus all the muscle fibers it innervates—is called a ***motor unit.***


Spinal cord
KEY
= Motor unit 1
= Motor unit 2
= Motor unit 3

Each muscle consists of an number of intermingled motor units.

For a weak contraction of the whole muscle, only one or a few of its motor units are activated.

For stronger and stronger contractions, more and more motor units are recruited,

or stimulated to contract simultaneously, a

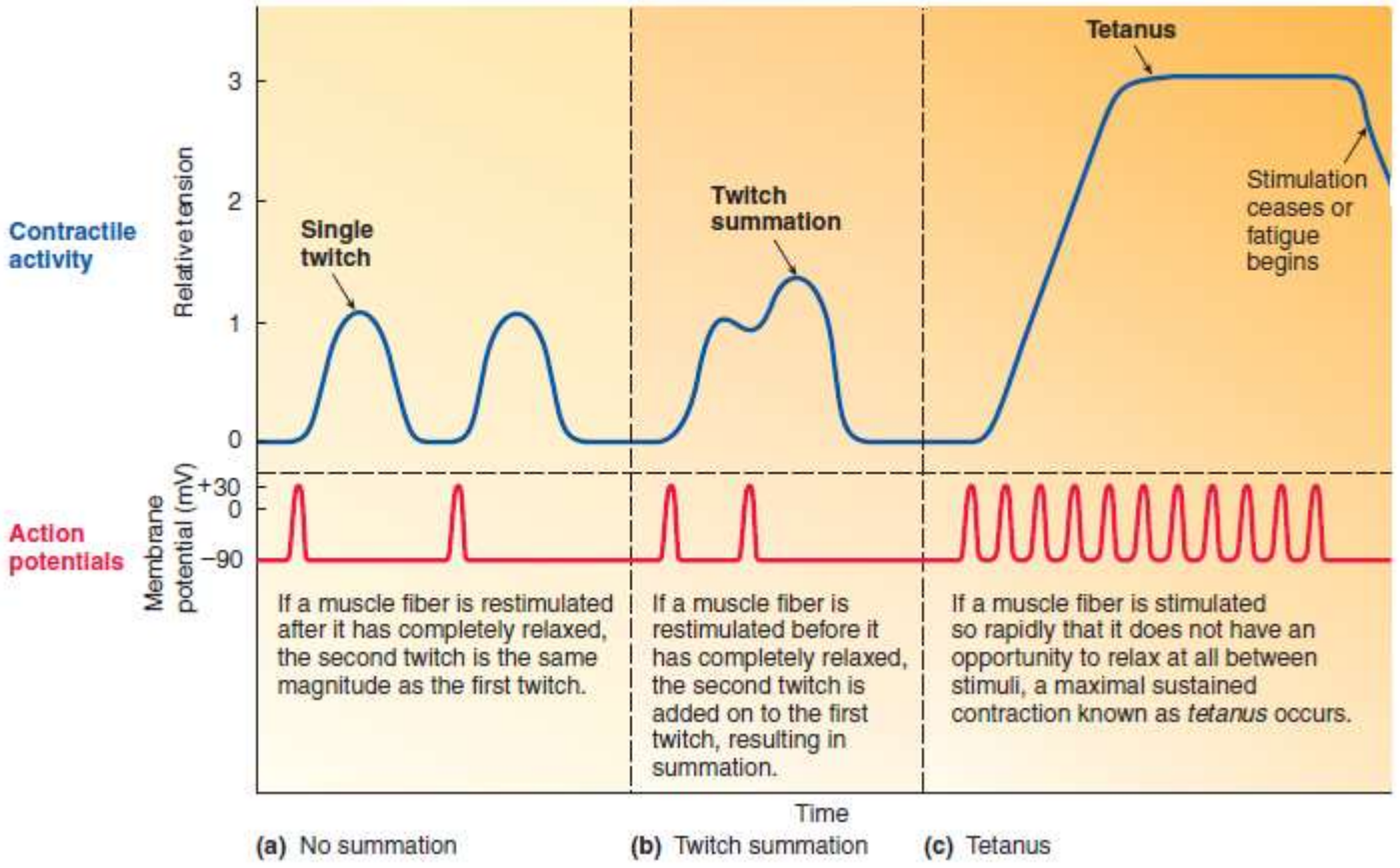
phenomenon known as ***motor unit recruitment****.*

The frequency of stimulation can influence the tension developed by each muscle fiber

Various factors influence the extent to which tension can be developed. These factors include the following:

1. *Frequency of stimulation.*
2. *Length of the fiber at the onset of contraction.*
3. *Extent of fatigue.*
4. *Thickness of the fiber.*

TWITCH SUMMATION AND TETANUS

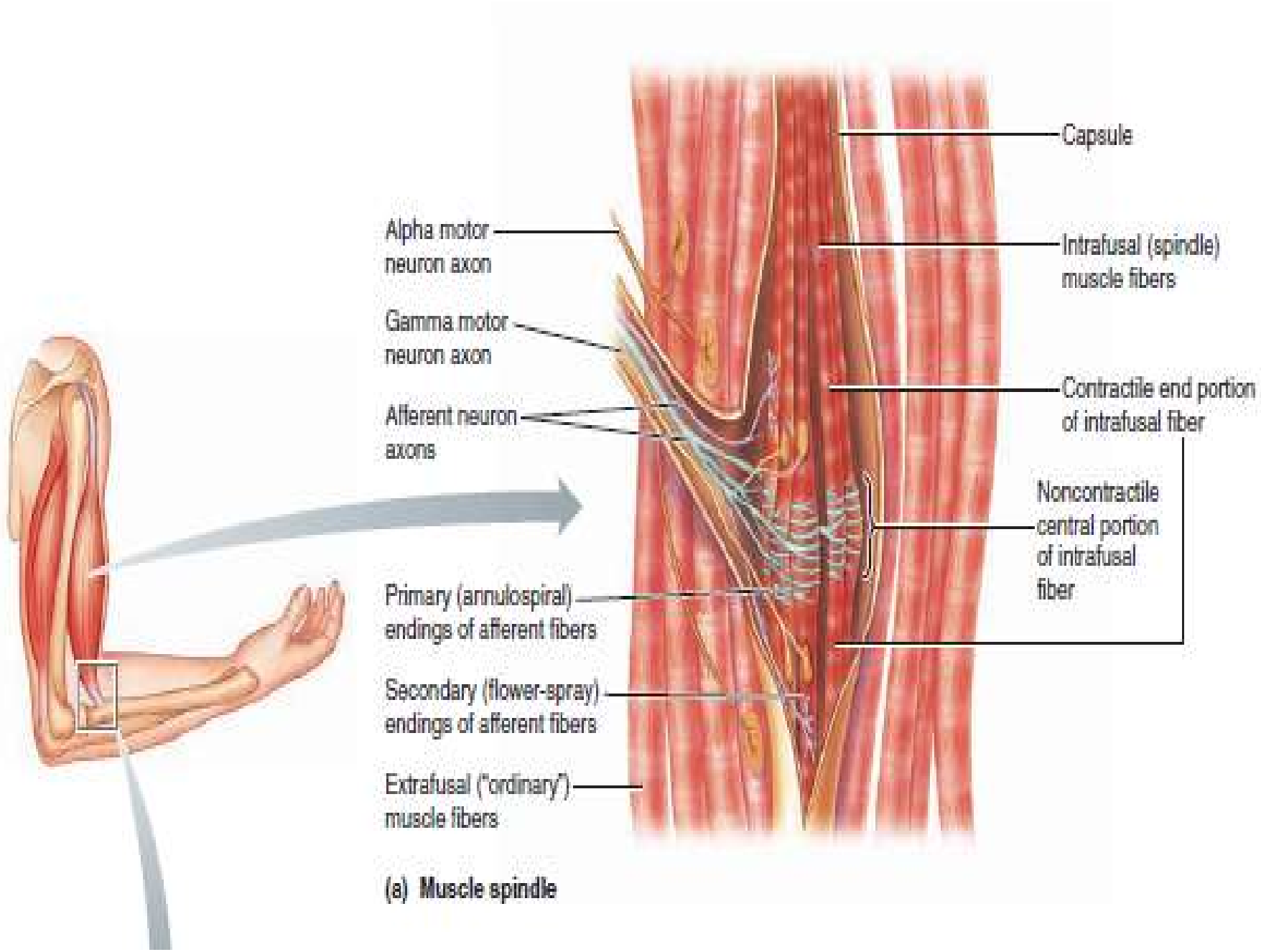


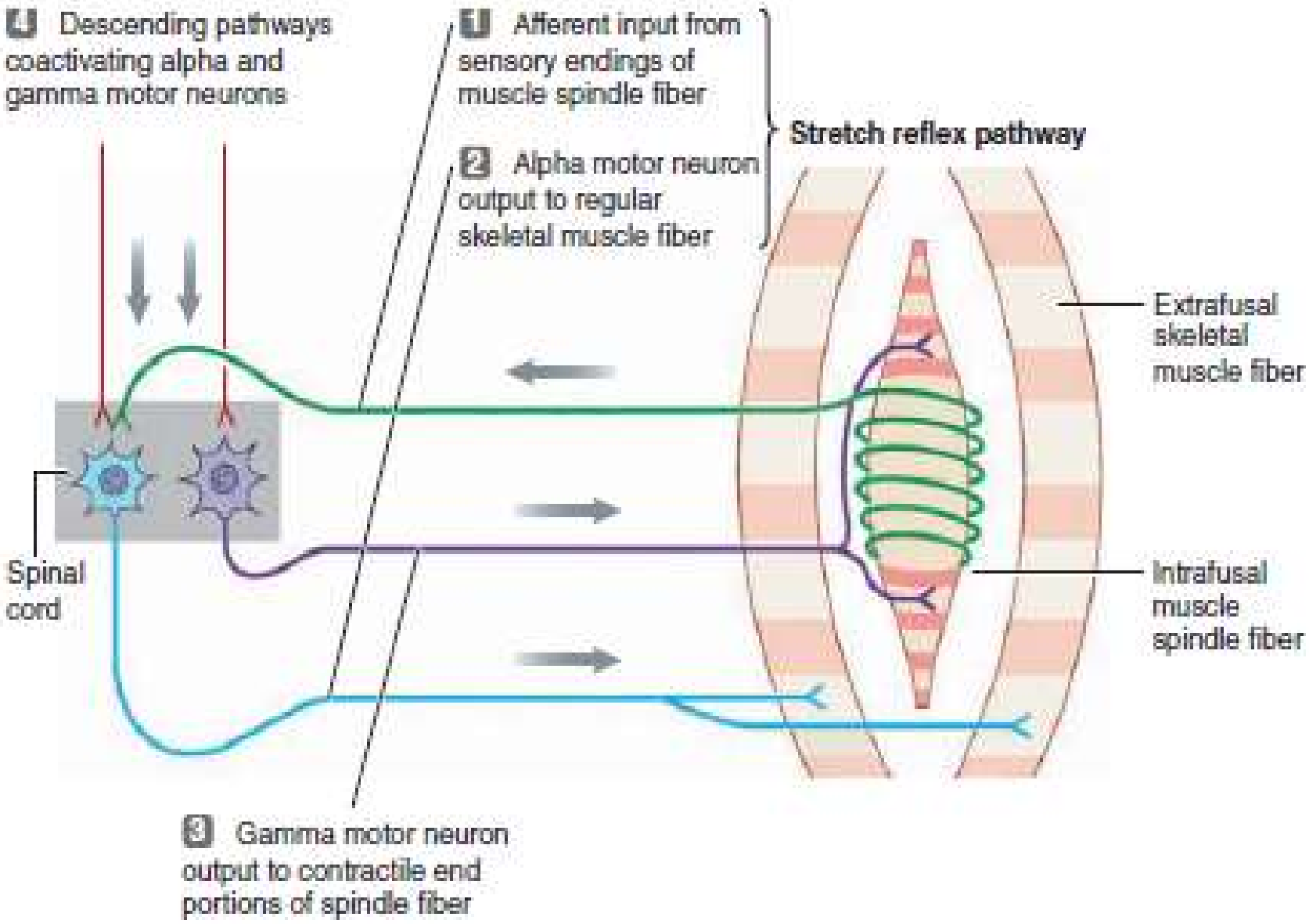
Muscle spindles

*It consist of collections of specialized muscle fibers known as **intrafusal fibers**, which lie within spindle-shaped connective tissue capsules parallel to the "ordinary" **extrafusal fibers** (fusus means "spindle")*

Each muscle spindle has its own private efferent and afferent nerve supply. The efferent neuron that innervates a muscle spindle's intrafusal fibers is known as a ***gamma motor neuron.***

whereas the motor neurons that supply the extrafusal fibers are called ***alpha motor neurons.***


Capsule
Alpha motor neuron axon
Intrafusal (spindle) muscle fibers
Gamma motor neuron axon
Contractile end portion of intrafusal fiber
Afferent neuron axons
Noncontractile central portion of intrafusal fiber
Primary (annulospiral) endings of afferent fibers
Secondary (flower-spray) endings of afferent fibers
Extrafusal ("ordinary") muscle fibers
(a) Muscle spindle


1 Descending pathways coactivating alpha and gamma motor neurons
1 Afferent input from sensory endings of muscle spindle fiber
2 Alpha motor neuron output to regular skeletal muscle fiber
Stretch reflex pathway
Extrafusal skeletal muscle fiber
Intrafusal muscle spindle fiber
Spinal cord
3 Gamma motor neuron output to contractile end portions of spindle fiber

Thank you