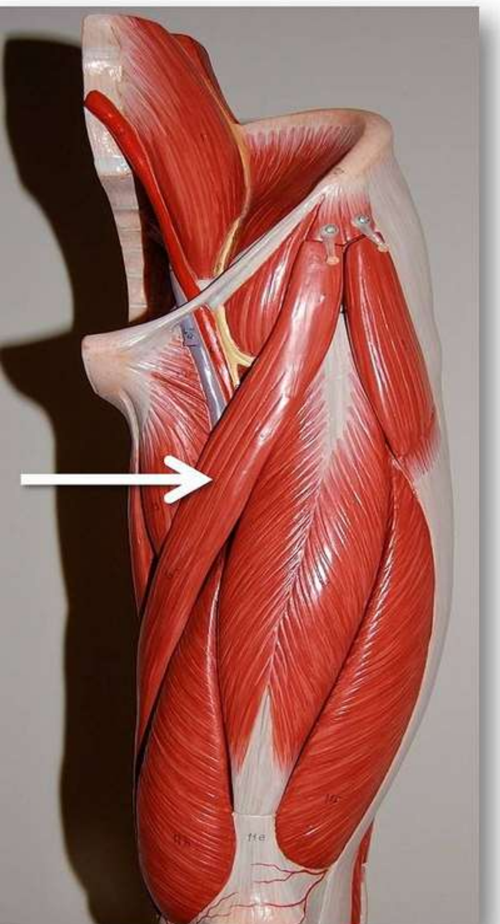
MUSCLE GENERALITY

DANIL HAMMOUDI.MD

http://www.brookscole.com/chemistry_d/templates/student_resources/shared_resources/animations/muscles/muscles.html

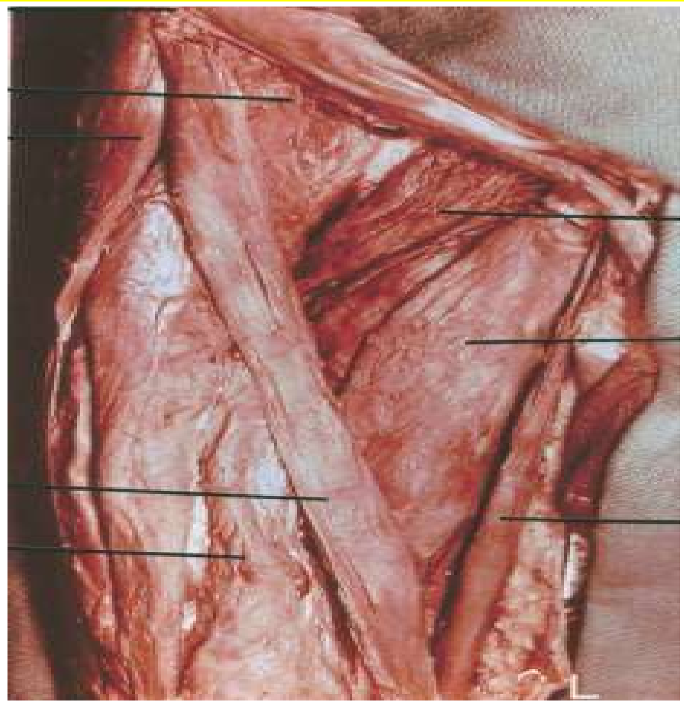
- We have over 600 major muscles.
- We have 240 muscles that have specific jobs

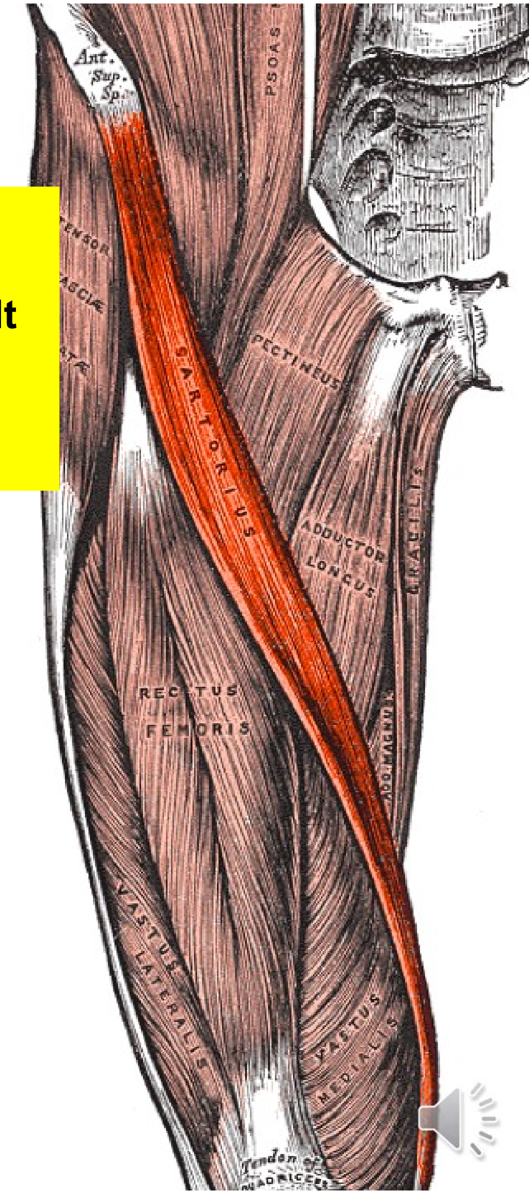


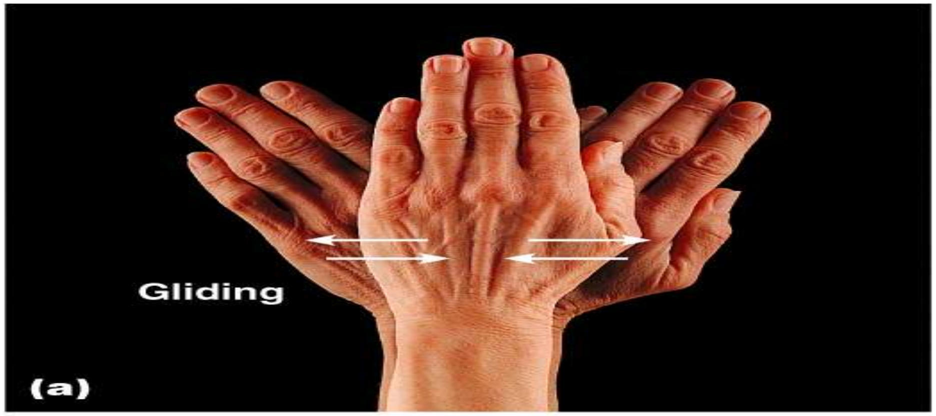
<u>Sartorius muscle</u>

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.

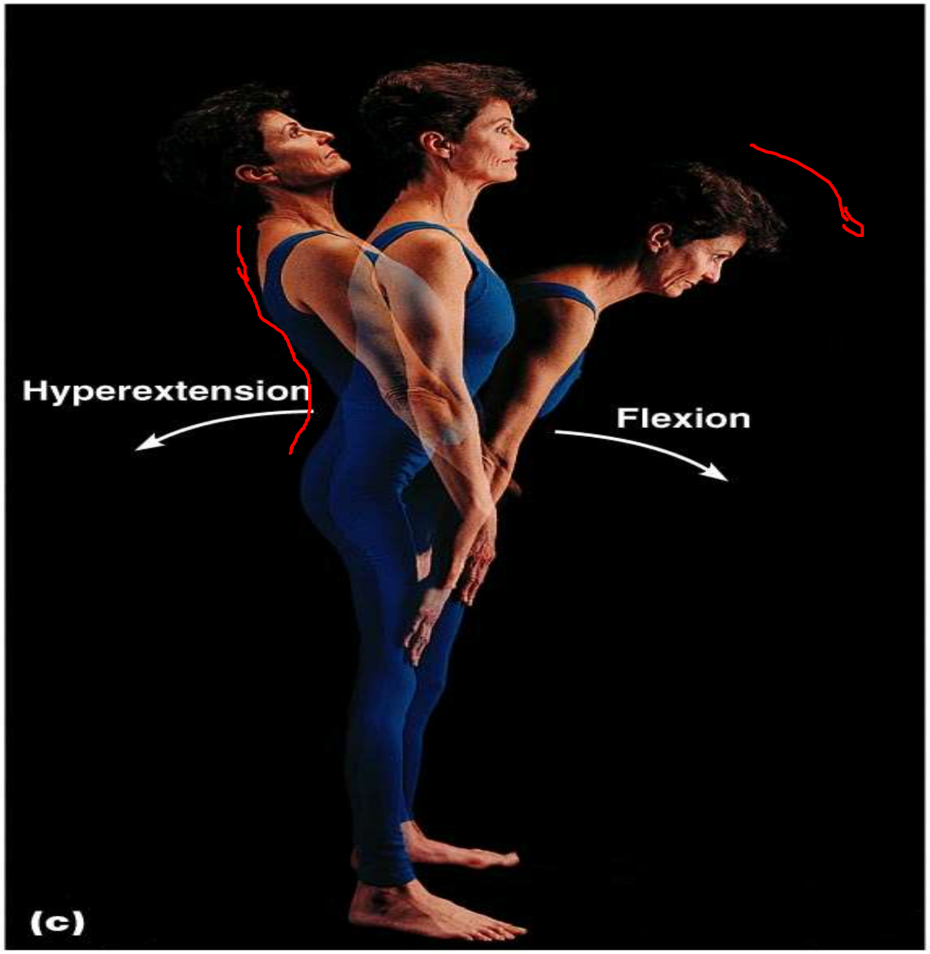
Flexes, abducts, and laterally rotates thigh at hip; flexes knee

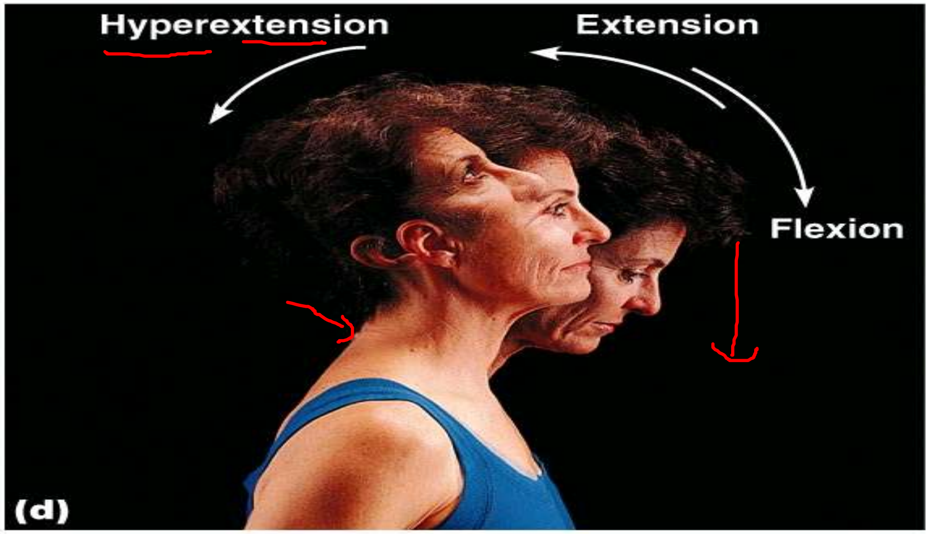





Gliding
(a)

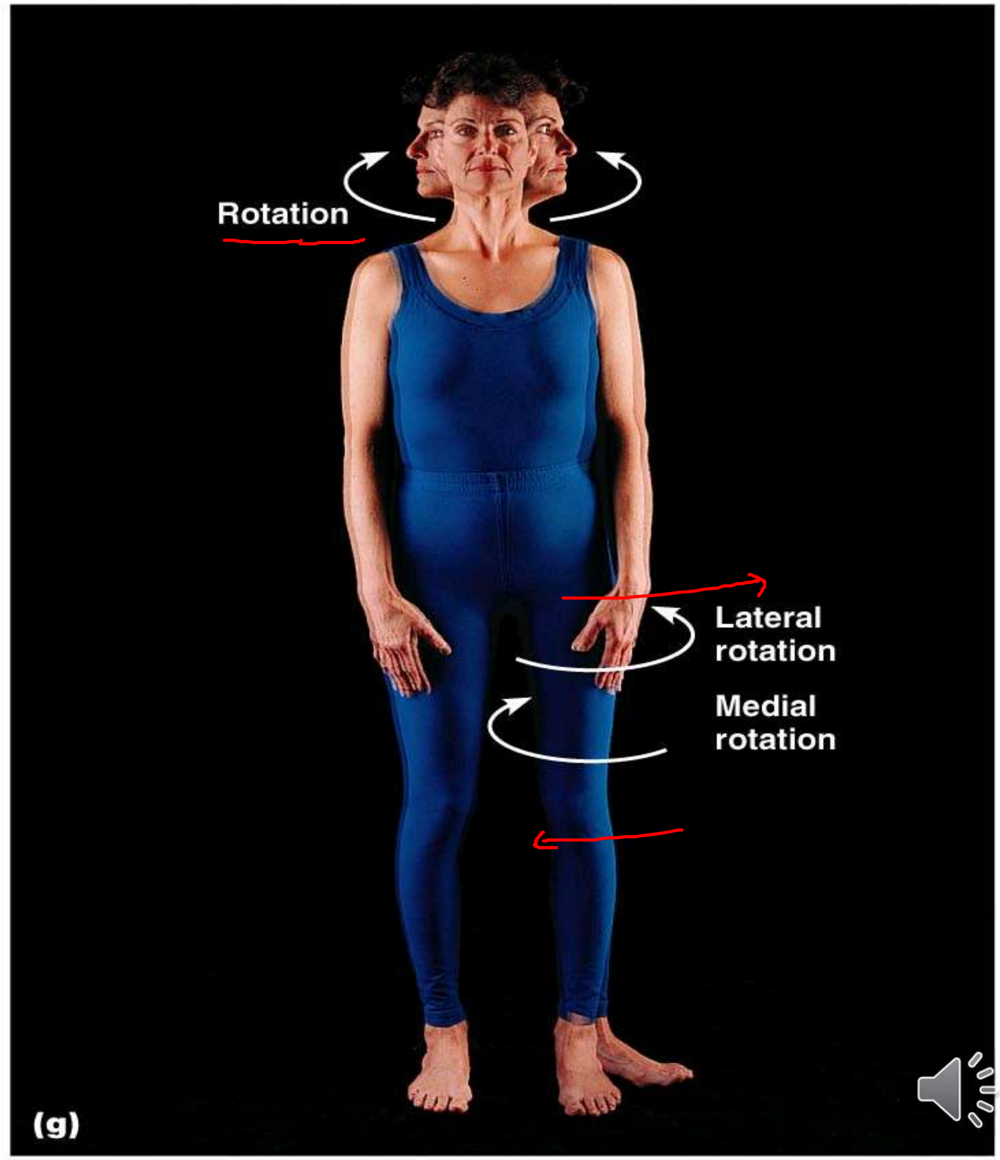

Flexion
Flexion
(b)
Extension
Extension

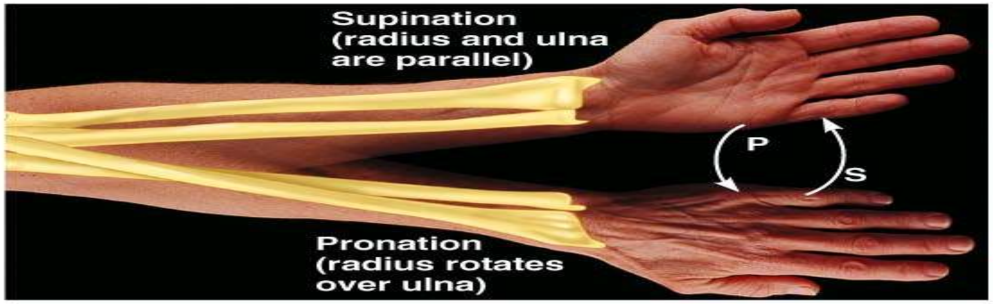

Hyperextension
Flexion
(c)


Hyperextension
Extension
Flexion
(d)

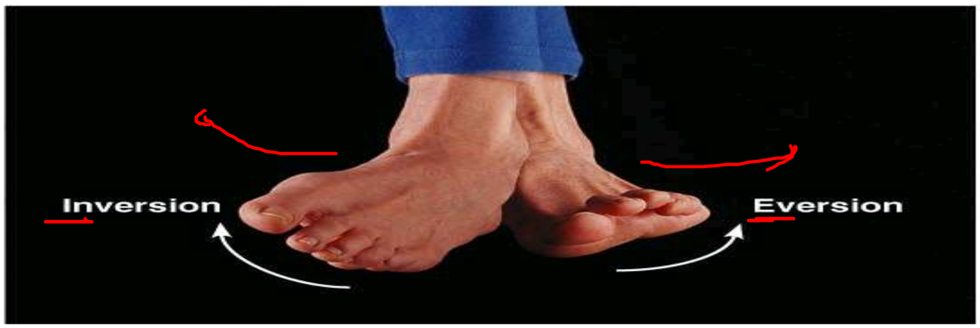

Dorsiflexion
Plantar flexion
(e)


Abduction
Adduction
Circumduction
(f)


Rotation
Lateral rotation
Medial rotation
(g)

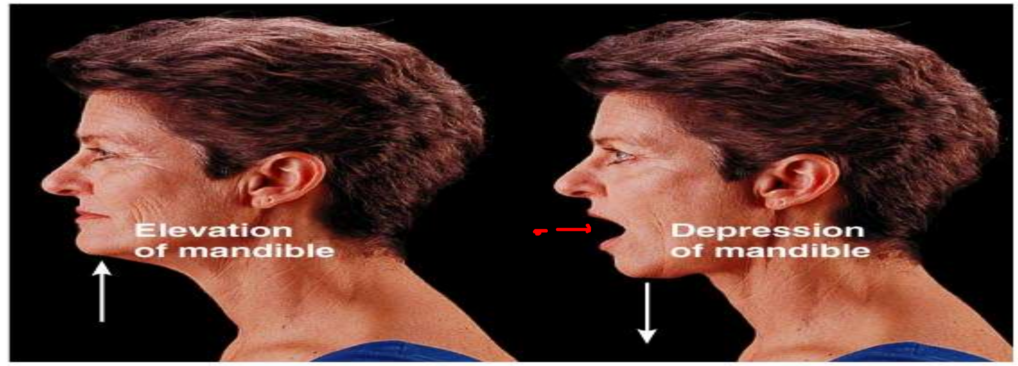


(a) Supination (S) and pronation (P)



(b) Inversion and eversion

(c) Protraction and retraction

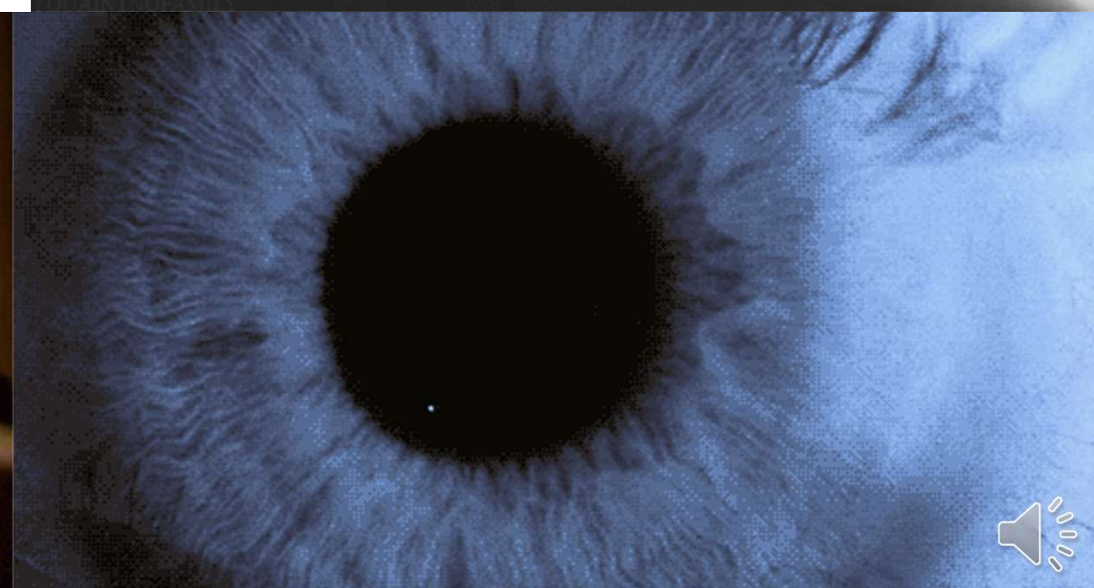


(d) Elevation and depression

(e) Opposition

Function of Muscles

- Produce movement
- Maintain posture
- Stabilize joints
- Support soft tissue
- Guard openings to the internal body
- Generate heat



Muscle Function

- Skeletal muscles are responsible for all locomotion
- Cardiac muscle is responsible for coursing the blood through the body
- Smooth muscle helps maintain blood pressure, and squeezes or propels substances (i.e., food, feces) through organs
- Muscles also maintain posture, stabilize joints, and generate heat

1. Production of Movement

- Movement of body parts and of the environment
- Movement of blood through the heart and the circulatory vessels.
- Movement of lymph through the lymphatic vessels
- Movement of food (and, subsequently, food waste) through the GI tract
- Movement of bile out of the gallbladder and into the digestive tract
- Movement of urine through the urinary tract
- Movement of semen through the male reproductive tract and female reproductive tract
- Movement of a newborn through the birth canal

2. **Maintenance of posture**
   - Muscle contraction is constantly allowing us to remain upright.
   - The muscles of your neck are keeping your head up right now.
   - As you stand, your leg muscles keep you on two feet.
3. **Thermogenesis**
   - Generation of heat. Occurs via shivering – an involuntary contraction of skeletal muscle.

4. Stabilization of joints

- Muscles keep the tendons that cross the joint nice and taut. This does a wonderful job of maintaining the integrity of the joint.

Origin (b): muscle attatchment that moves least, generally more proximal.

Insertion (a): muscle attatchment that moves most, generally more distal.

Abduction: Lateral movement away from the midline of the body

Adduction: Medial movement toward the midline of the body

Circumduction: circular movement (combining flexion, extension, adduction, and abduction) with no shaft rotation

Extension: Straightening the joint resulting in an increase of angle

Eversion: Moving sole of foot away from medial plane

Flexion: Bending the joint resulting in a decrease of angle

Hyperextension: extending the joint beyond anatomical position
Inversion: Moving sole of foot toward medial plane
Pronation: Internal rotation resulting in appendage facing downward
Protrusion: Moving anteriorly (eg: chin out)
Supination: External rotation resulting in appendage facing upward
Retrusion: Moving posteriorly (eg: chin in)
Rotation: Rotary movement around the longitudinal axis of the bone

Agonist
A muscle that causes motion.

Antagonist
A muscle that can move the joint opposite to the movement produced by the agonist.

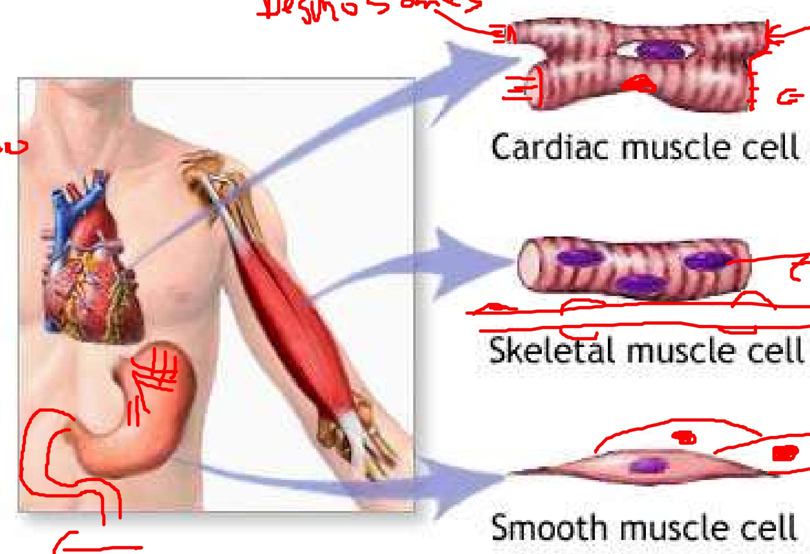
Target
The primary muscle intended for exercise.

Synergist
A muscle that assists another muscle to accomplish a movement.

Stabilizer
A muscle that contracts with no significant movement

Types of Muscles

- Skeletal muscle
- Cardiac muscle
- Smooth muscle



THREE HISTOLOGICAL TYPES OF MUSCLE FIBERS

1) Skeletal (Striated) = striated (striped in appearance under microscope), voluntary (under conscious control)
2) Cardiac = striated, involuntary
3) Smooth = non-striated, involuntary

Muscle Types

- Smooth
  - blood vessels
  - autonomic

GI, uterus, Bladder,

- Striated
  - voluntary
  - skeletal
- Cardiac
  - network
  - rhythmic

Autonomic →

Autonomic →

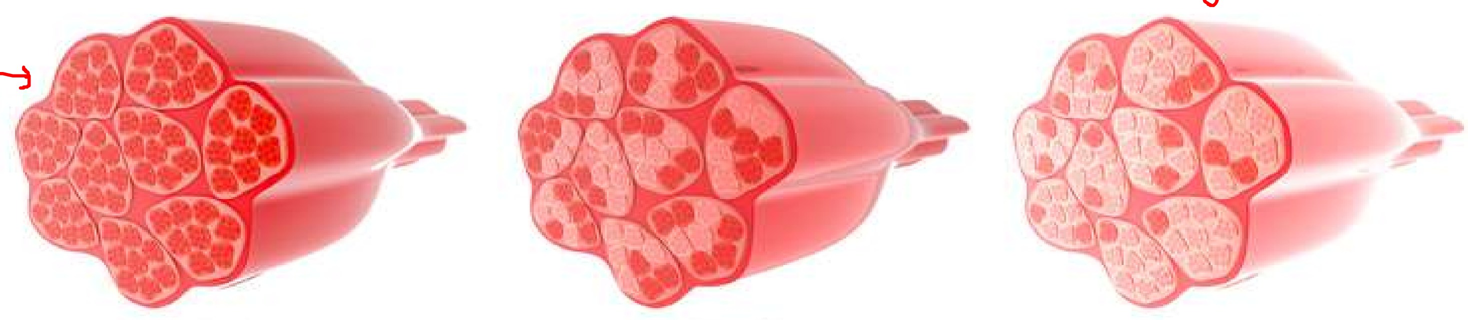
Pacemaker

The three types of human muscle tissue

- Smooth, nonstriated muscle is found in the walls of the hollow viscera and blood vessels.
- Skeletal, striated muscle is attached to the skeleton and provides the force for movement of the bony leverage system.
- Cardiac, striated muscle is found only in the heart.

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



RED MUSCLE high mitochondrial content

MIXED MUSCLE medium mitochondrial content

WHITE MUSCLE low mitochondrial content

Muscle Fibre Types

Long Distance

Type 1

Slow twitch

400m / 800m

Type 2A

Fast twitch oxydative

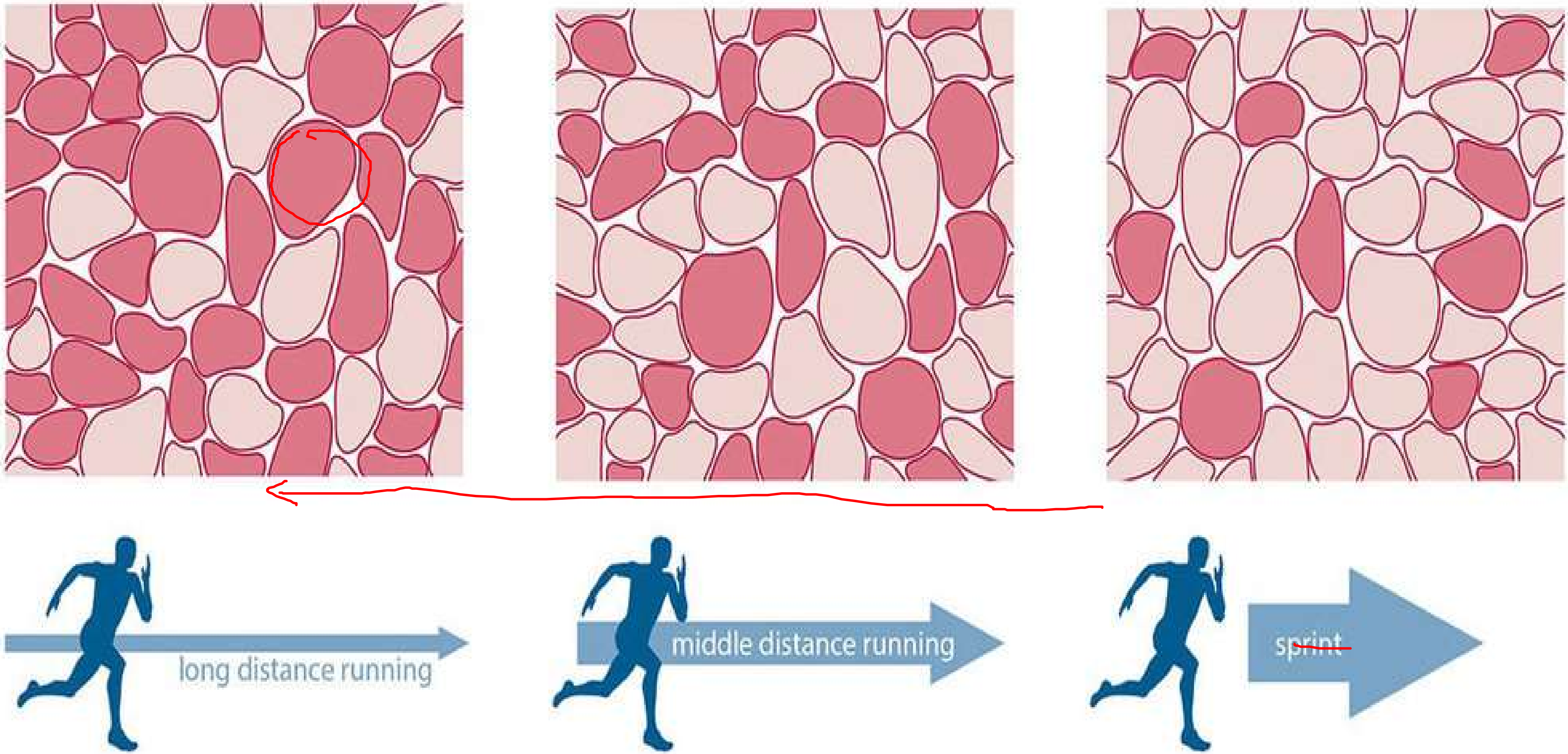
Short Sprints

Type 2B

Fast twitch glycolytic

Low → High

Fatigue rate


long distance running
middle distance running
sprint

	Type I fibers	Type II a fibers	Type II x fibers	Type II b fibers
Contraction time	Slow	Moderately Fast	Fast	Very fast
Size of motor neuron	Small	Medium	Large	Very large
Resistance to fatigue	High	Fairly high	Intermediate	Low
Activity Used for	Aerobic	Long-term anaerobic	Short-term anaerobic	Short-term anaerobic
Maximum duration of use	Hours	<30 minutes	<5 minutes	<1 minute
Power produced	Low	Medium	High	Very high
Mitochondrial density	High	High	Medium	Low
Capillary density	High	Intermediate	Low	Low
Oxidative capacity	High	High	Intermediate	Low
Glycolytic capacity	Low	High	High	High
Major storage fuel	Triglycerides	Creatine phosphate, glycogen	Creatine phosphate, glycogen	Creatine phosphate, glycogen
Myosin heavy chain, human genes	MYH7	MYH2	MYH1	MYH4

Muscle Classification cont…

- Change in the nerve root supply will change the muscles twitch properties.
- No gender differences.
- No change in the relative % of each type with training.
- Your birth determines your activity?

Muscle fiber types are classified by

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

Muscle Similarities

- Skeletal and smooth muscle cells are elongated and are called muscle fibers
- Muscle contraction depends on two kinds of myofilaments – actin and myosin
- Muscle terminology is similar
  - **Sarcolemma** – muscle plasma membrane
  - **Sarcoplasm** – cytoplasm of a muscle cell
  - **Prefixes** – myo, mys, and sarco all refer to muscle

Functional Characteristics of Muscle Tissue

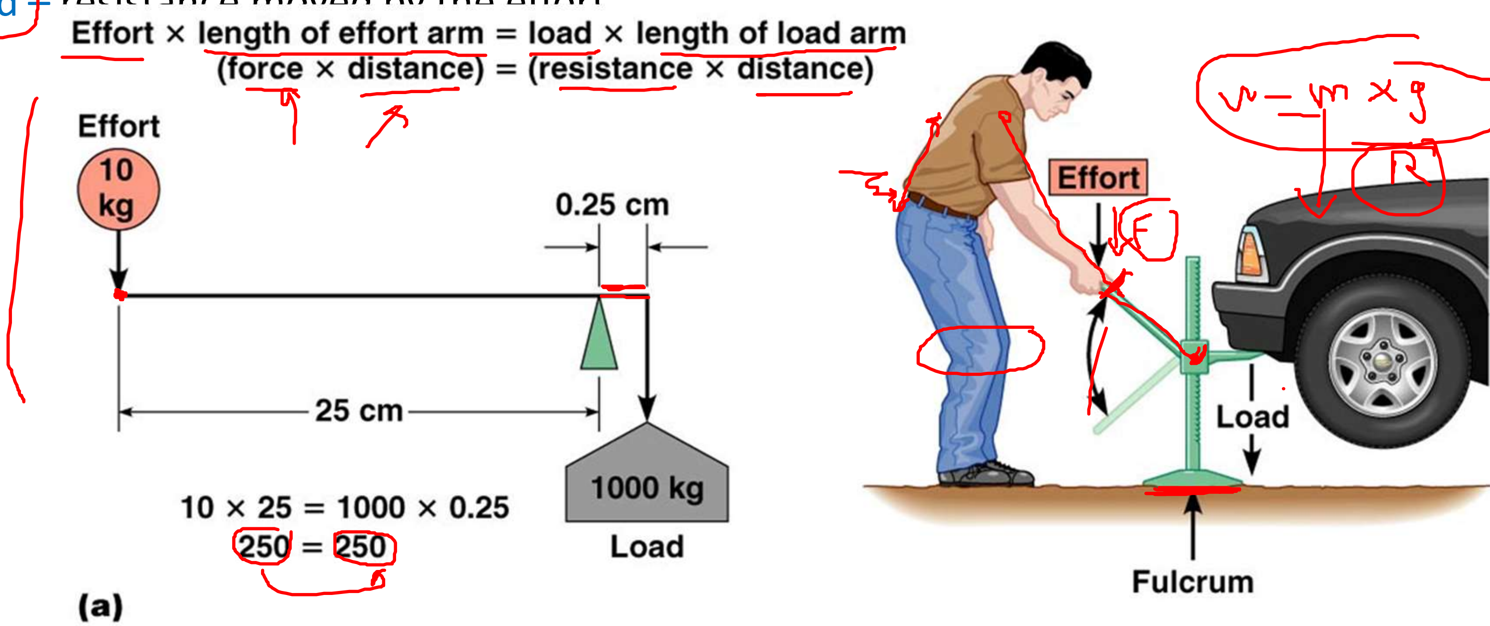
- **Excitability, or irritability** – the ability to receive and respond to stimuli
- **Contractility** – the ability to shorten forcibly
- **Extensibility** – the ability to be stretched or extended
- **Elasticity** – the ability to recoil and resume the original resting length

Interactions of Skeletal Muscles

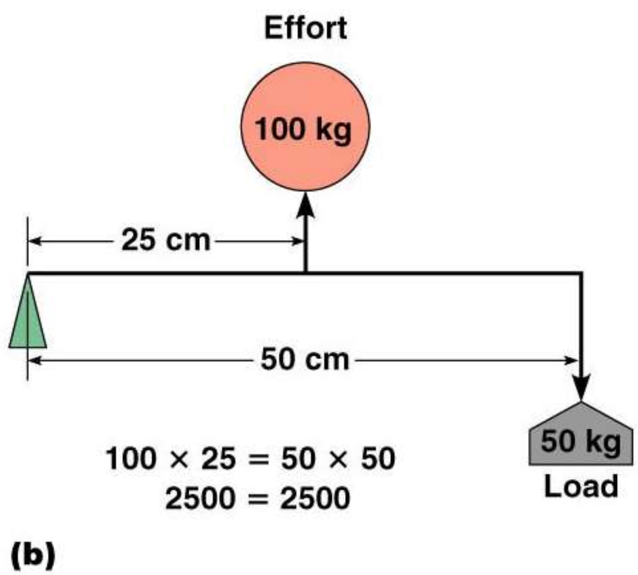
- Skeletal muscles work together or in opposition
- Muscles only pull (never push)
- As muscles shorten, the insertion generally moves toward the origin
- Whatever a muscle (or group of muscles) does, another muscle (or group) “undoes”

Bone-Muscle Relationships: Lever Systems

- Lever – a rigid bar that moves on a fulcrum, or fixed point
- Effort – force applied to a lever
- Load – resistance moved by the effort



Bone-Muscle Relationships: Lever Systems



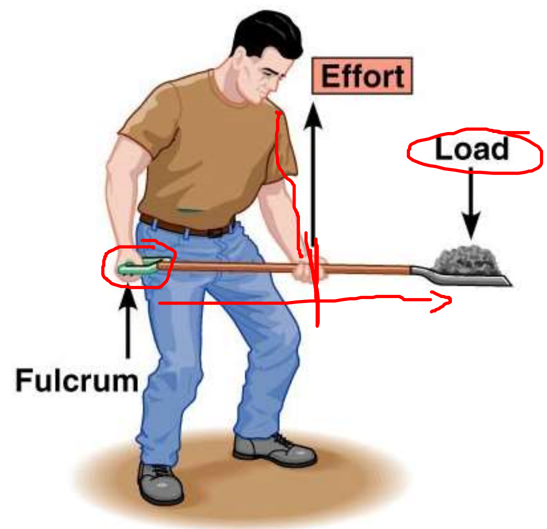
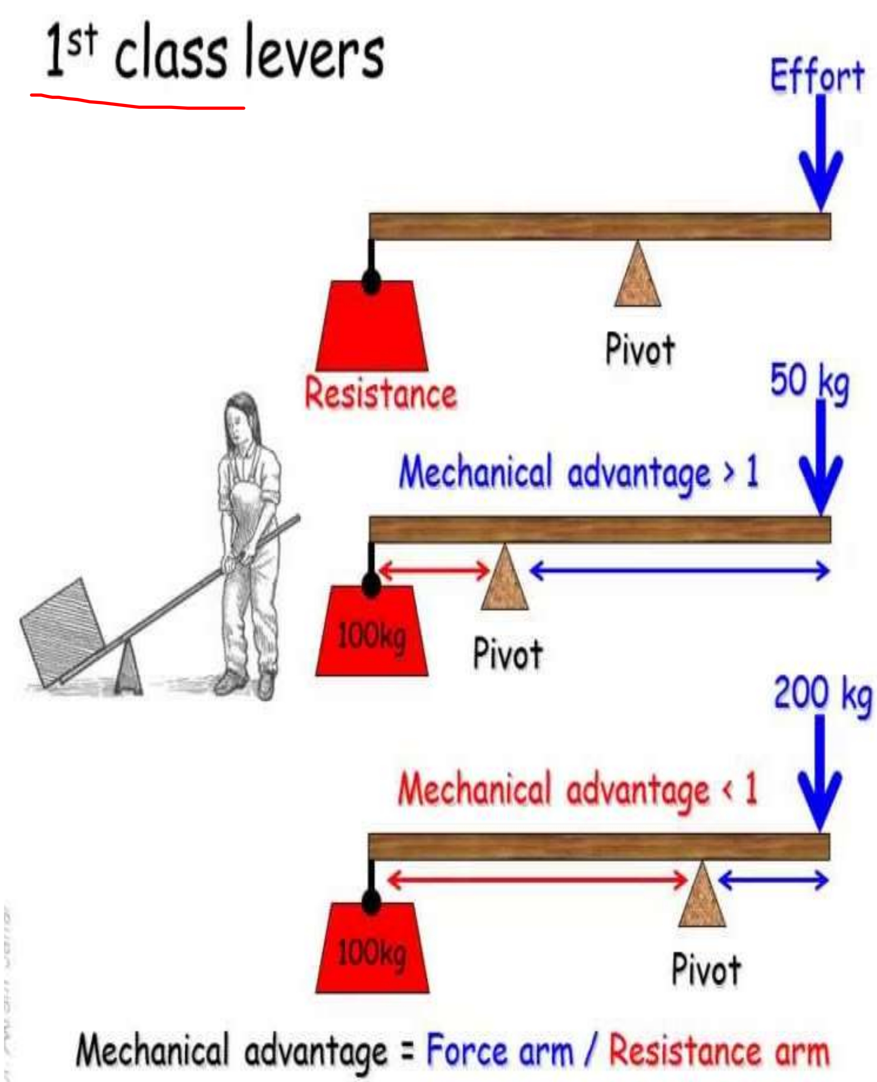
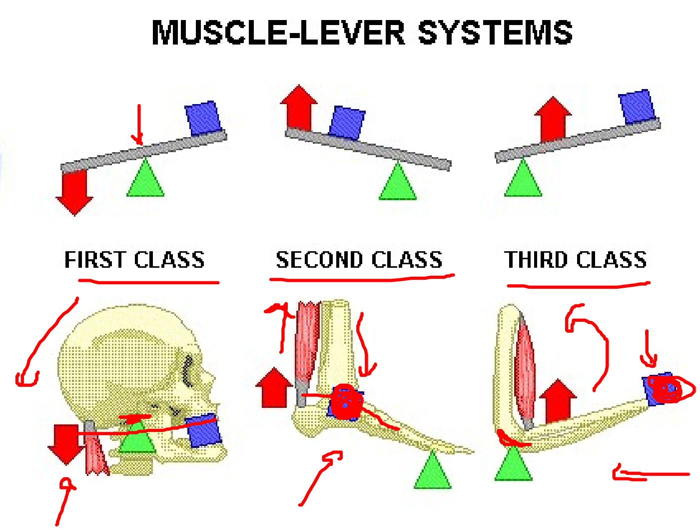


Figure 10.2b

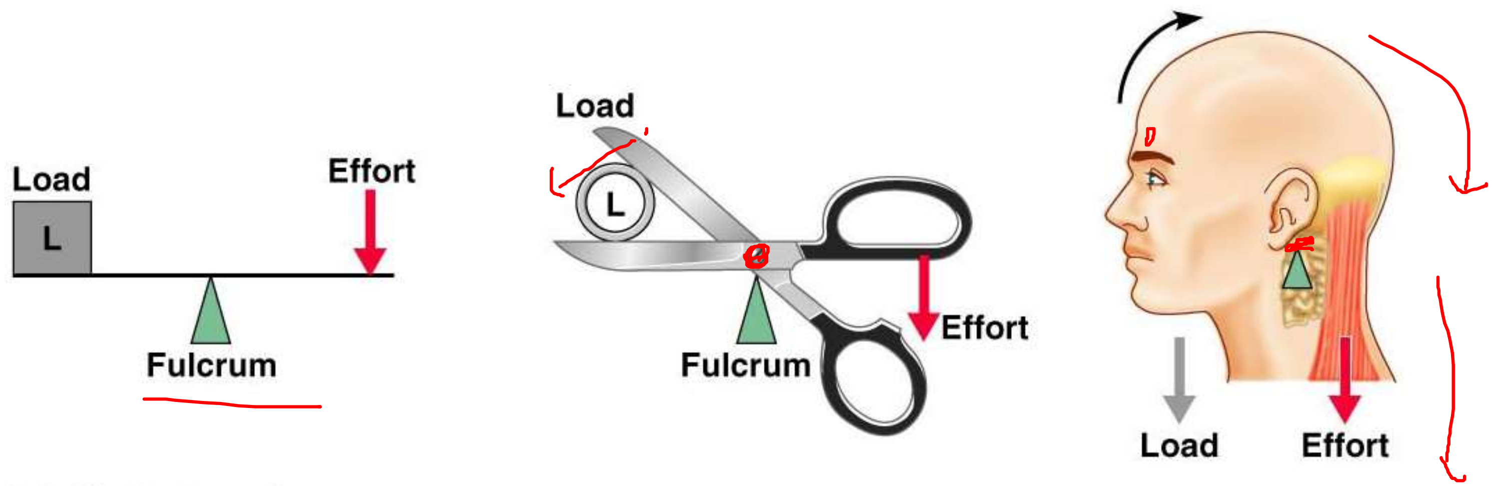
Lever Systems: Classes



- **First class –** the fulcrum is between the load and the effort
- **Second class** – the load is between the fulcrum and the effort
- **Third class** – the effort is applied between the fulcrum and the load



Lever Systems: First Class



(a) First-class lever

Figure 10.3a

Lever Systems: Second Class

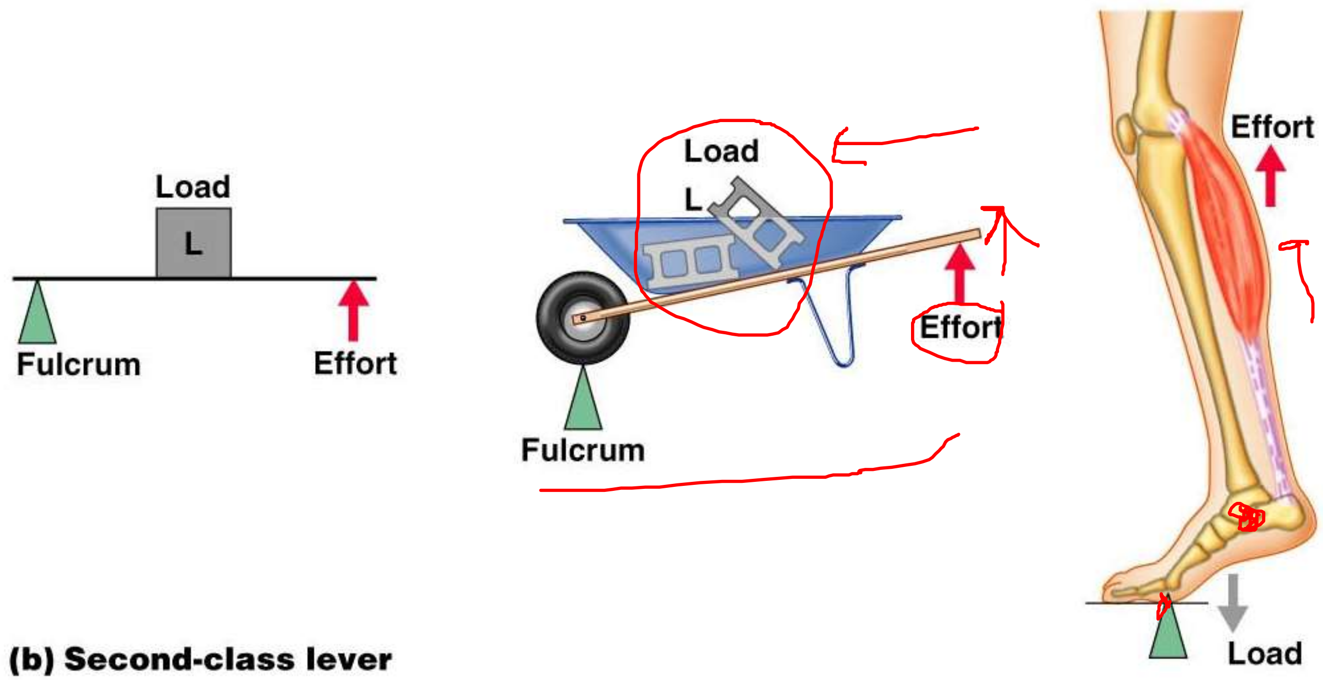
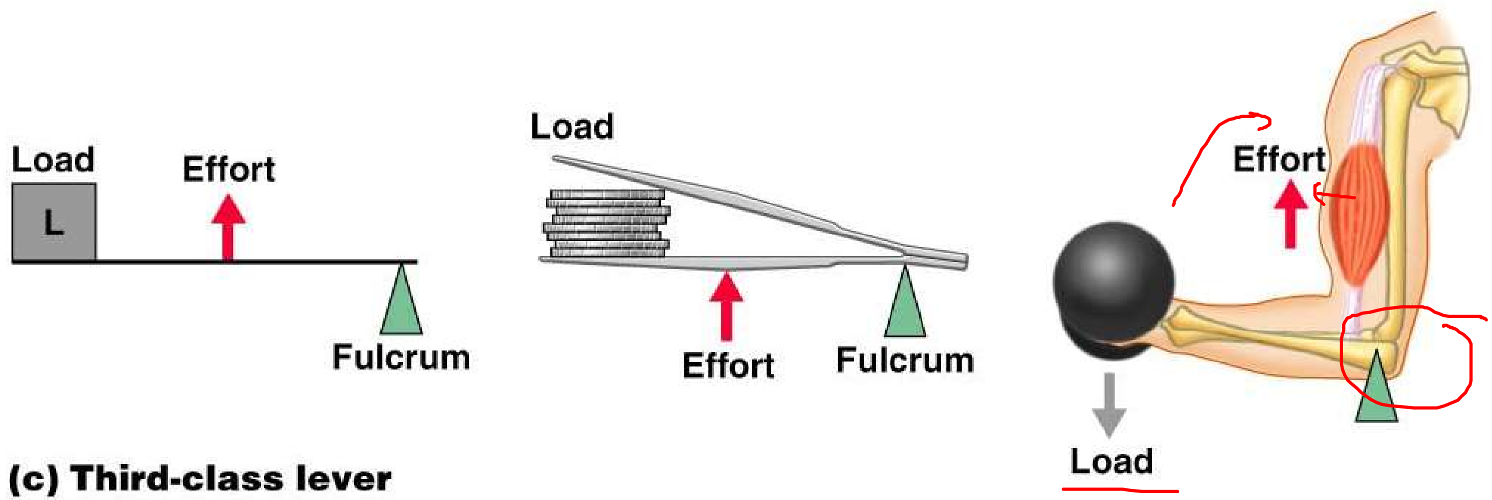


Figure 10.3b

Lever Systems: Third Class

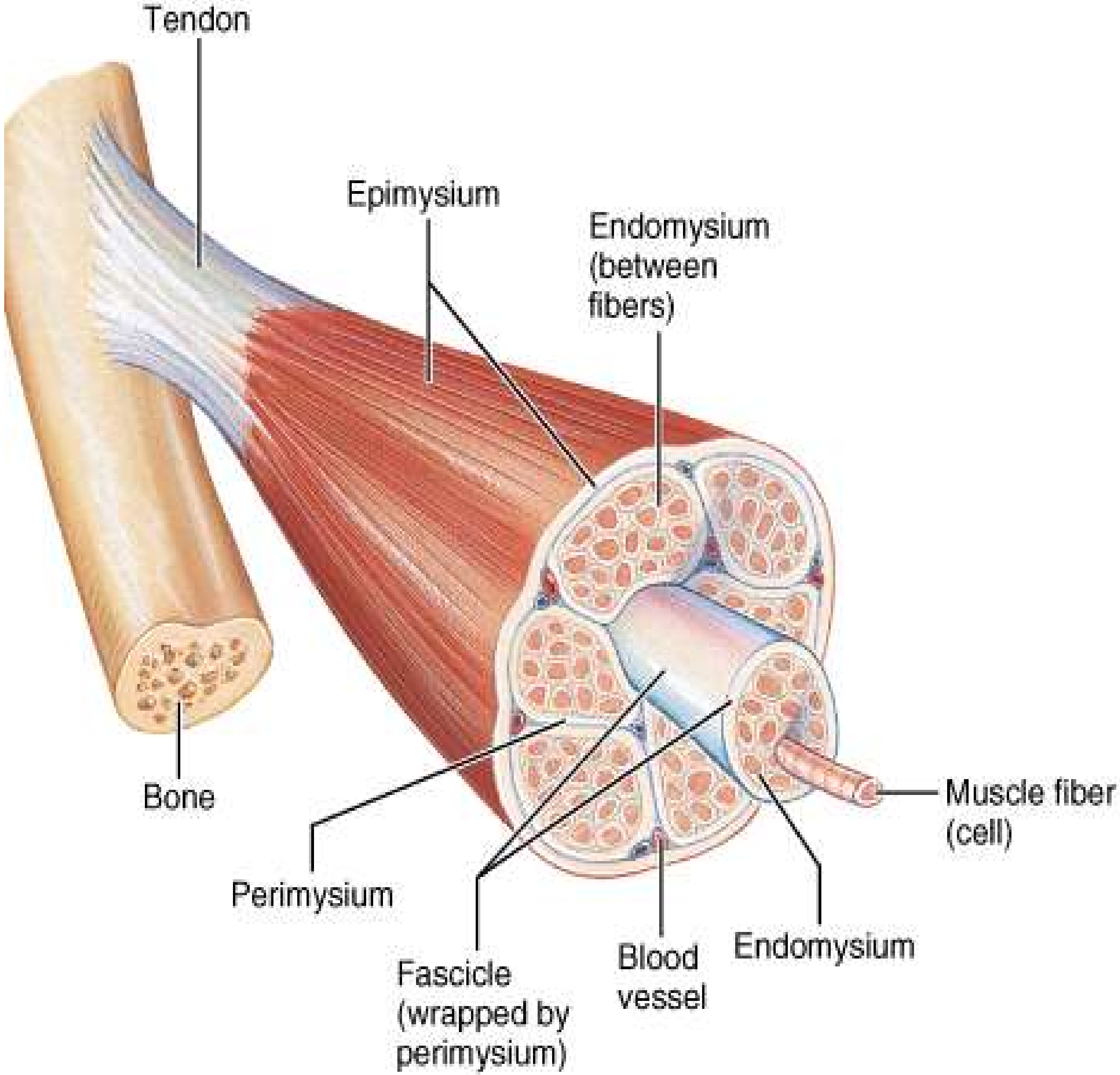


(c) Third-class lever

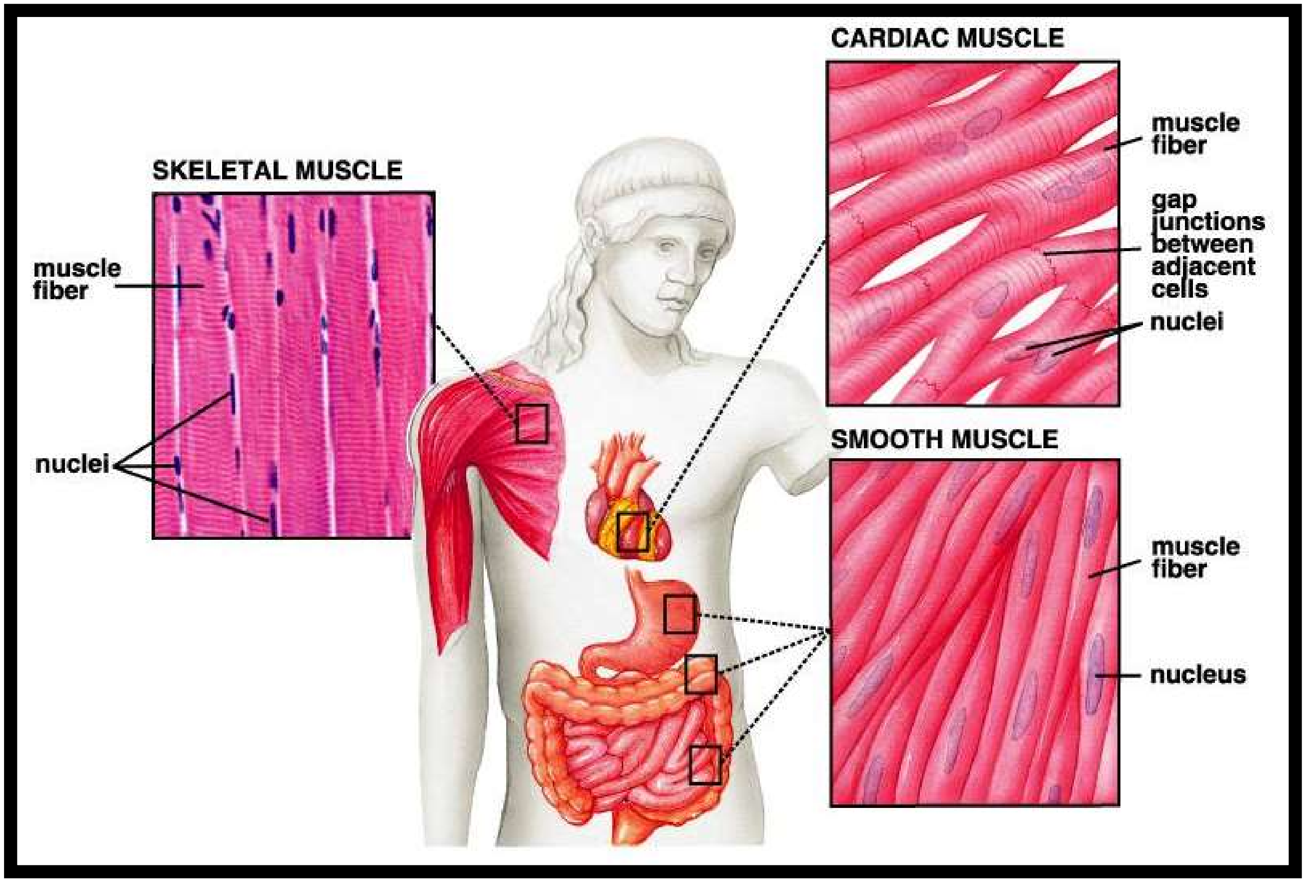
Figure 10.3c

Muscle Histology

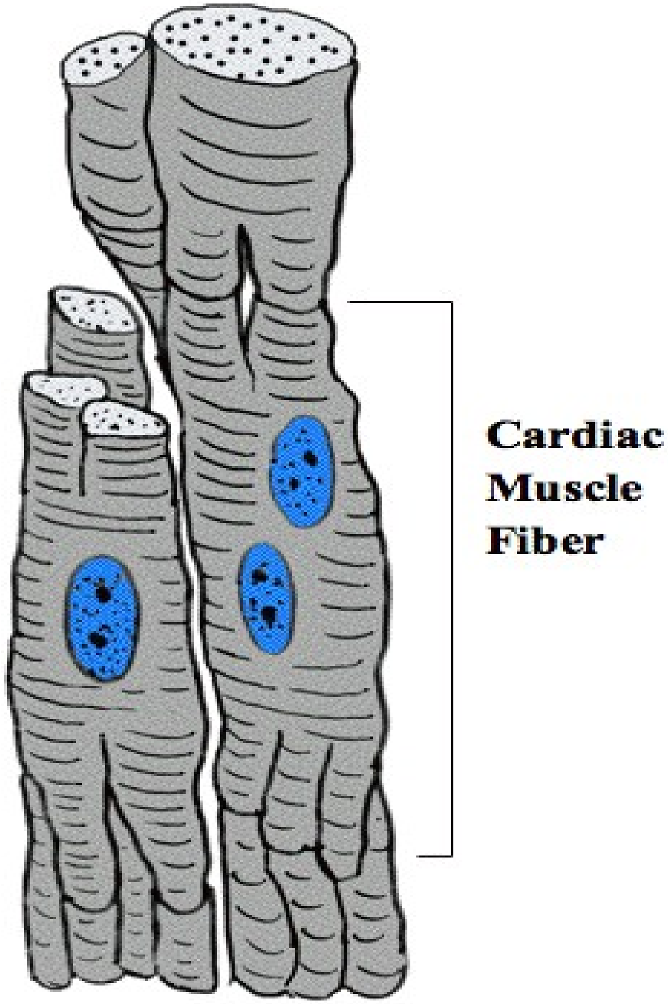
Skeletal Muscle – the organ

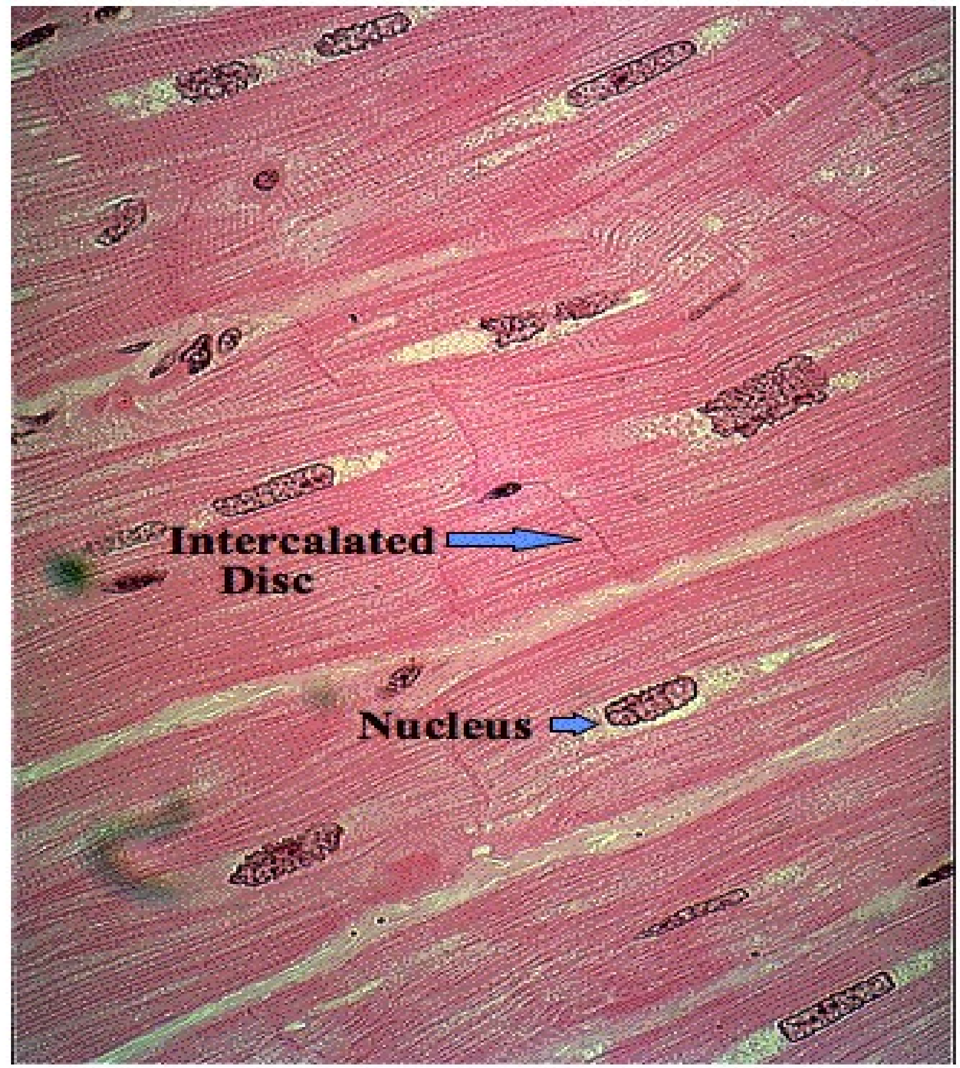


Three Muscle Types

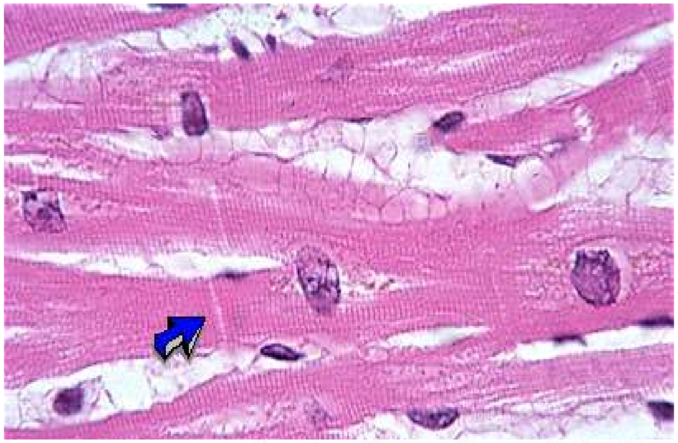


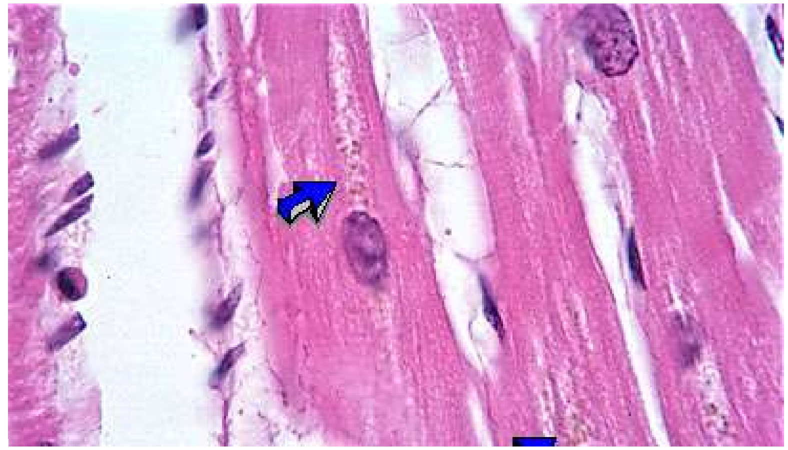
CARDIAC MUSCLE

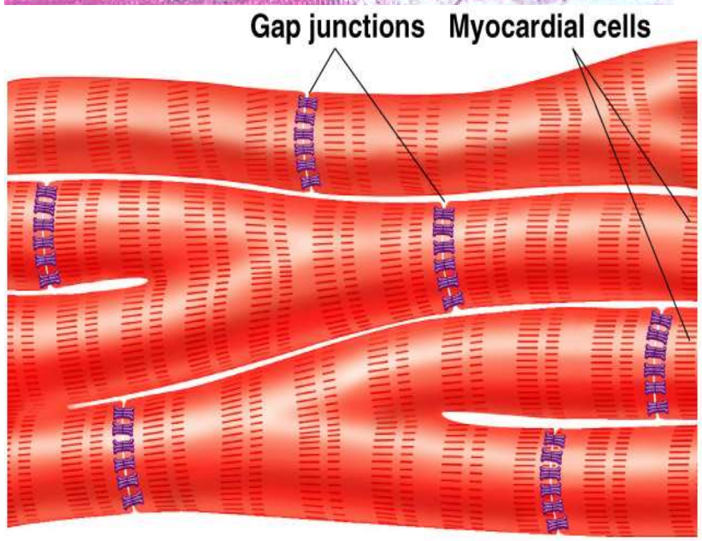




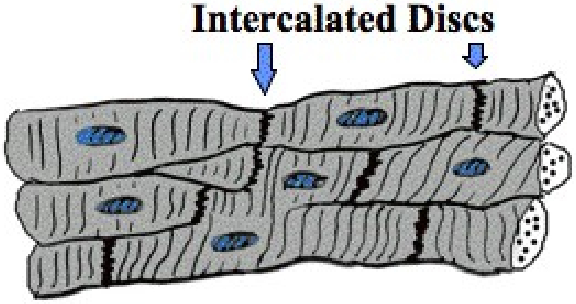
Cardiac Muscle

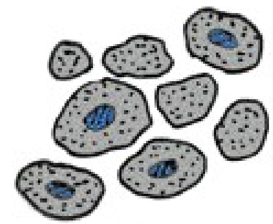




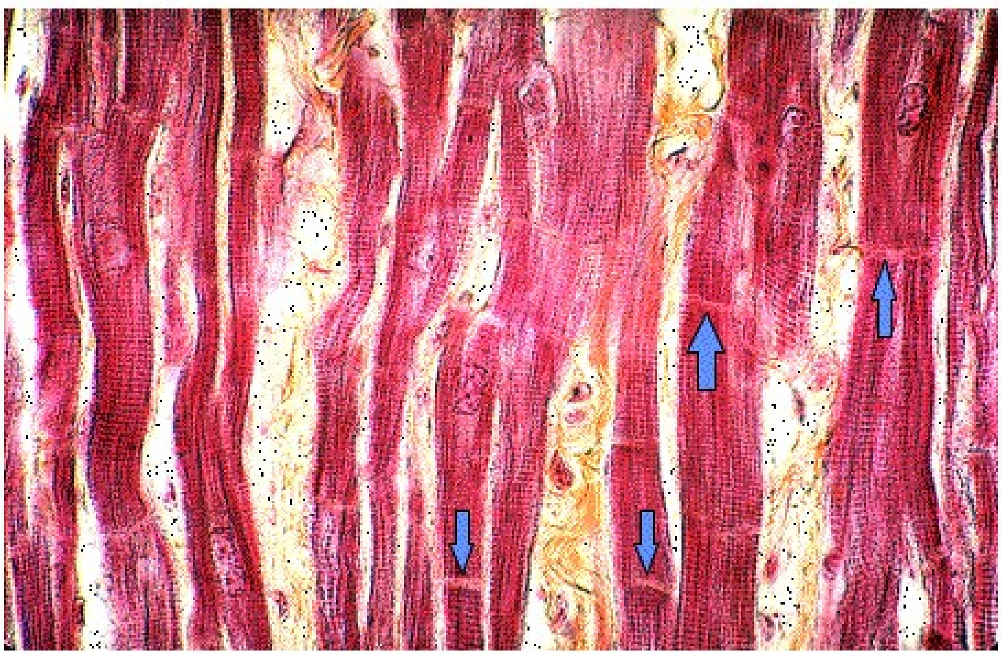


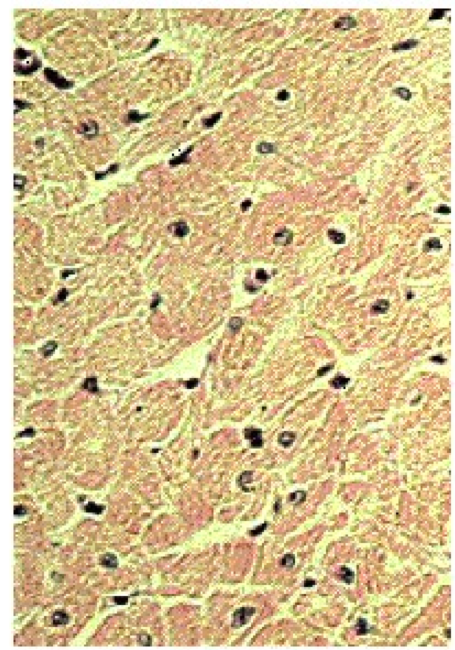
INTERCALATED DISCS



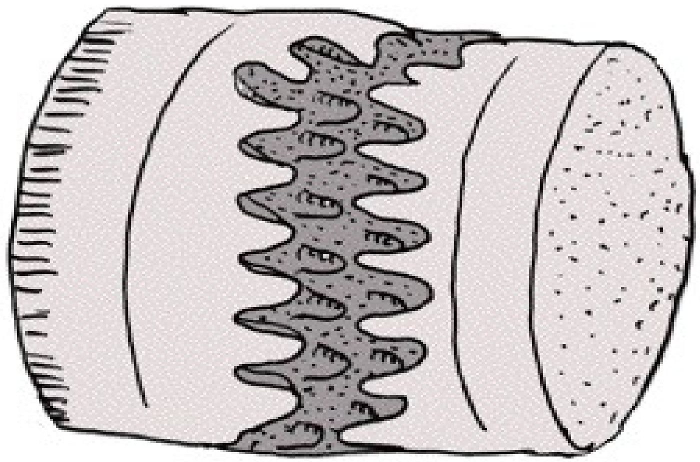


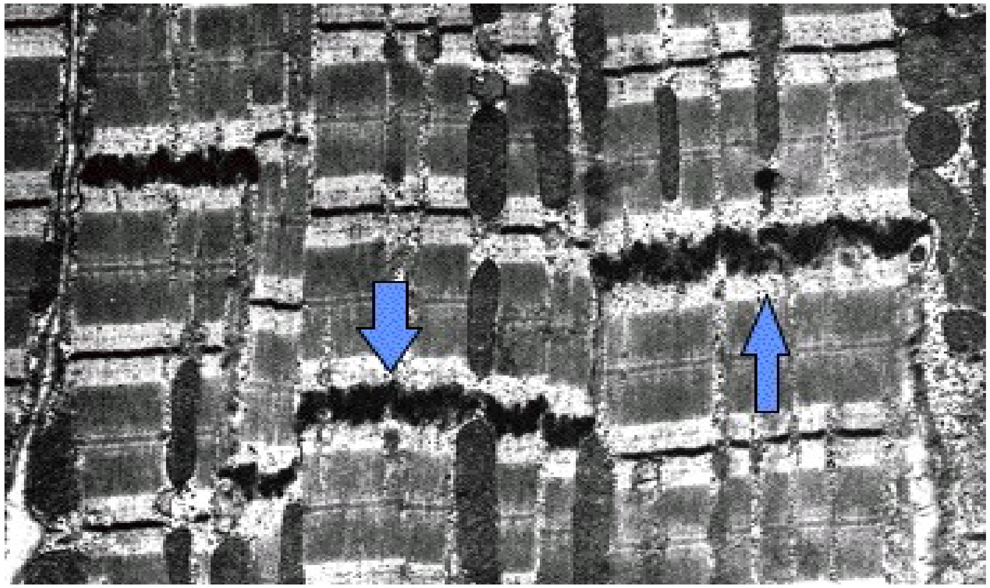
Cardiac Muscle Fibers
(transverse section)

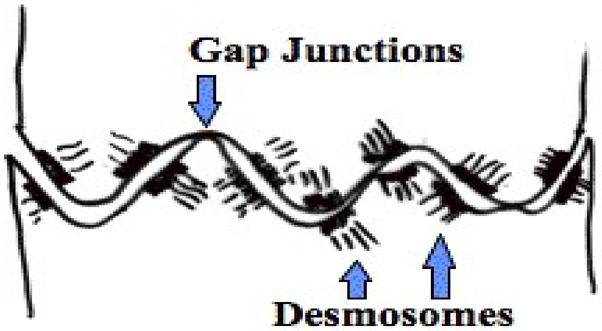


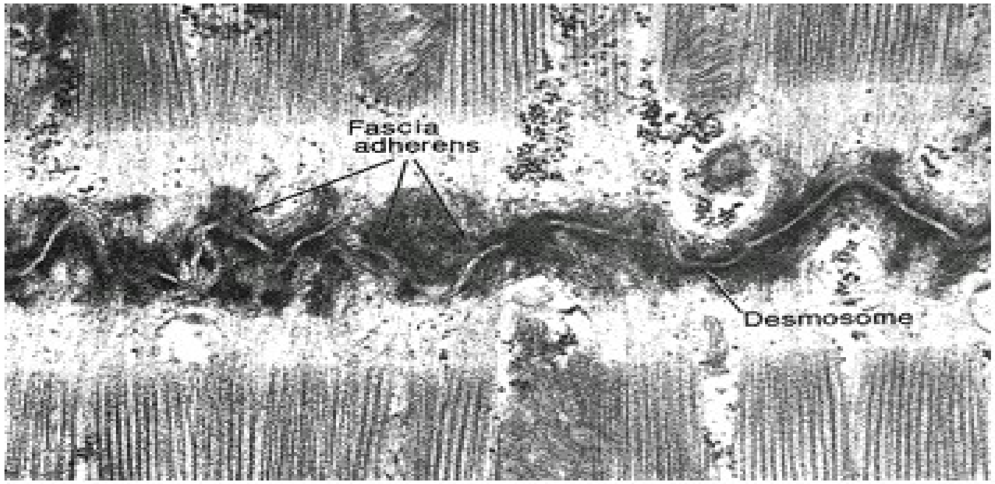


INTERCALATED DISCS



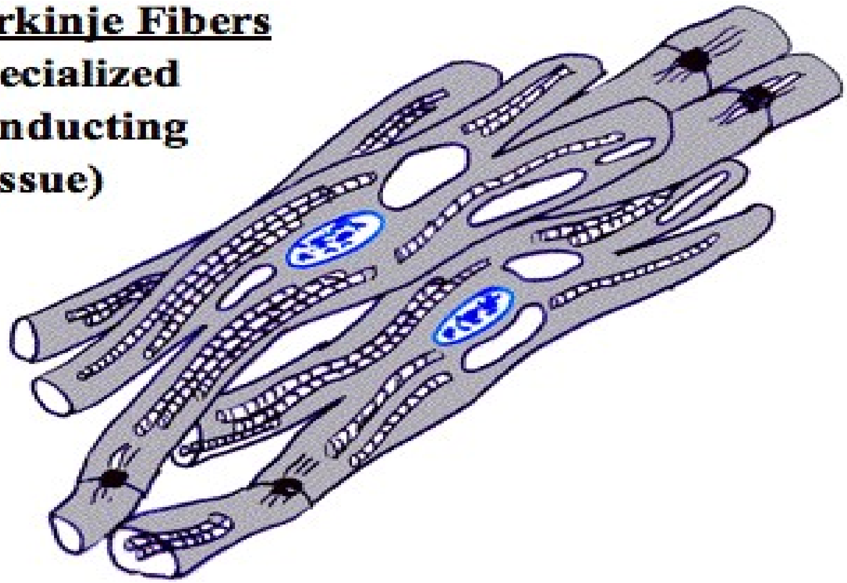




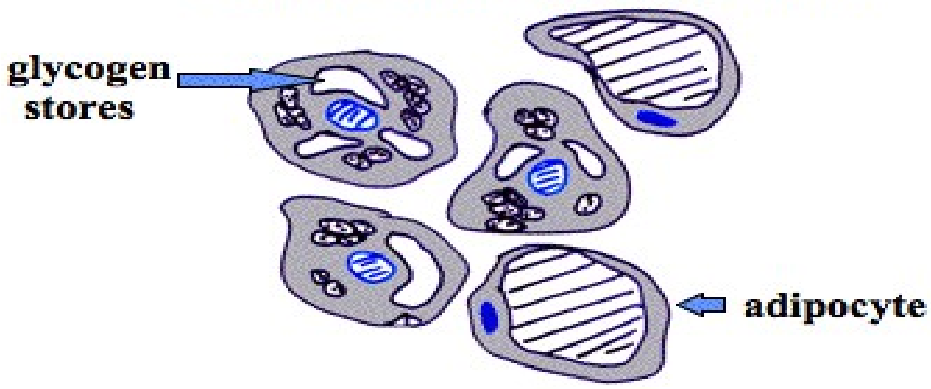


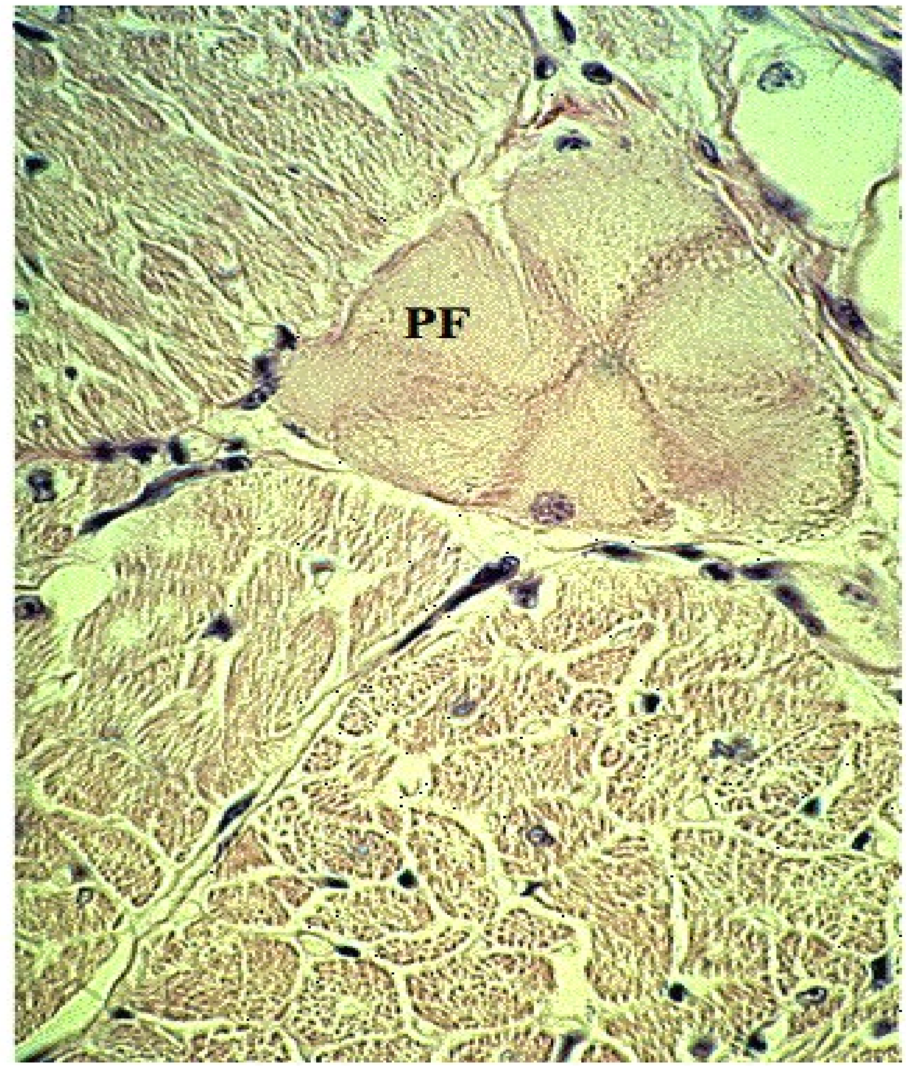
PURKINJE FIBERS

Purkinje Fibers
(specialized conducting tissue)



Purkinje Fibers (trans. section)





Cardiac Muscle

•Like skeletal muscle:

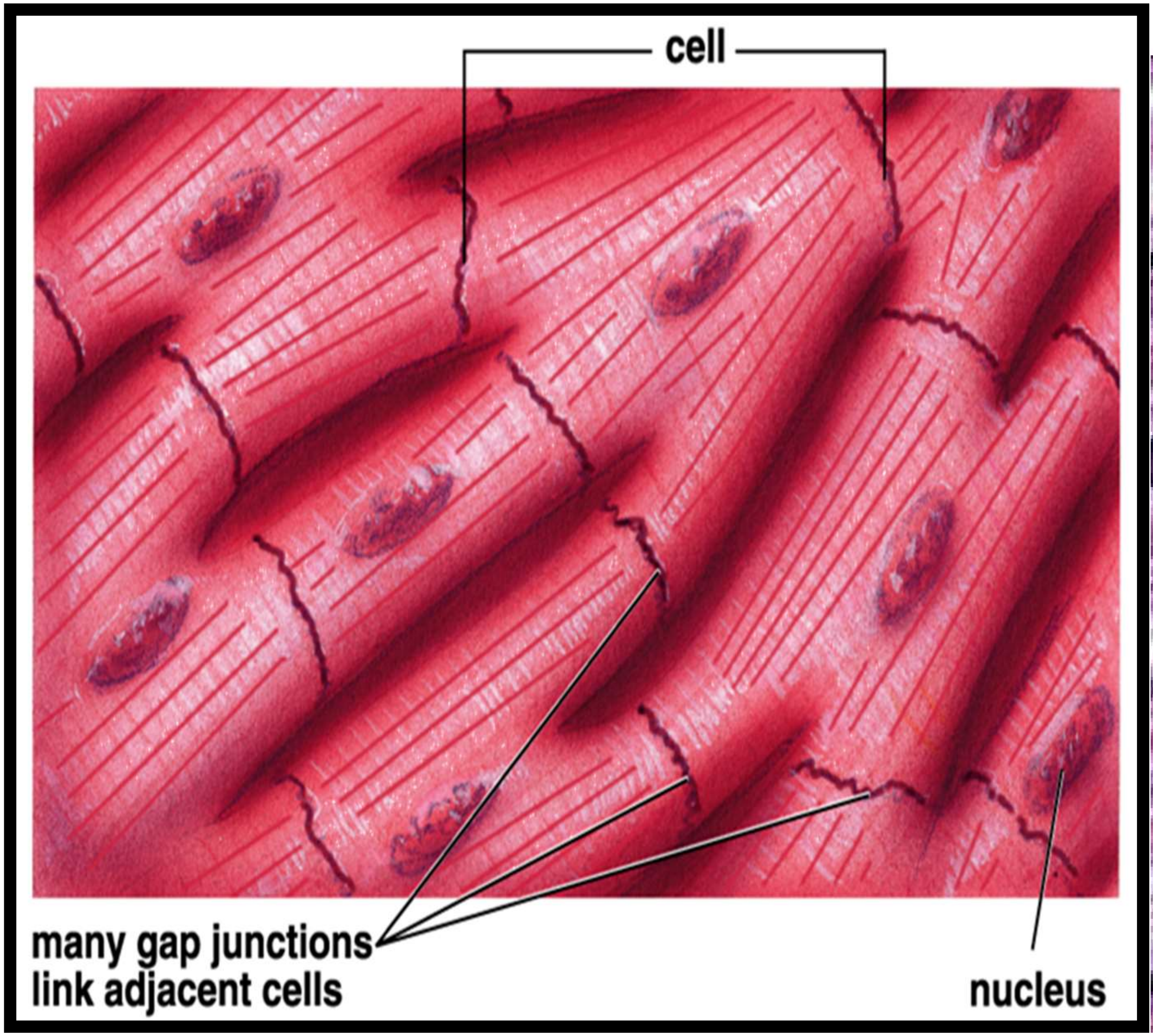
•- striated: actin and myosin in sarcomeres.

•- contract via sliding-filament mechanism.

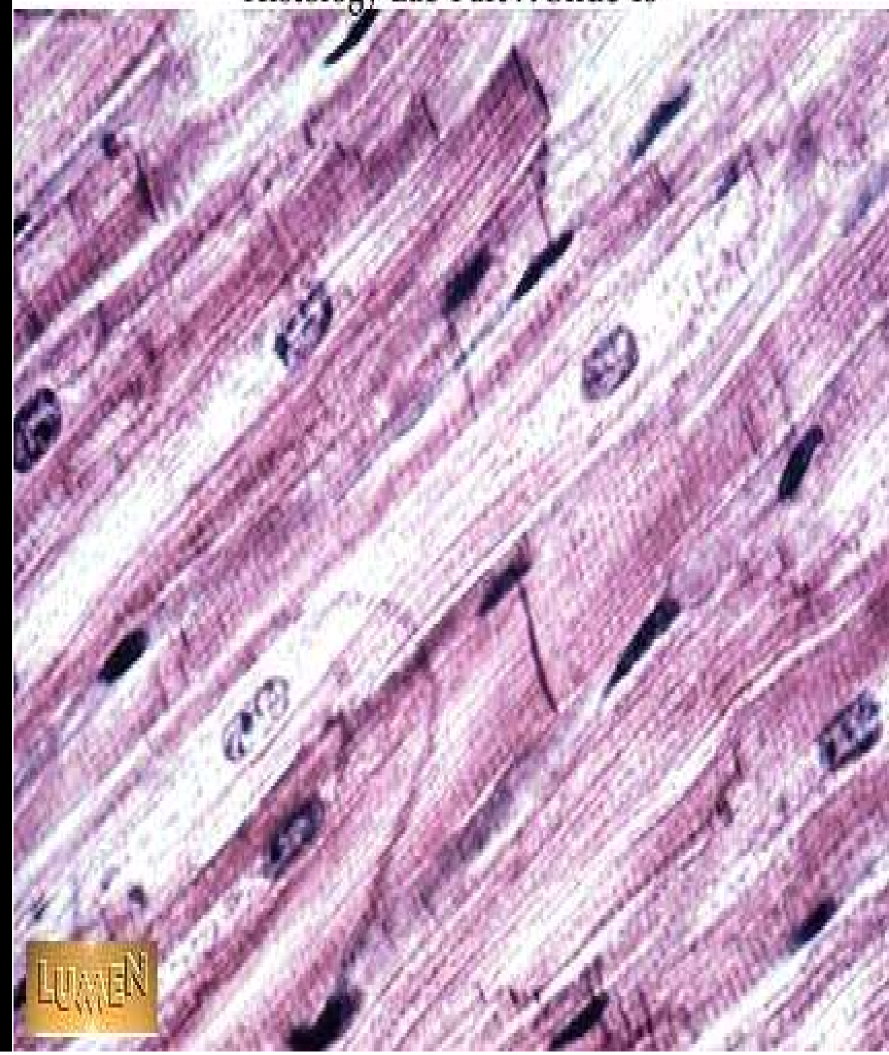
•Unique to cardiac muscle:

•- Adjacent myocardial cells joined by gap junctions= intercalated discs=electrical synapse.

Cardiac Muscle



Histology Lab Part 7: Slide 48



- SMOOTH MUSCLE

Smooth Mus

- •Not striated.
- •NO sarcomeres.
- •Lots of actin, some myosin
- •Can contract even when very stretched.
- •Graded contractions

LOCATIONS OF SMOOTH MUSCLE

DIGESTIVE TRACT

DUCTS OF GLANDS

RESPIRATORY PASSAGES

URINARY & GENETAL TRACT

ARTERIES AND VEINS

PILIERECTOR MUSCLES

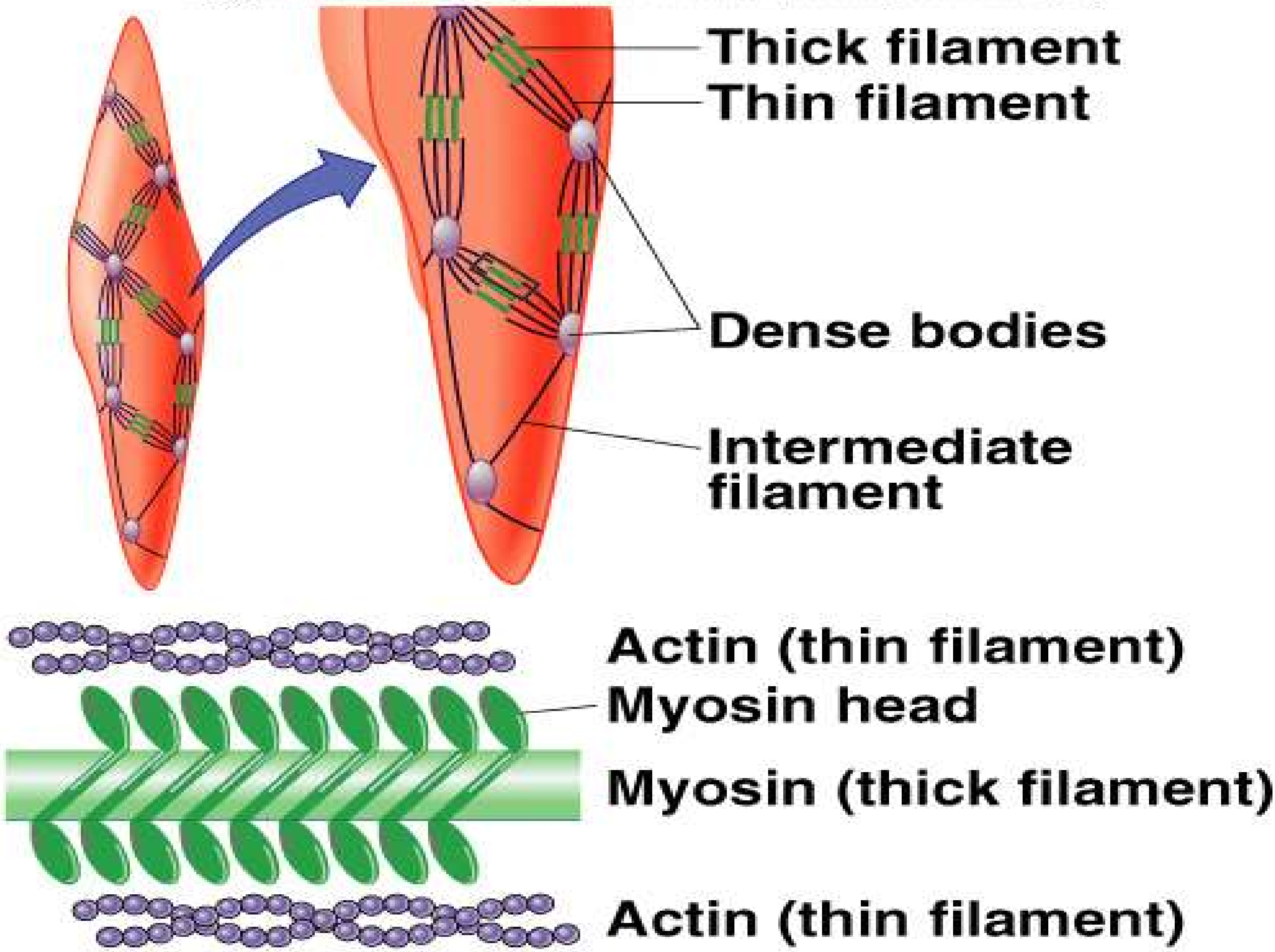
IRIS & CILIARY BODY

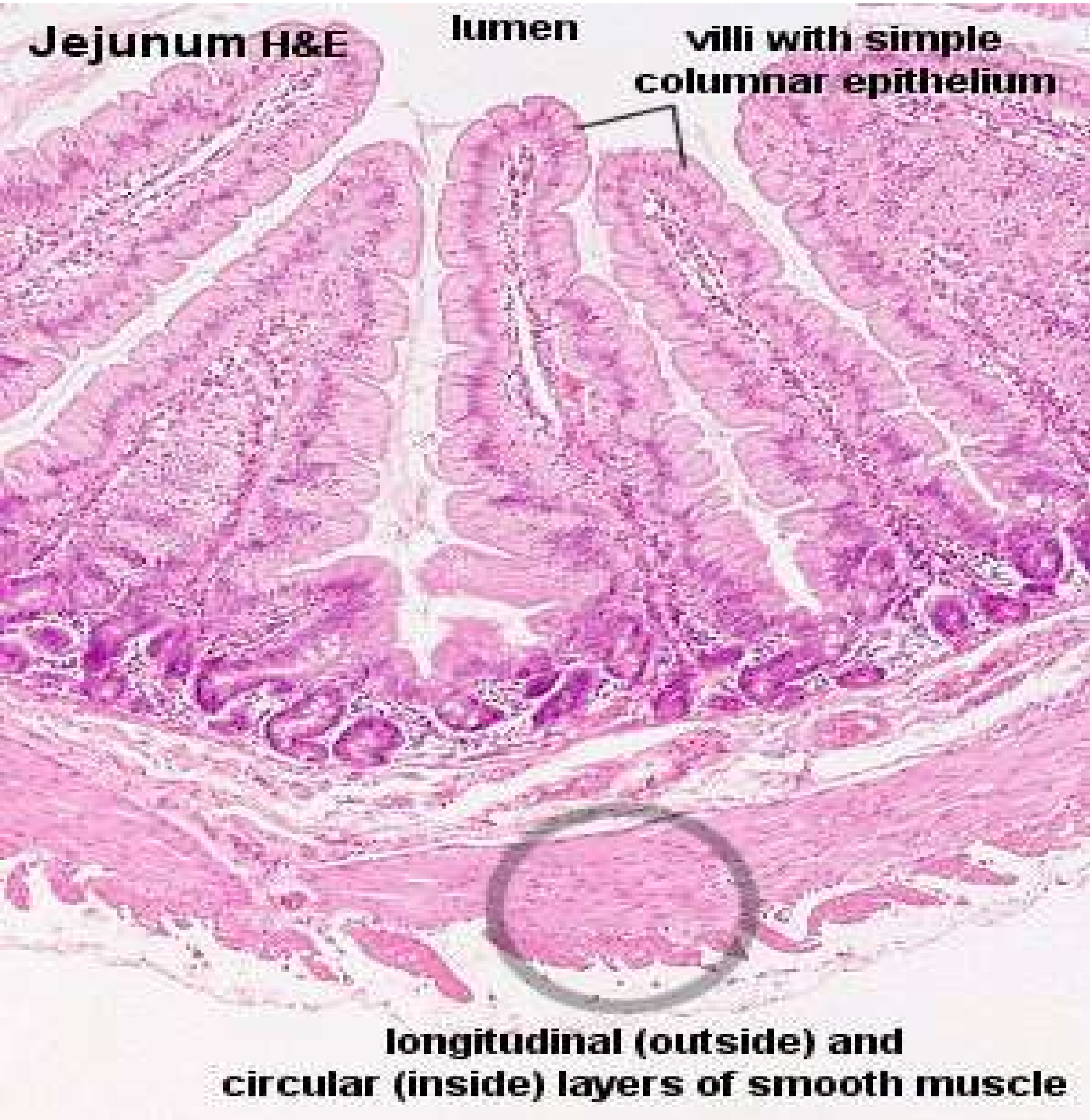
UTERUS

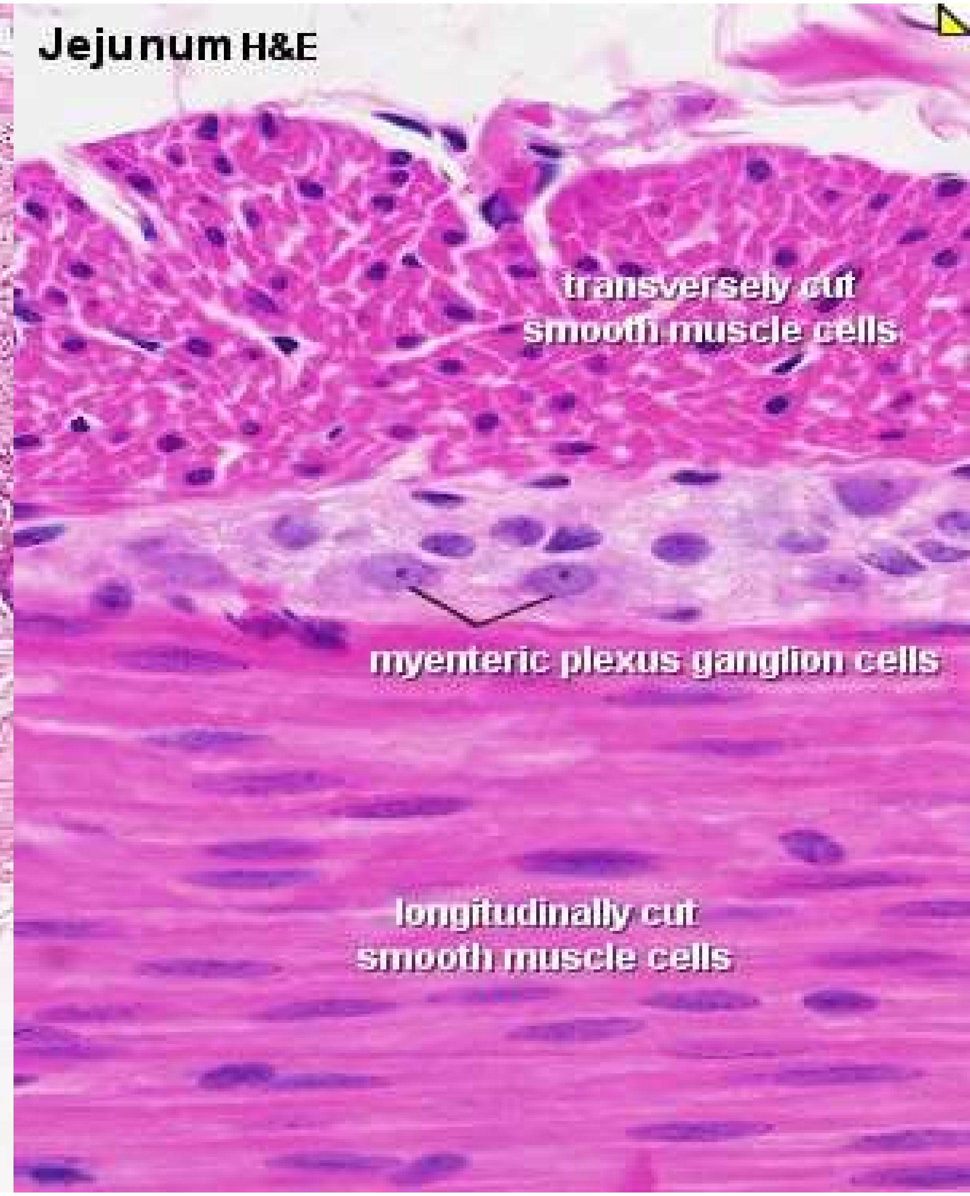
BLADDER

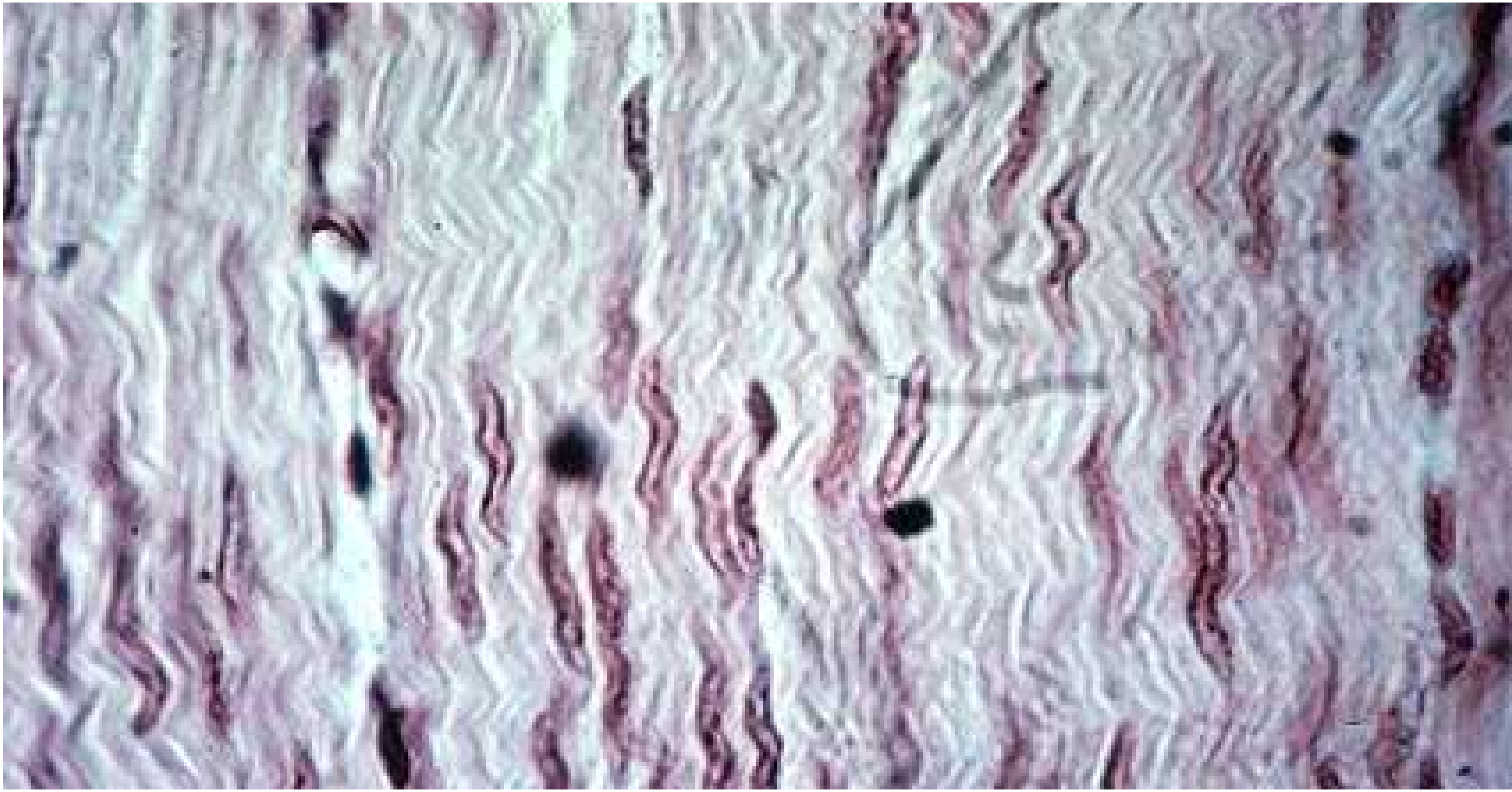
STOMACH

Smooth Muscle

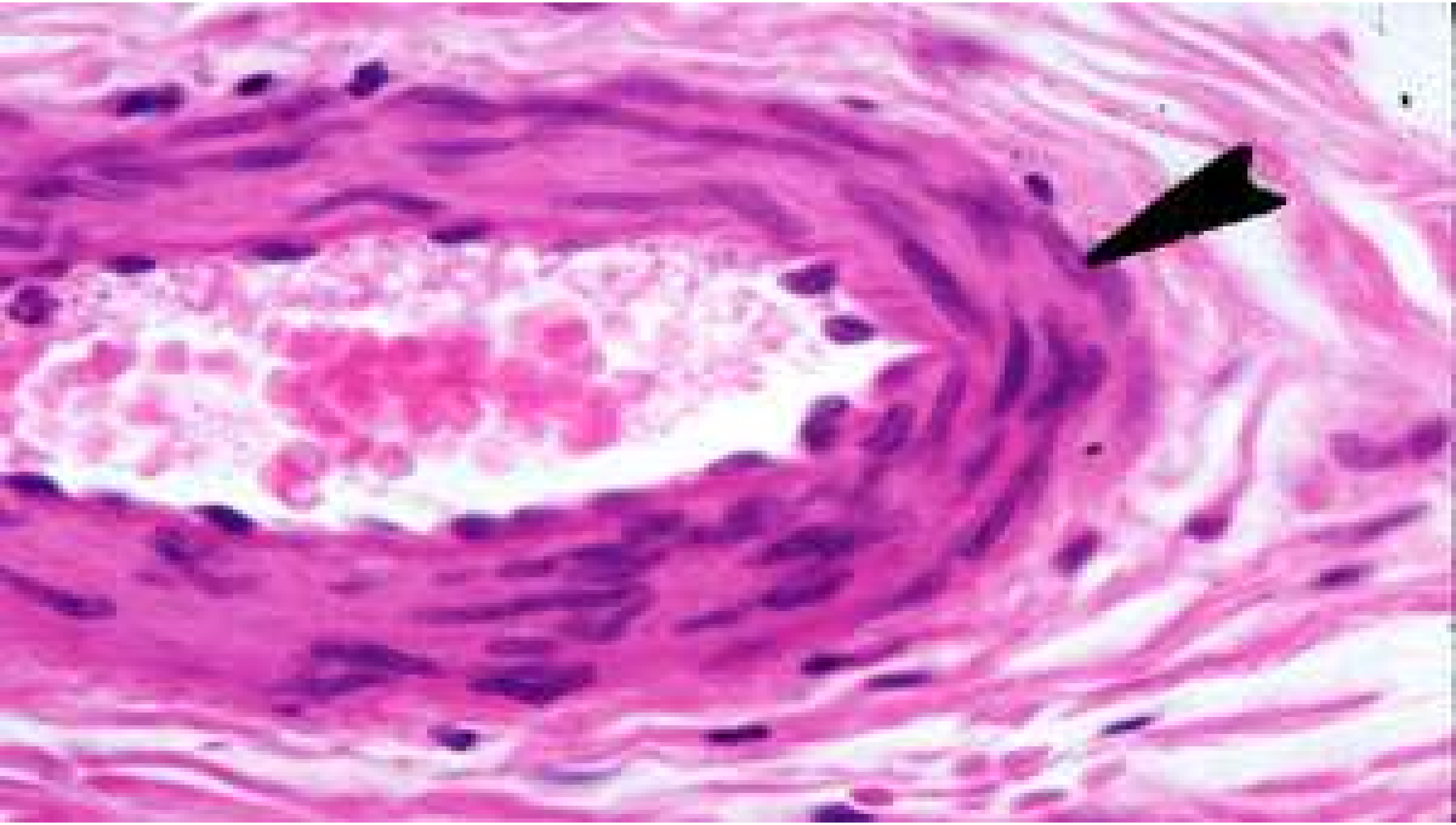



Jejunum H&E
lumen
villi with simple
columnar epithelium
longitudinal (outside) and
circular (inside) layers of smooth muscle

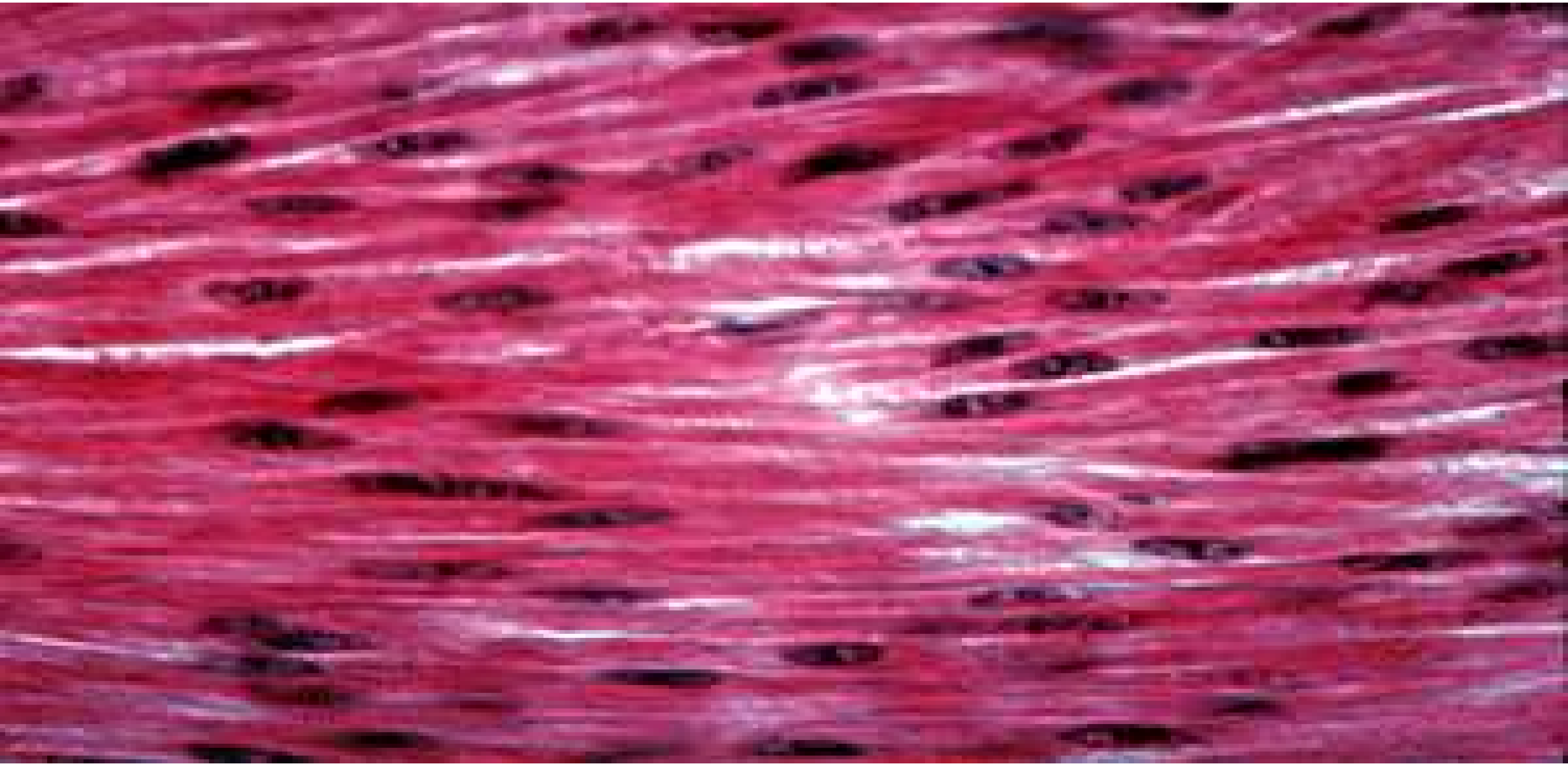

Jejunum H&E
transversely cut
smooth muscle cells
myenteric plexus ganglion cells
longitudinally cut
smooth muscle cells

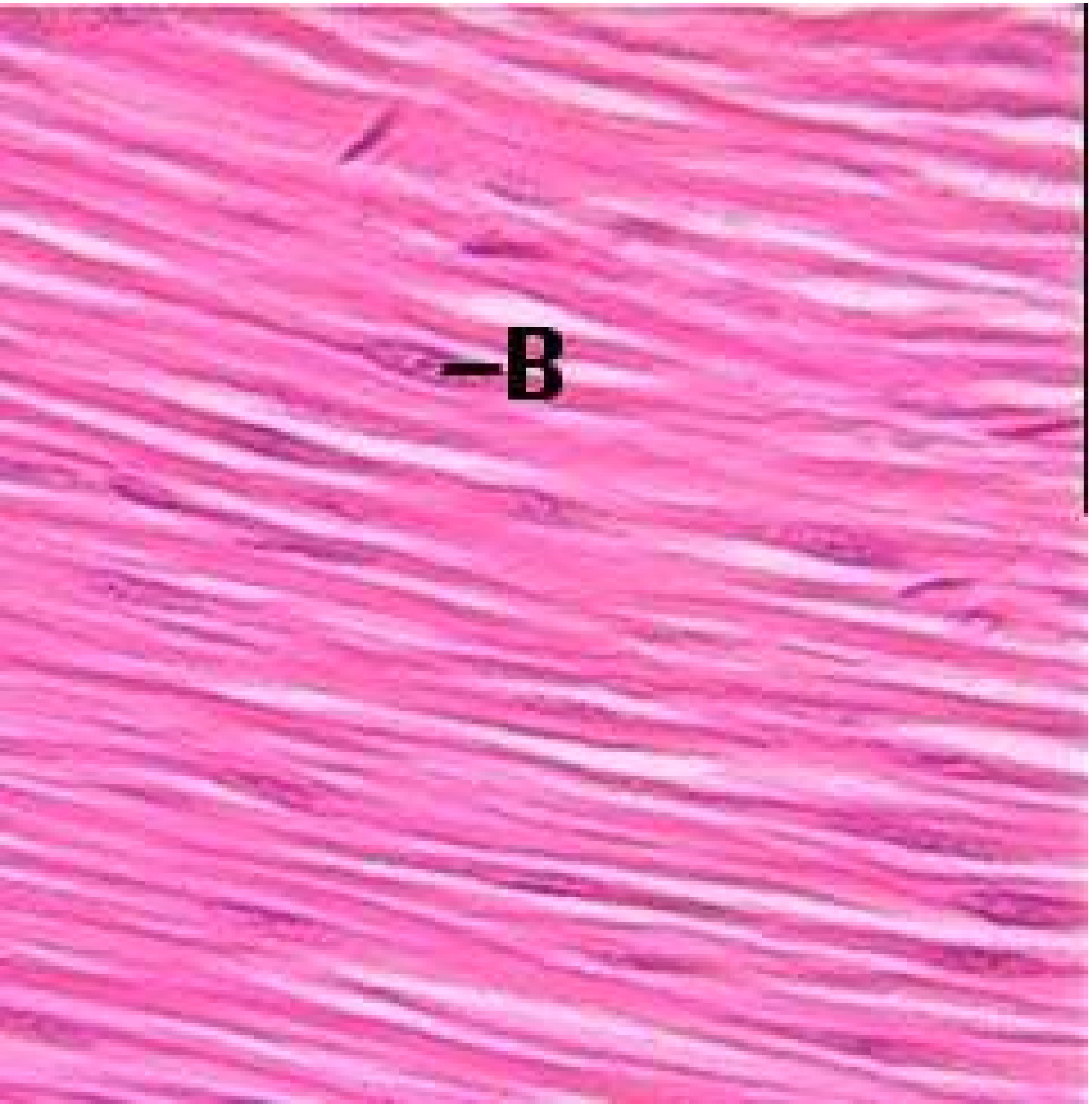


Smooth muscle with wrinkled nuclei due to contraction of cells.



Bladder smooth muscles





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

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

Smooth Muscle

- Actin all over the cell, linked by myosin (web-like pattern, not striations).
- Rise in Ca^{2+} -> Ca^{2+} binds with **calmodulin** -> activates **MLCK (**a kinase) -> Myosin heads are phosphorylated and can bind to actin.

Smooth Muscle

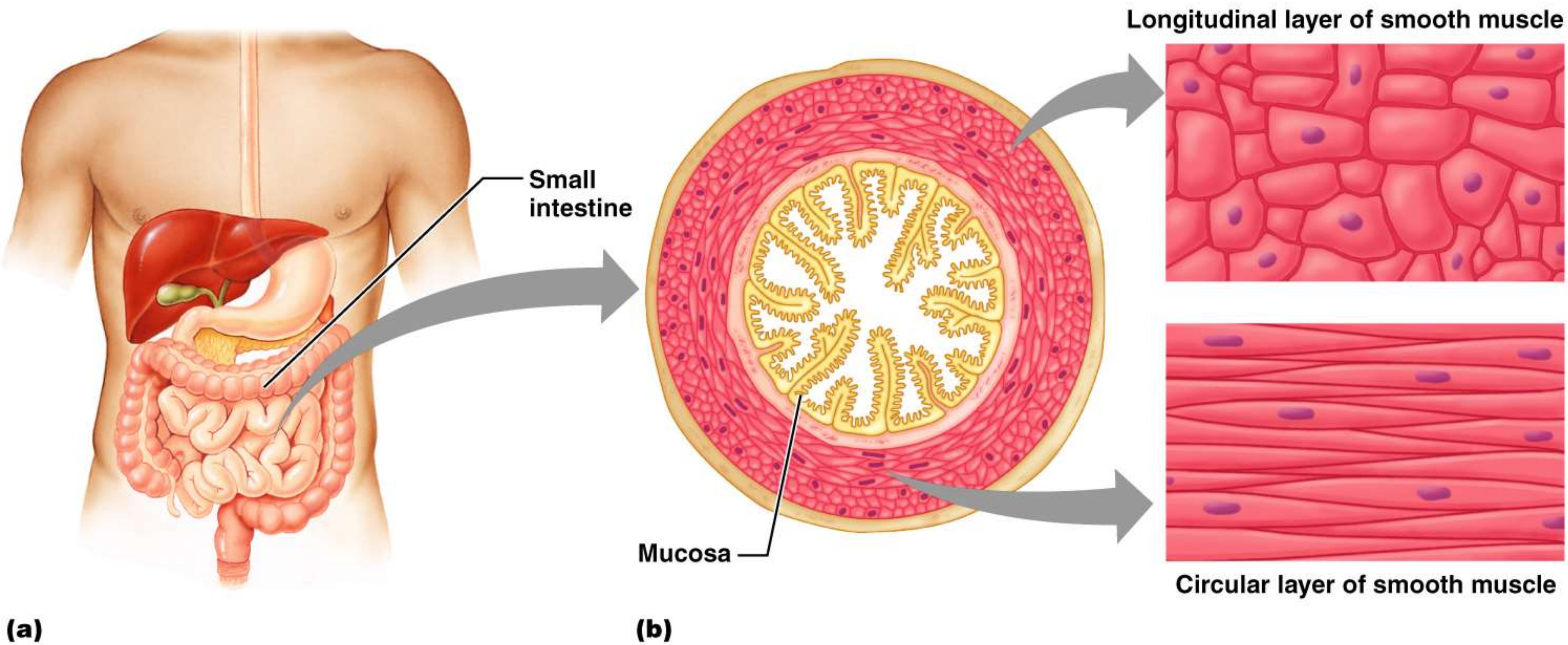


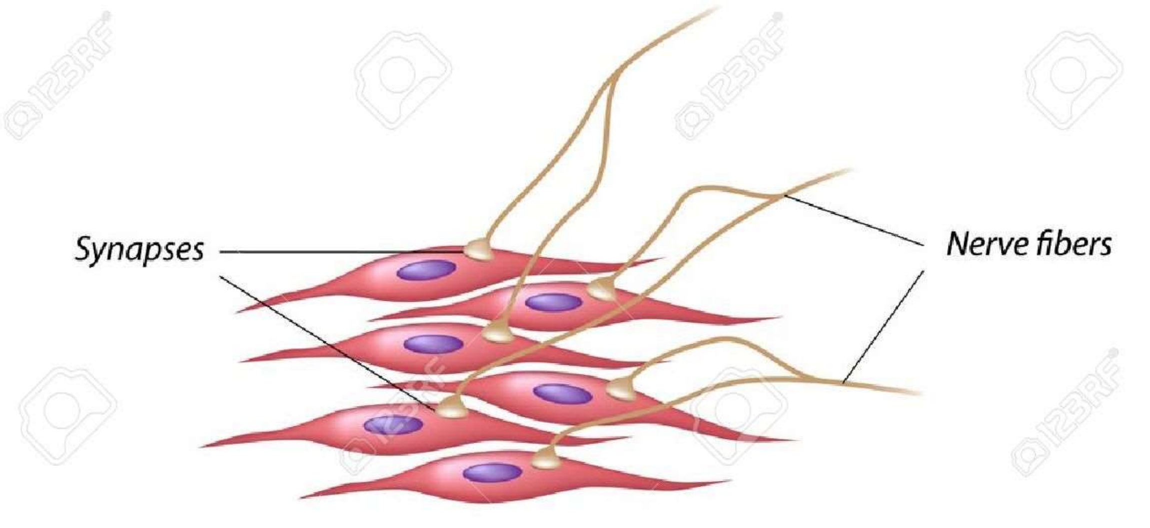
Figure 9.24

Peristalsis

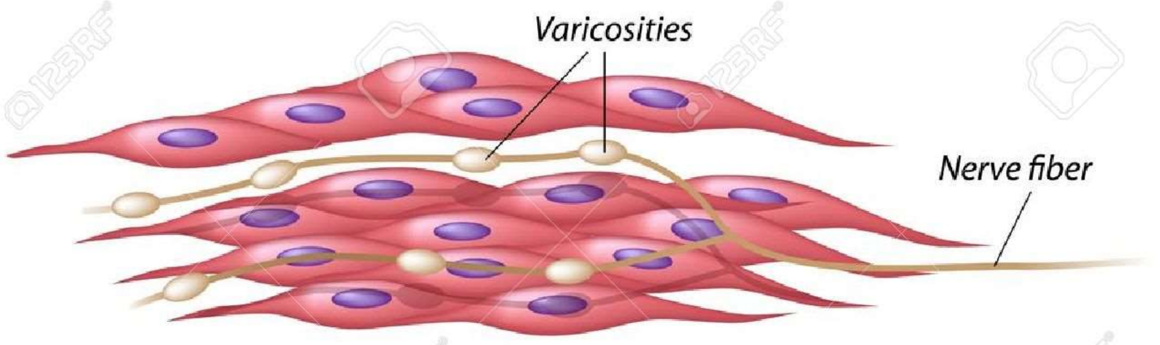
- When the longitudinal layer contracts, the organ dilates and contracts
- When the circular layer contracts, the organ elongates
- Peristalsis – alternating contractions and relaxations of smooth muscles that mix and squeeze substances through the lumen of hollow organs

Innervation of Smooth Muscle

- **Smooth muscle lacks neuromuscular junctions**
- **Innervating nerves have bulbous swellings called varicosities**
- **Varicosities release neurotransmitters into wide synaptic clefts called diffuse junctions**

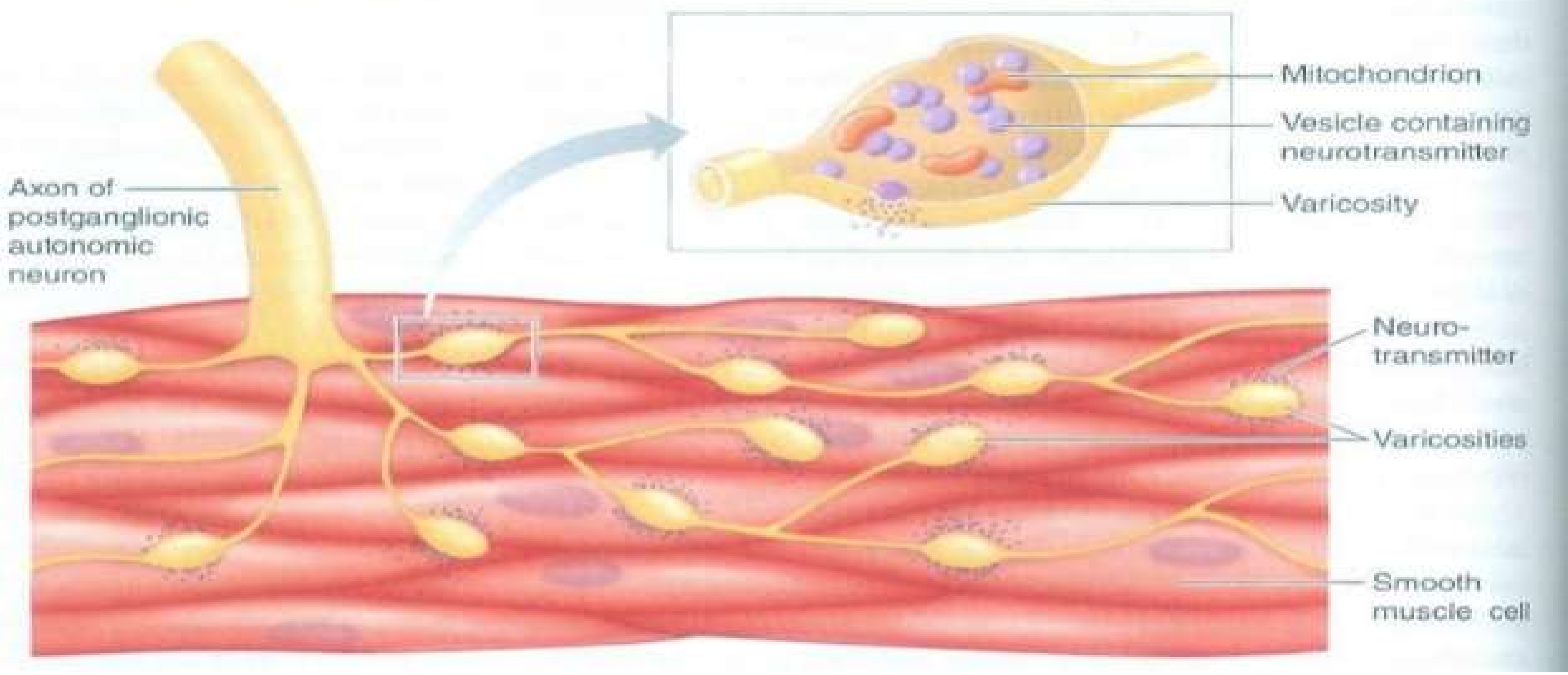


Multiunit Smooth Muscle

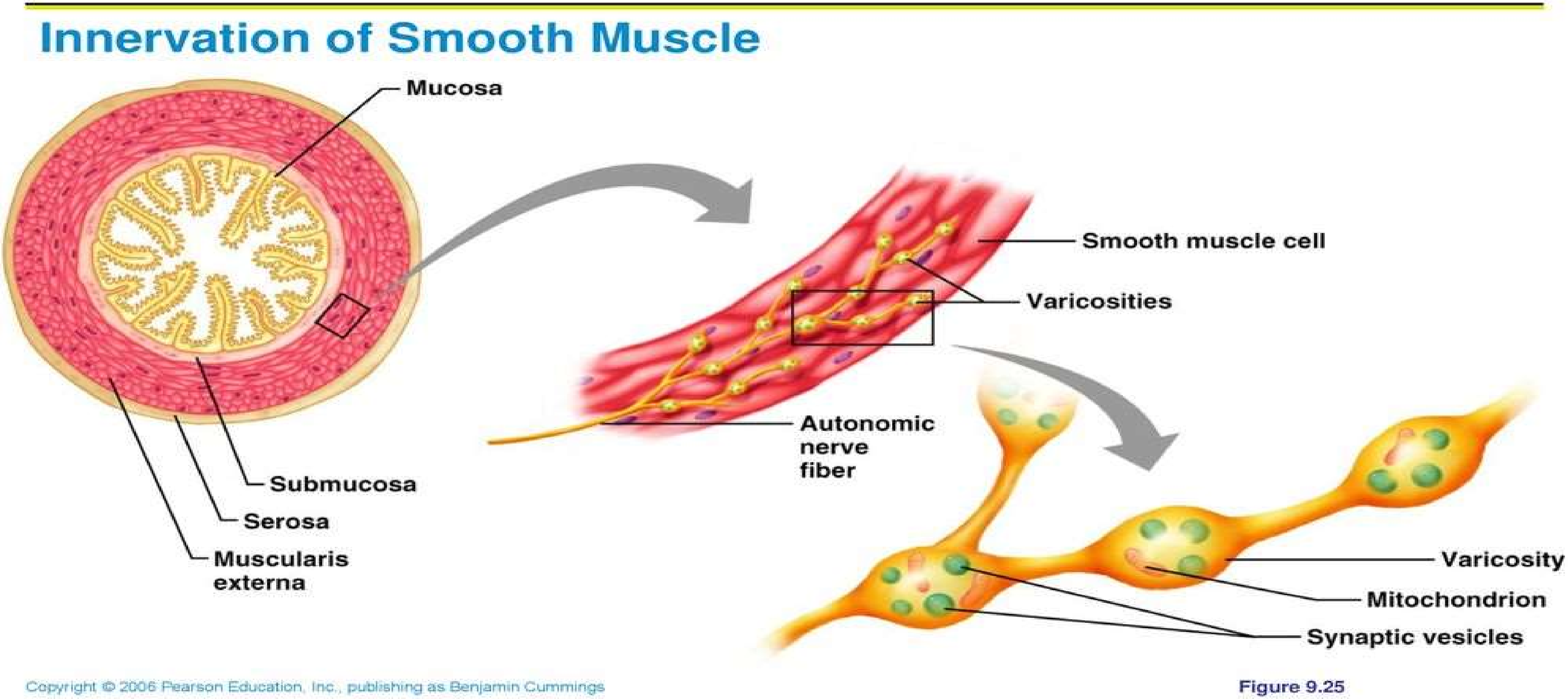


Single-unit Smooth Muscle

Innervation of smooth muscle



Innervation of Smooth Muscle



Microscopic Anatomy of Smooth Muscle

- SR is less developed than in skeletal muscle and lacks a specific pattern
- T tubules are absent
- Plasma membranes have pouchlike infoldings called caveoli
- Ca2+ is sequestered in the extracellular space near the caveoli, allowing rapid influx when channels are opened
- There are no visible striations and no sarcomeres
- Thin and thick filaments are present
- Ratio of thick to thin filaments is much lower than in skeletal muscle
- Thick filaments have heads along their entire length
- There is no troponin complex

Types of Smooth Muscle: Single Unit

- The cells of single-unit smooth muscle, commonly called visceral muscle:
  - Contract rhythmically as a unit
  - Are electrically coupled to one another via gap junctions
  - Often exhibit spontaneous action potentials
  - Are arranged in opposing sheets and exhibit stress-relaxation response

Types of Smooth Muscle: Multiunit

- Multiunit smooth muscles are found:
  - In large airways to the lungs
  - In large arteries
  - In arrector pili muscles
  - Attached to hair follicles
  - In the internal eye muscles
- Their characteristics include:
  - Rare gap junctions
  - Infrequent spontaneous depolarizations
  - Structurally independent muscle fibers
  - A rich nerve supply, which, with a number of muscle fibers, forms motor units
  - Graded contractions in response to neural stimuli

SKELETAL MUSCLE

<u>I. CELLS (FIBERS)</u>

1) Very long compared with most other cells, up to several cm long, 10-100 micrometers in diameter
2) Multinucleate, nuclei are located peripherally
3) Development:
Mesenchymal cell ---> Myoblast (proliferative) ---> Myotubule ---> Muscle Cell

<u>II. ARRANGEMENT OF FIBERS</u> - similar to tendon arrangement

- Blood vessels, lymph vessels, and nerves penetrate muscle with perimysium
- Endomysium contains capillaries and nerve fibers

<u>III. STRIATION ULTRASTRUCTURE</u> (Fibers ---> Myofibrils ---> Myofilaments)

- Proteins are *actin* (thin filaments) and myosin (thick filaments), also tropomyosin and troponin are associated with thin filaments

TABLE 9.1 Structure and Organizational Levels of Skeletal Muscle

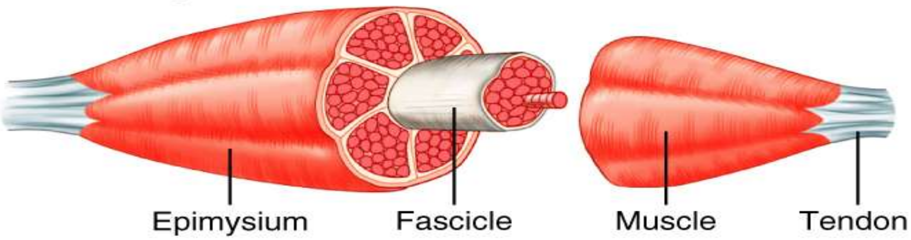
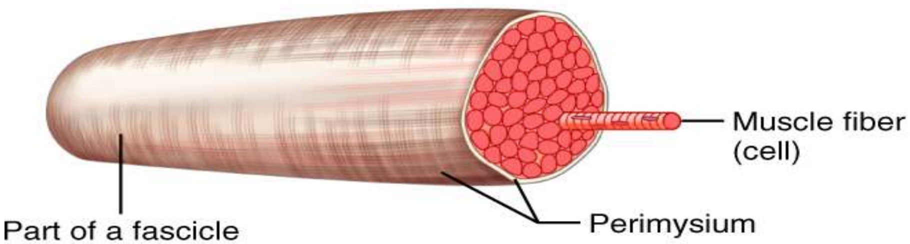
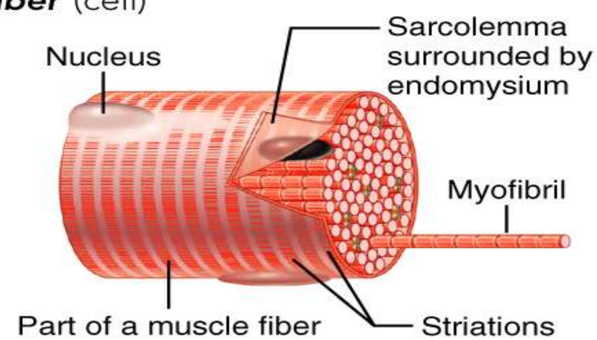
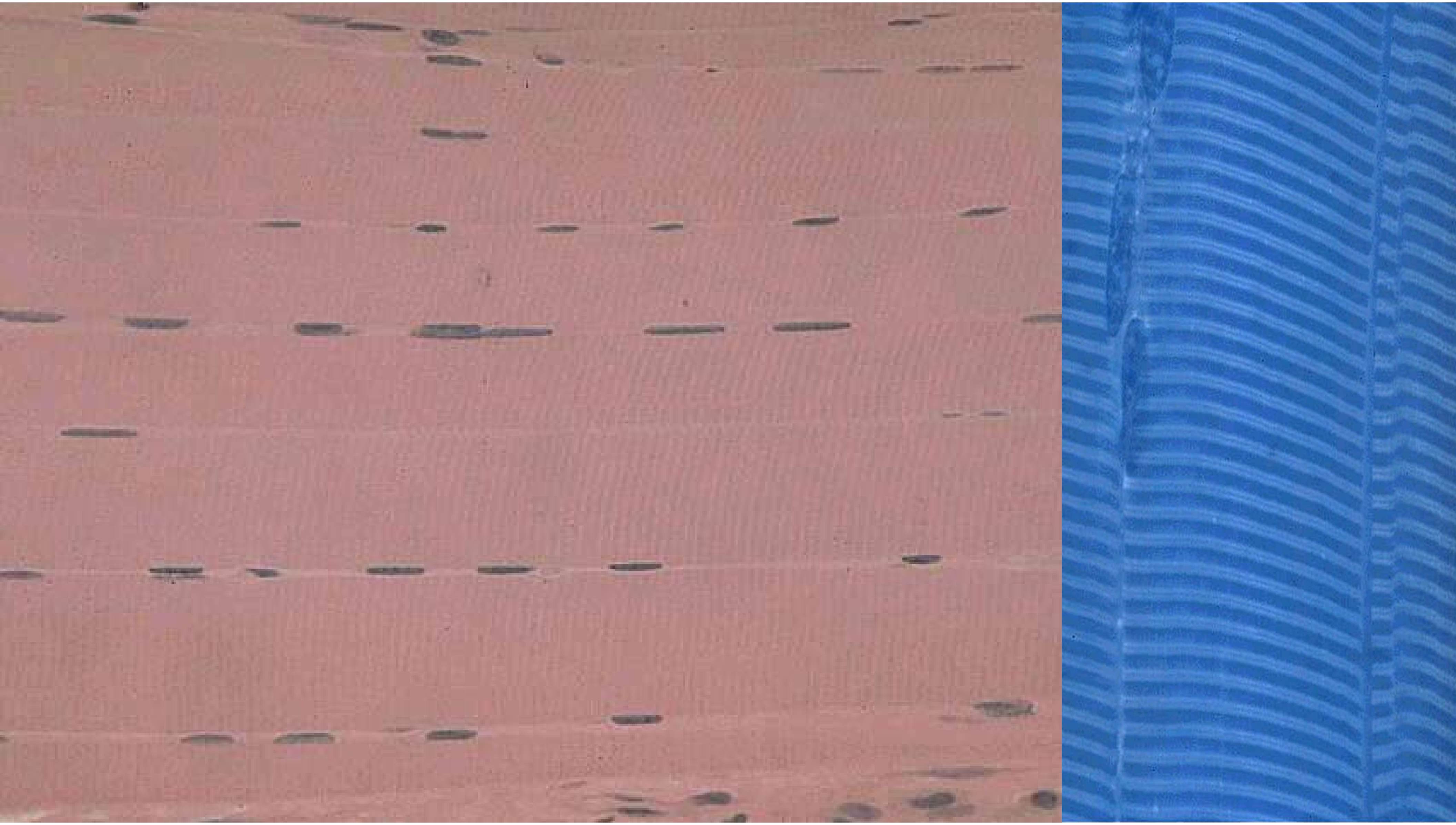
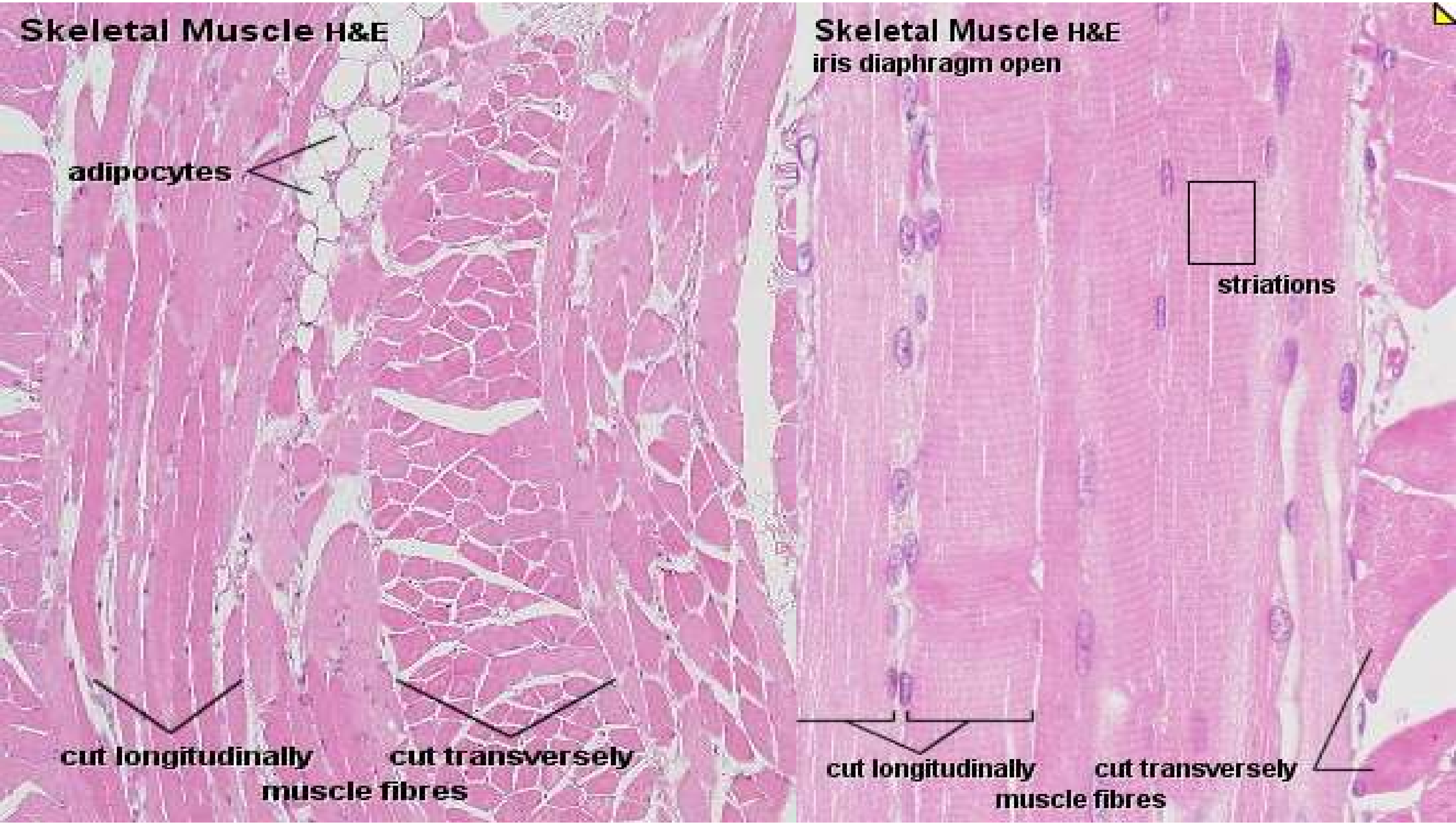
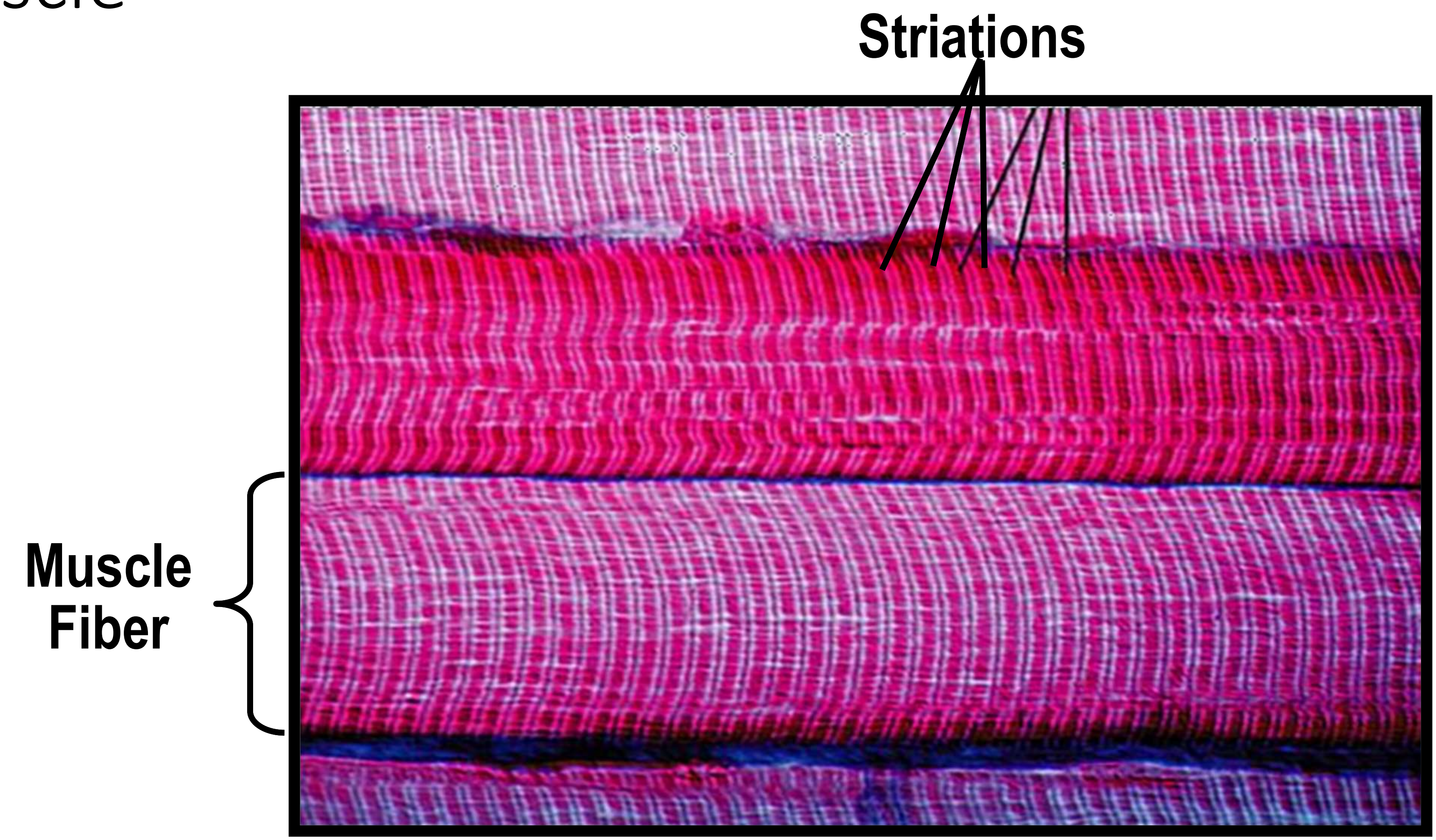
STRUCTURE AND ORGANIZATIONAL LEVEL	DESCRIPTION	CONNECTIVE TISSUE WRAPPINGS
Muscle (organ) 	Consists of hundreds to thousands of muscle cells, plus connective tissue wrappings, blood vessels, and nerve fibers	Covered externally by the epimysium
Fascicle (a portion of the muscle) 	Discrete bundle of muscle cells, segregated from the rest of the muscle by a connective tissue sheath	Surrounded by a perimysium
Muscle fiber (cell) 	Elongated multinucleate cell; has a banded (striated) appearance	Surrounded by the endomysium

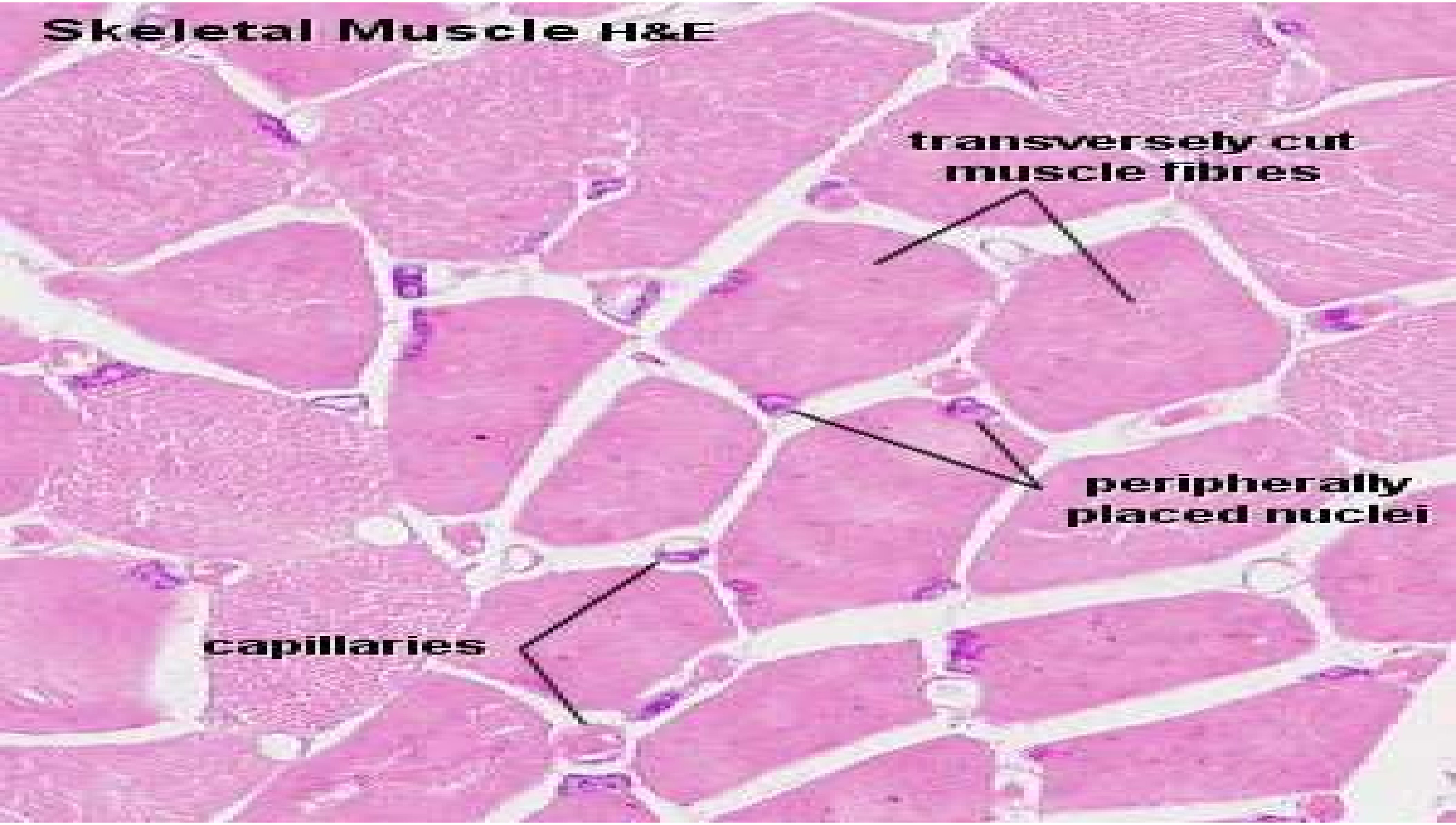
Table 9.1a

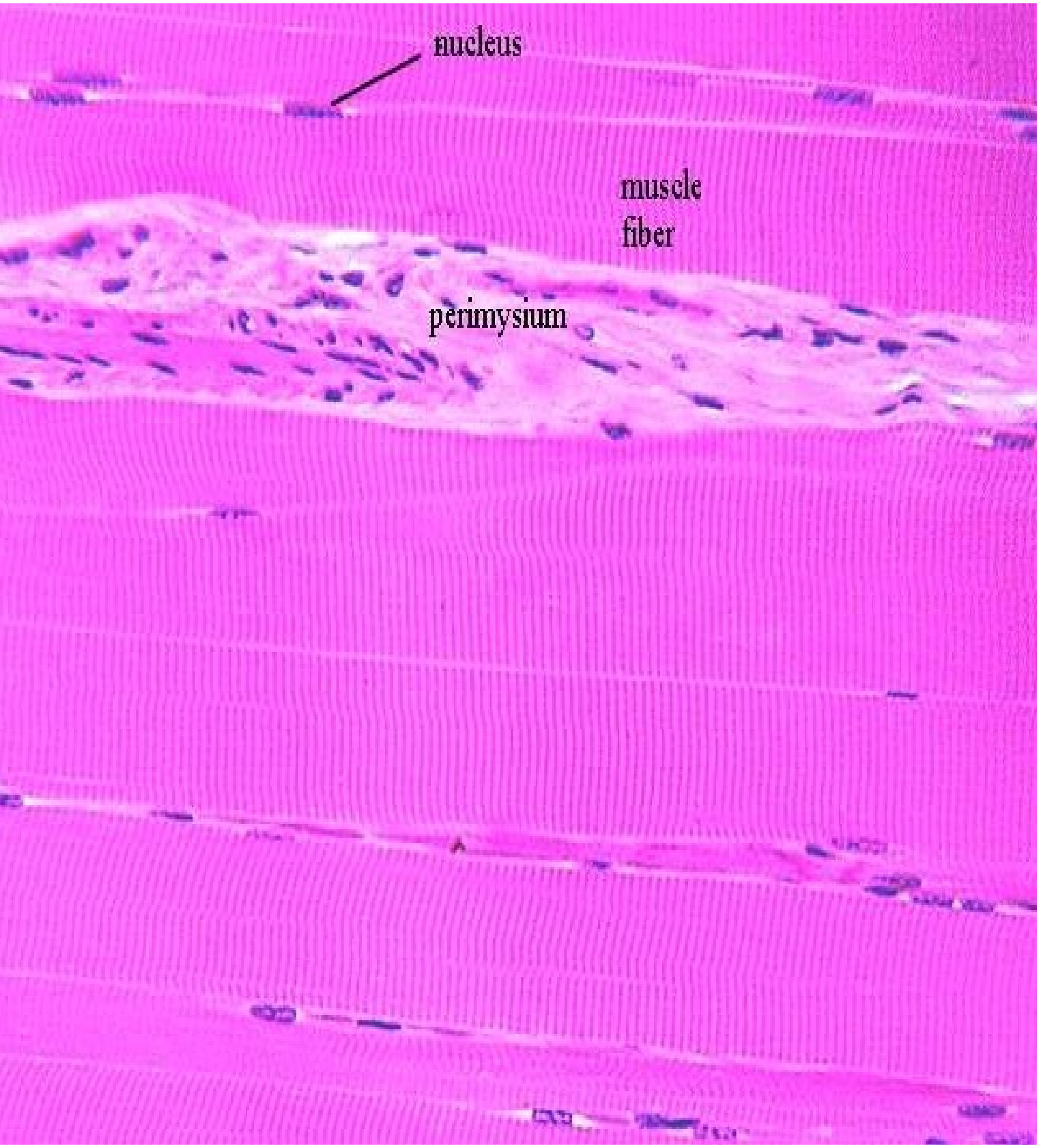


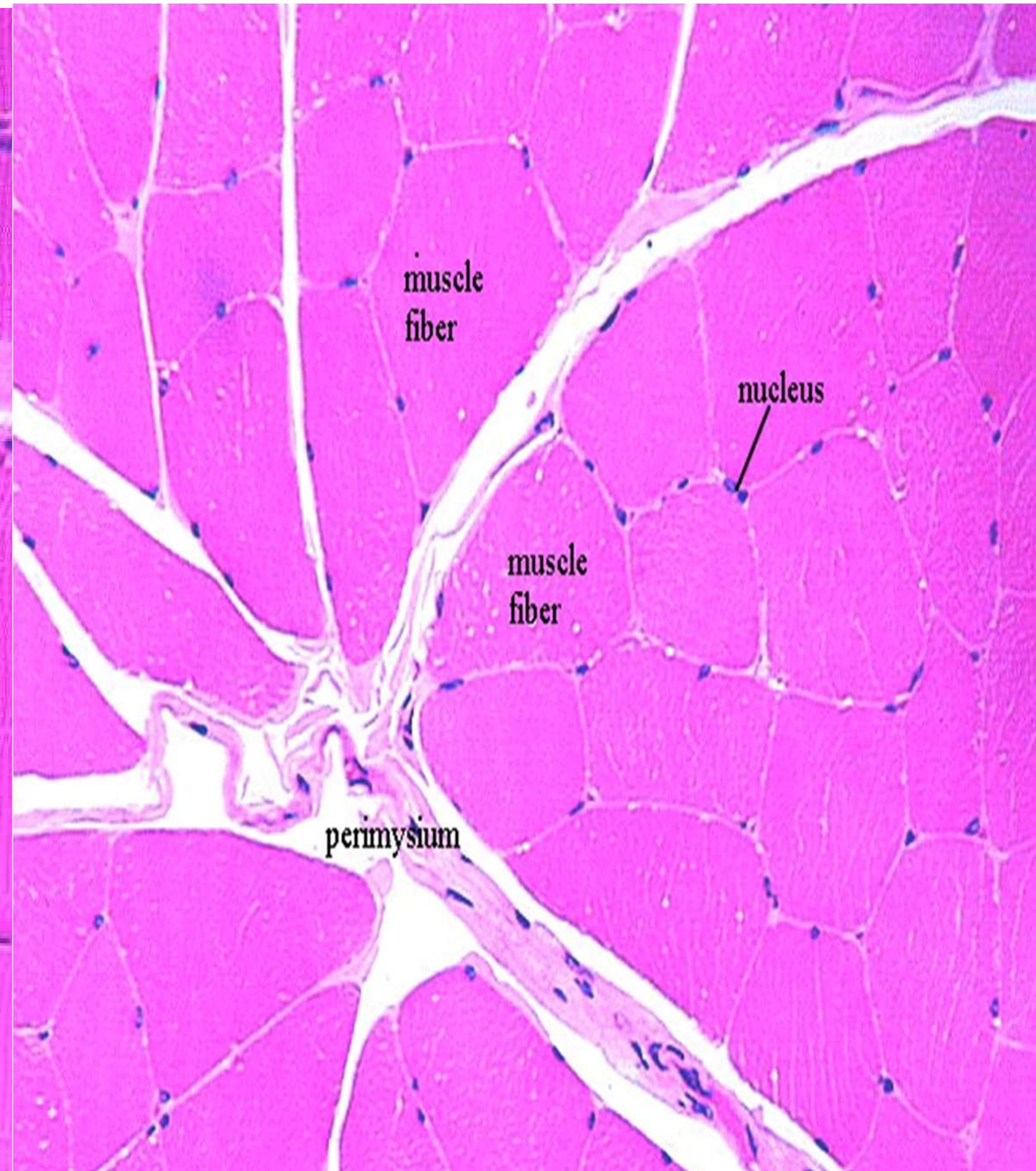

Skeletal Muscle H&E
adipocytes
cut longitudinally
cut transversely
muscle fibres
Skeletal Muscle H&E
iris diaphragm open
striations
cut longitudinally
cut transversely
muscle fibres

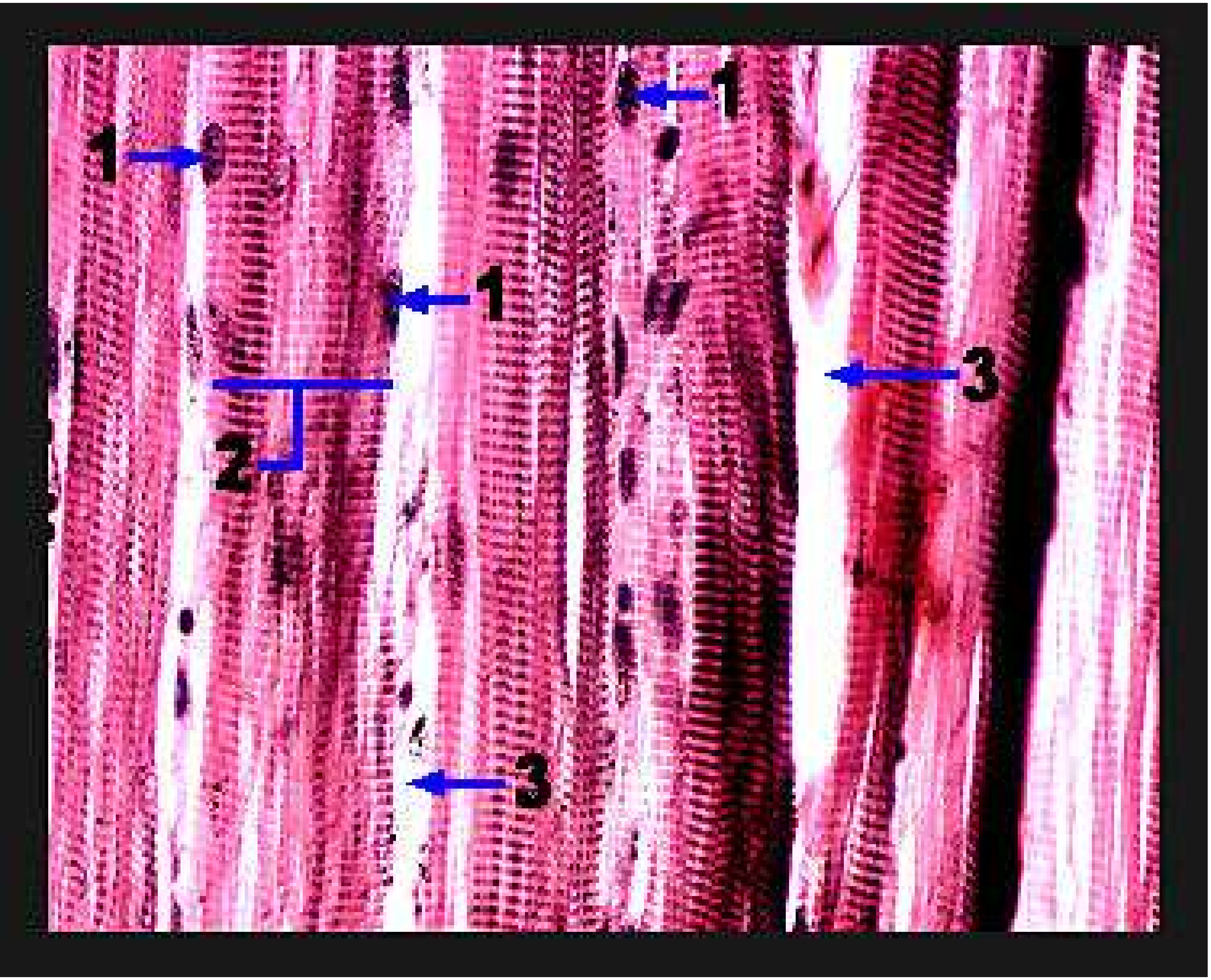
Muscle




Skeletal Muscle H&E
transversely cut muscle fibres
peripherally placed nuclei
capillaries


nucleus
muscle fiber
perimysium


muscle fiber
nucleus
muscle fiber
perimysium

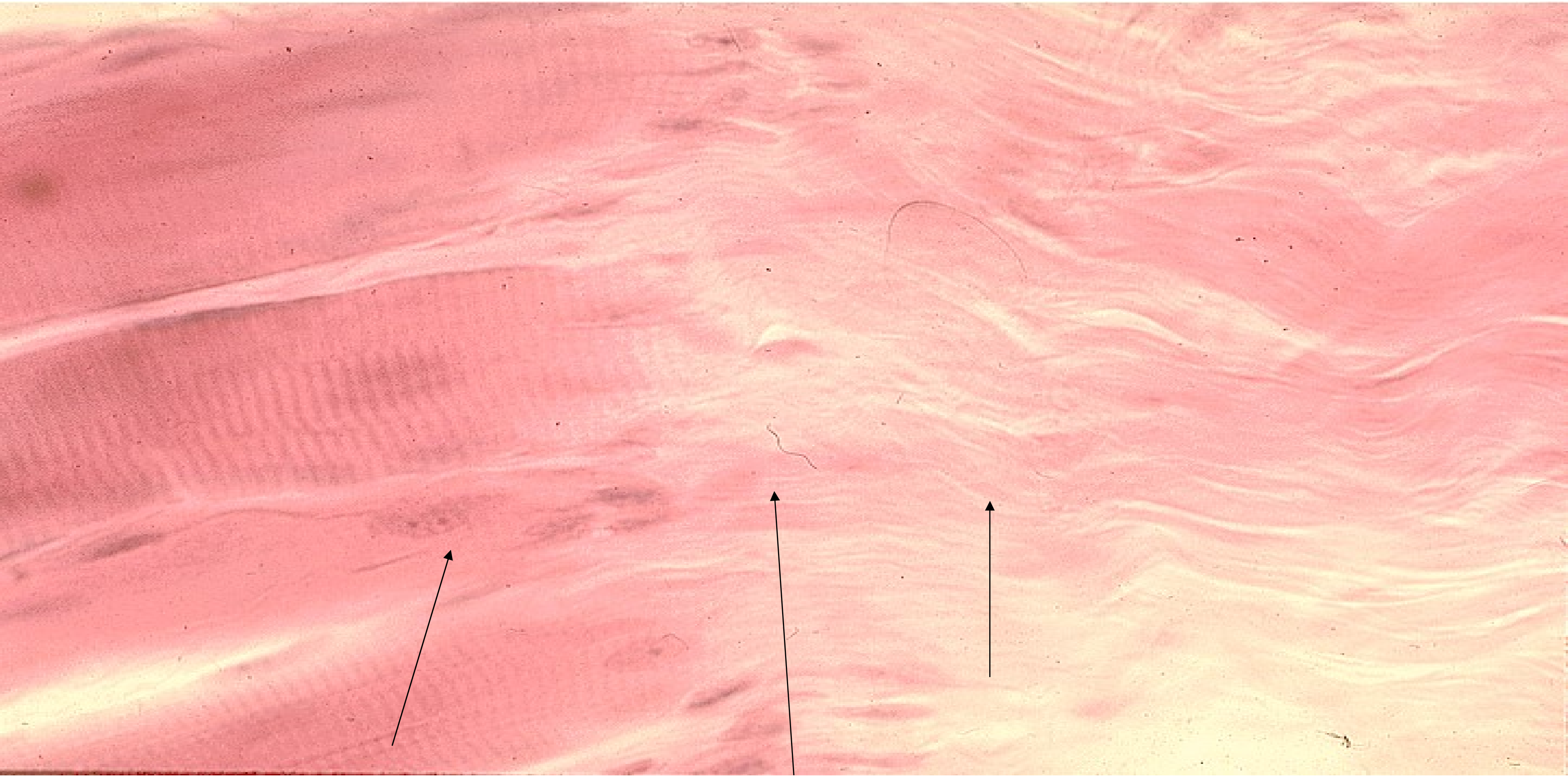


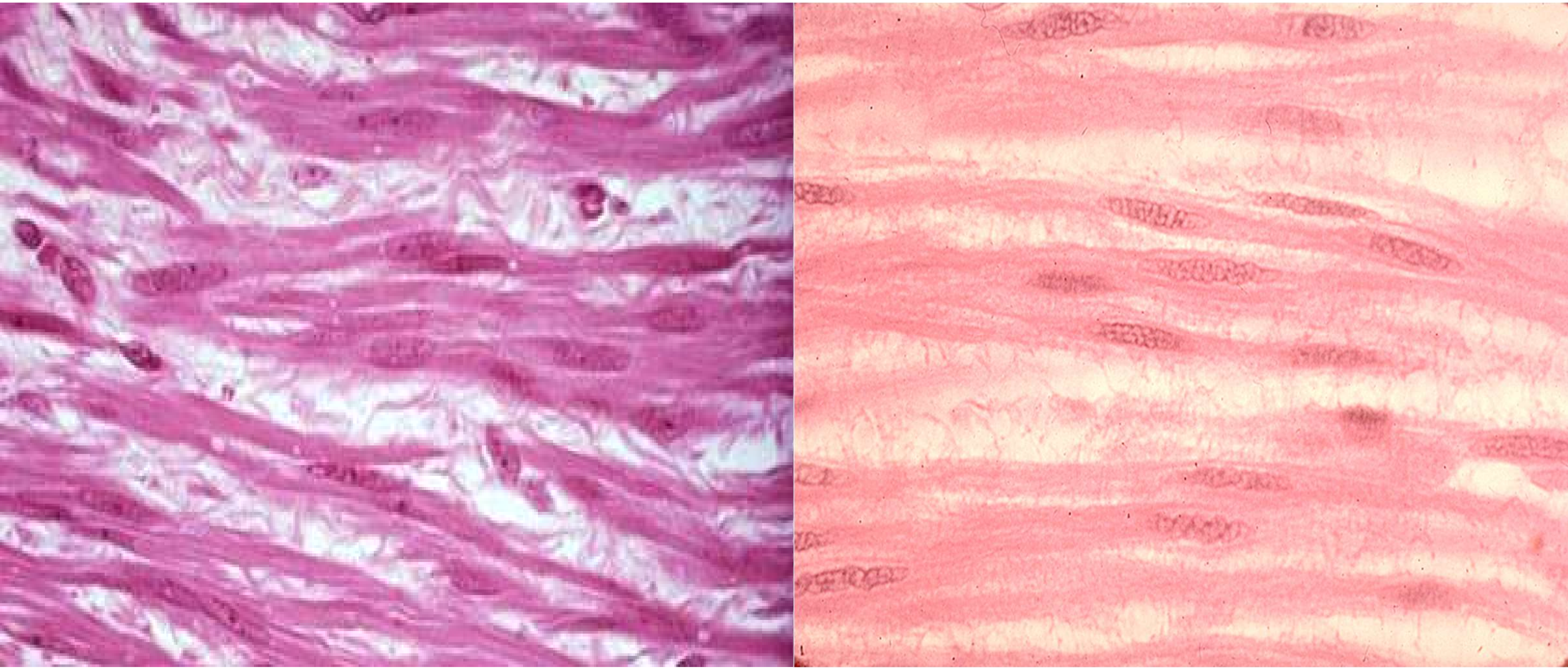
1. Muscle cell nuclei

2. Muscle fiber (cell)

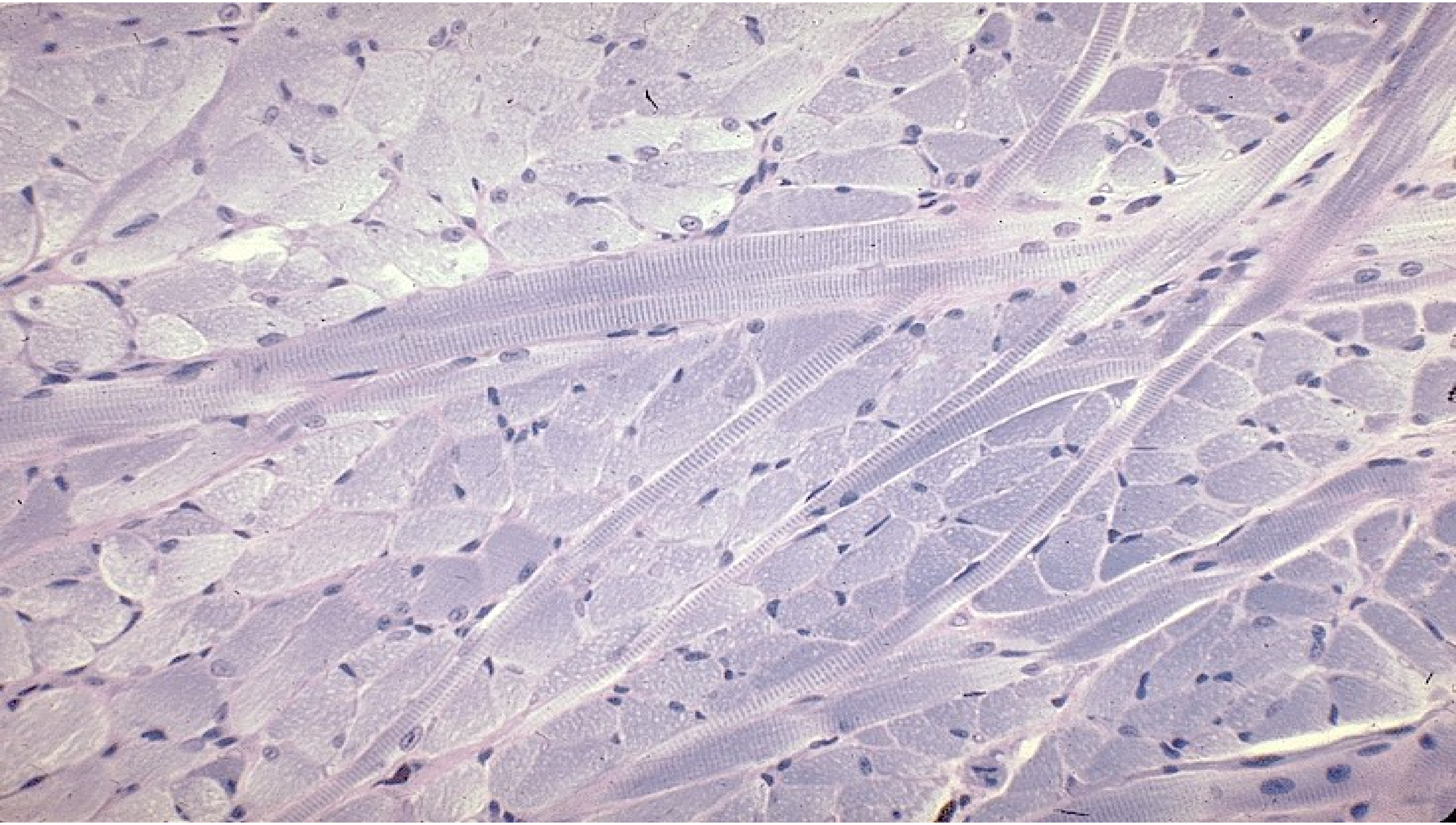
3. Endomysium

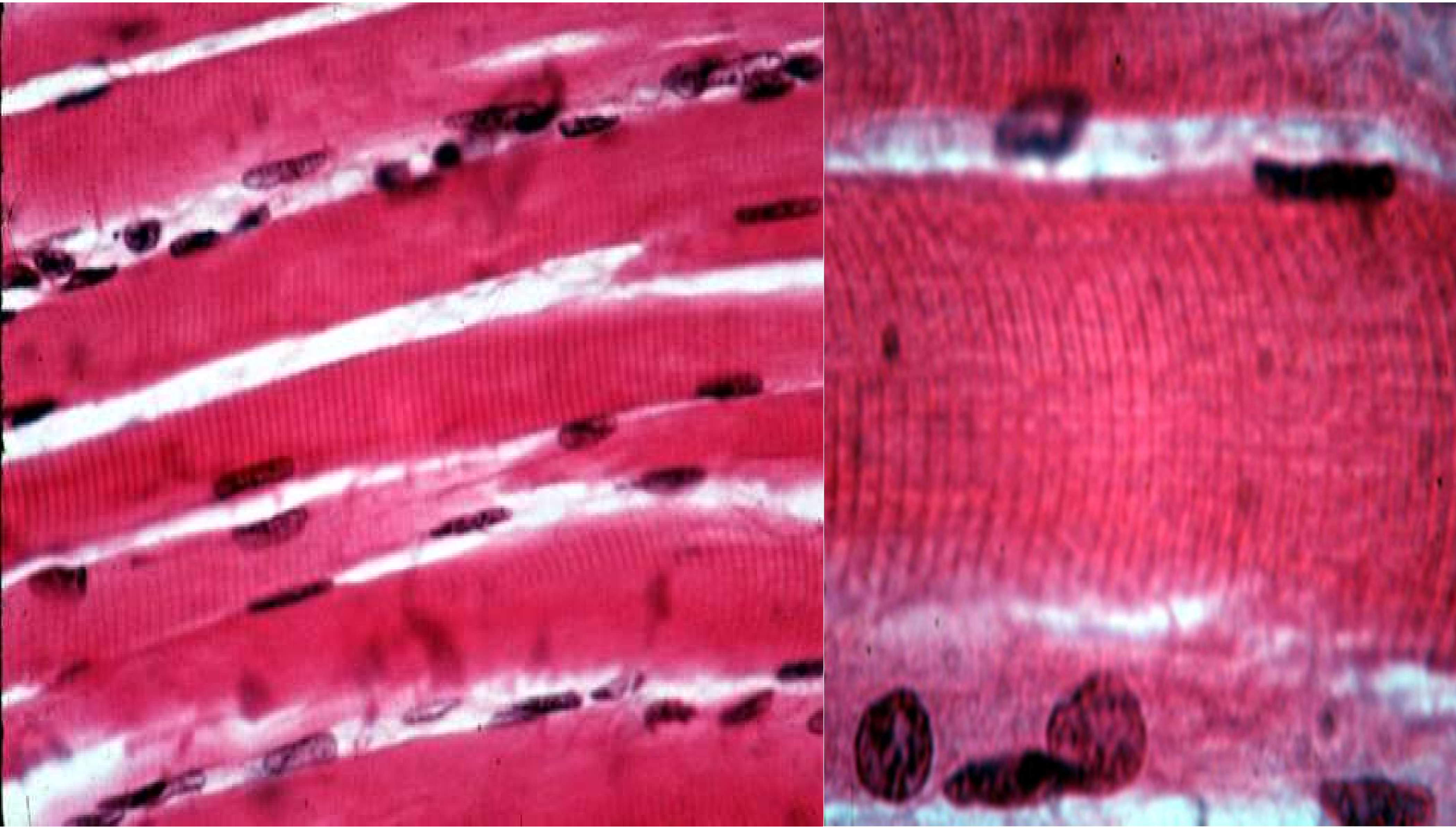
Myotendenous Junction

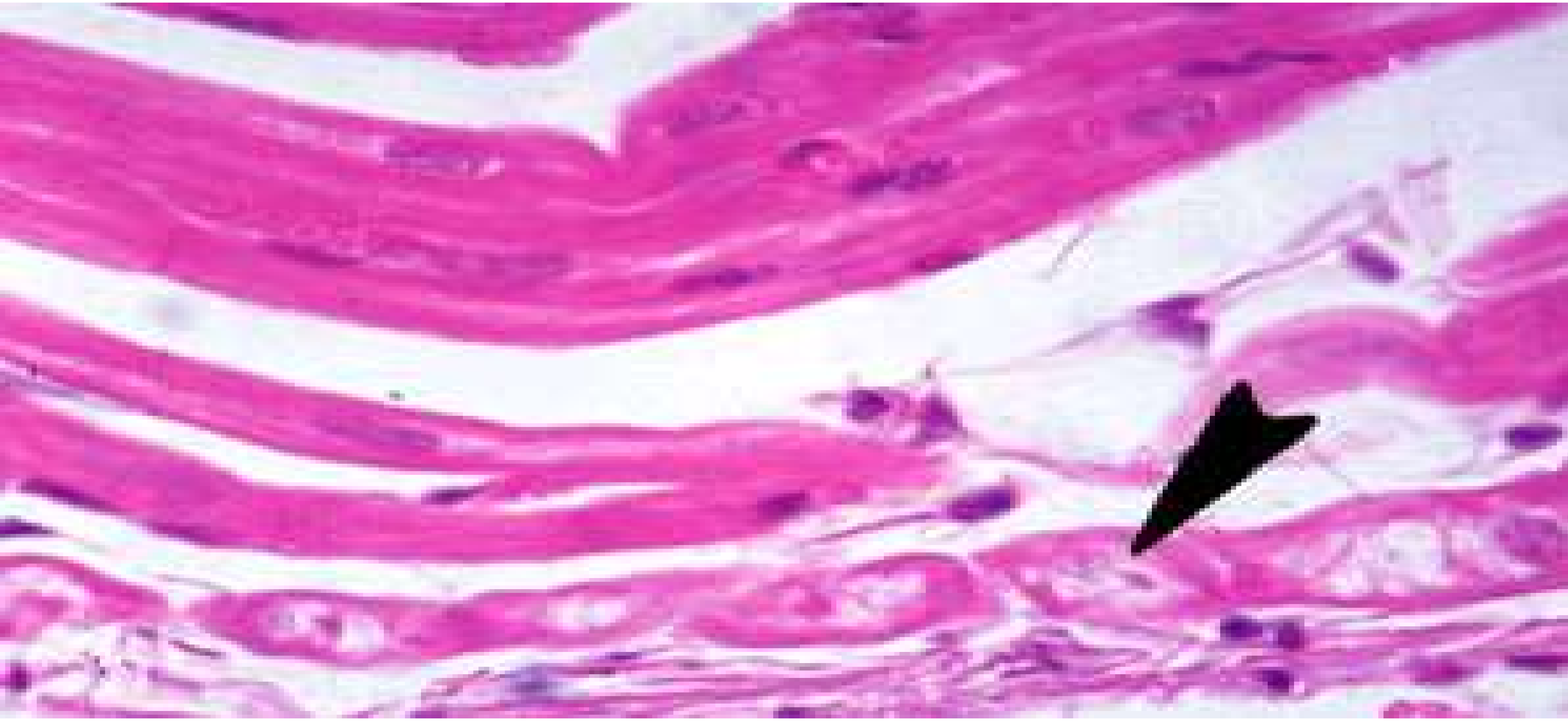




Smooth muscle - with cells more separated so as to see their extent and shape better, and the central position of their nuclei.
A loose, irregular connective tissue (endomysium) lies between the cells.
Nuclei seen in this c.t. belong to fibroblasts mainly.

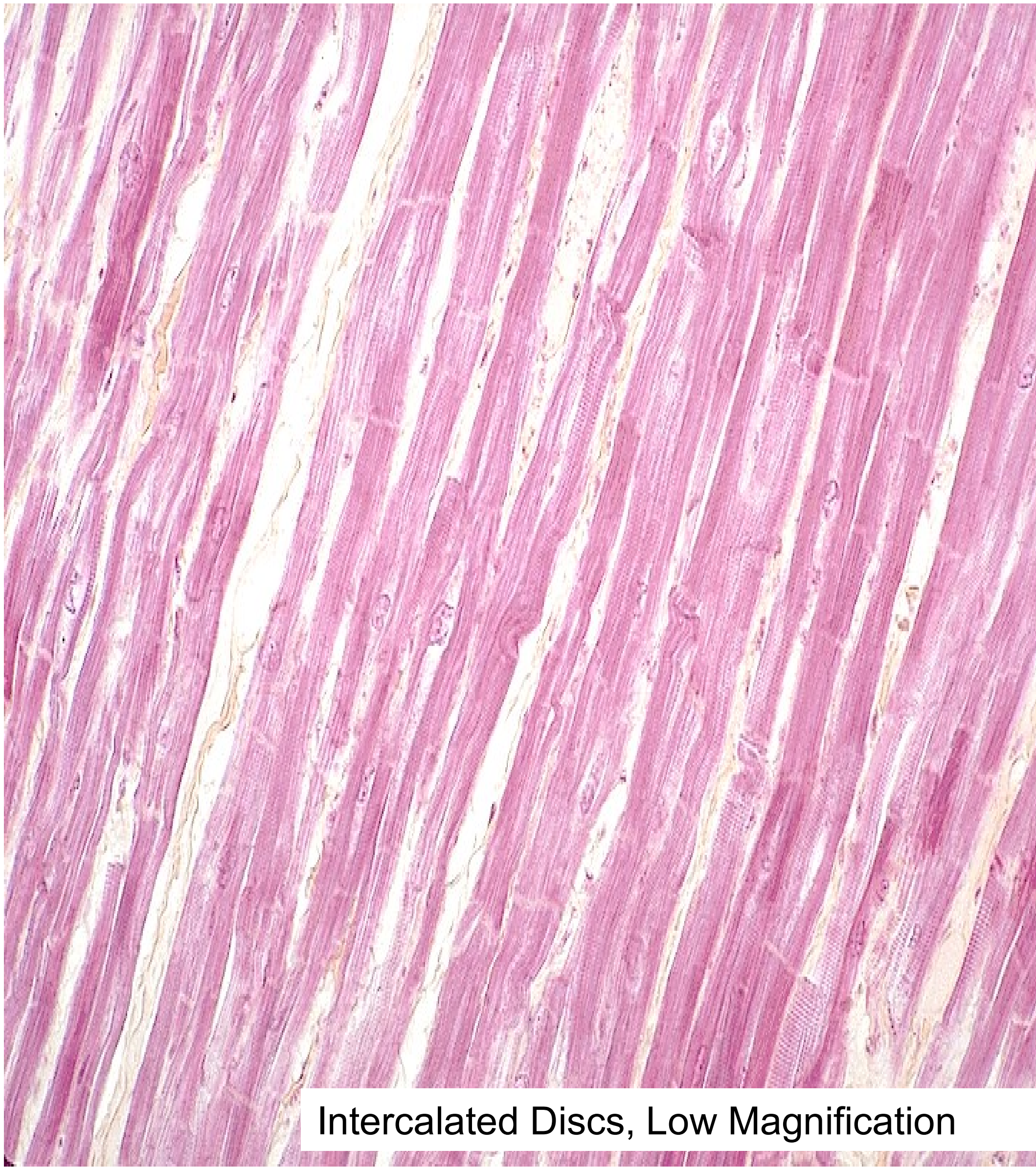




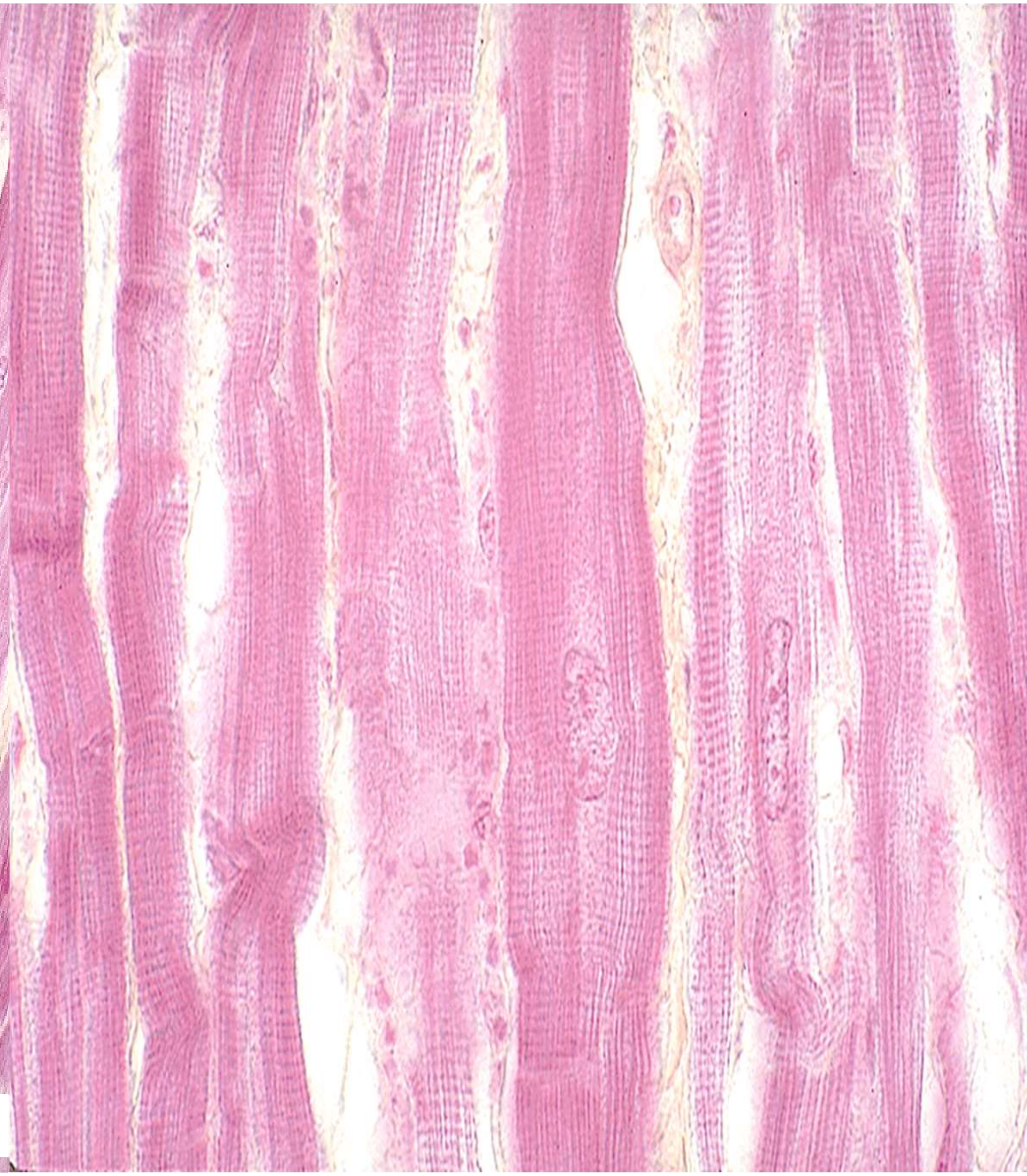


- pointer indicates the highly specialized cardiac muscle cells that are known as the Purkinje fibers.
- They are part of the impulse conducting system of the heart.
- The pale staining areas (pointer) within the Purkinje fibers are due to the presence of glycogen within the cytoplasm.

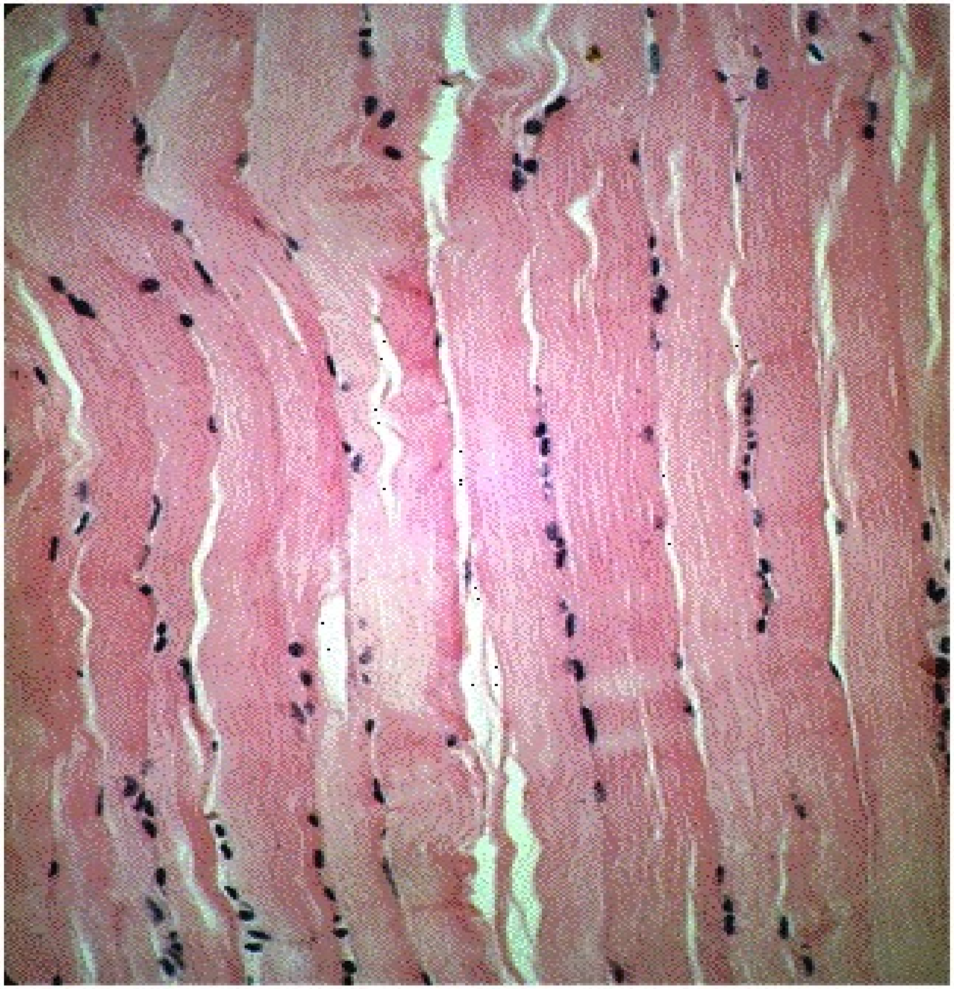

Cardiac muscle



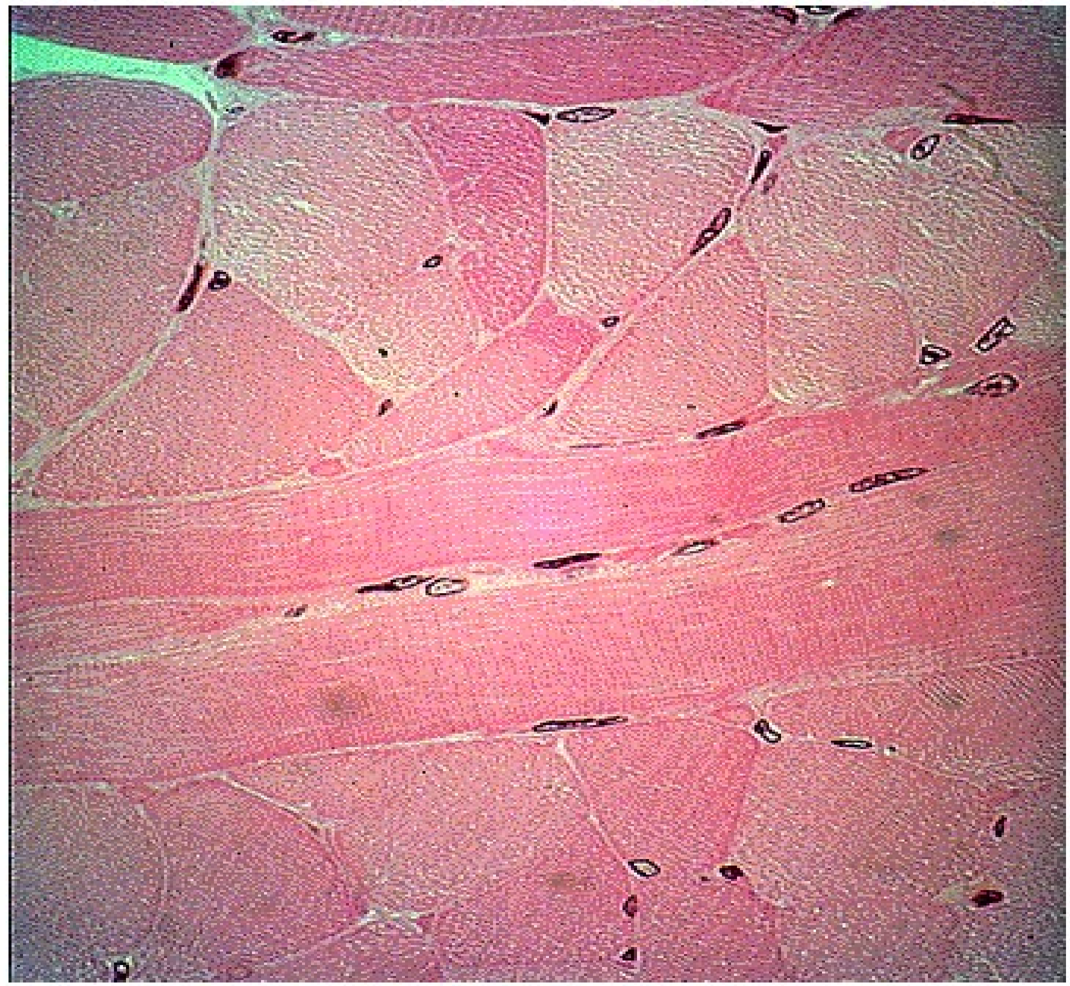
Intercalated Discs, Low Magnification



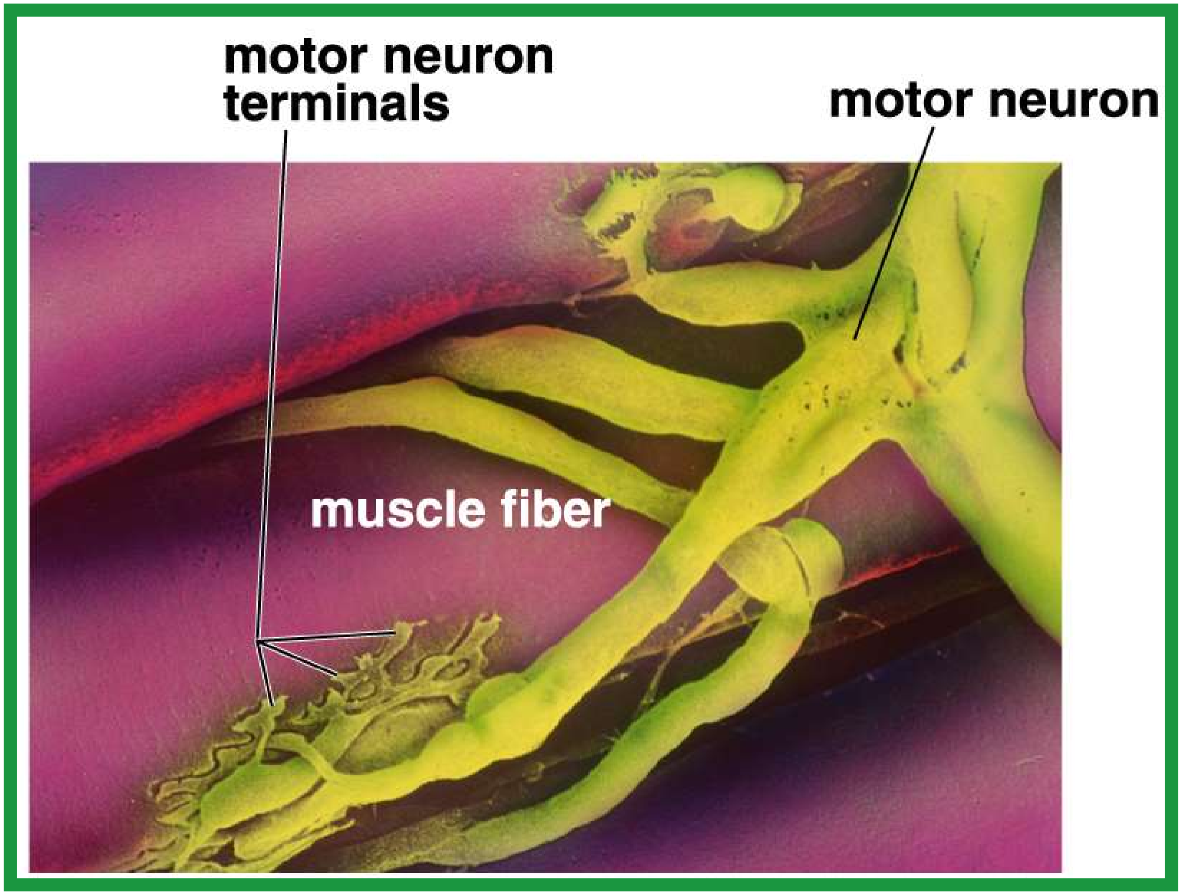
Striated Muscle Fibers-Long. Section



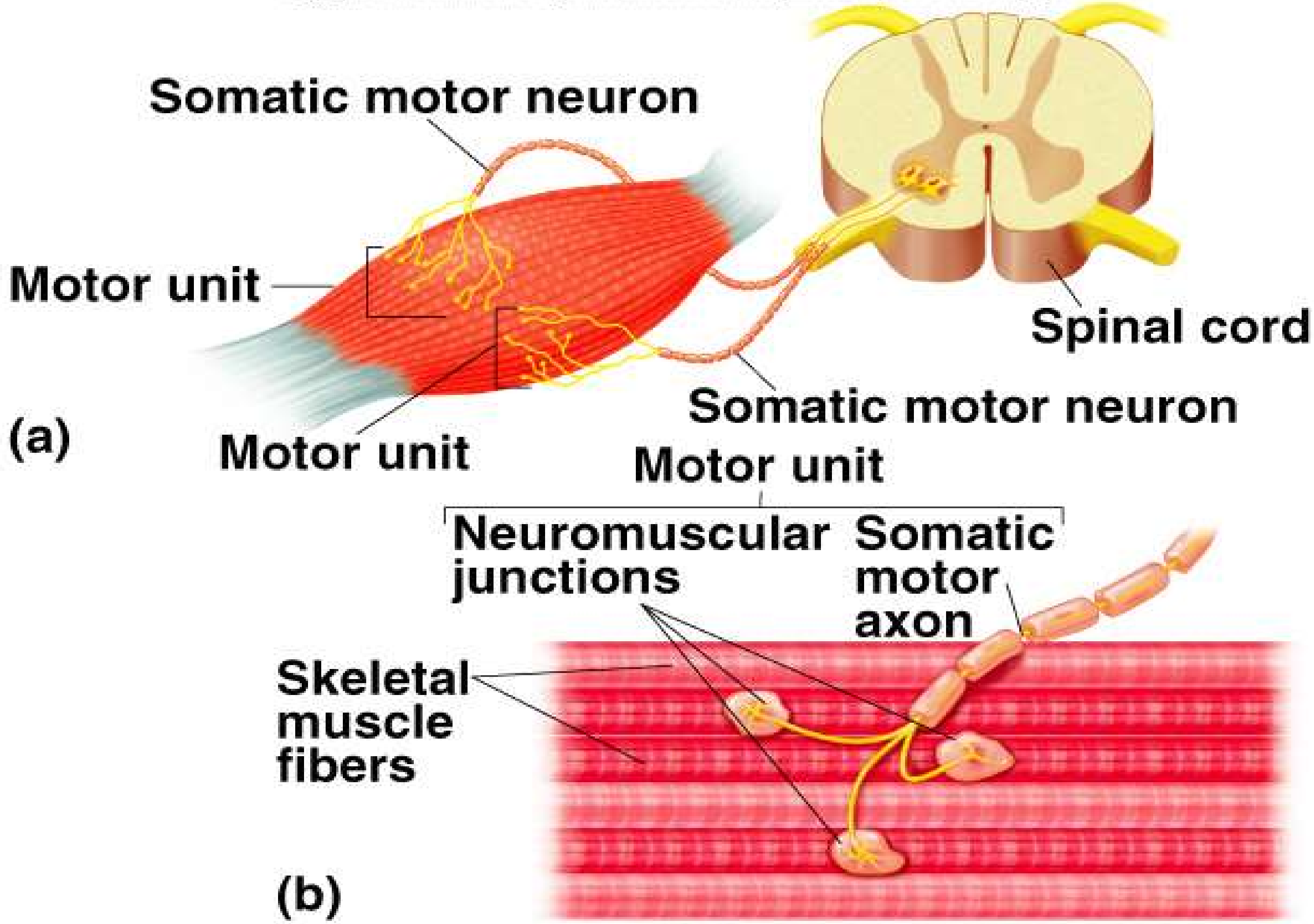
Striated Muscle Fibers- Long. & Trans. Sects.



The Neuromuscular Junction



Motor Unit

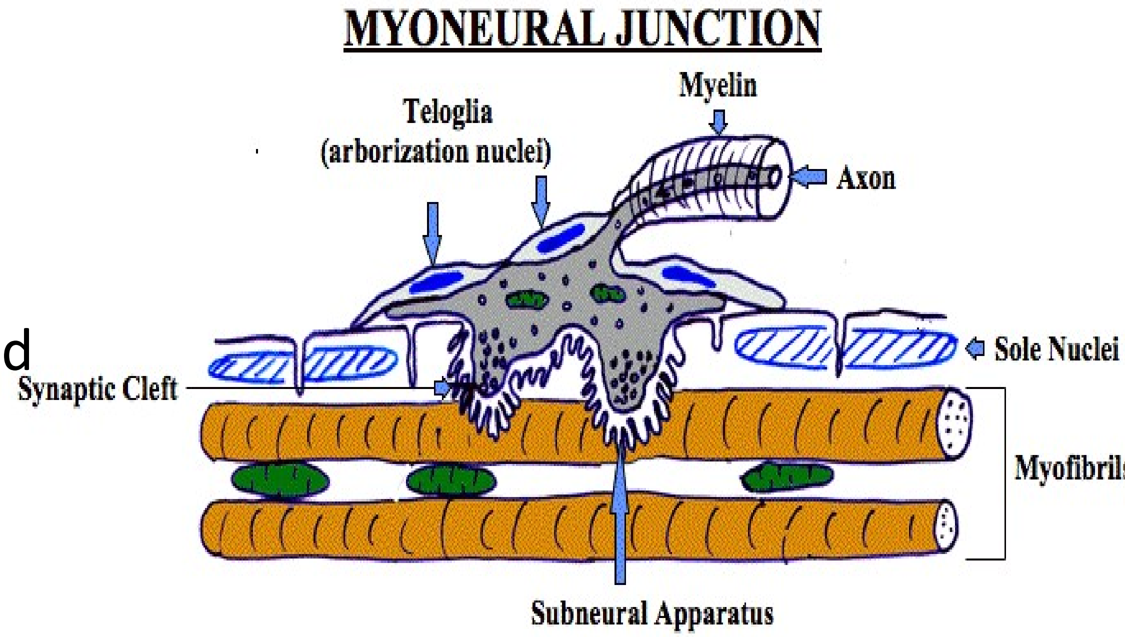

Somatic motor neuron
Motor unit
Spinal cord
Somatic motor neuron
Motor unit
(a)
Motor unit
Neuromuscular junctions
Somatic motor axon
Skeletal muscle fibers
(b)

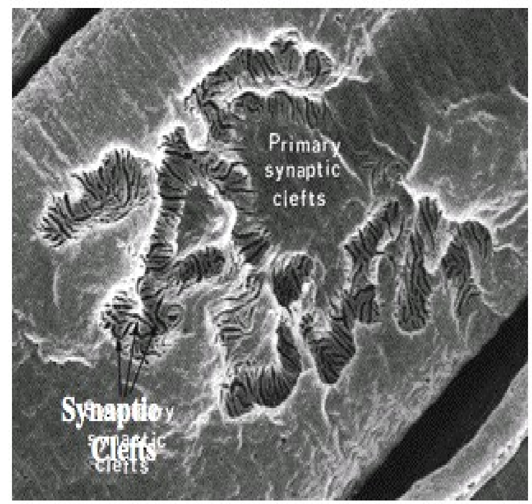
•**Motor unit**= myofibers innervated by same motor neuron

•Muscles:

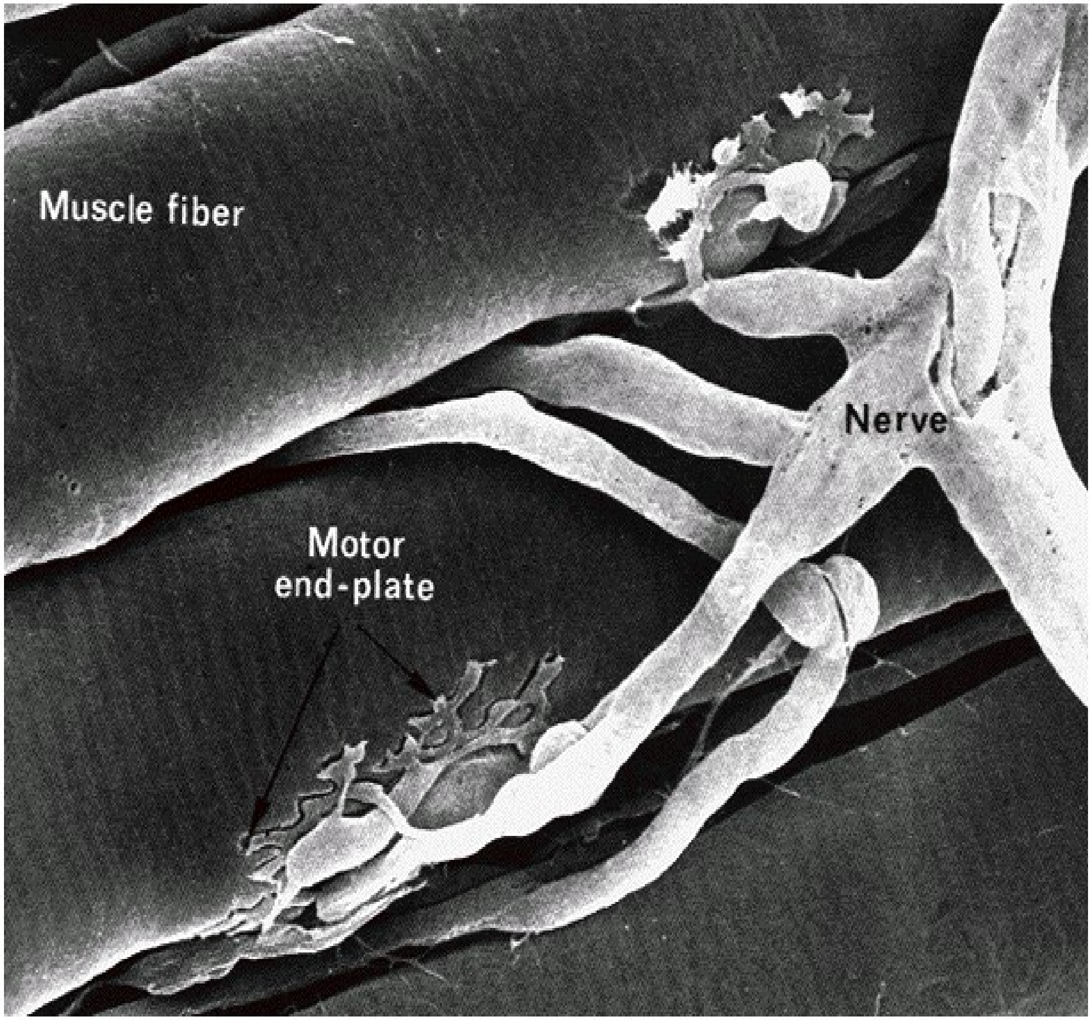
- •Graded contractions by how many motor units contract.

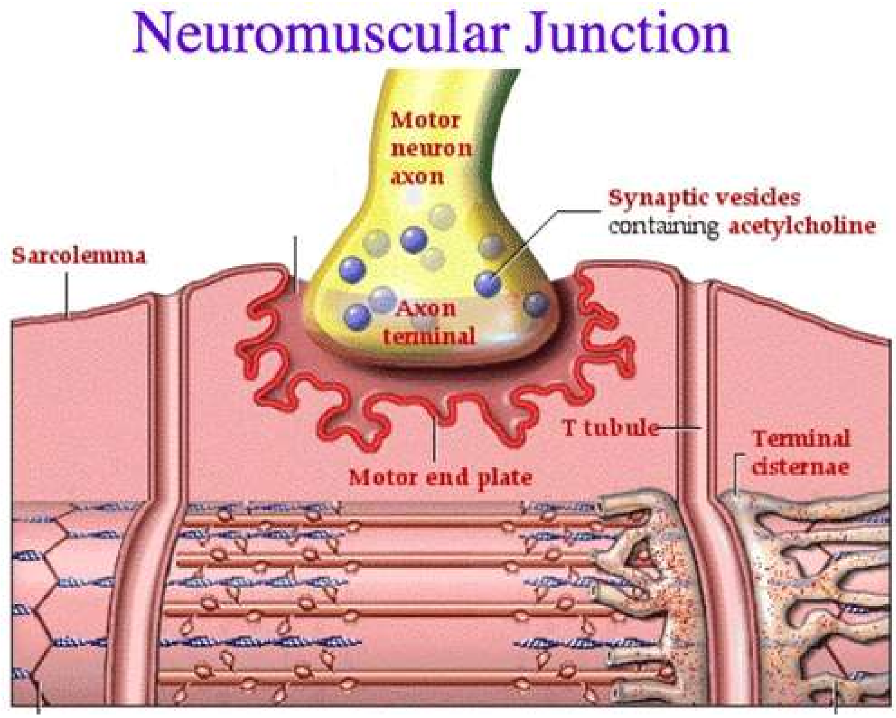
Motor end plate= sarcolemma at neuromuscular junction

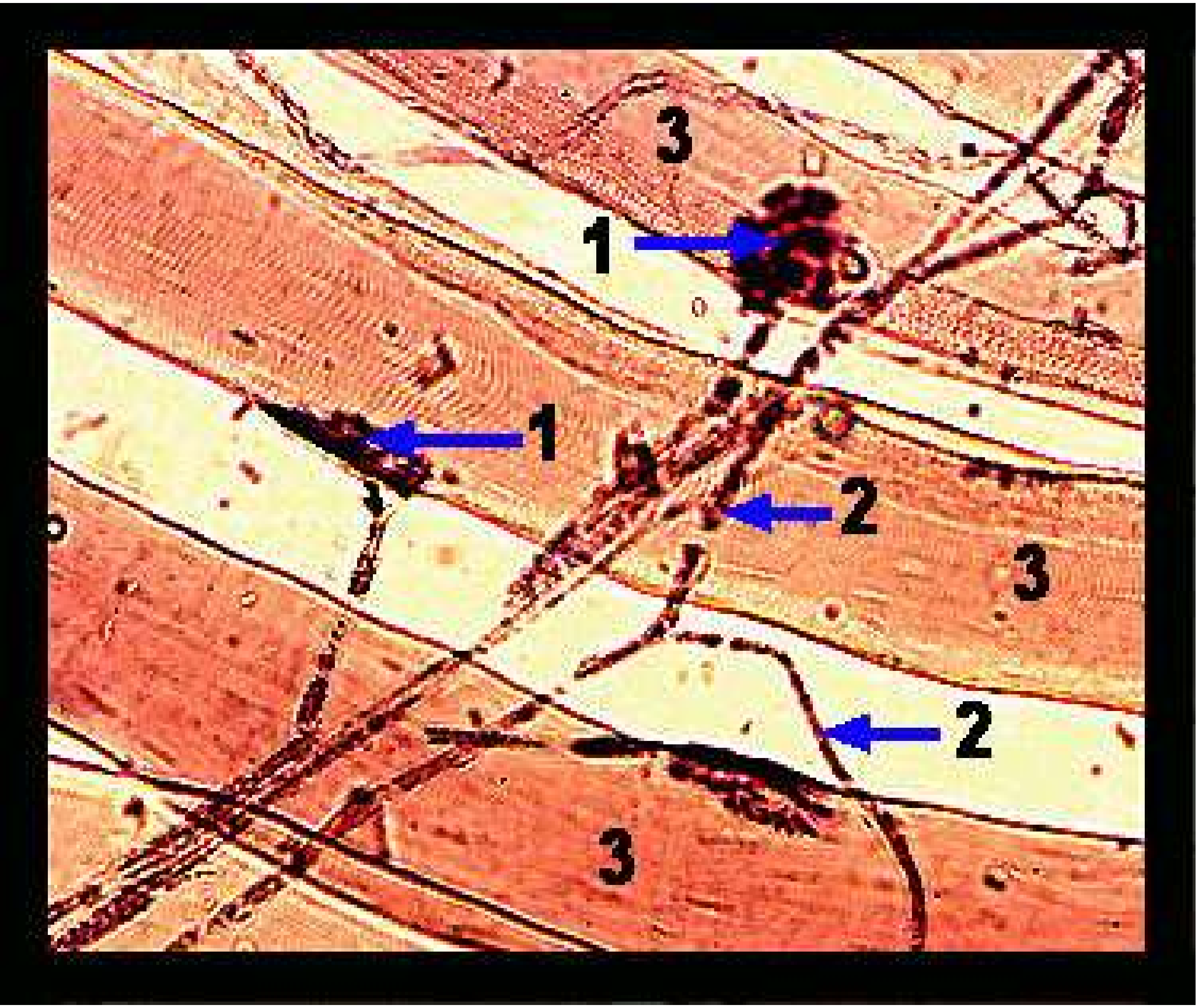




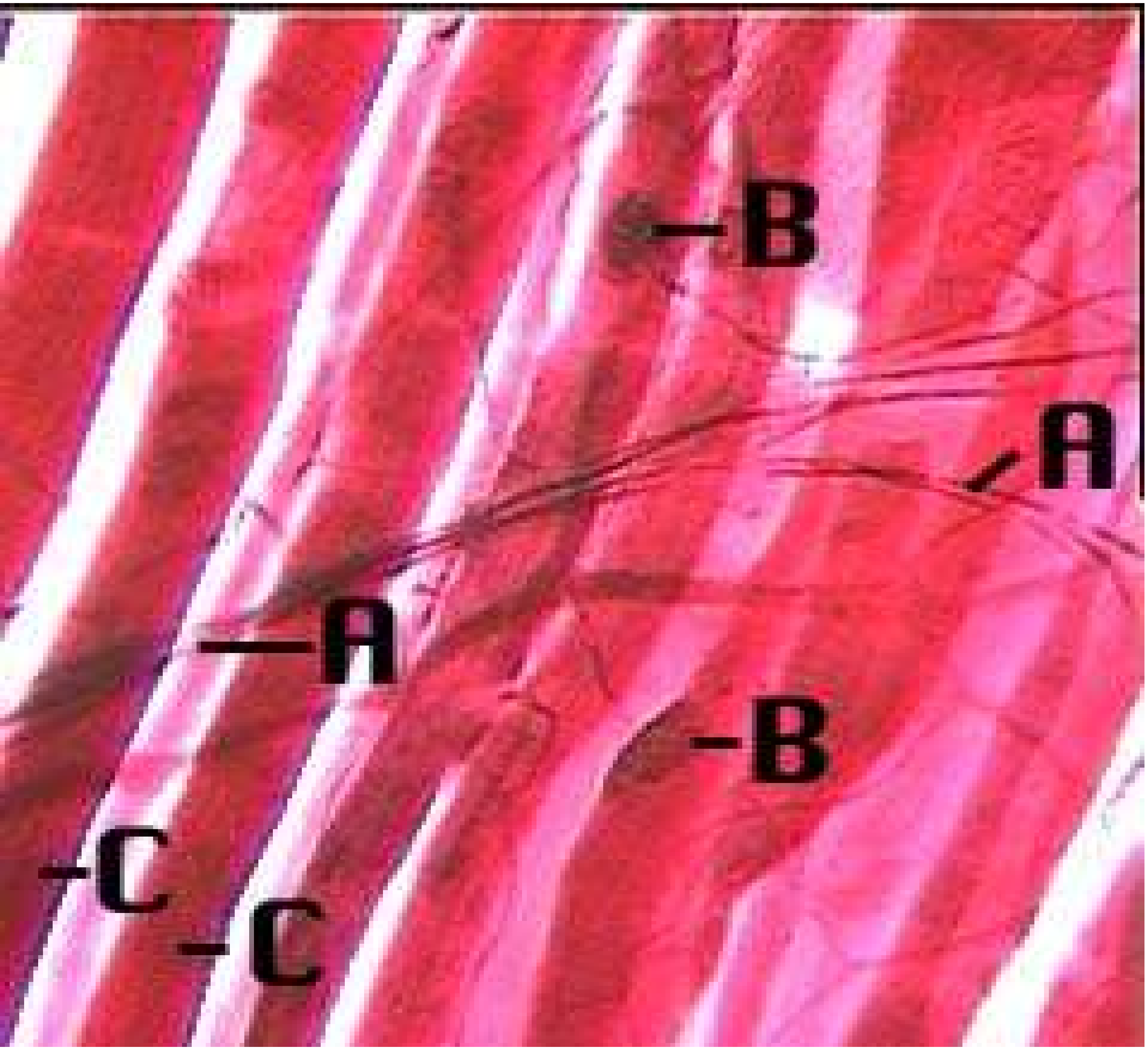
SEM OF MOTOR END PLATES





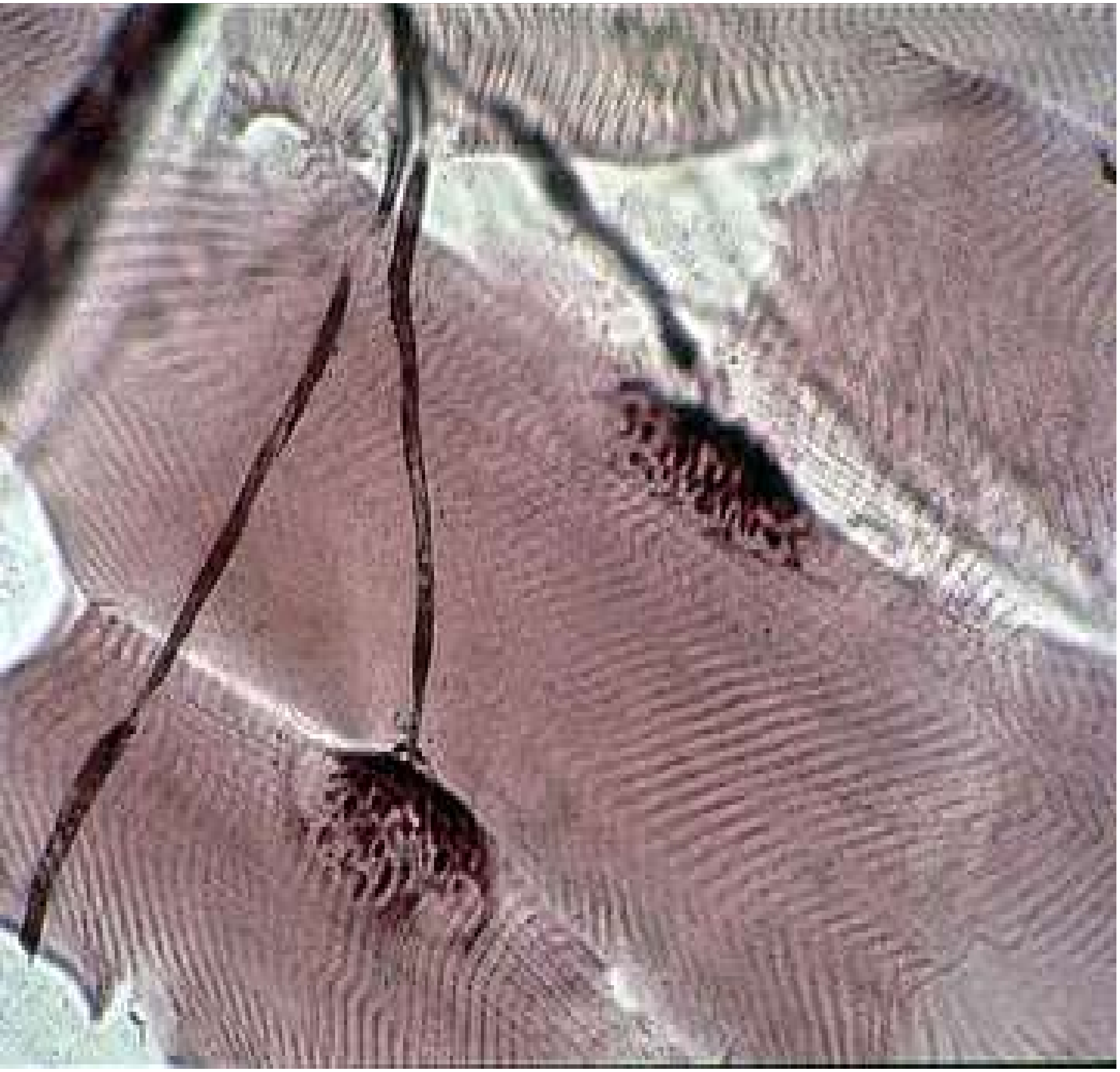


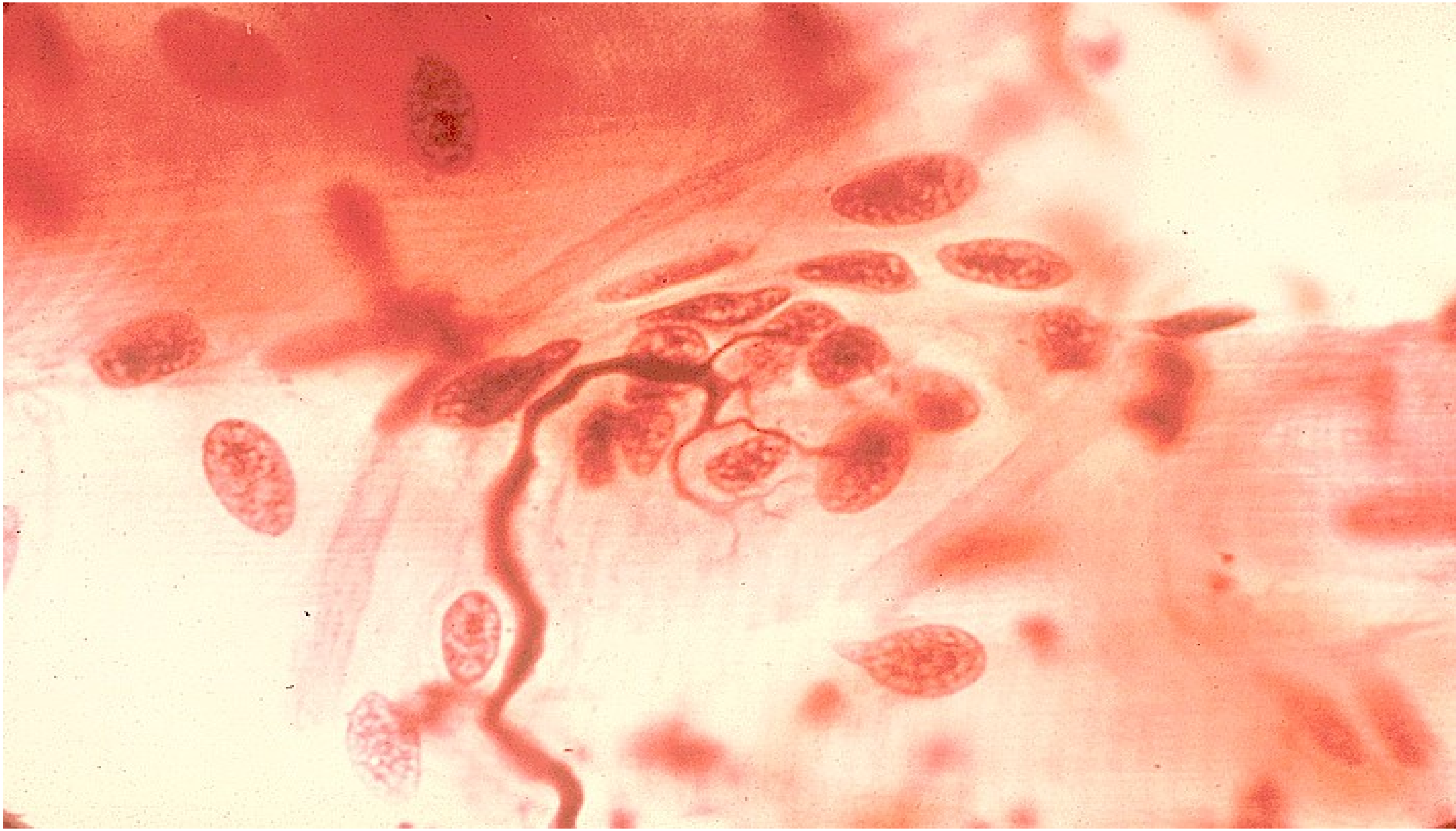
1. Motor end plates
2. Terminal axon fibers
3. Skeletal muscle fibers

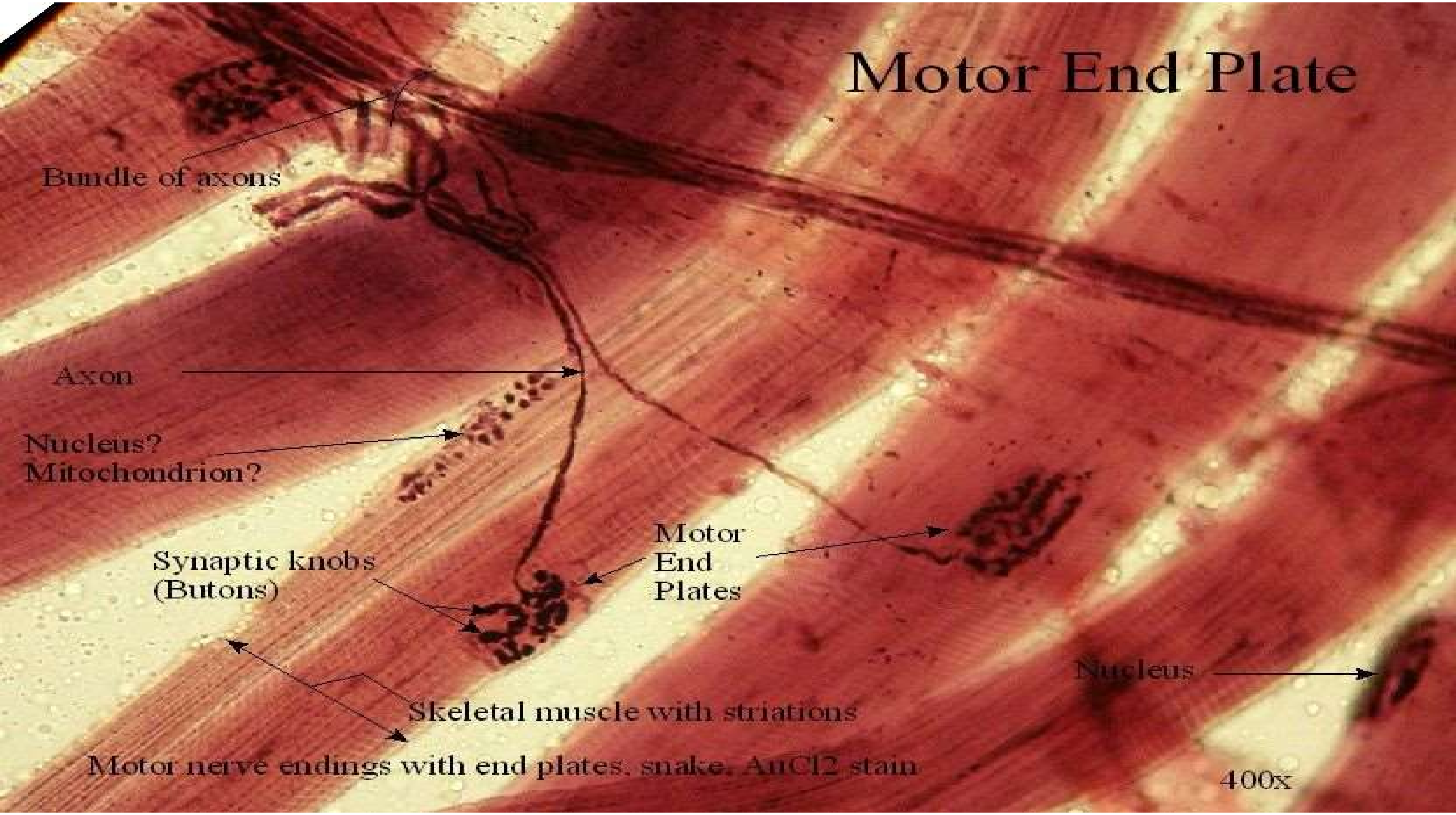


Skeletal muscles (C) are stimulated by nerve impulses carried by motor neurons.

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

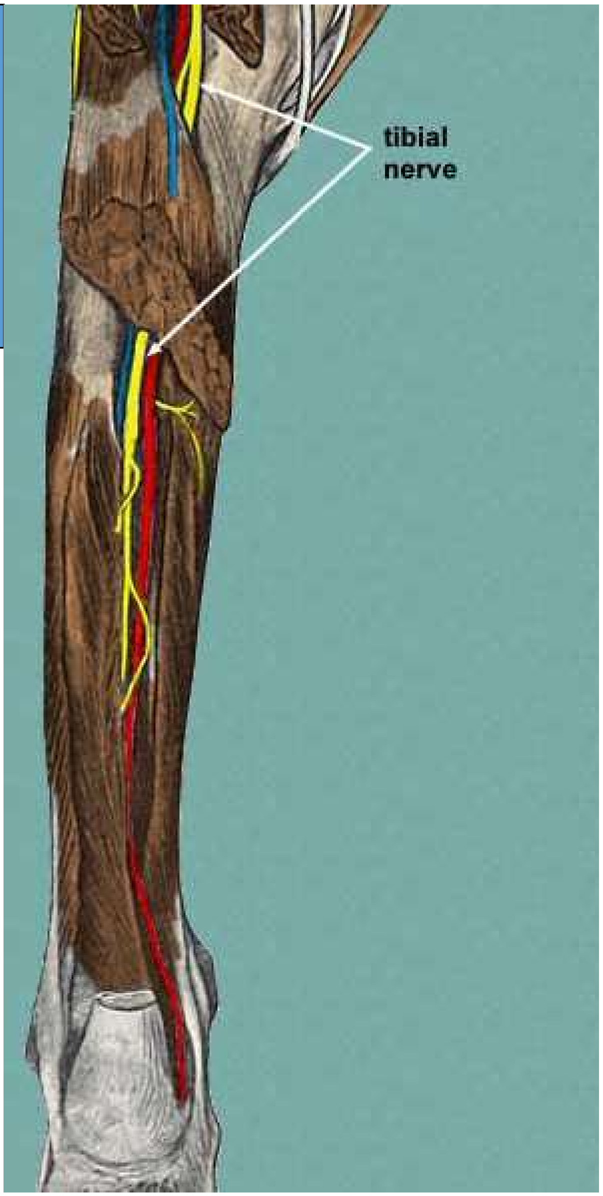





Motor End Plate
Bundle of axons
Axon
Nucleus?
Mitochondrion?
Synaptic knobs
(Butons)
Motor
End
Plates
Nucleus
Skeletal muscle with striations
Motor nerve endings with end plates, snake, AuCl2 stain
400x

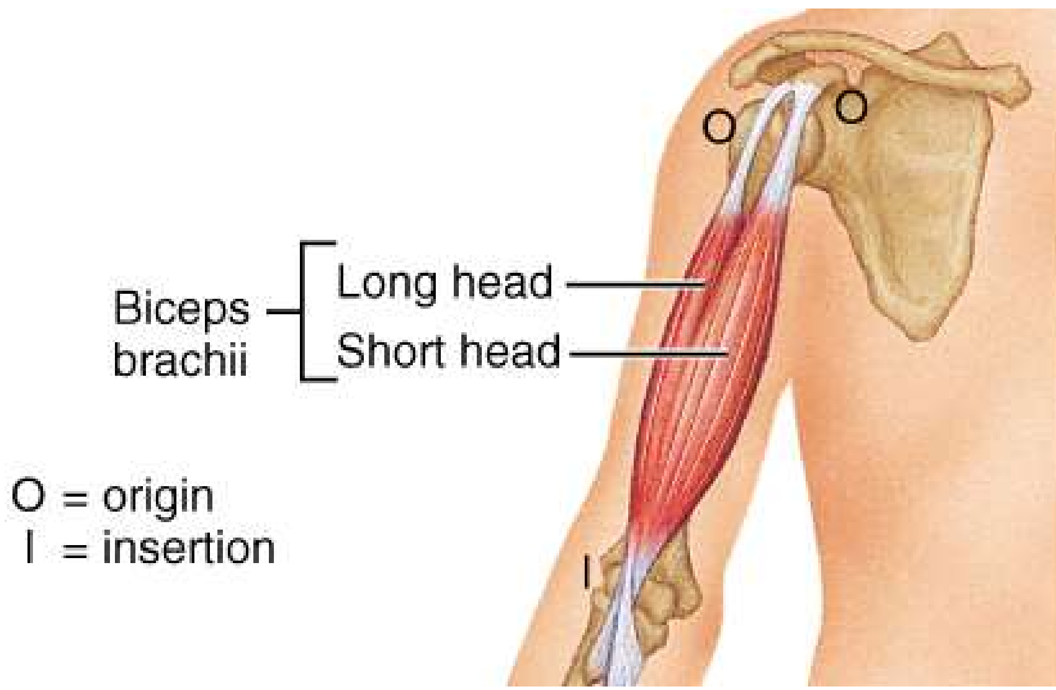
Skeletal Muscle – Blood & Nerve Supply

- Each skeletal muscle is typically supplied by one nerve, an artery and one or more veins.
  - What is the function of each of these 3 items?
- They all enter/exit via the connective tissue coverings and branch extensively.



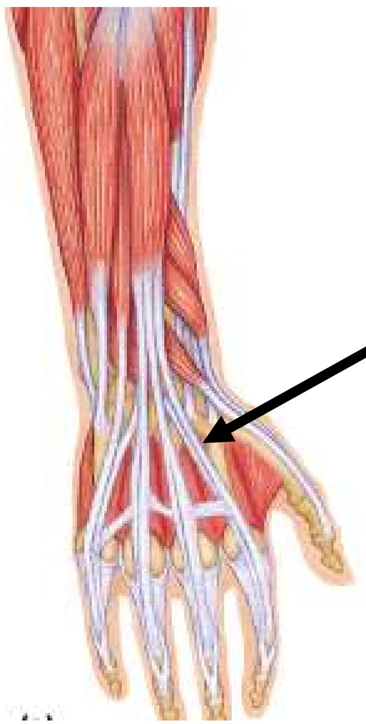
Skeletal Muscle Attachments

- Most span joints and are attached to bones.
  - The attachment of the muscle to the immoveable bone in a joint is its origin, while the attachment to the moveable bone is its insertion.

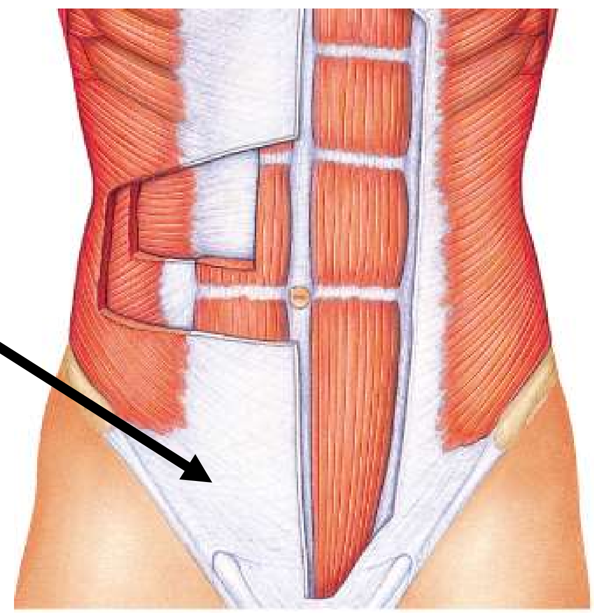


Muscle attachments may be direct or indirect.

Direct attachments are less common. The epimysium is fused to a periosteum or a perichondrium.

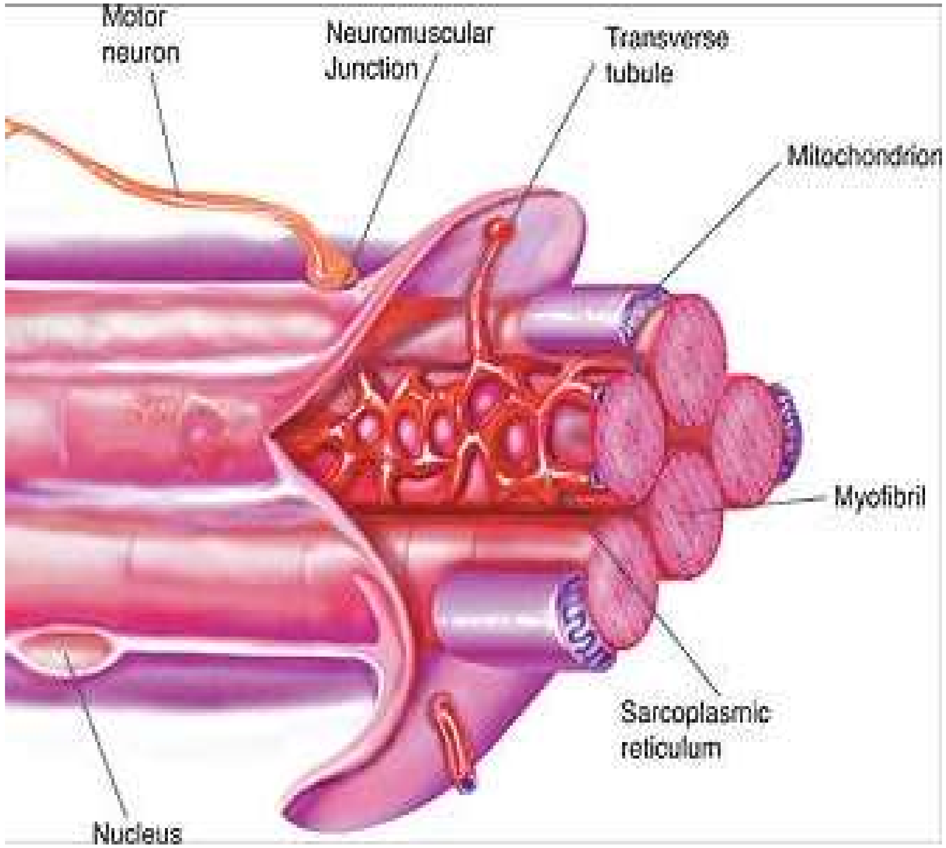


Indirect attachments are typical. The muscle CT extends and forms either a cordlike structure (a tendon) or a sheetlike structure (aponeurosis) which attaches to the periosteum or perichondrium.

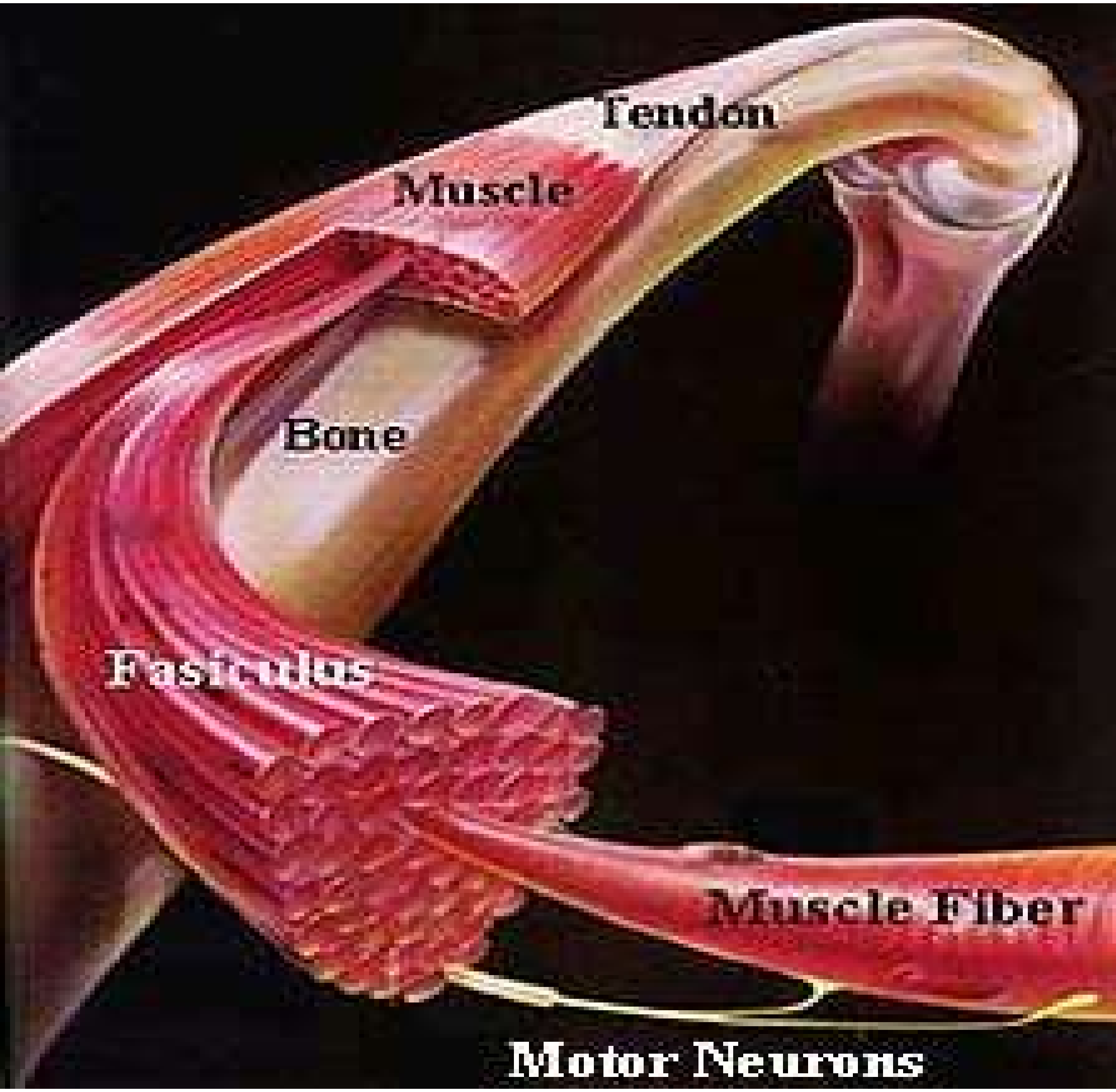


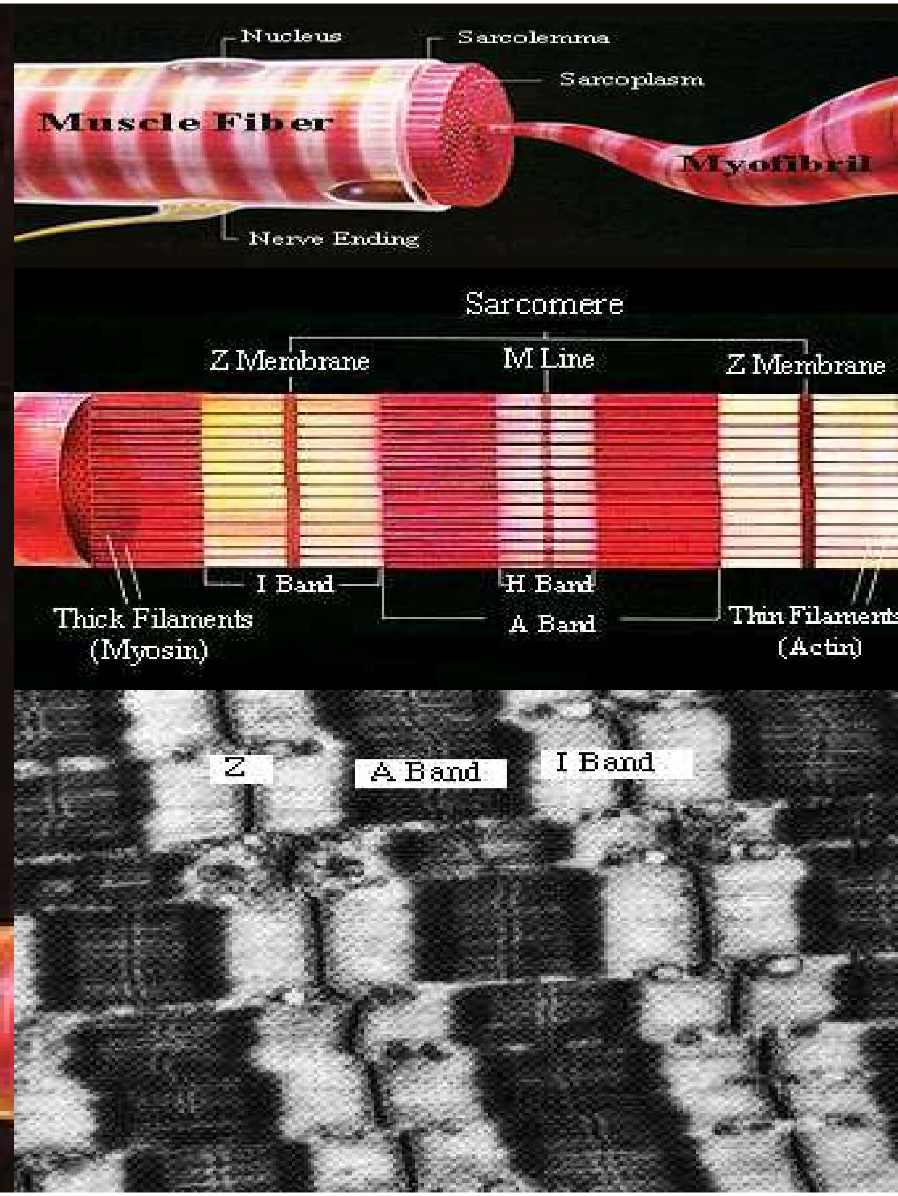
Sarcoplasmic Reticulum

- Muscle cell version of the smooth endoplasmic reticulum.
- Functions as a calcium storage depot in muscle cells.
- Loose network of this membrane bound organelle surrounds all the myofibrils in a muscle fiber. We will see why this is so important soon.



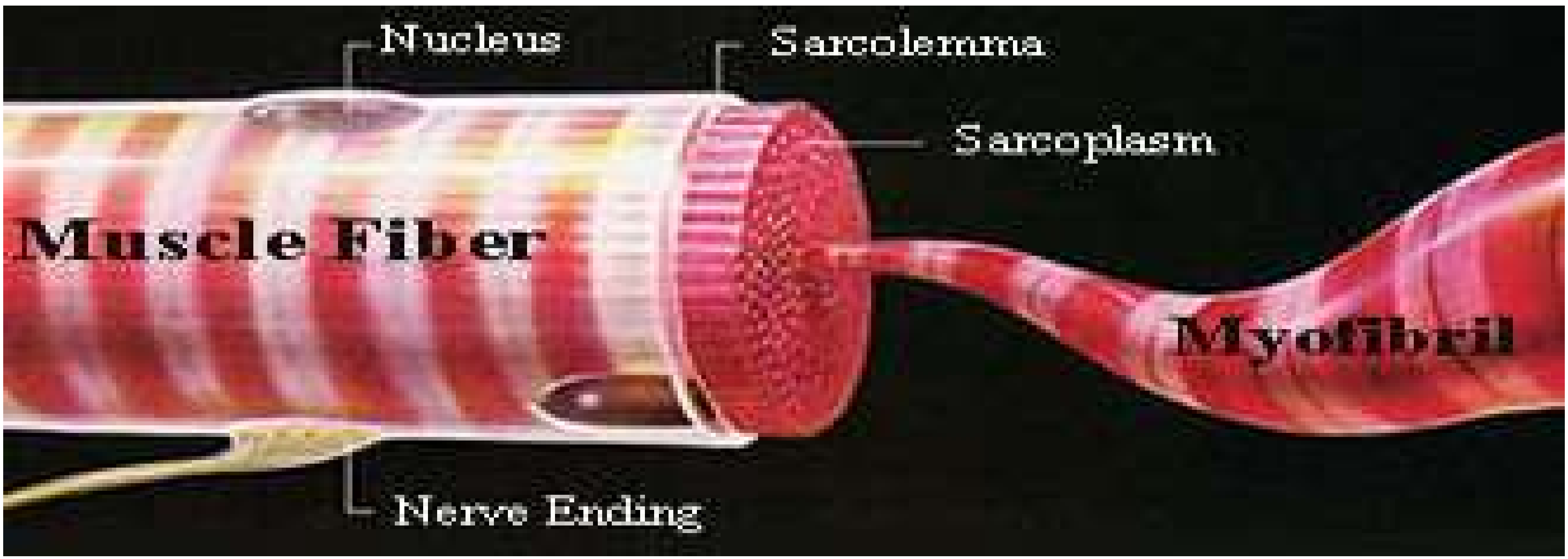
- Myofibers

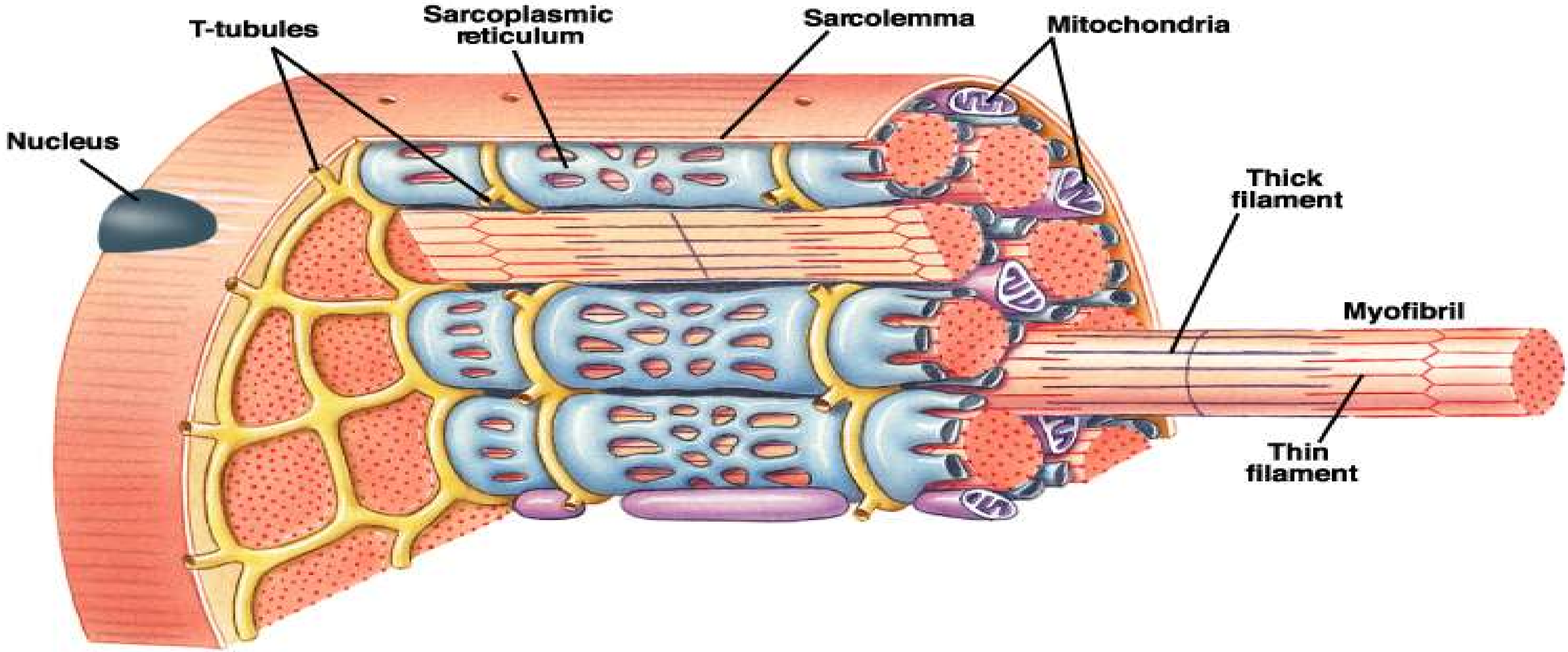

Tendon
Muscle
Bone
Fasiculus
Muscle Fiber
Motor Neurons


Nucleus
Sarcolemma
Sarcoplasm
Muscle Fiber
Myofibril
Nerve Ending
Sarcomere
Z Membrane
M Line
Z Membrane
I Band
H Band
A Band
Thick Filaments
(Myosin)
Thin Filaments
(Actin)
Z
A Band
I Band

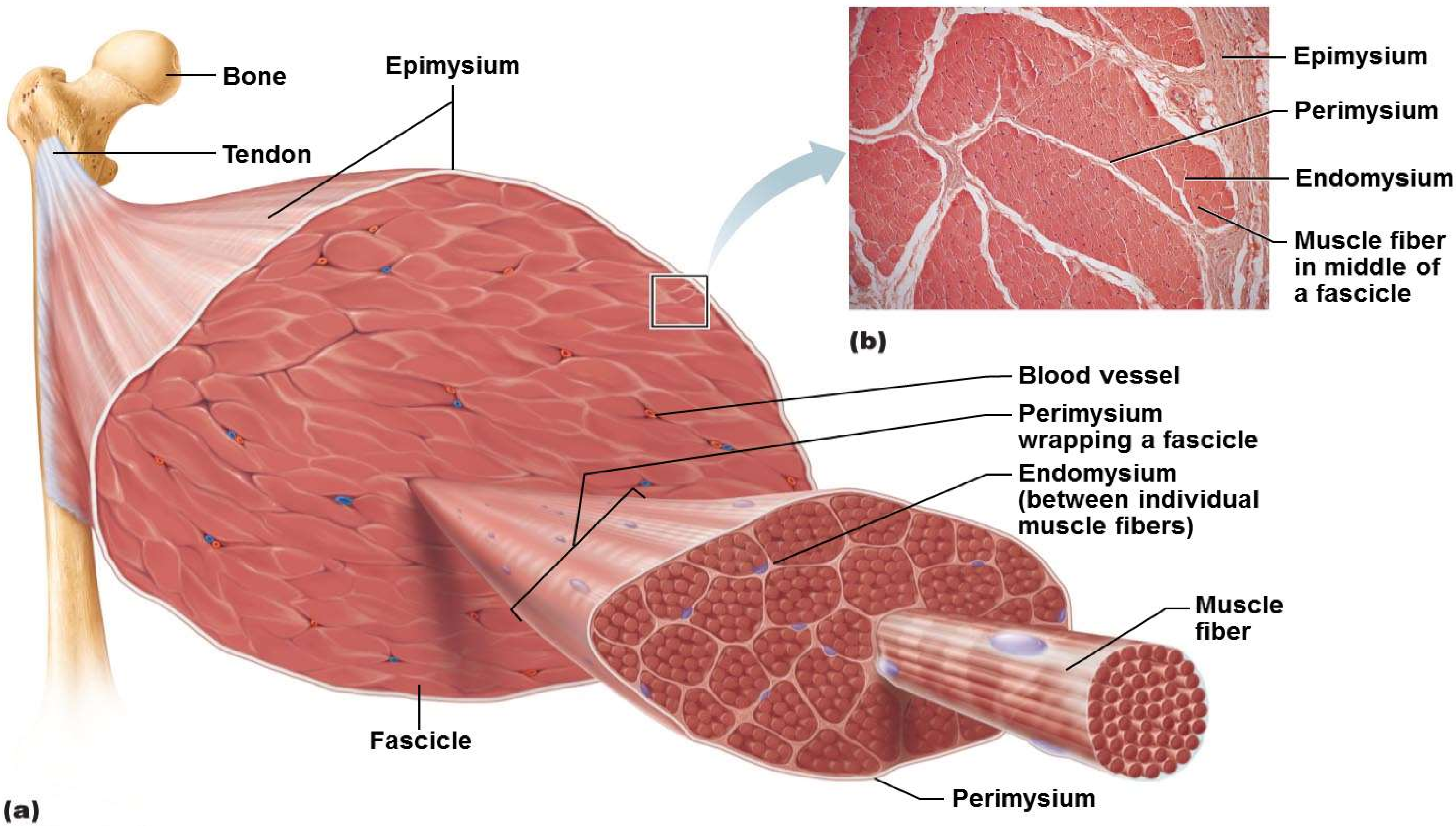
Myofibrils

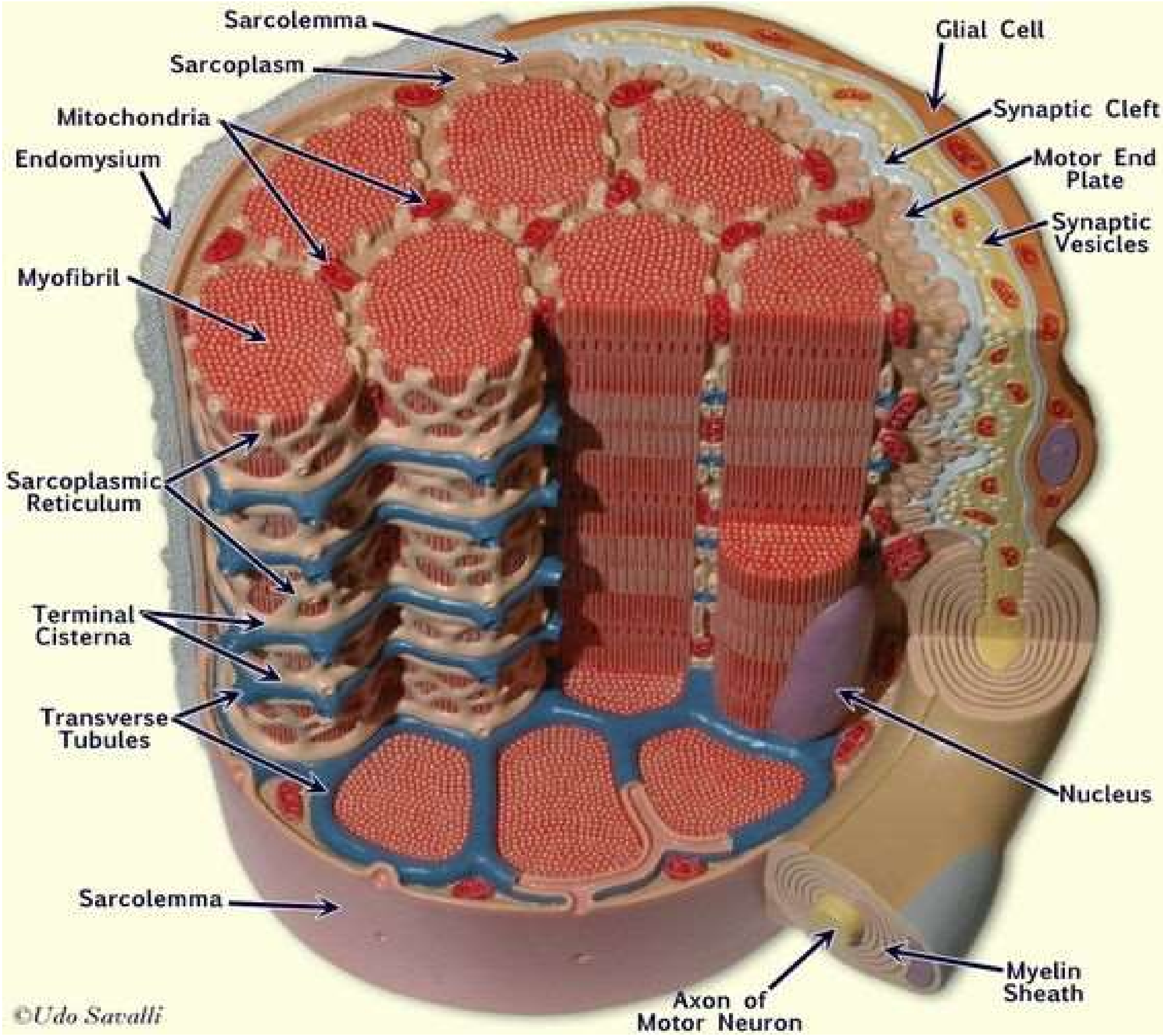
- Each muscle fiber contains rodlike structures called myofibrils that extend the length of the cell. They are basically long bundles of protein structures called myofilaments and their actions give muscle the ability to contract.
- The myofilaments are classified as thick filaments and thin filaments.





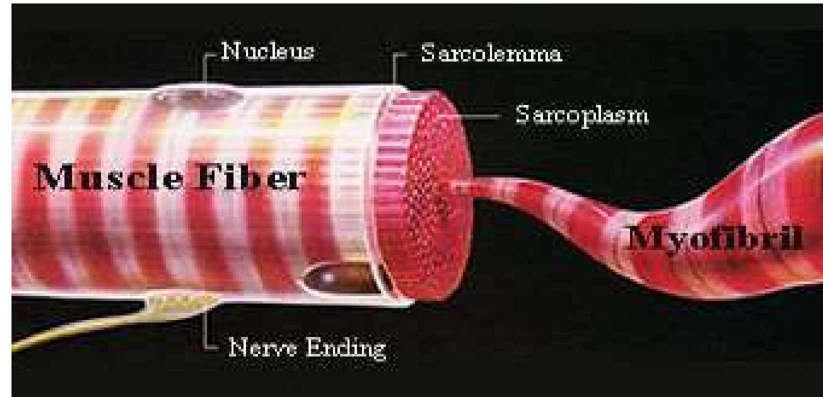
T-tubules
Sarcoplasmic reticulum
Sarcolemma
Mitochondria
Nucleus
Thick filament
Myofibril
Thin filament

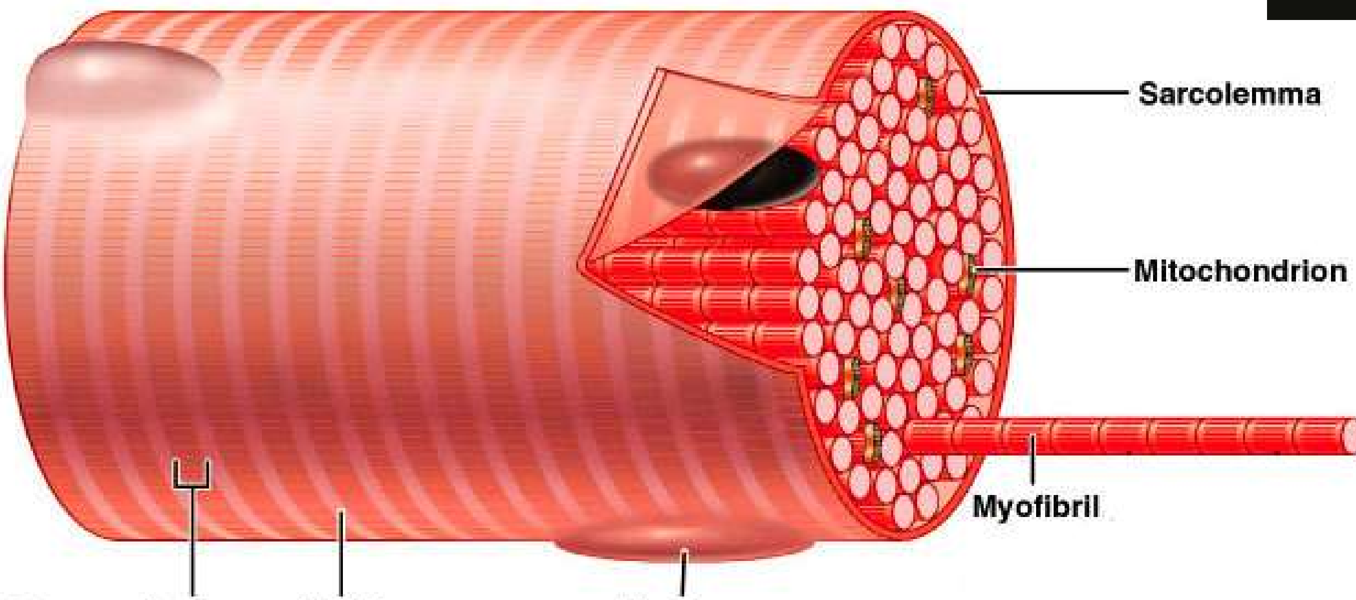

Bone
Tendon
Epimysium
Epimysium
Perimysium
Endomysium
Muscle fiber in middle of a fascicle
(b)
Blood vessel
Perimysium wrapping a fascicle
Endomysium (between individual muscle fibers)
Muscle fiber
Fascicle
Perimysium
(a)


Sarcolemma
Sarcoplasm
Mitochondria
Endomysium
Myofibril
Sarcoplasmic Reticulum
Terminal Cisterna
Transverse Tubules
Sarcolemma
Glial Cell
Synaptic Cleft
Motor End Plate
Synaptic Vesicles
Nucleus
Myelin Sheath
Axon of Motor Neuron
©Udo Savalli

Myofibrils

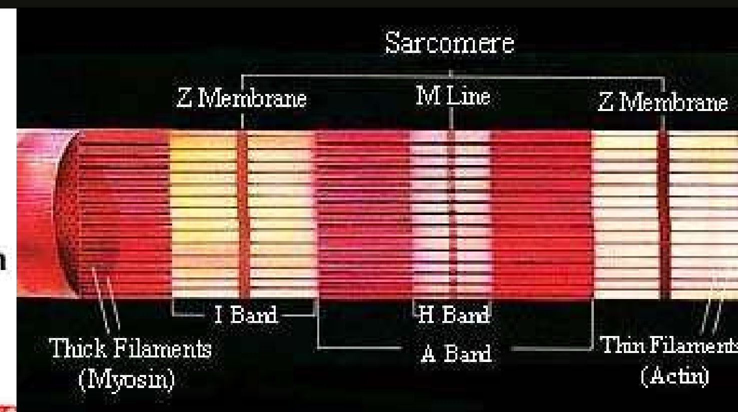
Muscle Fiber
- Each muscle fiber is made up of thousands of myofibrils.



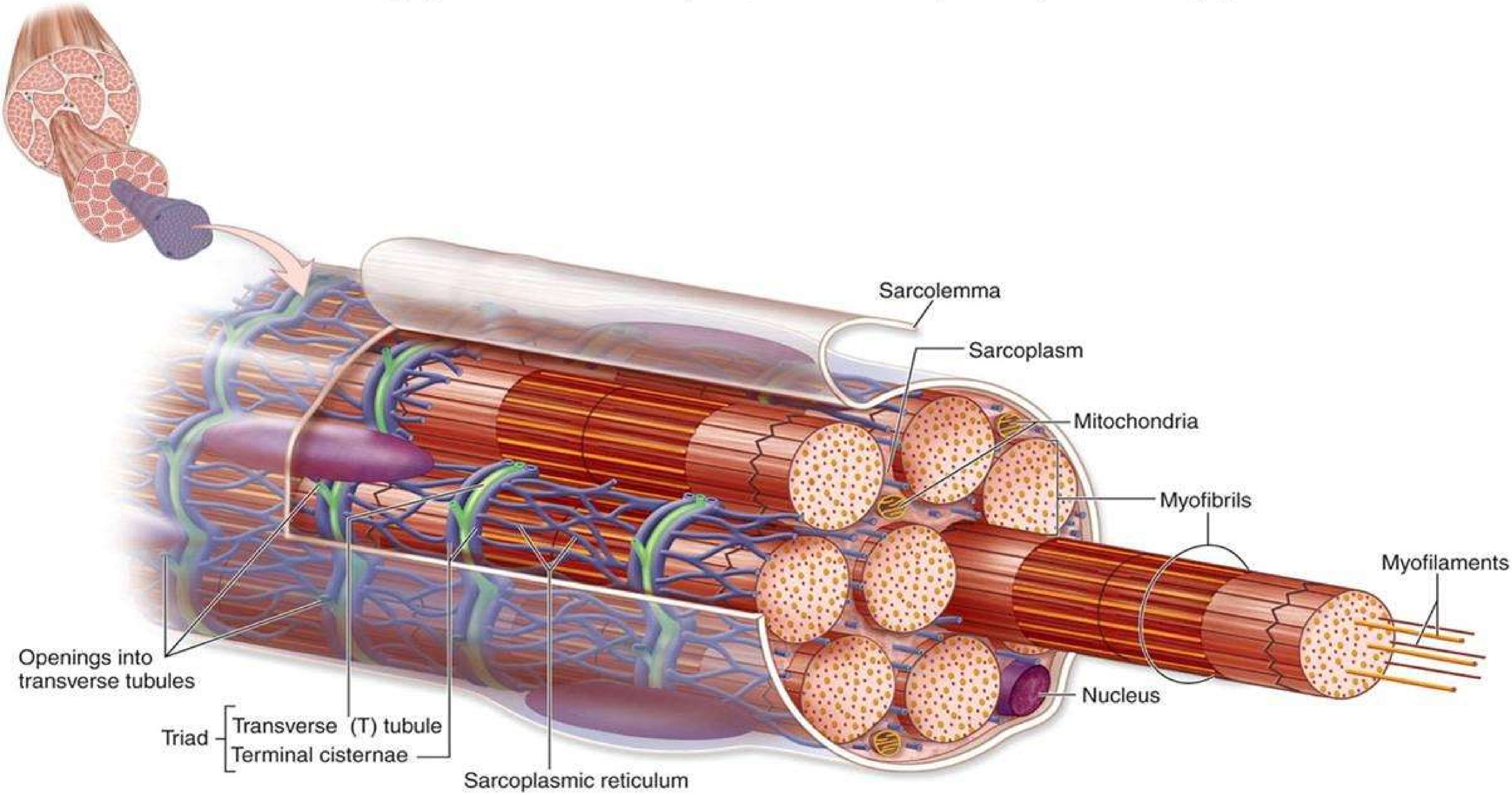


(b)

InterActive Physiology ®:
Anatomy Review: Skeletal Muscle Tissue, pages 7-8



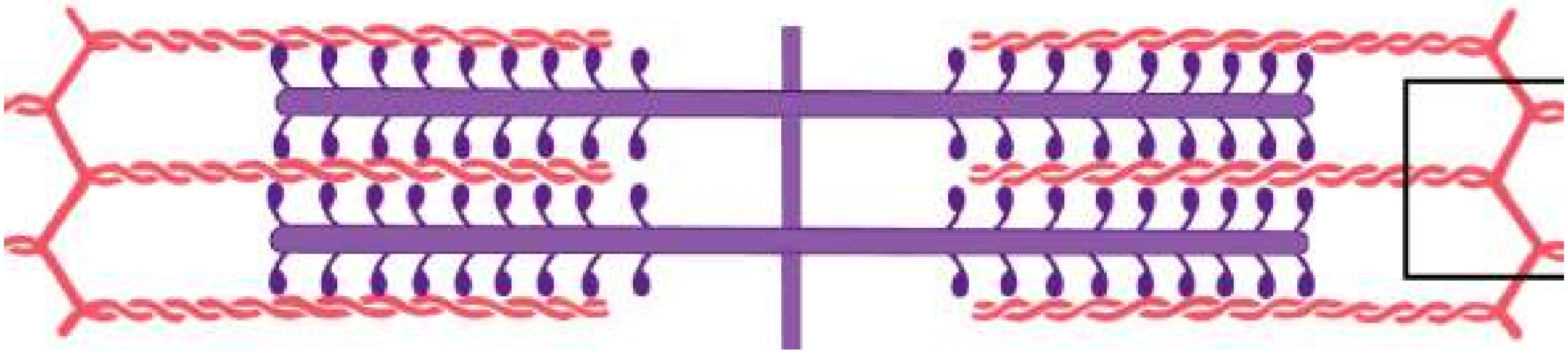
<u>Myofibril</u>
- Myofibrils contain filaments of actin and myosin.
- The filaments form an ordered array and make up sarcomeres, the functional units of muscle.

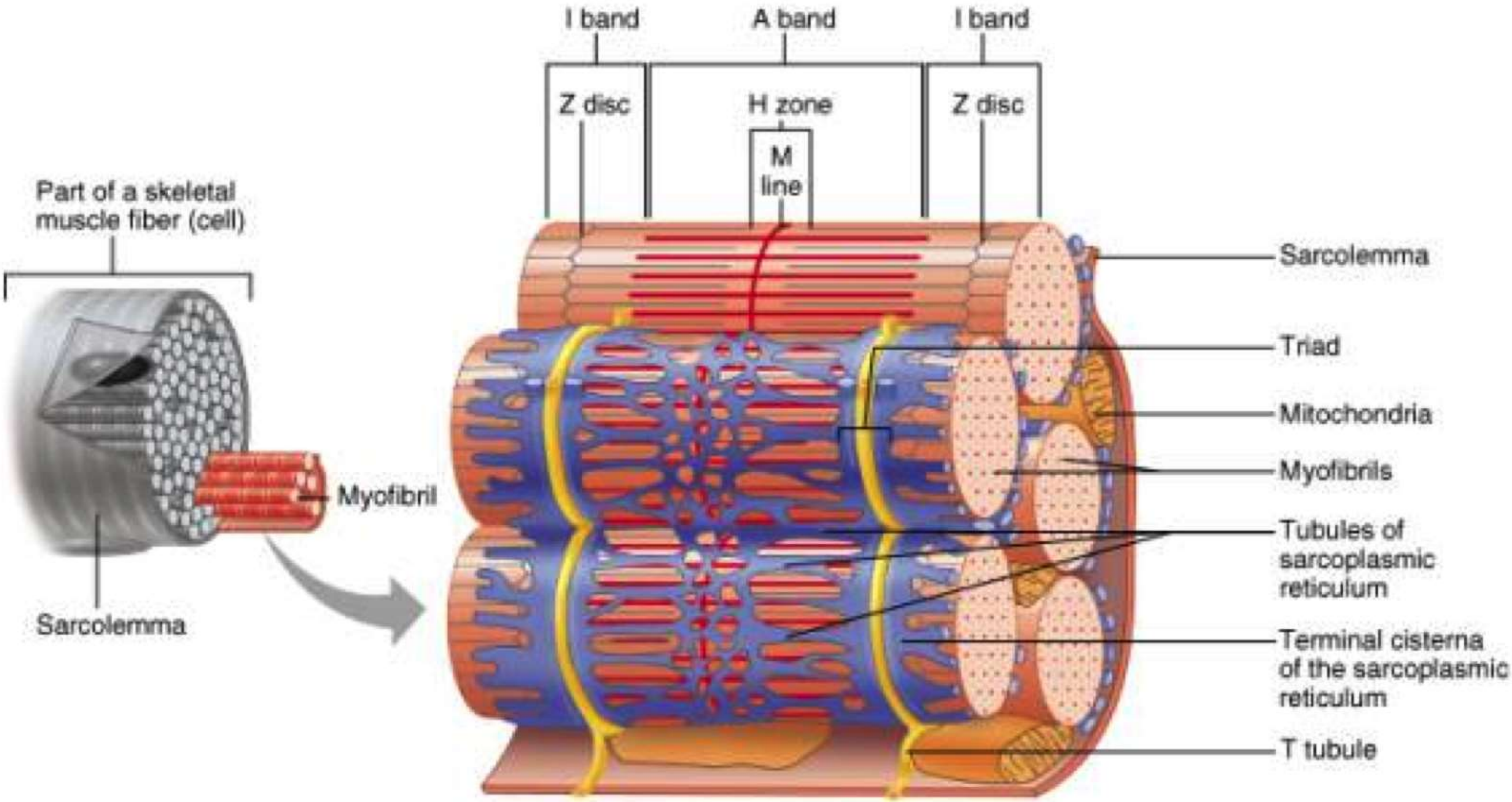


Sarcolemma
Sarcoplasm
Mitochondria
Myofibrils
Myofilaments
Nucleus
Openings into transverse tubules
Triad
Transverse (T) tubule
Terminal cisternae
Sarcoplasmic reticulum

Myofibrils

- Each sarcomere is an ordered arrangement of thick and thin filaments. Notice that it has:
  - regions of thin filaments by themselves (pinkish fibers)
  - a region of thick filaments by themselves (purple fibers)
  - regions of thick filaments and thin filaments overlapping.

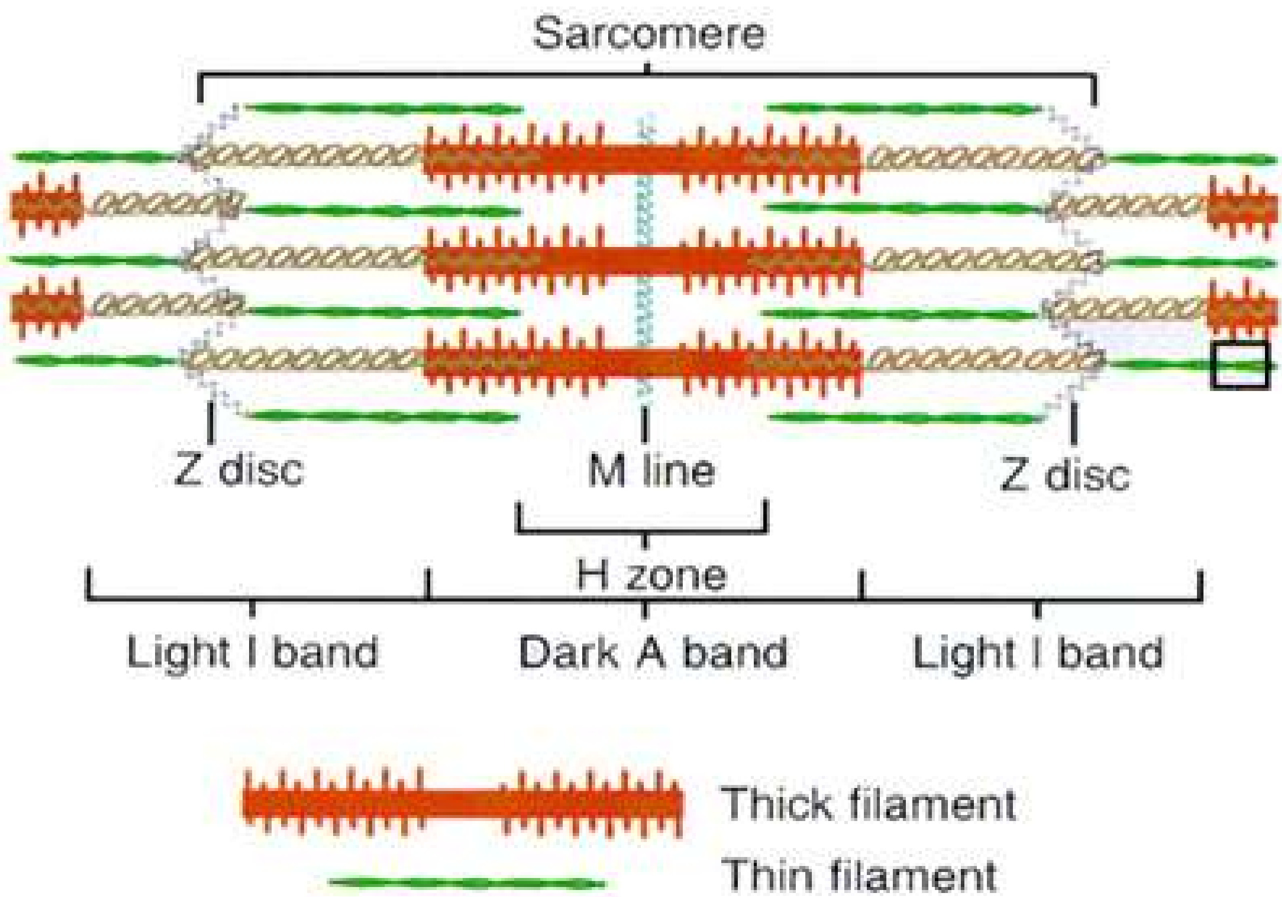




Part of a skeletal muscle fiber (cell)
Myofibril
Sarcolemma
I band
A band
I band
Z disc
H zone
Z disc
M line
Sarcolemma
Triad
Mitochondria
Myofibrils
Tubules of sarcoplasmic reticulum
Terminal cisterna of the sarcoplasmic reticulum
T tubule

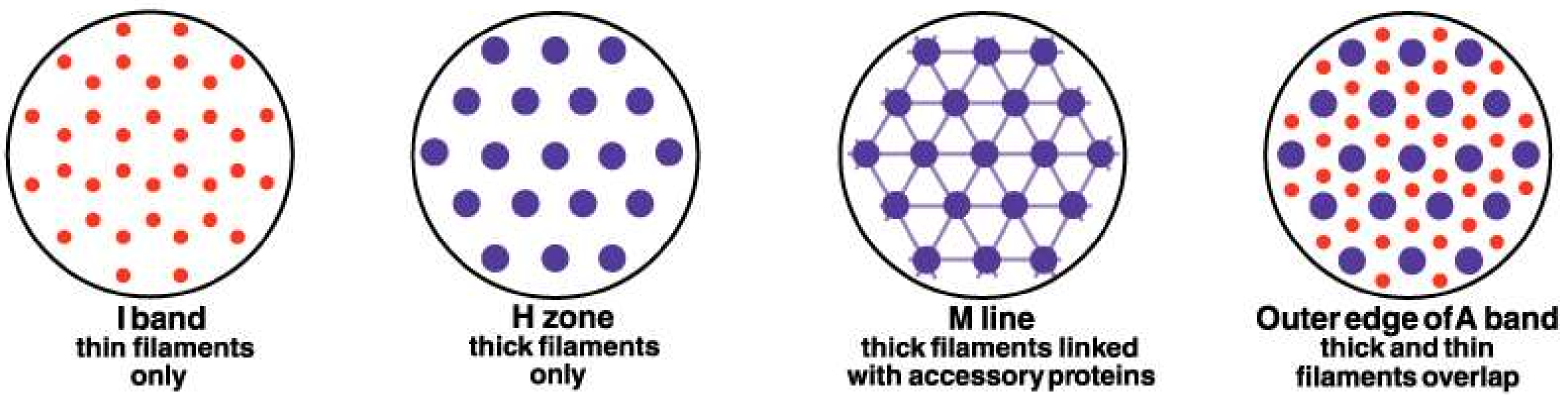
The portion of the sarcomere which does not contain any thick filament is known as the I band. The I band contains only thin filament and is light under the microscope (*it is isotropic*).

- One I band is actually part of 2 sarcomeres at once.



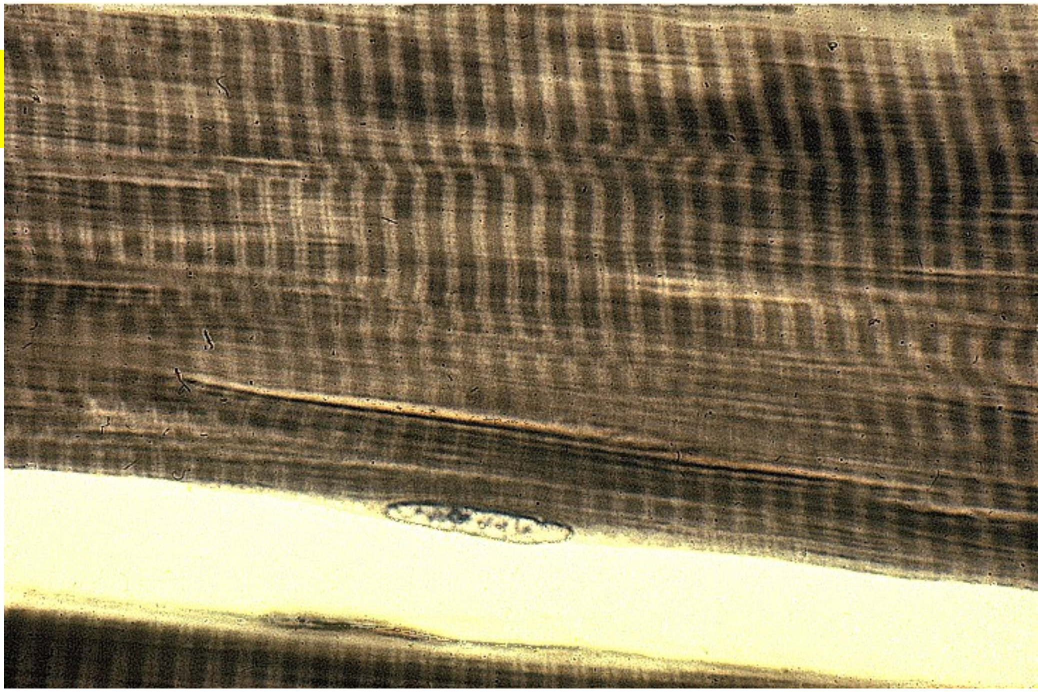
In the middle of the H zone is a structure called **the M line** which functions to hold the thick filaments to one another

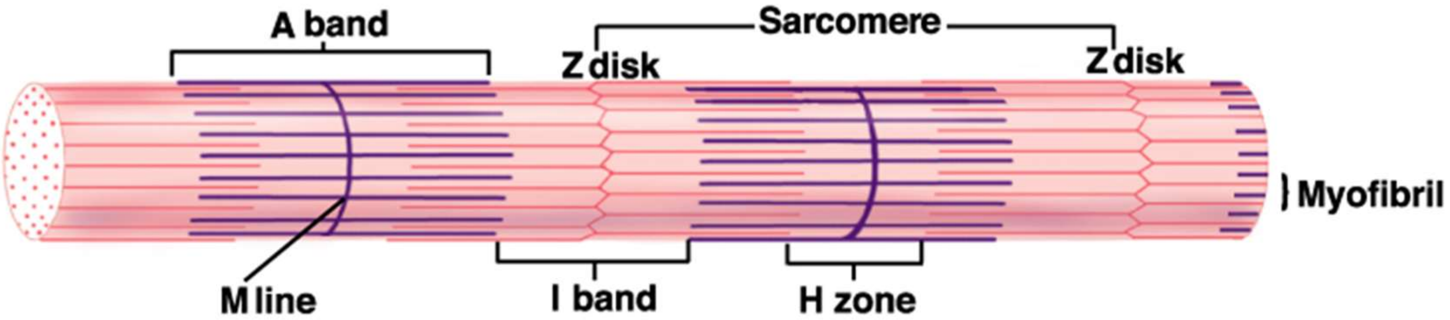
Here we have several different cross sections of a myofibril. Why are they different?



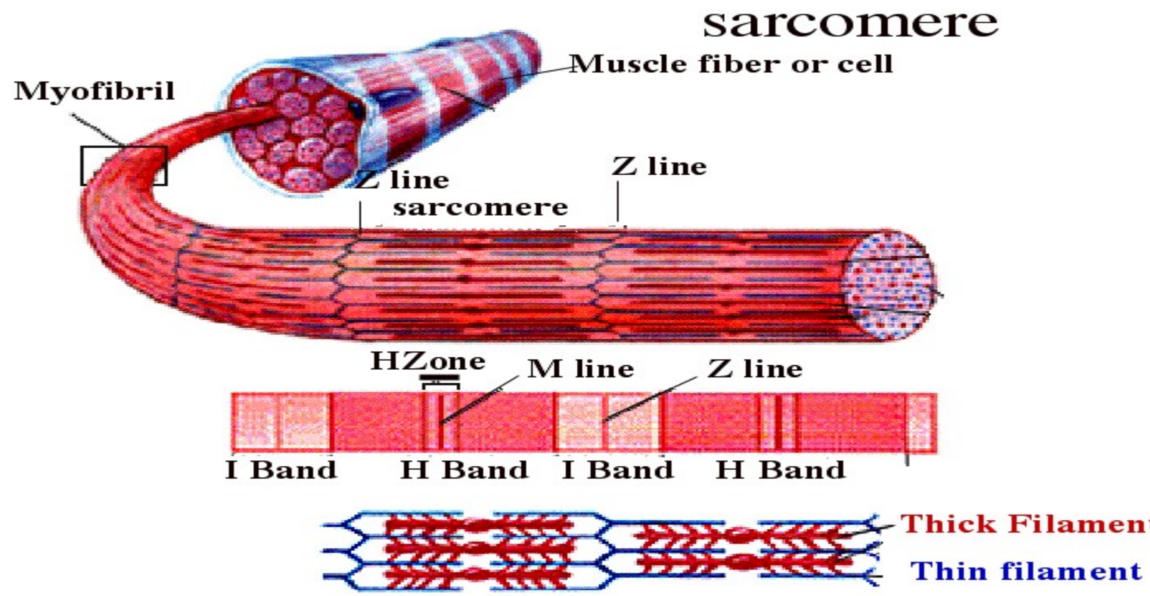
Sarcomeres

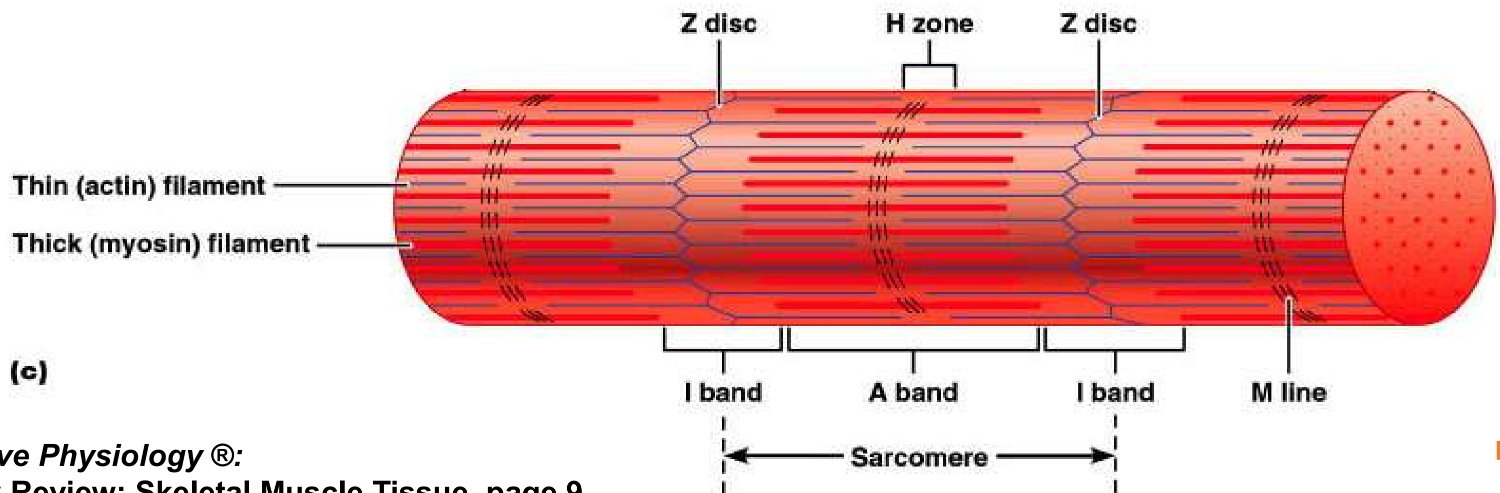
- The smallest contractile unit of a muscle
- The region of a myofibril between two successive Z discs
- Composed of myofilaments made up of contractile proteins
  - Myofilaments are of two types – thick and thin





Sarcomeres





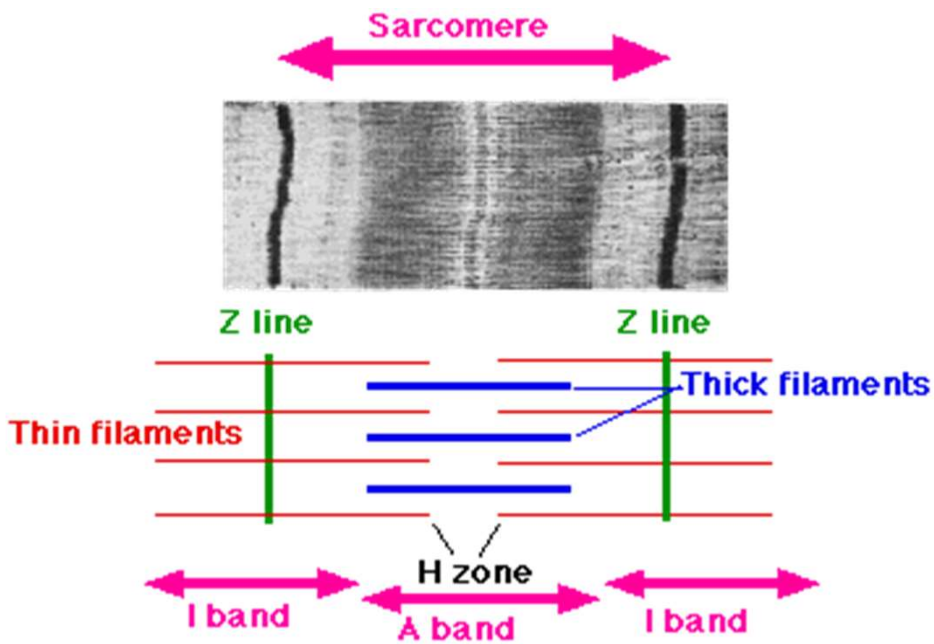
(c)

InterActive Physiology ®:
Anatomy Review: Skeletal Muscle Tissue, page 9

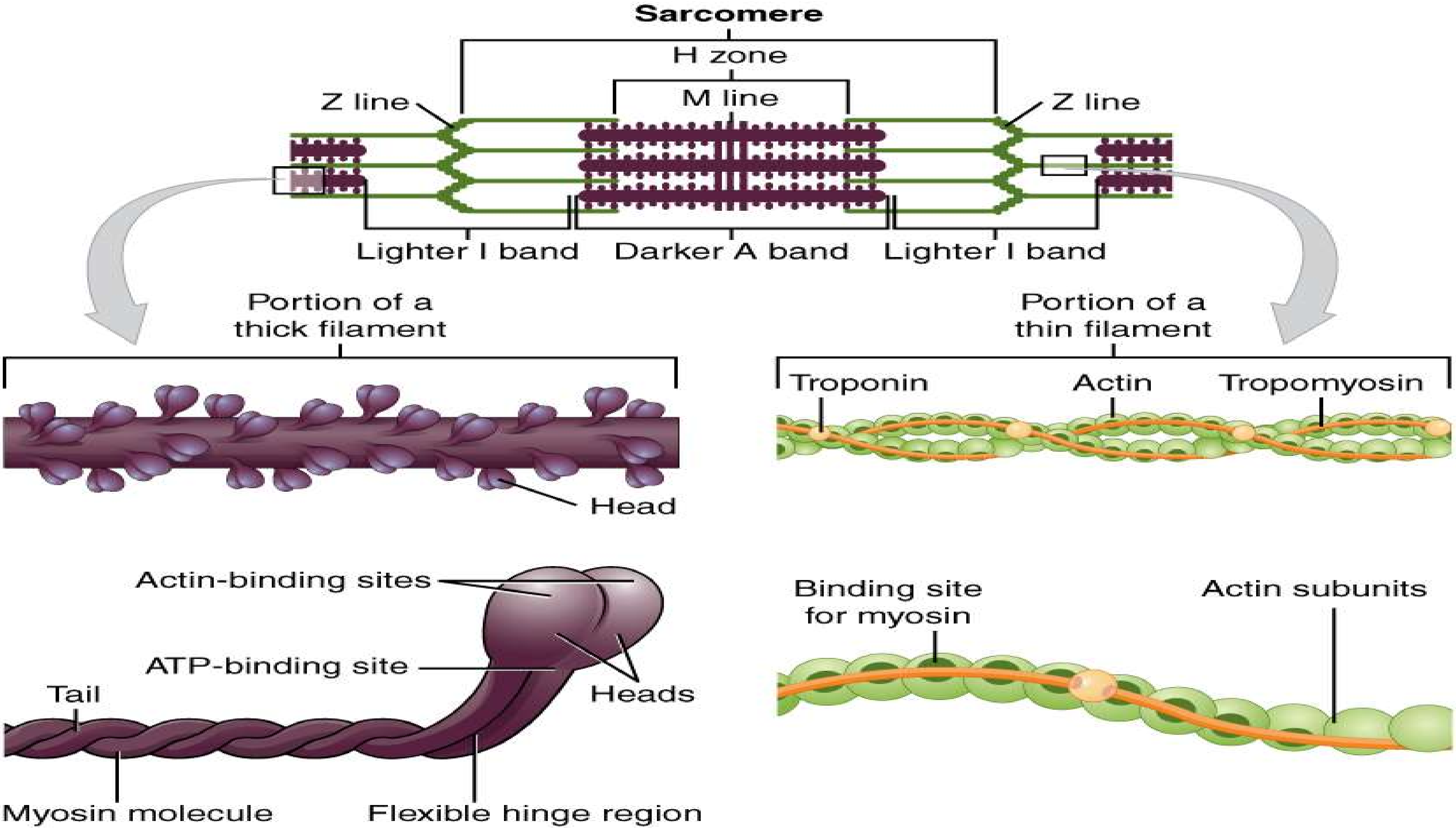
Figure 9.3c

Myofilaments: Banding Pattern

- Thin filaments do not overlap thick filaments in the lighter H zone
- M lines appear darker due to the presence of the protein desmin



- Thick filaments – extend the entire length of an A band
- Thin filaments – extend across the I band and partway into the A band
- Z-disc – coin-shaped sheet of proteins (connectins) that anchors the thin filaments and connects myofibrils to one another


Sarcomere
H zone
M line
Z line
Z line
Lighter I band
Darker A band
Lighter I band
Portion of a thick filament
Head
Portion of a thin filament
Troponin
Actin
Tropomyosin
Actin-binding sites
ATP-binding site
Heads
Tail
Myosin molecule
Flexible hinge region
Binding site for myosin
Actin subunits

Myofilaments: Banding Pattern

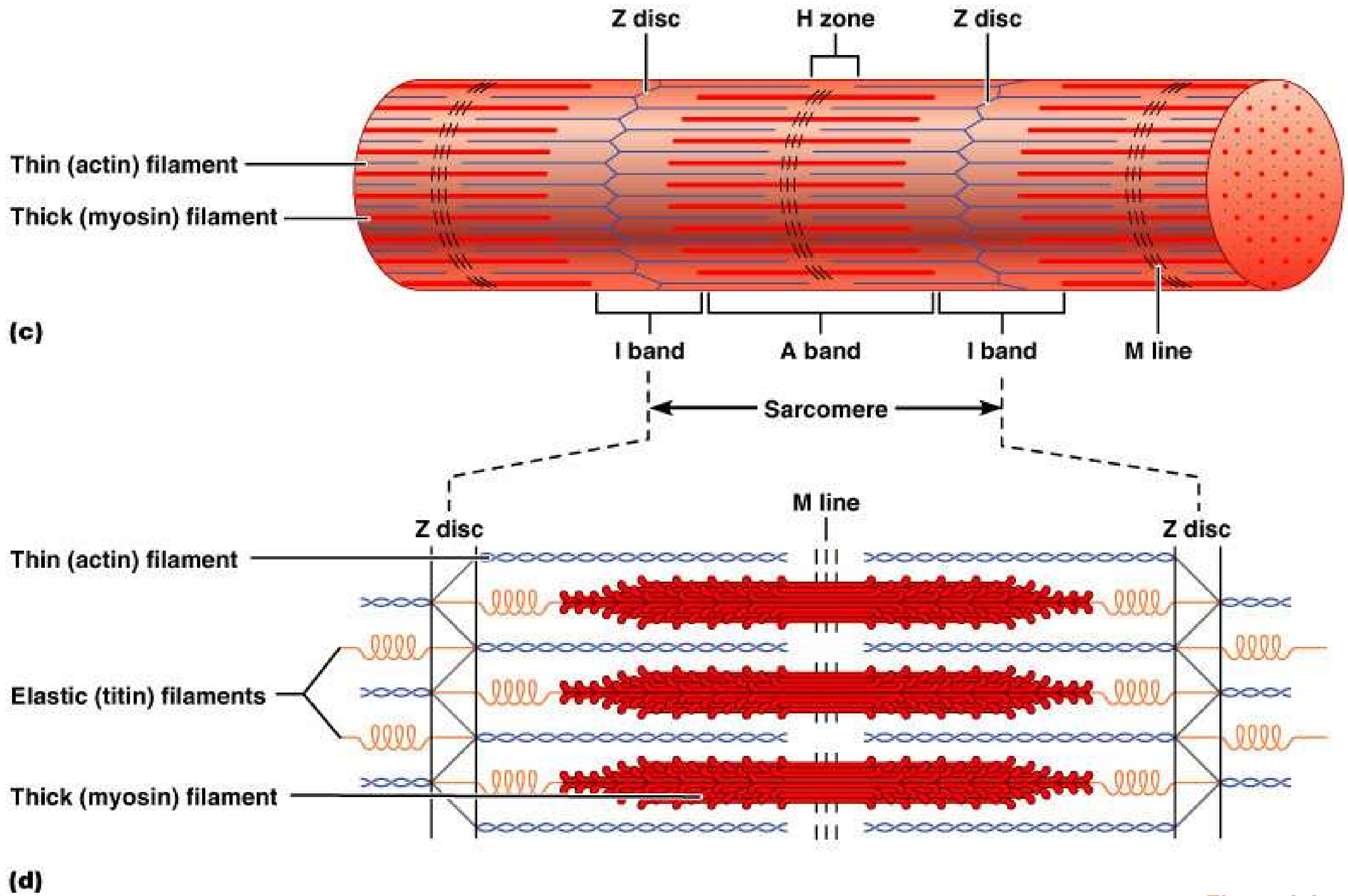


Figure 9.3c,d

Struc … scle

TABLE 9.1 Structure and Organizational Levels of Skeletal Muscle

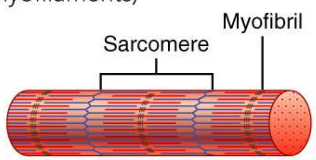
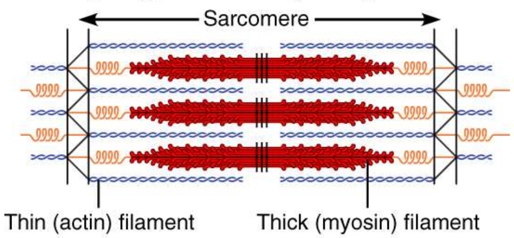
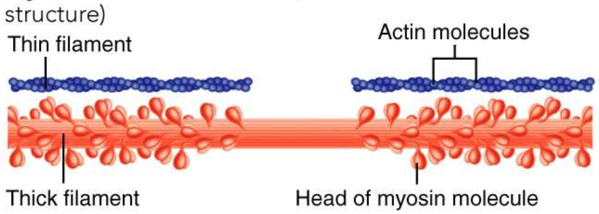
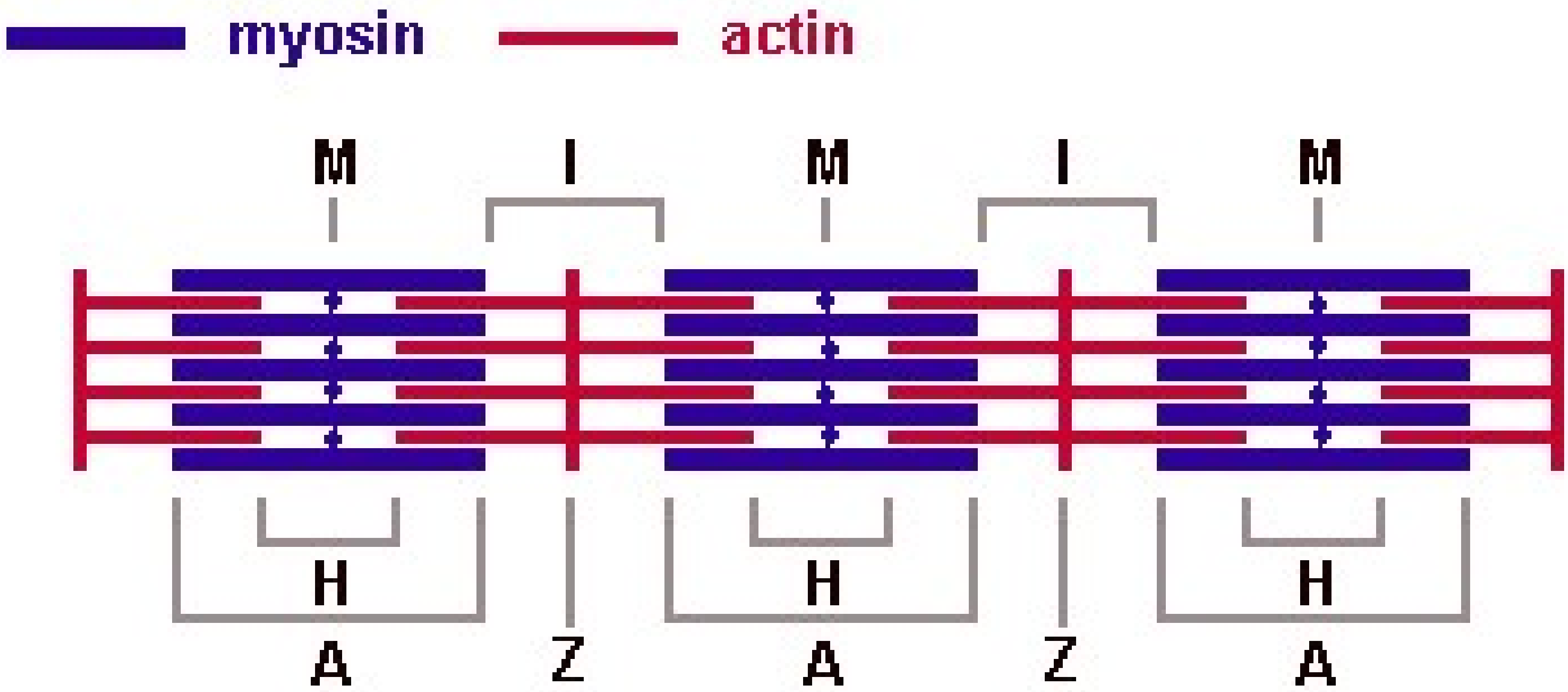
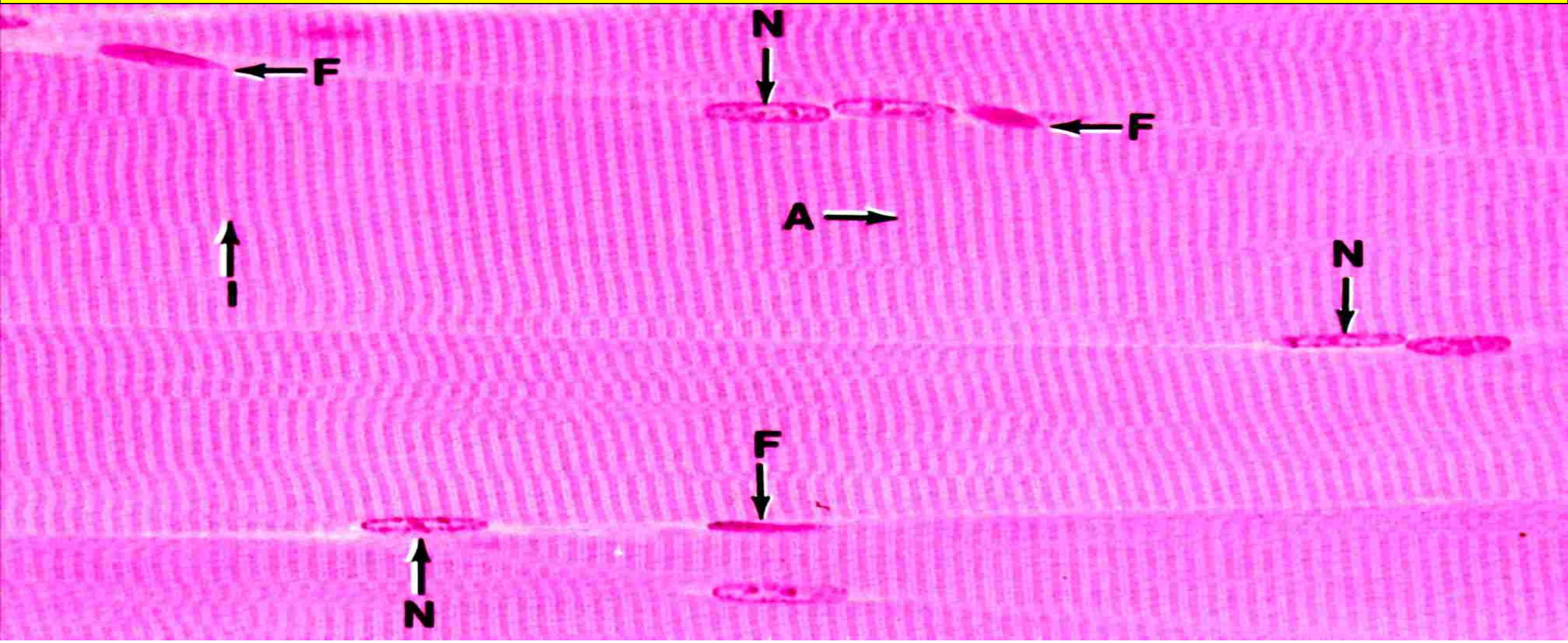
STRUCTURE AND ORGANIZATIONAL LEVEL	DESCRIPTION	CONNECTIVE TISSUE WRAPPINGS
Myofibril or fibril (complex organelle composed of bundles of myofilaments) 	Rodlike contractile element; myofibrils occupy most of the muscle cell volume; composed of sarcomeres arranged end to end; appear banded, and bands of adjacent myofibrils are aligned	
Sarcomere (a segment of a myofibril) 	The contractile unit, composed of myofilaments made up of contractile proteins	
Myofilament or filament (extended macromolecular structure) 	Contractile myofilaments are of two types—thick and thin: the thick filaments contain bundled myosin molecules; the thin filaments contain actin molecules (plus other proteins); the sliding of the thin filaments past the thick filaments produces muscle shortening. Elastic filaments (not shown here) maintain the organization of the A band and provide for elastic recoil when muscle contraction ends	

Table 9.1b



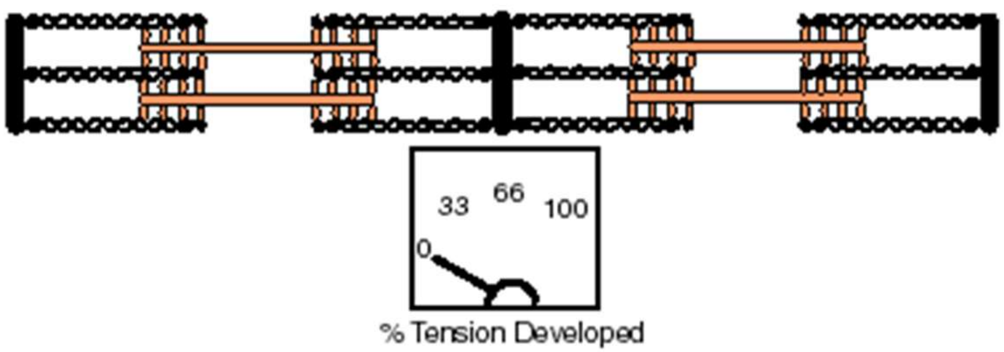
Bands and lines in the contractile apparatus of skeletal muscle

Here is a longitudinal section of skeletal muscle. See the multiple nuclei (N) pressed against the side of the muscle fibers. The light I bands and dark A bands are labeled for you. What do you think the F stands for?



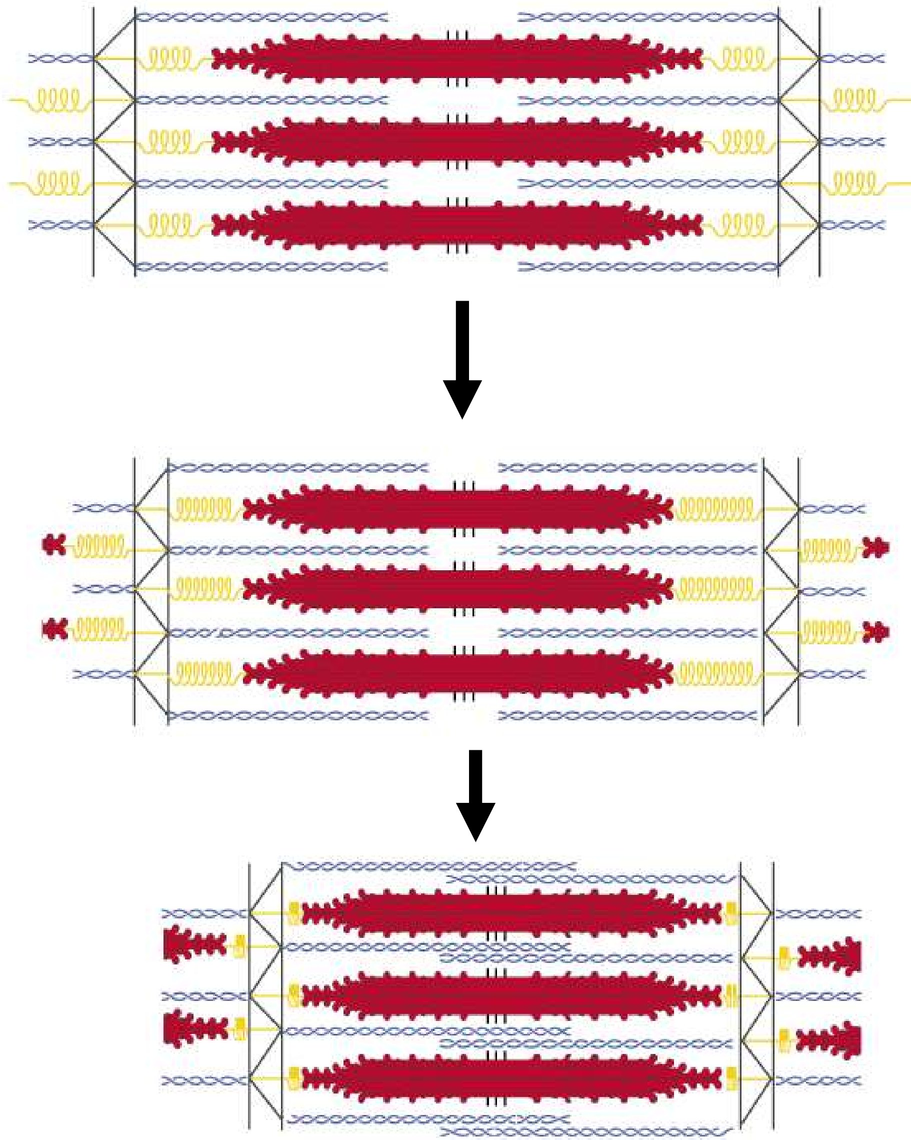
Muscle Contraction: The Sliding Filament Hypothesis

- Place your right palm on the back of your left hand. Now slide your right palm toward your left elbow.
  - What happened to the distance between your elbows?
    - It got shorter!
  - This is how muscle contraction occurs.
  - The thin filaments slide over the thick filaments. This pulls the Z discs closer together. When all the sarcomeres in a fiber do this, the entire fiber gets shorter which pulls on the endomysium, perimysium, epimysium and attached tendon and then pulls on the bone. Voila, we ha

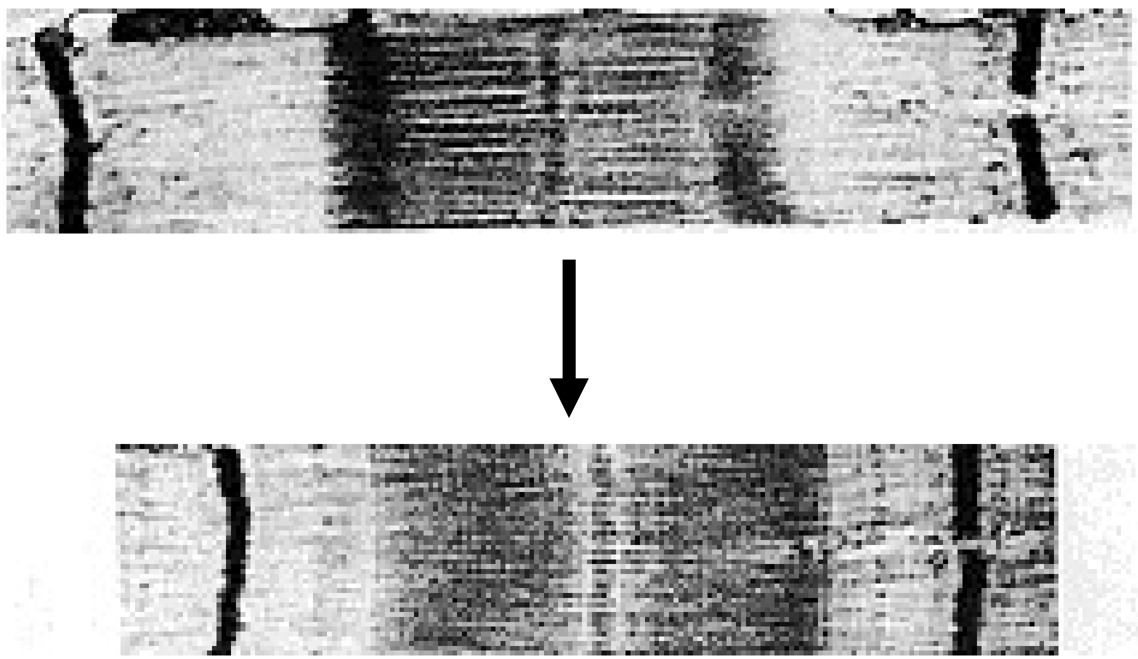


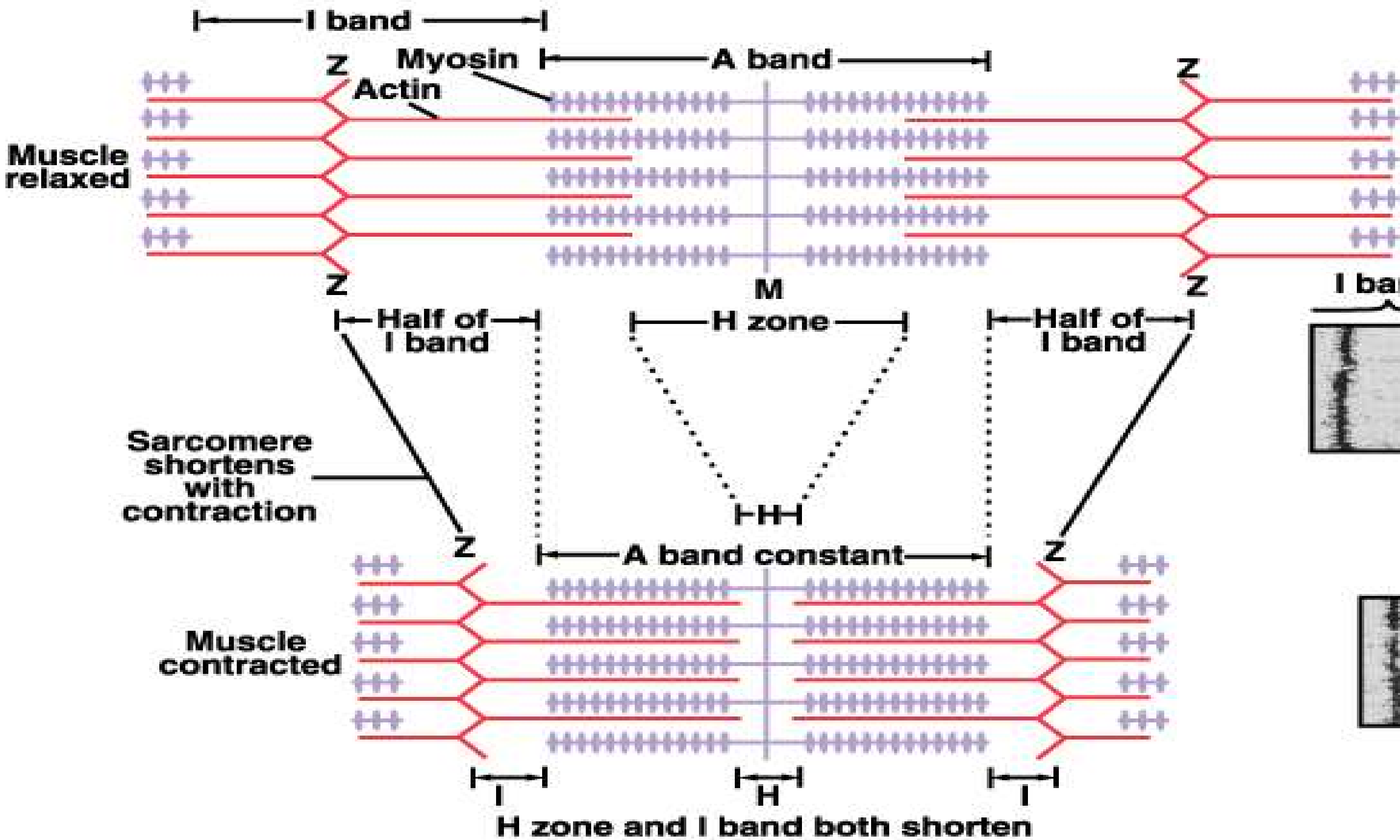
Here is what happens as the filaments slide and the sarcomere and the muscle fiber shortens. In the process of contraction, what happens to the:

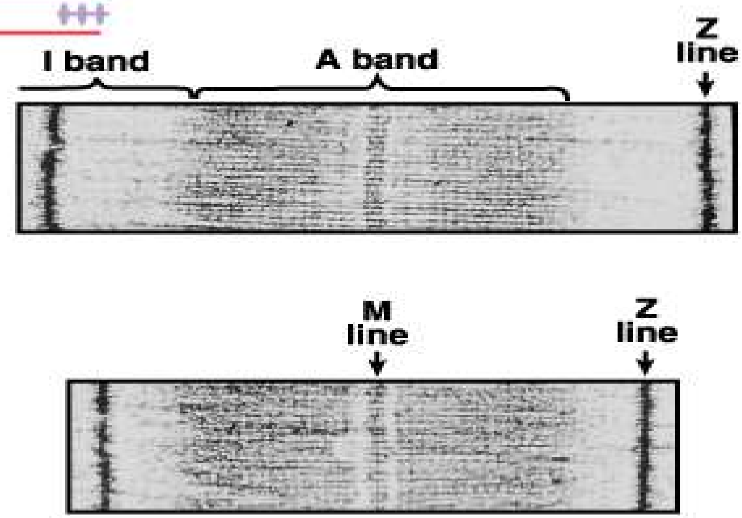
1. Distance btwn Z discs
2. Length of the A band
3. Length of the H zone
4. Length of the I band



Here are 2 electron micrographs of the same sarcomere. Do you see the Z discs, A band, H zone, M line, and I bands? How do the 2 pictures differ? What happened?




I band
Myosin
A band
Z
Actin
Z
Muscle relaxed
Z
M
Z
Half of I band
H zone
Half of I band
Sarcomere shortens with contraction
H
Z
A band constant
Z
Muscle contracted
I
H
I
H zone and I band both shorten

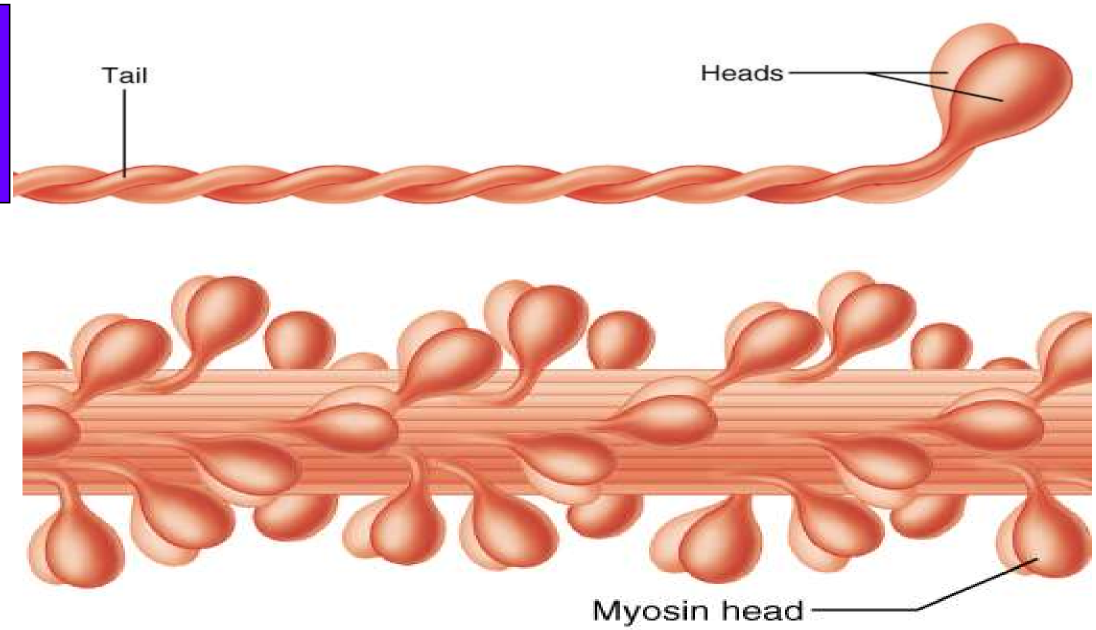

I band
A band
Z line
M line
Z line

Myofilaments

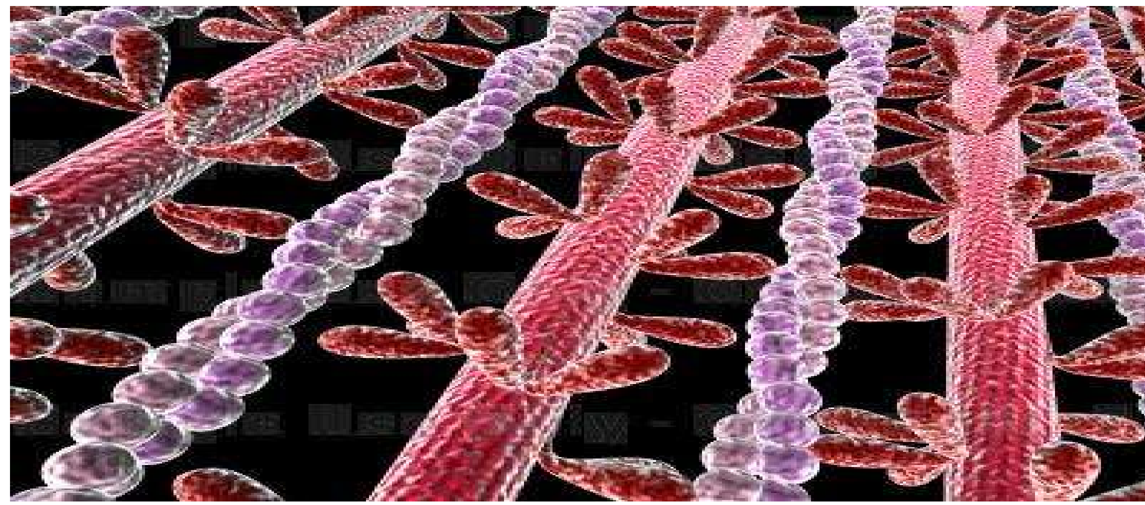
- 2 types of myofilaments (thick & thin) make up myofibrils.
- Thick myofilaments are made the protein myosin

A single myosin protein resembles 2 golf clubs whose shafts have been twisted about one another

About 300 of these myosin molecules are joined together to form a single thick filament



Portion of a thick filament



Ultrastructure of Myofilaments: Thick Filaments

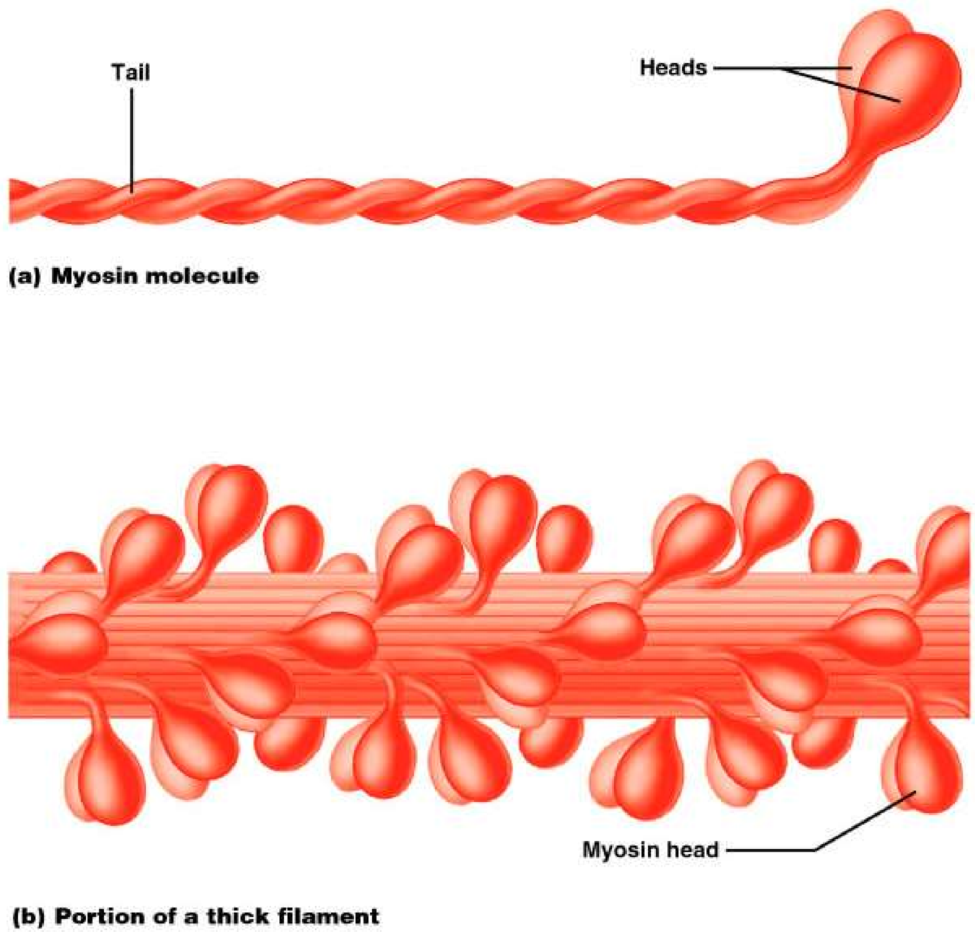
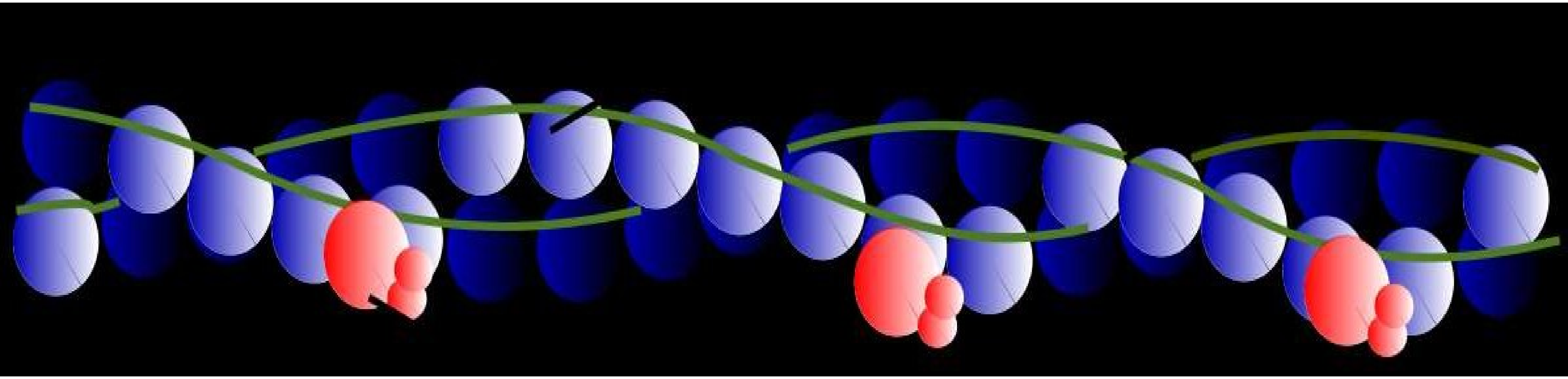
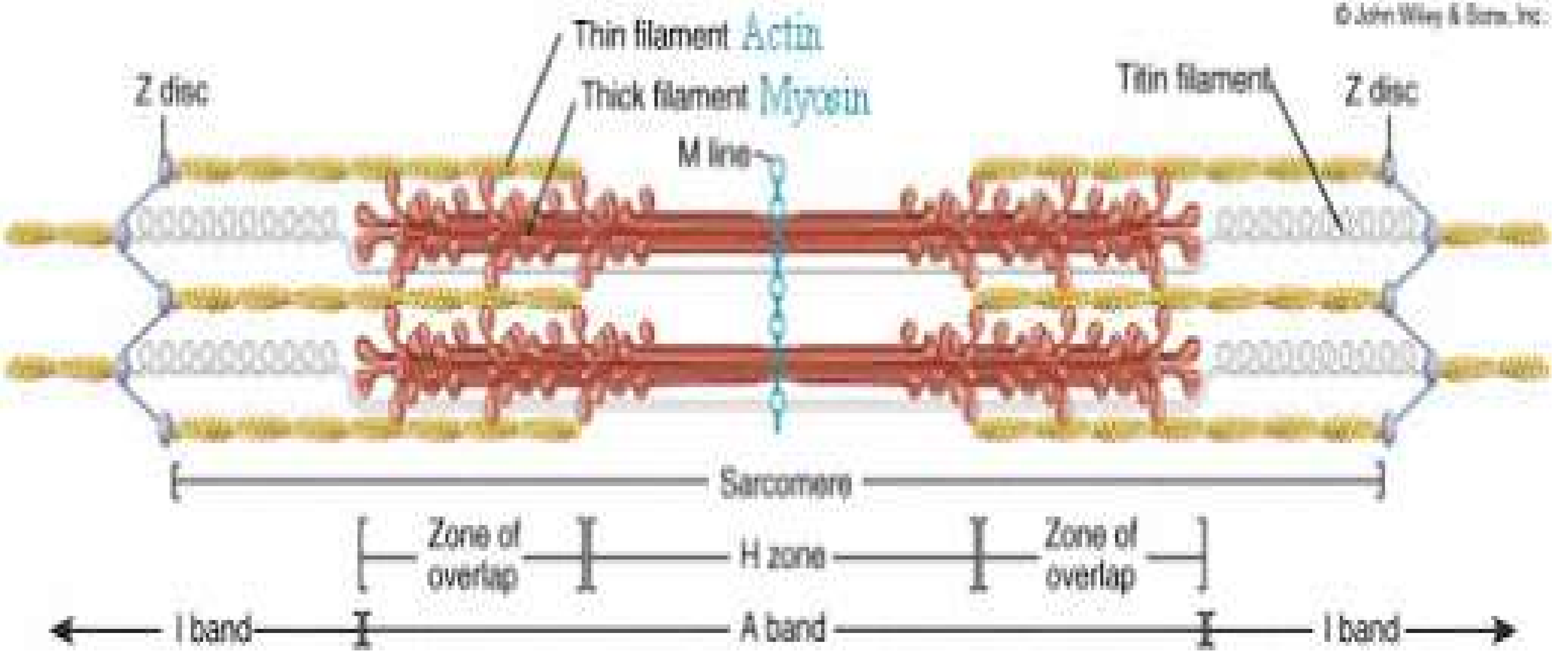


Figure 9.4a,b

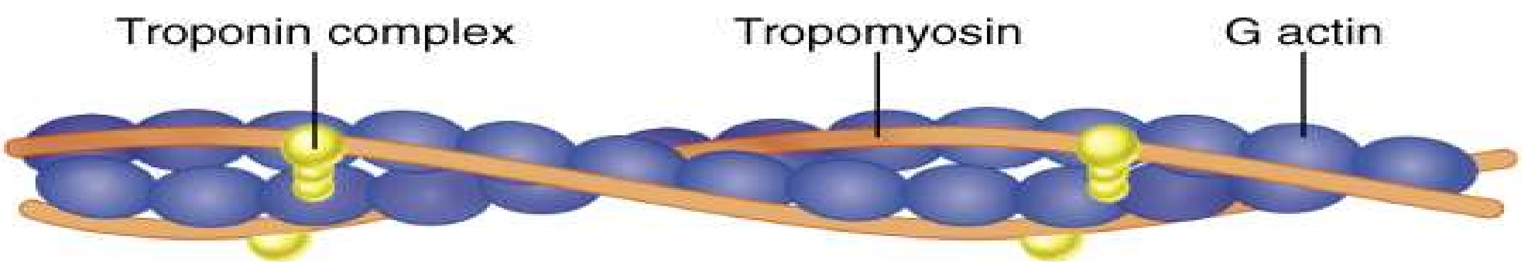
Ultrastructure of Myofilaments: Thin Filaments

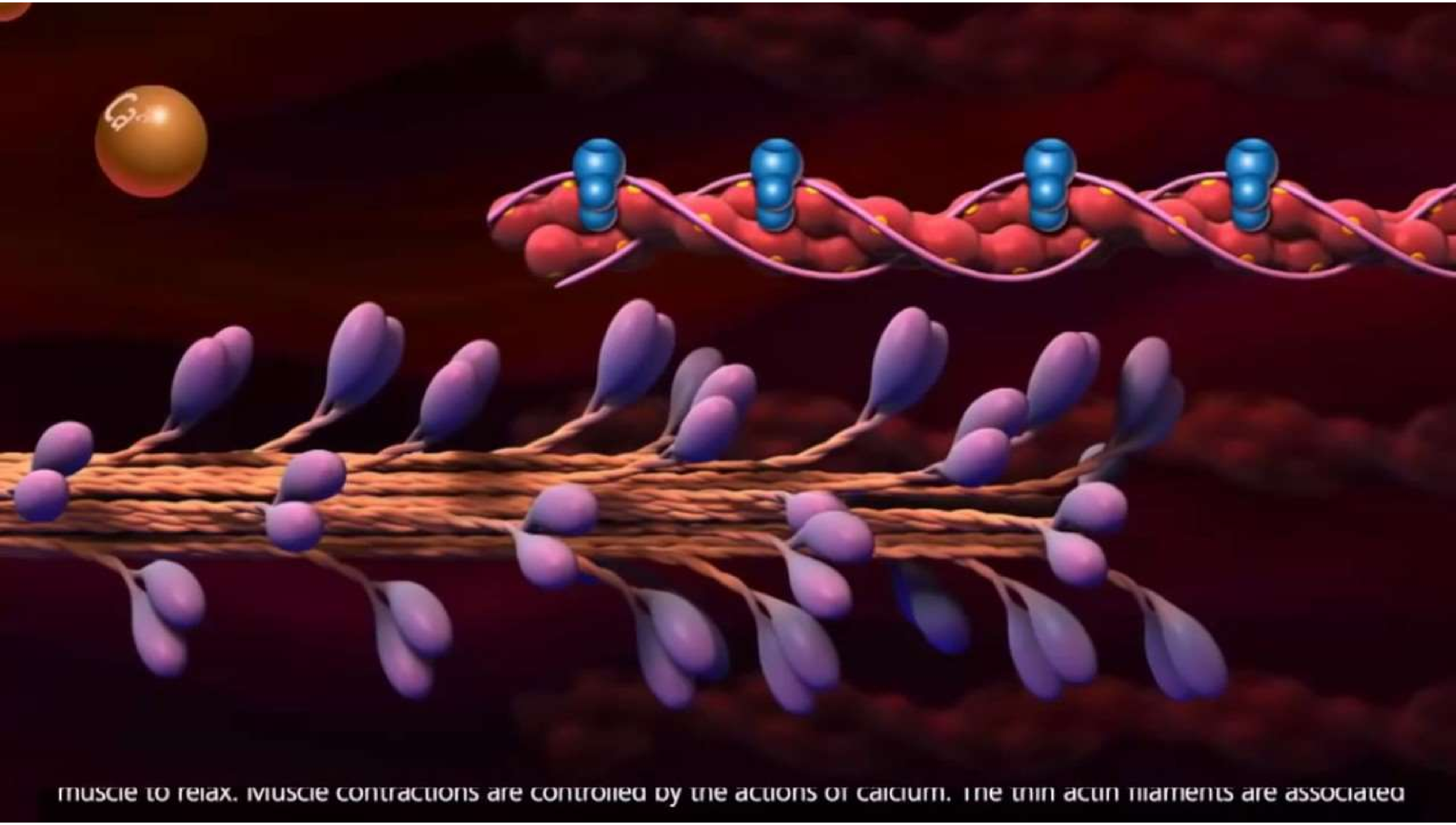
- **Thin filaments are chiefly composed of the protein actin**
- **Each actin molecule is a helical polymer of globular subunits called G actin**
- **The subunits contain the active sites to which myosin heads attach during contraction**
- **Tropomyosin and troponin are regulatory subunits bound to actin**



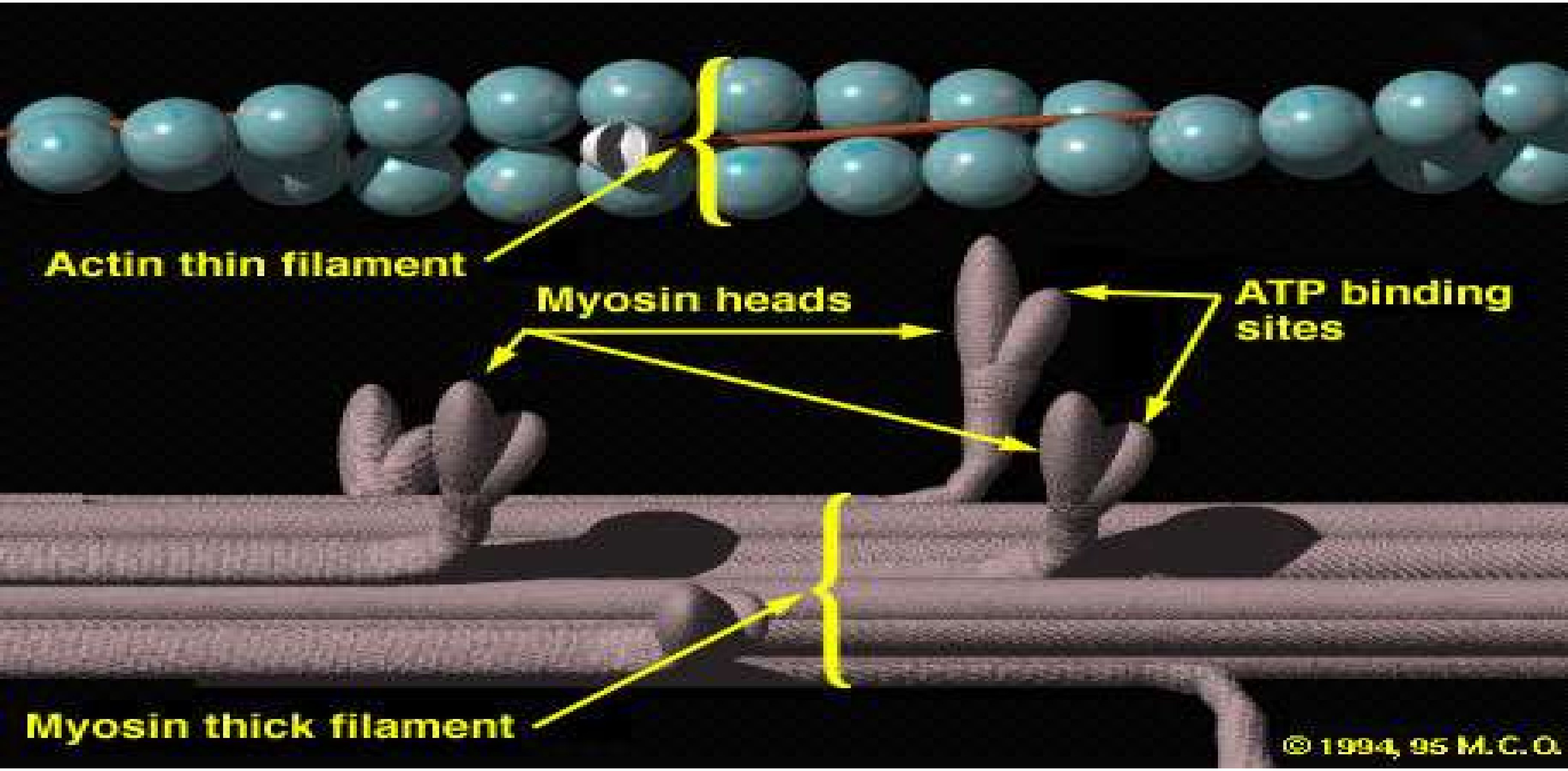

© John Wiley & Sons, Inc.
Thin filament Actin
Thick filament Mycein
Z disc
Titin filament
Z disc
M line
Sarcomere
Zone of overlap
H zone
Zone of overlap
I band
A band
I band

- Each thin filament is made up of 3 different types of protein: actin, tropomyosin, and troponin.
  - Each thin filament consists of a long helical double strand. This strand is a polymer that resembles a string of beads. Each "bead" is the globular protein actin. On each actin subunit, there is a myosin binding site.
  - Loosely wrapped around the actin helix and covering the myosin binding site is the filamentous protein, tropomyosin.
  - Bound to both the actin and the tropomyosin is a trio of proteins collectively known as troponin.

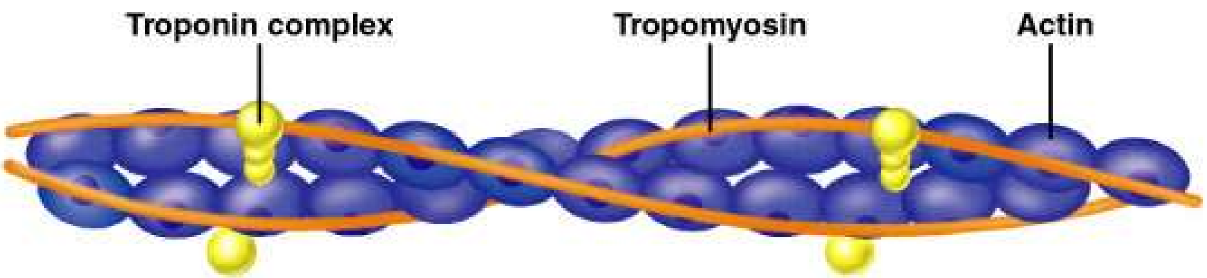



Ca
muscle to relax. Muscle contractions are controlled by the actions of calcium. The thin actin filaments are associated

Note the relationship between the thin and thick filaments



Ultrastructure of Myofilaments: Thin Filaments

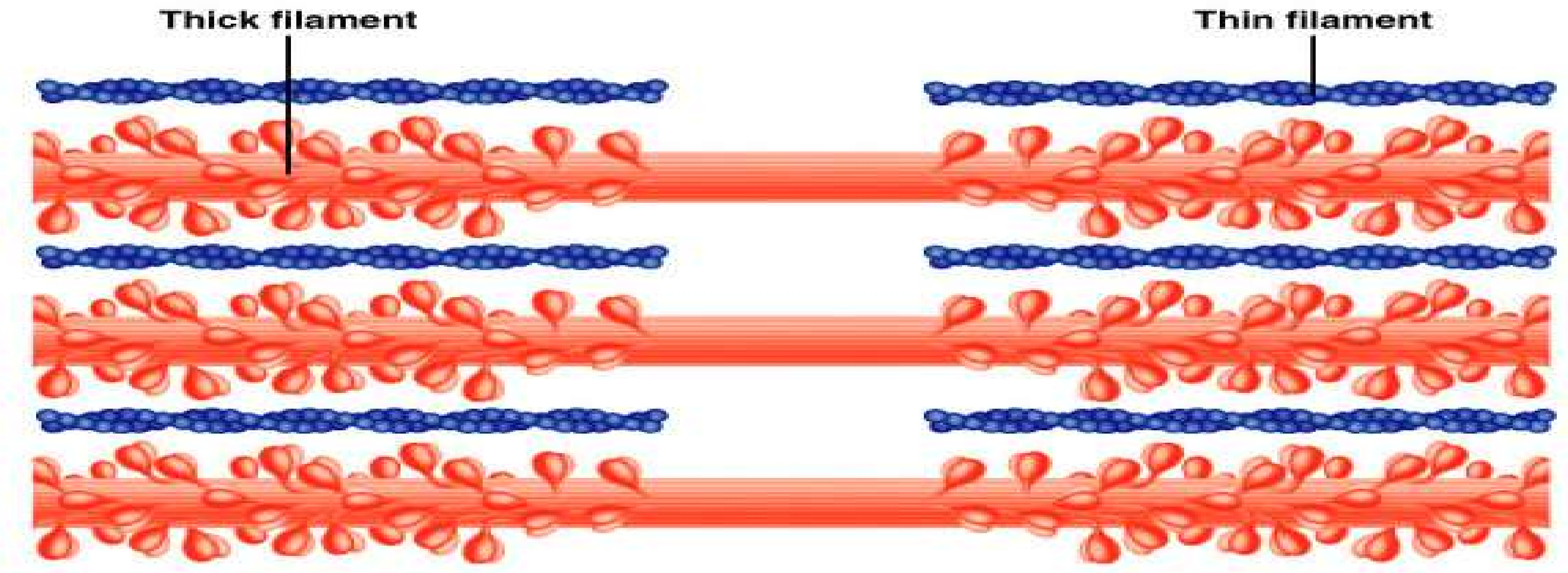


(c) Portion of a thin filament

Figure 9.4c

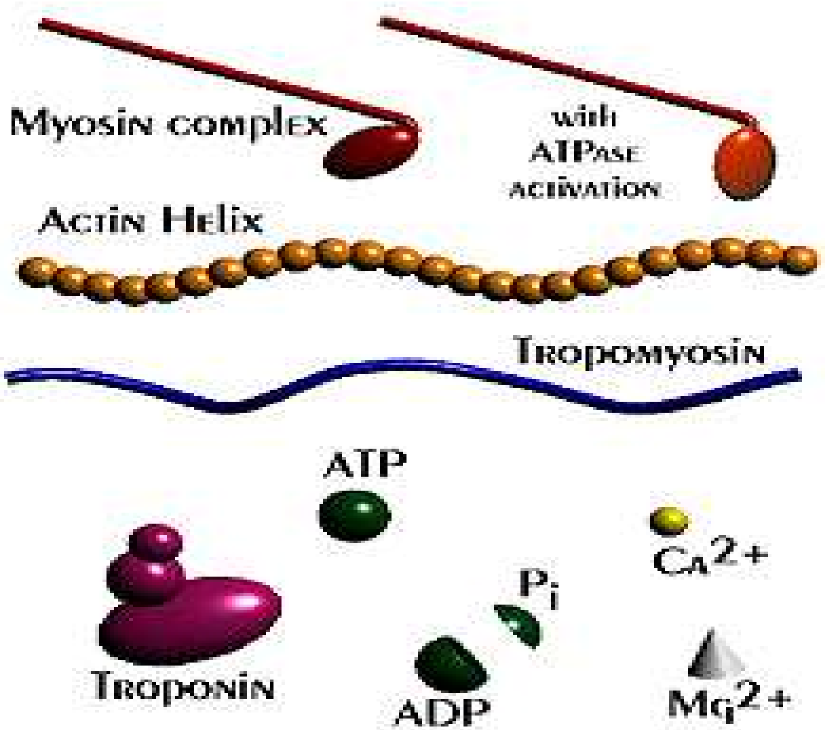
Arrangement of the Filaments in a Sarcomere

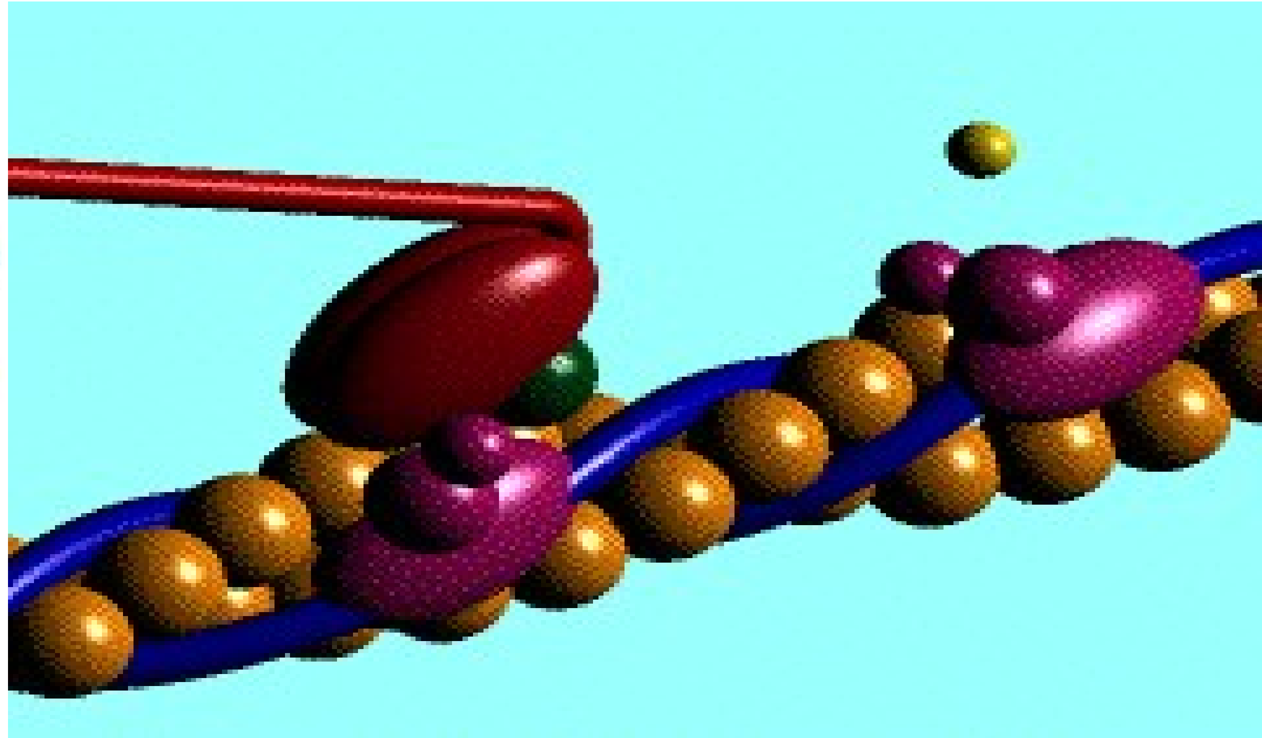
- Longitudinal section within one sarcomere



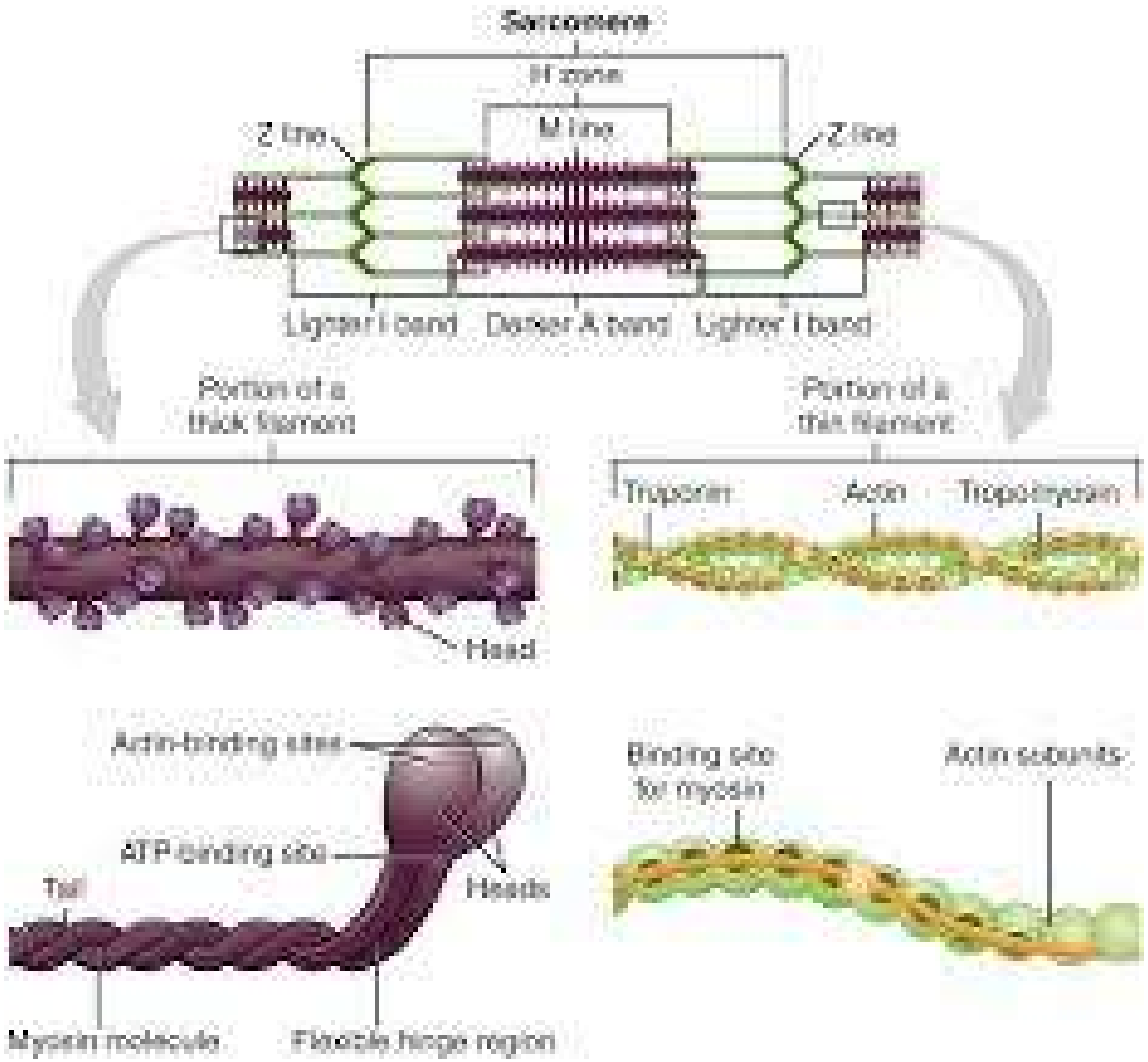
(d) Longitudinal section of filaments within one sarcomere of a myofibril

Figure 9.4d





Actin Myosin Crossbridge 3D Animation



Sarcomere
H zone
M line
Z line
Z line
Lighter I band
Darker A band
Lighter I band
Portion of a thick filament
Portion of a thin filament
Troponin
Actin
Tropomyosin
Head
Actin-binding sites
ATP-binding site
Heads
Tail
Myosin molecule
Flexible hinge region
Binding site for myosin
Actin subunits

Sarcoplasmic Reticulum (SR)

- SR is an elaborate, smooth endoplasmic reticulum that mostly runs longitudinally and surrounds each myofibril
- Paired terminal cisternae form perpendicular cross channels
- Functions in the regulation of intracellular calcium levels
- Elongated tubes called T tubules penetrate into the cell's interior at each A band–I band junction
- T tubules associate with the paired terminal cisternae to form triads

Sarcoplasmic Reticulum (SR)

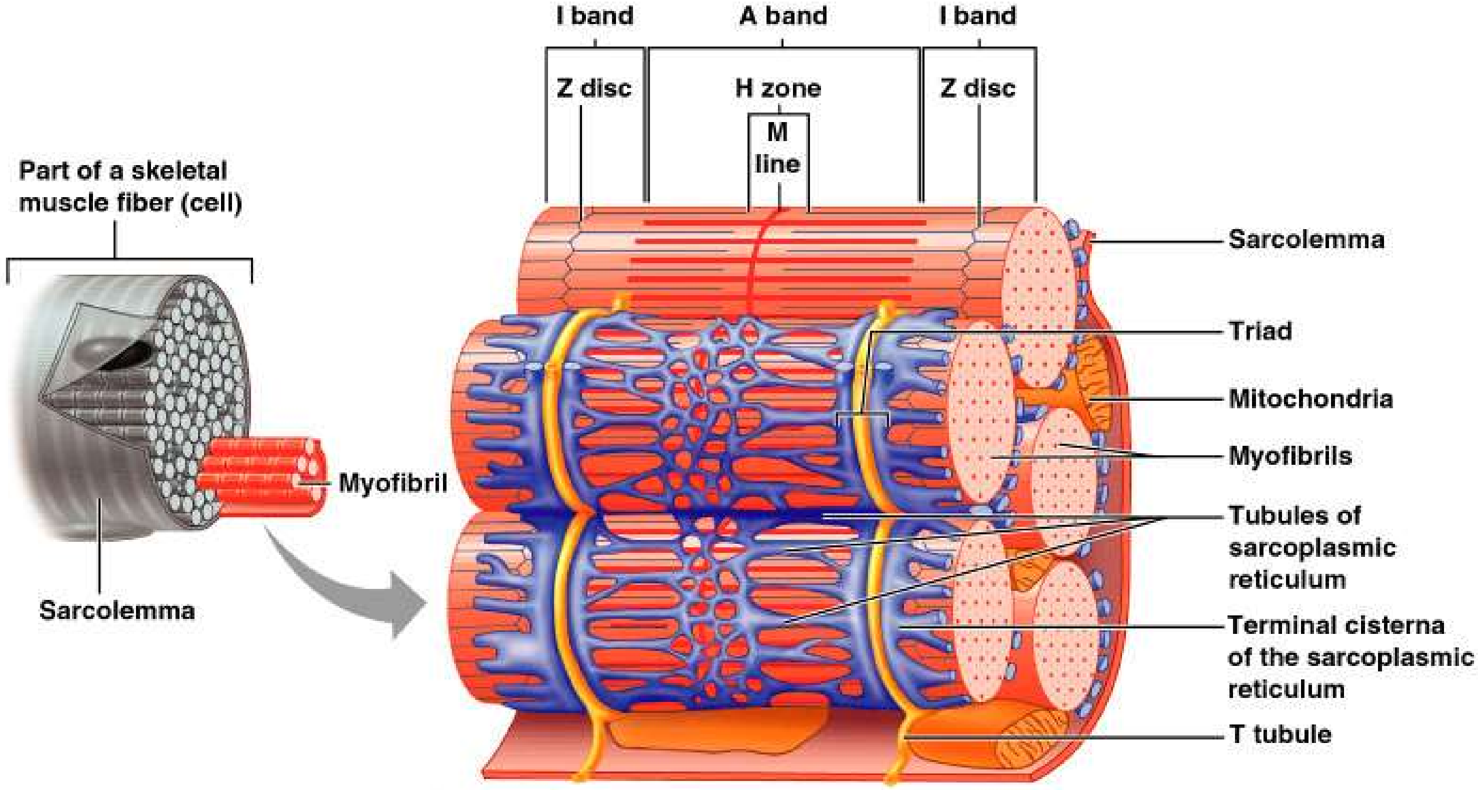


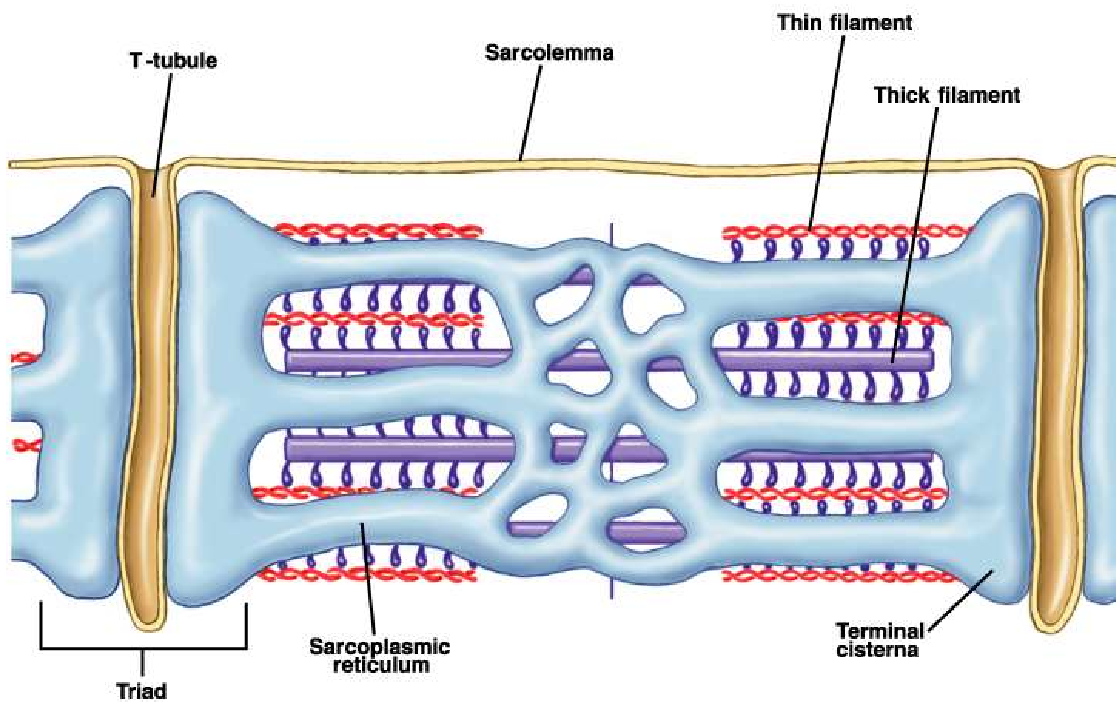
Figure 9.5

T Tubules

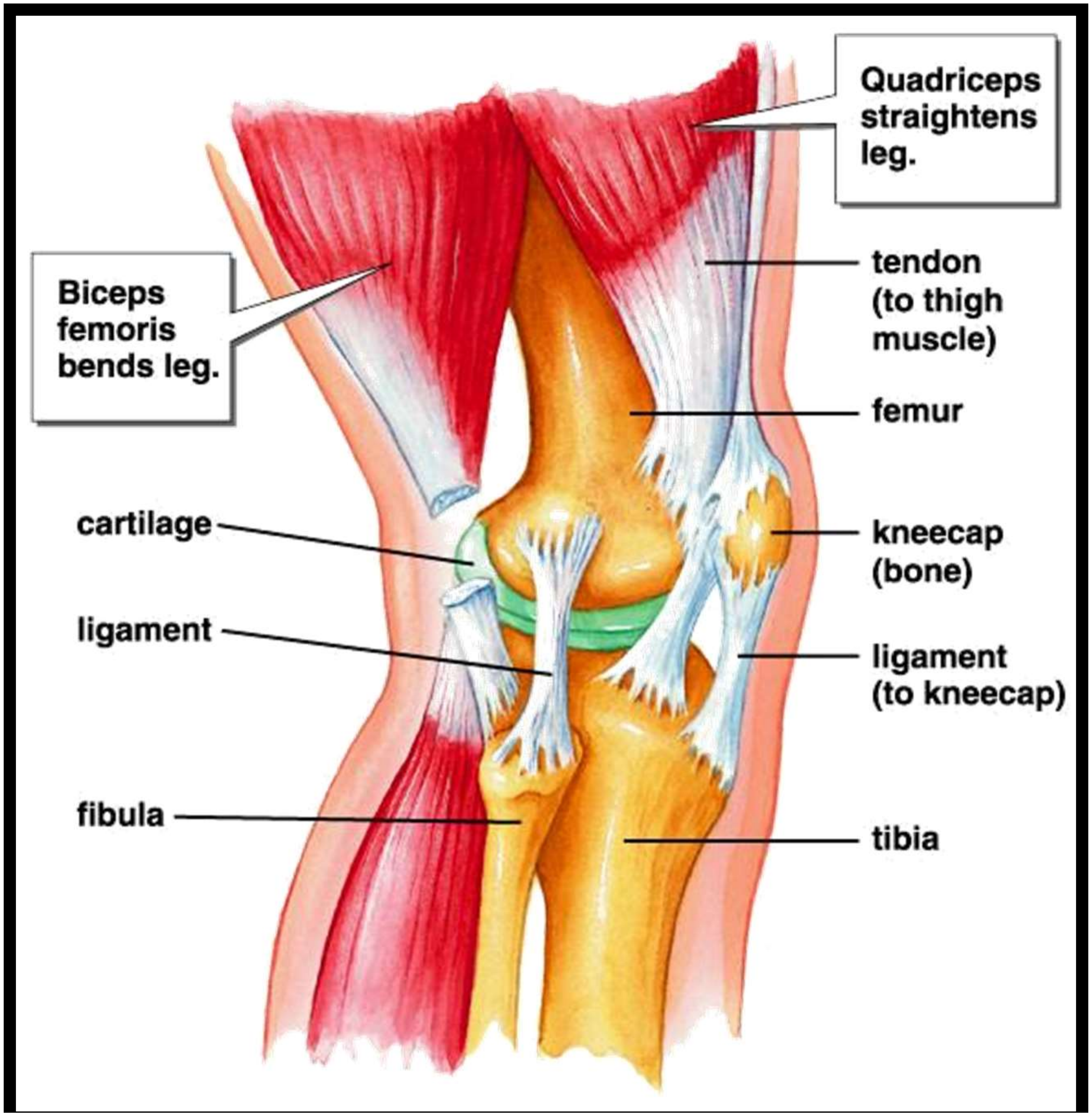
- T tubules are continuous with the sarcolemma
- They conduct impulses to the deepest regions of the muscle
- These impulses signal for the release of Ca^{2+} from adjacent terminal cisternae

T-Tubules and the SR

- Each muscle fiber has many T-tubules
  - Typically each myofibril has a branch of a T-tubule encircling it at each A-I junction
- At each A-I junction, the SR will expand and form a dilated sac (terminal cisterna).



Each T-tubule will be flanked by a terminal cisterna. This forms a so-called triad consisting of 2 terminal cisternae and one T-tubule branch.


Quadriceps straightens leg.
Biceps femoris bends leg.
tendon (to thigh muscle)
femur
cartilage
kneecap (bone)
ligament
ligament (to kneecap)
fibula
tibia

The Overload Principle

- Forcing a muscle to work promotes increased muscular strength
- Muscles adapt to increased demands
- Muscles must be overloaded to produce further gains

Hyperplasia

- Certain smooth muscles can divide and increase their numbers by undergoing hyperplasia
- This is shown by estrogen's effect on the uterus
  - At puberty, estrogen stimulates the synthesis of more smooth muscle, causing the uterus to grow to adult size
  - During pregnancy, estrogen stimulates uterine growth to accommodate the increasing size of the growing fetus

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

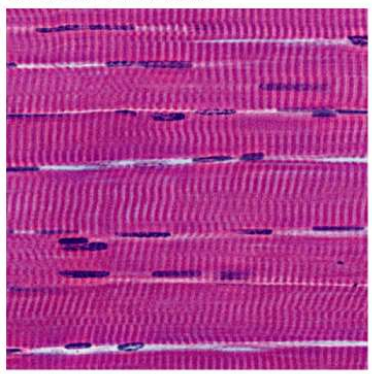
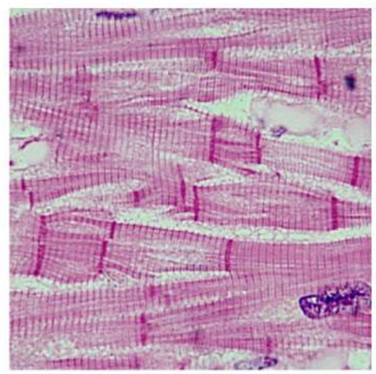
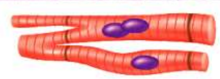
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Body location	Attached to bones or (some facial muscles) to skin 	Walls of the heart 	Single-unit muscle in walls of hollow visceral organs (other than the heart); multiunit muscle in intrinsic eye muscles, airways, large arteries 
Cell shape and appearance	Single,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

Table 9.3.1

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

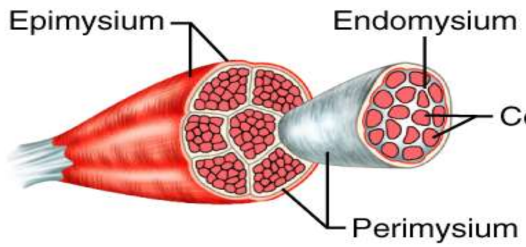
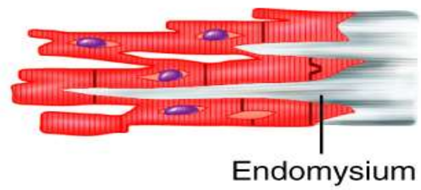
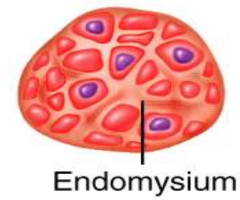
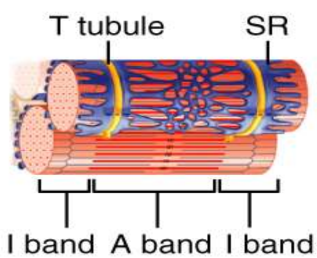
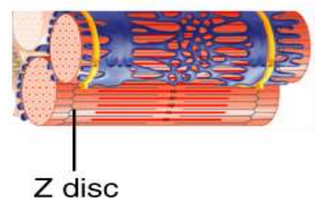
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Connective tissue components	Epimysium, perimysium, and endomysium	Endomysium attached to fibrous skeleton of heart	Endomysium
			
Presence of myofibrils composed of sarcomeres	Yes	Yes, but myofibrils are of irregular thickness	No, but actin and myosin filaments 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
			
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

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

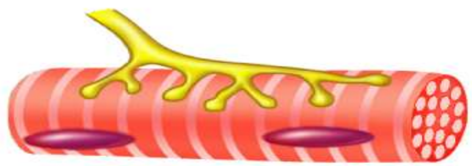
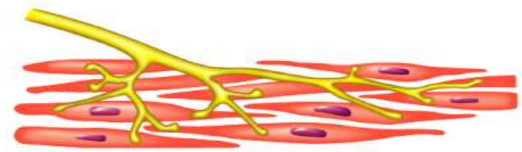
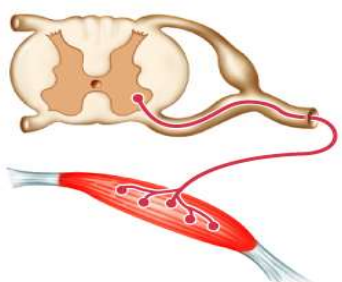
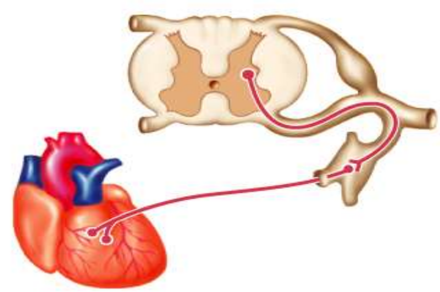
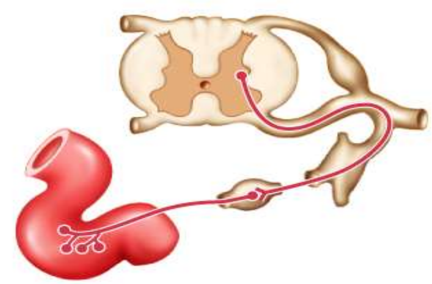
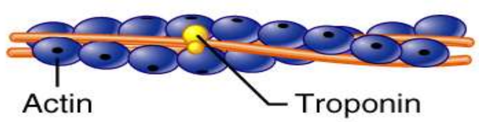
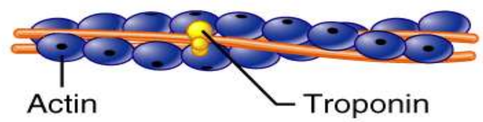
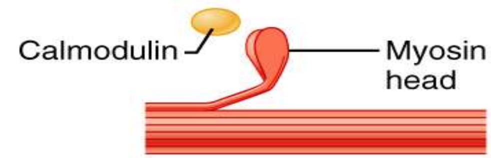
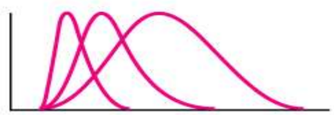
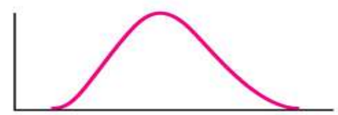
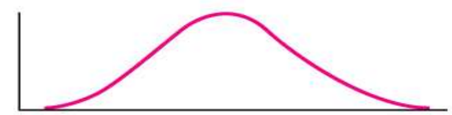
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Presence of gap junctions	No	Yes; at intercalated discs	Yes; in single-unit muscle
Cells exhibit individual neuromuscular junctions	Yes	No	Not in single-unit muscle; yes in multiunit muscle
			
Regulation of contraction	Voluntary via axon terminals of the somatic nervous system	Involuntary; intrinsic system regulation; also autonomic nervous system controls; hormones; stretch	Involuntary; autonomic nerves, hormones, local chemicals; stretch
			
Source of Ca^{2+} for calcium pulse	Sarcoplasmic reticulum (SR)	SR and from extracellular fluid	SR and from extracellular fluid

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Site of calcium regulation	Troponin on actin-containing thin filaments 	Troponin on actin-containing thin filaments 	Calmodulin in the sarcoplasm 
Presence of pacemaker(s)	No	Yes	Yes (in single-unit muscle only)
Effect of nervous system stimulation	Excitation	Excitation or inhibition	Excitation or inhibition
Speed of contraction	Slow to fast 	Slow 	Very slow 
Rhythmic contraction	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