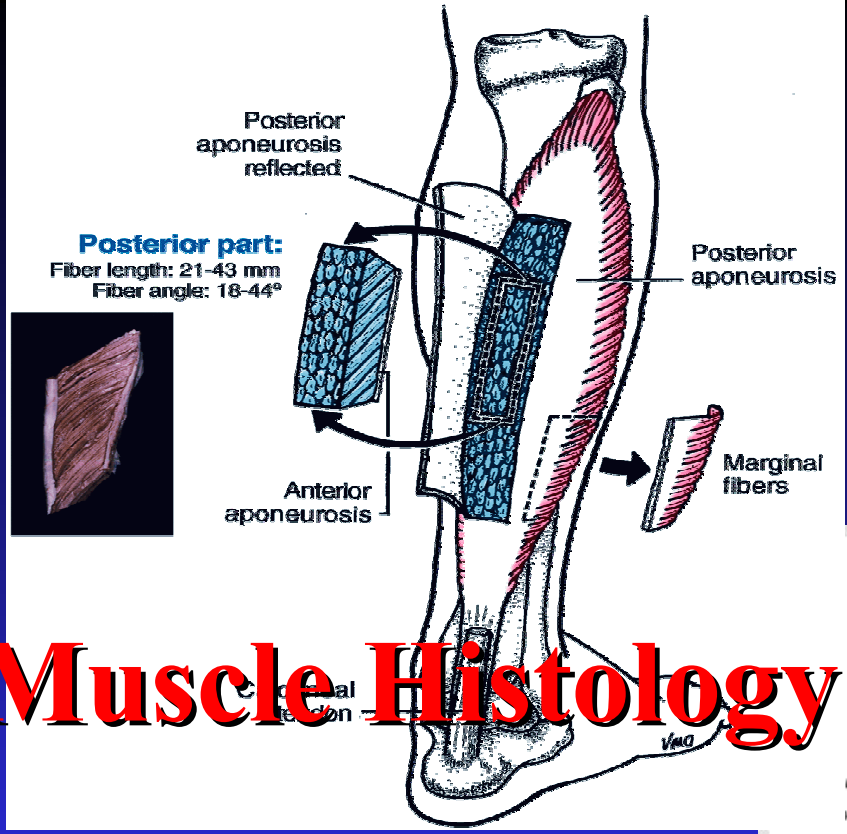
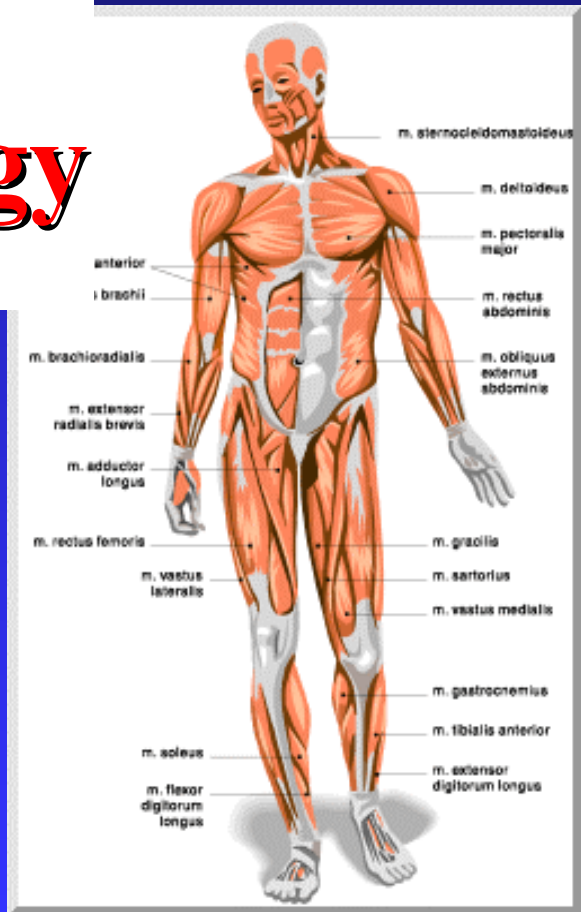
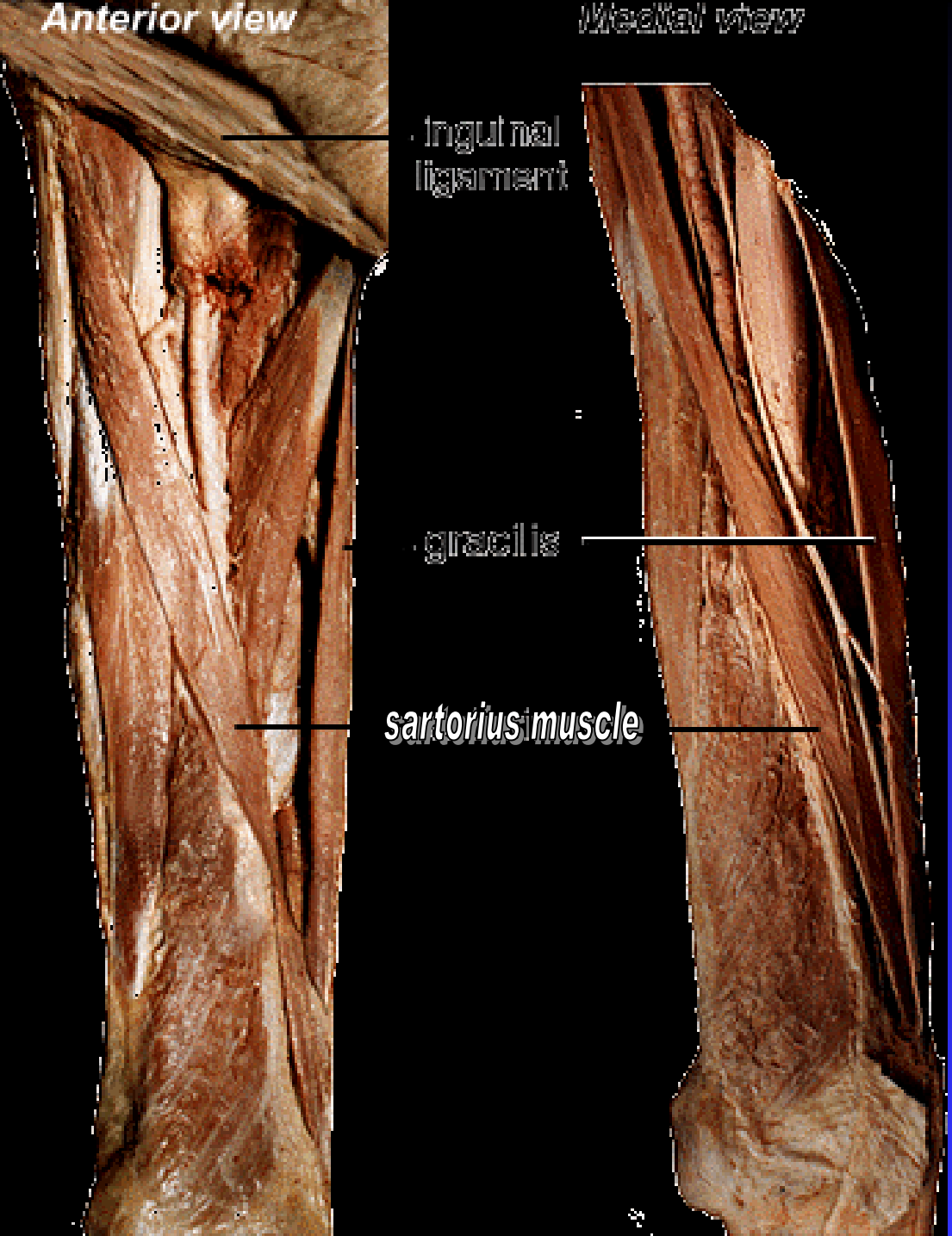


Muscle Histology

Danil Hammoudi.MD



- We have over 600 major muscles.
- We have 240 muscles that have specific jobs



Sartorius muscle

It is the longest muscle in the body. It runs from the anterior superior iliac spine of the hip bone to the medial surface of the shaft of the tibia.

The following are some terms relating to muscle features that are used in naming muscles.

- Size:
- Shape:
- Direction of fibers: Location:
- Number of origins:
- Origin and insertion:
- Action:

•**Size**: vastus (huge); maximus (large); longus (long); minimus (small); brevis (short).

•**Shape:** deltoid (triangular); rhomboid (like a rhombus with equal and parallel sides); latissimus (wide); teres (round); trapezius (like a trapezoid, a four-sided figure with two sides parallel).

•**Direction of fibers:** rectus (straight); transverse (across); oblique (diagonally); orbicularis (circular).

•**Location:** pectoralis (chest); gluteus (buttock or rump); brachii (arm); supra- (above); infra- (below); sub- (under or beneath); lateralis (lateral).
•Number of origins: biceps (two heads); triceps (three heads); quadriceps (four heads).

•**Origin and insertion:** sternocleidomastoideus (origin on the sternum and clavicle, insertion on the mastoid process); brachioradialis (origin on the brachium or arm, insertion on the radius).
•
•**Action:** abductor (to abduct a structure); adductor (to adduct a structure); flexor (to flex a structure); extensor (to extend a structure); levator (to lift or elevate a structure); masseter (a chewer).

Four major muscle groups of the body include:

- Muscles of the head and neck;
- Muscles of the trunk;
- Muscles of the upper extremity; and
- Muscles of the lower extremity.

The basis for motion mediated by muscle cells is the conversion of chemical energy (ATP) into mechanical energy by the contractile apparatus of muscle cells.

The proteins actin and myosin are part of the contractile apparatus. The interaction of these two proteins mediates the contraction of muscle cells.

Actin and myosin form myofilaments arranged parallel to the direction of cellular contraction.

A further specialisation of muscle cells is an excitable cell membrane which propagates the stimuli which initiate cellular contraction.

Myofibers

In order of decreasing size…

- **Myofiber= entire cell.**
- **Myofibrils: bundles of myofilaments inside myofiber.**
- **Myofilaments: actin and myosin proteins**

SARCOTERMS

- **Sarcolemma: pm of myofiber**
- **Sarcoplasm: cytoplasm of myofiber**
- **Sarcoplasmic reticulum (SR): ER of myofiber**
- **Sarcomere: contractile unit inside myofiber**

Twitch = muscle contraction

Summation:

If second stimulus is administered before complete relaxation of muscle.

Complete tetanus:

Fusion frequency of stimulation.

No visible relaxation between twitches.

Smooth sustained contraction.

Treppe:

Second stimulus elicits a stronger response

Perhaps due to increase in intracellular Ca^{2+}.

Isotonic contractions:

Force of contraction remains constant throughout the shortening process.

Isometric contractions:

Length of muscle fibers remain constant.

Eccentric contractions:

Force exerted on a muscle to stretch is greater than the force of muscle contraction.

Running downhill

Muscle fiber types are classified by

- Anatomical appearance: red versus white
- Muscle function: fast-slow or fatigable versus fatigue resistant
- Biochemical properties: such as high or low aerobic capacity
- Histochemical properties: such as enzyme profile

Muscle Classification

- As many as eight types
- Red (type I)
  - long term
  - slow contractions
- White (type IIa)
  - short term
  - fast contractions
- White (type IIb)
- No change from one type to another
  - change within fast types

Agonist muscle:

Prime mover.

Antagonist muscle:

Flexors and extensors that act on the same joint to produce opposite actions

Reciprocal innervation:

motor neurons of antagonistic muscles inhibit each other (through interneurons) so they don't both contract simultaneously.

When limb is flexed, antagonistic extensor muscles are passively stretched

Type of muscles

- **Smooth Muscle**
- **Skeletal Muscle**
- **Cardiac Muscle**

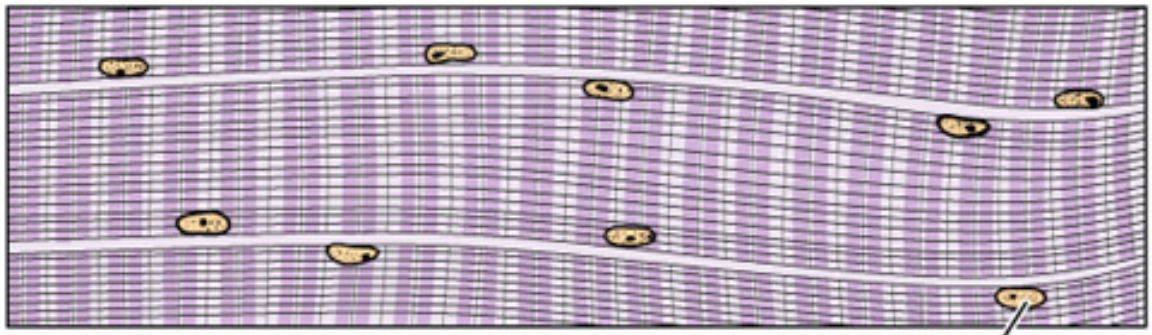
Cardiac muscle	Involuntary controlled by autonomic nervous system
Smooth muscle	
Skeletal muscle (aka striped or striated muscle)	voluntary controlled by somatic nervous system

An interesting exception to the visceral muscles being under involuntary control is the **diaphragm**, which controls breathing. This muscle is normally under involuntary control (we don't usually have to think about breathing), but a person can exert a limited amount of voluntary control also (for example, purposely holding one's breath or breathing quickly or deeply).

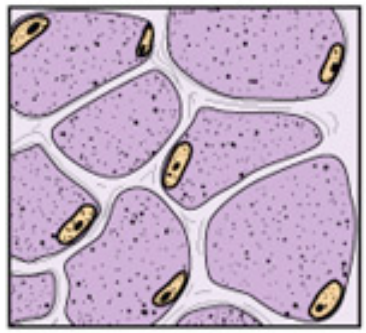
Muscle types

Activity

Skeletal muscle



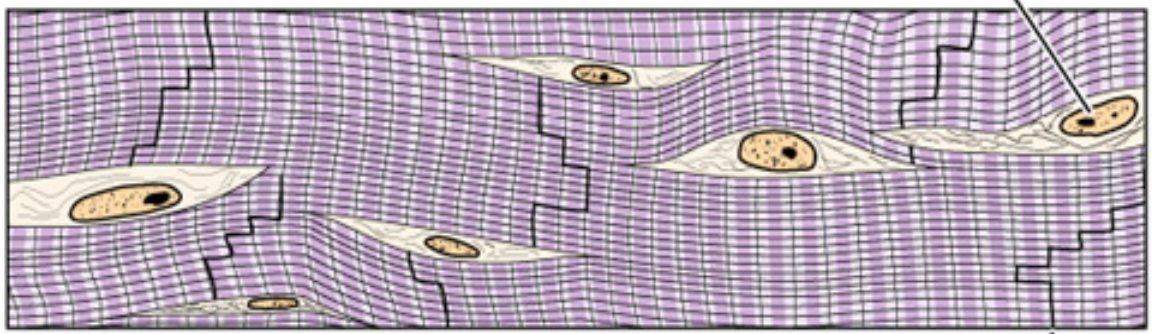
Cross sections

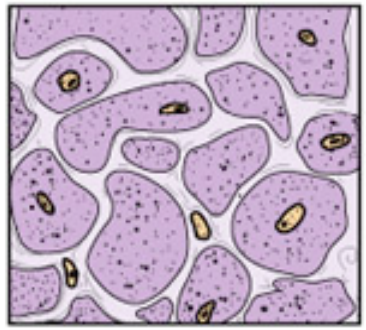


Strong, quick discontinuous voluntary contraction

Nuclei

Cardiac muscle

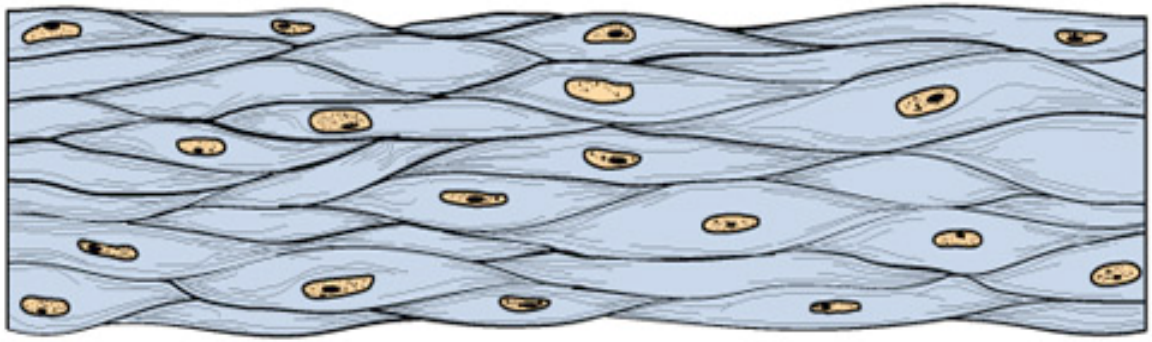


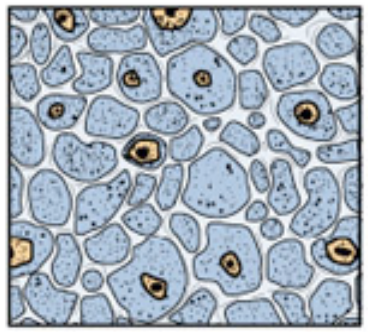


Strong, quick continuous involuntary contraction

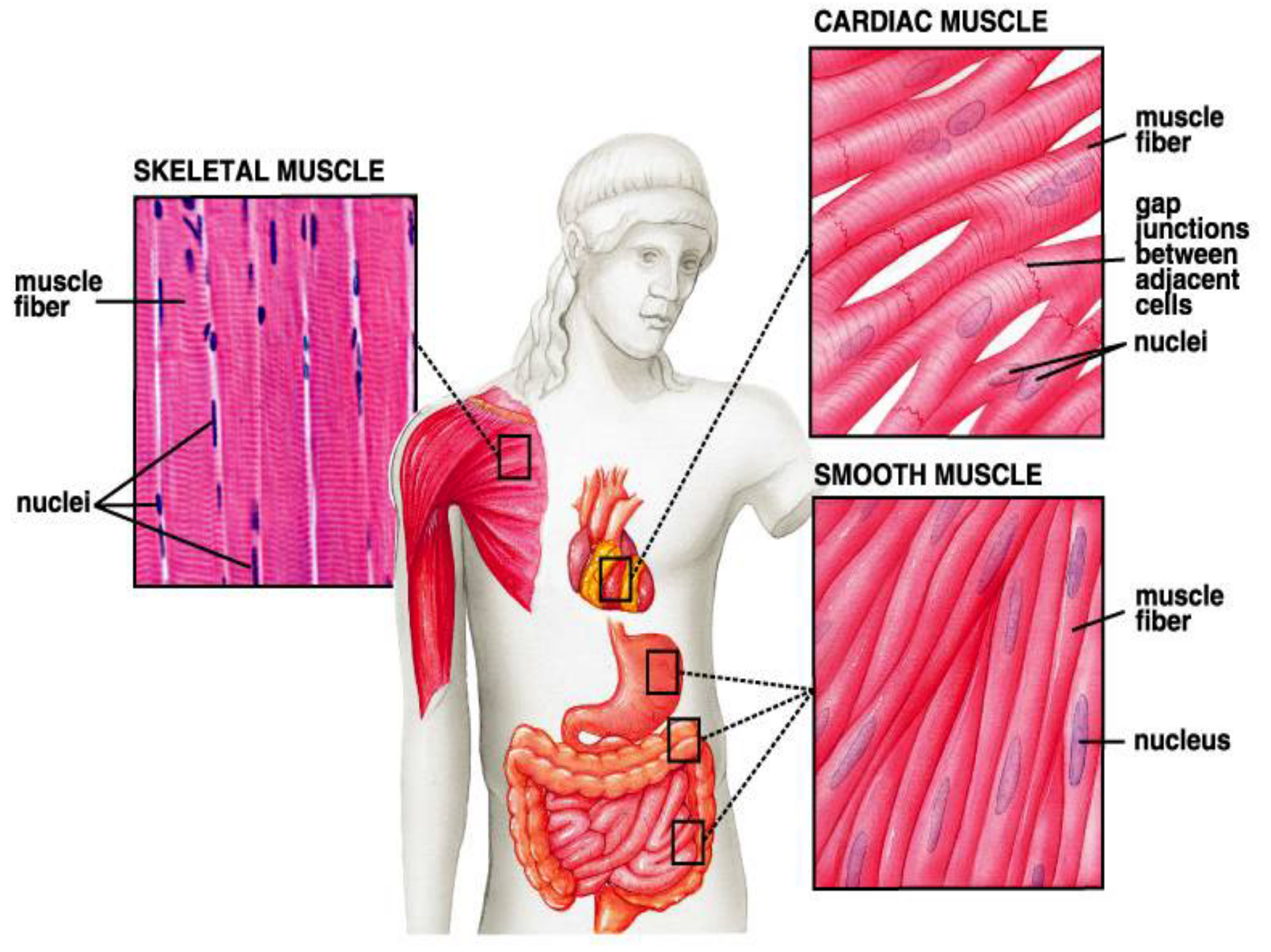
Intercalated disks

Smooth muscle





Weak, slow involuntary contraction


CARDIAC MUSCLE
muscle fiber
gap junctions between adjacent cells
nuclei
SKELETAL MUSCLE
muscle fiber
nuclei
SMOOTH MUSCLE
muscle fiber
nucleus

Individual Fiber Types

Fast fibers

- **Type IIb fibers**
  - Fast-twitch fibers
  - Fast-glycolytic fibers
- **Type IIa fibers**
  - Intermediate fibers
  - Fast-oxidative glycolytic fibers

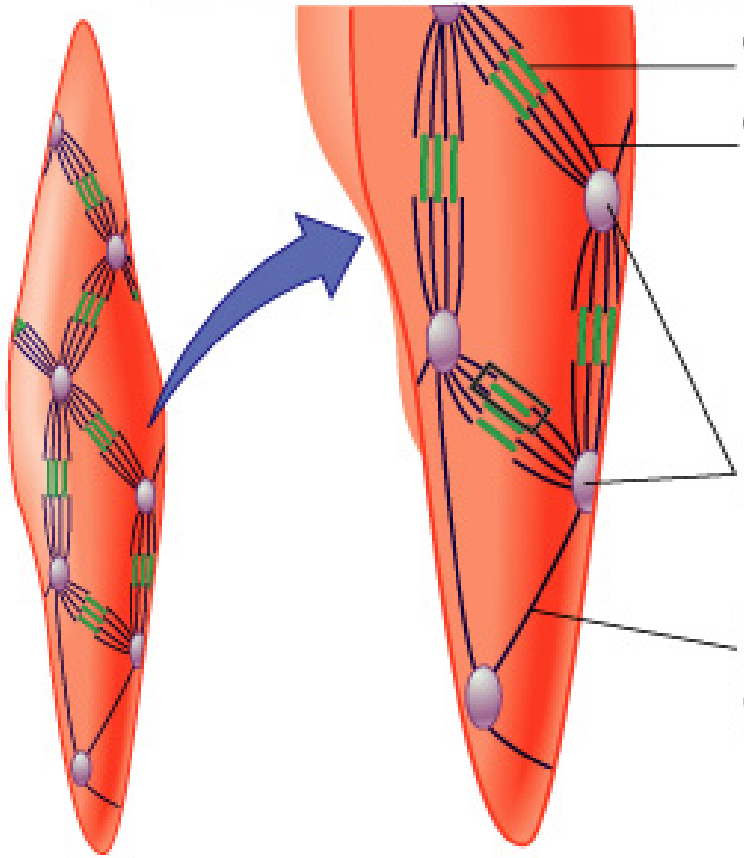
Slow fibers

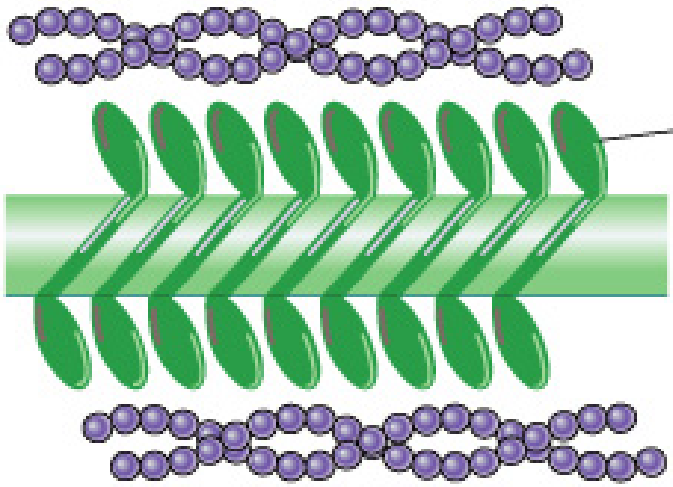
- **Type I fibers**
  - Slow-twitch fibers
  - Slow-oxidative fibers

Types of Muscle Action

- **Concentric** – shortening
- **Eccentric** – lengthening (20% greater than concentric with less energy)
- **Isometric** – no change in length

SMOOTH MUSCLE





SMOOTH MUSCLE

Smooth muscle cells are **spindle shaped** and **uninucleate.** .

Locations: walls of hollow organs, i.e. stomach, intestine, uterus, ureter

Functions: involuntary movement - i.e. churning of food, movement of urine from the kidney to the bladder, partuition

Not striated.

NO sarcomeres.

Lots of actin, some myosin

Can contract even when very stretched.

Graded contractions

•Smooth muscle consists of spindle shaped cells of variable size.

•The largest smooth muscle cells occur in the uterus during pregnancy (12x600 μm).

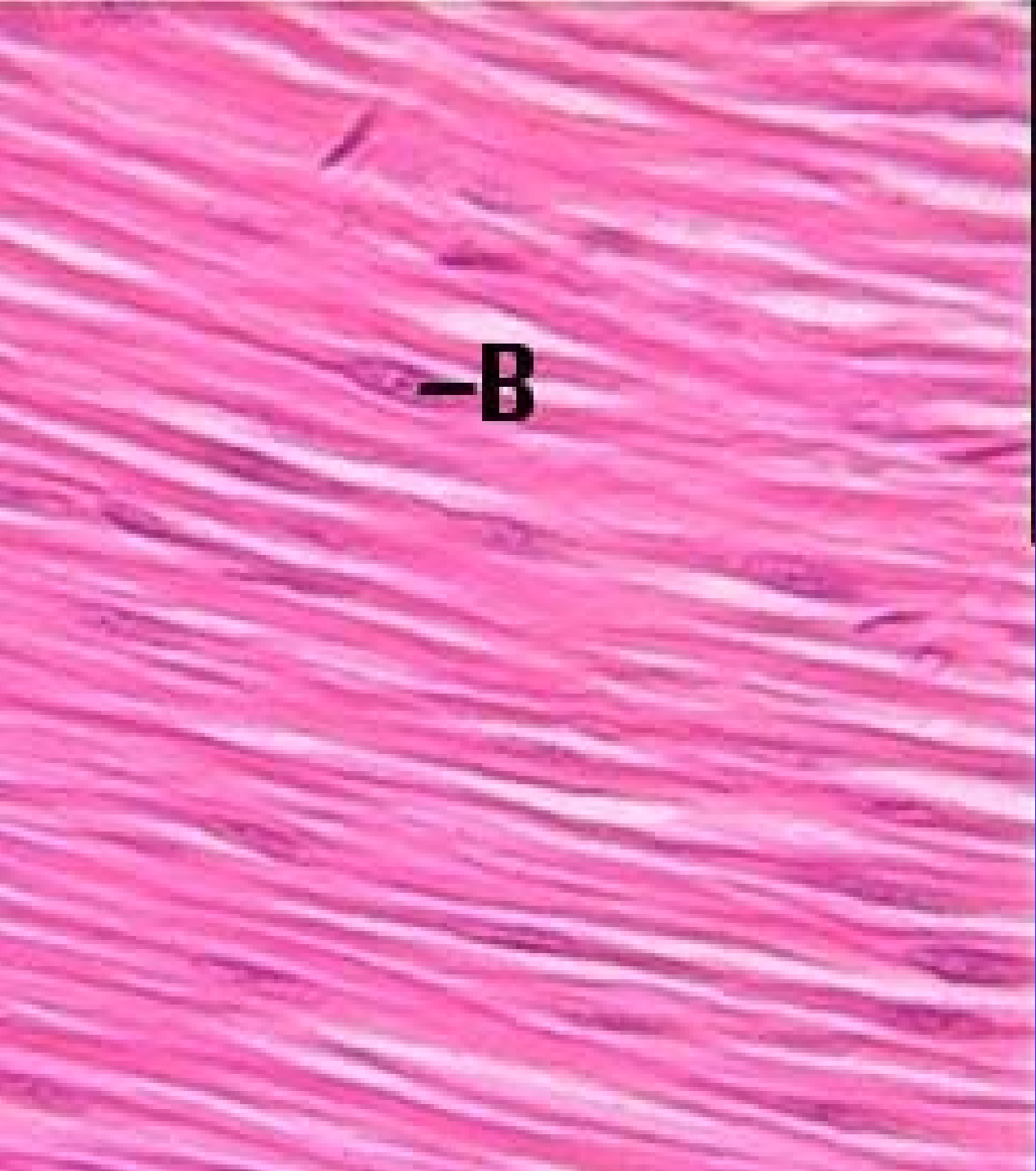
•The smallest are found around small arterioles (1x10 μm).
•Smooth muscle cells contain one centrally placed nucleus.
The chromatin is finely granular and the nucleus contains 2-5 nucleoli.
•The innervation of smooth muscle is provided by the **autonomic nervous system.**
•**Smooth muscle makes up the visceral or involuntary muscle**.

Types of smooth muscle

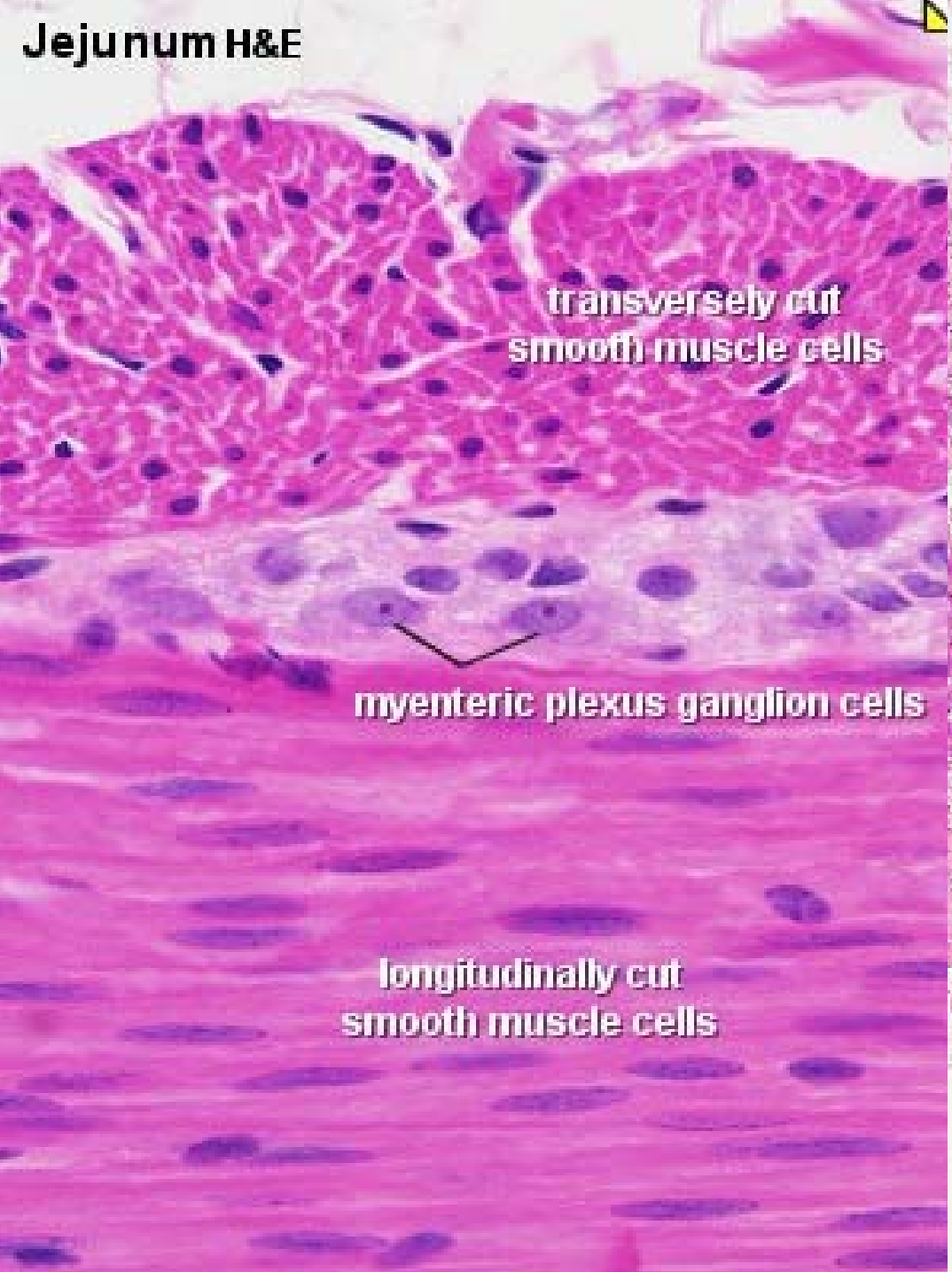
Two broad types of smooth muscle can be distinguished on the basis of **the type of stimulus which results in contraction and the specificity with which individual smooth muscle cells react to the stimulus:**

1. The multiunit type represents functionally independent smooth muscle cells which are often innervated by a single nerve terminal and which never contract spontaneously (e.g. smooth muscle in the walls of blood vessels).

2. The visceral type represents bundles of smooth muscle cells connected by GAP junctions, which contract spontaneously if stretched beyond a certain limit (e.g. smooth muscle in the walls of the intestines).



Smooth muscle cells are spindle shaped and uninucleate. (B).


Jejunum H&E
transversely cut
smooth muscle cells
myenteric plexus ganglion cells
longitudinally cut
smooth muscle cells


Jejunum H&E
lumen
villi with simple
columnar epithelium
longitudinal (outside) and
circular (inside) layers of smooth muscle

SKELETAL MUSCLE

Skeletal muscle cells run the full length of a muscle.

Note the striations characteristics of this muscle type.

These cells are multicellular, **Location:** muscles associated with the skeleton

Function: voluntary movement

Muscles are connected to bones by tendons. Bones are connected to other bones at their joints by ligaments.

Skeletal muscles are composed of fibers (cells) bound together by connective tissue.

- Connective tissue associated with muscle [endomysium, perimysium, epimysium, fascia]
- Muscle attachments
  - Tendons are bands of dense connective tissue attaching muscle to bone.
  - Most moveable attachment is **insertion**
  - Least moveable attachment is **origin**
  - **Aponeurosis** is a flattened sheetlike muscle attachment.

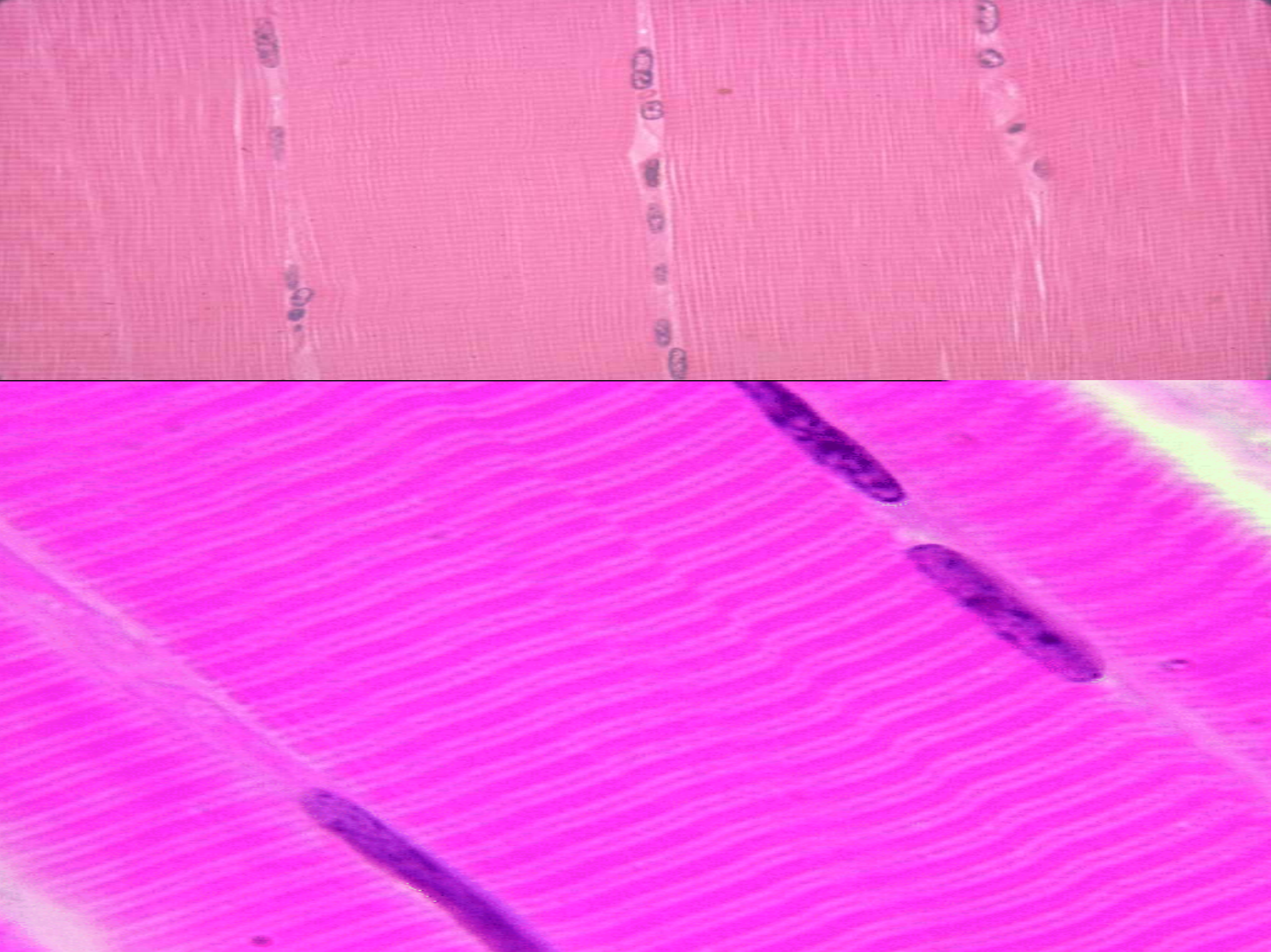
  - Four principal fiber patterns in skeletal muscle

  1. Parallel fibers [rectus abdominus]
  2. Convergent fibers [pectoralis major]
  3. Circular fibers [orbicularis oris]
  4. Pennate fibers [rectus femoris]

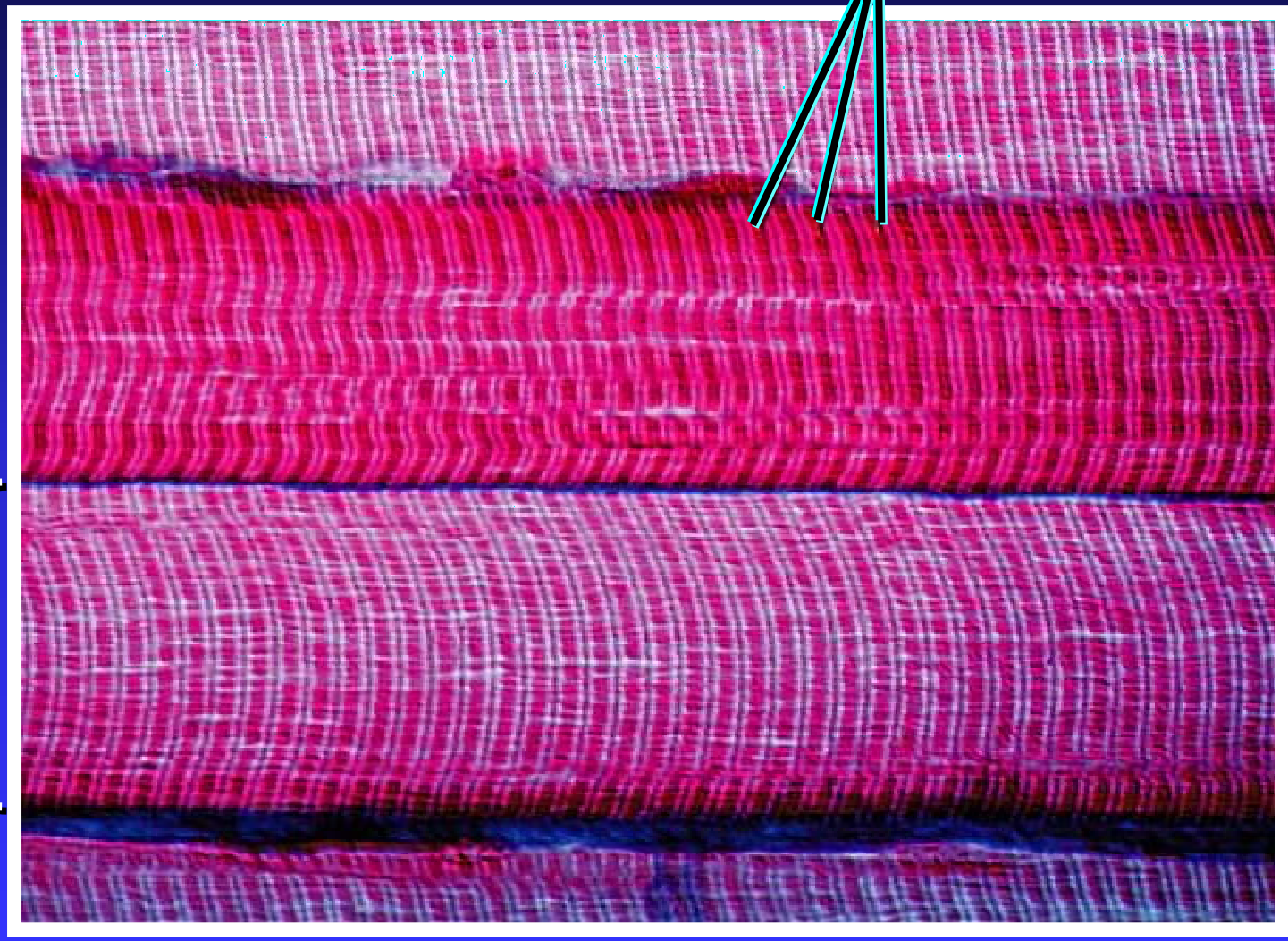
- Muscle cells contract when stimulated by nerve impulses
  - Isotonic & Isometric Contractions
  - Motor Unit is a motor neuron + muscle fibers it innervates
  - Myoneural Junction is the contact site between the end of the motor neuron and muscle fiber
  - Motor End Plate is the portion of the sarcolemma in contact with motor neuron.

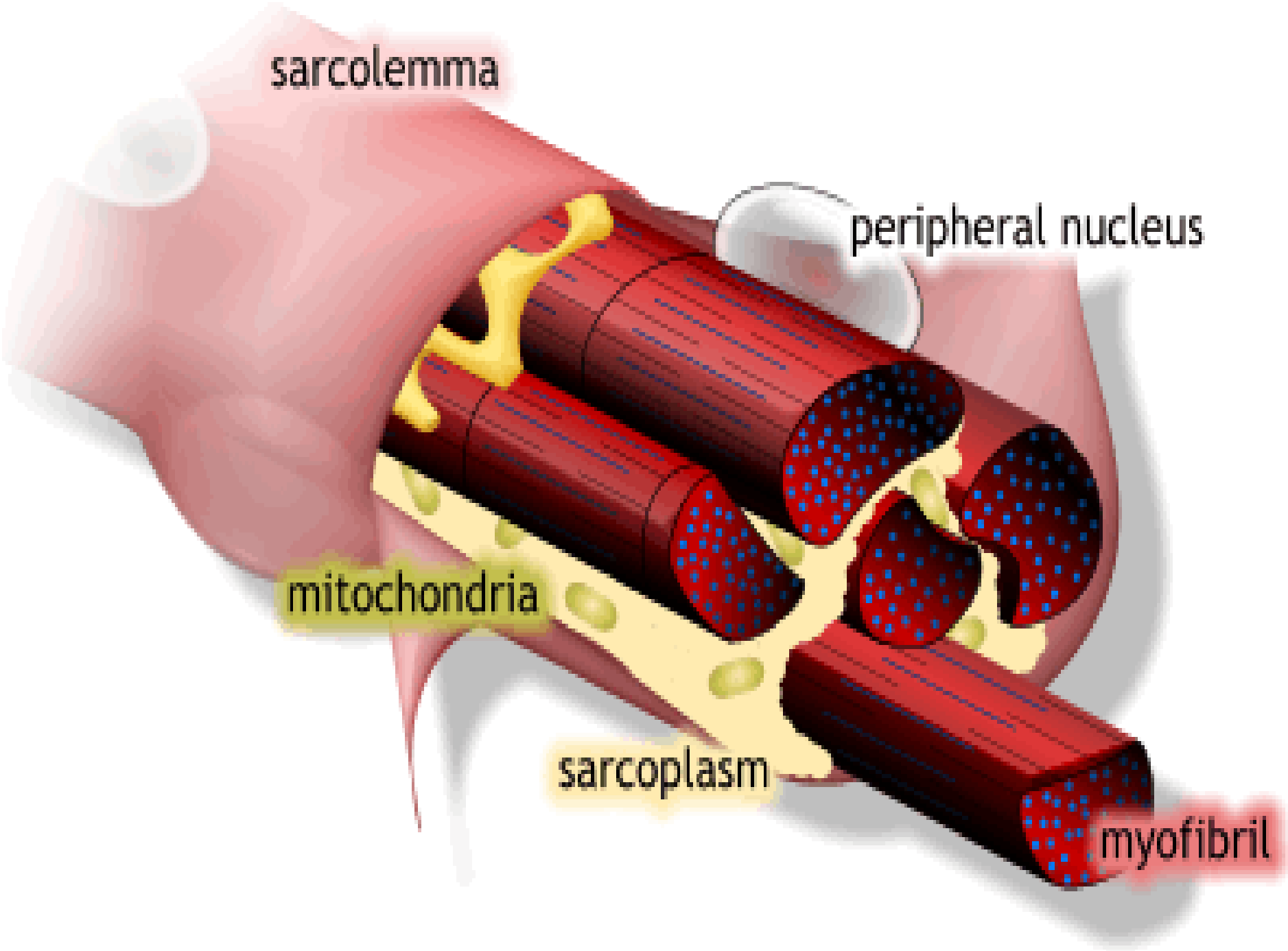
NAMING OF MUSCLES

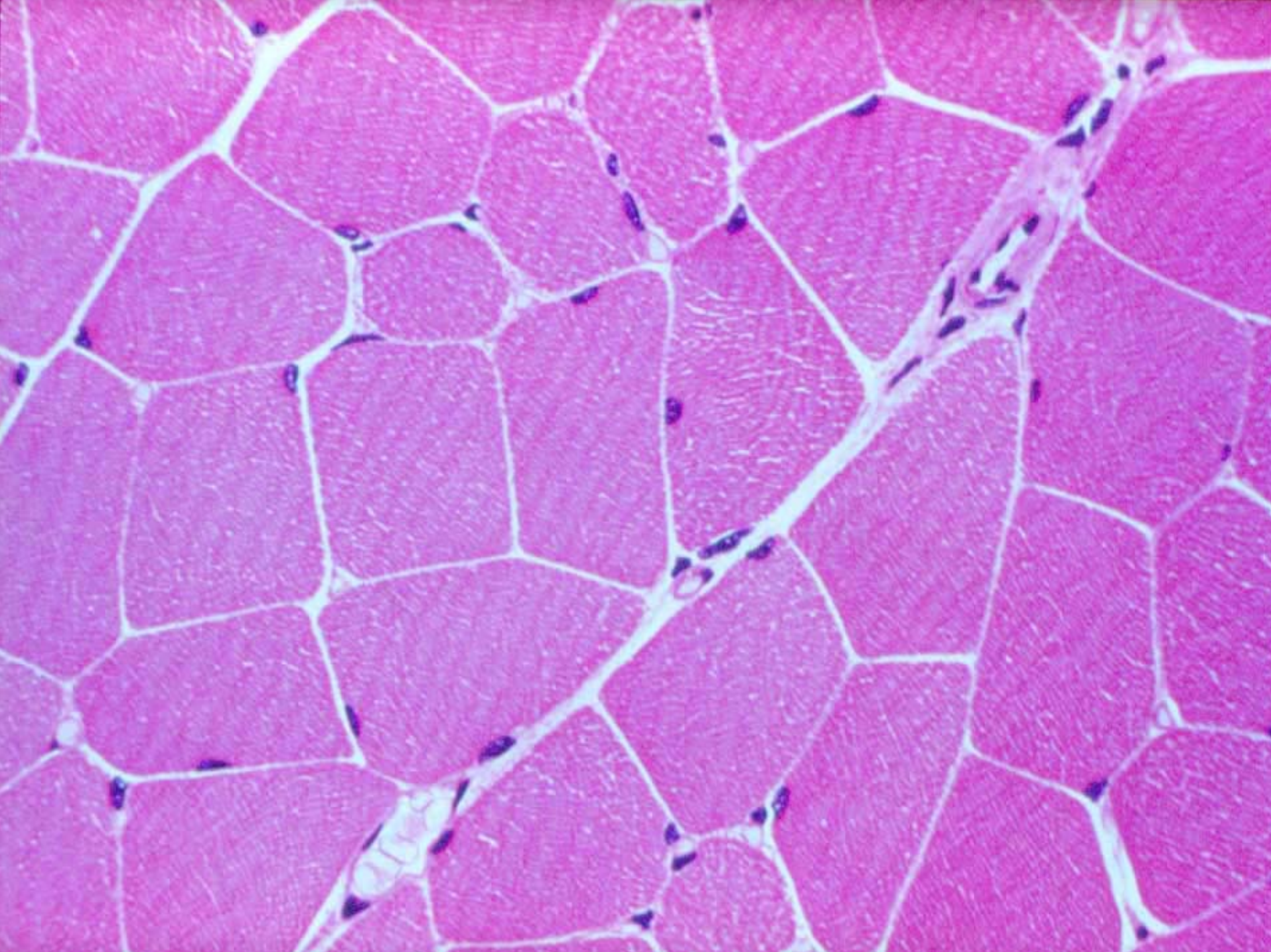
1. Shape	Trapezius Serratus anterior
2. Location	Biceps femoris Biceps brachialis
3. Attachment	Sternocleidomastoid Supraspinatus
4. Size	Gluteus maximus
5. Orientation of fibers	Rectus abdominus External oblique
6. Relative position	Vastus medialis Vastus lateralis
7. Function or Action	Pronator teres Supinator
8. Other	Sartorius



Muscle




sarcolemma
peripheral nucleus
mitochondria
sarcoplasm
myofibril

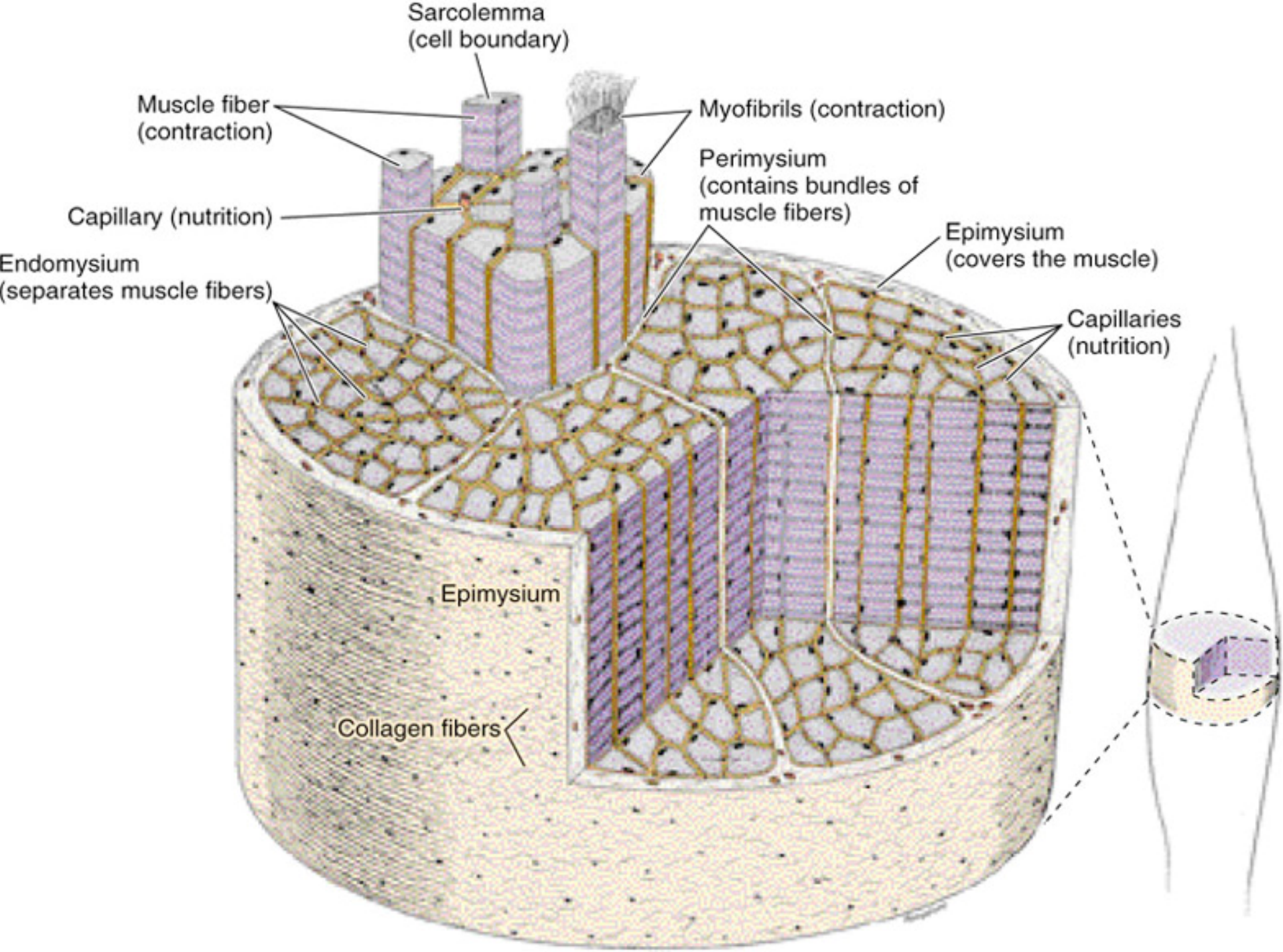


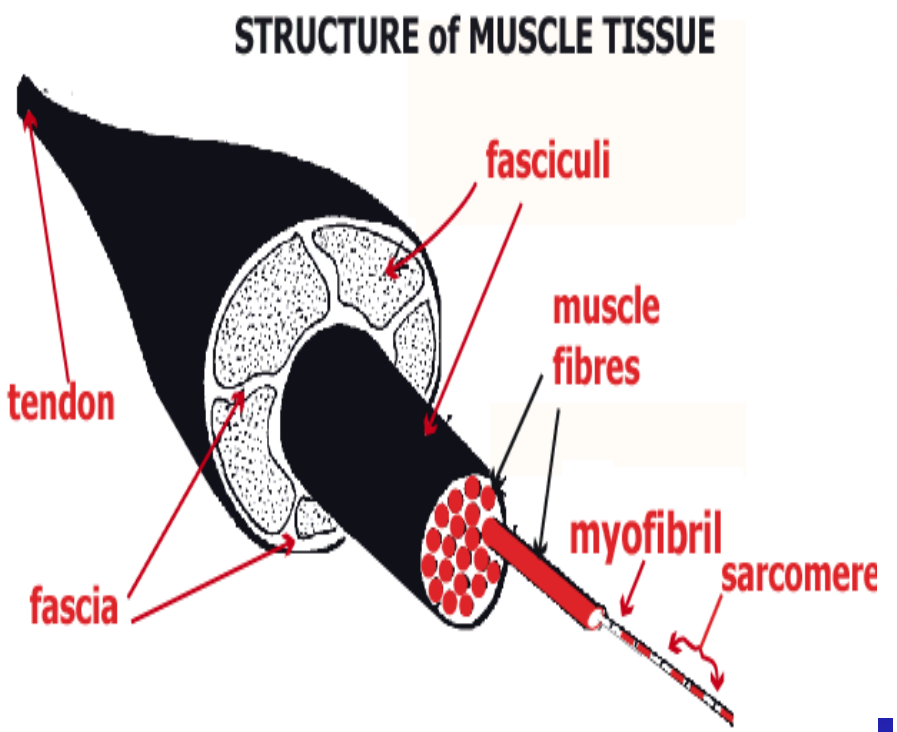
•Skeletal muscle is described as *striated* because of its appearance. Under the microscope it is possible to see parallel lines - 'striations' - running across the muscle cells.
•These are due to the **myofibrils** found in skeletal muscle cells, which will be discussed shortly.

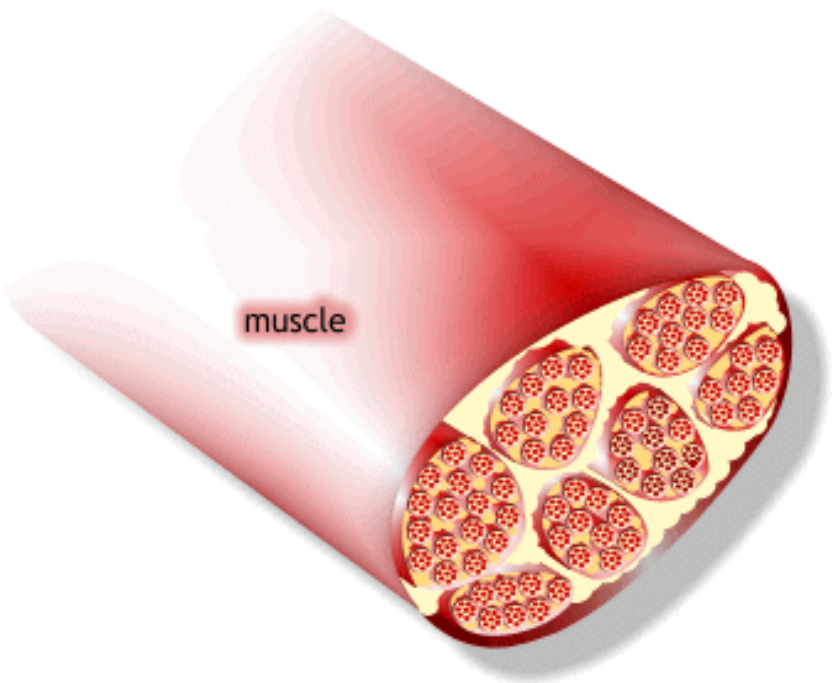
Each muscle, then, can be split into compartments known as fasicles, with each **fascicle wrapped in a sheath of connective tissue known as the perimysium**.

•**Surrounding the whole bundle of fascicles is the epimysium**, keeping the muscle together.
•Within each fasicle are the **muscle fibres** or muscle cells, each wrapped in **endomysium**.
•Within each of these fibres, are the myofibrils, which are the functional part of muscle contraction.

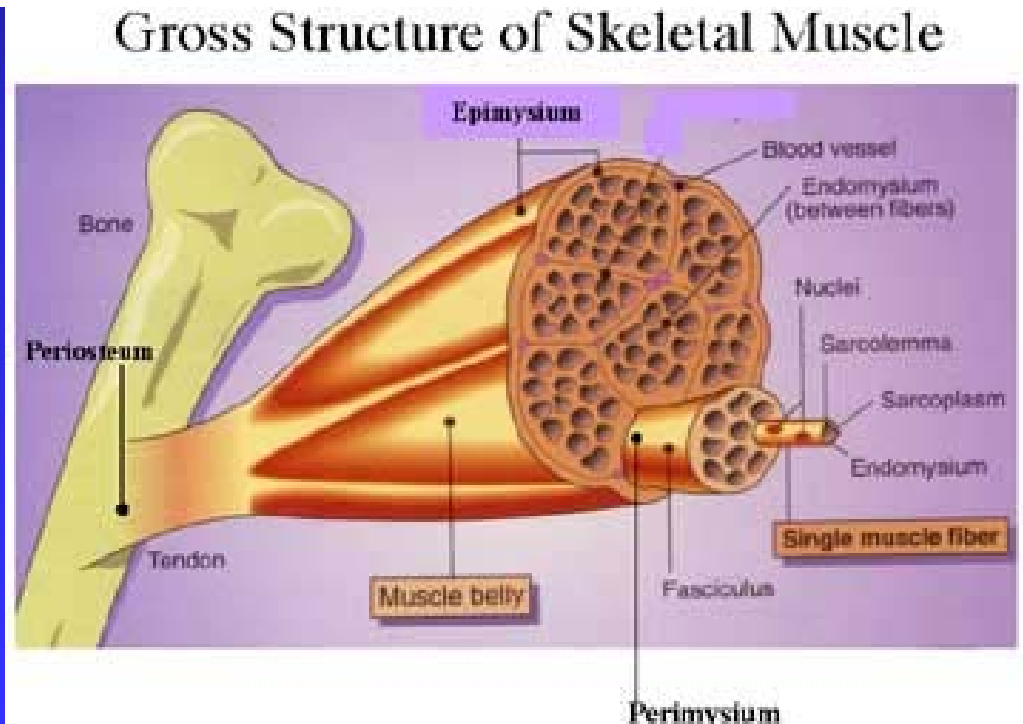
Skeletal muscle, then, is the tissue that connect bones causing movement, with contraction stimulated voluntarily, and comprising of collections of muscle fibres collected together and cleverly organised to maximise efficiency and power.

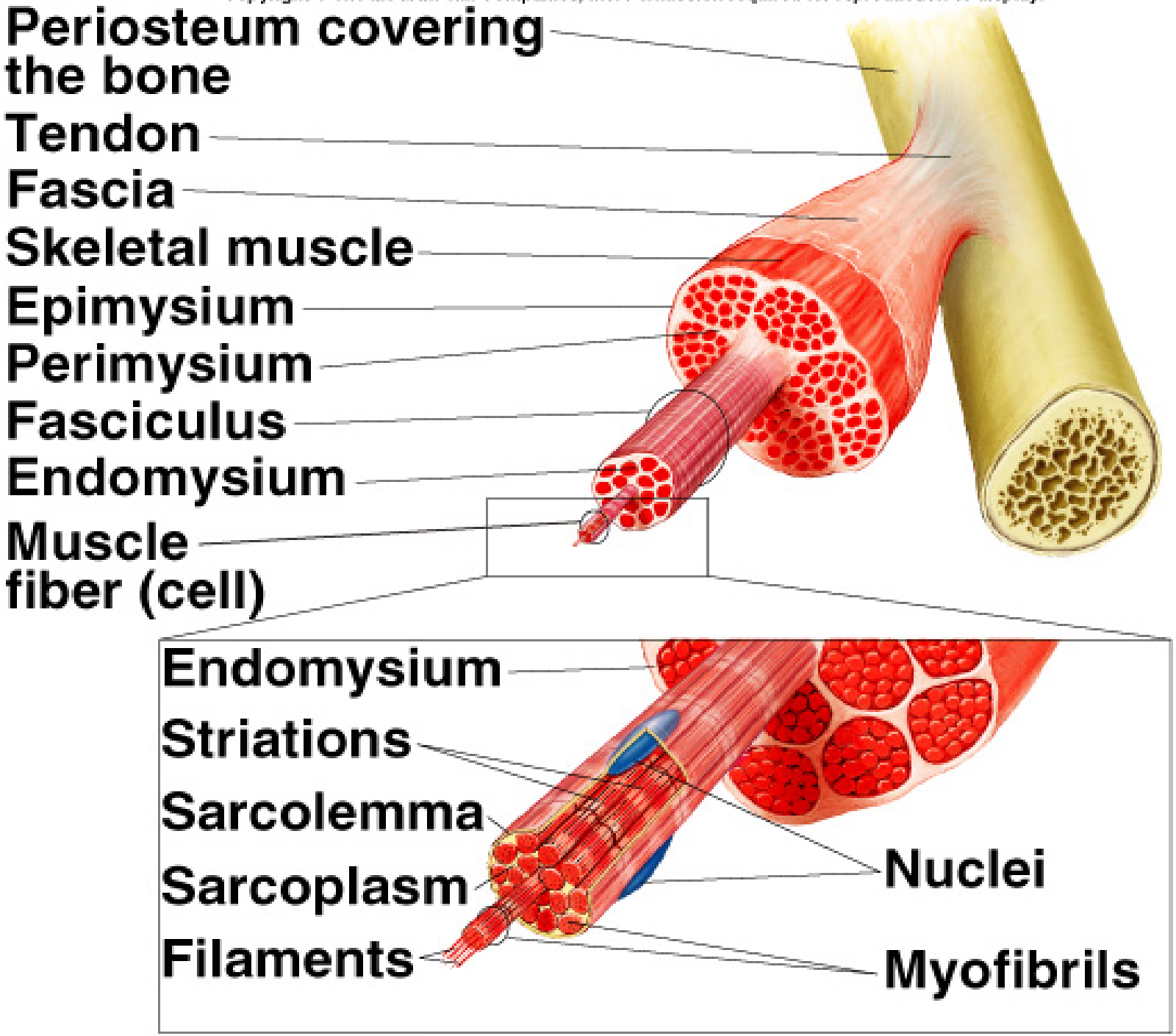

Sarcolemma
(cell boundary)
Muscle fiber
(contraction)
Myofibrils (contraction)
Perimysium
(contains bundles of
muscle fibers)
Capillary (nutrition)
Epimysium
(covers the muscle)
Endomysium
(separates muscle fibers)
Capillaries
(nutrition)
Epimysium
Collagen fibers

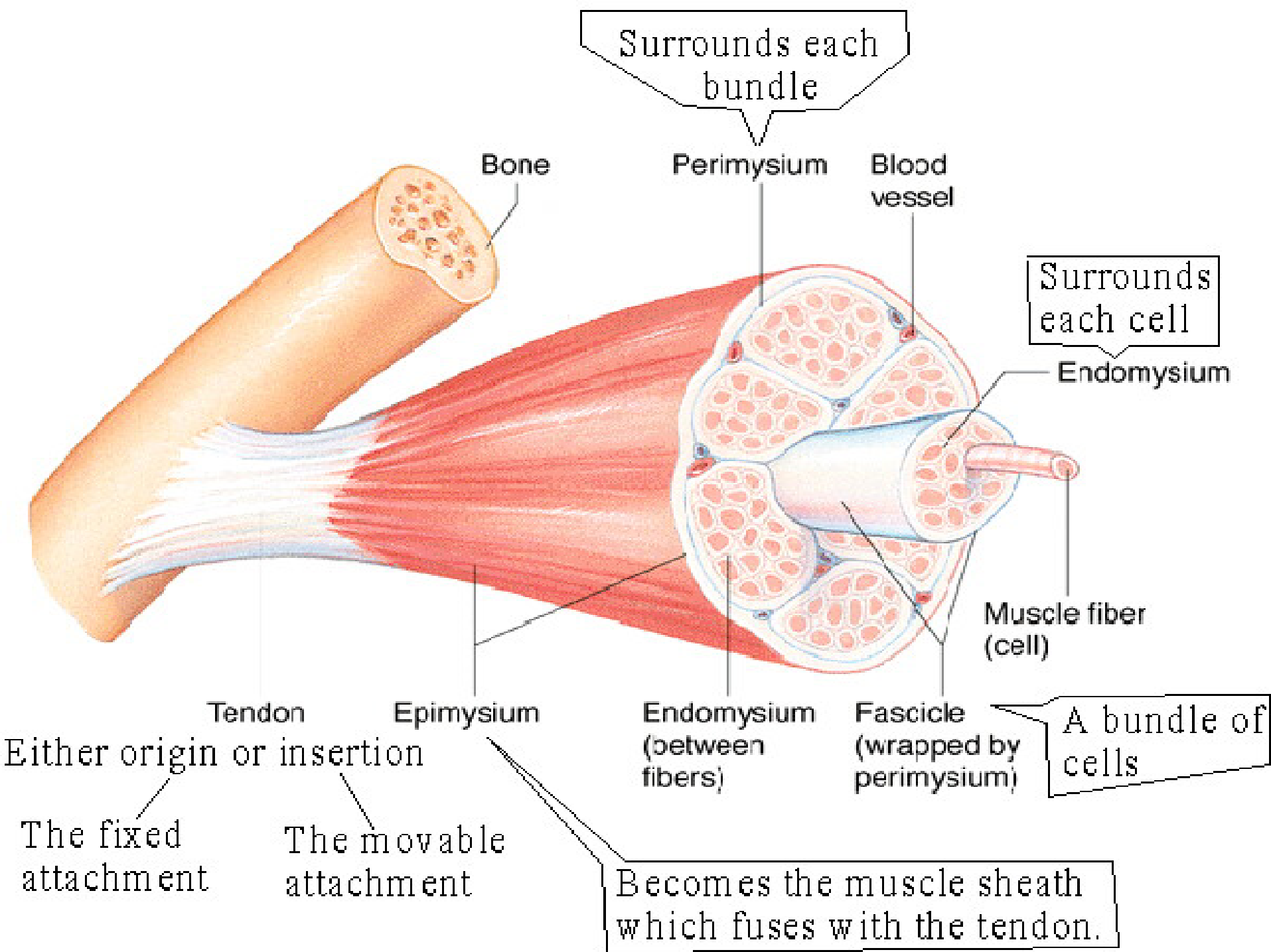




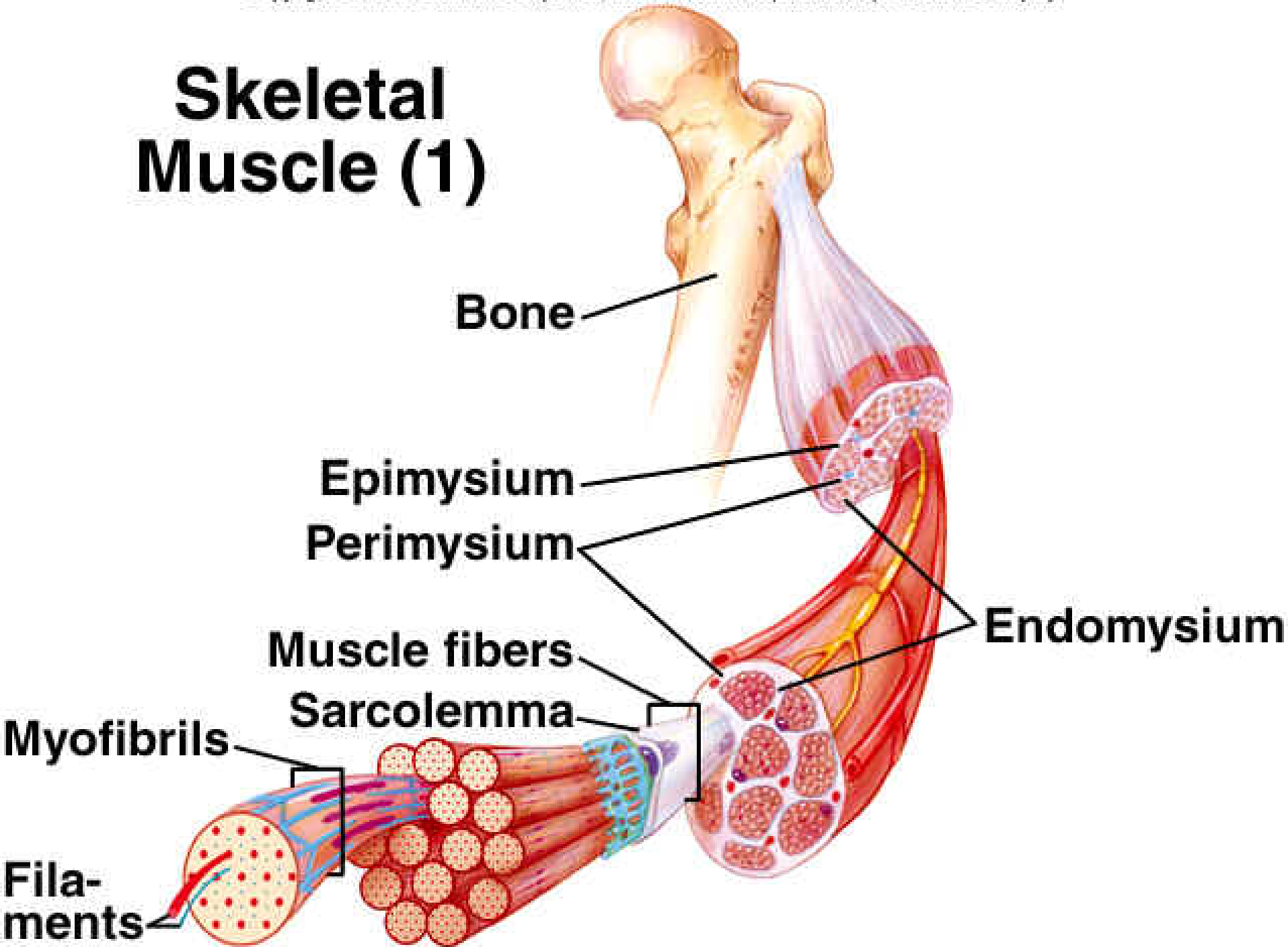
Sarcomere = the basic contractile unit



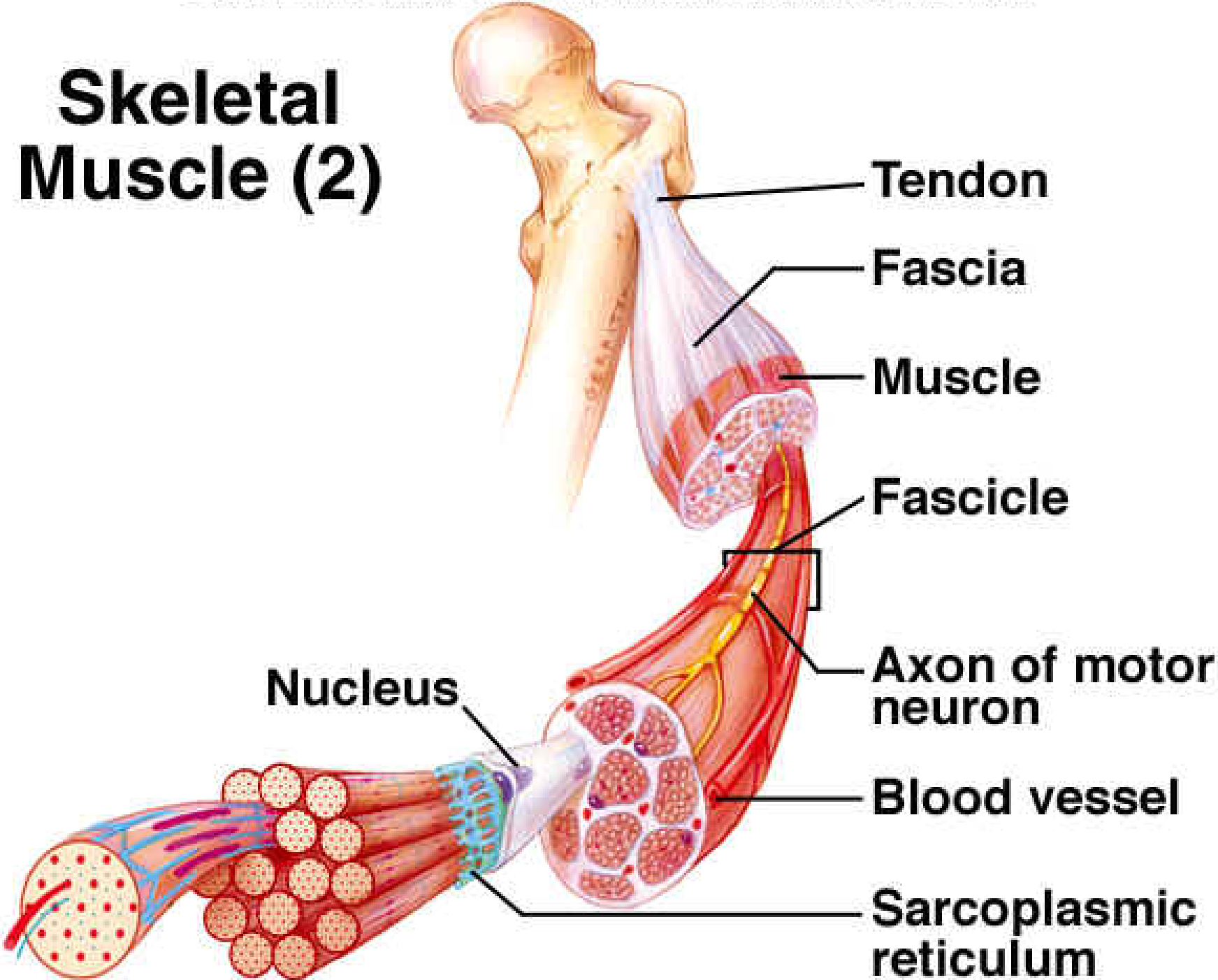



Surrounds each bundle
Bone
Perimysium
Blood vessel
Surrounds each cell
Endomysium
Muscle fiber (cell)
Tendon
Epimysium
Endomysium (between fibers)
Fascicle (wrapped by perimysium)
A bundle of cells
Either origin or insertion
The fixed attachment
The movable attachment
Becomes the muscle sheath which fuses with the tendon.

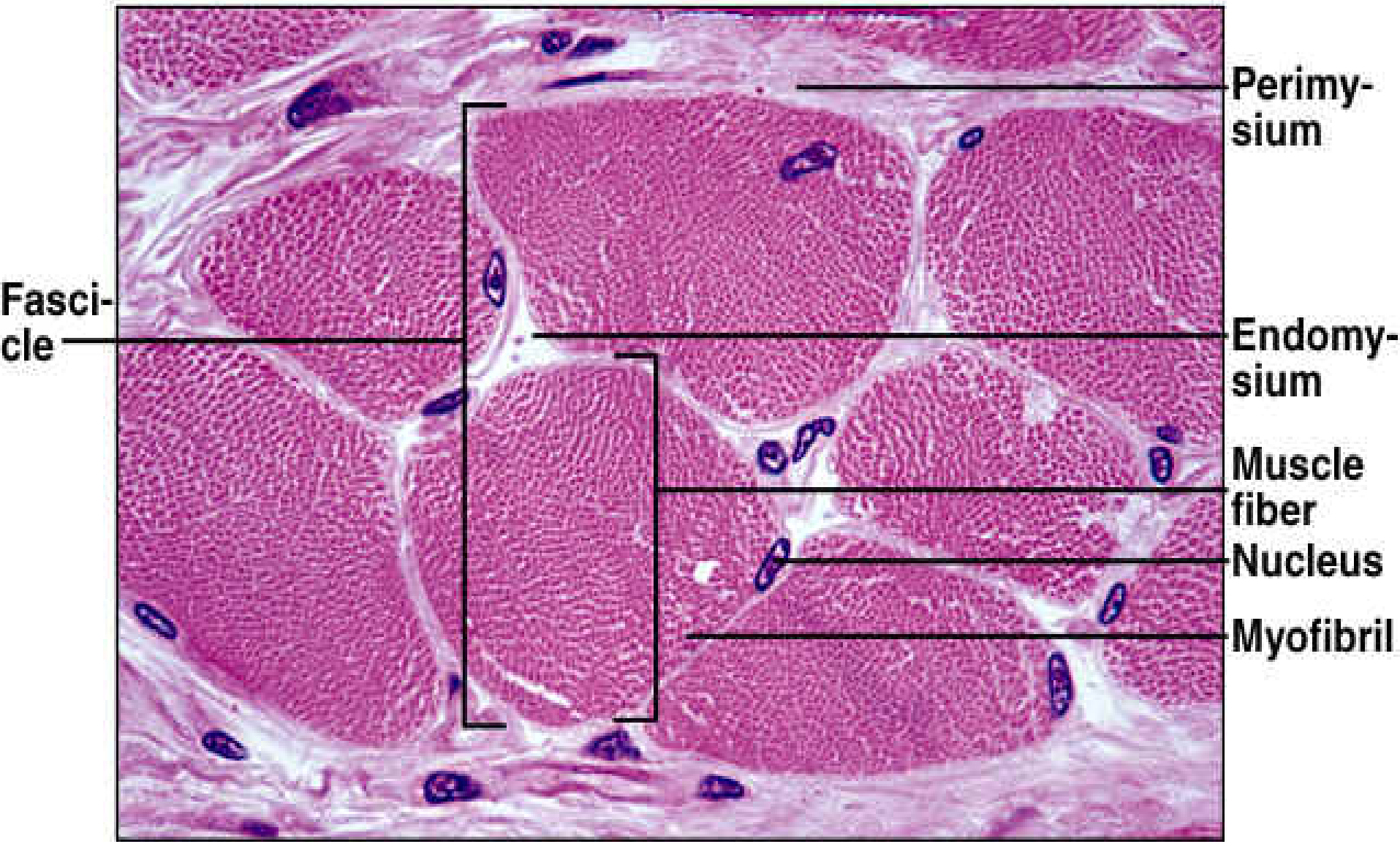
Skeletal Muscle (1)

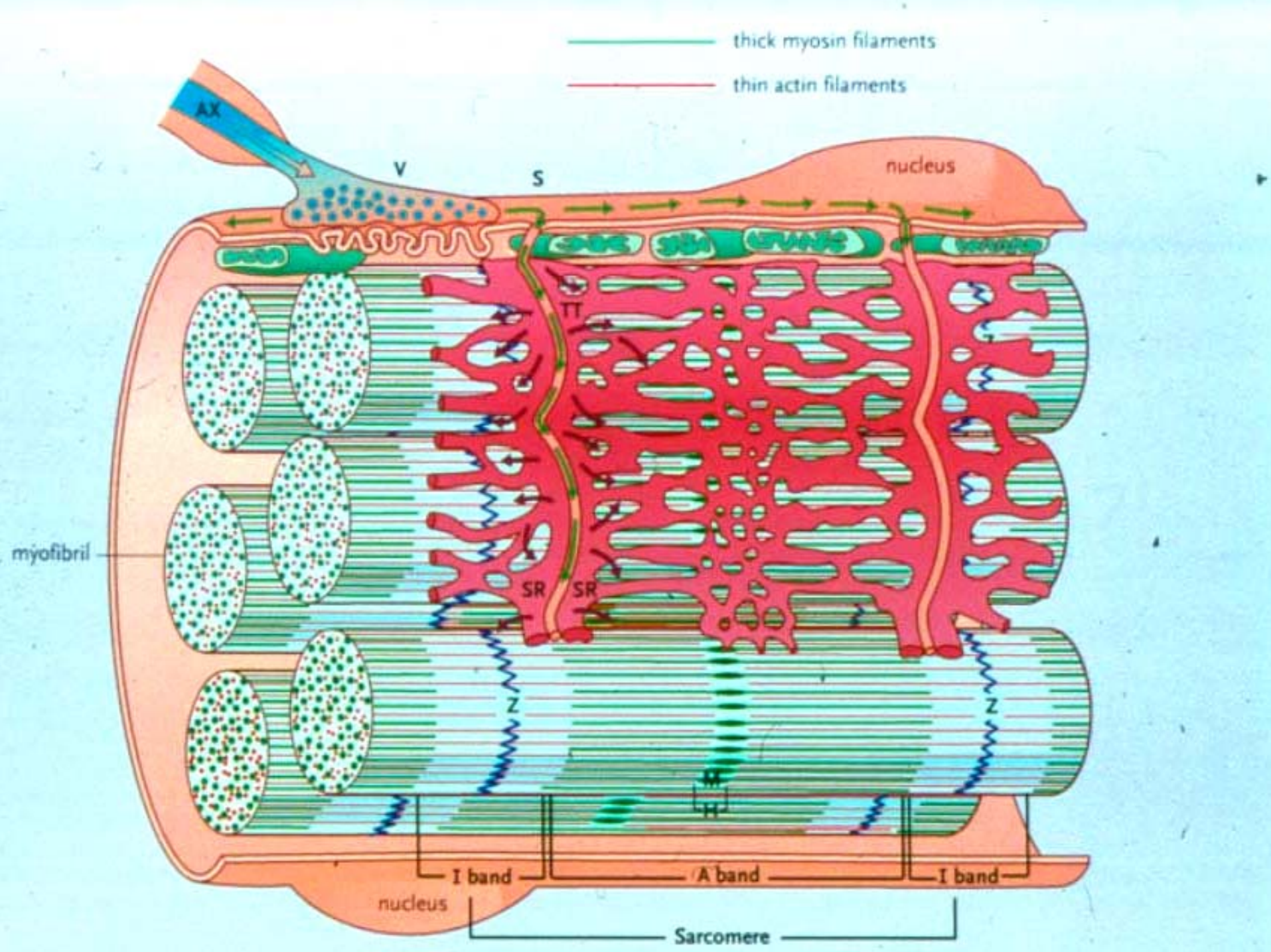


Skeletal Muscle (2)

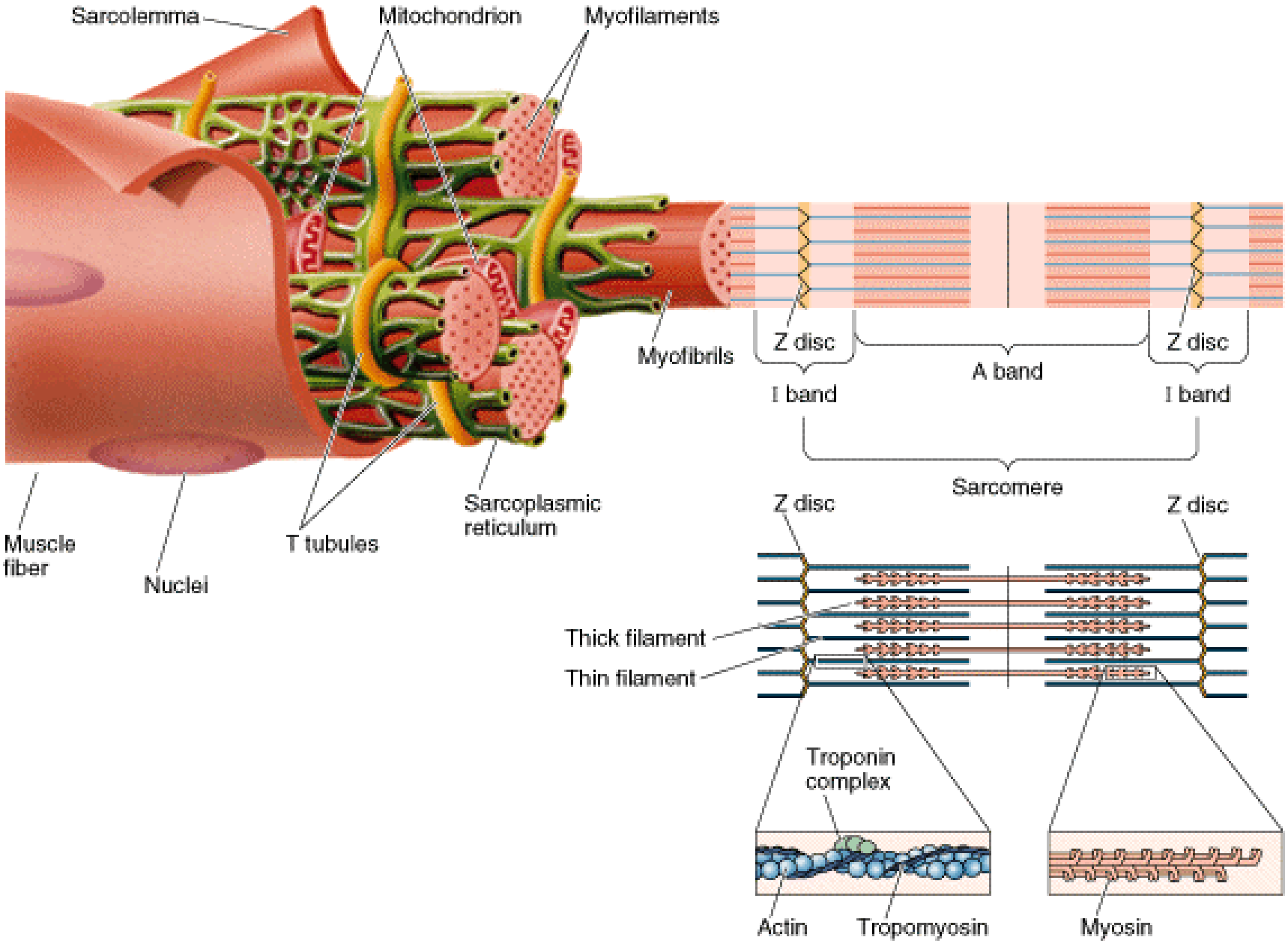


Fascicle and Perimysium

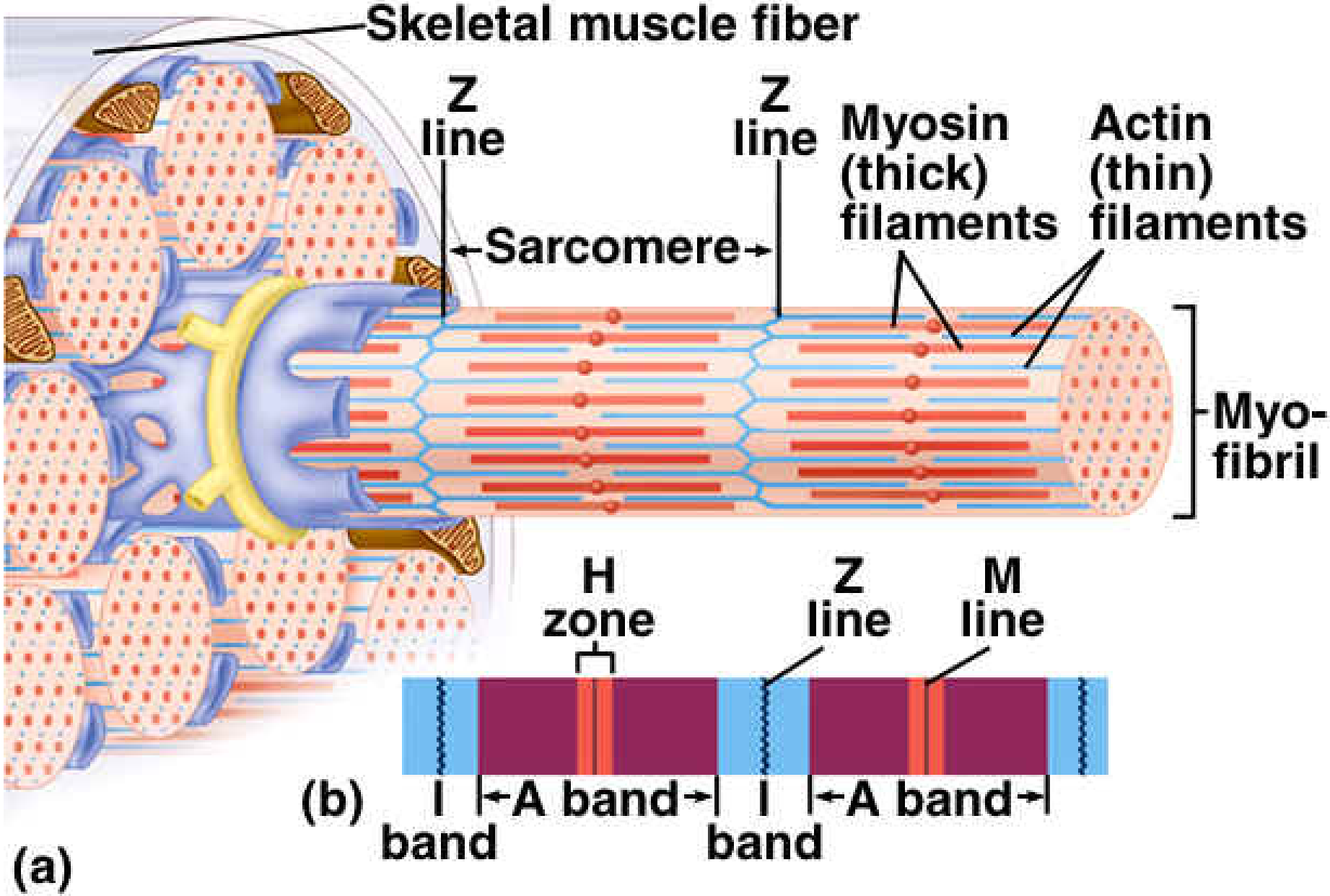


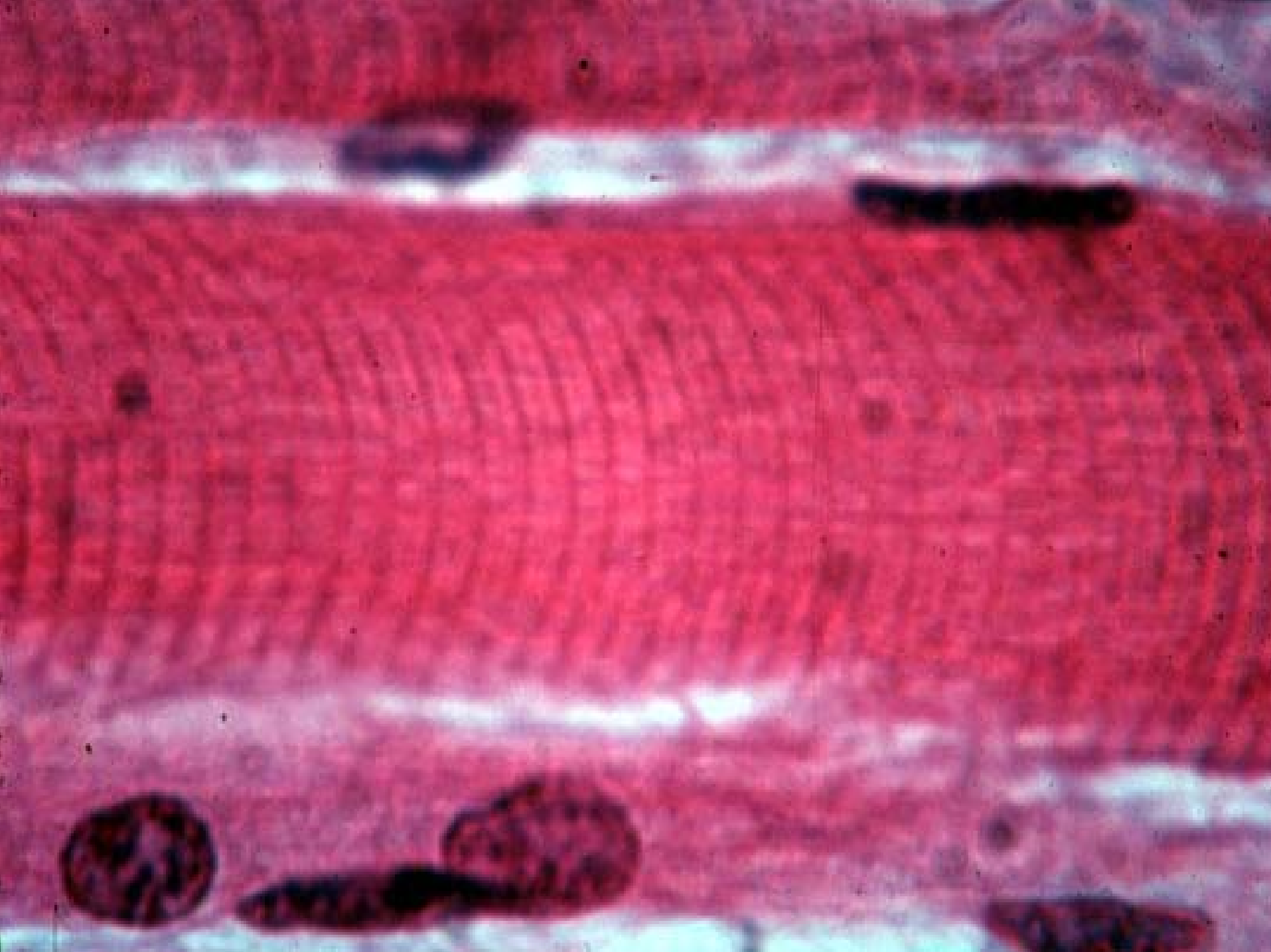

thick myosin filaments
thin actin filaments
AX
V
S
nucleus
myofibril
SR
SR
Z
Z
M
H
I band
A band
I band
nucleus
Sarcomere

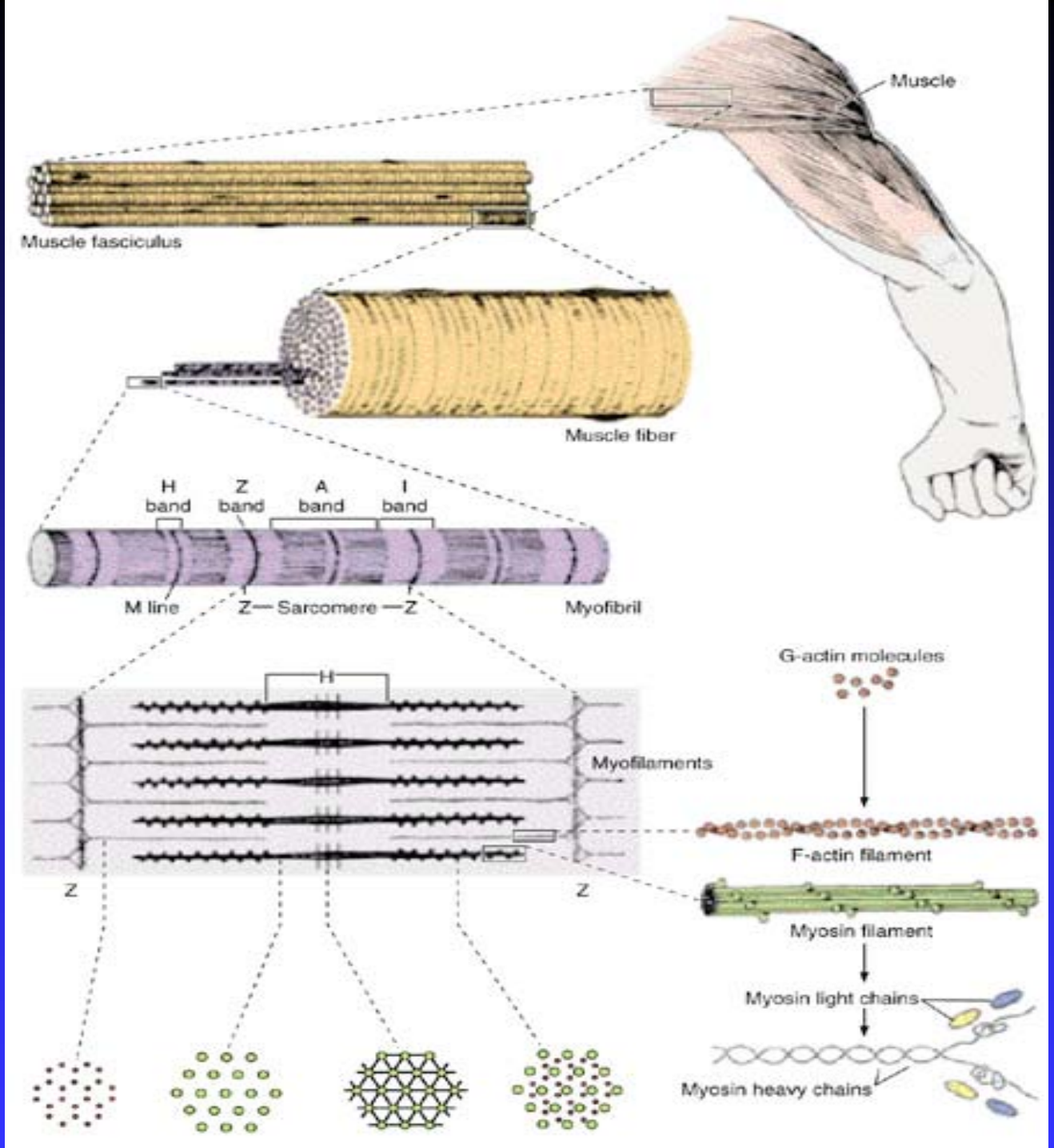
▶ Organization of a Muscle Fiber



Skeletal Muscle Fiber






Muscle
Muscle fasciculus
Muscle fiber
H band
Z band
A band
I band
M line
Z
Sarcomere
Z
Myofibril
H
Myofilaments
Z
Z
G-actin molecules
F-actin filament
Myosin filament
Myosin light chains
Myosin heavy chains

- Epimysium
  - Surrounds entire muscle
- Perimysium
  - Surrounds bundles of muscle fibers
    - Fascicles
- Endomysium
  - Surrounds individual muscle fibers

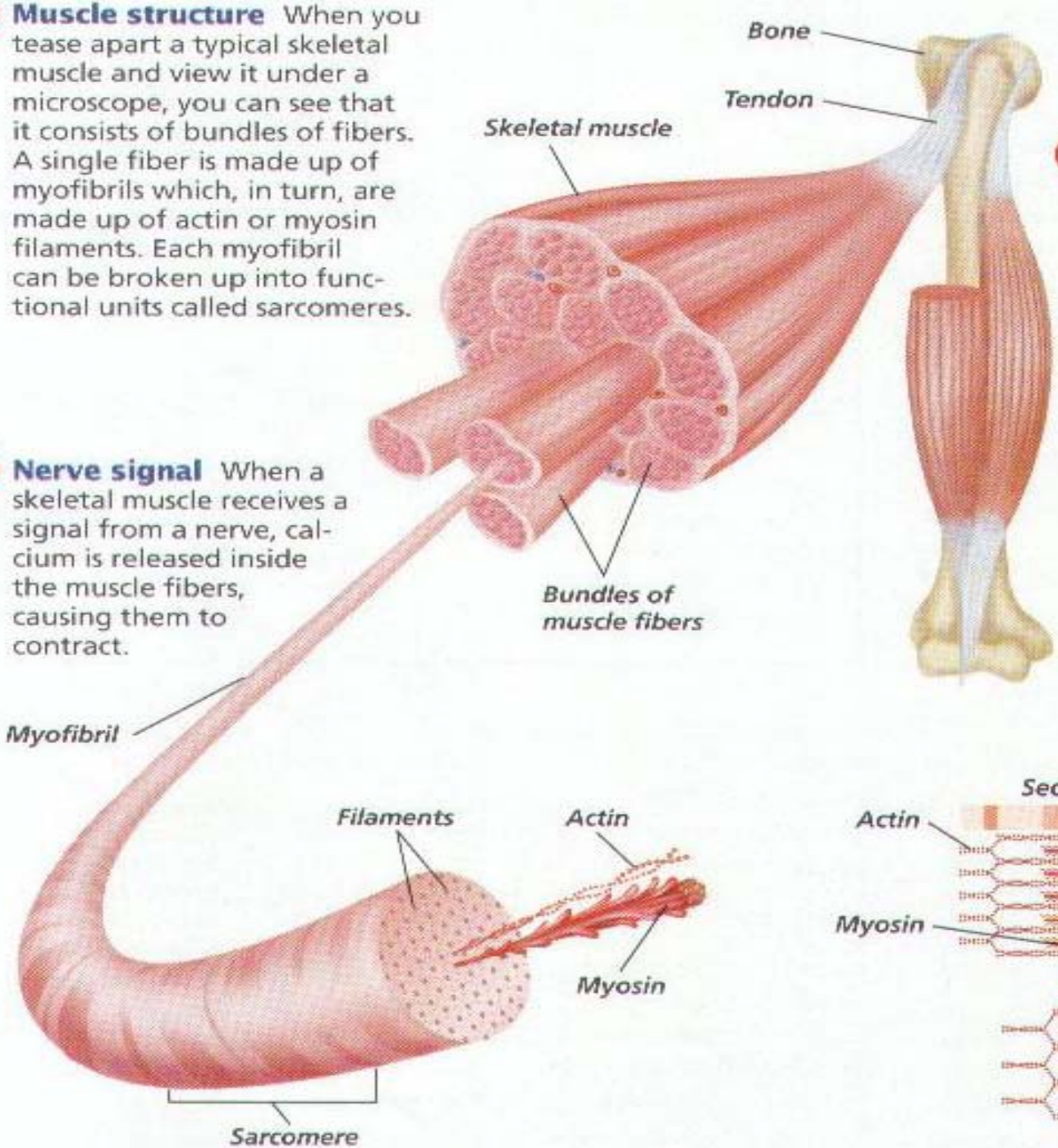
- Sarcolemma
  - Muscle cell membrane
- Myofibrils
  - Threadlike strands within muscle fibers
  - Actin (thin filament)
    - Troponin
    - Tropomyosin
  - Myosin (thick filament)

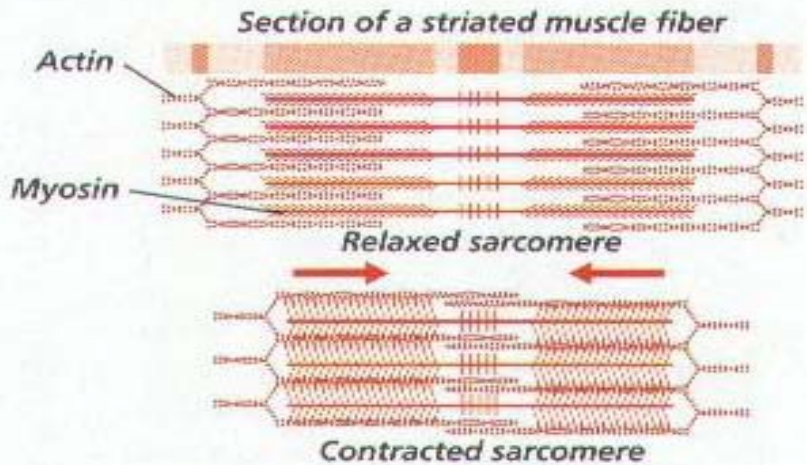
for moving your bones.

1 Muscle structure When you tease apart a typical skeletal muscle and view it under a microscope, you can see that it consists of bundles of fibers. A single fiber is made up of myofibrils which, in turn, are made up of actin or myosin filaments. Each myofibril can be broken up into functional units called sarcomeres.

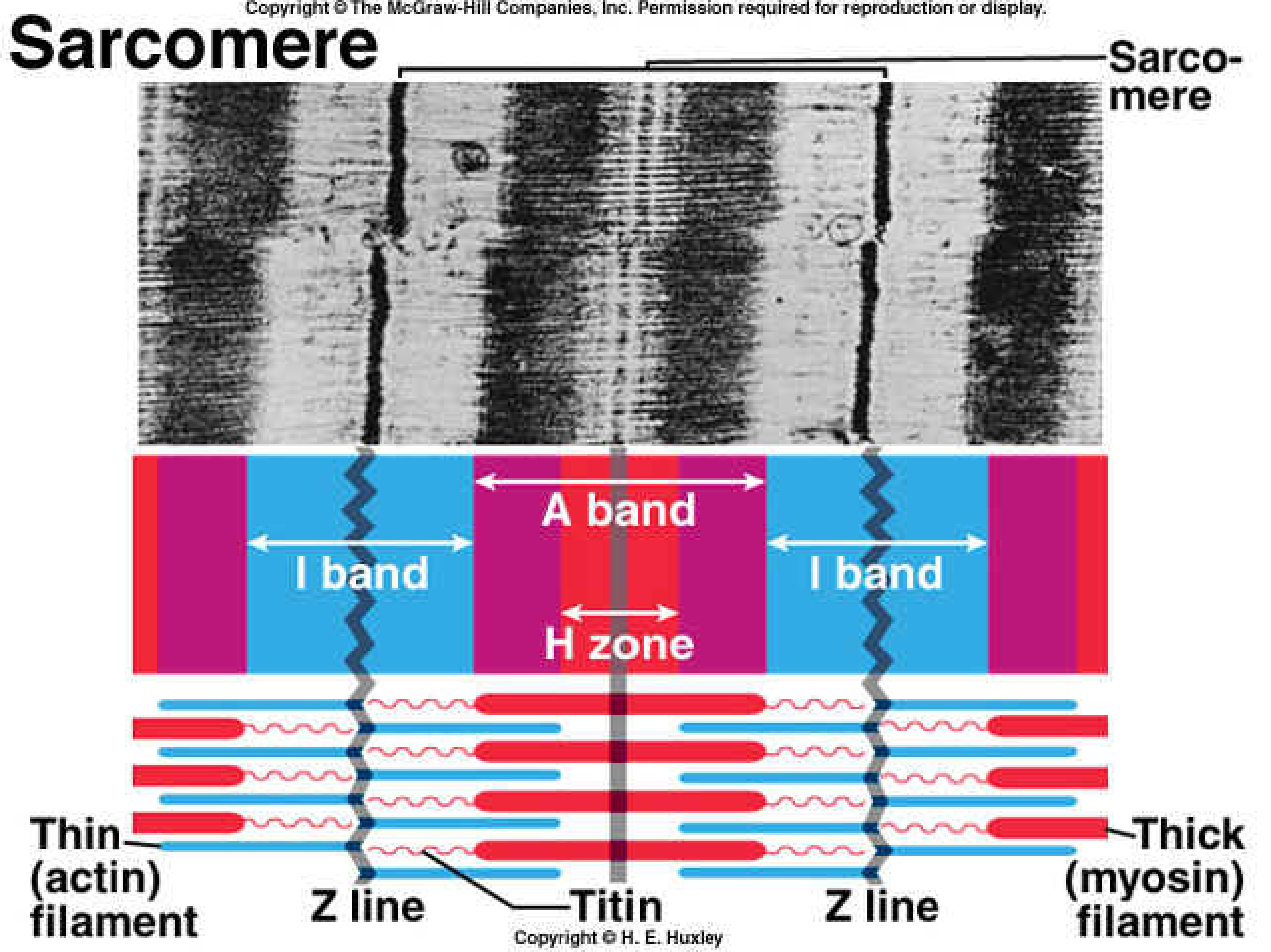
2 Nerve signal When a skeletal muscle receives a signal from a nerve, calcium is released inside the muscle fibers, causing them to contract.

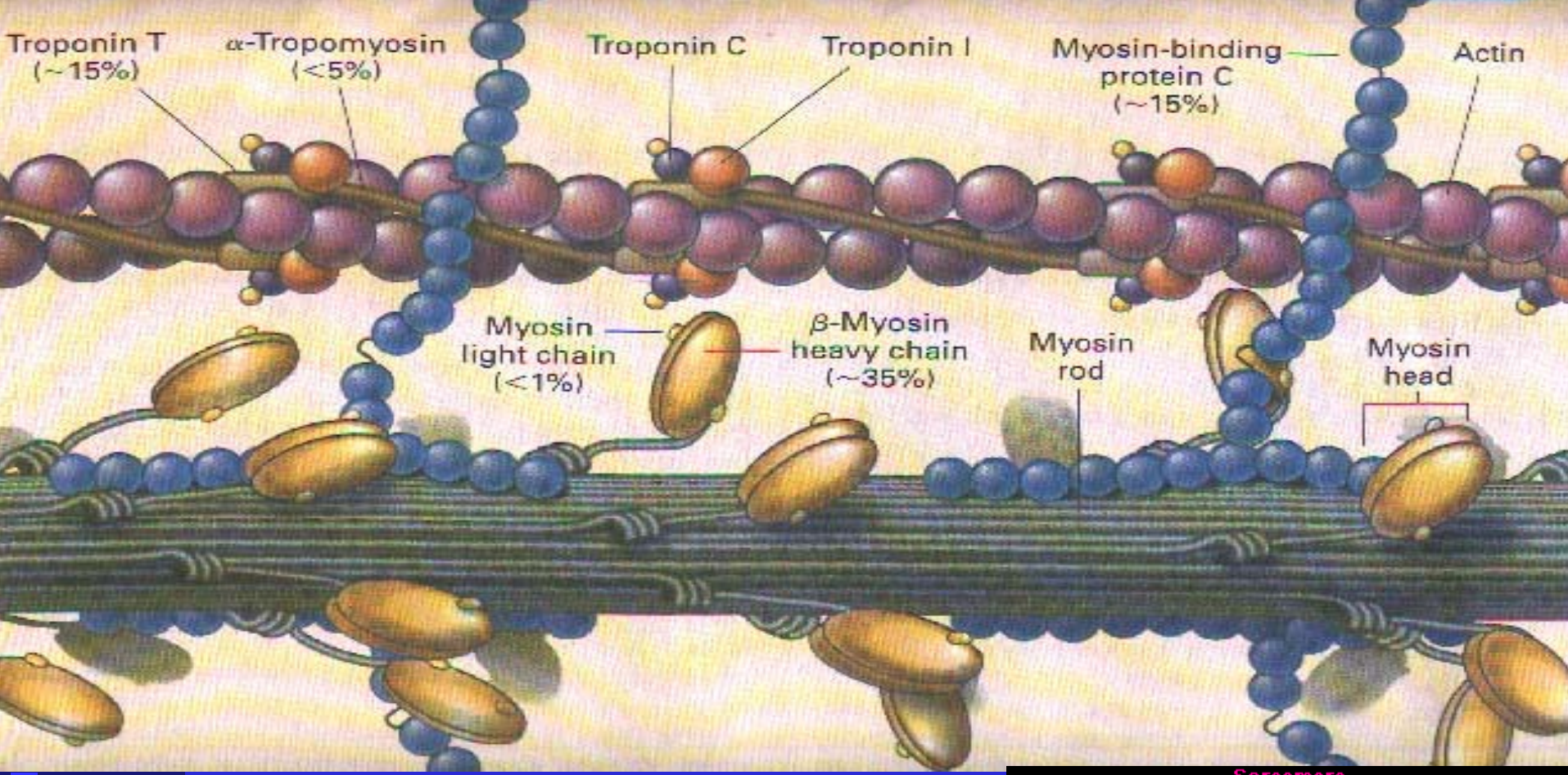
3 Contraction The presence of calcium causes attachments to form between the thick myosin and thin actin filaments. The actin filaments are then pulled inward toward the center of each sarcomere, shortening the sarco-mere and producing a muscle contraction. When the muscle relaxes, the filaments slide back into their original positions.



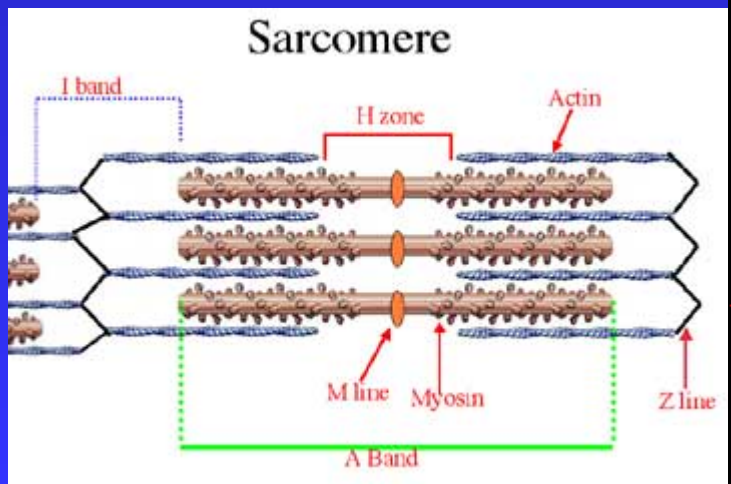


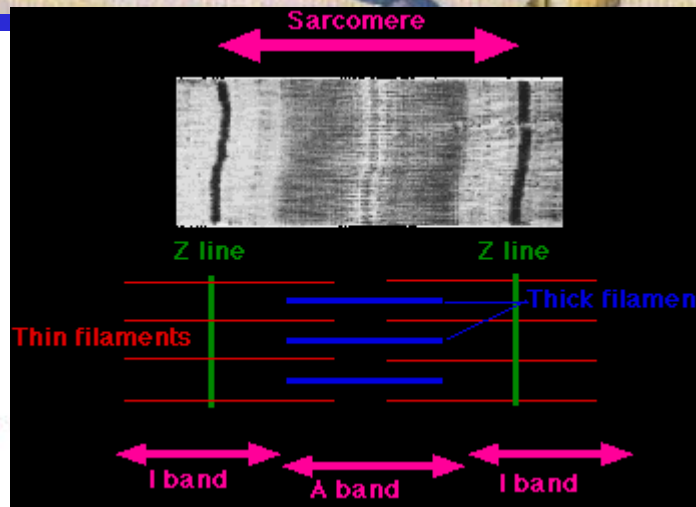
Sarcomere

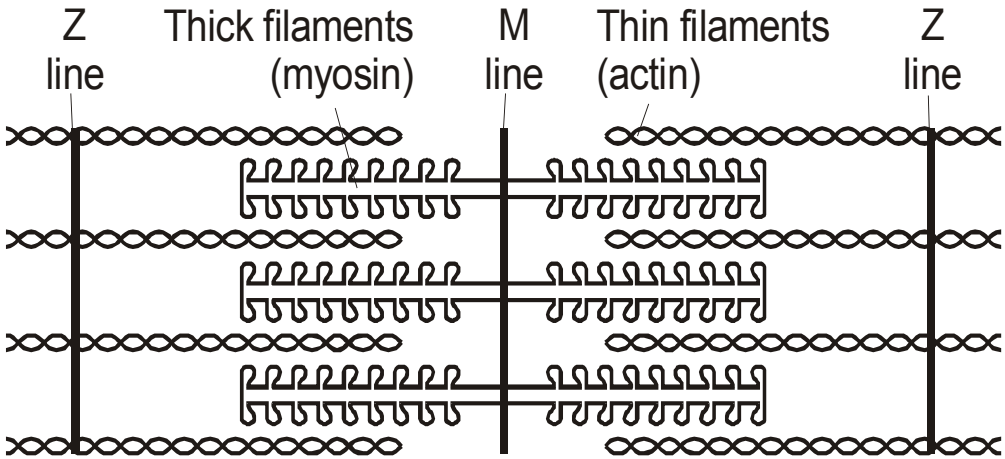


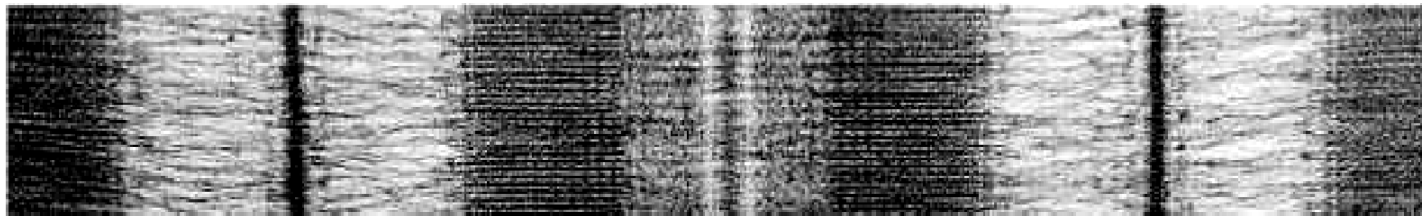

Troponin T
(~15%)
α-Tropomyosin
(<5%)
Troponin C
Troponin I
Myosin-binding
protein C
(~15%)
Actin
Myosin
light chain
(<1%)
β-Myosin
heavy chain
(~35%)
Myosin
rod
Myosin
head

Sarcomere


Sarcomere
I band
H zone
Actin
M line
Myosin
Z line
A Band


Sarcomere
Z line
Z line
Thick filamen
Thin filaments
I band
A band
I band





proteins in the Z line

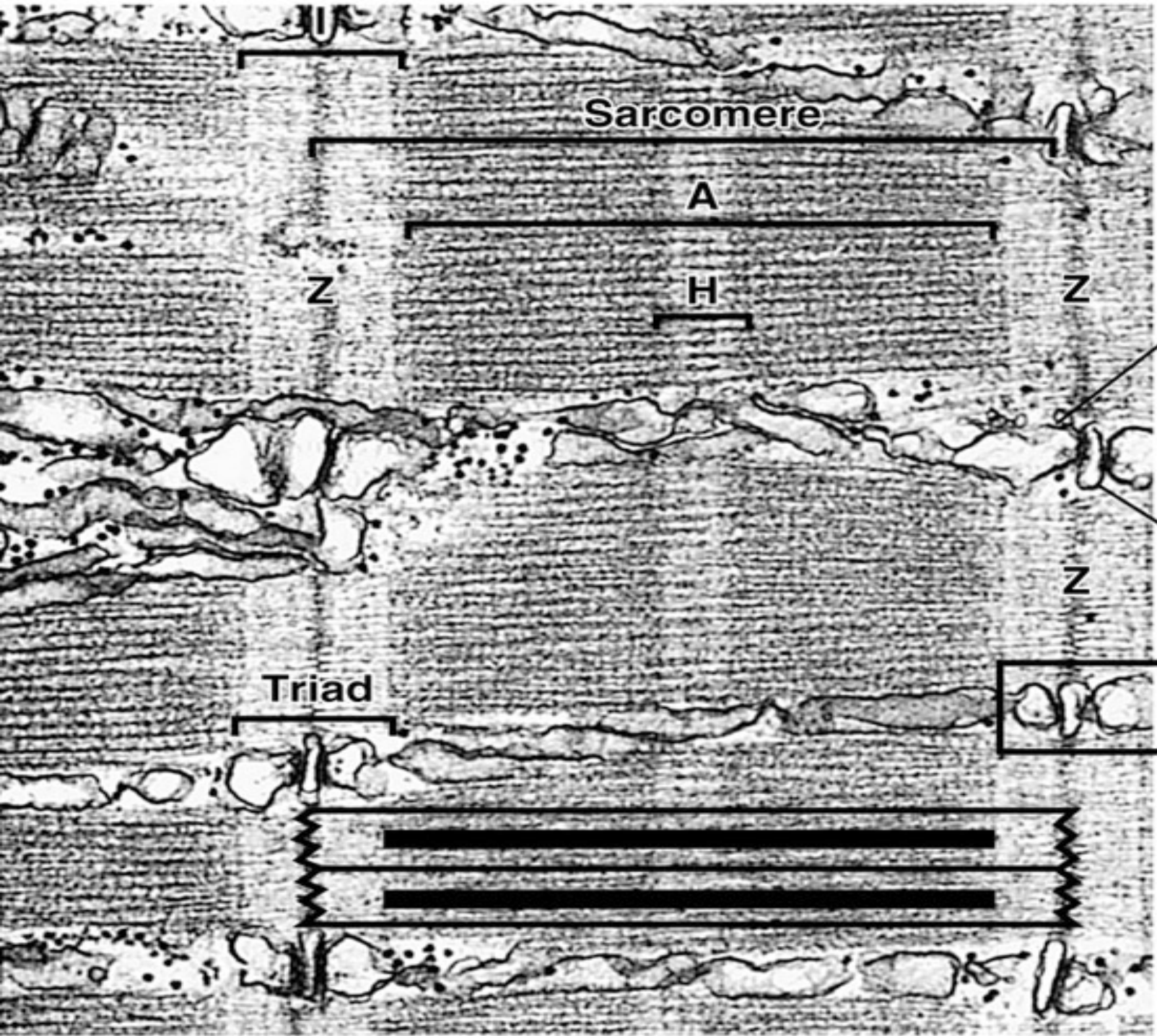
just thin filament

overlap zone - both thick & thin filaments

just thick filament

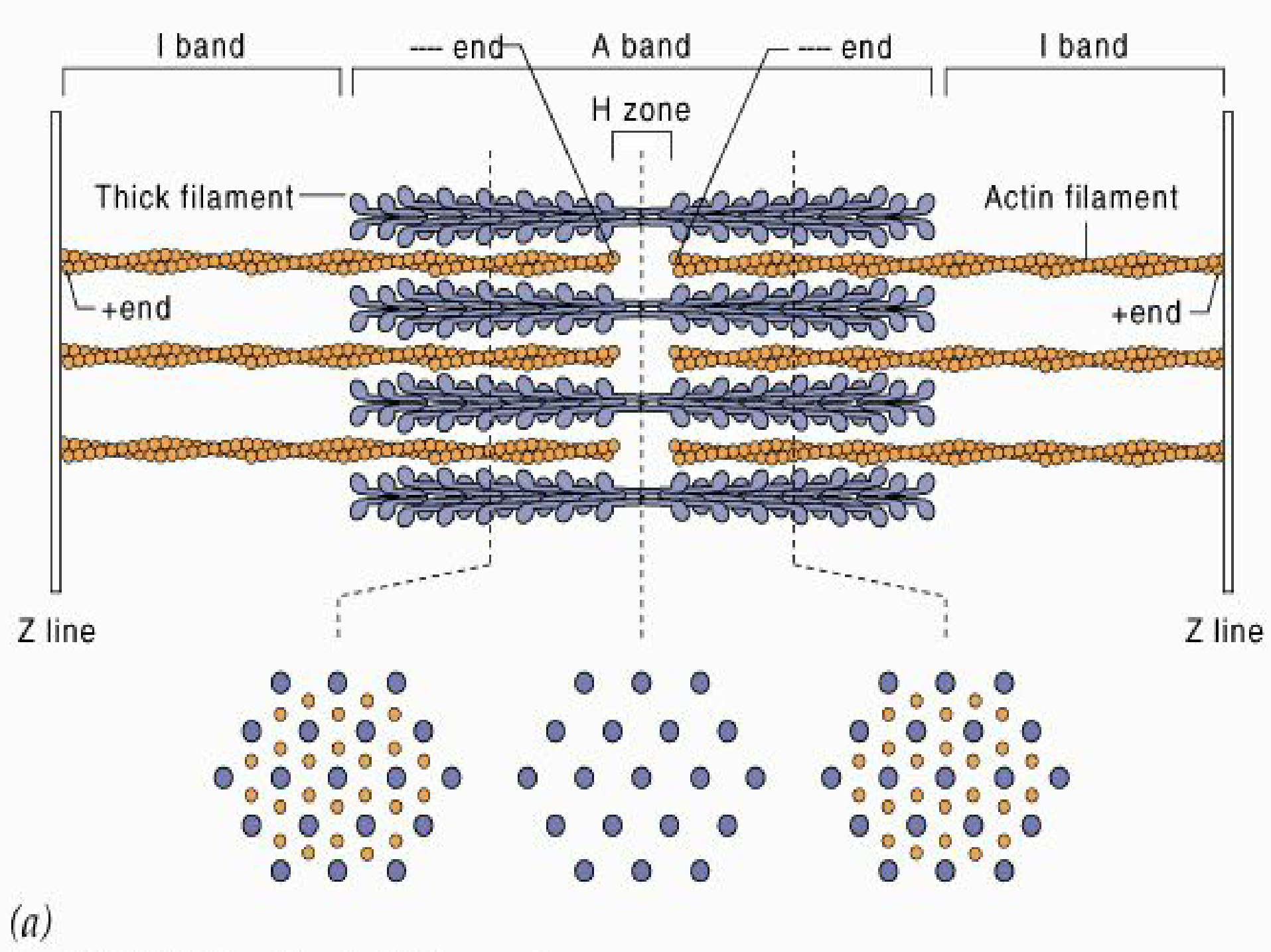
myosin bare zone - no cross bridges

proteins in the M line

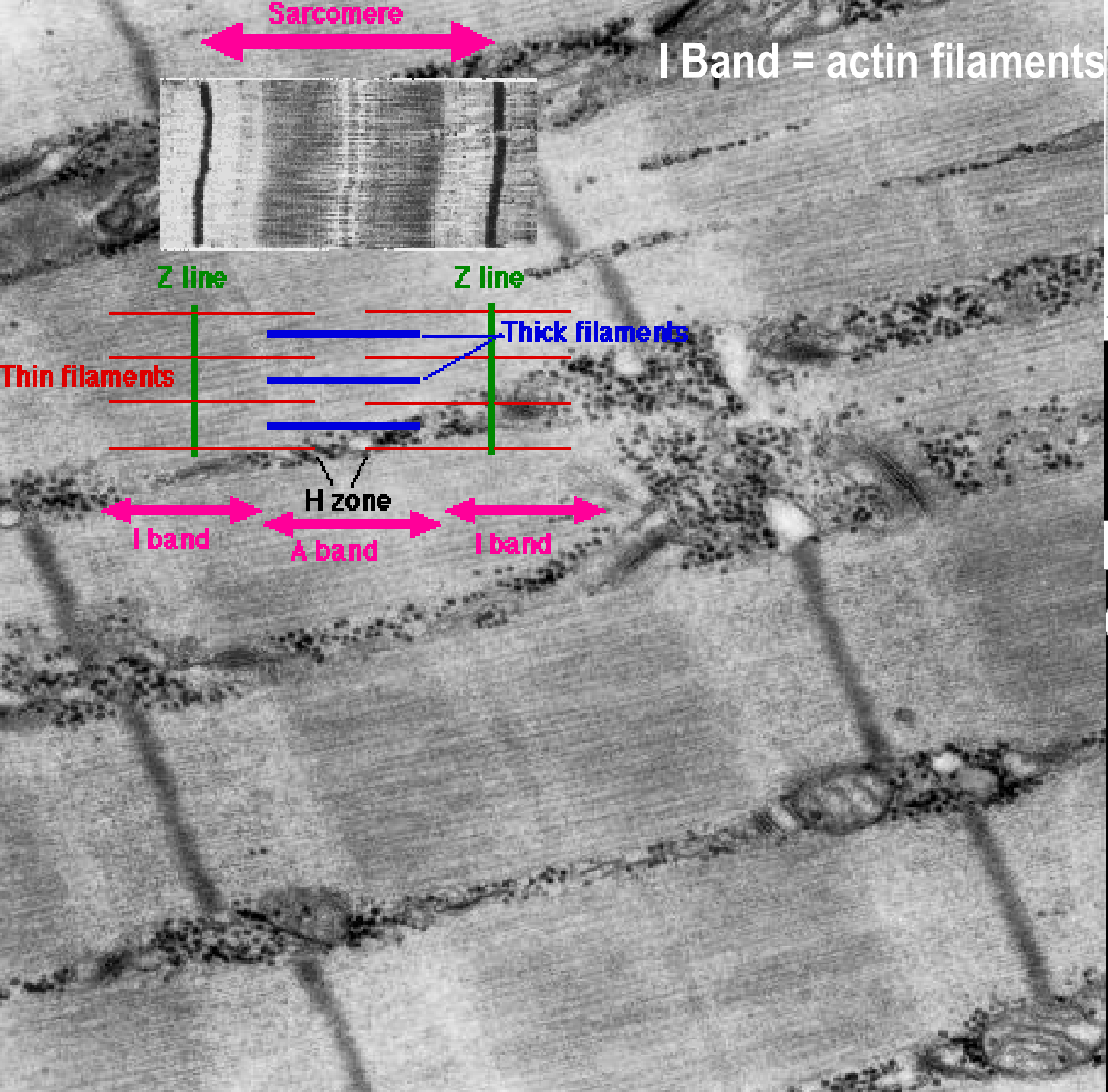

I
Sarcomere
A
Z
H
Z
Sarcoplasmic reticulum
T tubule
Z
Triad
Triad

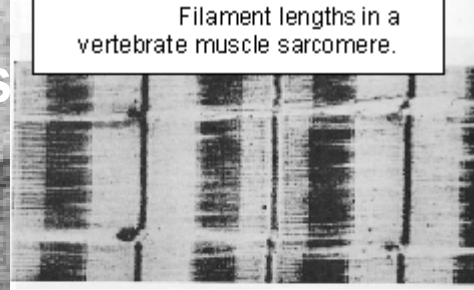
A **sarcomere** is the basic unit of a cross striated muscle's myofibril.
Sarcomeres are multi-protein complexes composed of three different filament systems.

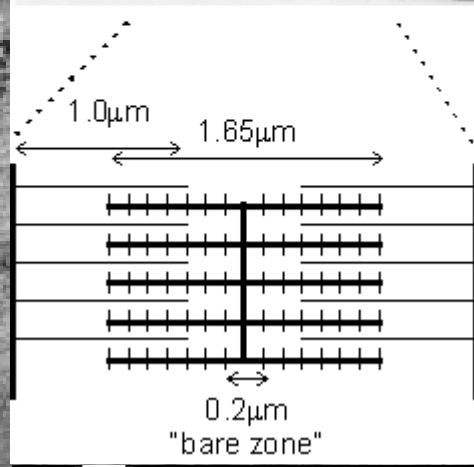
- The thick filament system is composed of myosin protein.
- The thin filaments are assembled by actin monomers.
- The elastic filament system is composed of the giant protein titin (also called connectin).

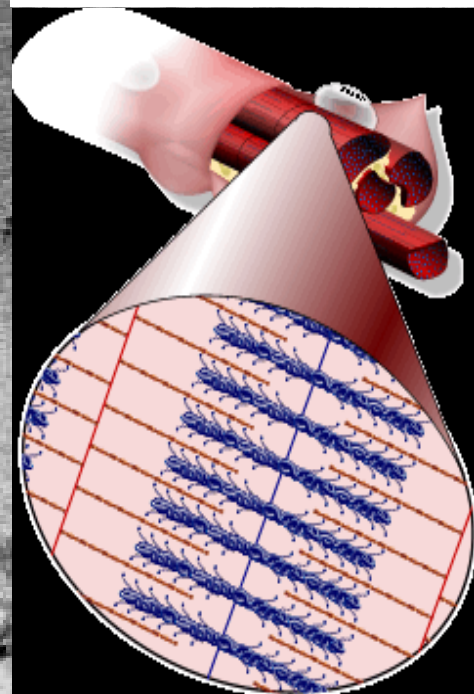

I band
--- end
A band
--- end
I band
H zone
Thick filament
Actin filament
+end
+end
Z line
Z line

(a)


Sarcomere
I Band = actin filaments
Z line
Z line
Thick filaments
Thin filaments
H zone
I band
A band
I band

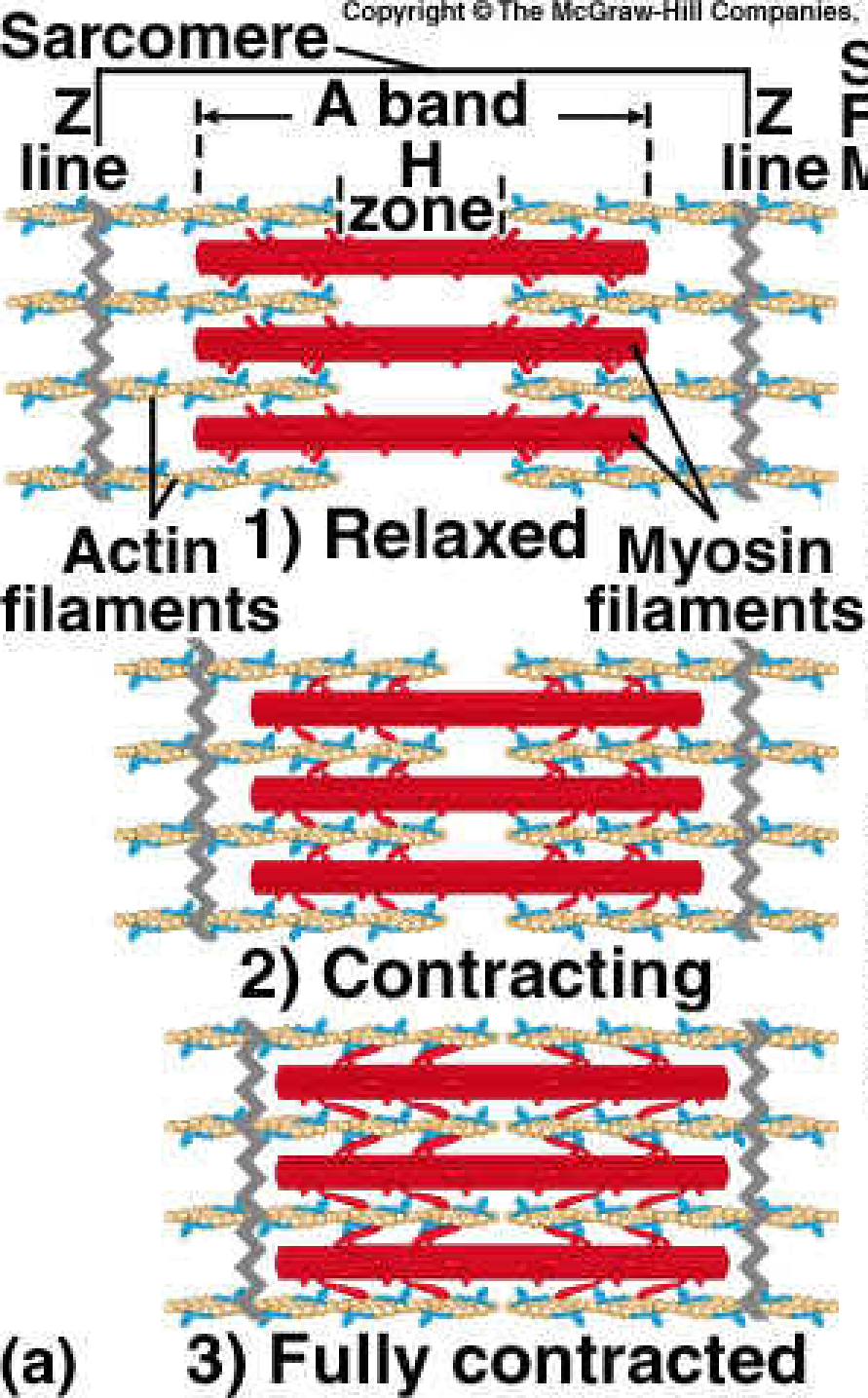

Filament lengths in a vertebrate muscle sarcomere.

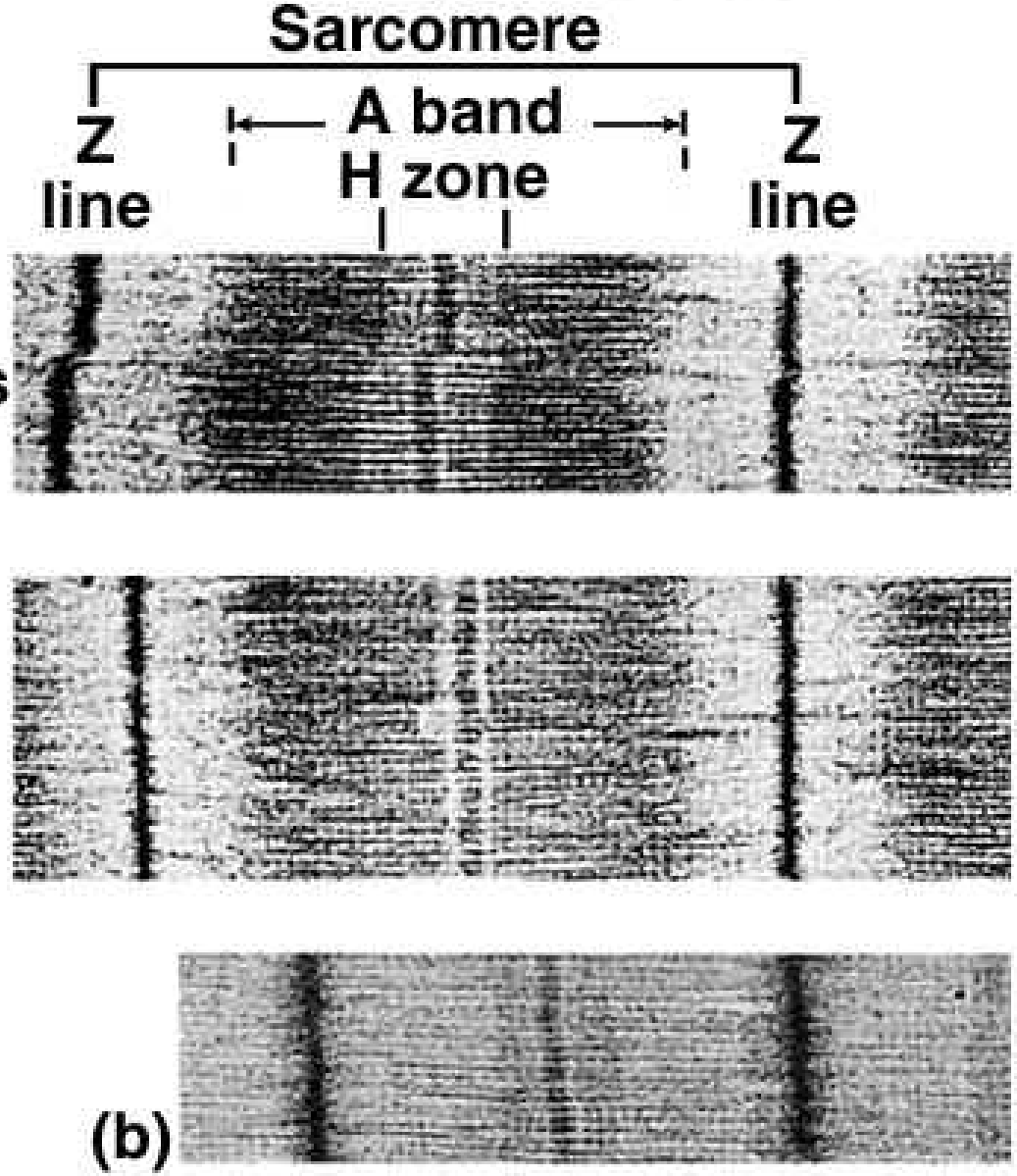

1.0µm
1.65µm
0.2µm
"bare zone"

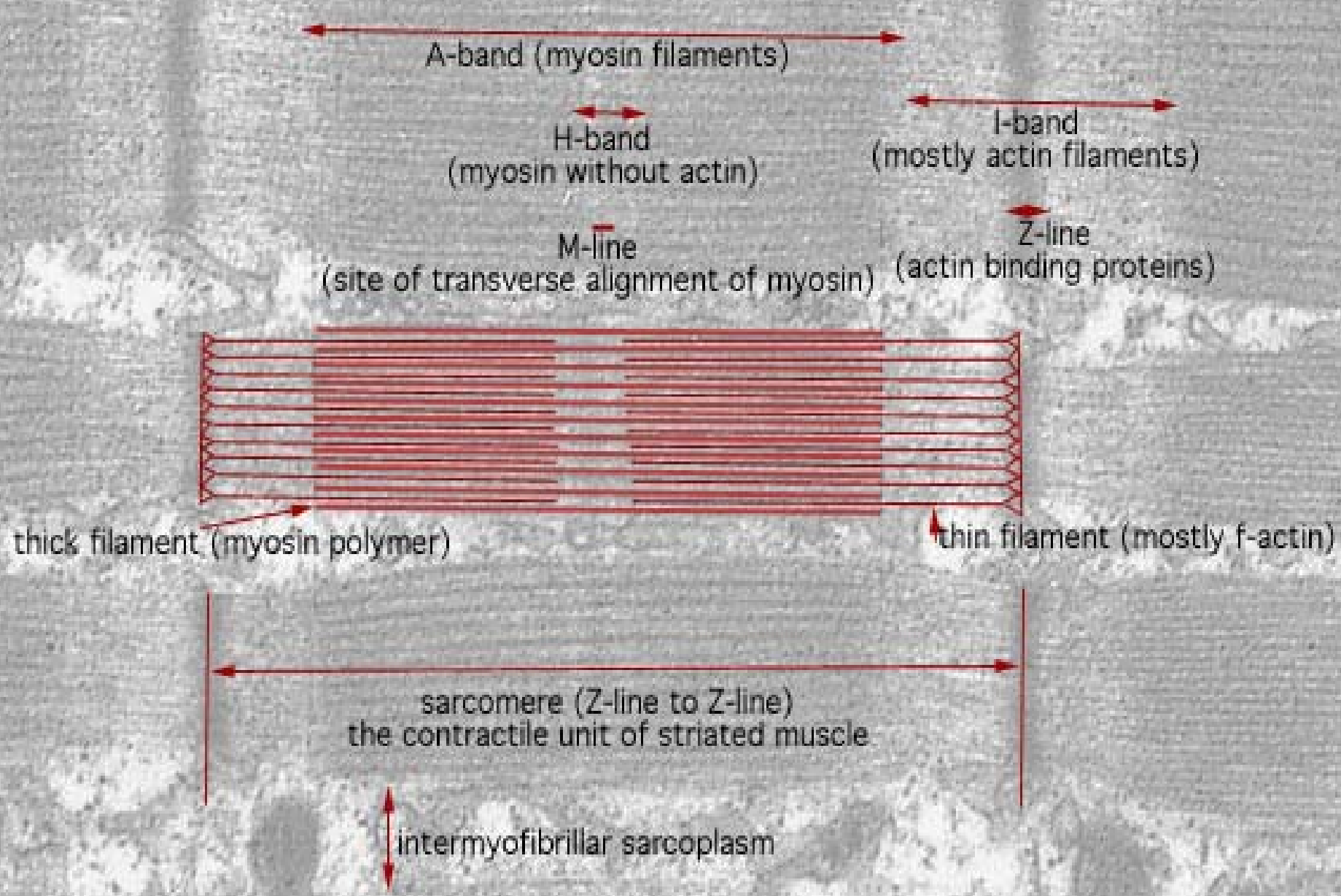


Skeletal Muscle Contraction

SLIDING FILAMENT MODEL

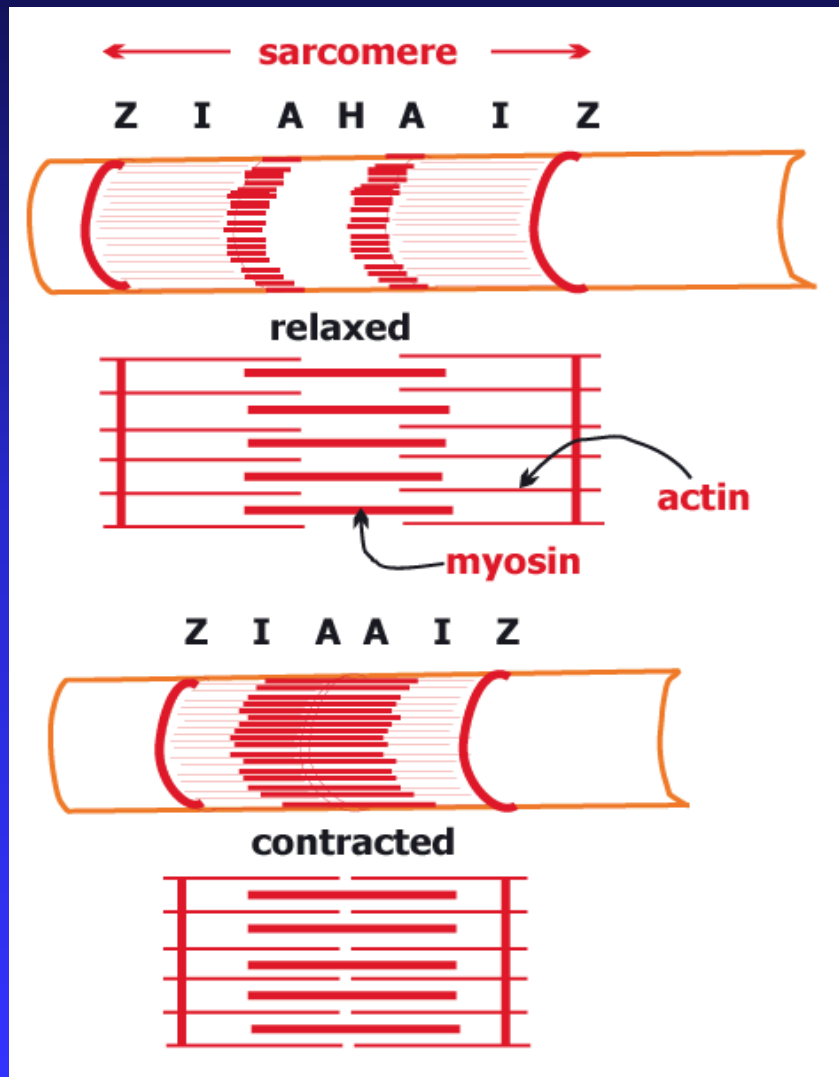





A-band (myosin filaments)
H-band
(myosin without actin)
I-band
(mostly actin filaments)
Z-line
(actin binding proteins)
M-line
(site of transverse alignment of myosin)
thick filament (myosin polymer)
thin filament (mostly f-actin)
sarcomere (Z-line to Z-line)
the contractile unit of striated muscle
intermyofibrillar sarcoplasm

Sarcomere shortens when muscle contracts

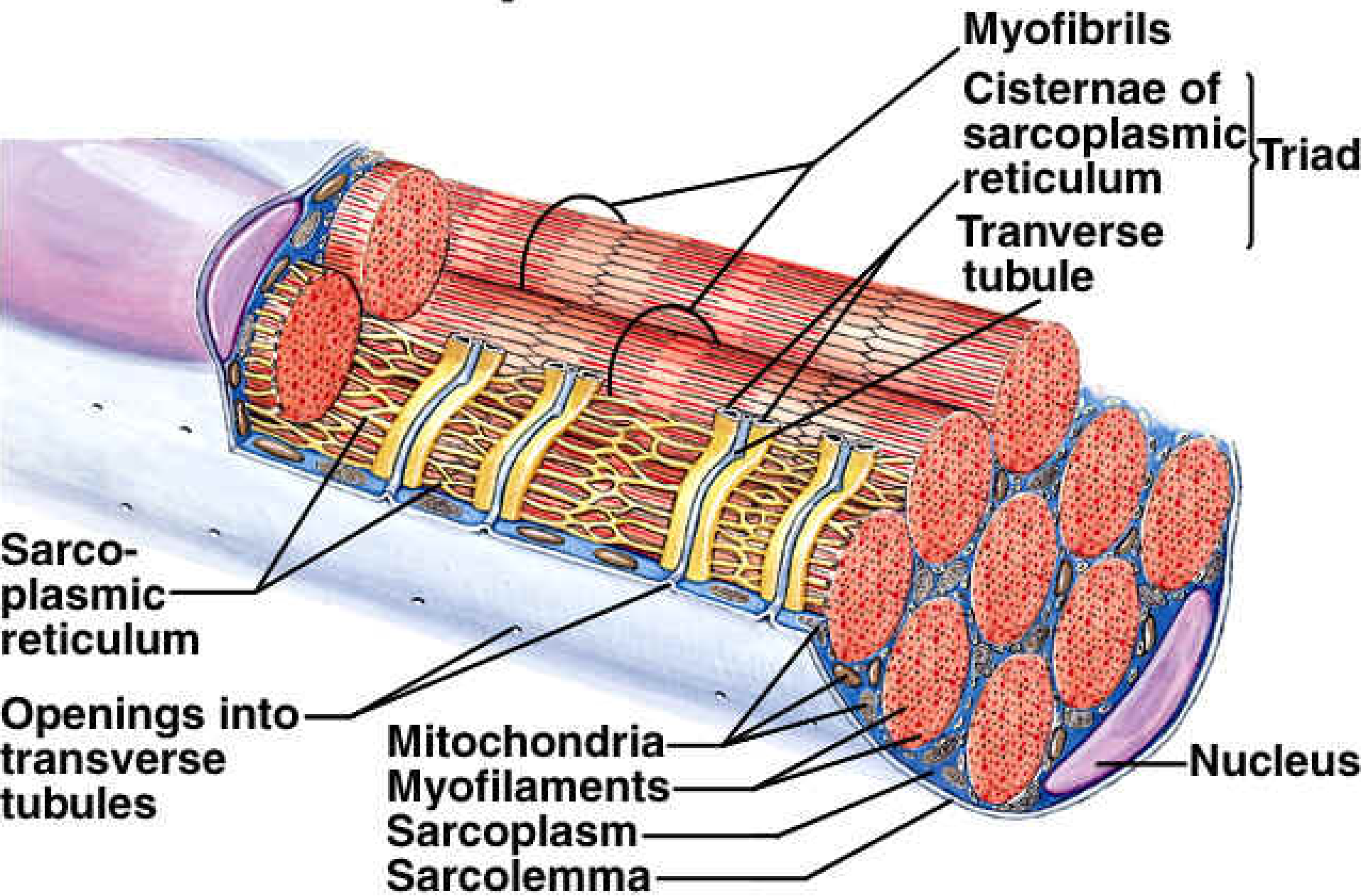
- Shortening of the sarcomeres in a myofibril produces the shortening of the myofibril
- And, in turn, of the muscle fibre of which it is a part



The sarcomeres are what give skeletal and cardiac muscles their striated appearance.

- A sarcomere is defined as the segment between two neighbouring Z-lines (or Z-discs, or Z bodies). In electron micrographs of cross striated muscle the **Z-line** (from the German "Zwischen", *between* the I bands) appears as a series of dark lines.
- Surrounding the Z-line is the region of the **I-band** (for *isotropic*).
- Following the I-band is the **A-band** (for *anisotropic*). Named for their properties under a polarizing microscope.
- Within the A-band is a paler region called the **H-band** (from the German "Heller", *bright*). Named for their properties under a polarizing microscope.
- Finally, inside the H-band is a thin **M-line** (from the German "Mittel", *middle* of the sarcomere).

Sarcoplasm Contents



The relationship between the proteins and the regions of the sarcomere are as follows:

- *Actin* filaments are the major component of the I-band and extend into the A-band.
- *Myosin* filaments extend throughout the A-band and are thought to overlap in the M-band.
- The giant protein *titin* (connectin) extends from the Z-line of the sarcomere, where it binds to the thin filament system, to the M-band, where it is thought to interact with the thick filaments. Titin (and its splice isoforms) is the biggest single protein found in nature. It provides binding sites for numerous proteins and is thought to play an important role as sarcomeric ruler and as blueprint for the assembly of the sarcomere.
- Several proteins important for the stability of the sarcomeric structure are found in the Z-line as well as in the M-band of the sarcomere.
- Actin filaments and Titin molecules are cross-linked in the Z-disc via the Z-line protein alpha-Actinin.
- The M-band proteins myomesin as well as M-protein crosslink the thick filament system (myosins) and the M-band part of titin (the elastic filaments).
- The interaction between actin and myosin filaments in the A-band of the sarcomere is responsible for the muscle contraction (sliding filament model).

- Skeletal muscles cause the skeleton to move at joints
- They are attached to skeleton by tendons.
- Tendons **transmit** muscle force to the bone.
- Tendons are made of collagen fibres & are very strong & stiff

•A skeletal muscle cell is a fibre which, along with many others, comprise a fasicle in a skeletal muscle. It is essentially what muscles are made of, containing the functional part of the muscle, the myofibril. Myofibrils are cleverly organised strands of the proteins *actin* and *myosin*, which work together to cause shortening of the muscle.

Peripheral nuclei is a characteristic feature of skeletal muscle cells, and shows how these cells originally came from lots of young muscle cells fused together. They are essential since they contain the code for producing protein, which enables the actin and myosin of the myofibrils to be replaced when necessary.

Mitochondria are rampant in muscle cells as they are the energy factories of the cell, producing lots of energy for the costly process of muscle contraction.

The **sacroplasm** is the name given to the cytoplasm of the muscle cell - it is simply the mixture which fills the spaces between the other parts of the cell. The **sarcolemma** is the membrane that surrounds the muscle fibre. It has in-growths known as T-tubules in places, which enables signals in the form of action potentials to penetrate down into the cell and activate the sarcoplasmic reticulum.

Muscle Classification

Red Muscle vs. White Muscle

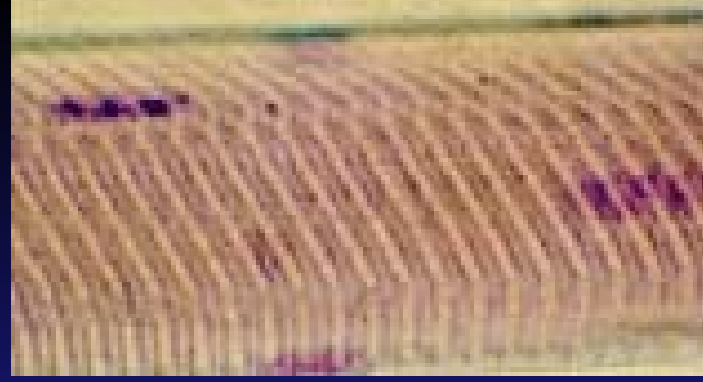
- Red muscle has more myoglobin, similar to hemoglobin, than white muscle.
- White muscle is better for quick bursts of motion while red is better for sustained motion.
- The two categories are somatic muscles which move bone and cartilage and visceral muscles which control the actions of organs, vessels and ducts.

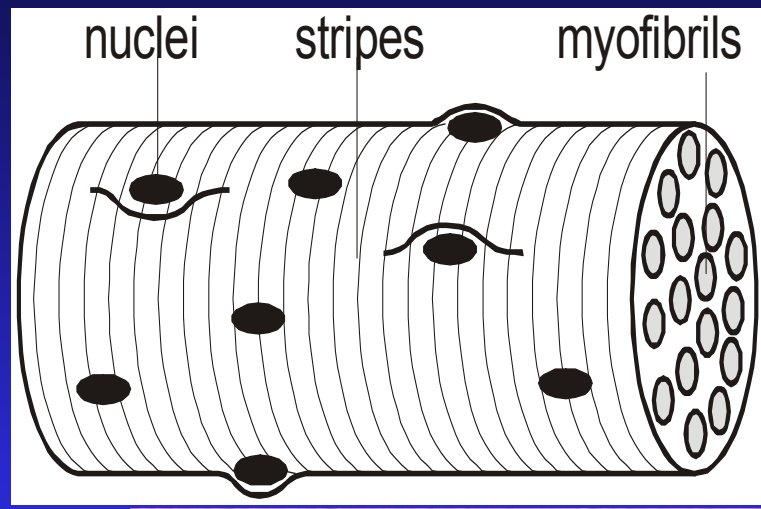
Antagonistic Muscle Action

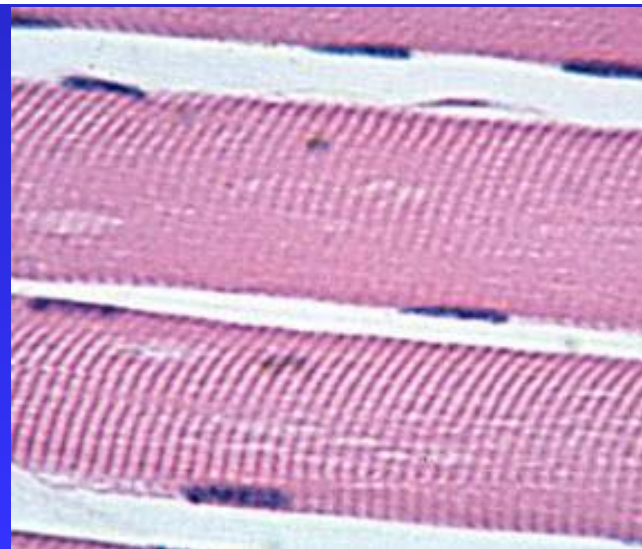
- Muscles are either contracted or relaxed
- When contracted the muscle exerts a pulling force, causing it to shorten
- Since muscles can only pull (not push), they work in pairs called *antagonistic muscles*
- The muscle that bends the joint is called the *flexor* muscle
- The muscle that straightens the joint is called the *extensor* muscle

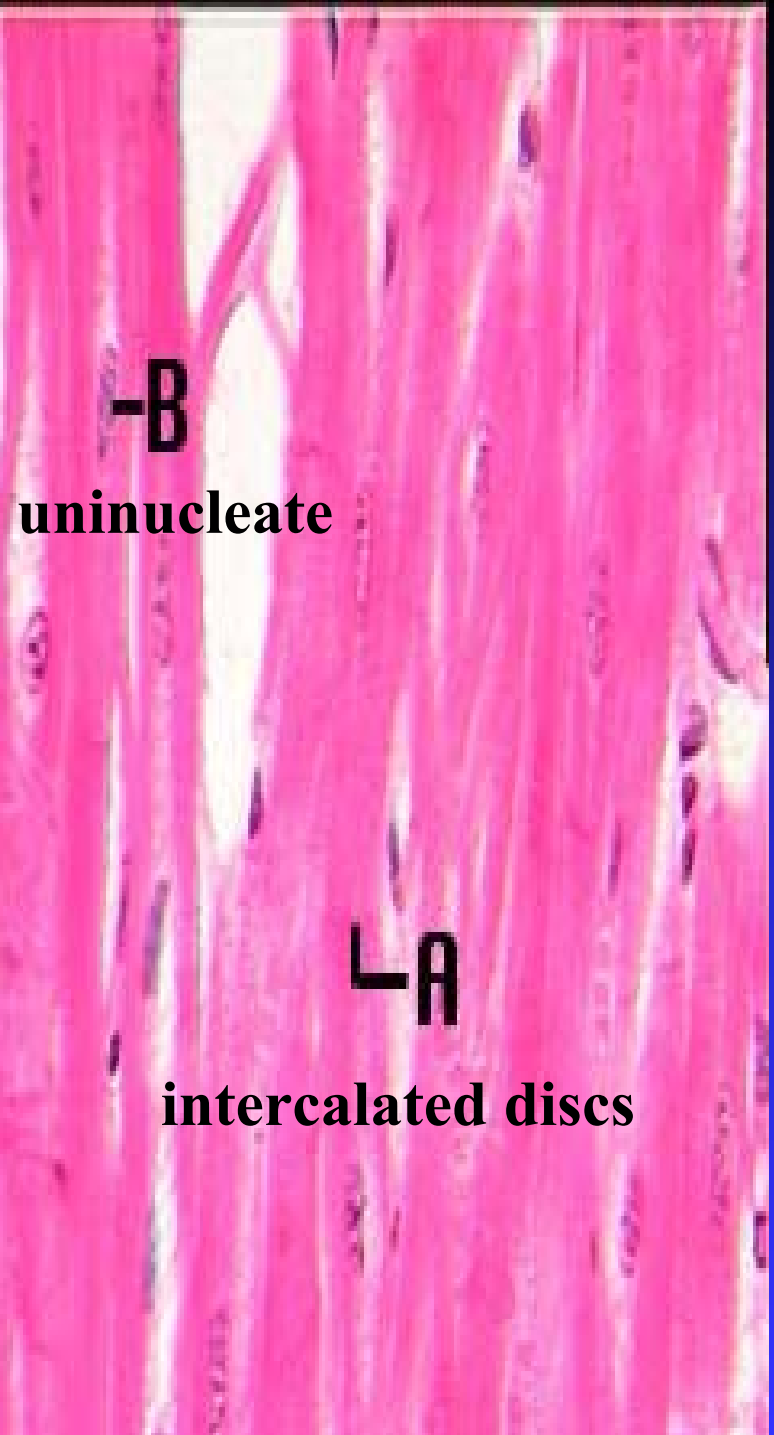
Muscle Structure

- Each muscle fibre is actually a single muscle cell
- This cell is approx 100 μm in diameter & a few cm long
- These giant cells have many nuclei
- Their cytoplasm is packed full of *myofibrils*
- These are bundles of protein filaments that cause contraction
- Sarcoplasm (muscle cytoplasm) also contains mitochondria to provide energy for contraction







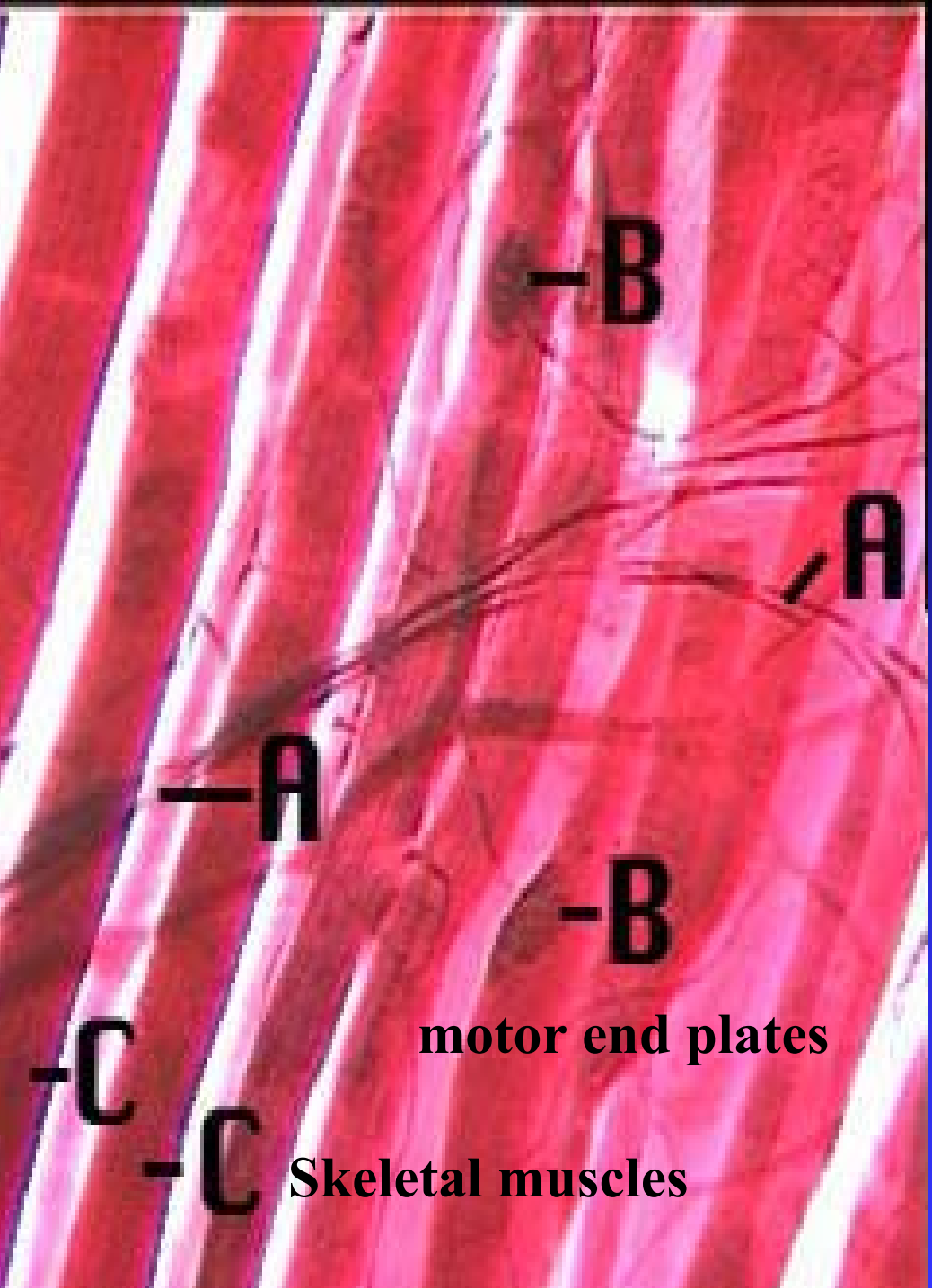


CARDIAC MUSCLE

Cardiac muscle cells branch, are striated, are uninucleate (B) and have **intercalated discs** (A).

Locations: heart

Function: involuntary, rhythmic contraction



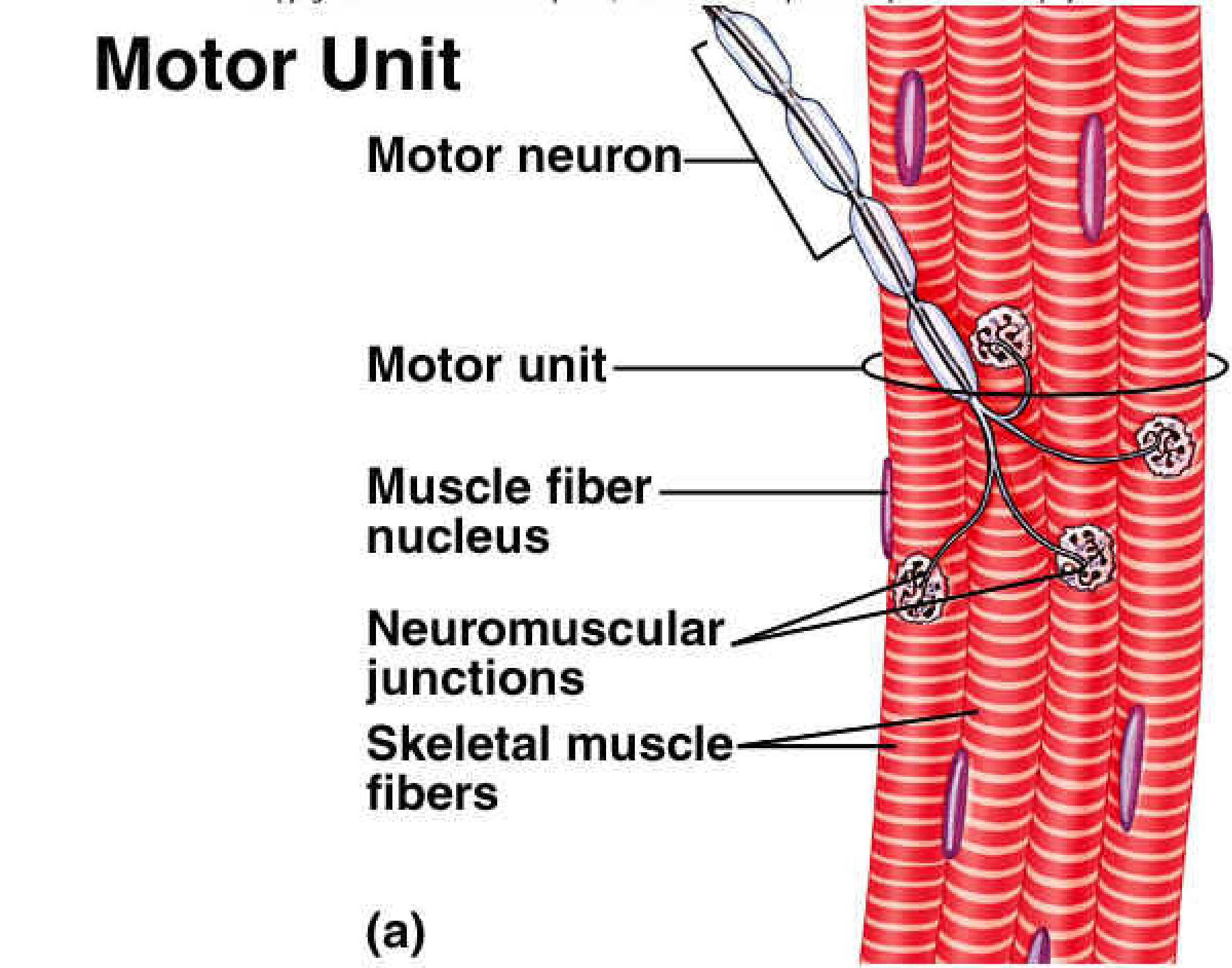
MOTOR END PLATE

Skeletal muscles (C) are stimulated by nerve impulses carried by motor neurons.

The **axon** (A) that carries the impulse away from the nerve body ends on muscle fibers in little pads called **motor end plates** (B).

Motor end plate= sarcolemma at neuromuscular junction

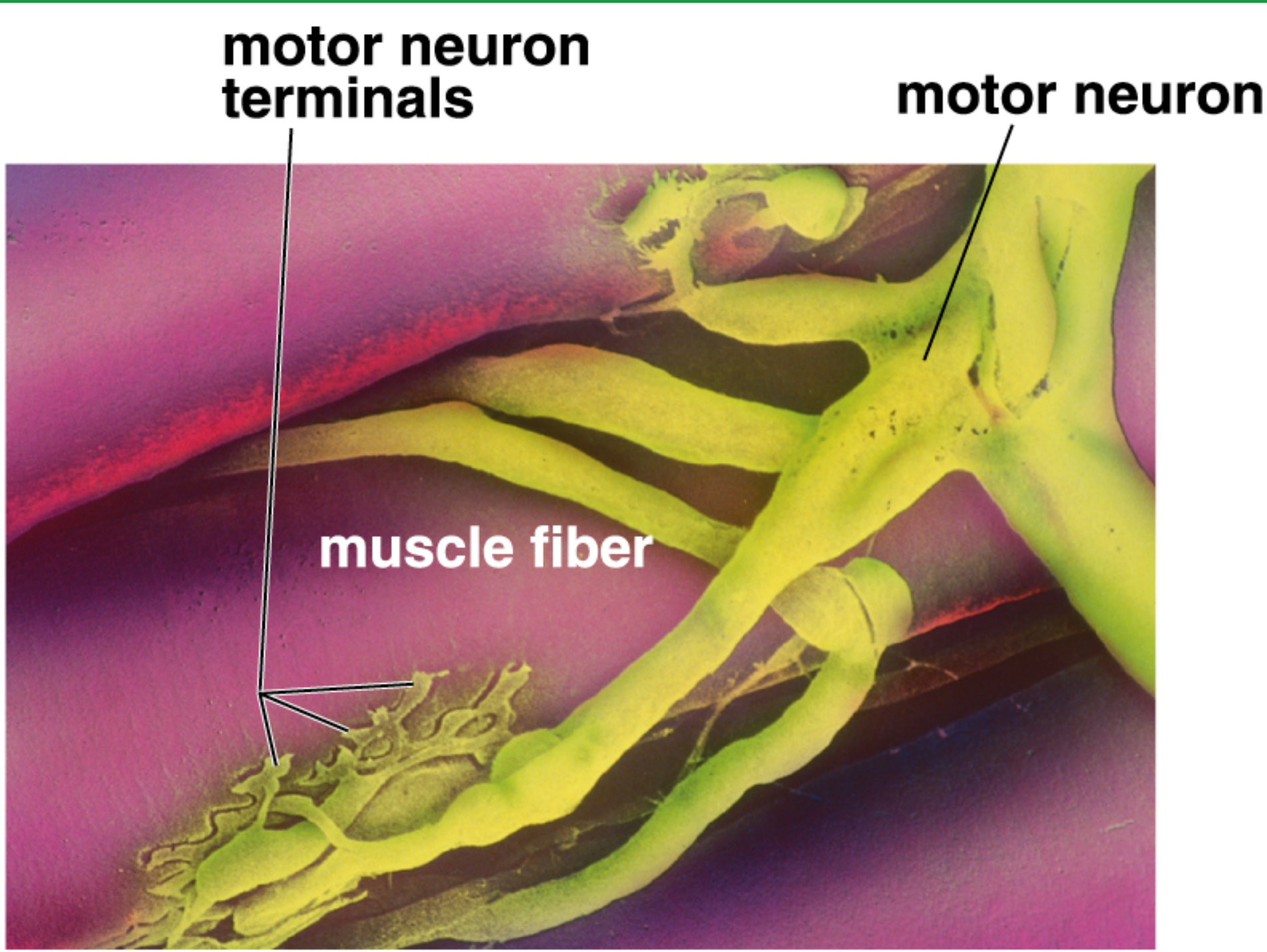
Motor Unit

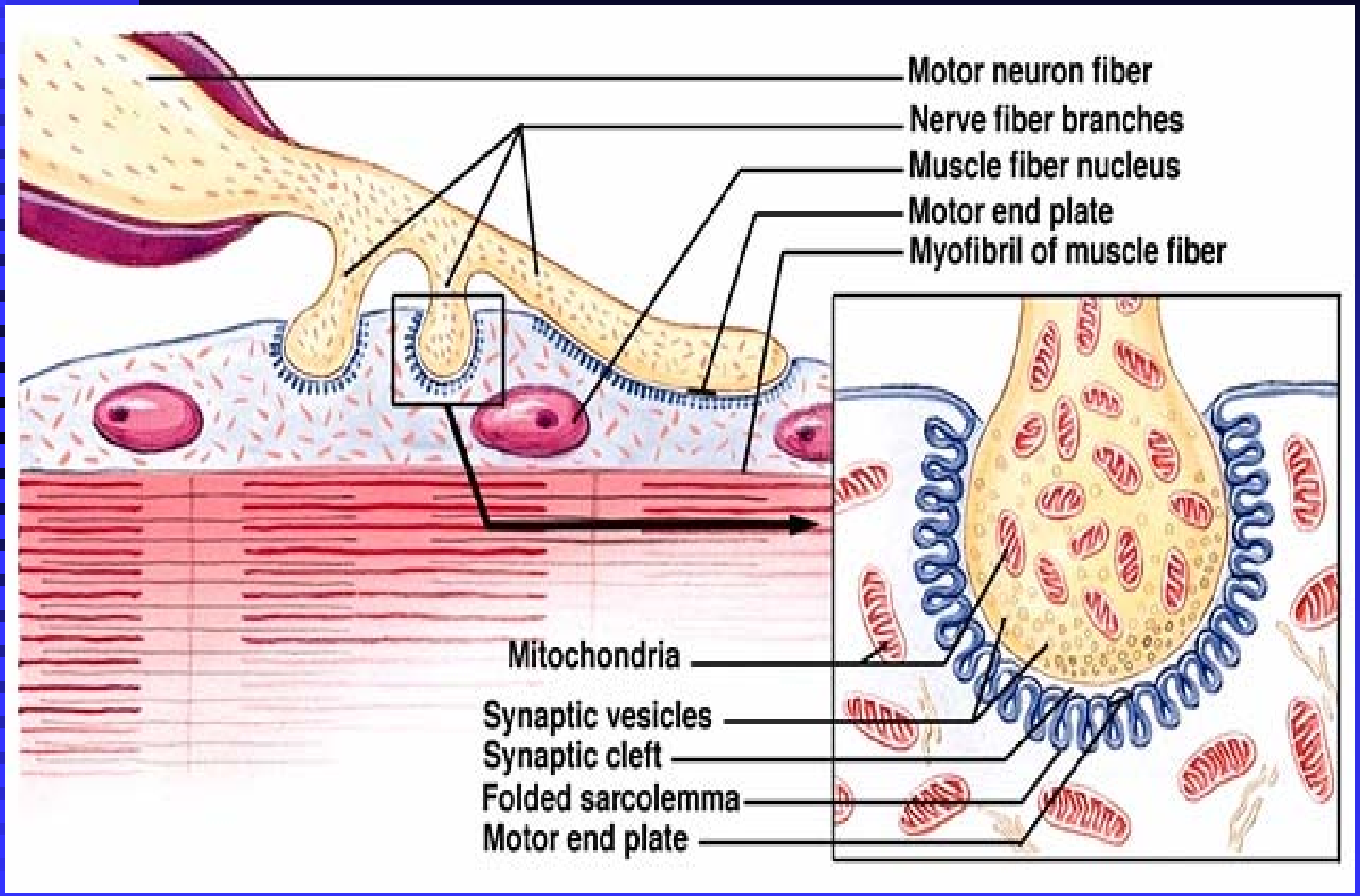


Motor unit= myofibers innervated by same motor neuron

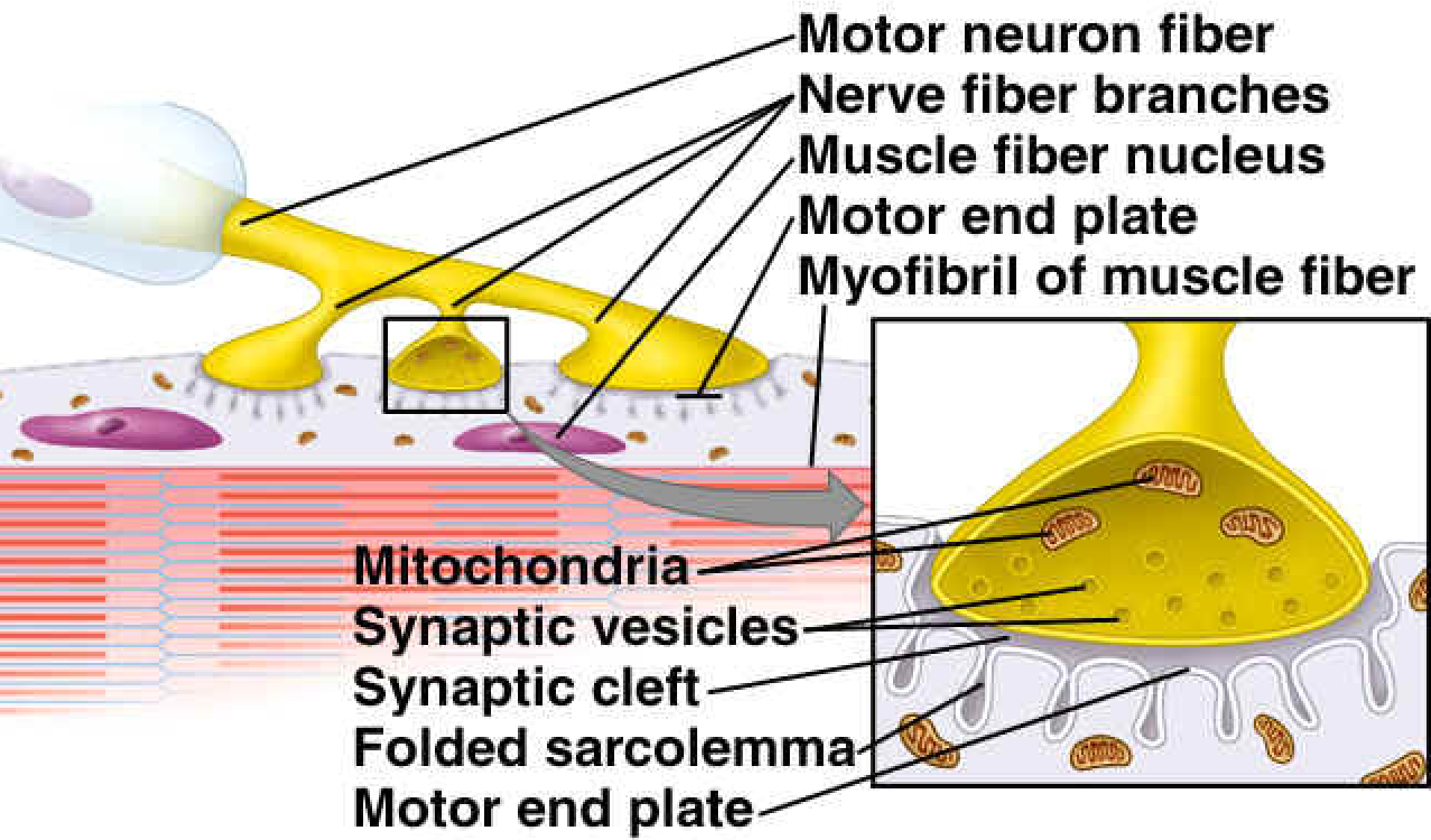
Muscles:

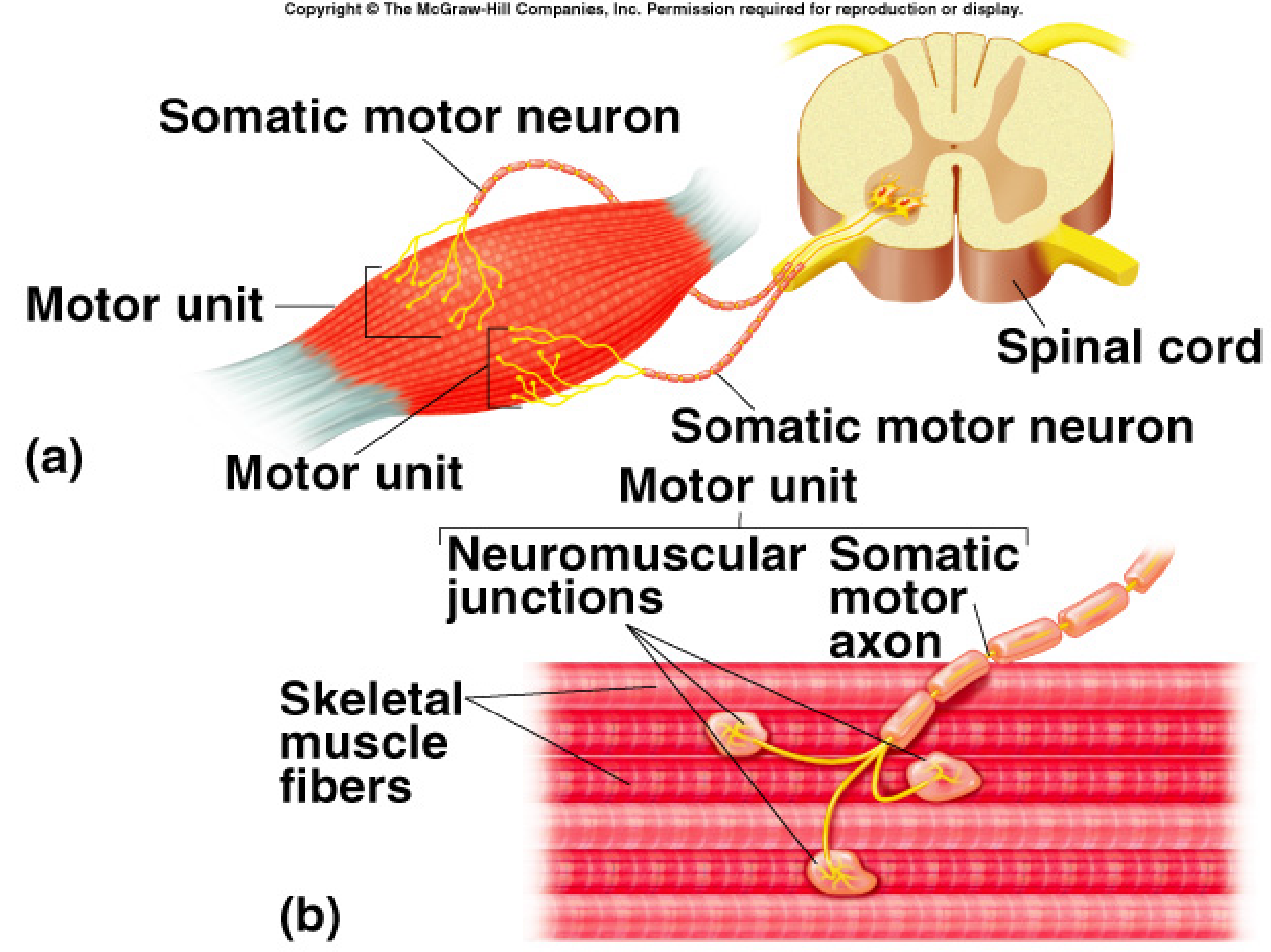
- **Graded contractions by how many motor units contract**

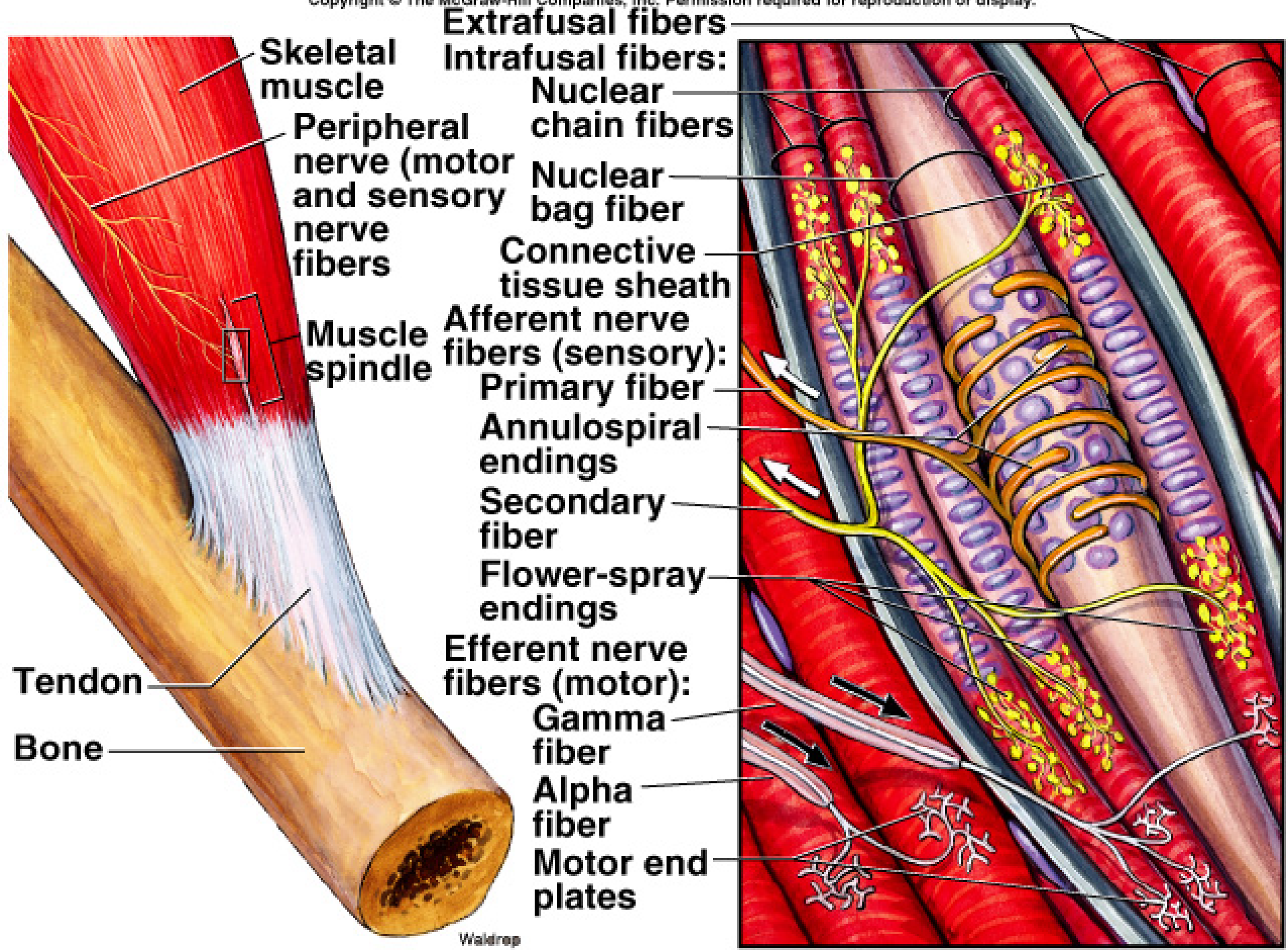

motor neuron terminals
motor neuron
muscle fiber

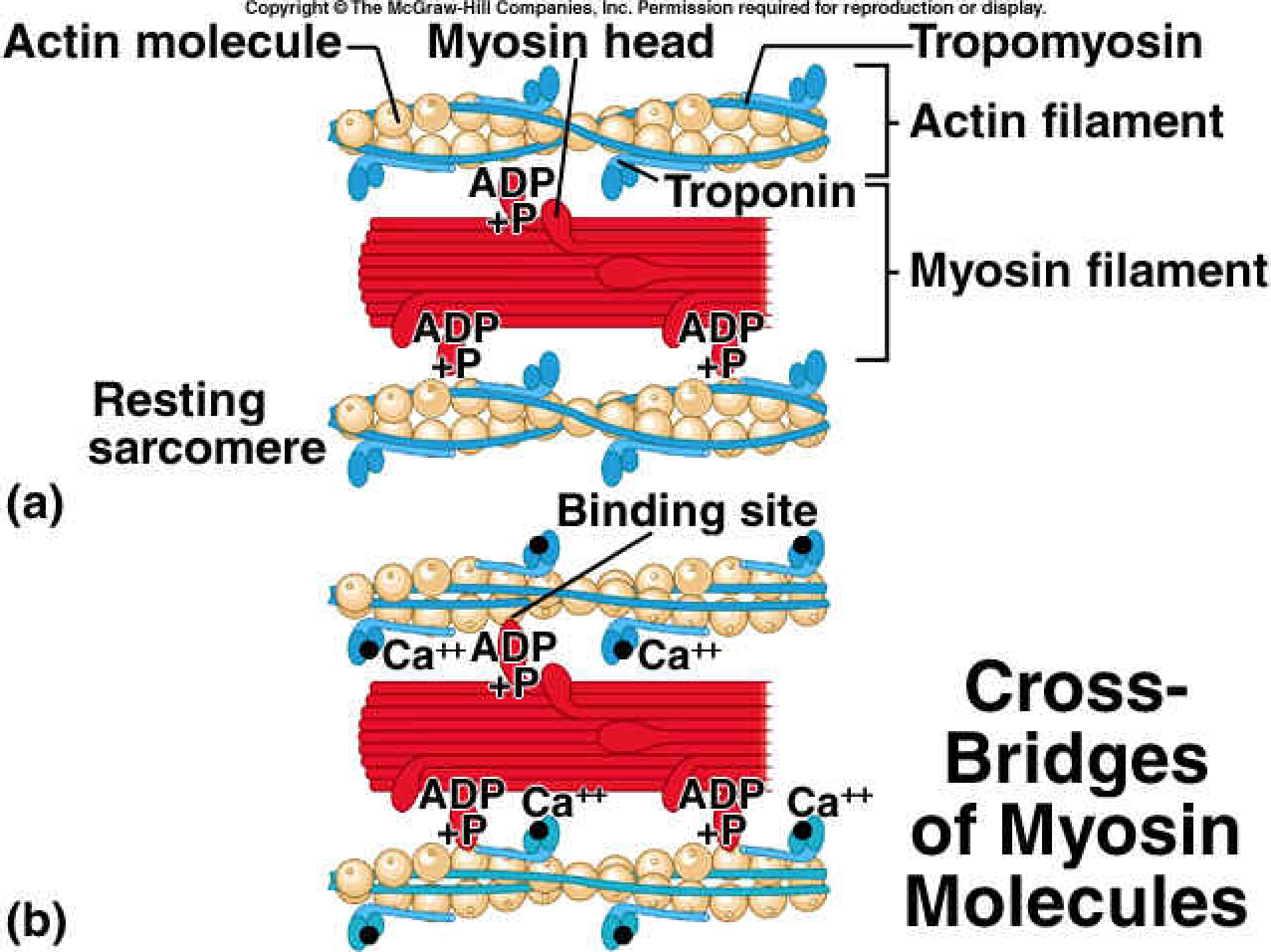

Motor neuron fiber
Nerve fiber branches
Muscle fiber nucleus
Motor end plate
Myofibril of muscle fiber
Mitochondria
Synaptic vesicles
Synaptic cleft
Folded sarcolemma
Motor end plate

Neuromuscular Junction



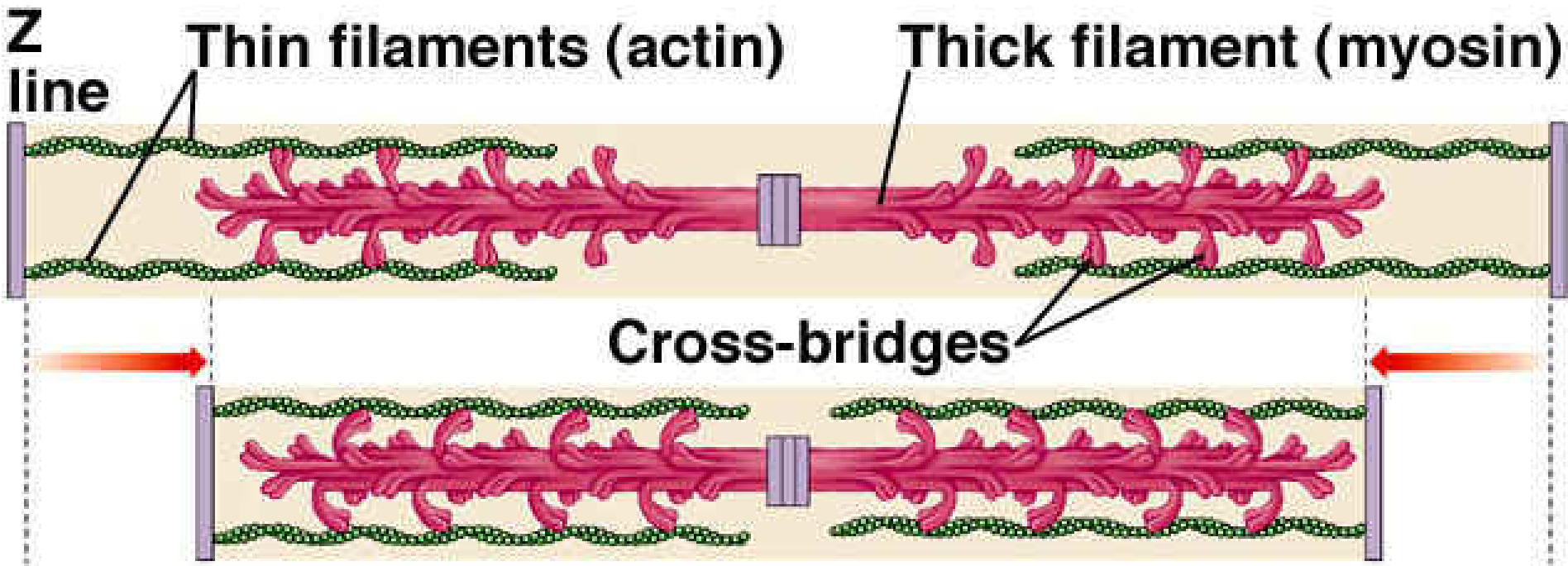






Cross-Bridges of Myosin Molecules

Interaction of Thick and Thin Filaments



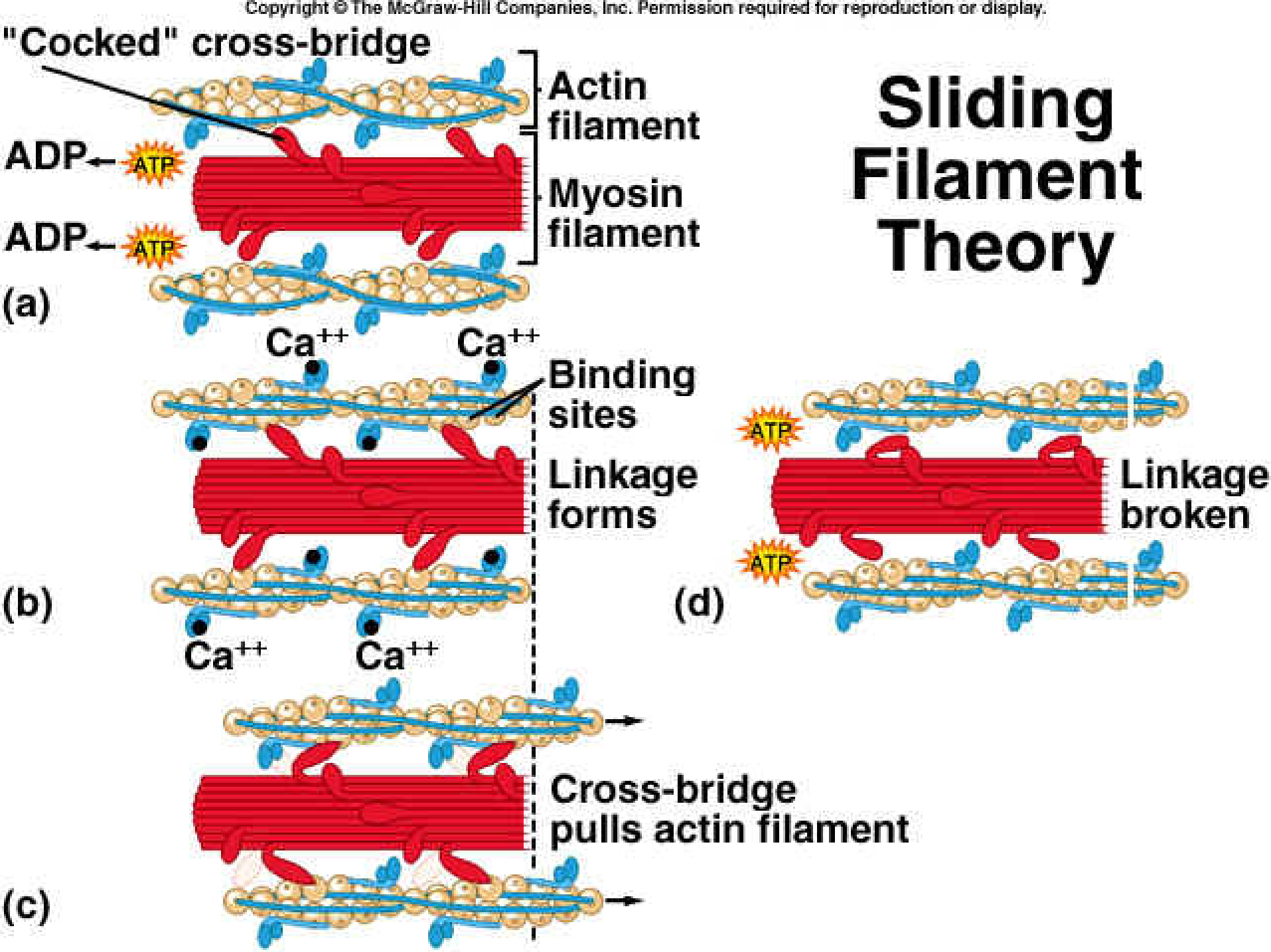
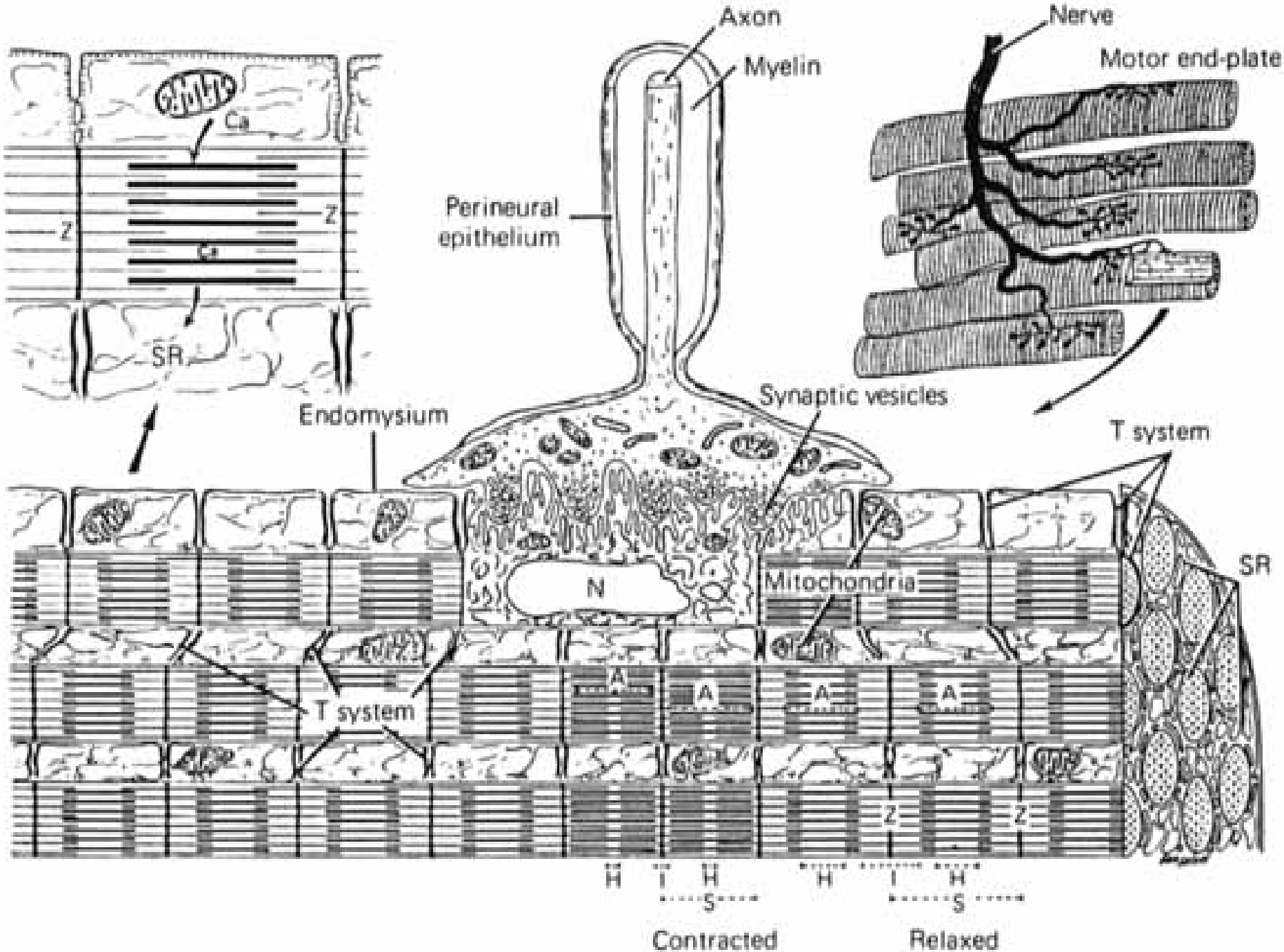


TABLE 9.1

Muscular Contraction and Relaxation

Muscle Fiber Contraction	Muscle Fiber Relaxation
1. The distal end of a motor neuron releases acetylcholine.	1. Acetylcholinesterase decomposes acetylcholine, and the muscle fiber membrane is no longer stimulated.
2. Acetylcholine diffuses across the gap at the neuromuscular junction.	2. Calcium ions are actively transported into the sarcoplasmic reticulum.
3. The sarcolemma is stimulated, and a muscle impulse travels over the surface of the muscle fiber and deep into the fiber through the transverse tubules and reaches the sarcoplasmic reticulum.	3. ATP causes linkages between actin and myosin filaments to break without ATP breakdown.
4. Calcium ions diffuse from the sarcoplasmic reticulum into the sarcoplasm and bind to troponin molecules.	4. Cross-bridges recock.
5. Tropomyosin molecules move and expose specific sites on actin filaments.	5. Troponin and tropomyosin molecules inhibit the interaction between myosin and actin filaments.
6. Actin and myosin filaments form linkages.	6. Muscle fiber remains relaxed, yet ready until stimulated again.
7. Actin filaments are pulled inward by myosin cross-bridges.	
8. Muscle fiber shortens as a contraction occurs.	


Axon
Myelin
Nerve
Motor end-plate
Perineural epithelium
Synaptic vesicles
Endomysium
T system
SR
N
Mitochondria
T system
SR
A
A
A
A
Z
Z
Z
Z
H
I
H
S
H
I
H
S
Contracted
Relaxed