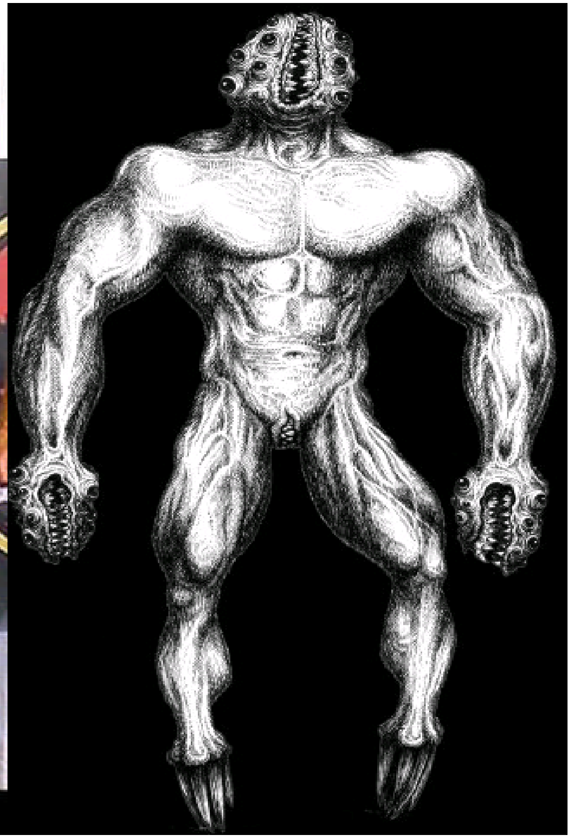
MUSCLE GENERALITY

DANIL HAMMOUDI.MD

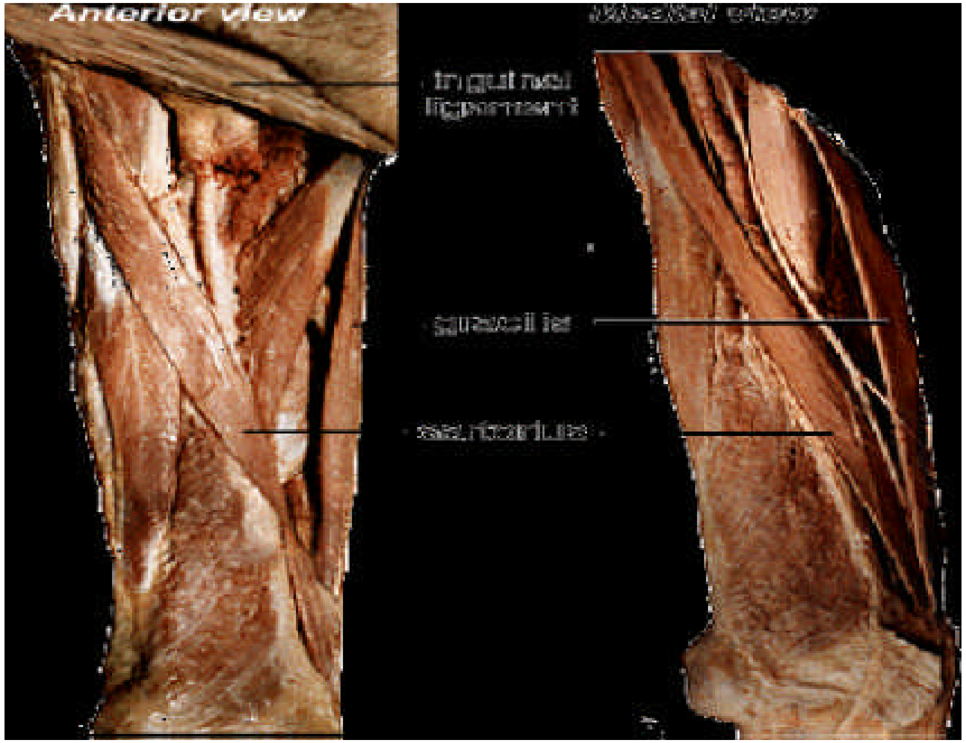


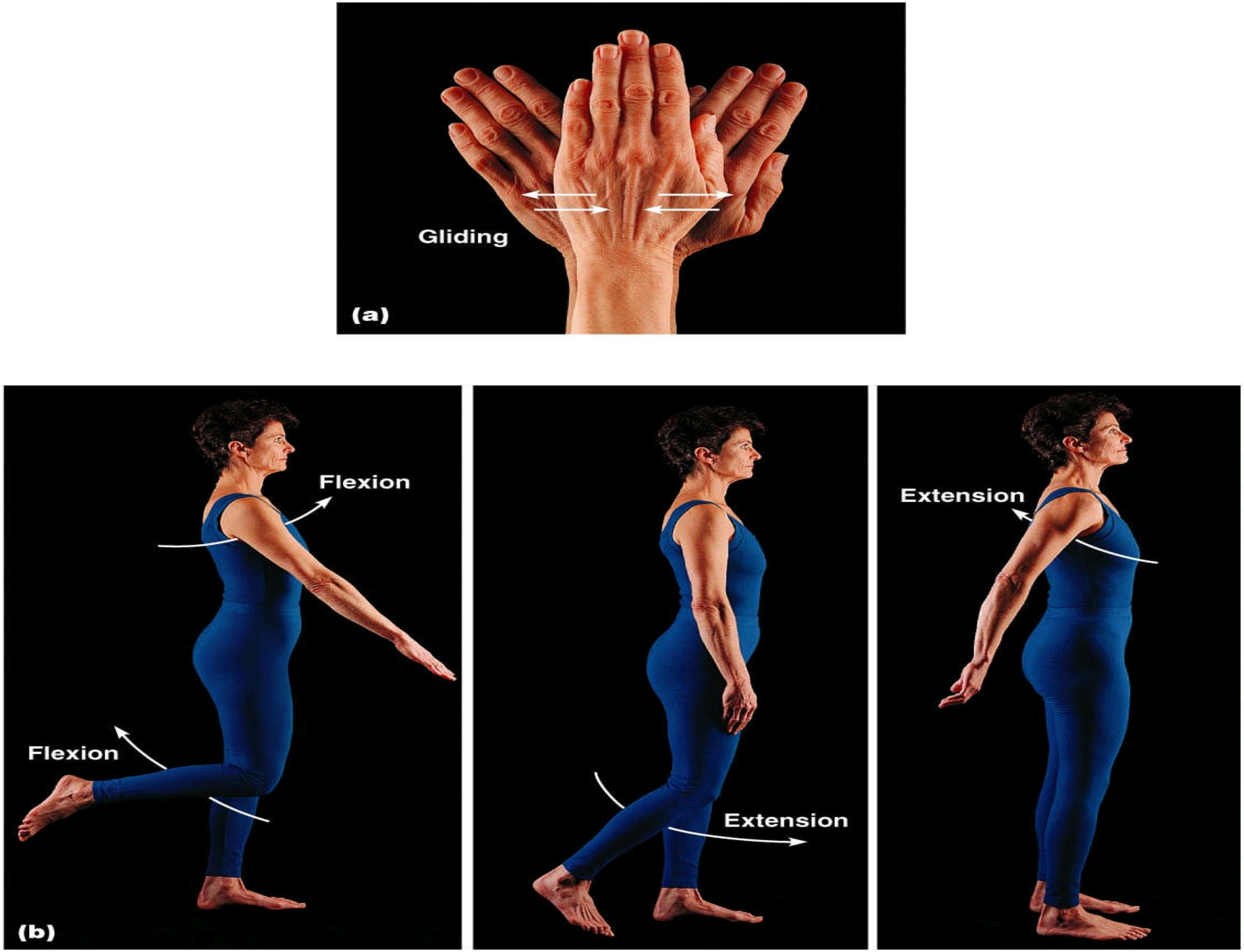
http://www.brookscole.com/chemistry_d/templates/student_resources/shared_resources/animations/muscles/muscles.html

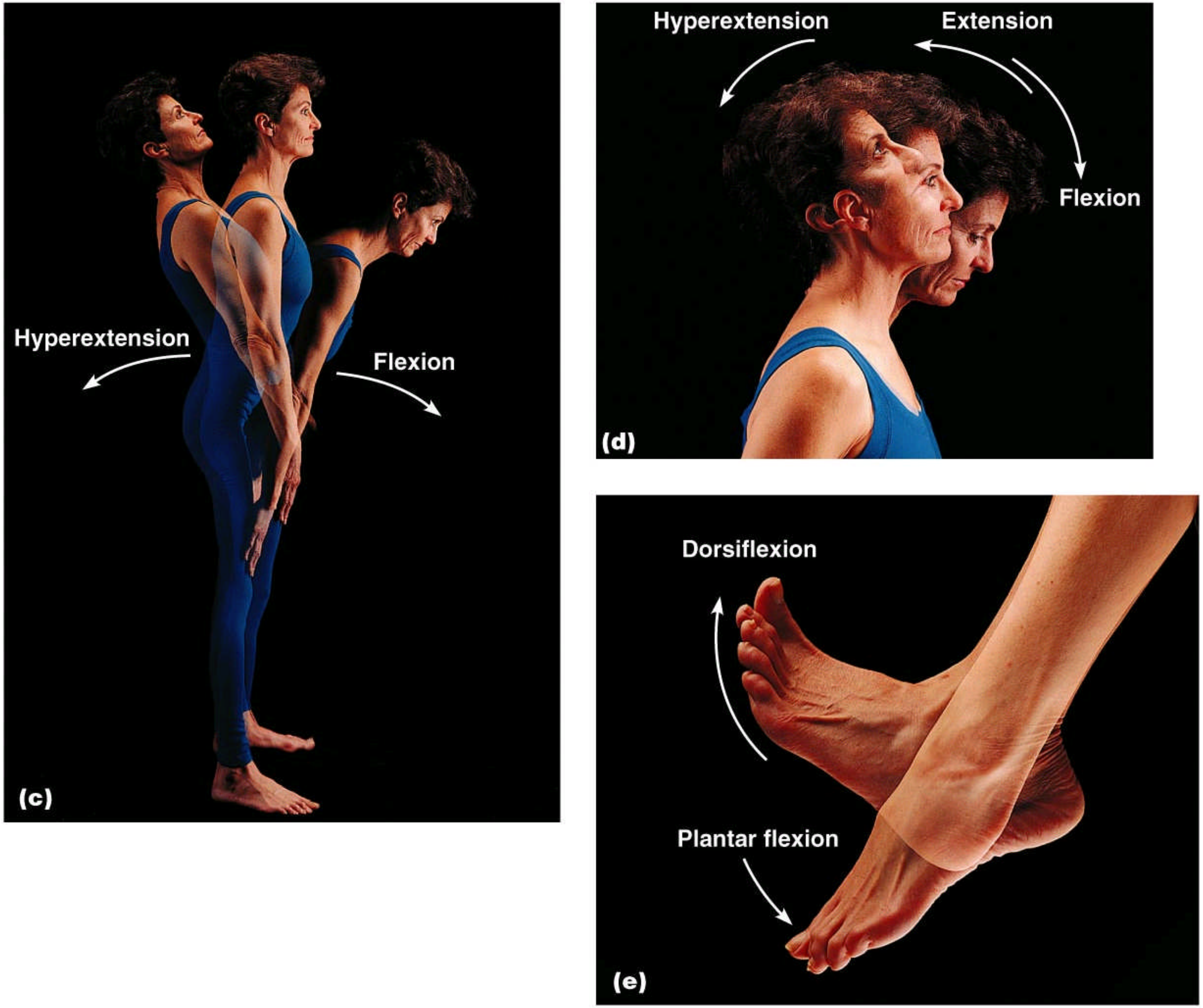
- We have over 600 major muscles.
- We have 240 muscles that have specific jobs

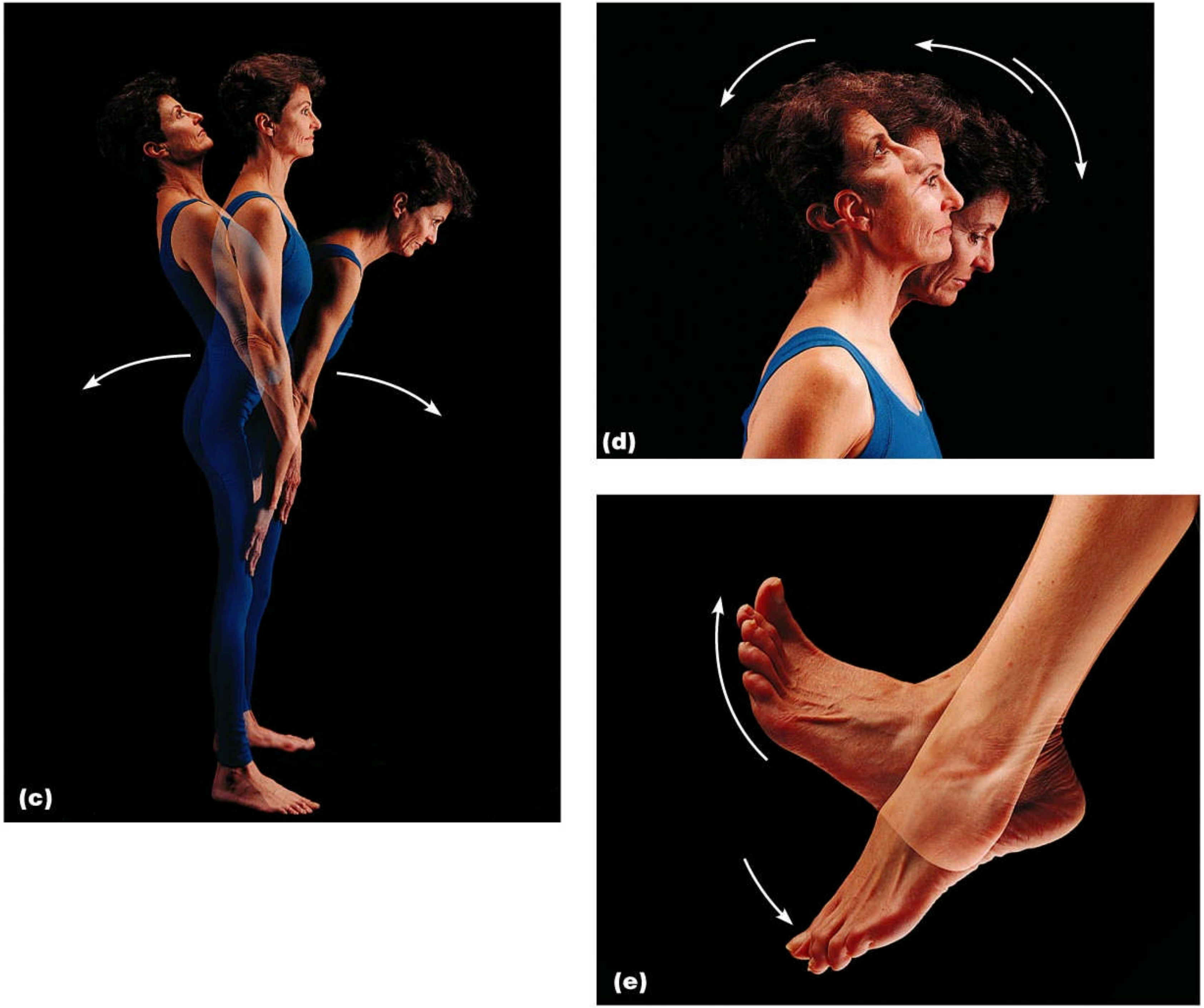
<u>Sartorius muscle</u>

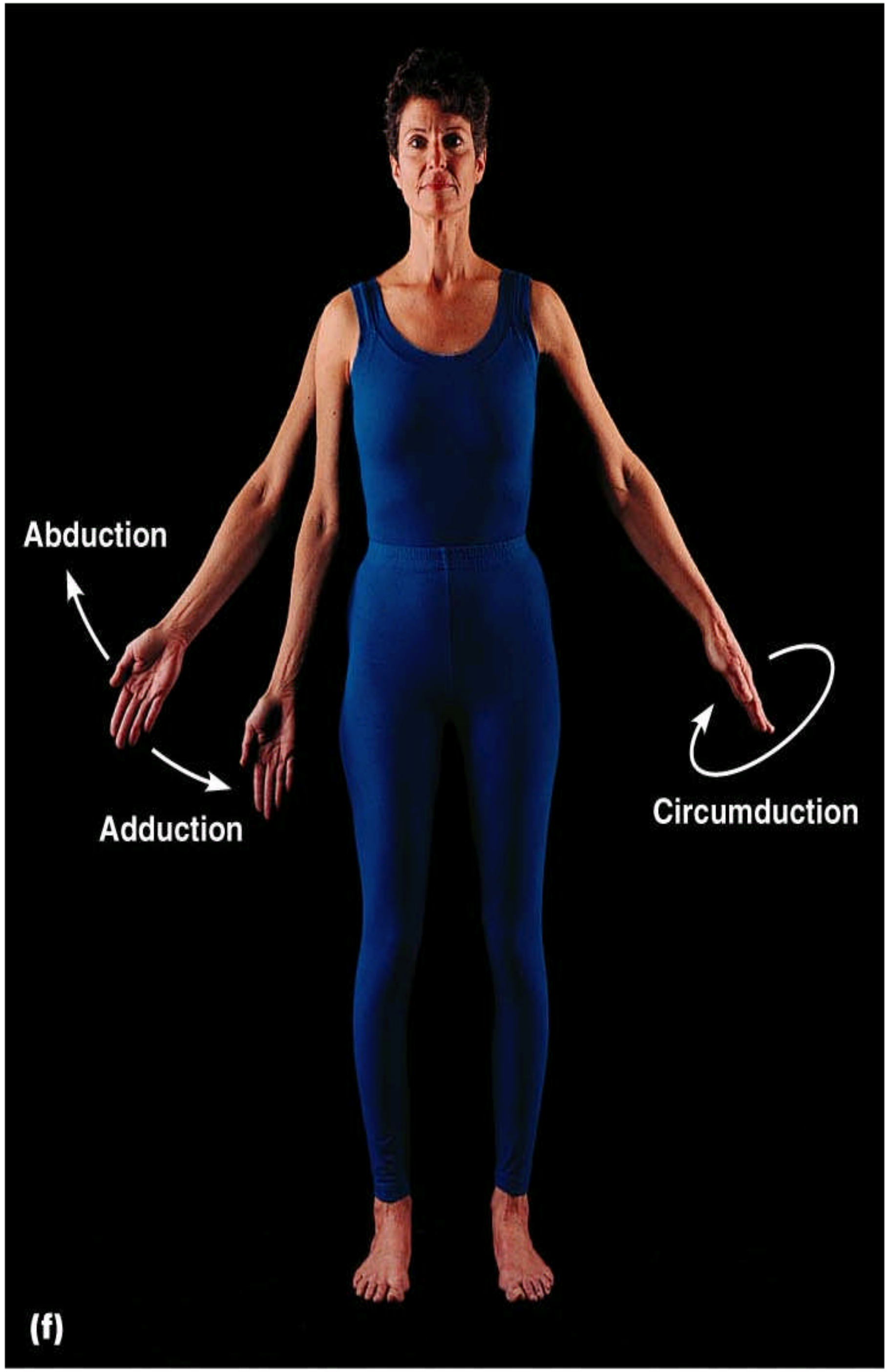
It is the longest muscle in the body. It runs from the anterior superior iliac spine of the hip bone to the medial surface of the shaft of the tibia.

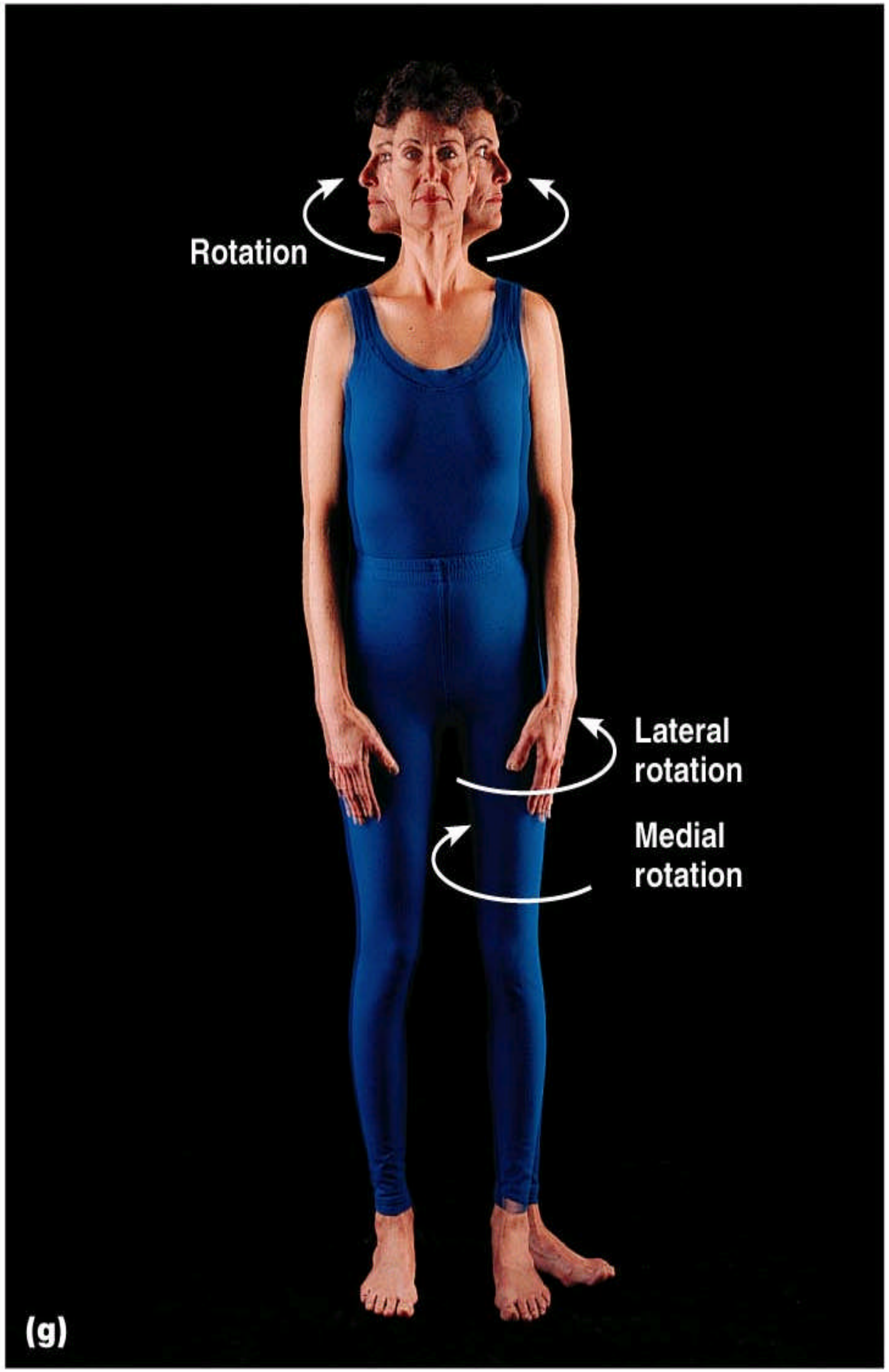


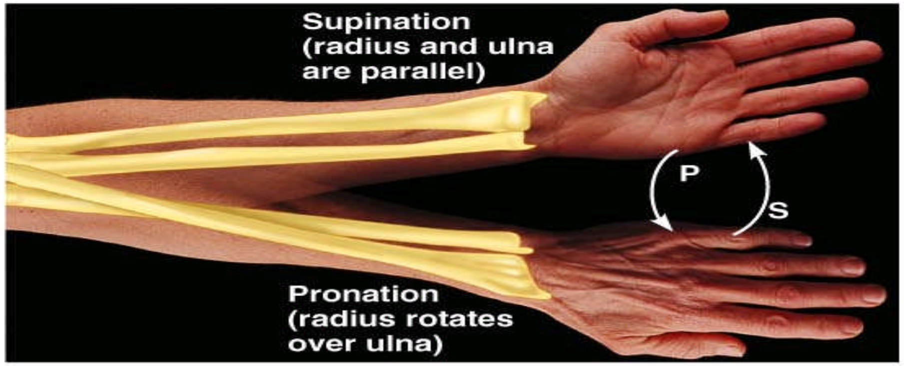

Gliding
(a)
Flexion
Flexion
(b)
Extension
Extension


Hyperextension
Flexion
(c)
Hyperextension
Extension
Flexion
(d)
Dorsiflexion
Plantar flexion
(e)


(c)
(d)
(e)

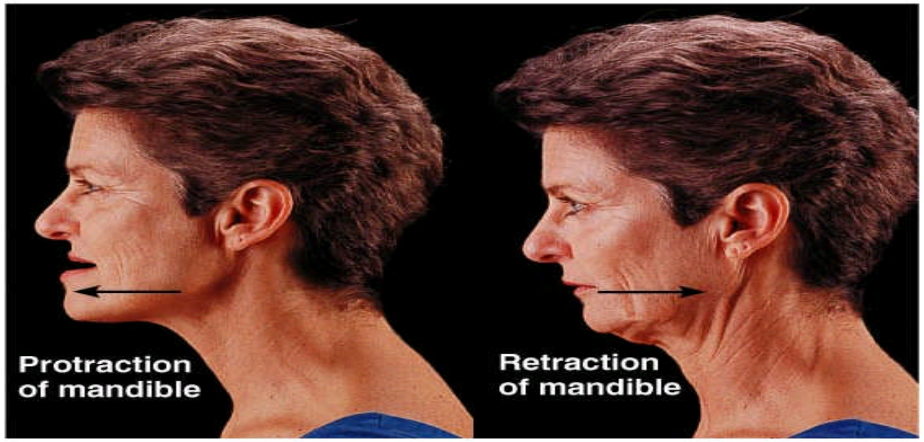

Abduction
Adduction
Circumduction
(f)


Rotation
Lateral rotation
Medial rotation
(g)

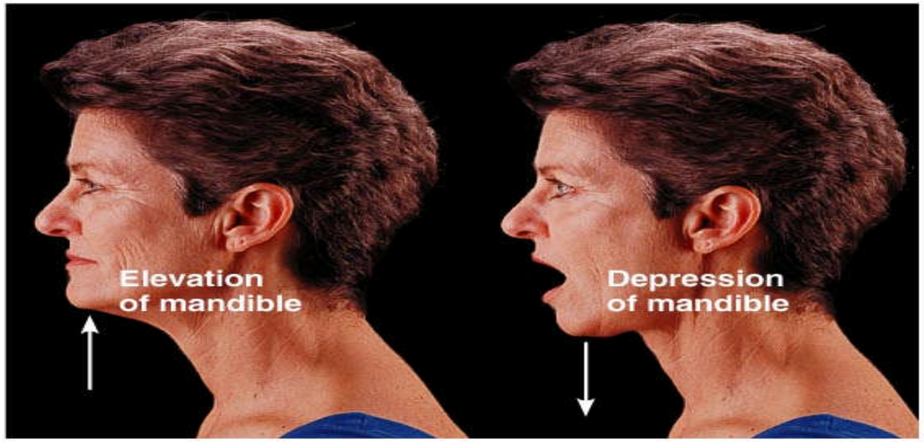


(a) Supination (S) and pronation (P)

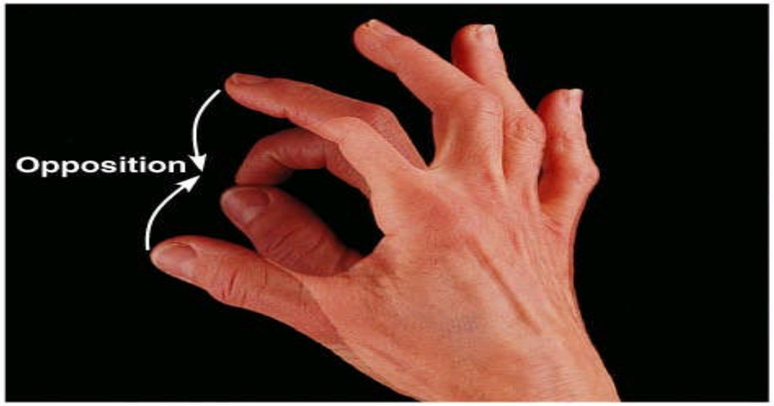
(b) Inversion and eversion



(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

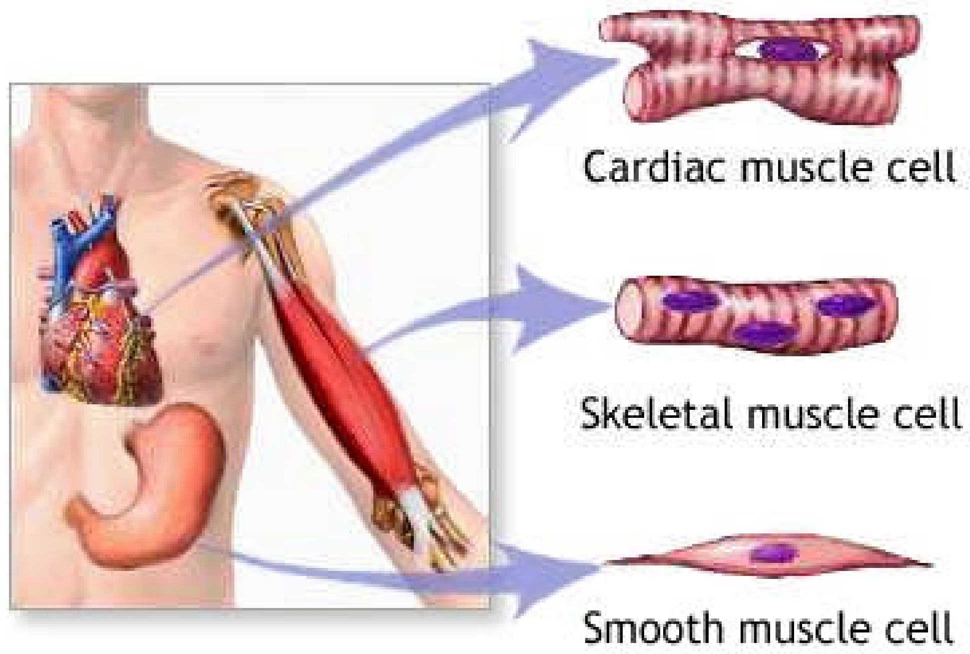
- Muscles keep the tendons that cross the joint nice and taut. This does a wonderful job of maintaining the integrity of the joint.

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

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

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

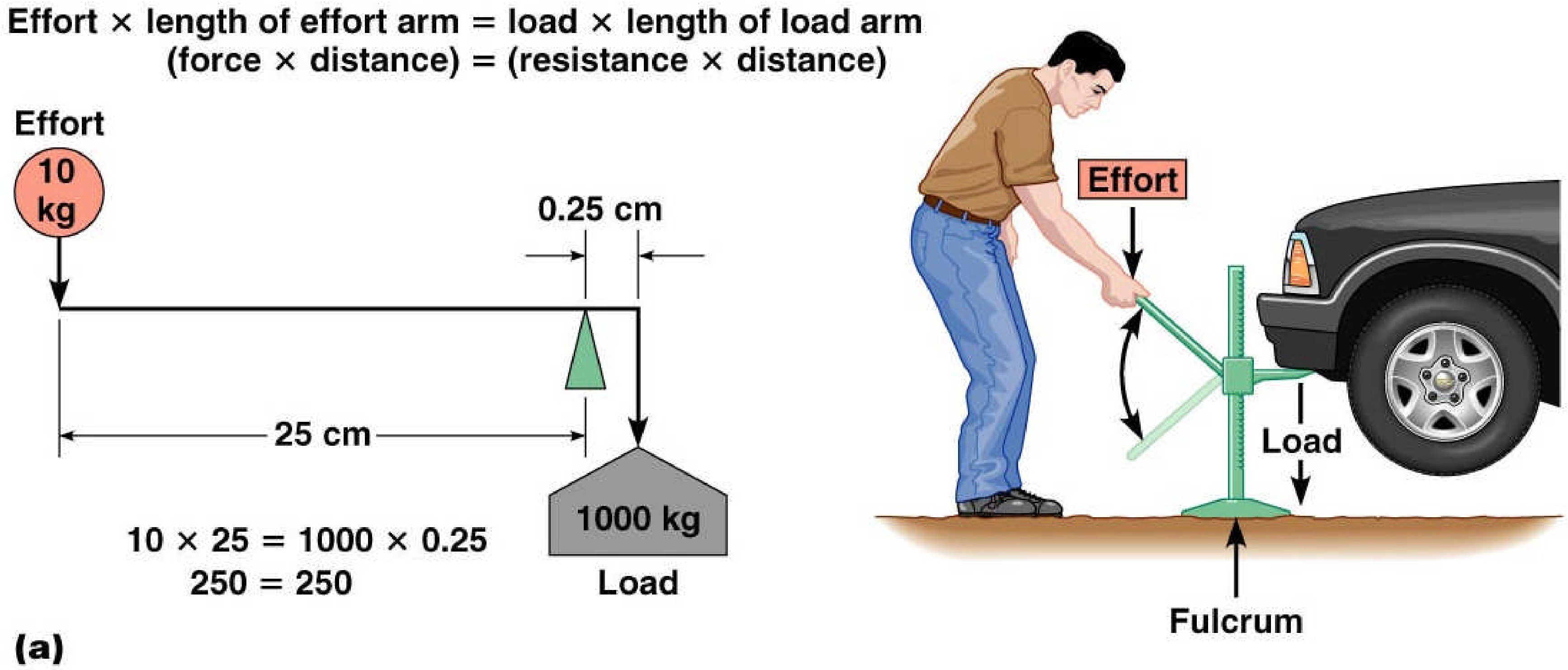


Figure 10.2a

Bone-Muscle Relationships: Lever Systems

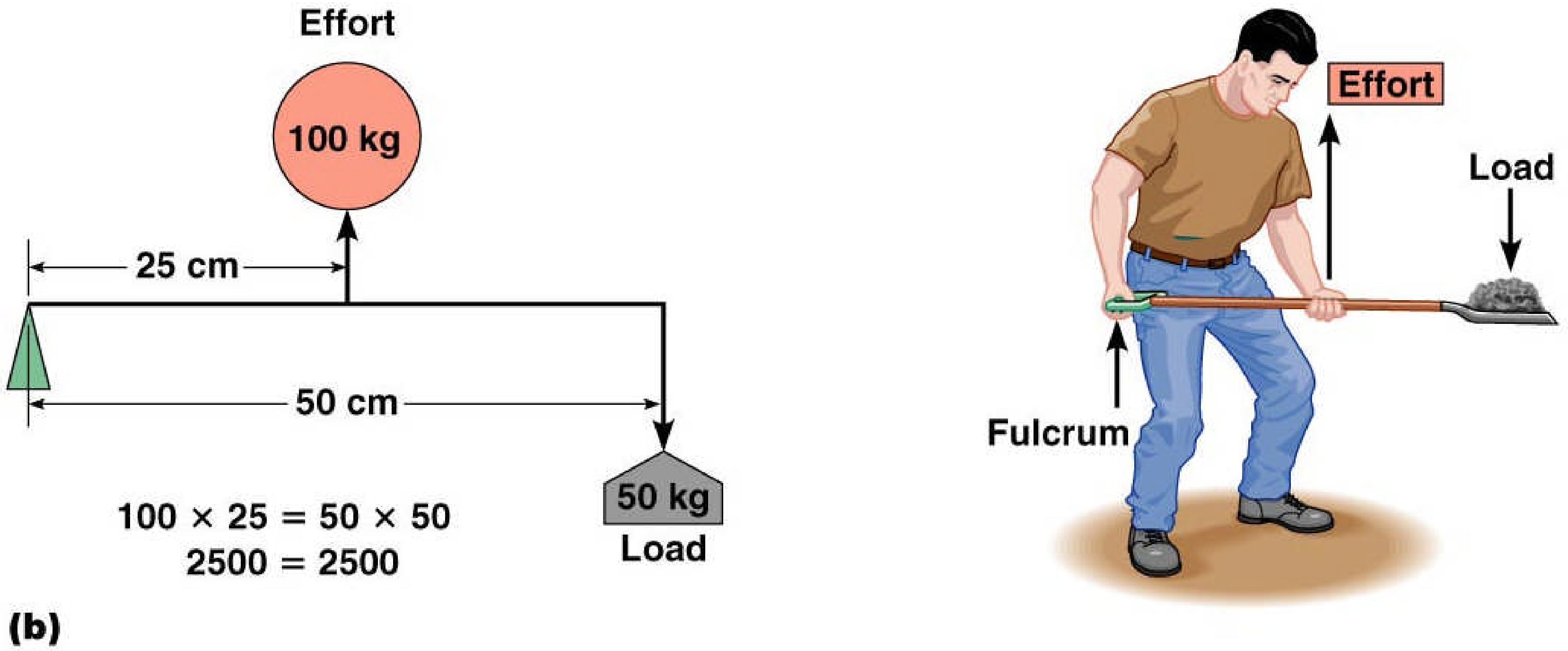
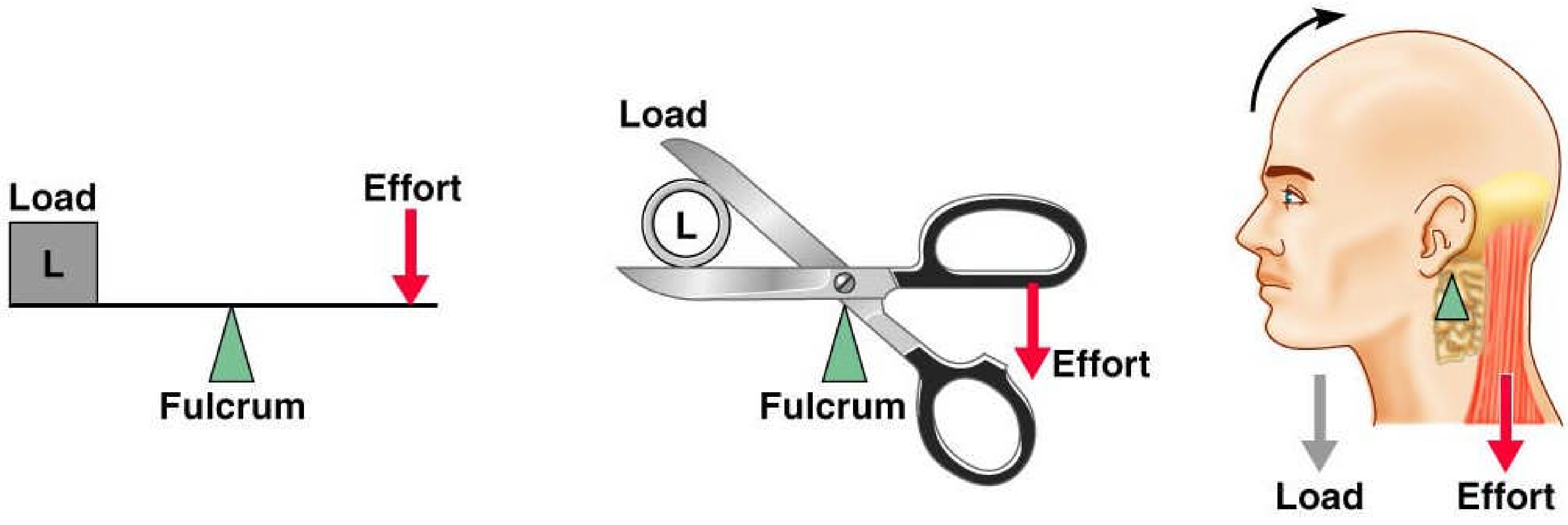


Figure 10.2b

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

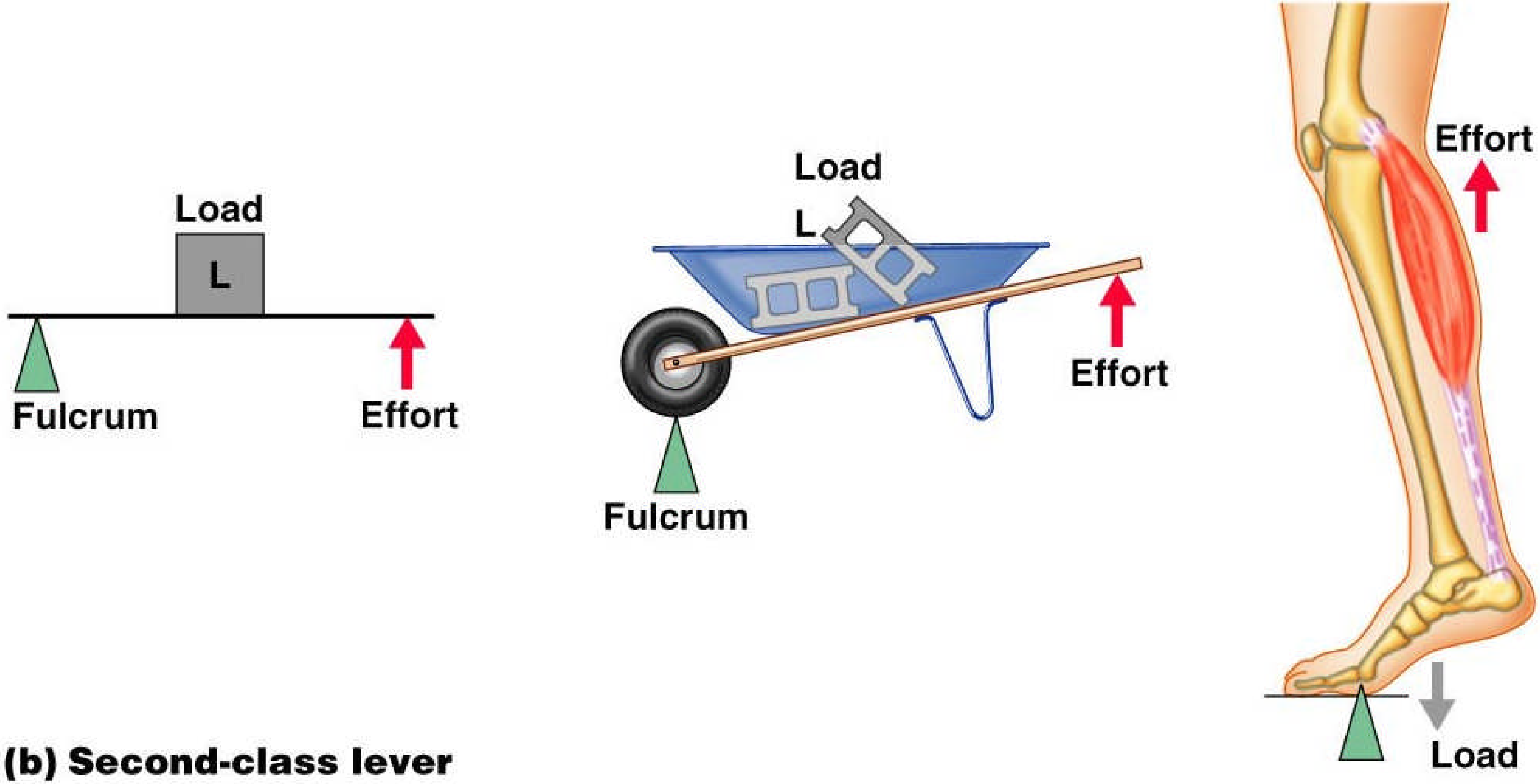
Lever Systems: First Class



(a) First-class lever

Figure 10.3a

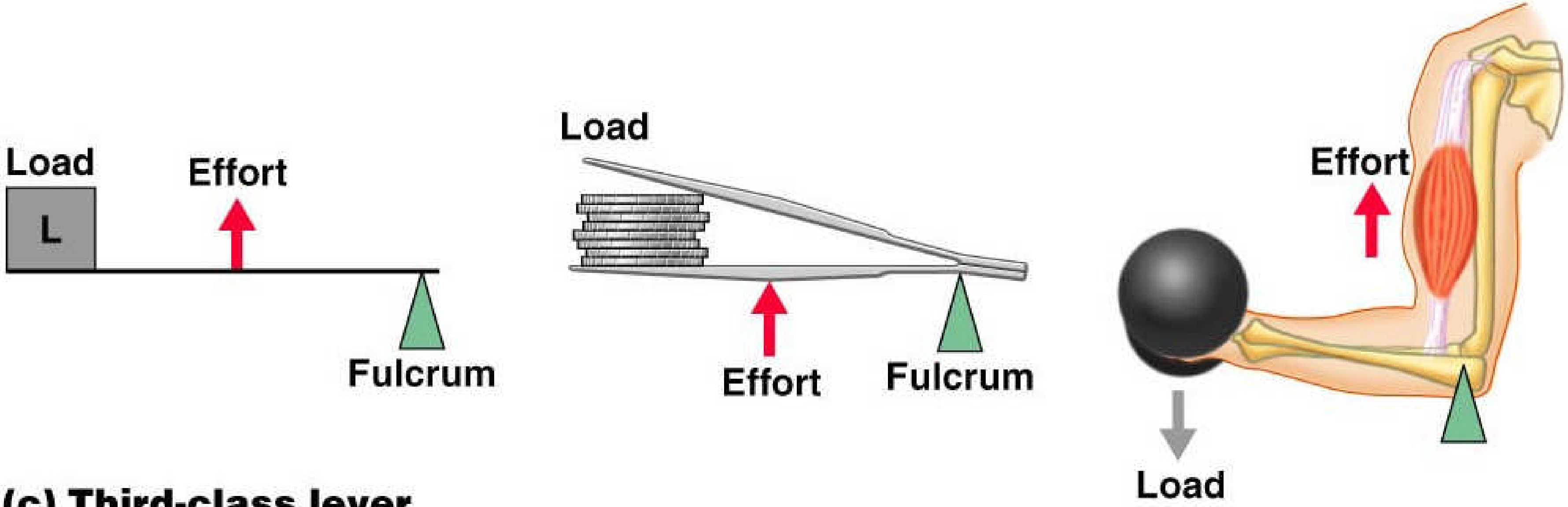
Lever Systems: Second Class



(b) Second-class lever

Figure 10.3b

Lever Systems: Third Class



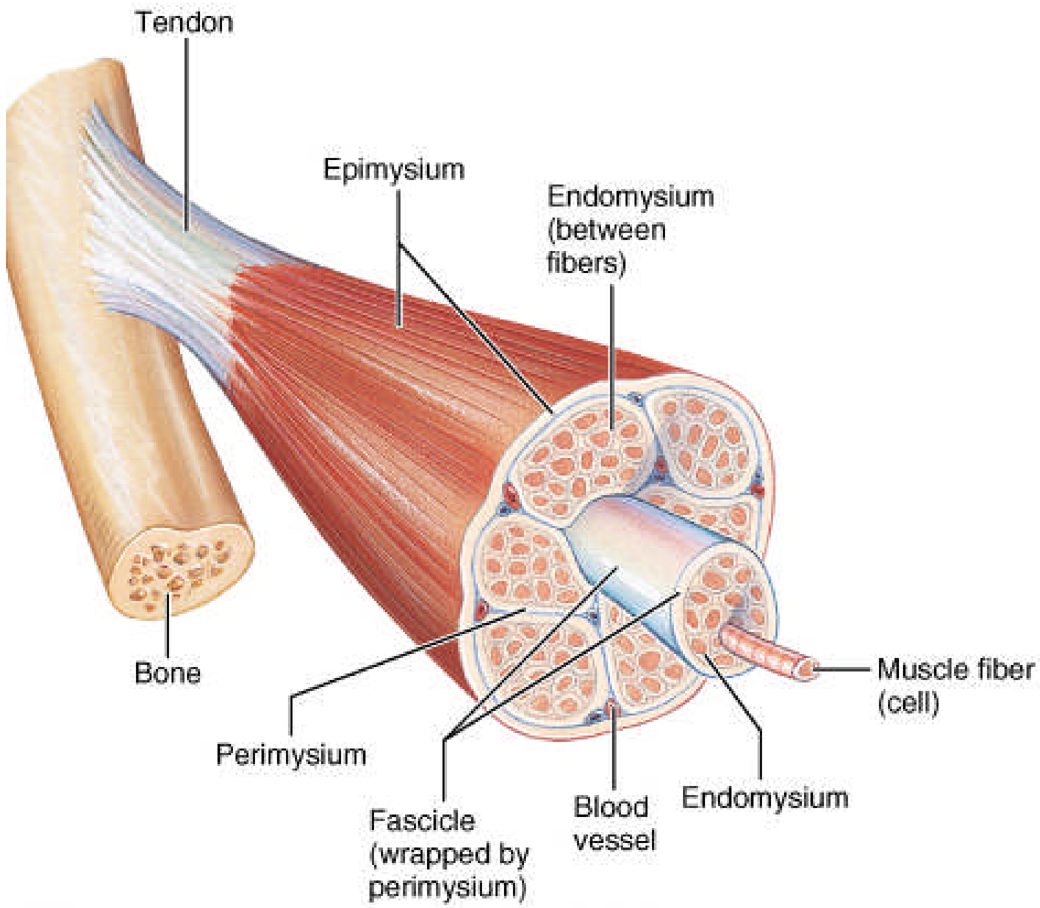
(c) Third-class lever

Figure 10.3c

Muscle Histology

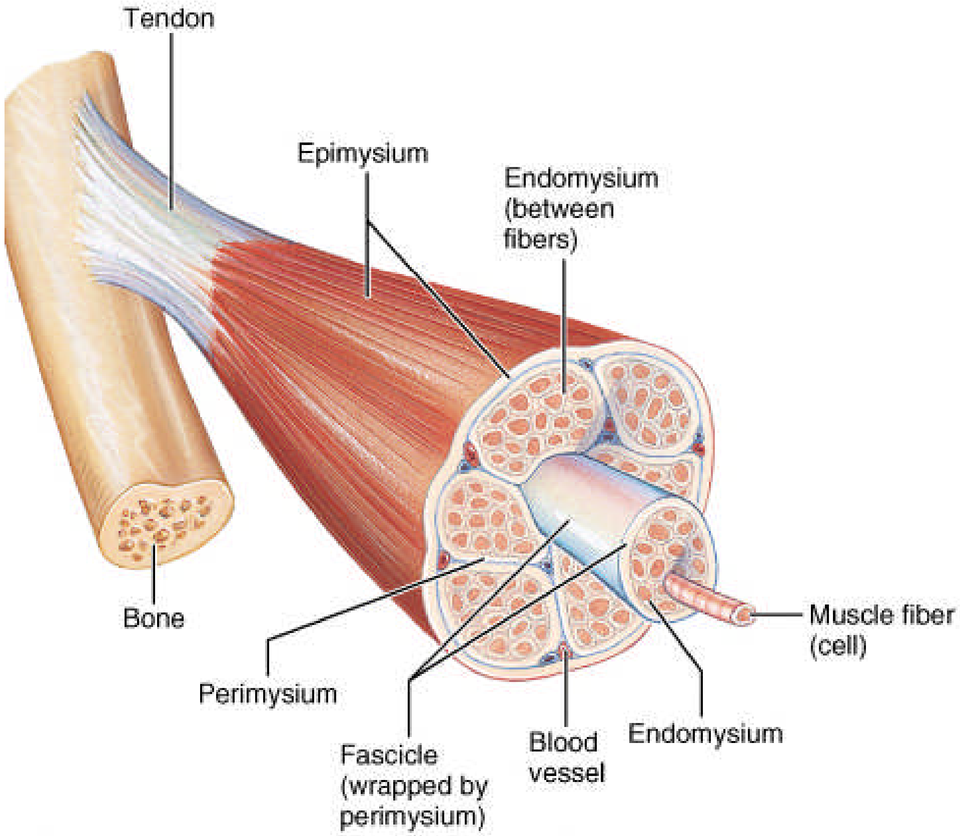
Skeletal Muscle – the organ

- Skeletal muscle organs are dominated by muscle tissue but also contain nervous, vascular and assorted connective tissues.
- The whole muscle is surrounded by a layer of dense irregular connective tissue known as the epimysium.(*epi*= ?, *mysium*=muscle).

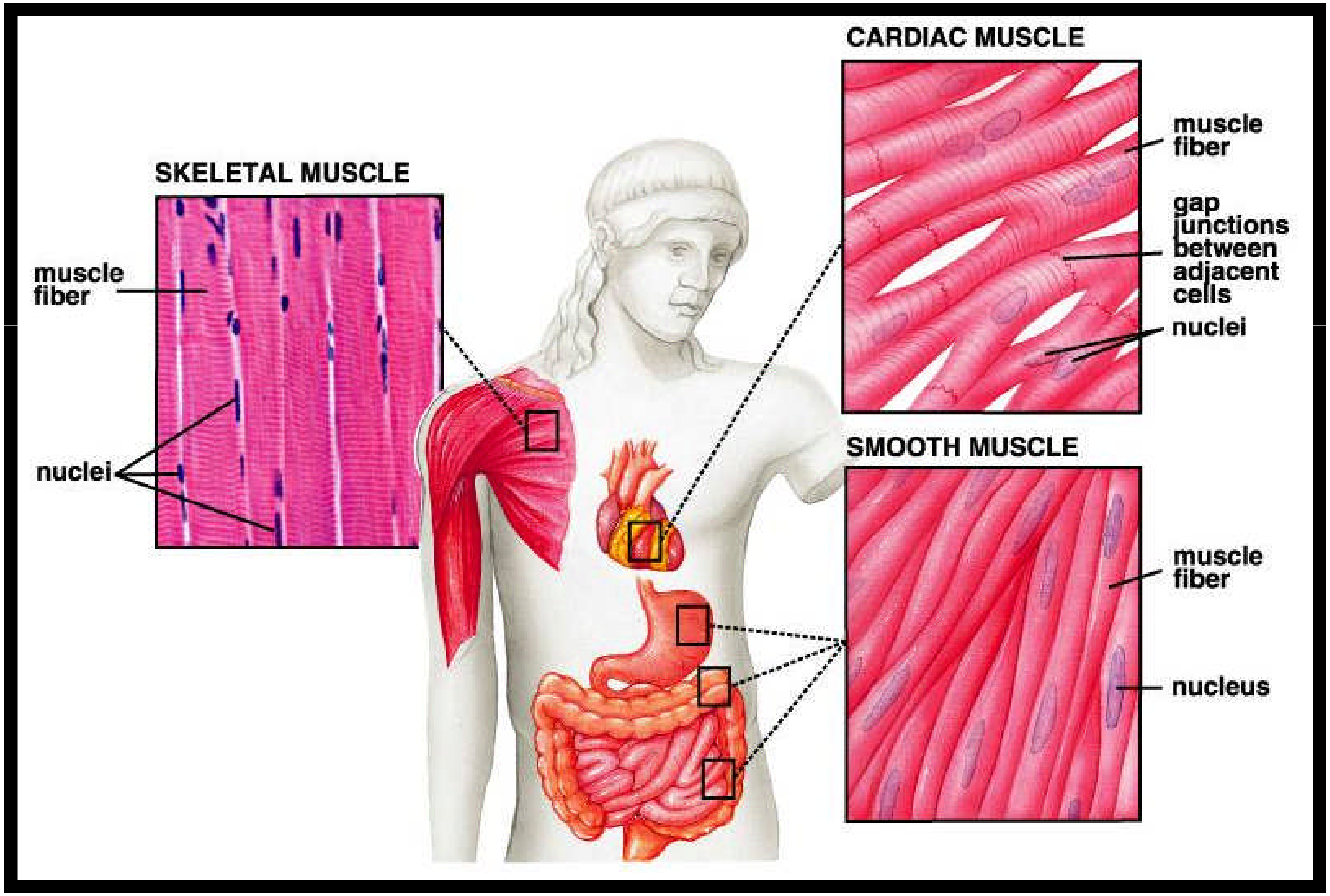


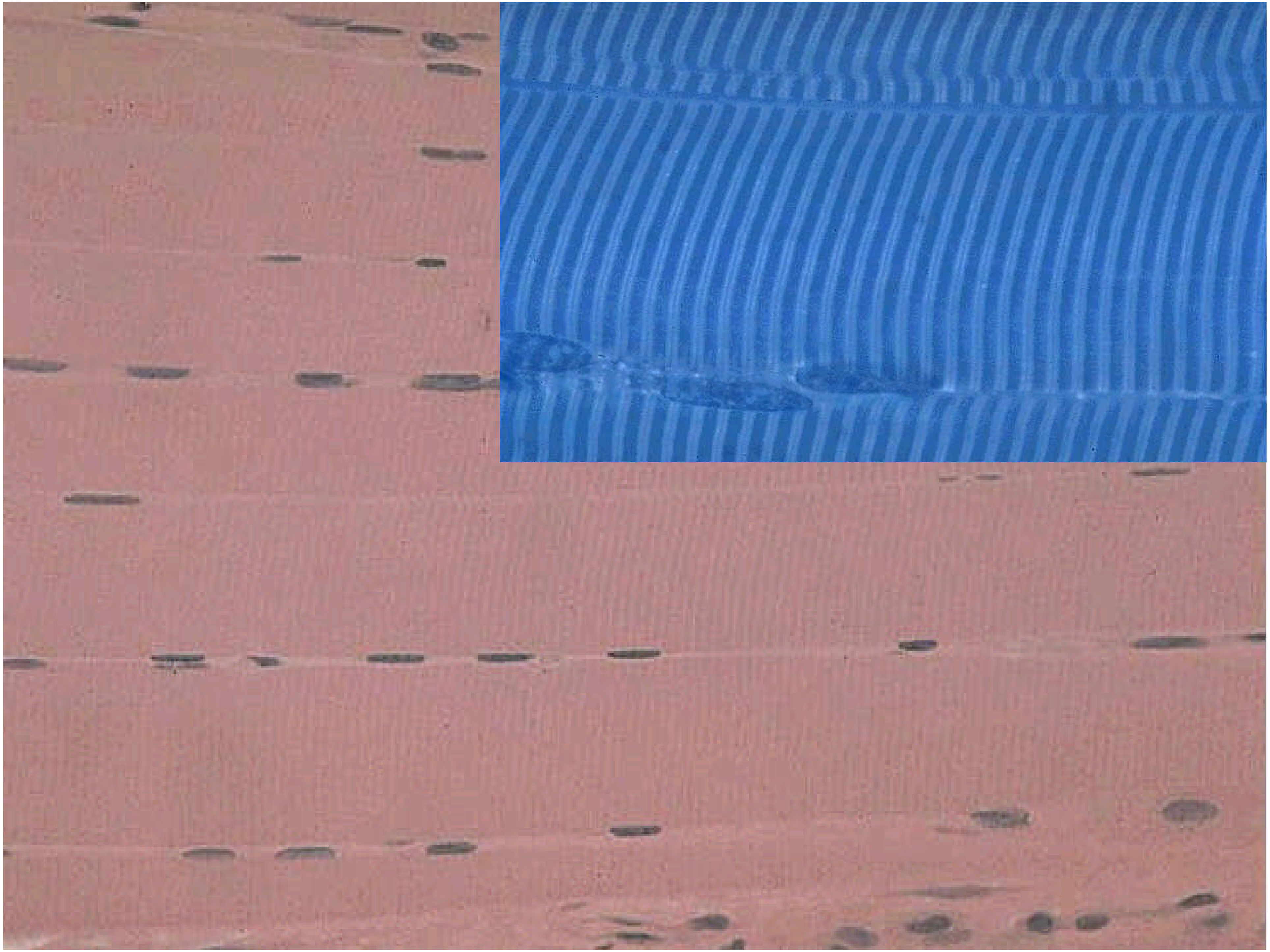
Skeletal Muscle – the organ

- Epimysium surrounds several bundles known as fascicles.
- Each fascicle is a bundle of super-long skeletal muscle cells (muscle fibers), surrounded by a layer of dense irregular CT called the perimysium (*peri*=around).
- Each muscle cell extends the length of the whole muscle organ and is surrounded by a fine layer of loose connective tissue, the endomysium.
- The epi-, peri-, and endomysium are all continuous with one another.



Three Muscle Types





Structure and Organization of Skeletal Muscle

TABLE 9.1 Structure and Organizational Levels of Skeletal Muscle

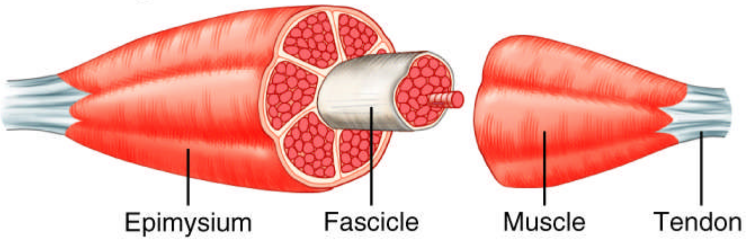
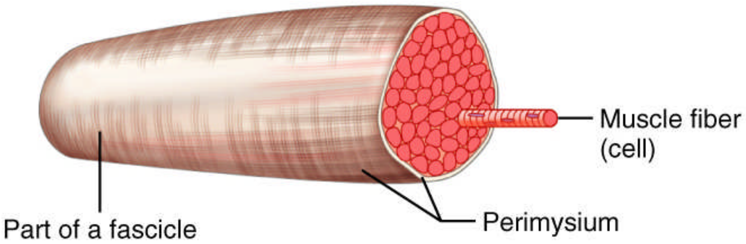
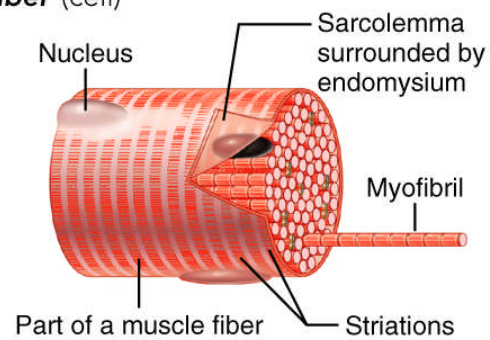
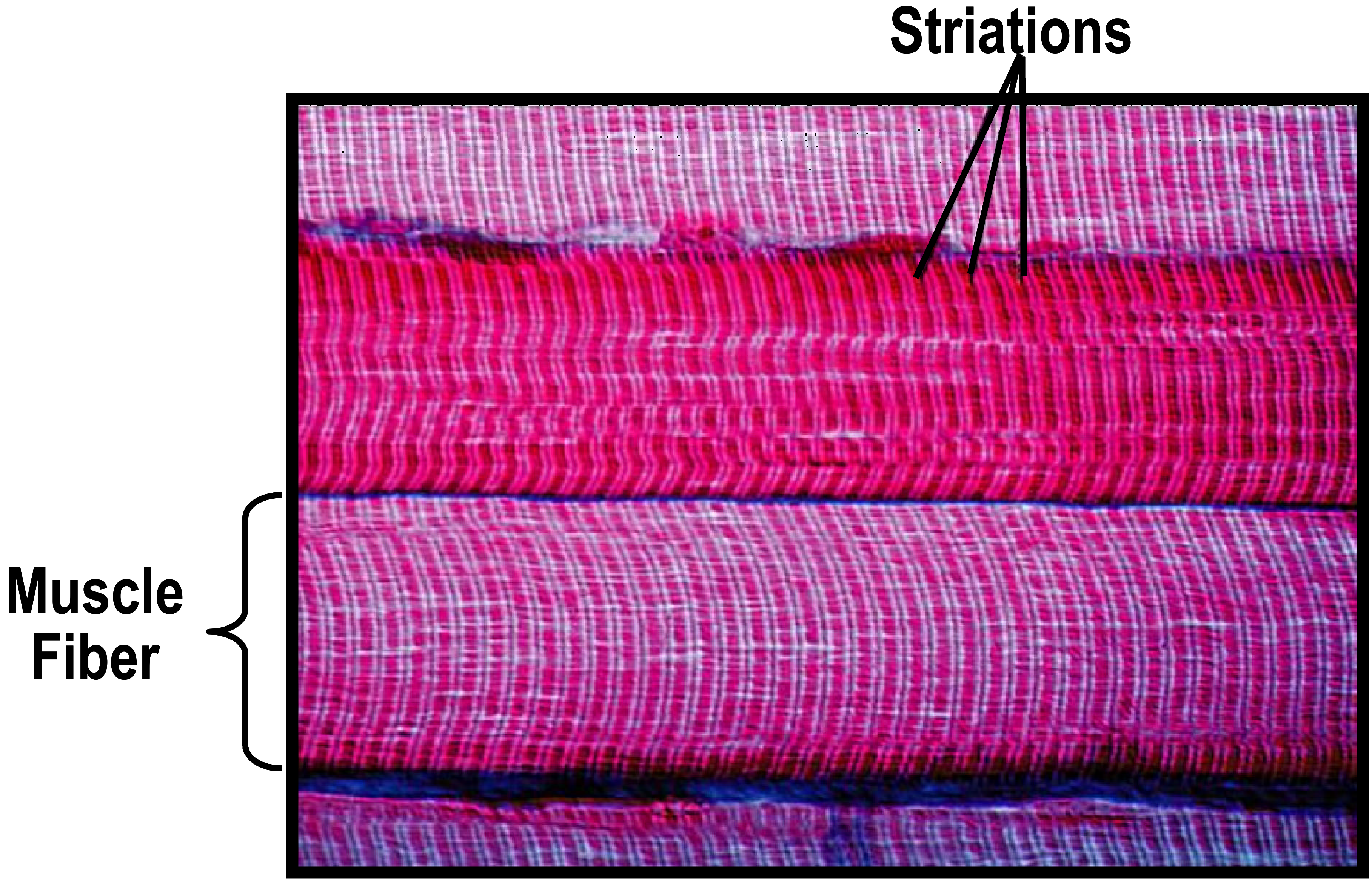
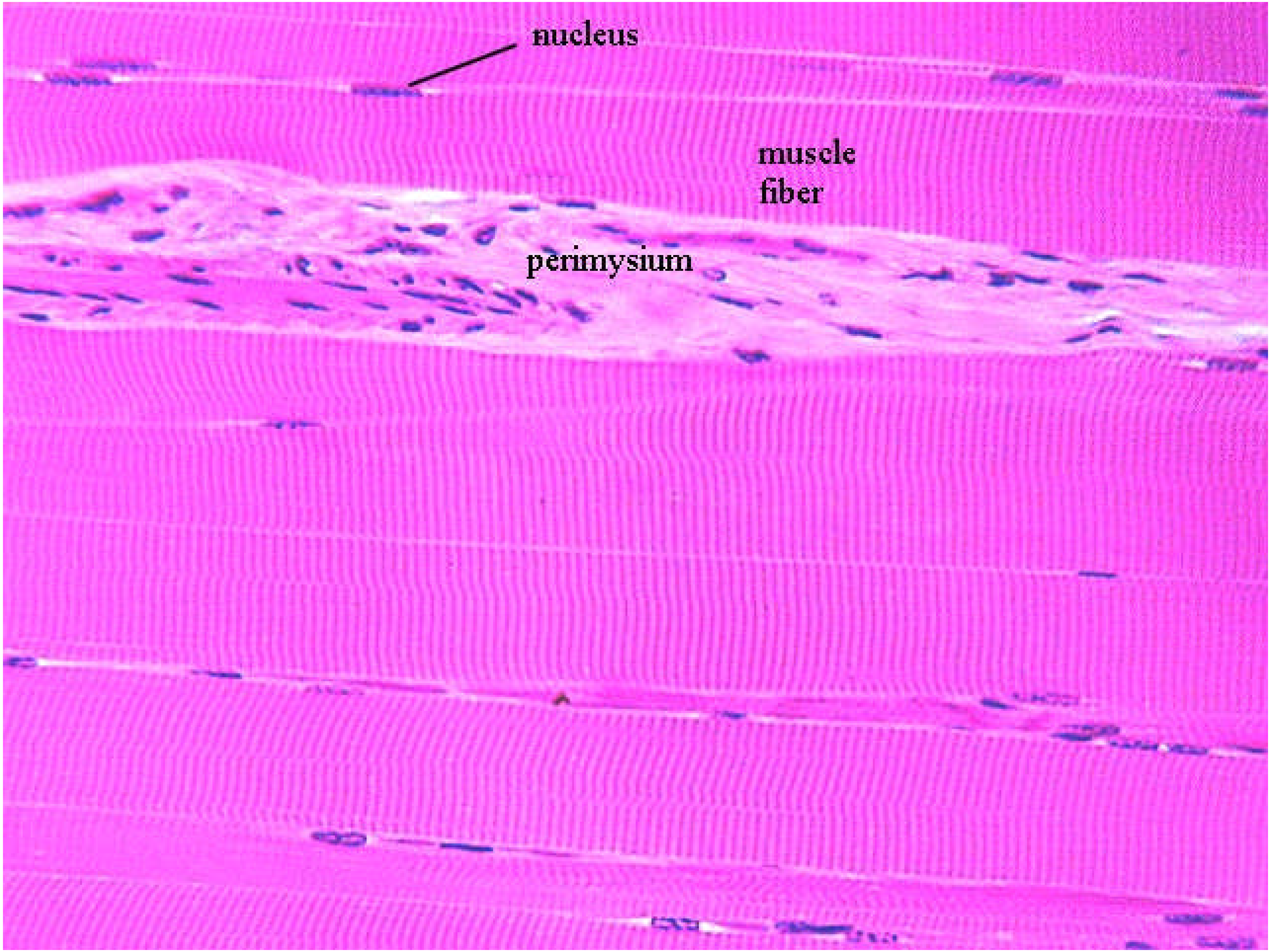
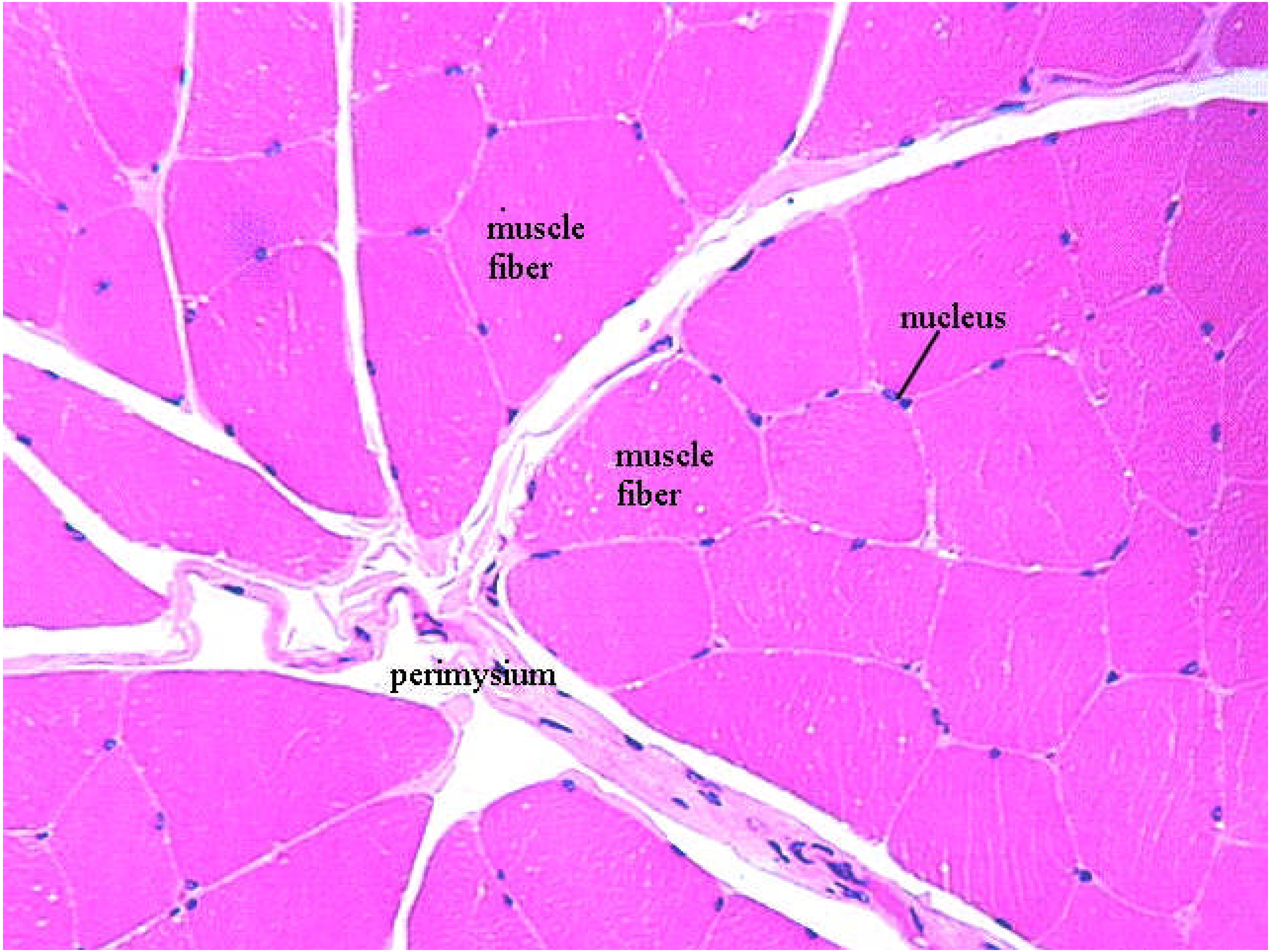
STRUCTURE AND ORGANIZATIONAL LEVEL	DESCRIPTION	CONNECTIVE TISSUE WRAPPINGS
Muscle (organ) 	Consists of hundreds to thousands of muscle cells, plus connective tissue wrappings, blood vessels, and nerve fibers	Covered externally by the epimysium
Fascicle (a portion of the muscle) 	Discrete bundle of muscle 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

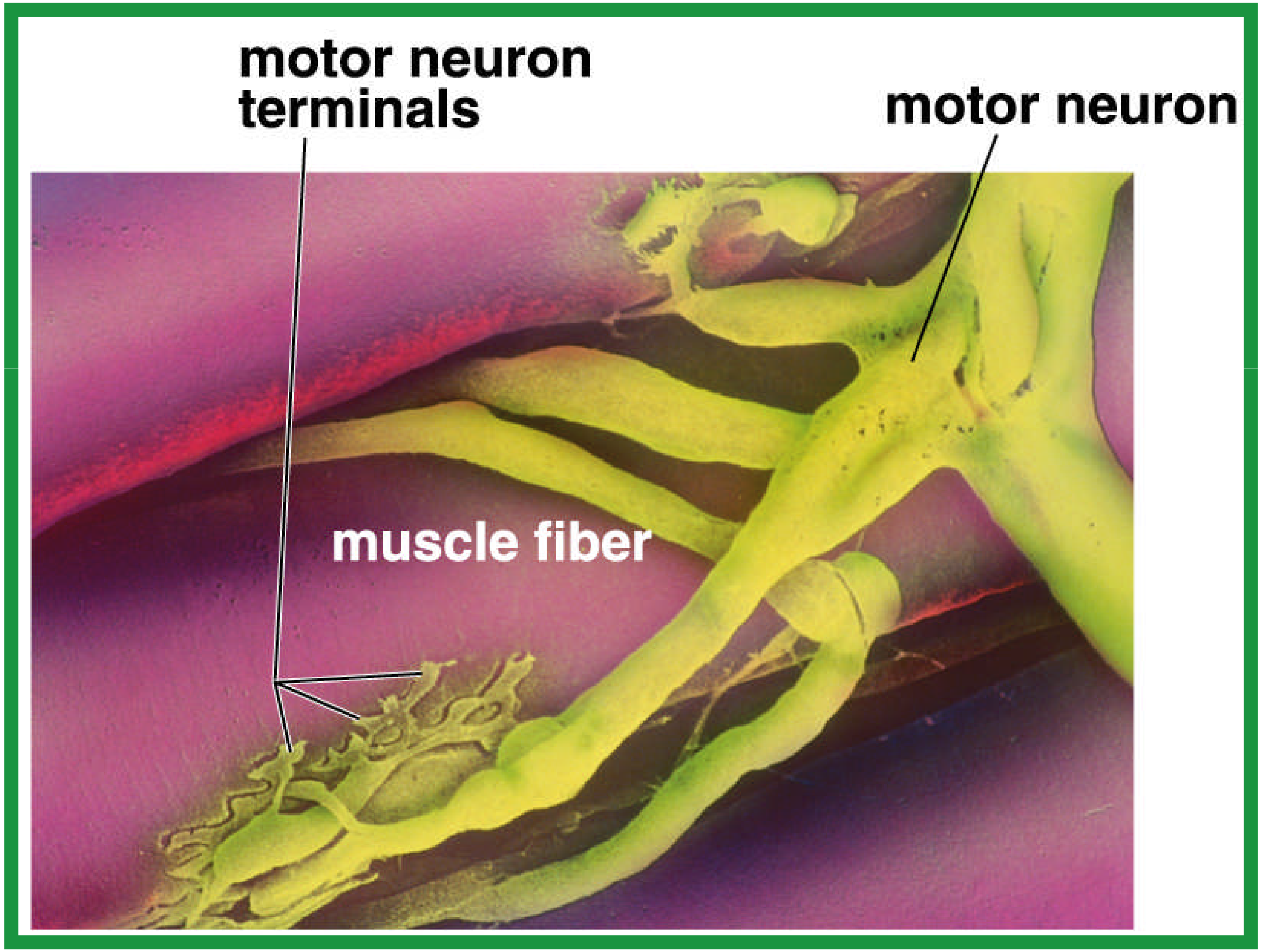
Muscle



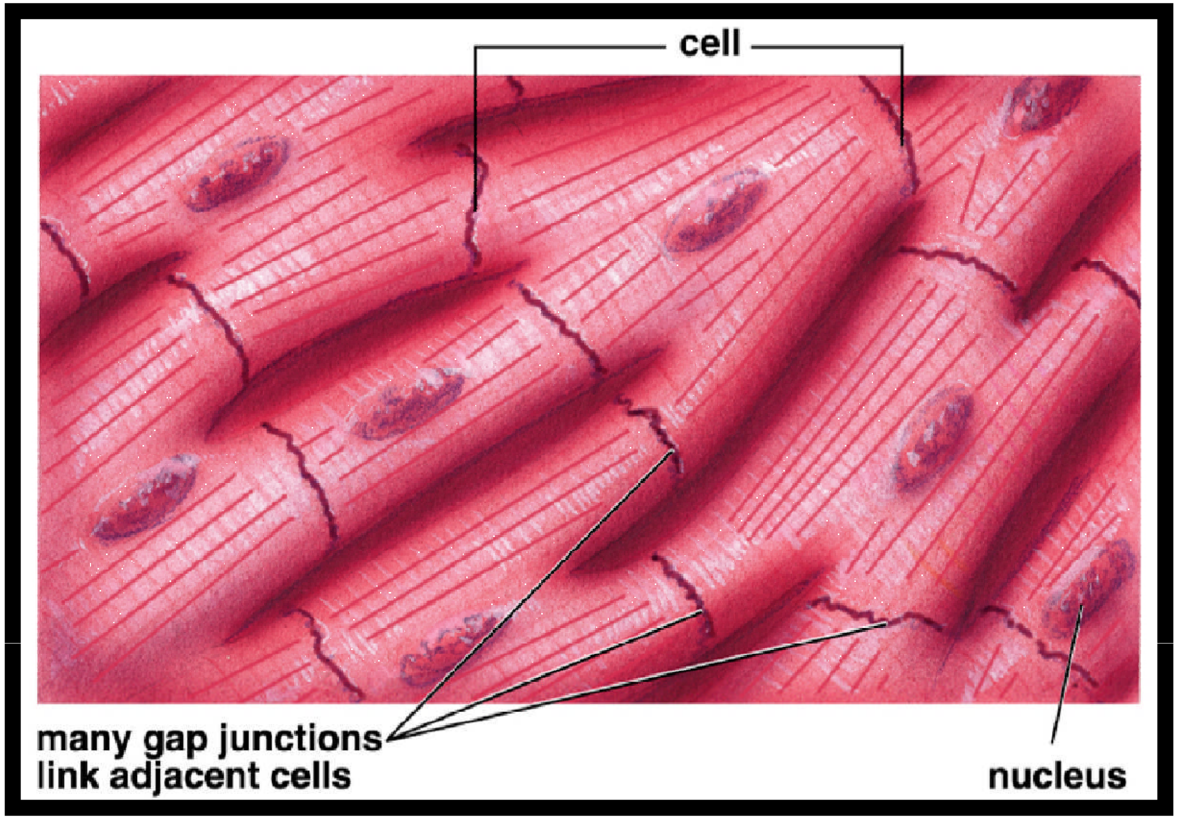

nucleus
muscle fiber
perimysium

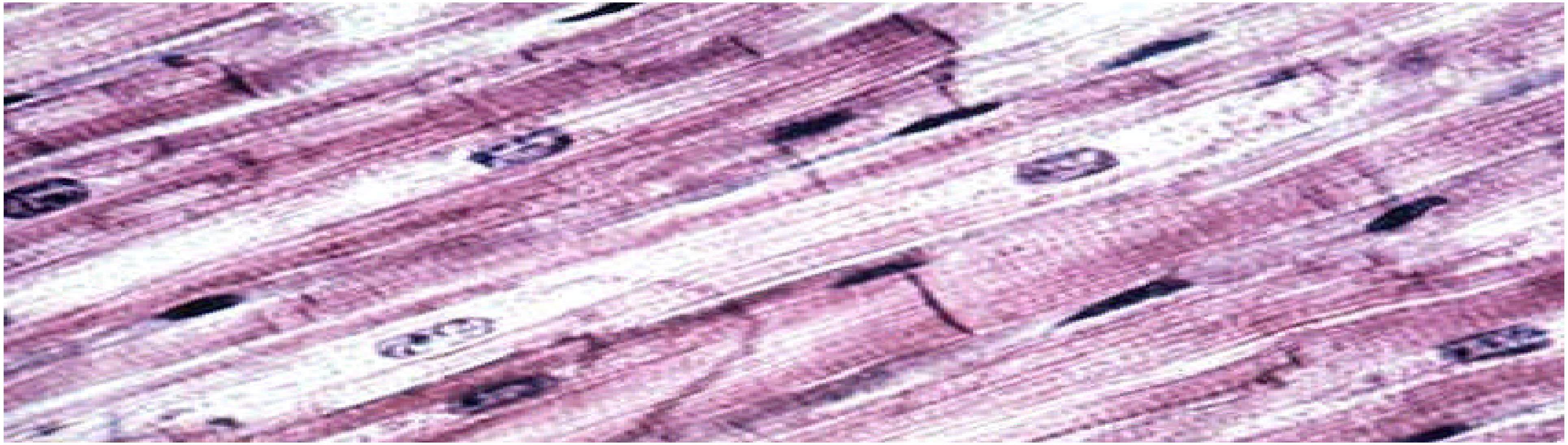

muscle fiber
nucleus
muscle fiber
perimysium

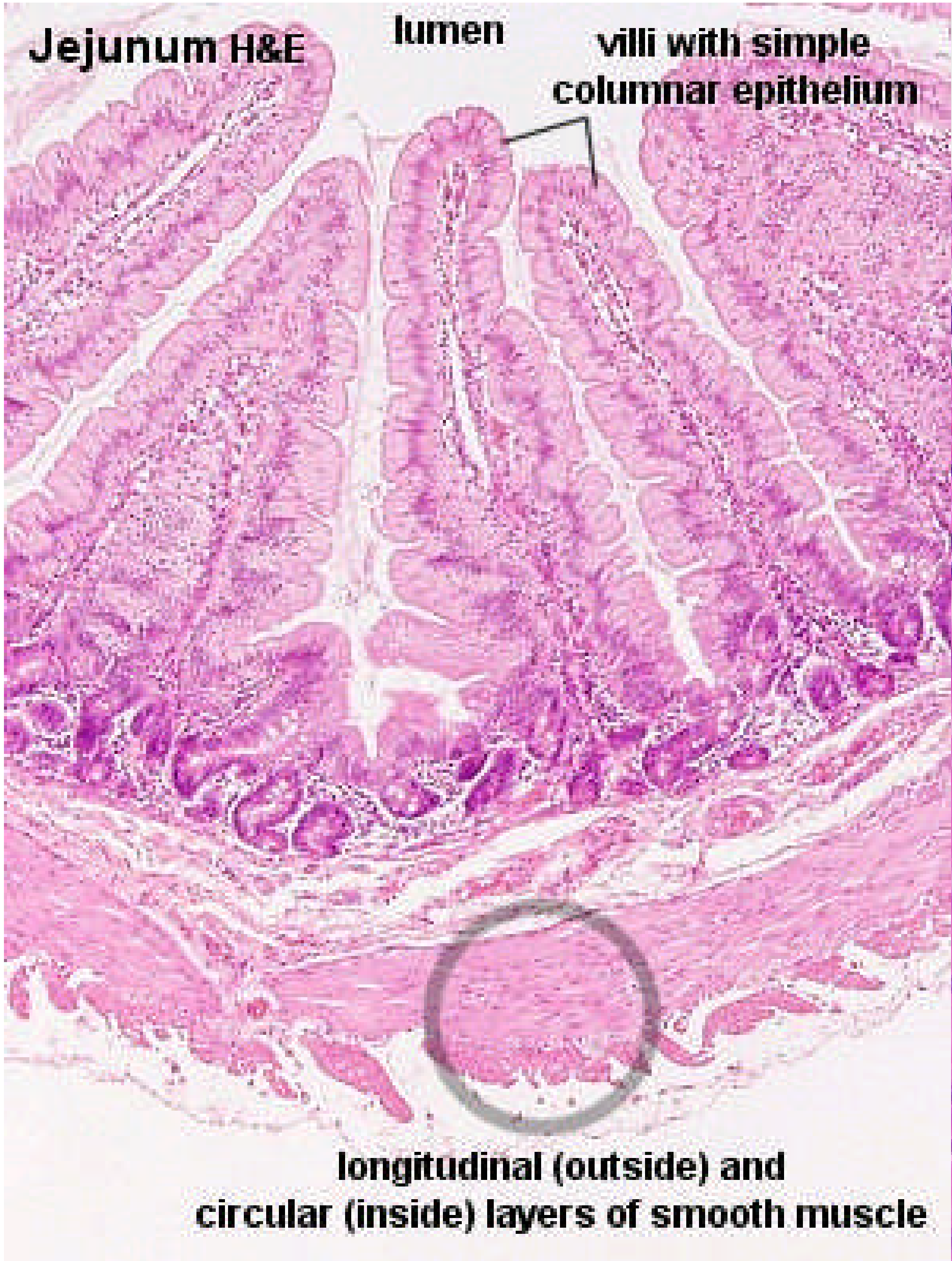
The Neuromuscular Junction

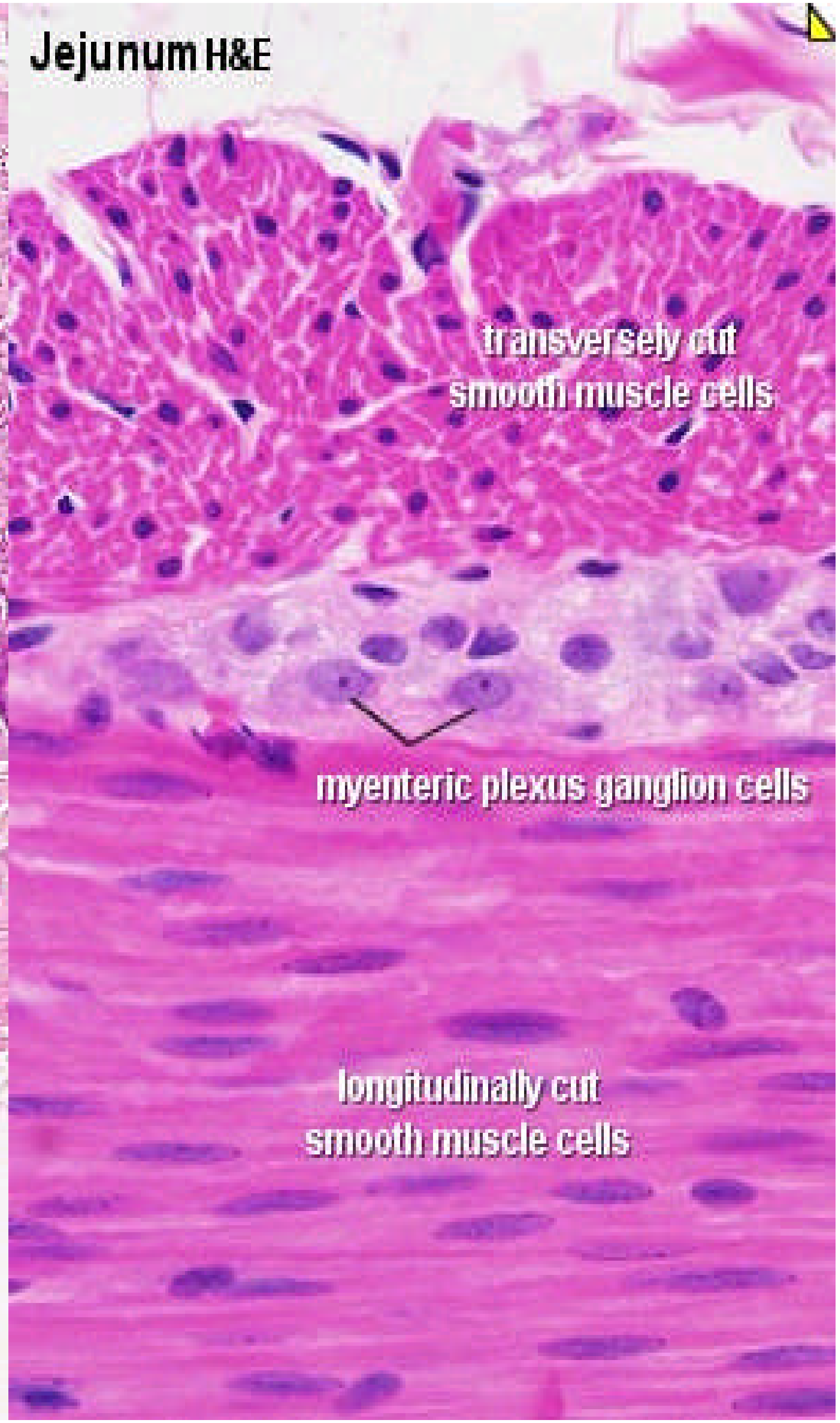


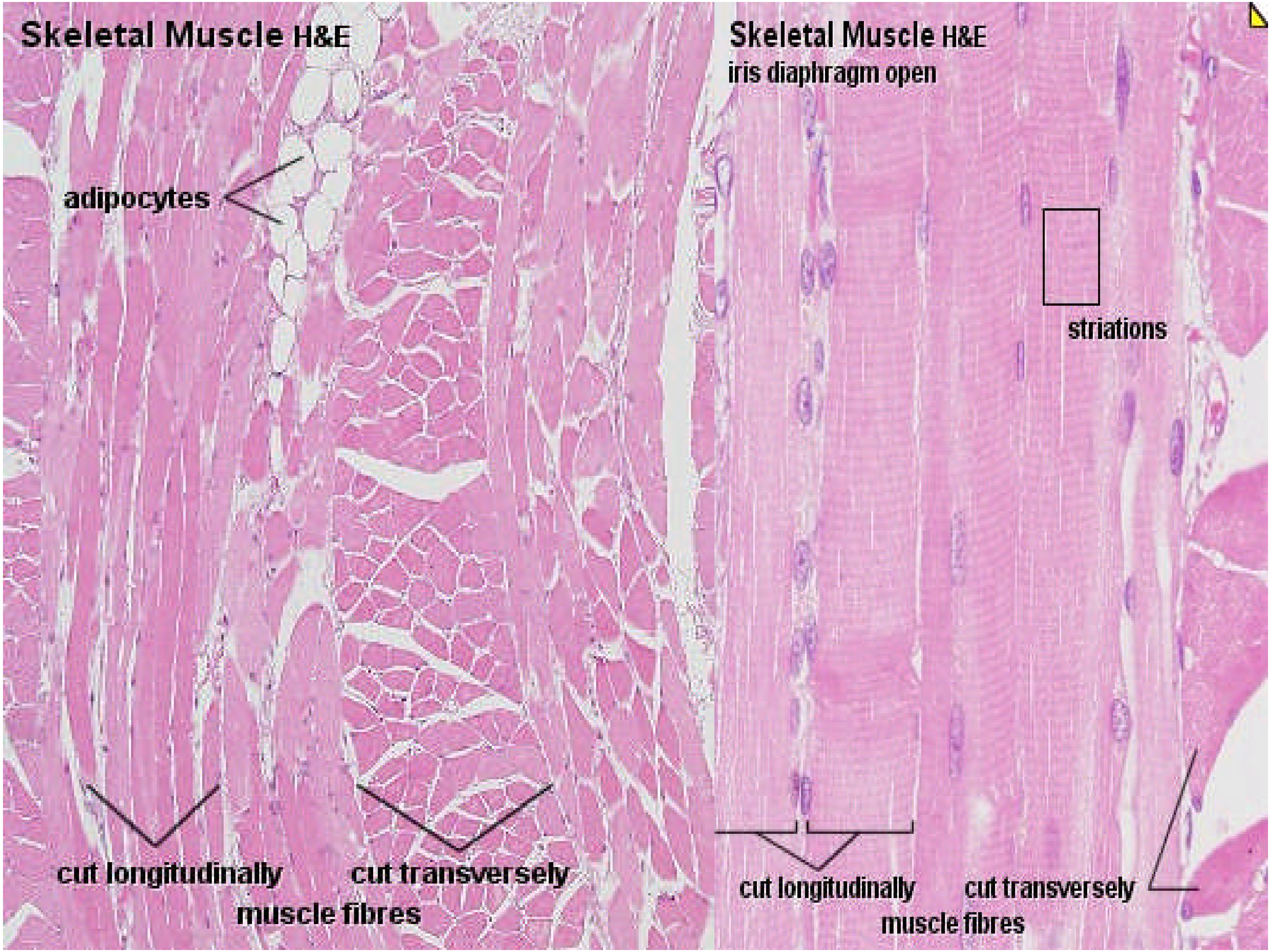
Cardiac Muscle

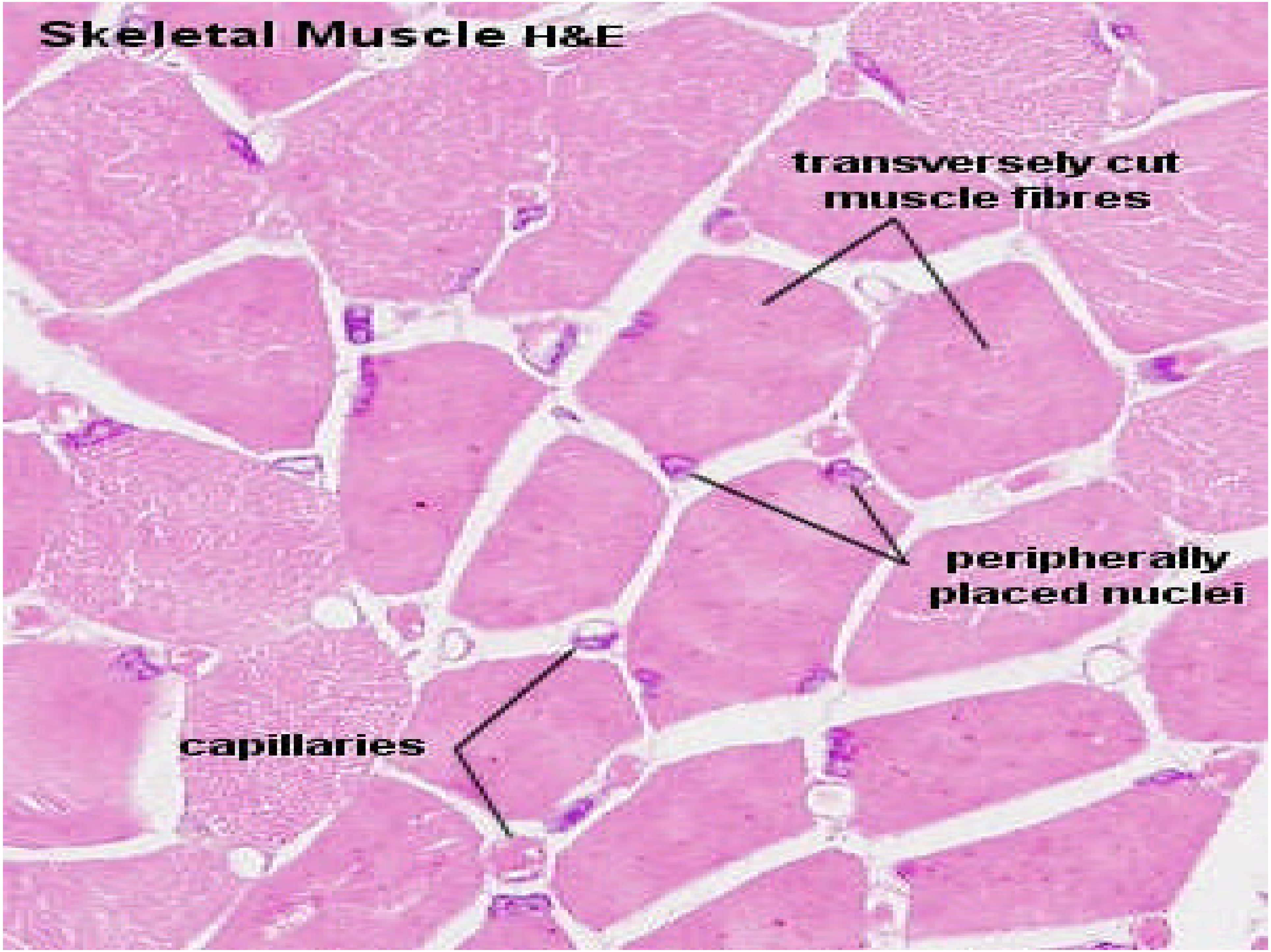


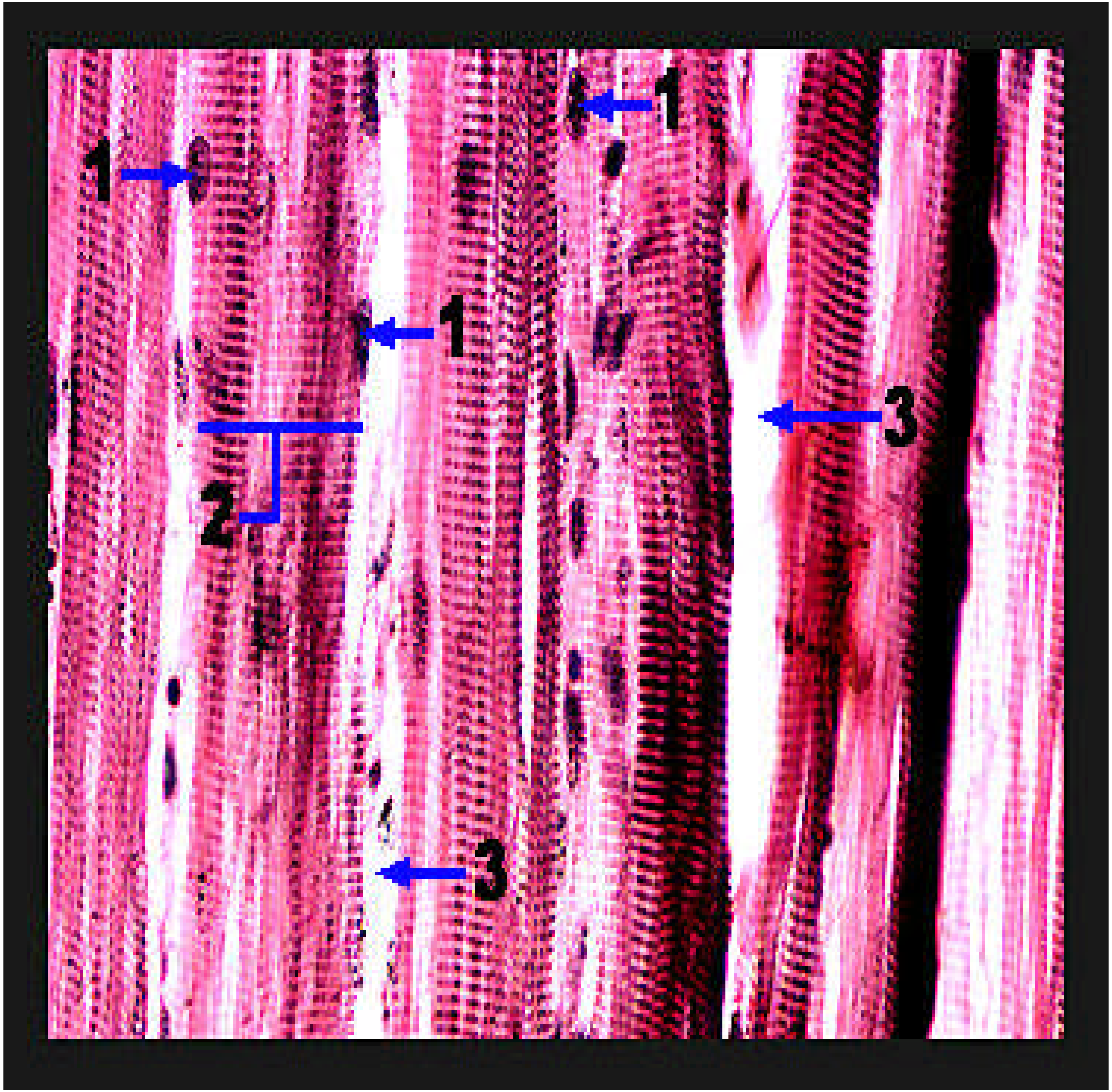



Jejunum H&E
lumen
villi with simple
columnar epithelium
longitudinal (outside) and
circular (inside) layers of smooth muscle


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


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

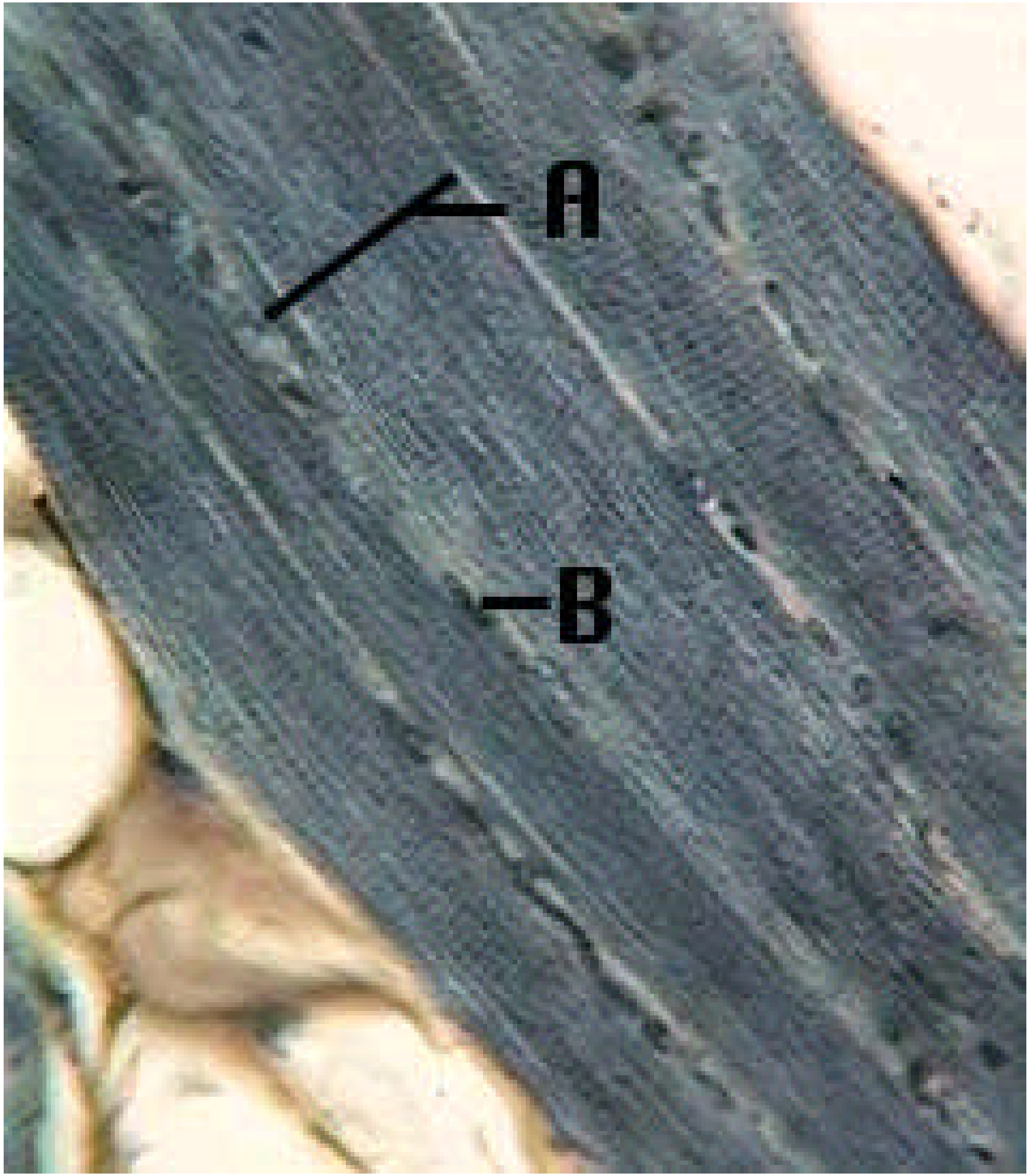

Skeletal Muscle H&E
transversely cut
muscle fibres
peripherally
placed nuclei
capillaries



1. Muscle cell nuclei

2. Muscle fiber (cell)

3. Endomysium

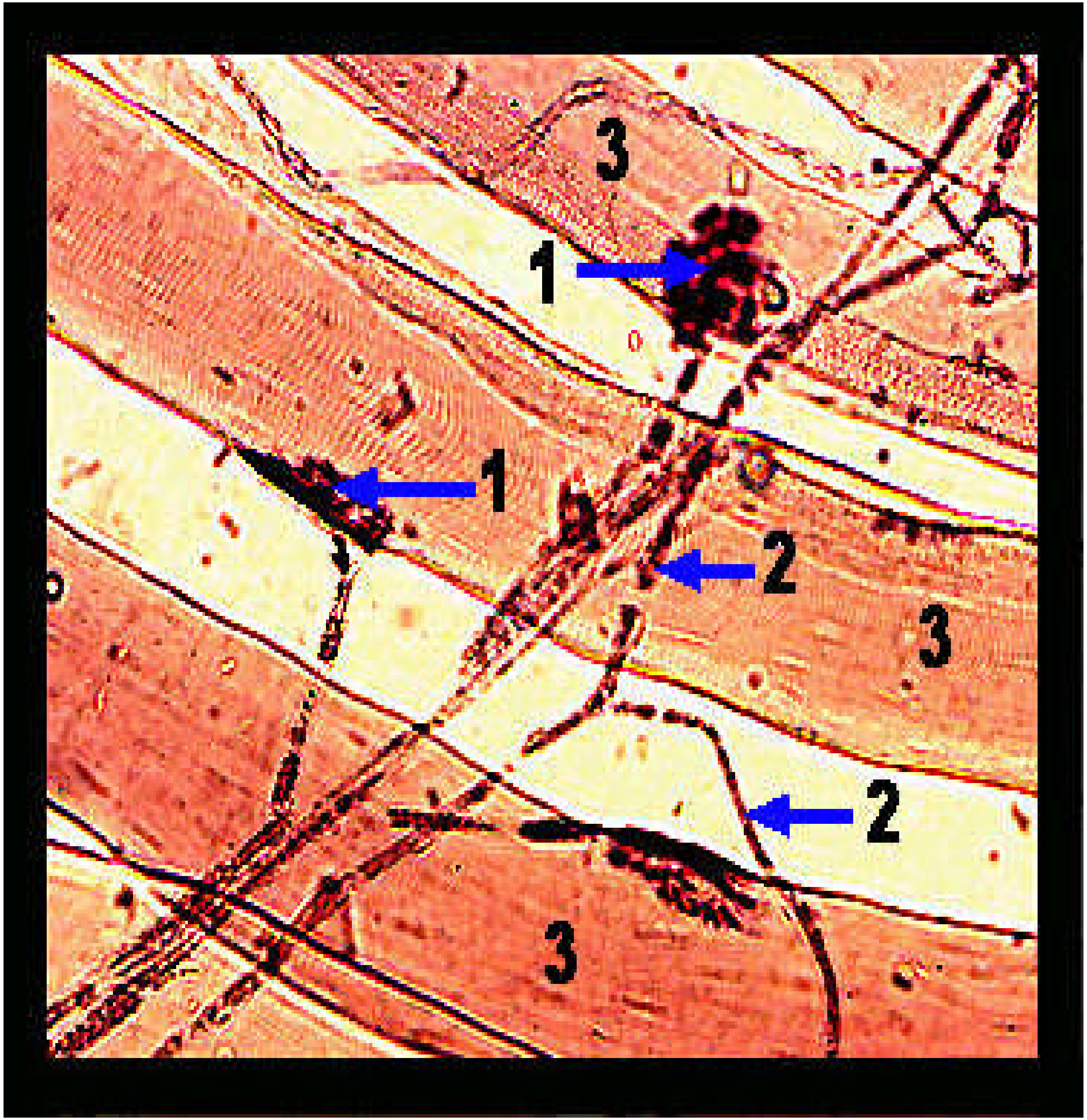


Skeletal muscle cells run the full length of a muscle.
Line A show the width of one cell (fiber). Note the striations characteristics of this muscle type.

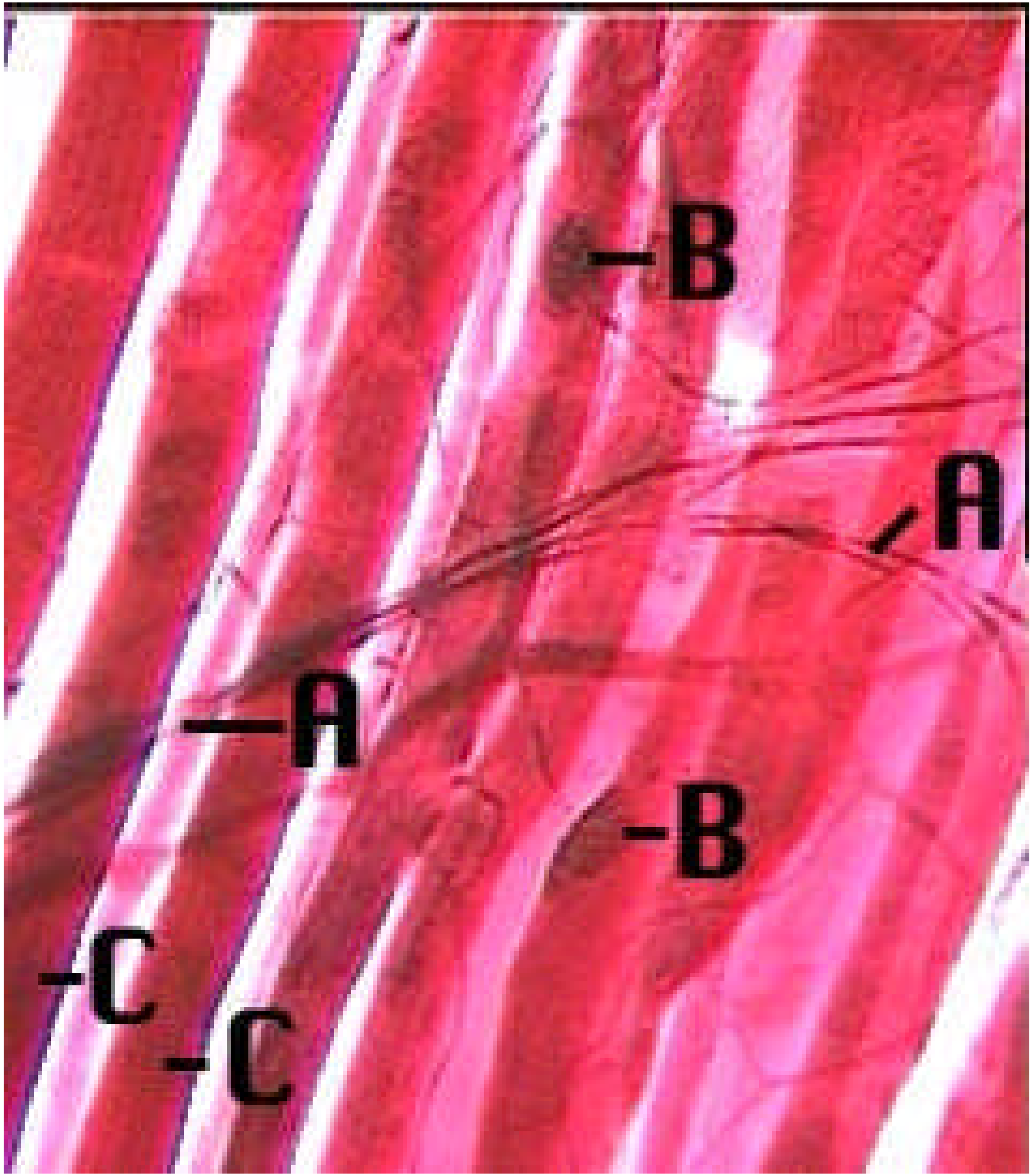
These cells are multicellular, B marks one nucleus.

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.

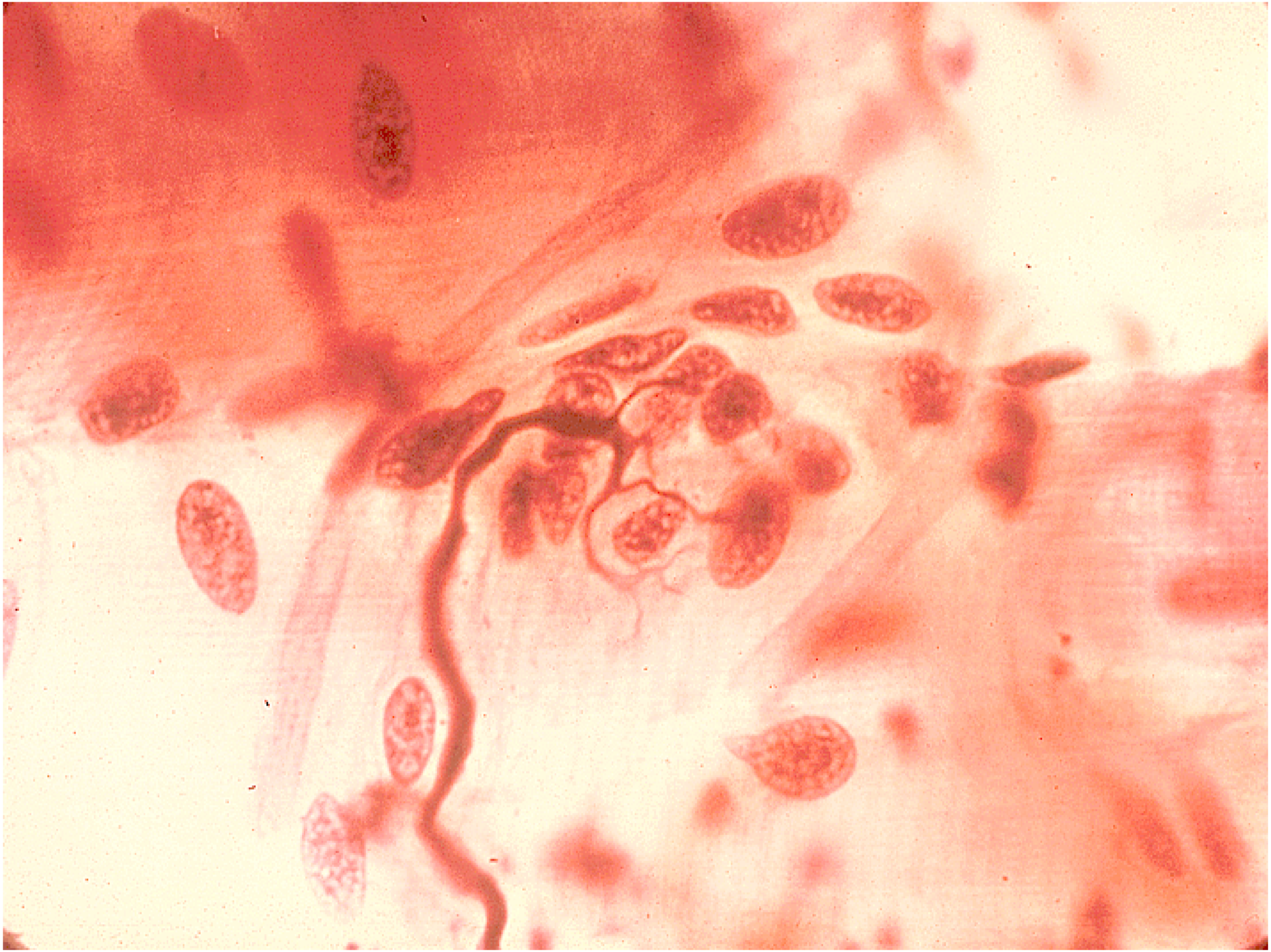


1. Motor end plates
2. Terminal axon fibers
3. Skeletal muscle fibers

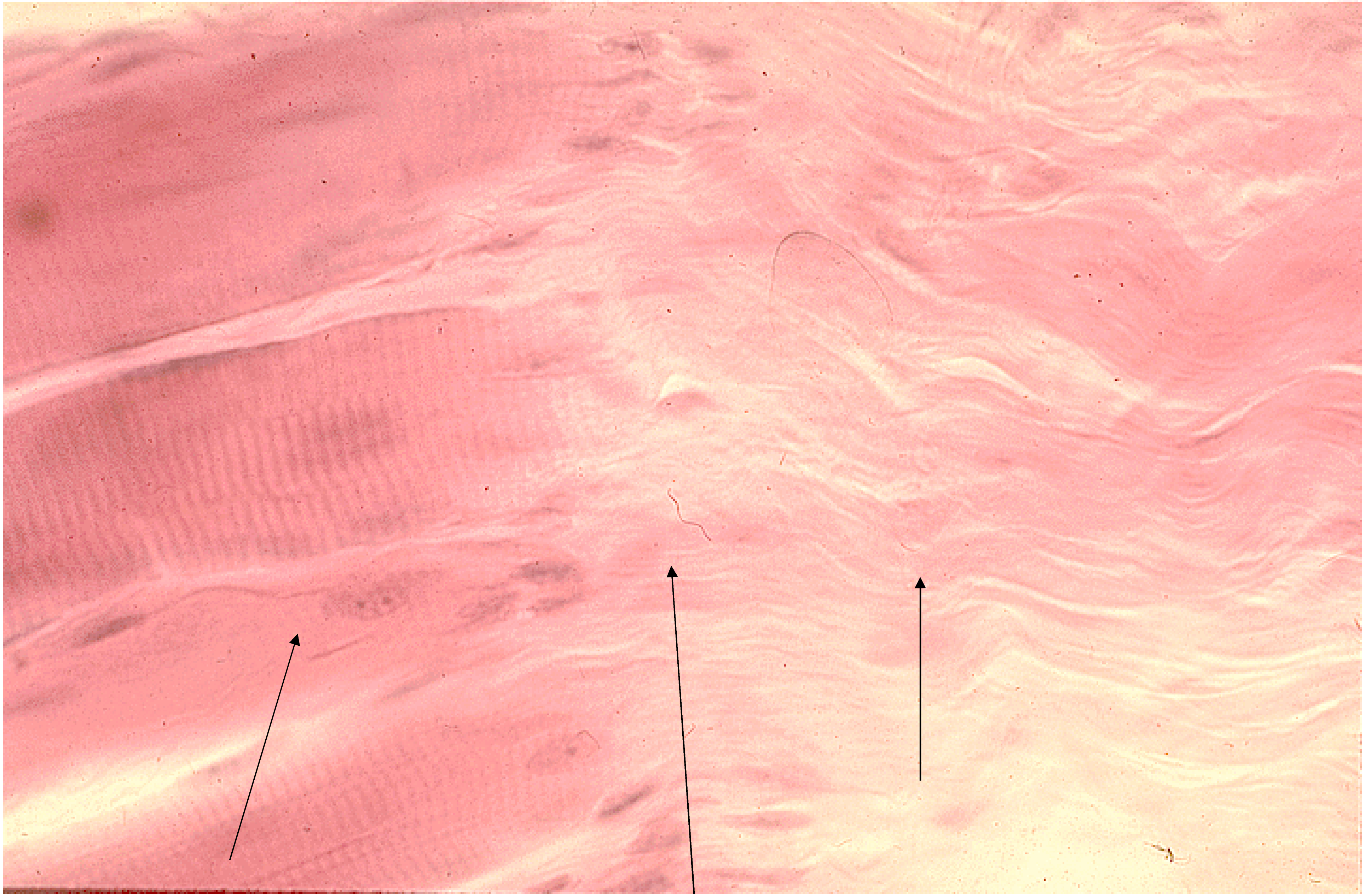


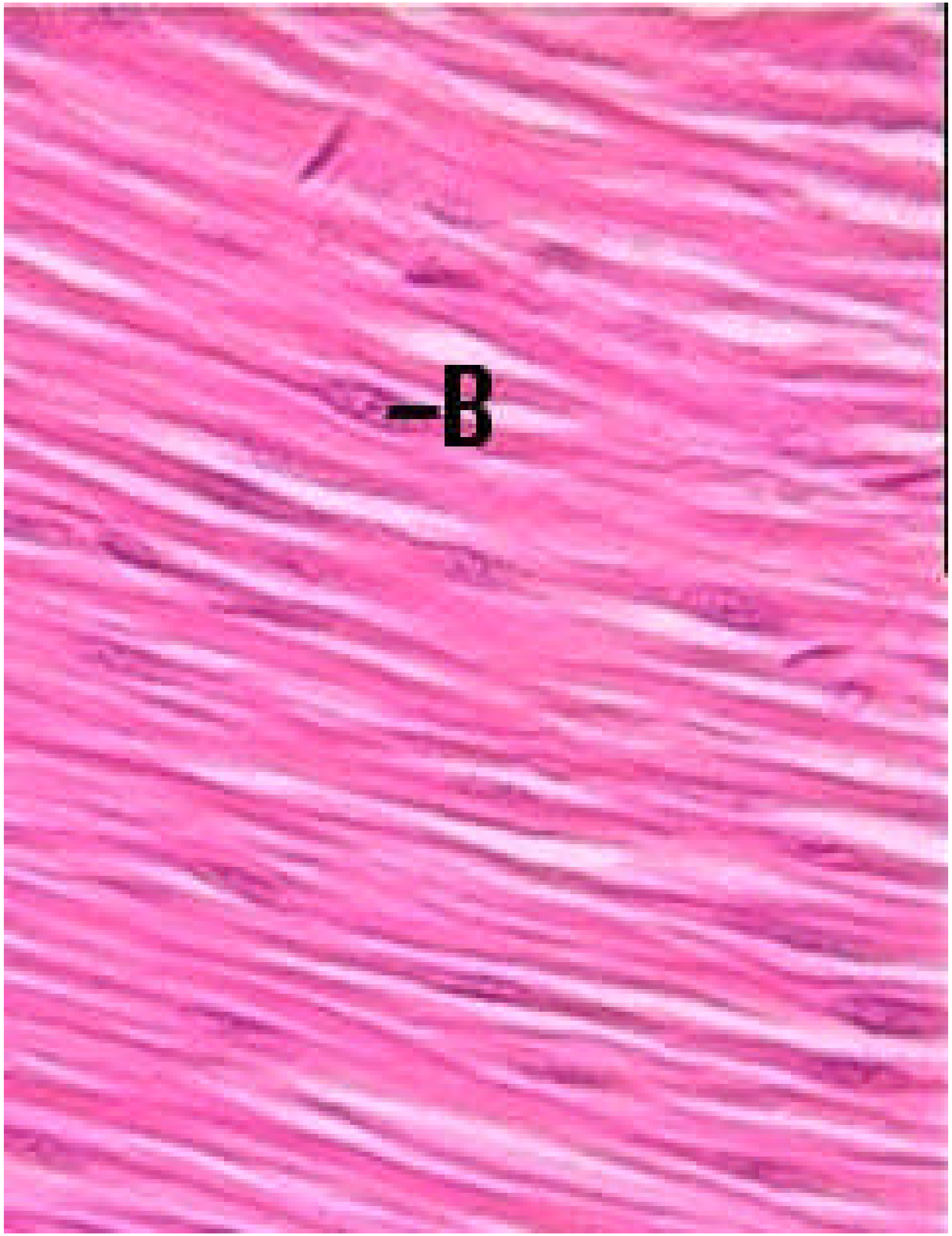
Skeletal muscles (C) are stimulated by nerve impulses carried by motor neurons.

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



Myotendenous Junction

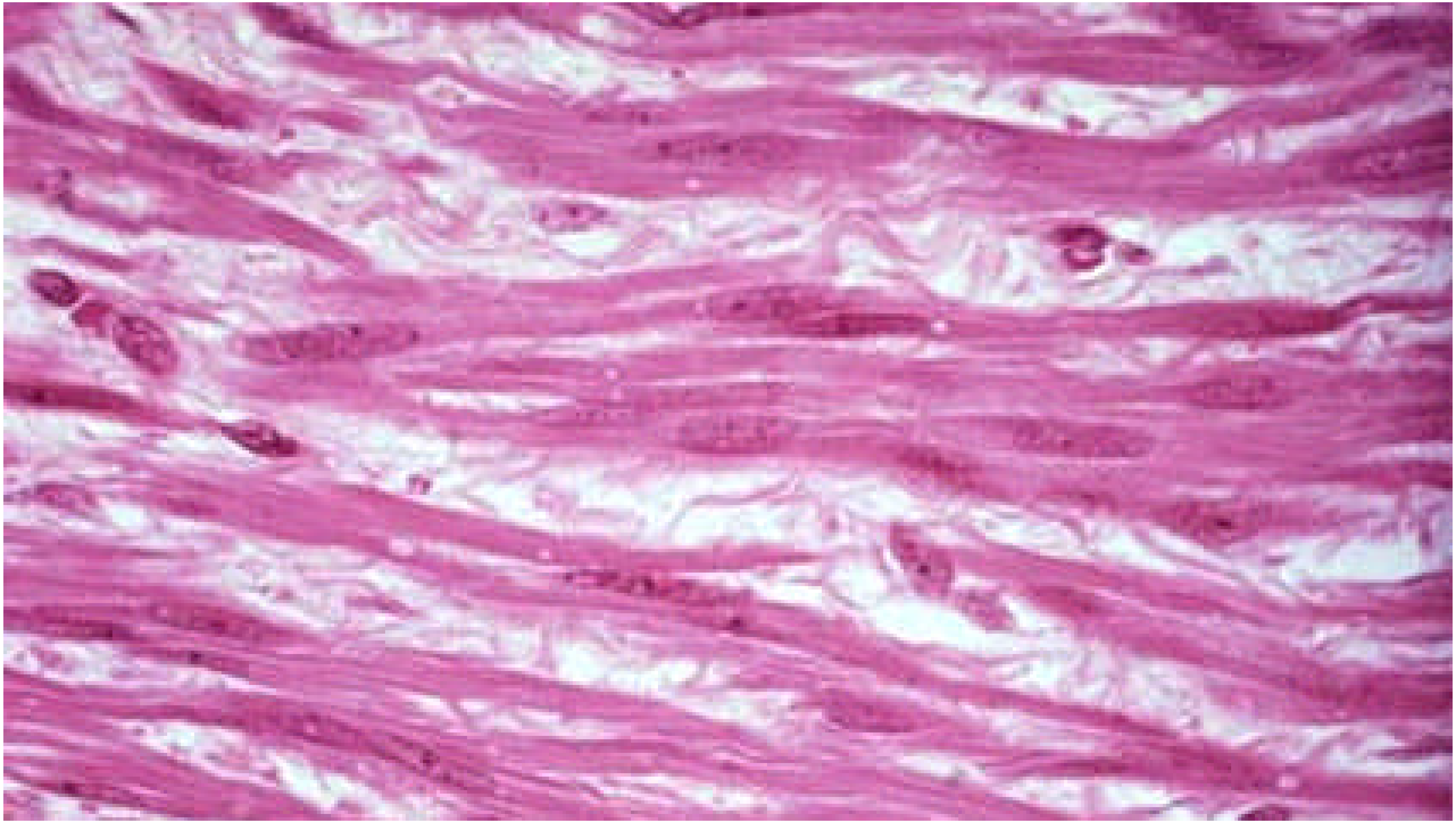




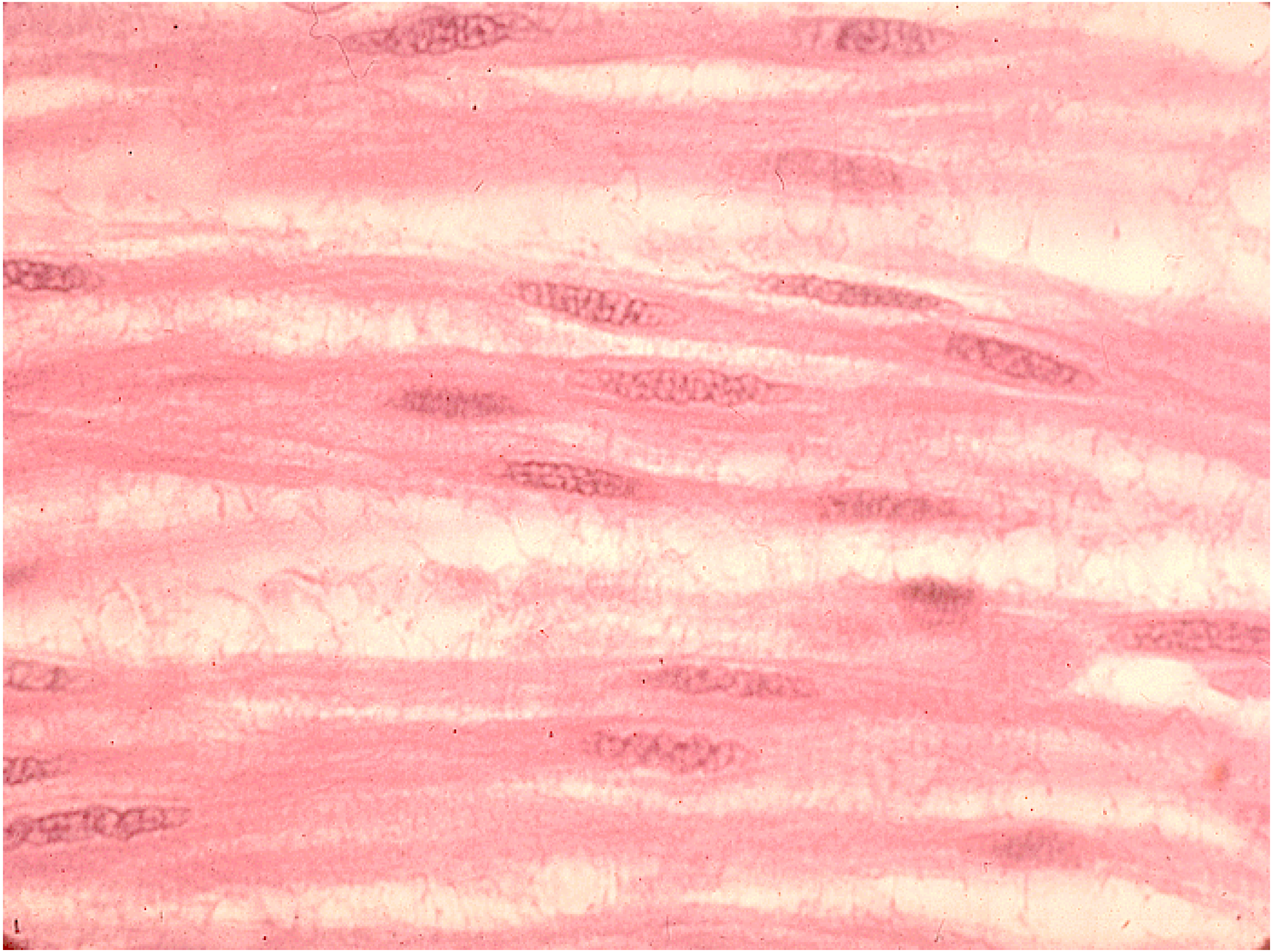
Smooth muscle cells are spindle shaped and uninucleate. (B).

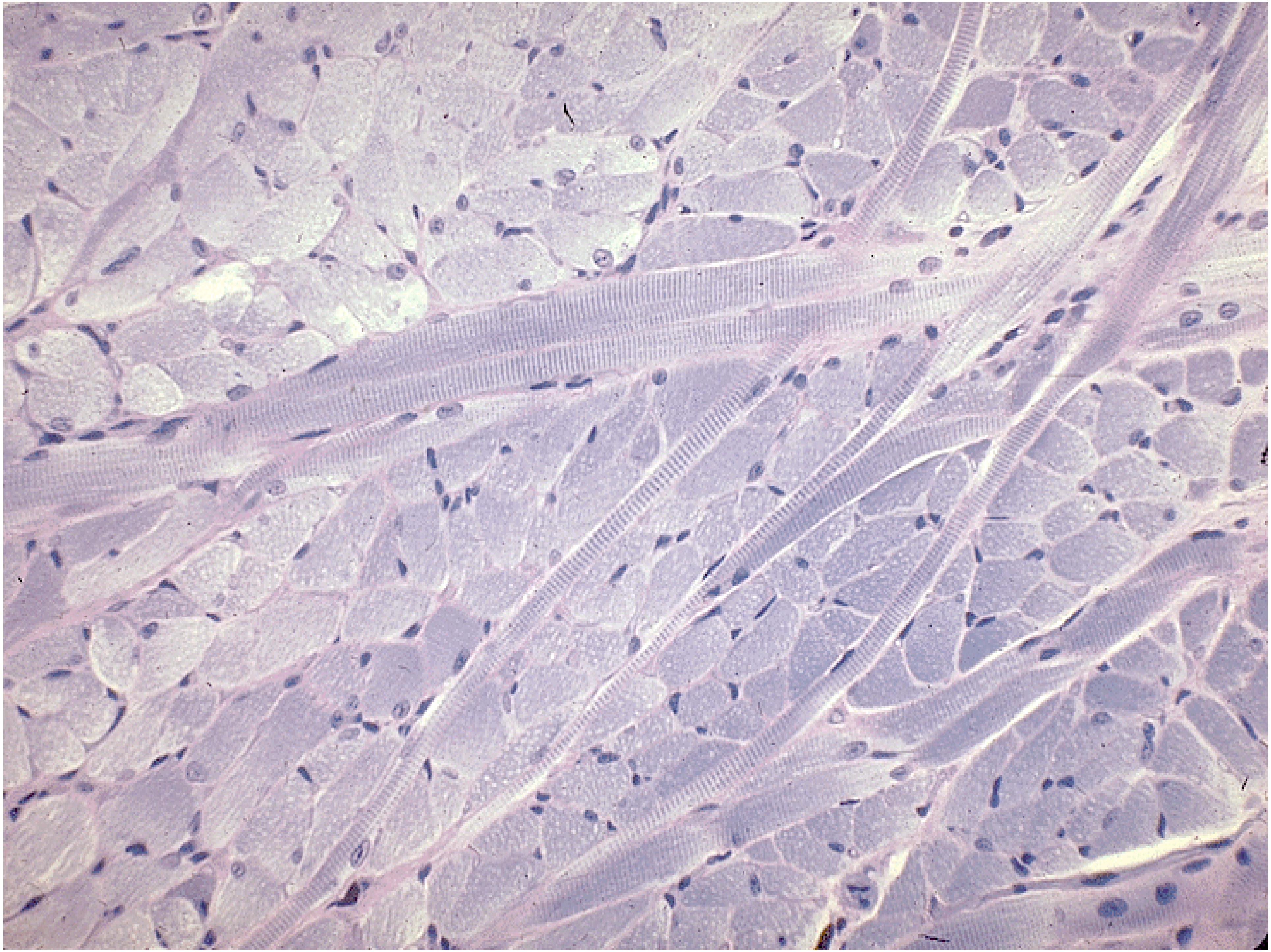
Locations: walls of hollow organs, i.e. stomach, intestine, uterus, ureter

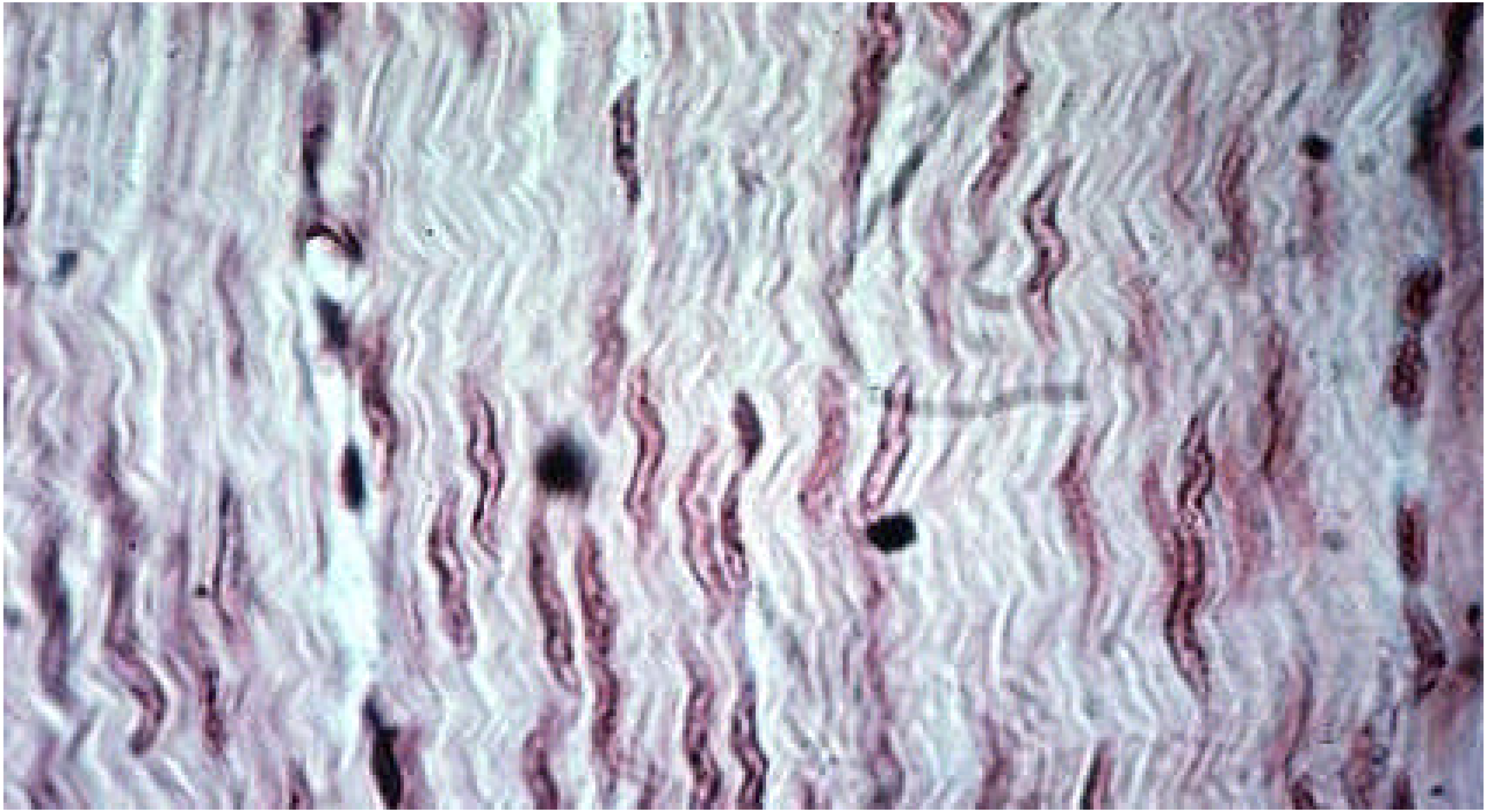
Functions: involuntary movement - i.e. churning of food, movement of urine from the kidney to the bladder, partuition



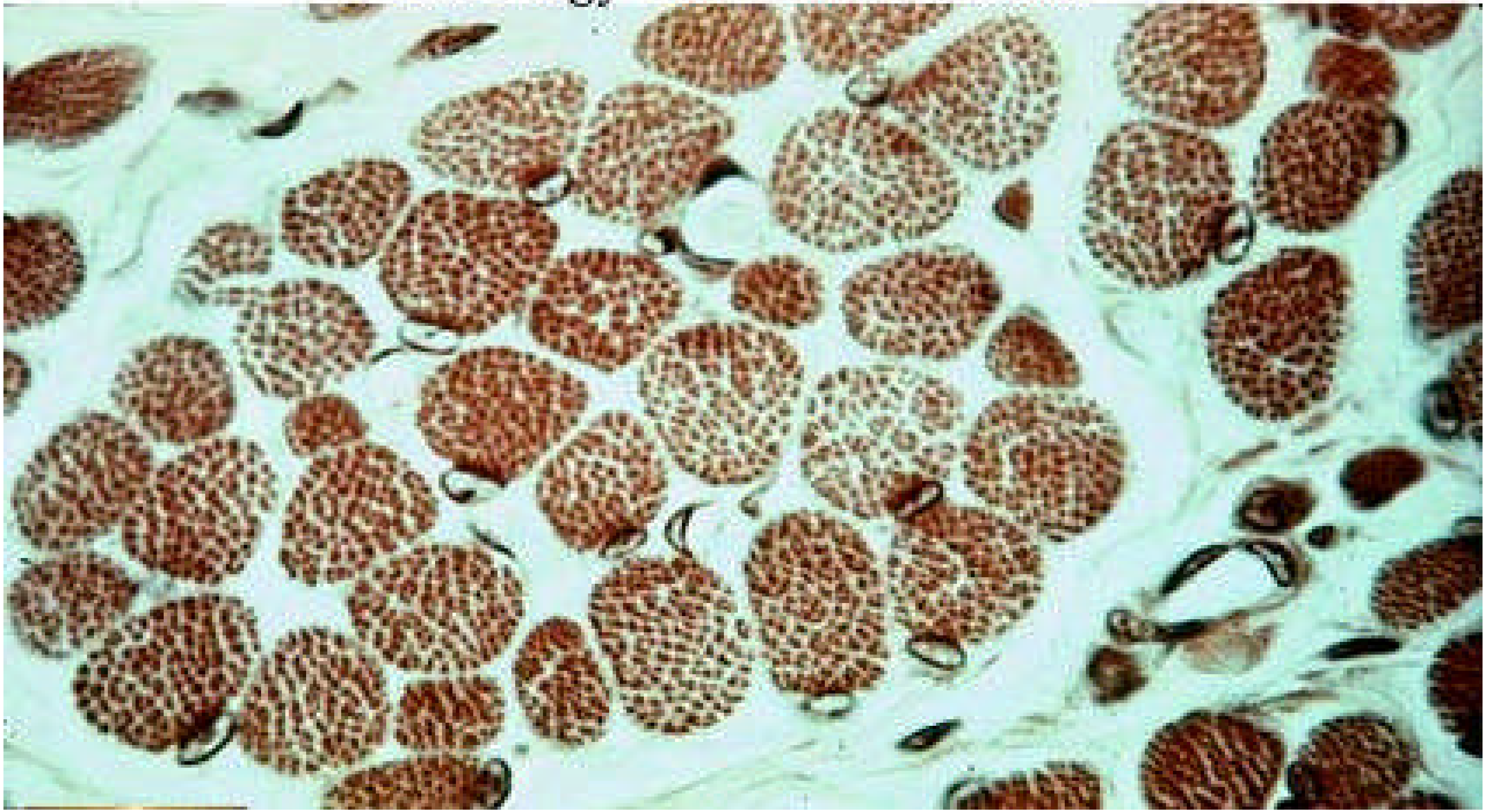
Smooth muscle - with cells more separated so as to see their extent and shape better, and the central position of their nuclei.
A loose, irregular connective tissue (endomysium) lies between the cells.
Nuclei seen in this c.t. belong to fibroblasts mainly.



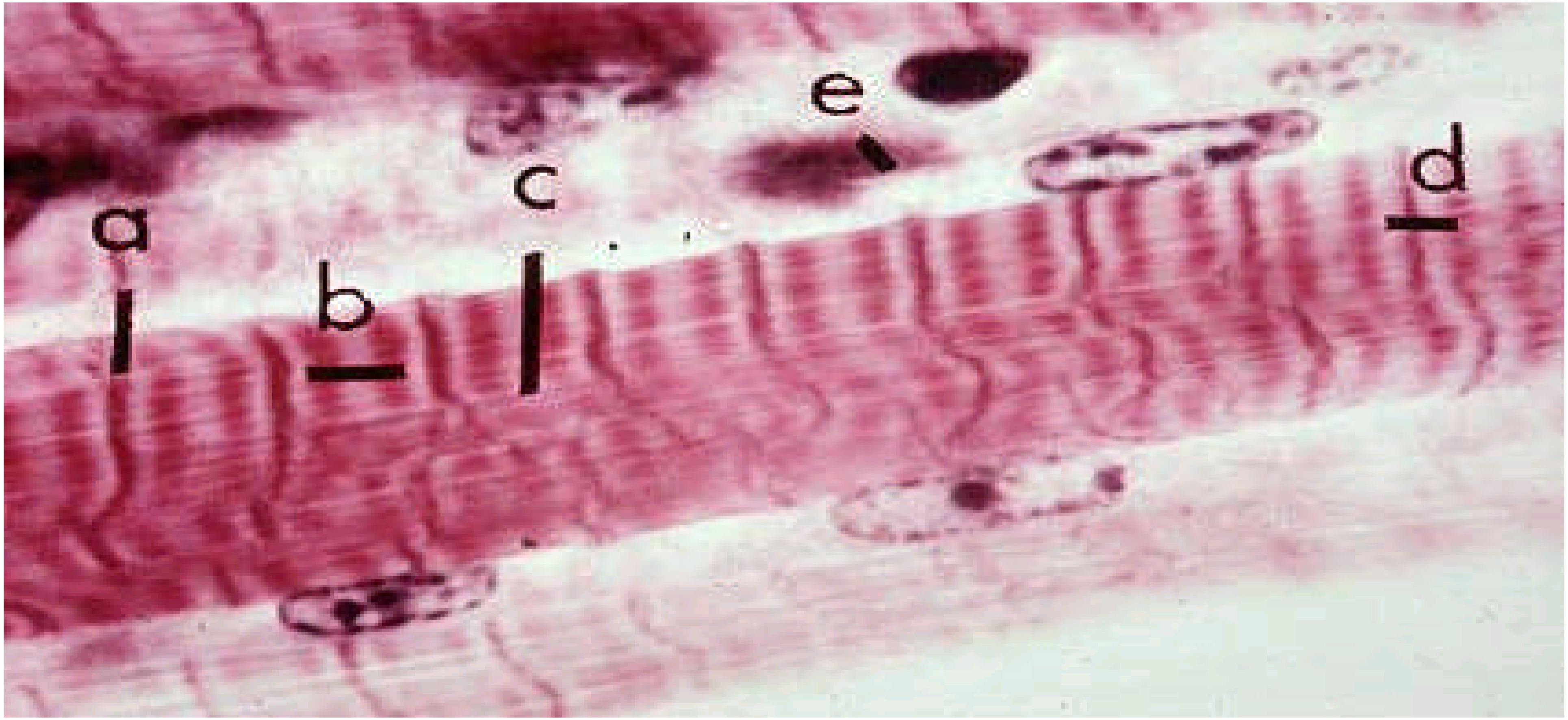




Smooth muscle with wrinkled nuclei due to contraction of cells.



Cross-cut of skeletal muscle to show connective tissue partitioning of muscle into groups or bundles of fibers. Endomysium is very delicate and lies between individual fibers, while perimysium is more visible and lies around a group of fibers. Epimysium is not seen here but ensheaths a whole muscle. In this picture notice the presence of small blood vessels in both perimysium and endomysium. Notice also the cross-cuts of myofibrils within the muscle cells, making them look grainy.



Longitudinal view of skeletal muscle cell with unusually clear cross-striations. This muscle is stretched, so that the A band is widely split.

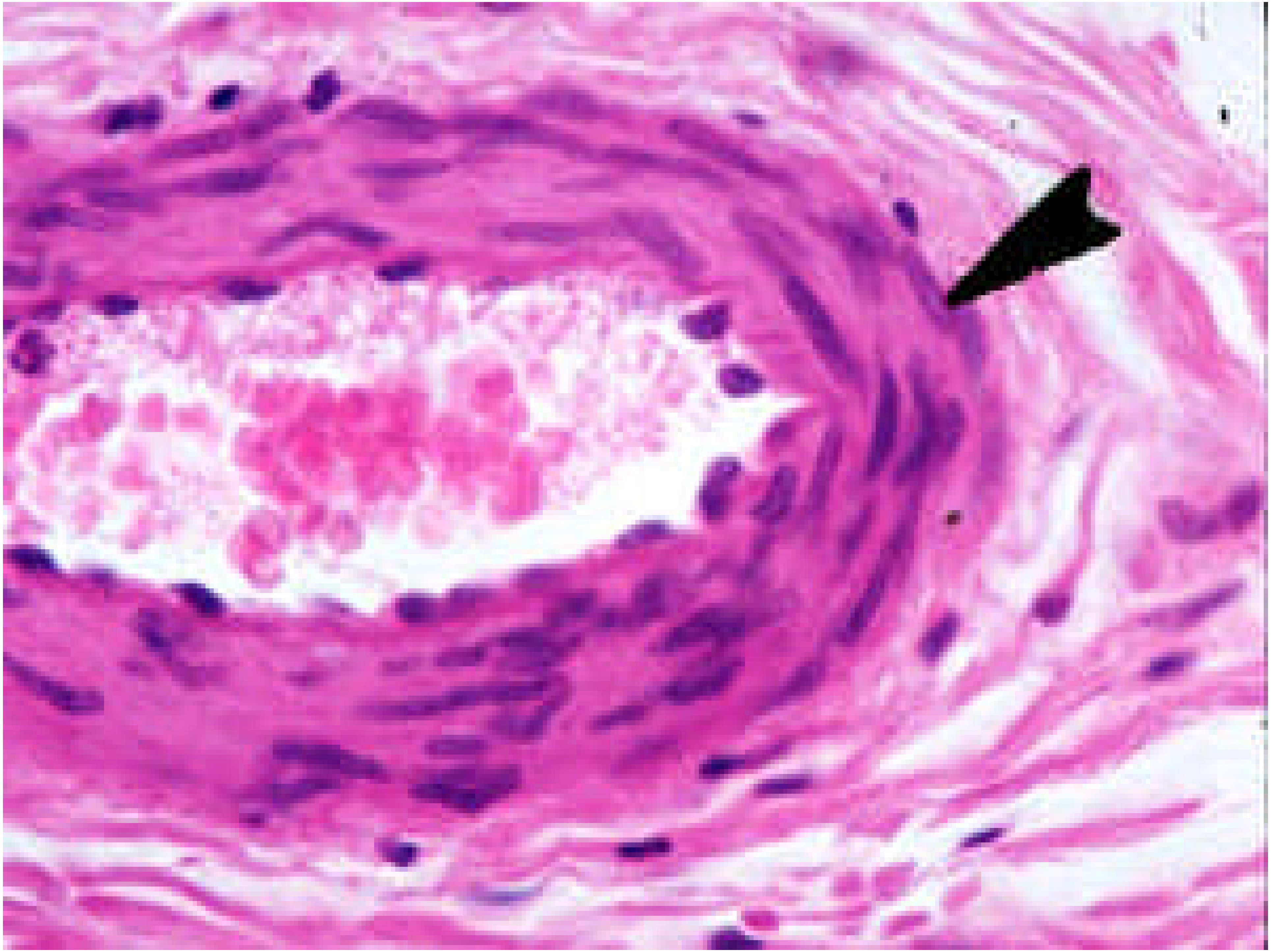
a)Z disc

b)A band, split -- with pale H band in the middle

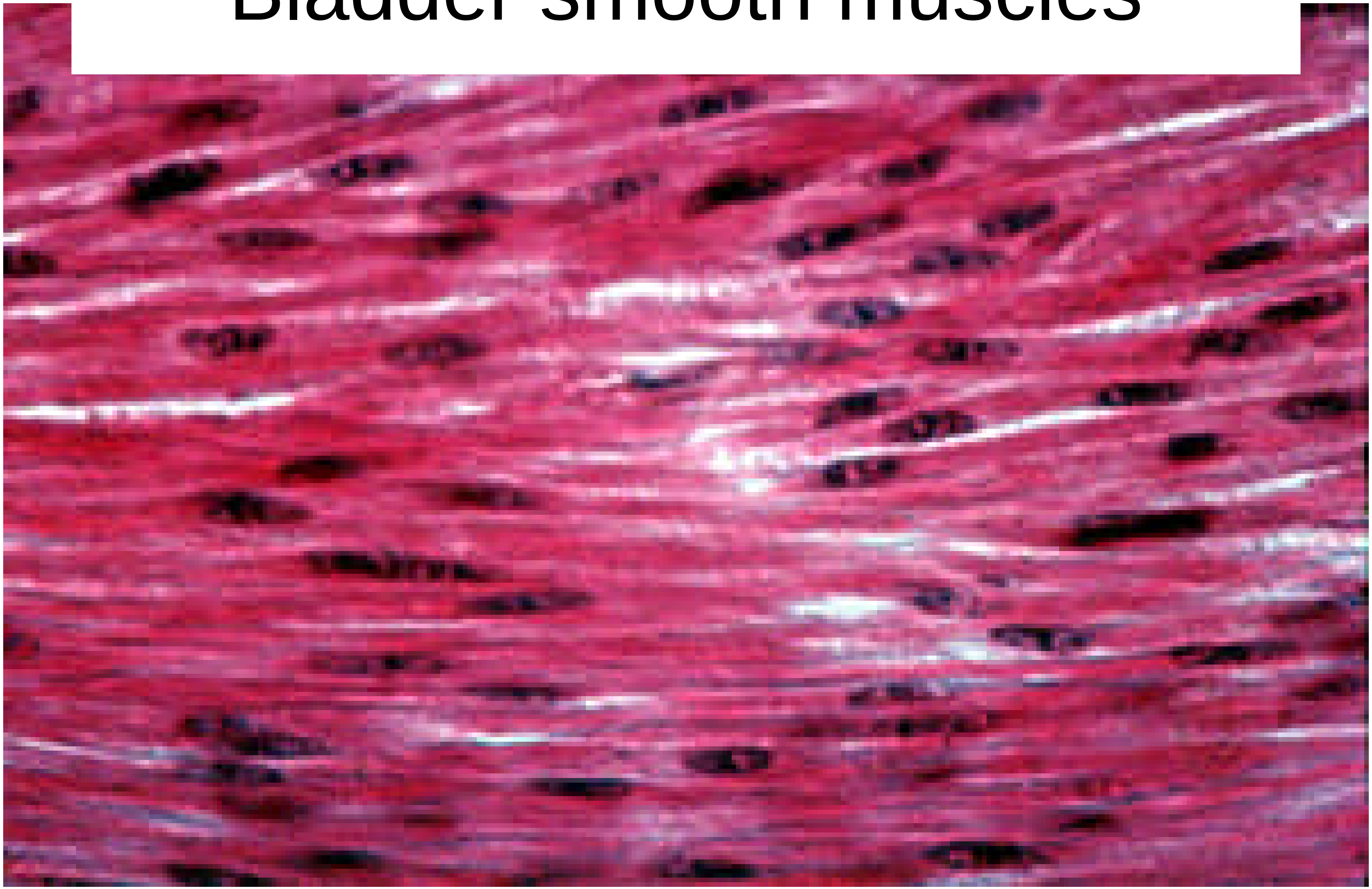
c)the line lies right in an H band

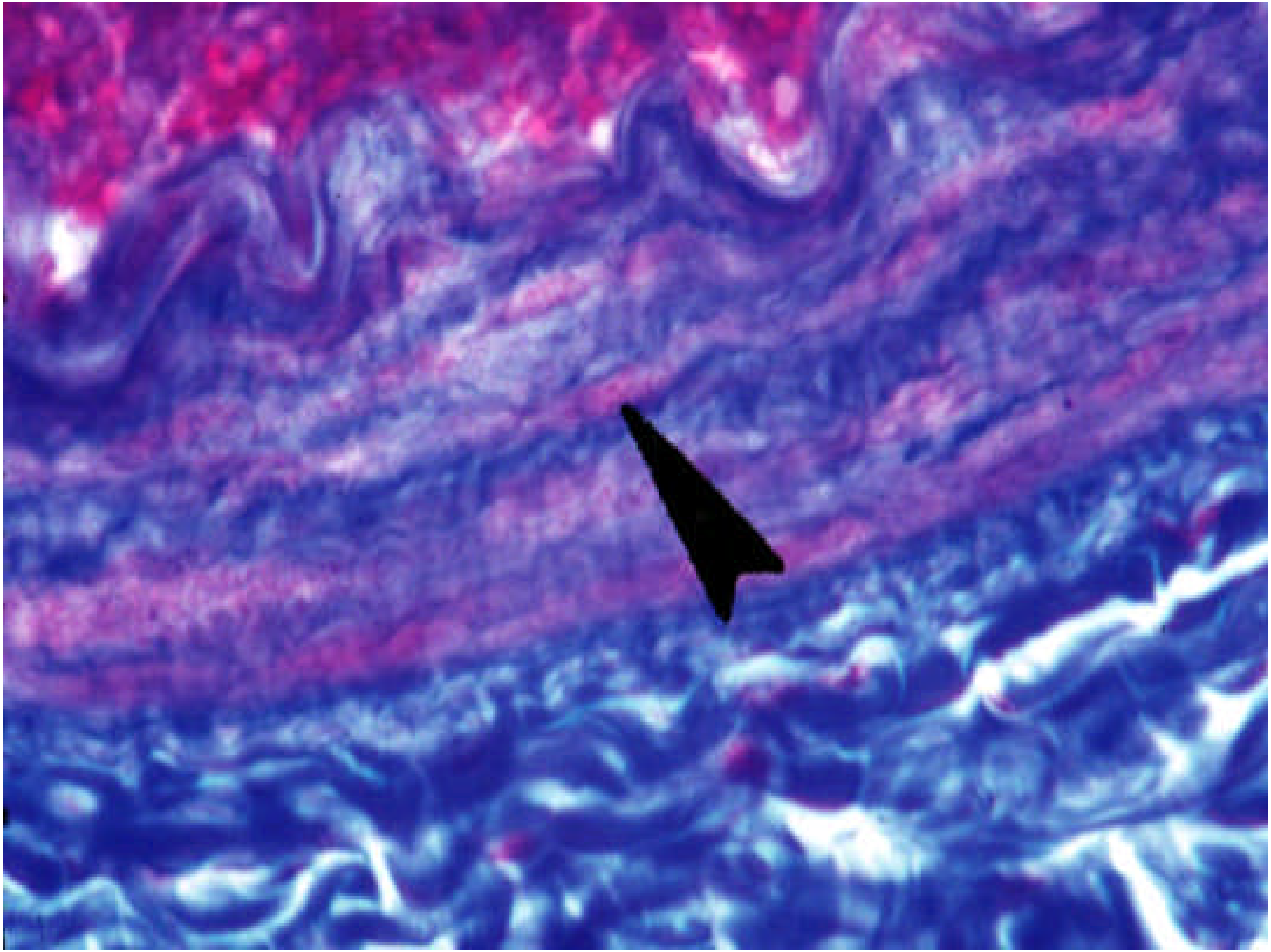
d)width of I band, with Z disc in the middle

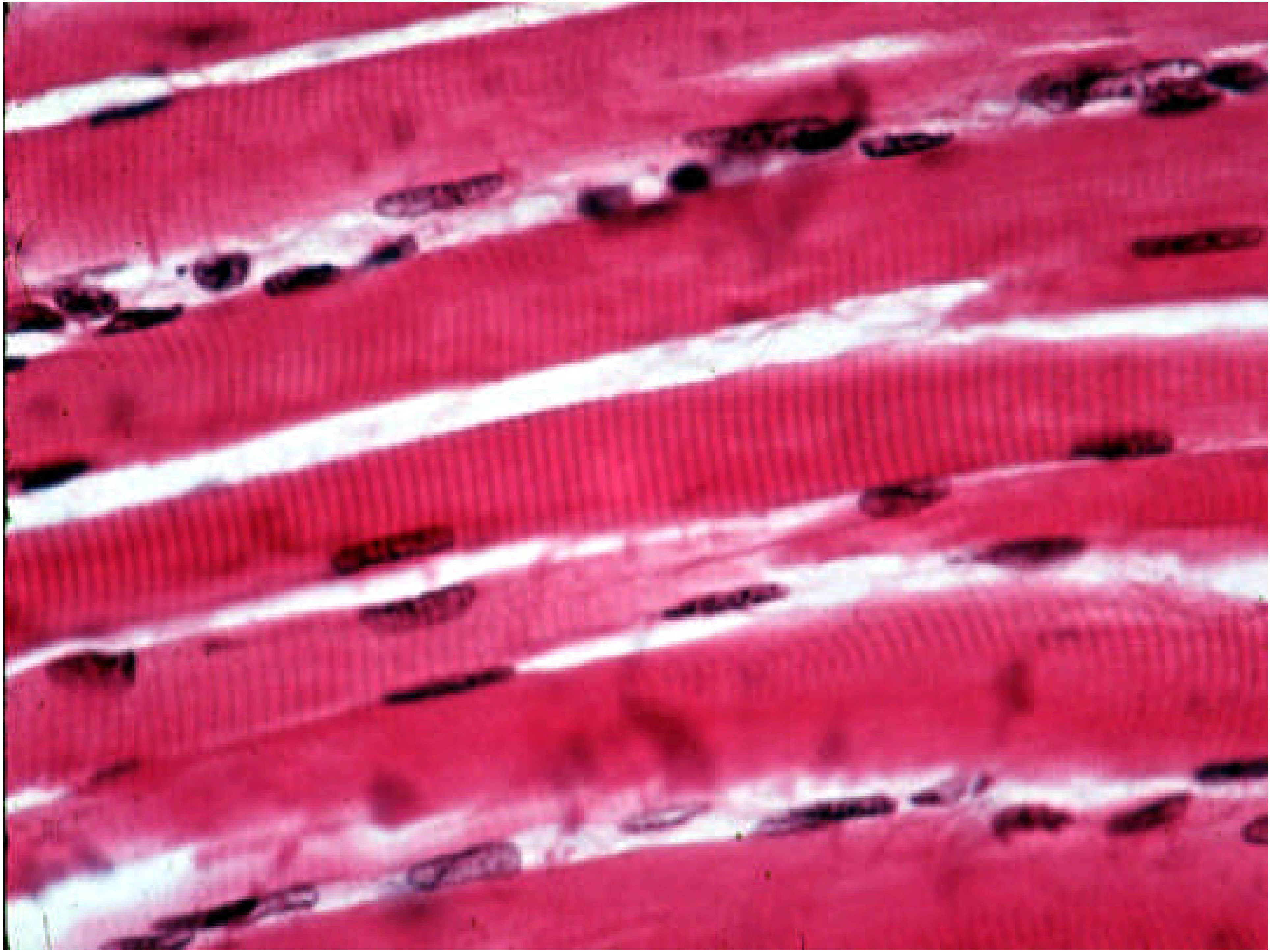
e)pointing to a practically invisible thin line, the sarcolemma (or cell membrane), which lies outside the pale peripheral nucleus seen to the right.

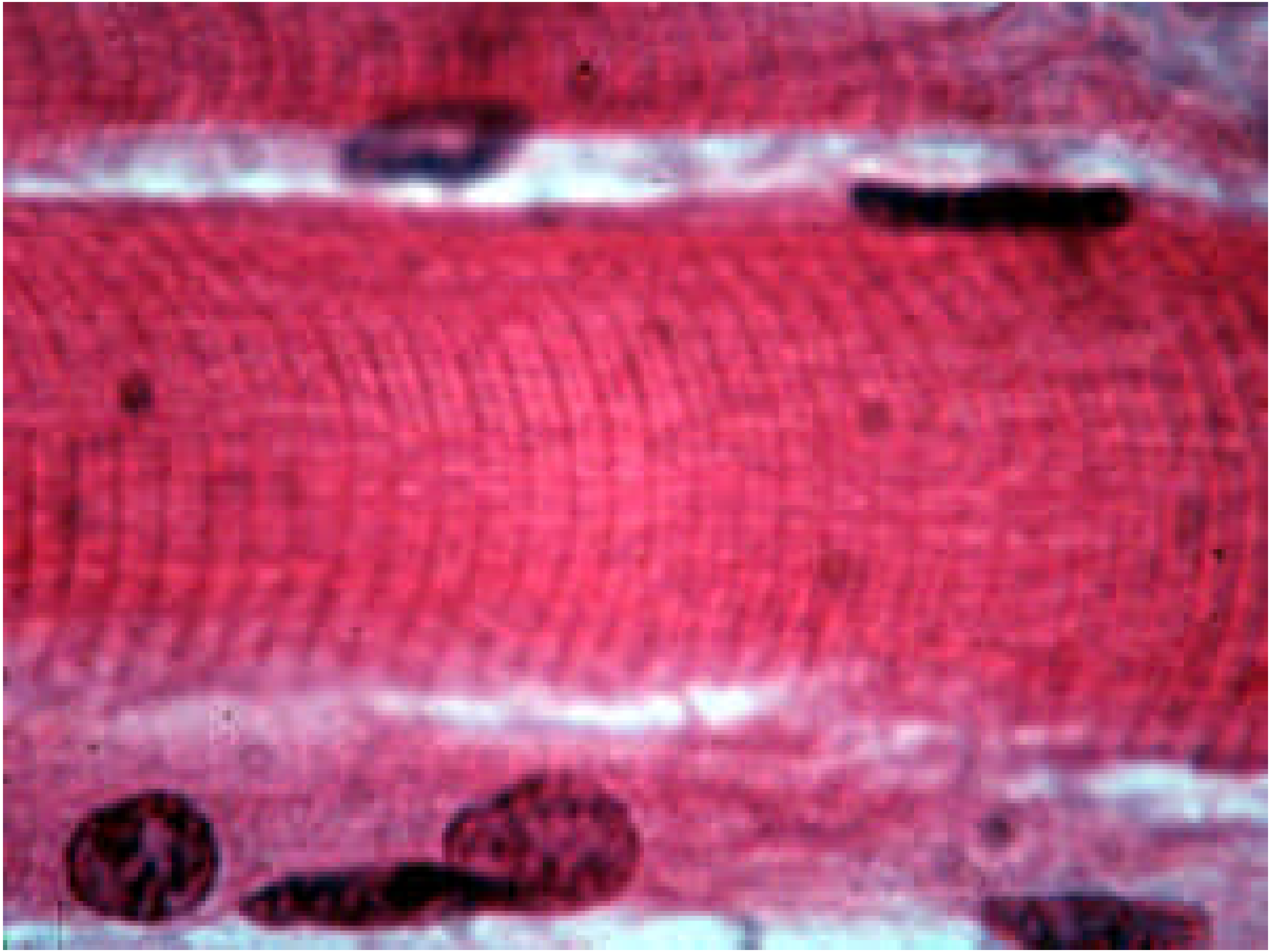


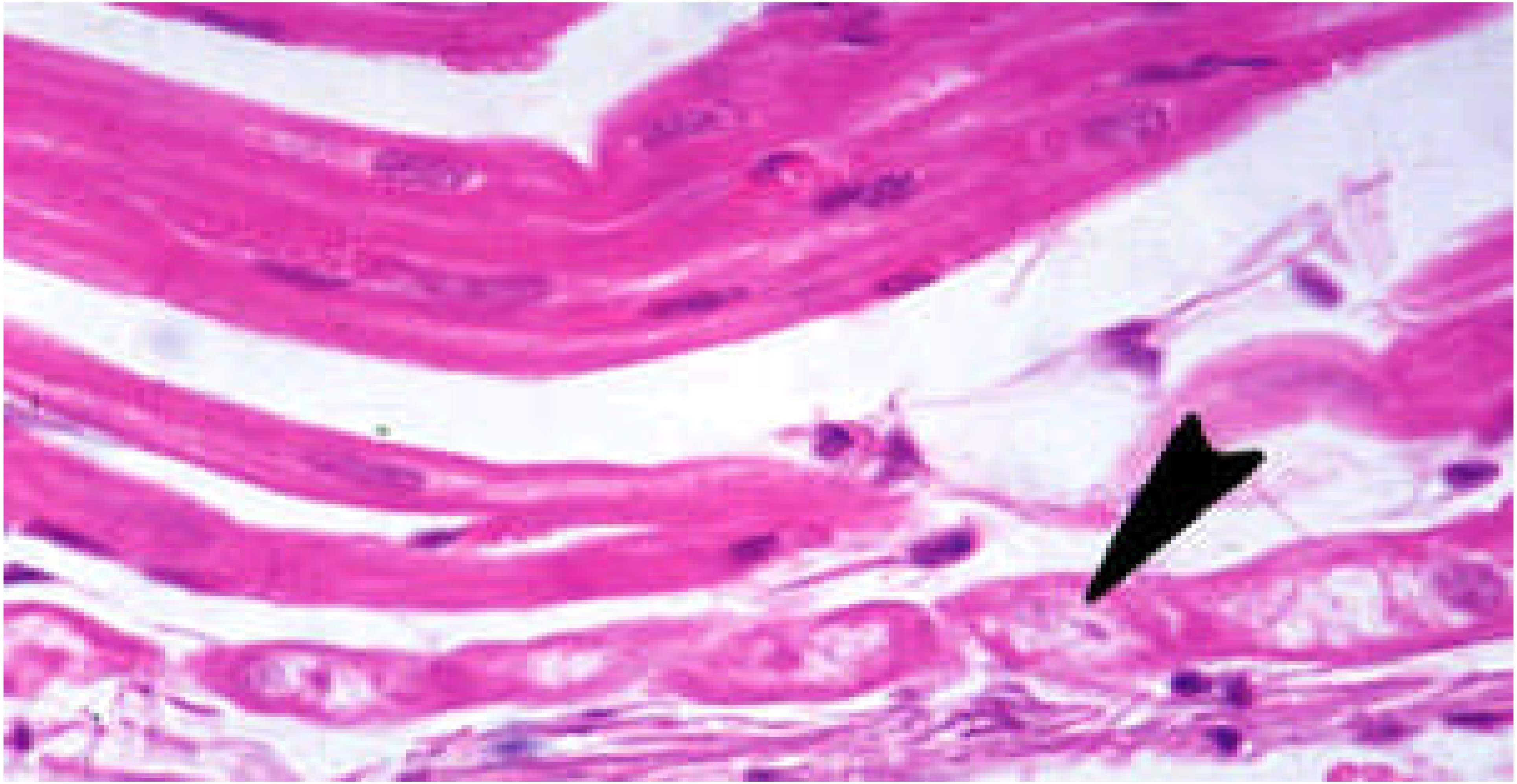
Bladder smooth muscles







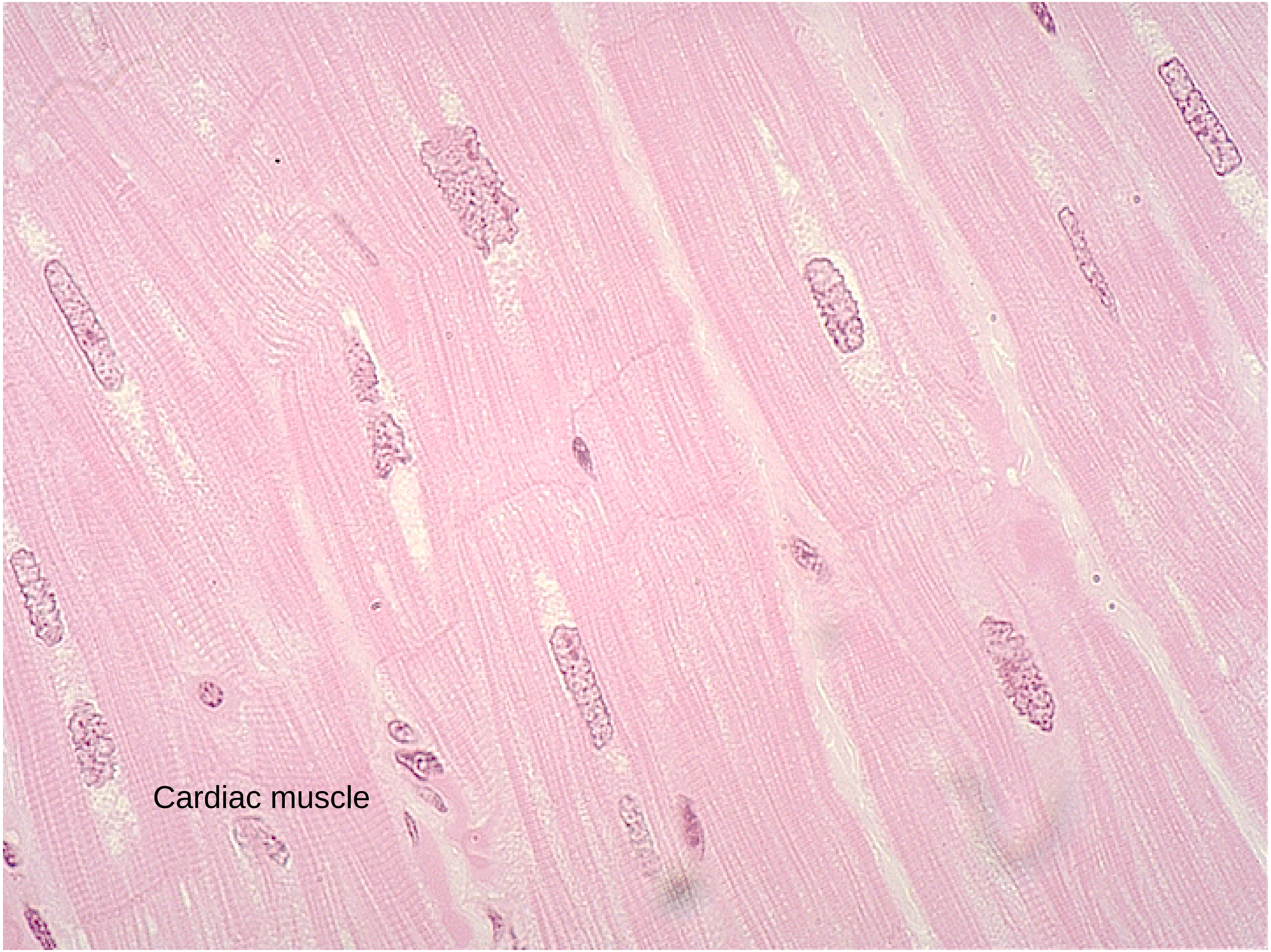


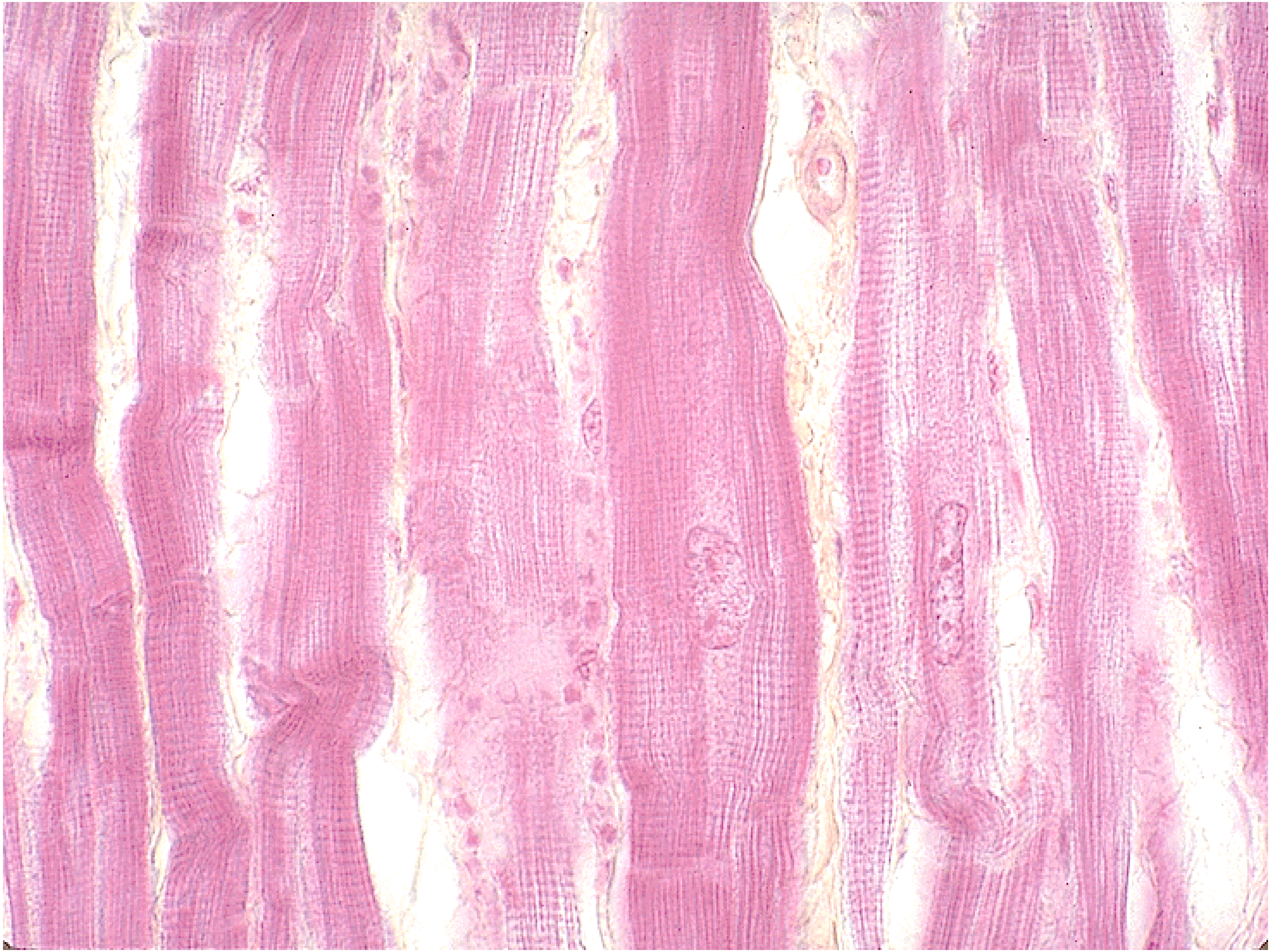


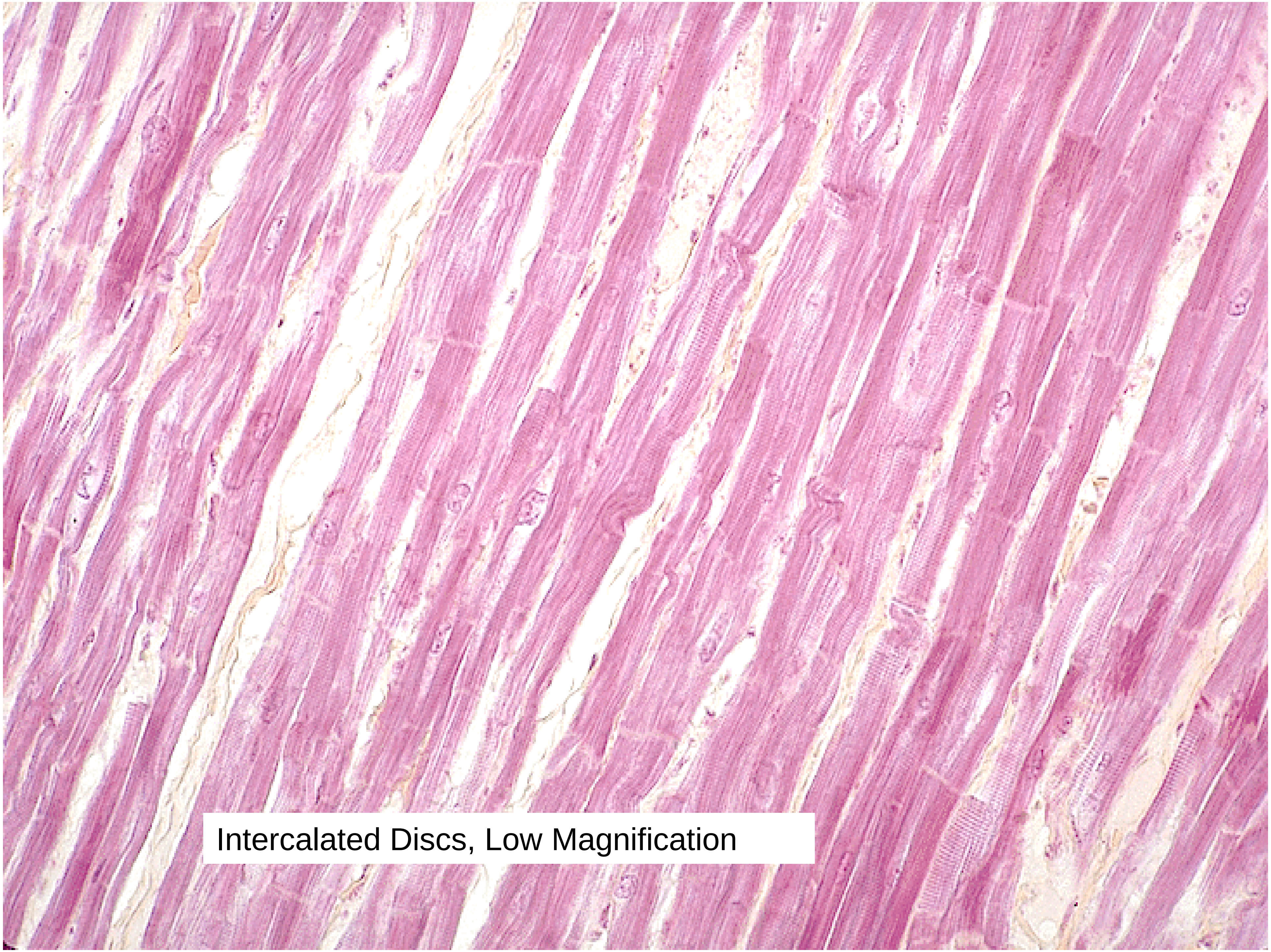
pointer indicates the highly specialized cardiac muscle cells that are known as the Purkinje fibers.

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.

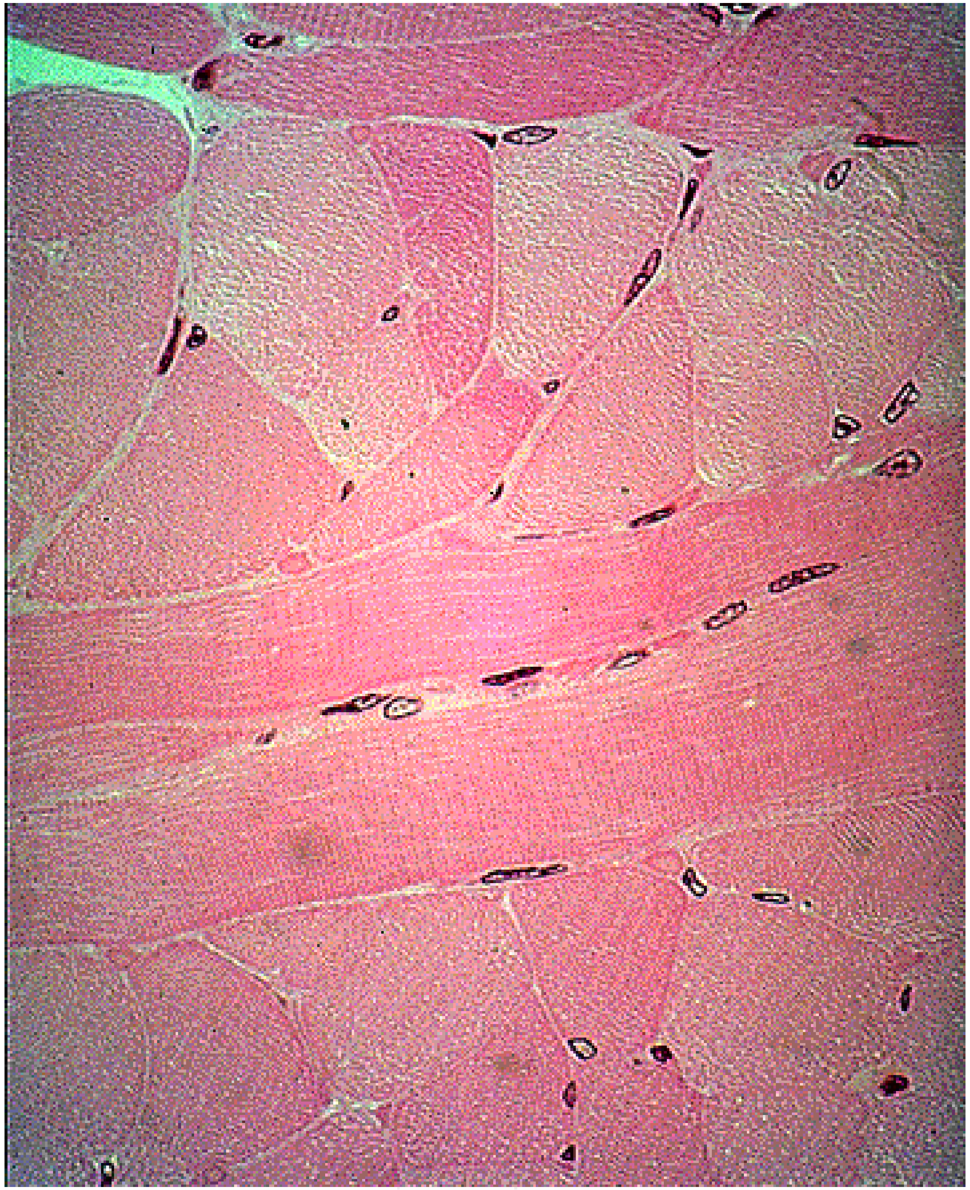

Cardiac muscle



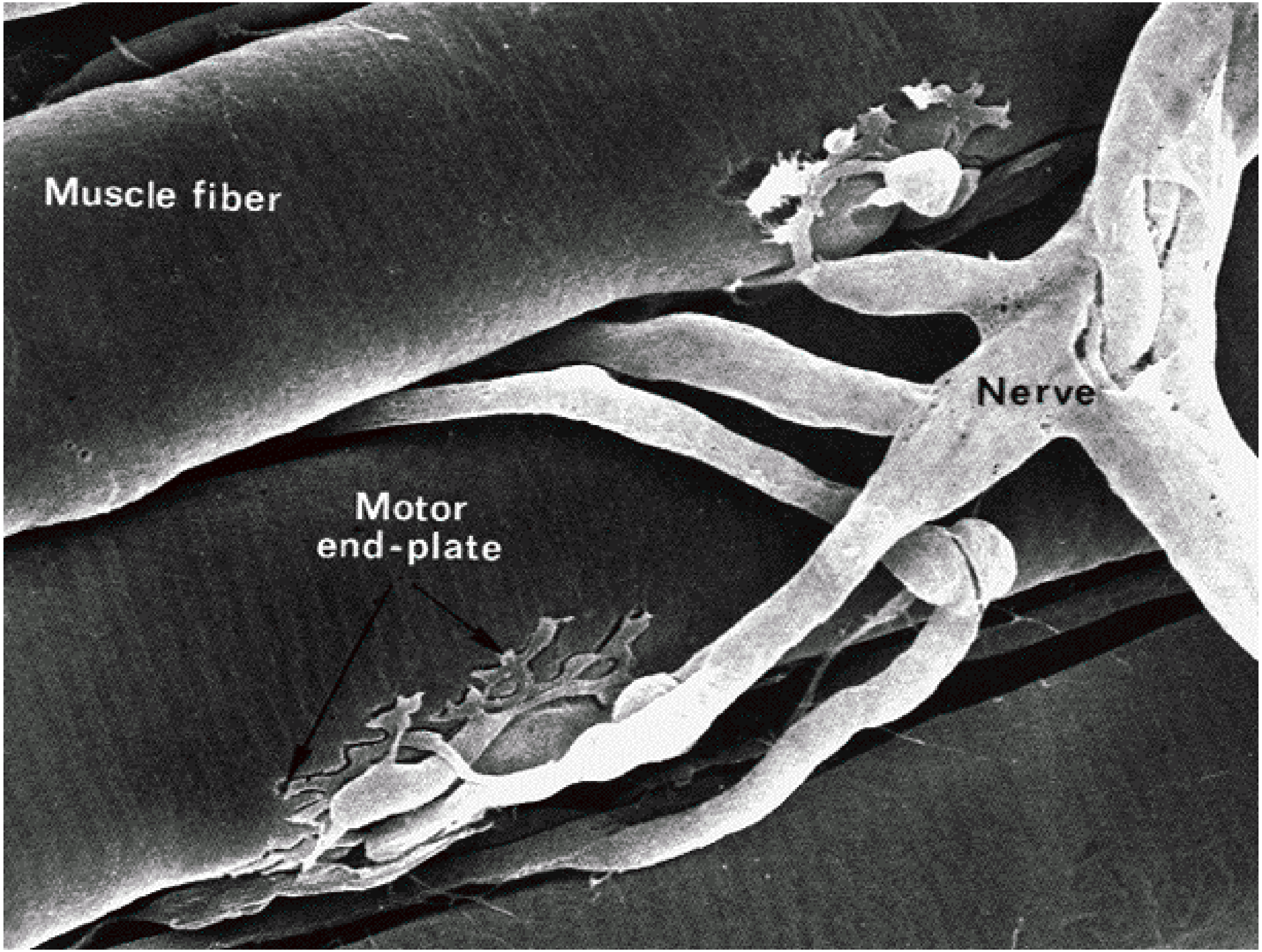

Intercalated Discs, Low Magnification

Striated Muscle Fibers-Long. Section

Striated Muscle Fibers- Long. & Trans. Sects.

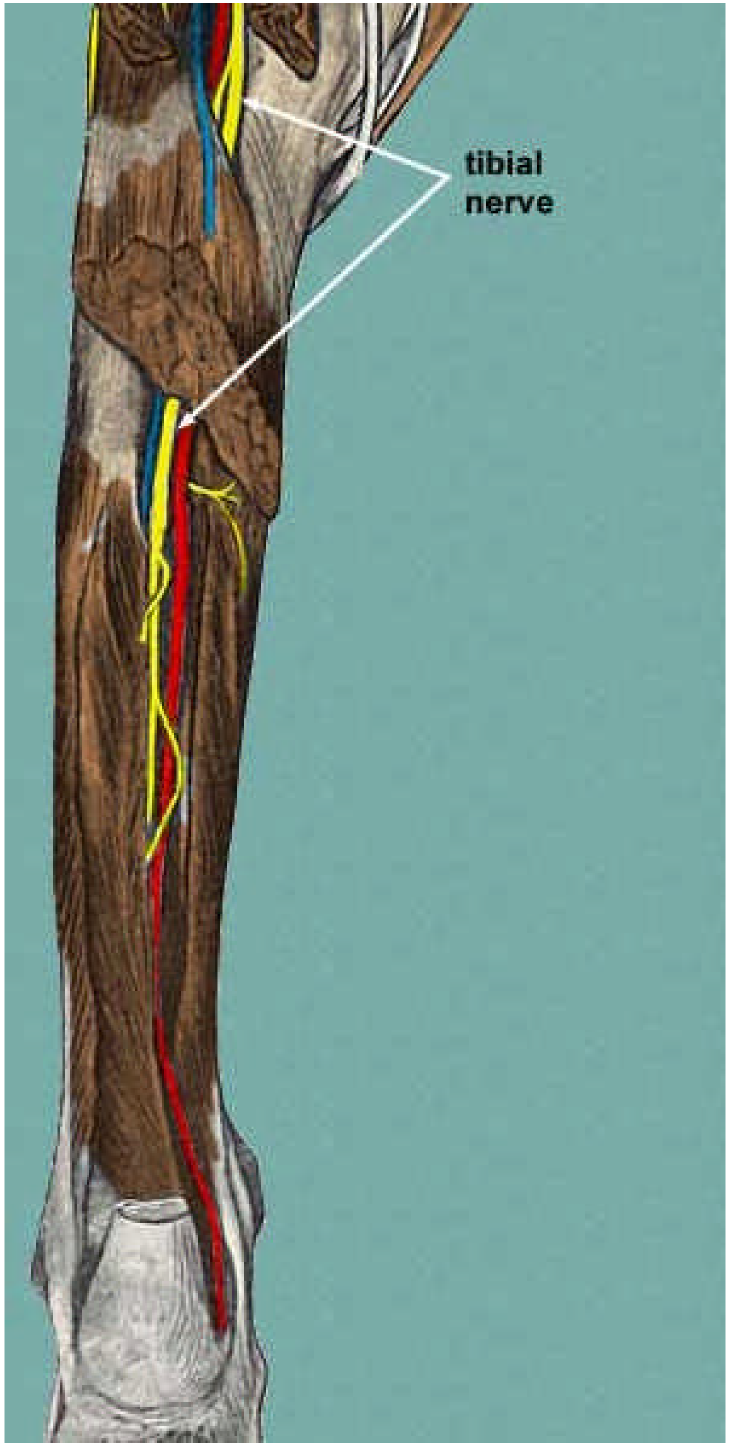


SEM OF MOTOR END PLATES



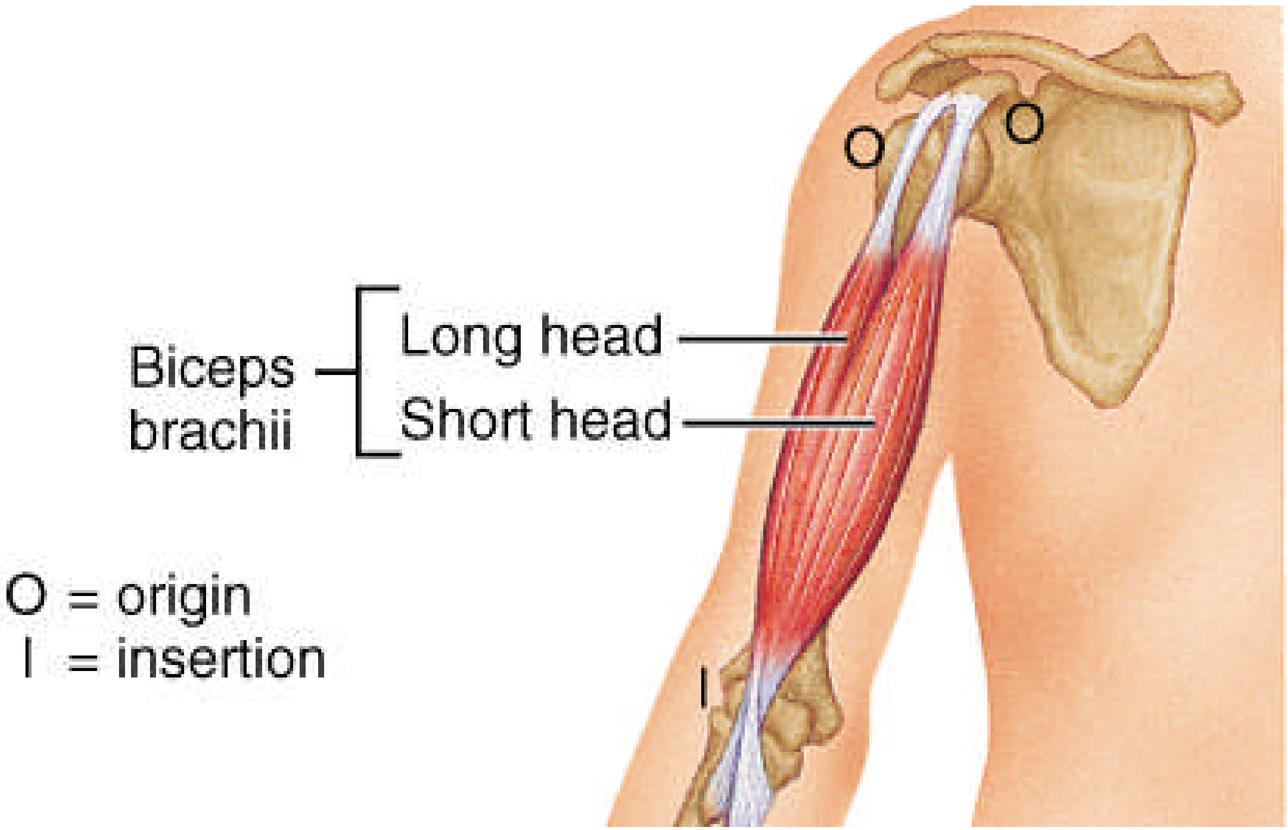
Skeletal Muscle – Blood & Nerve Supply

- 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.



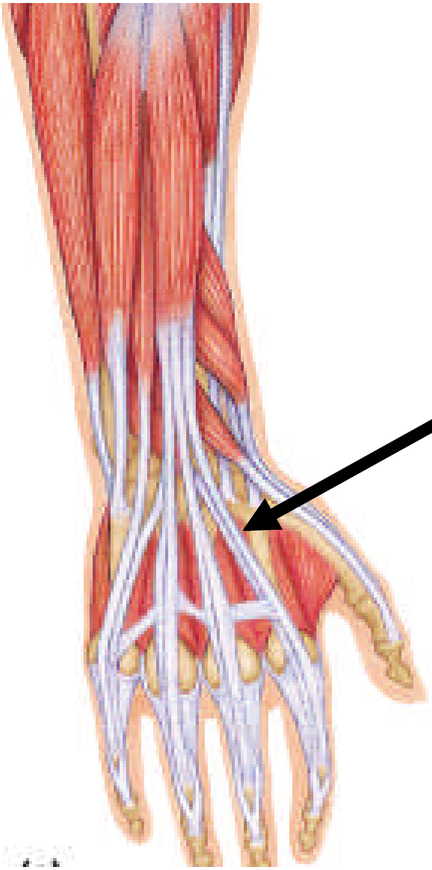
Skeletal Muscle Attachments

- 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.

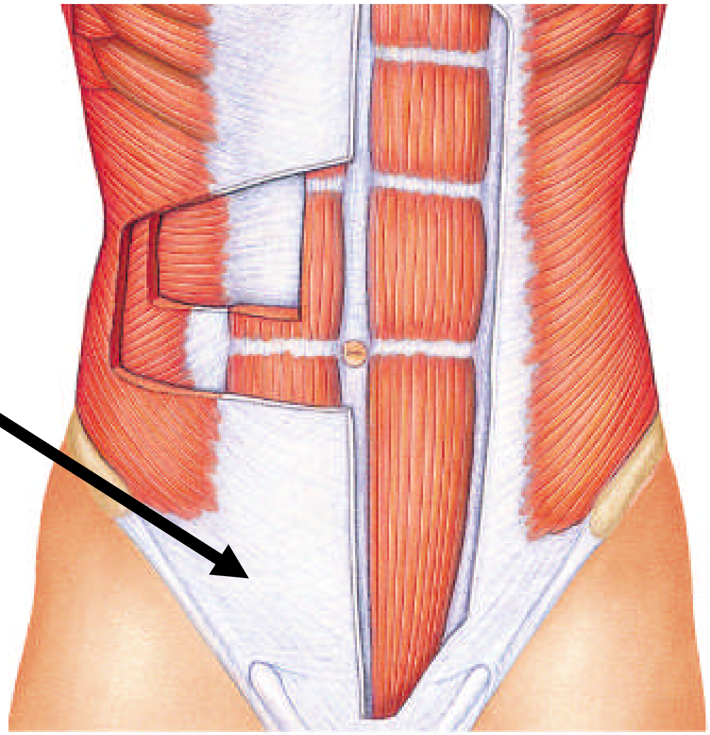


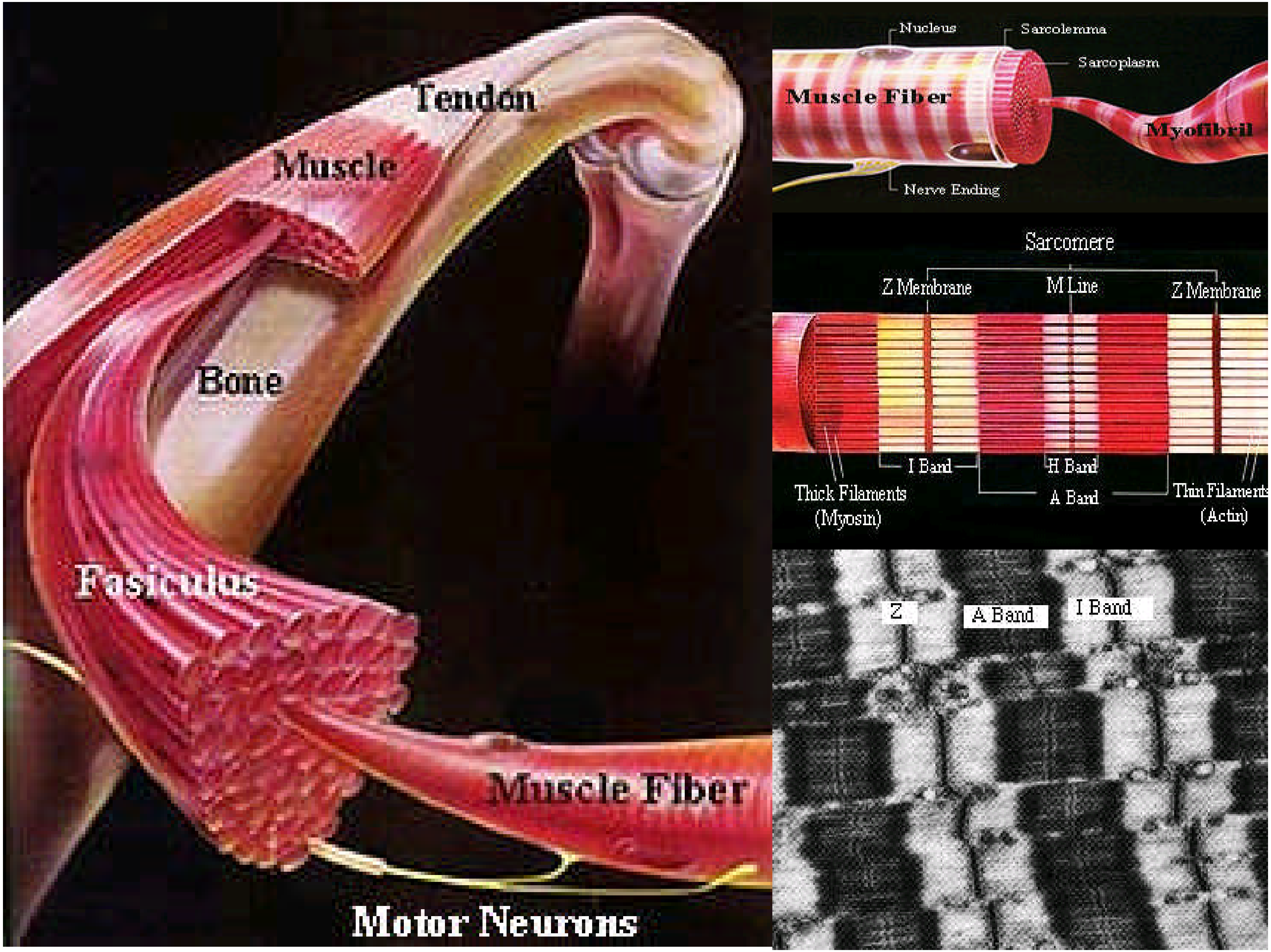
Muscle attachments may be direct or indirect.

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



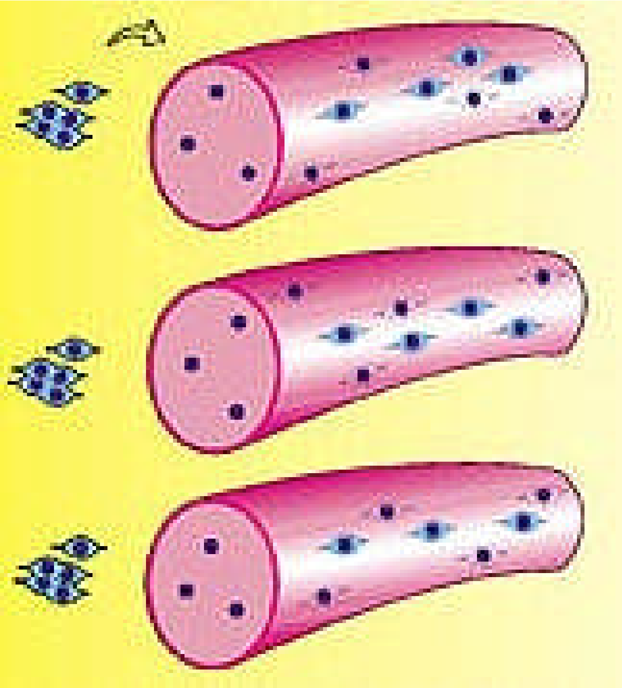
Indirect attachments are typical. The muscle CT extends and forms either a cordlike structure (a tendon) or a sheetlike structure (aponeurosis) which attaches to the periosteum or perichondrium.





Tendon
Muscle
Bone
Fasiculos
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

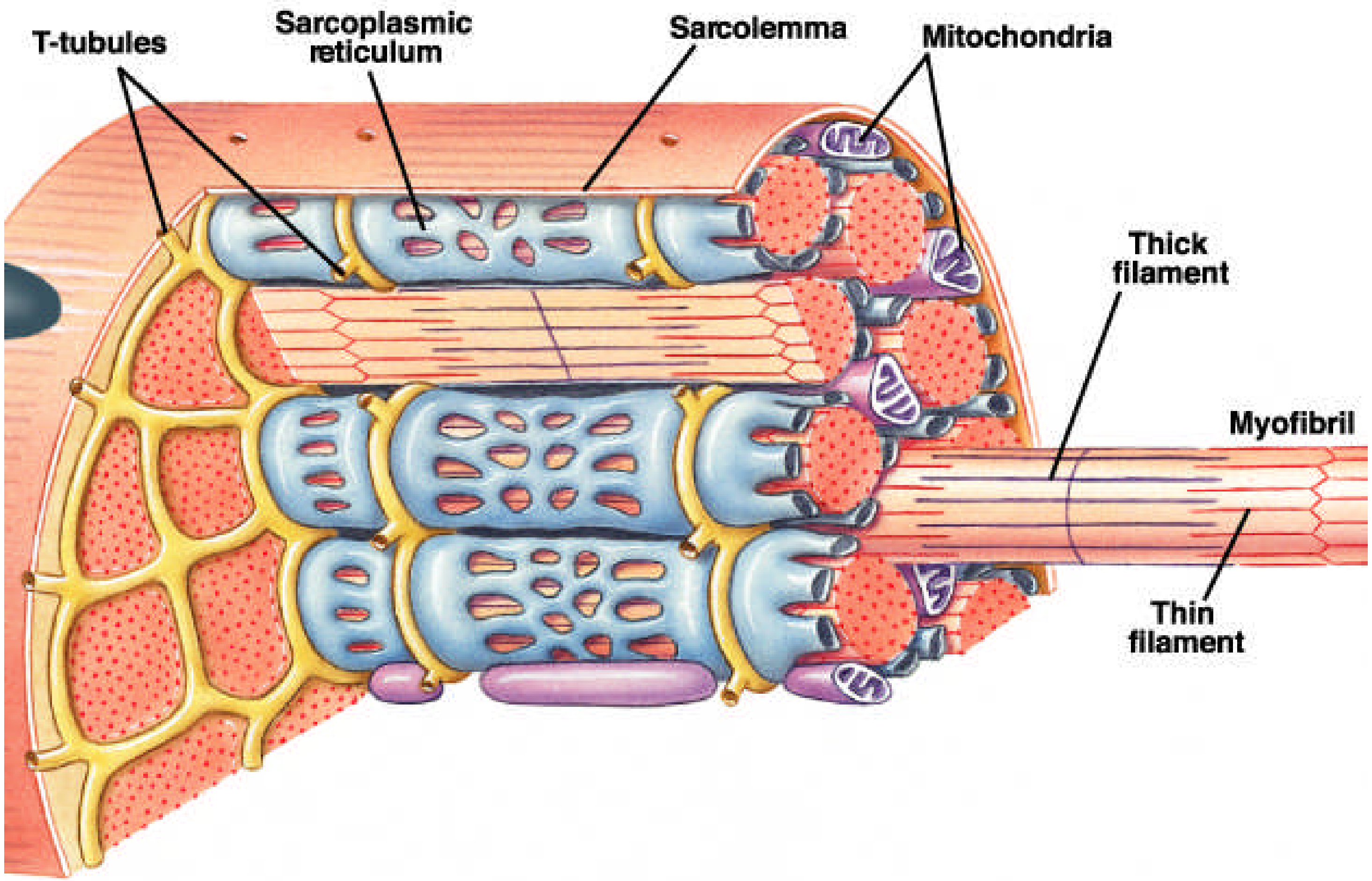
Skeletal Muscle Microanatomy



- Each skeletal muscle cell is known as a skeletal muscle fiber because they are so long.
  - Their diameter can be up to 100um and their length can be as long as 30cm.
  - They're so large because a single skeletal muscle cell results from the fusion of hundreds of embryonic precursor cells called myoblasts.
    - A cell made from the fusion of many others is known as a syncytium.
  - Each skeletal muscle fiber will have multiple nuclei. Why?

Muscle fiber PM is known as sarcolemma

Muscle fiber cytoplasm is known as sarcoplasm

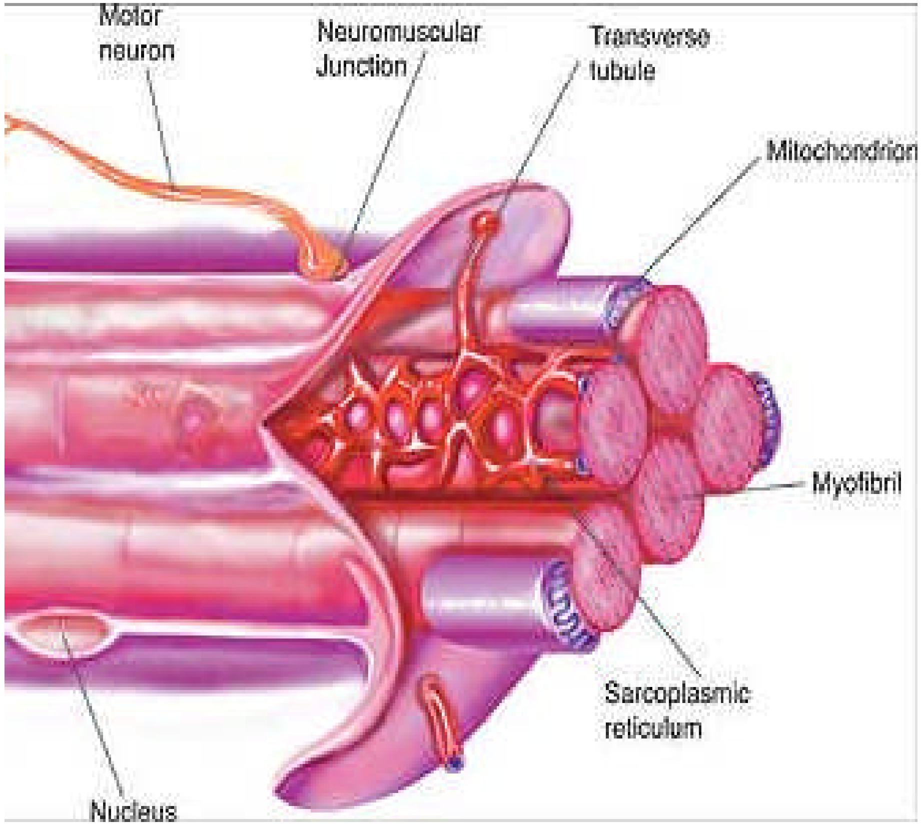


Sarcolemma has invaginations that penetrate through the cell called transverse tubules or T tubules.

Sarcoplasm has lots of mitochondria (*why*?), lots of glycogen granules (to provide glucose for energy needs) as well as myofibrils and sarcoplasmic reticuli.

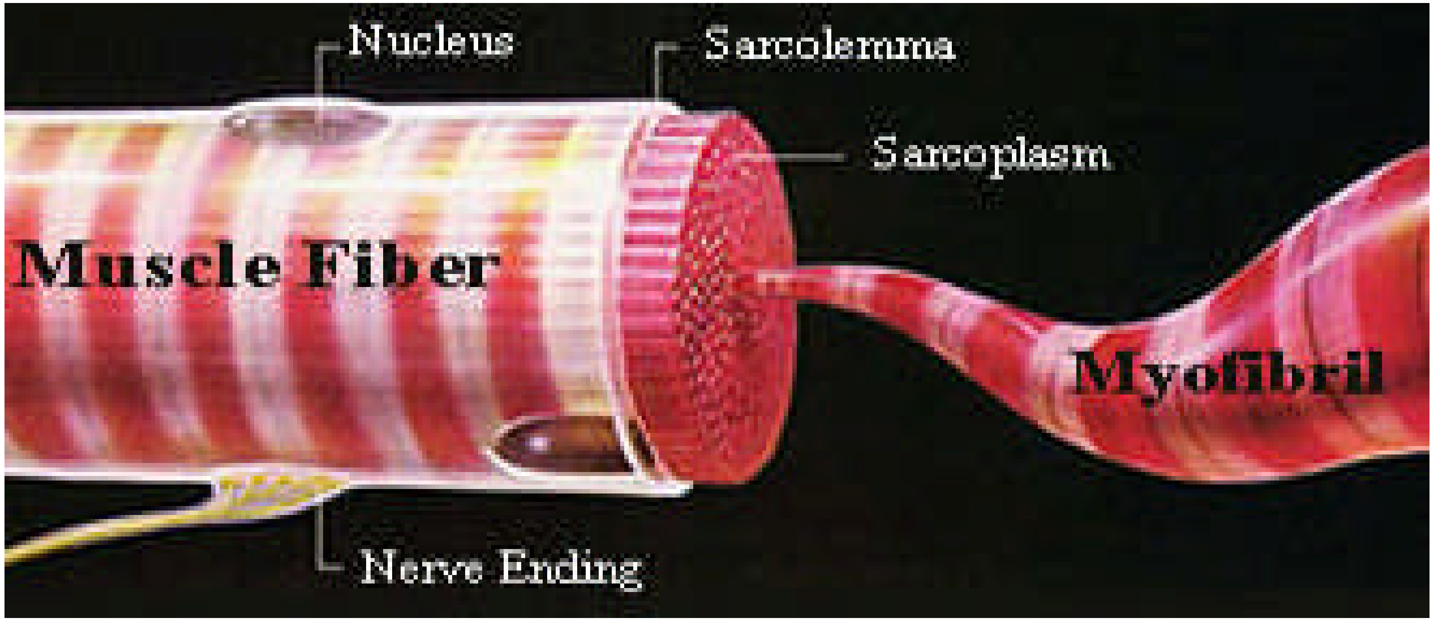
Sarcoplasmic Reticulum

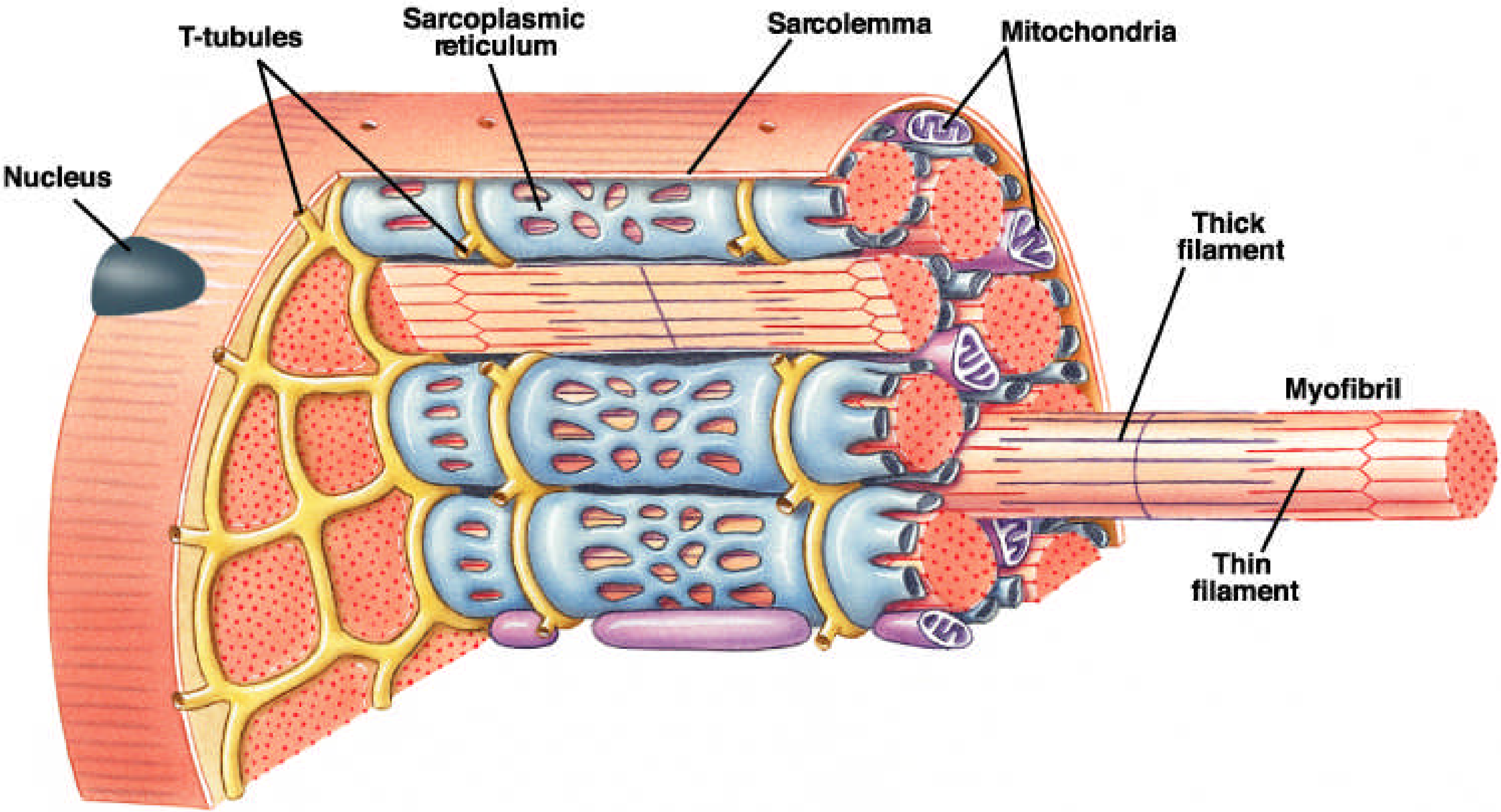
- Muscle cell version of the smooth endoplasmic reticulum.
- Functions as a calcium storage depot in muscle cells.
- Loose network of this membrane bound organelle surrounds all the myofibrils in a muscle fiber. We will see why this is so important soon.



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

- **Myofibers**

Myofibers

- **<u>Myofiber</u>= one muscle cell= muscle fiber**
- Myofiber is <u>syncytial</u> (multinucleate).
- Myofibers are long!

Myofibers

•In order of decreasing size…

•Myo**fiber**= entire cell.

•Myo**fibrils**: bundles of myofilaments inside myofiber.

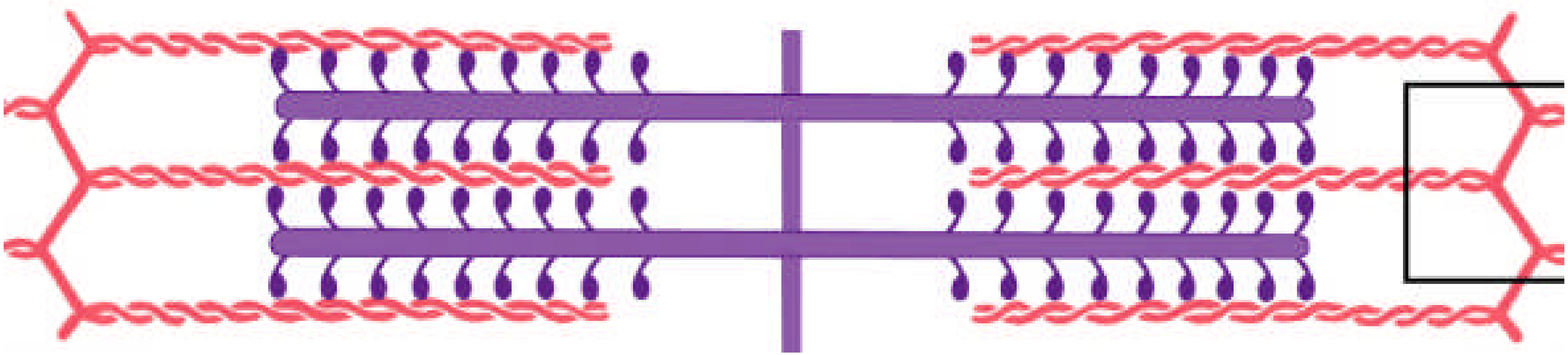
•Myo**filaments**: actin and myosin proteins.

Myofibrils

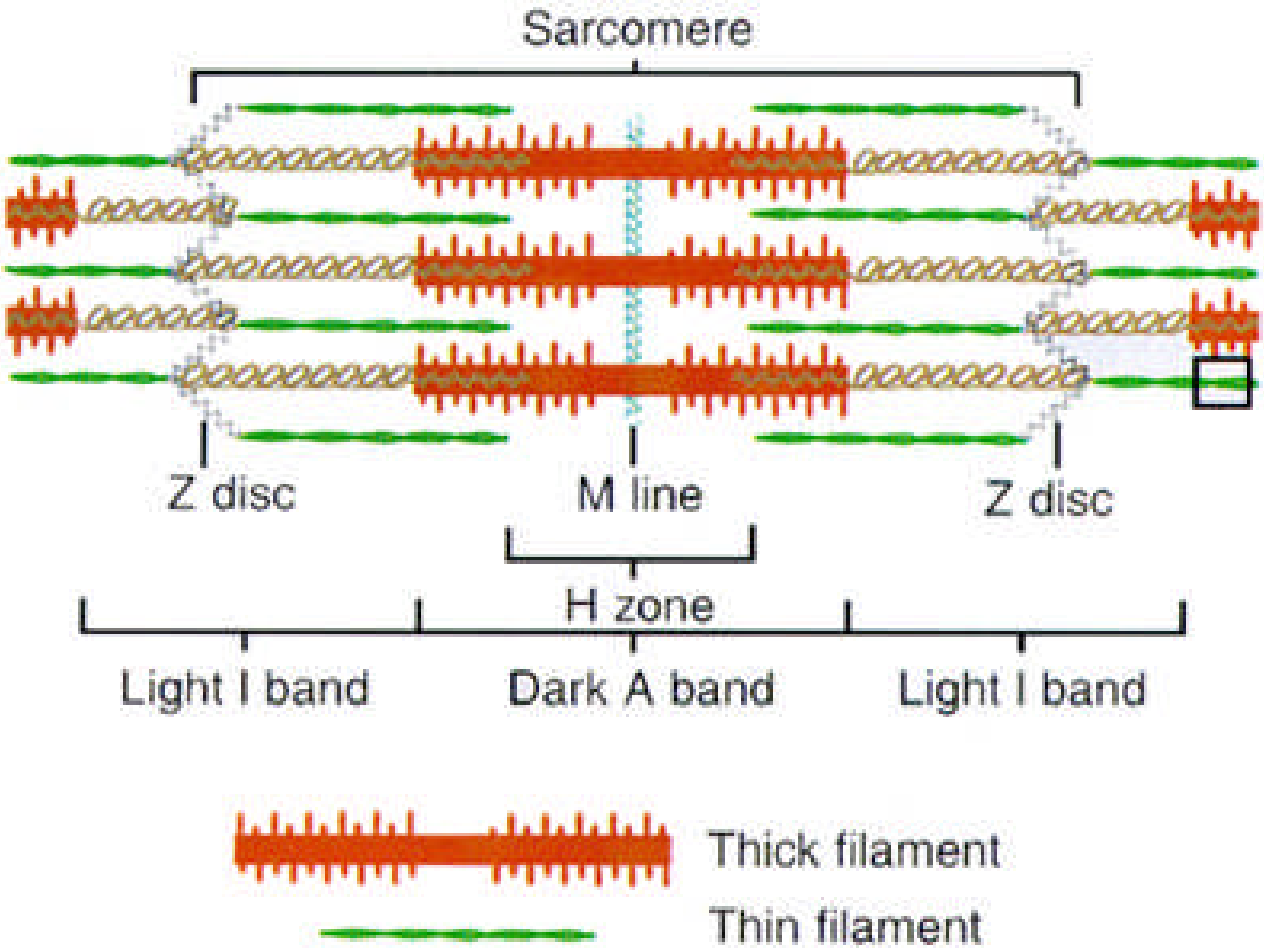
- Myofibrils are densely packed, rodlike contractile elements
- They make up most of the muscle volume
- The arrangement of myofibrils within a fiber is such that a perfectly aligned repeating series of dark A bands and light I bands is evident

Myofibrils

- Each myofibril is made up 1000's of repeating individual units known as sarcomeres (pictured below)
- 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.

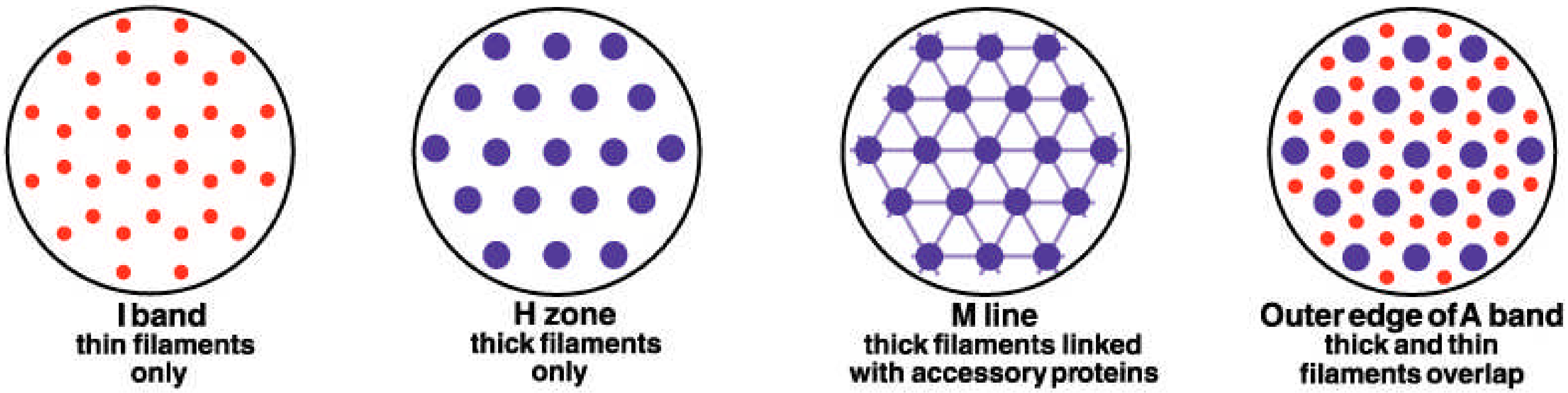


- The portion of the sarcomere which does not contain any thick filament is known as the I band. The I band contains only thin filament and is light under the microscope (*it is isotropic*).
  - One I band is actually part of 2 sarcomeres at once.



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?



Myofibrils

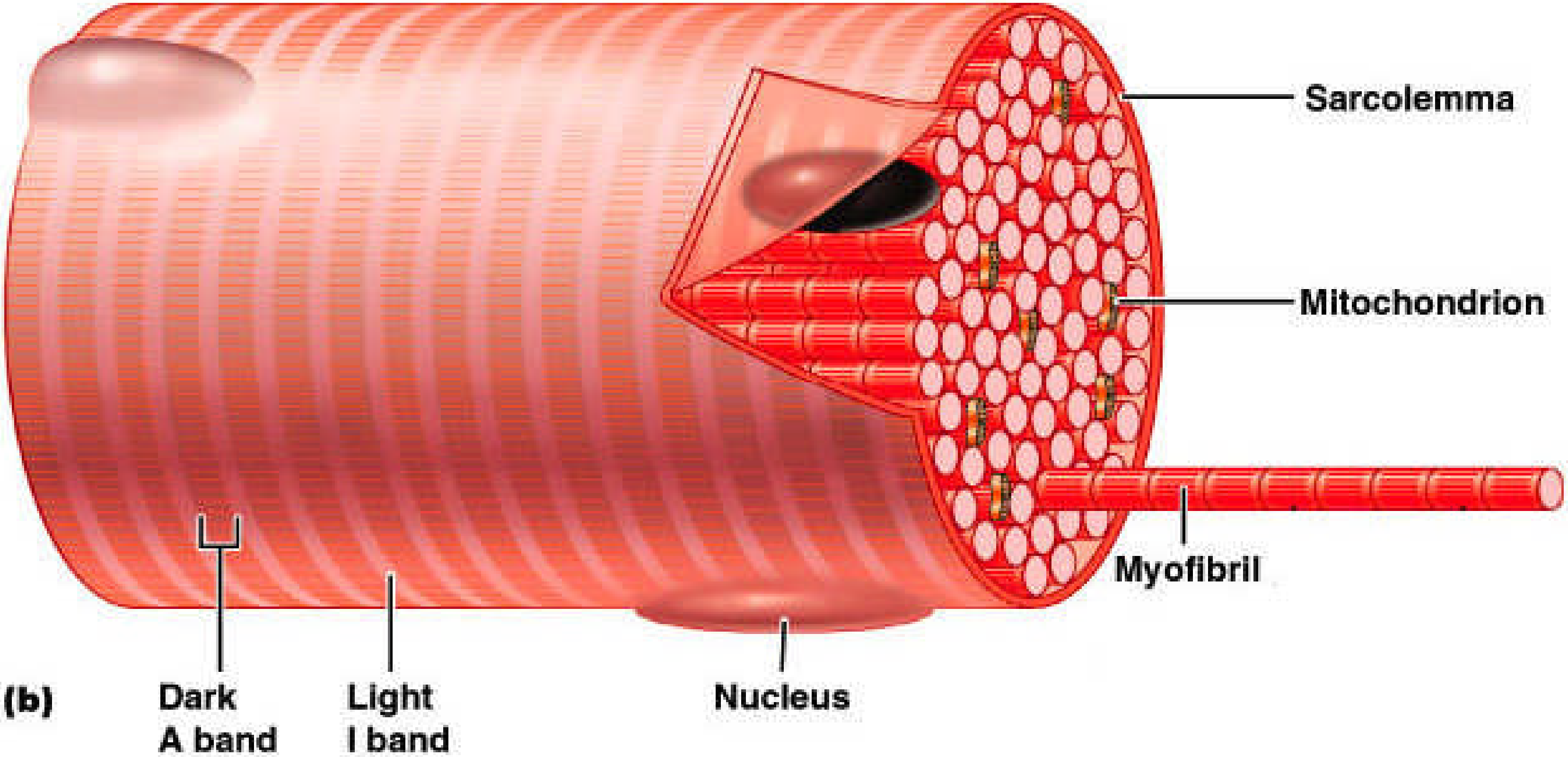


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Figure 9.3b

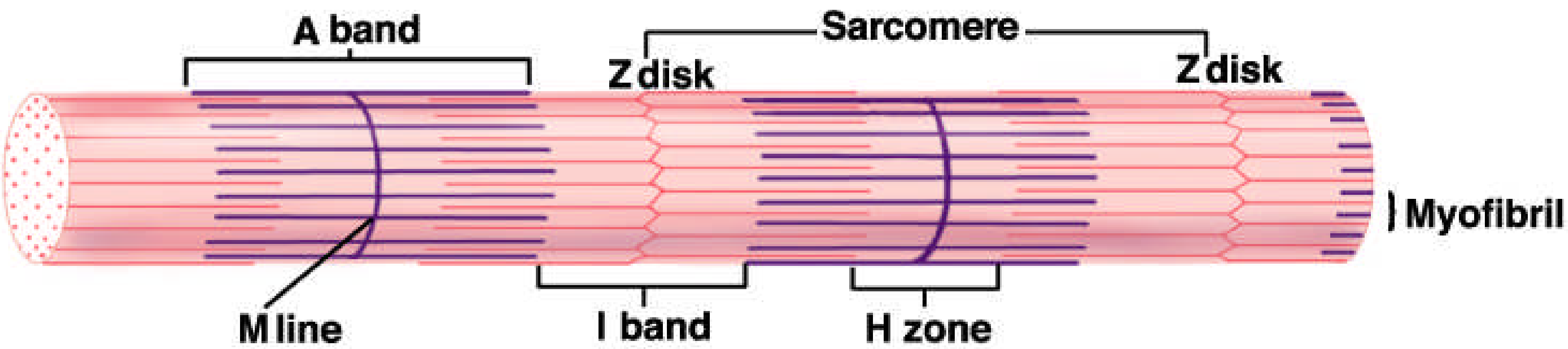
“SARCOTERMS”

- **Sarcolemma**: pm of myofiber
- **Sarcoplasm**: cytoplasm of myofiber
- **Sarcoplasmic reticulum (SR)**: ER of myofiber

- **Sarcomere:** contractile unit inside myofiber

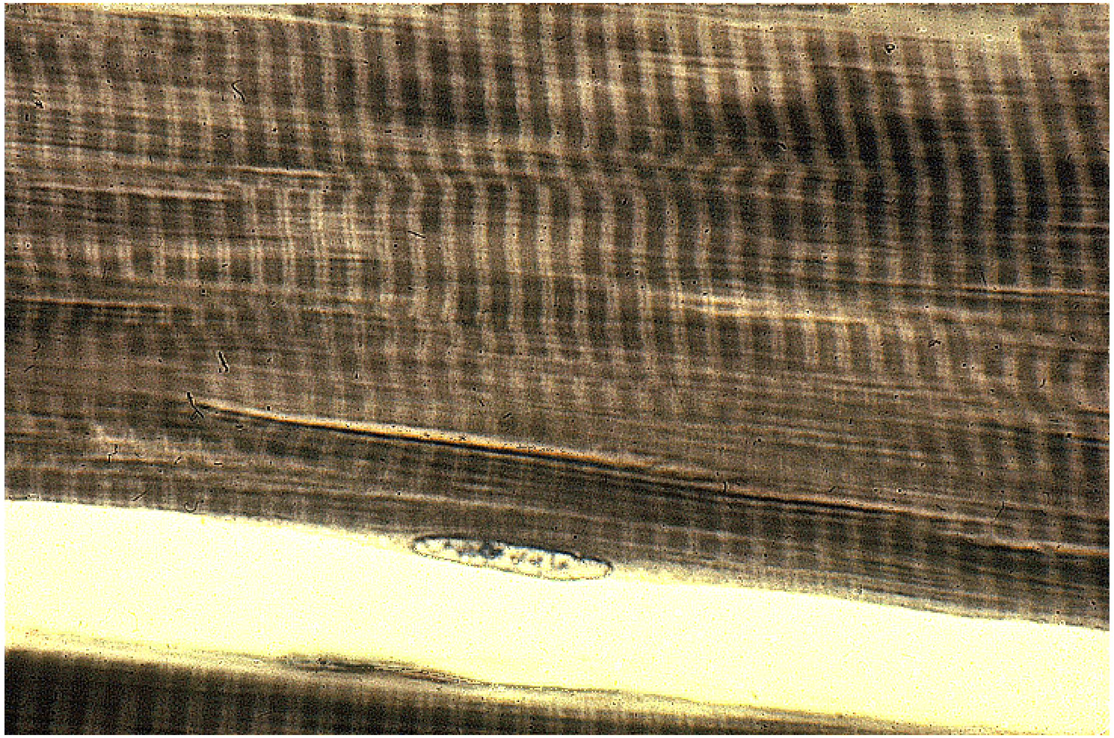
Sarcomere

- The sarcomere is flanked by 2 protein structures known as Z discs.
- The portion of the sarcomere which contains the thick filament is known as the A band. *A* stands for *anisotropic* which is a fancy way of saying that it appears dark under the microscope.
  - The A band contains a zone of overlap (btwn thick & thin filaments) and an H zone which contains only thick filaments

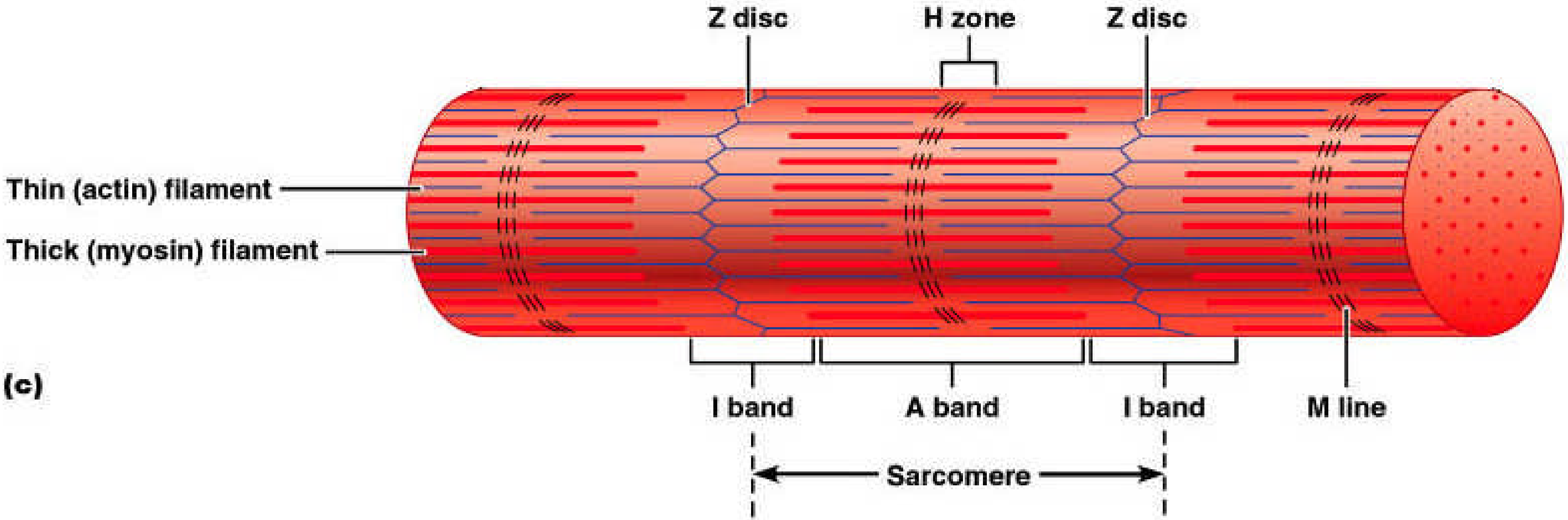


Sarcomeres

- 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



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Anatomy Review: Skeletal Muscle Tissue, page 9

Figure 9.3c

Myofilaments: Banding Pattern

- 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

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

Myofilaments: Banding Pattern

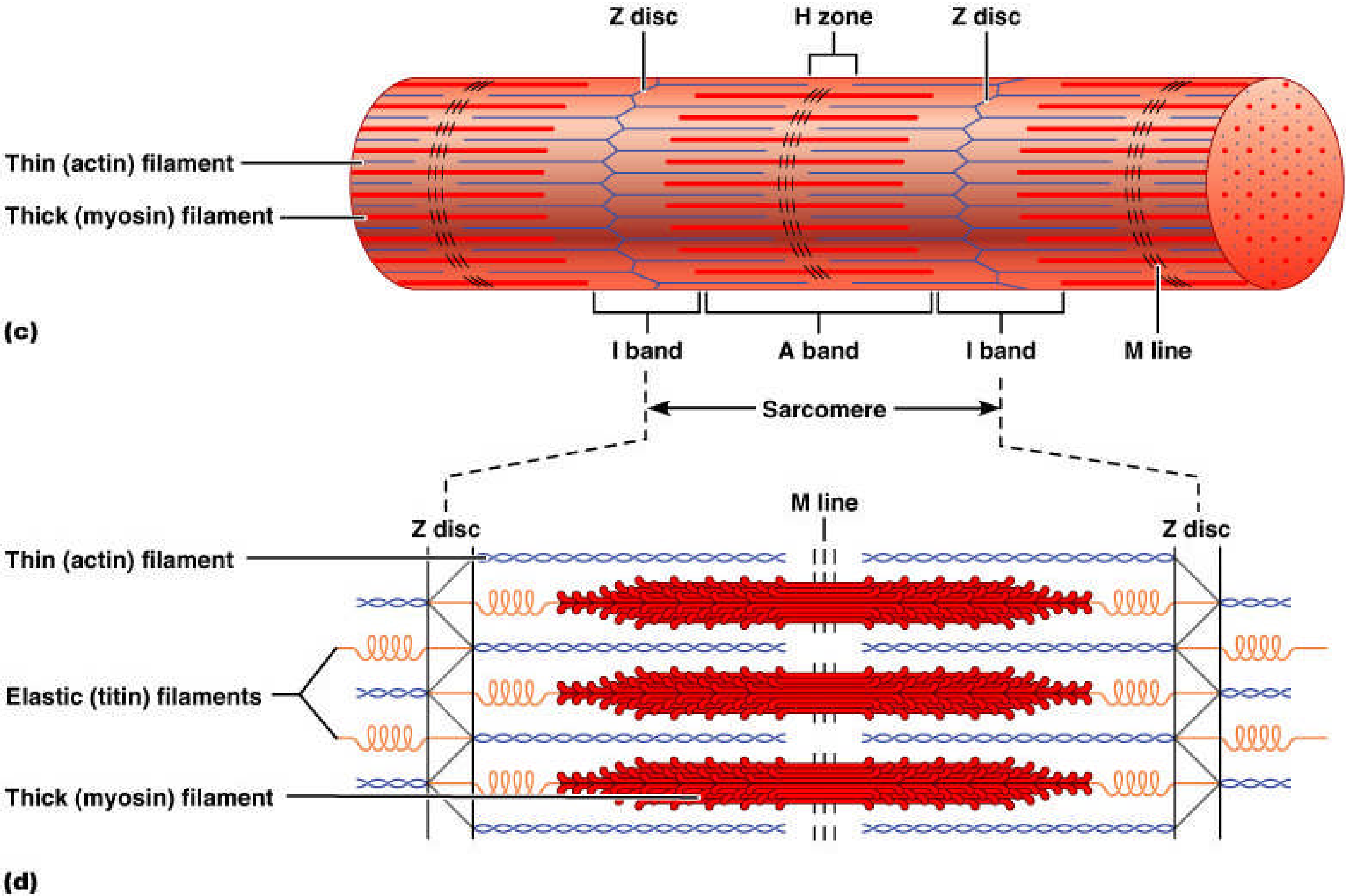


Figure 9.3c,d

Structure and Organization of

TABLE 9.1 Structure and Organizational Levels of Skeletal Muscle

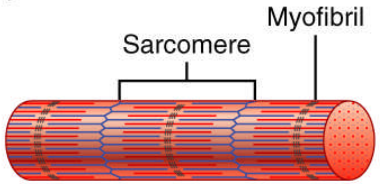
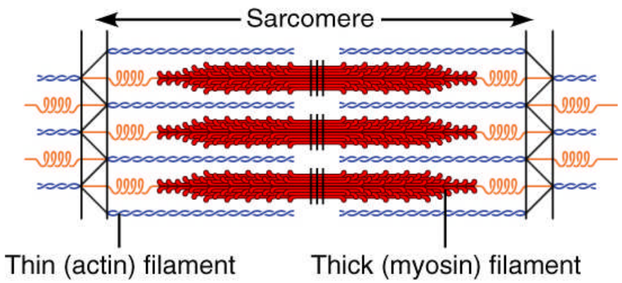
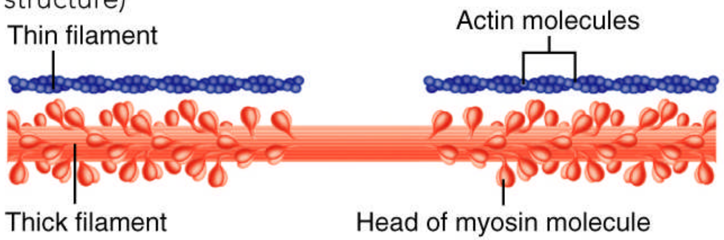
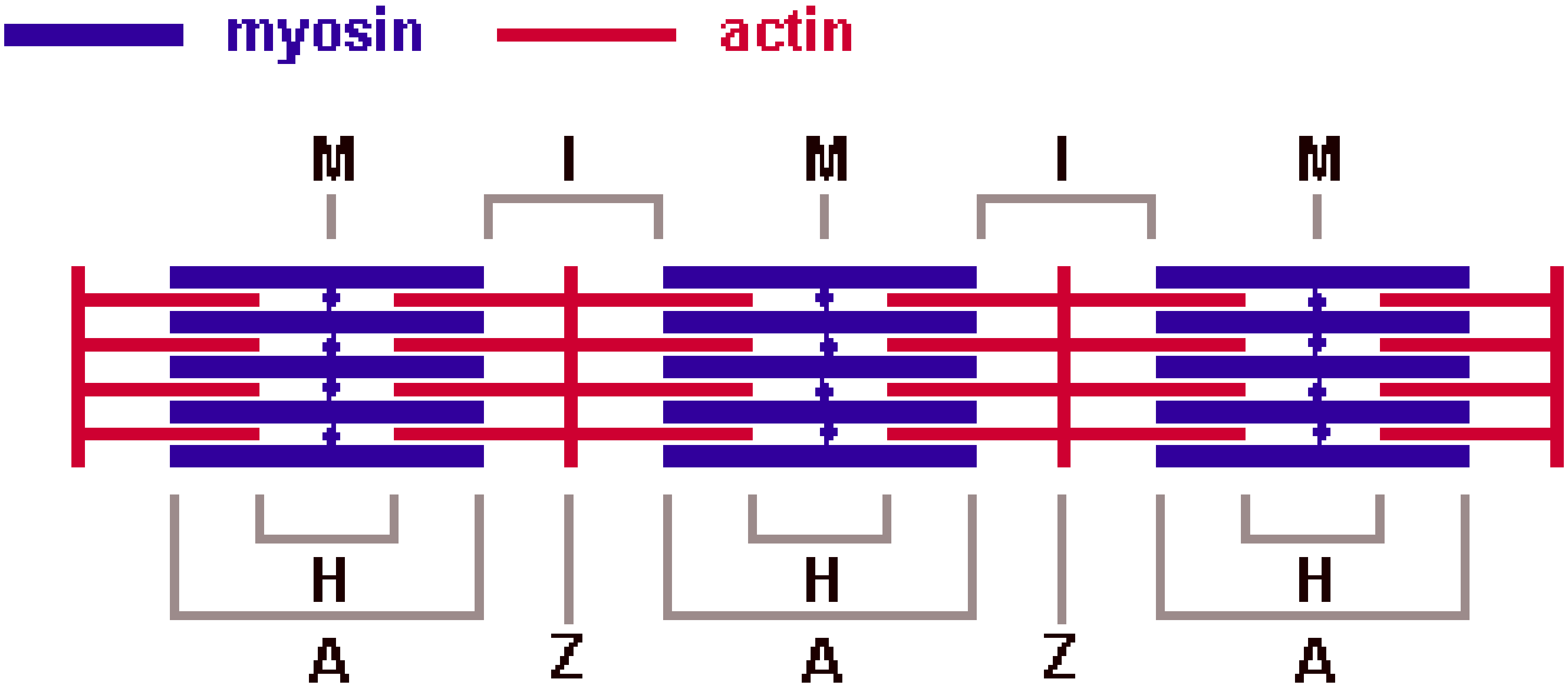
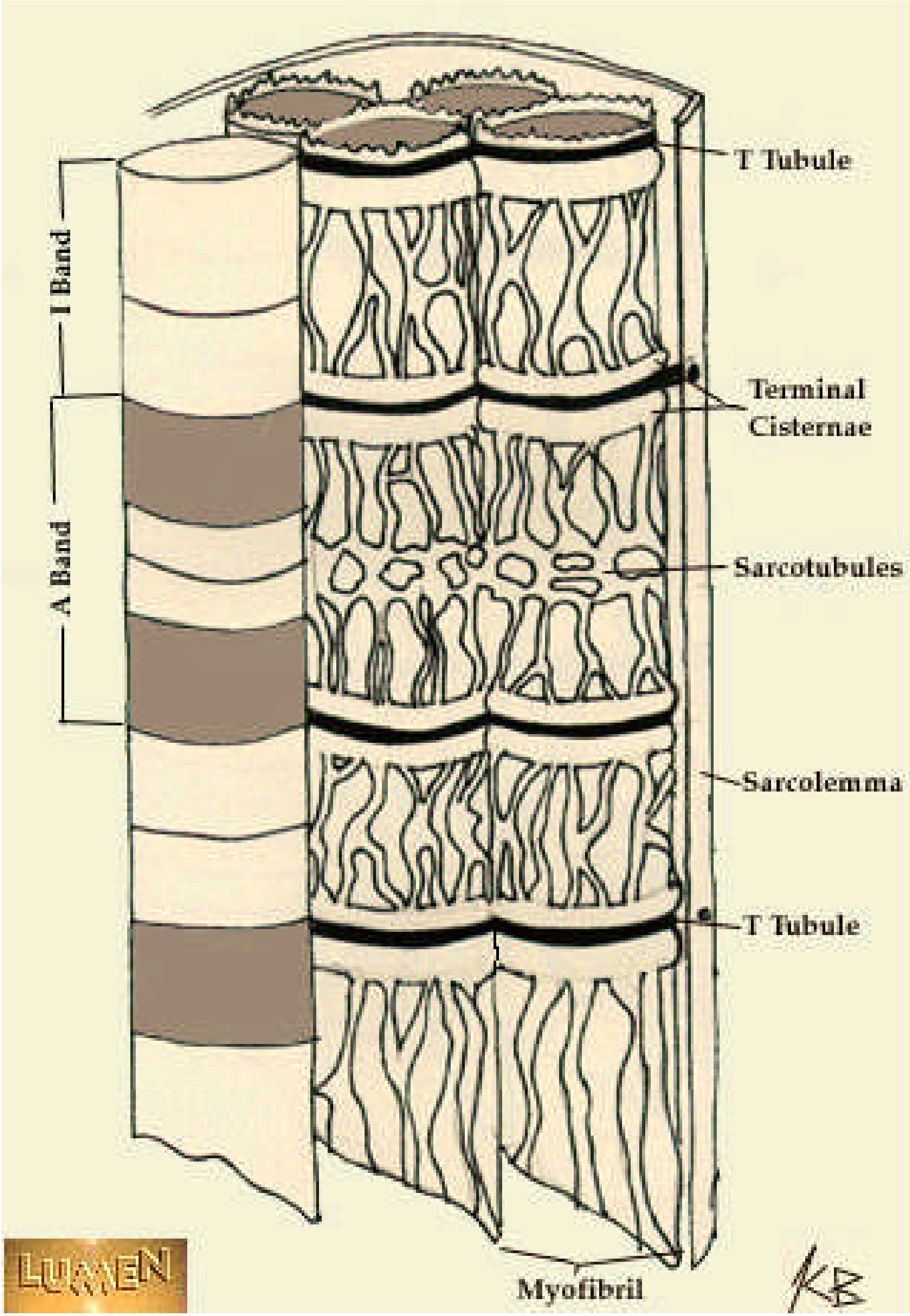
STRUCTURE AND ORGANIZATIONAL LEVEL	DESCRIPTION	CONNECTIVE TISSUE WRAPPINGS
Myofibril or fibril (complex organelle composed of bundles of myofilaments) 	Rodlike contractile element; myofibrils occupy most of the muscle cell volume; composed of sarcomeres arranged end to end; appear banded, and bands of 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	

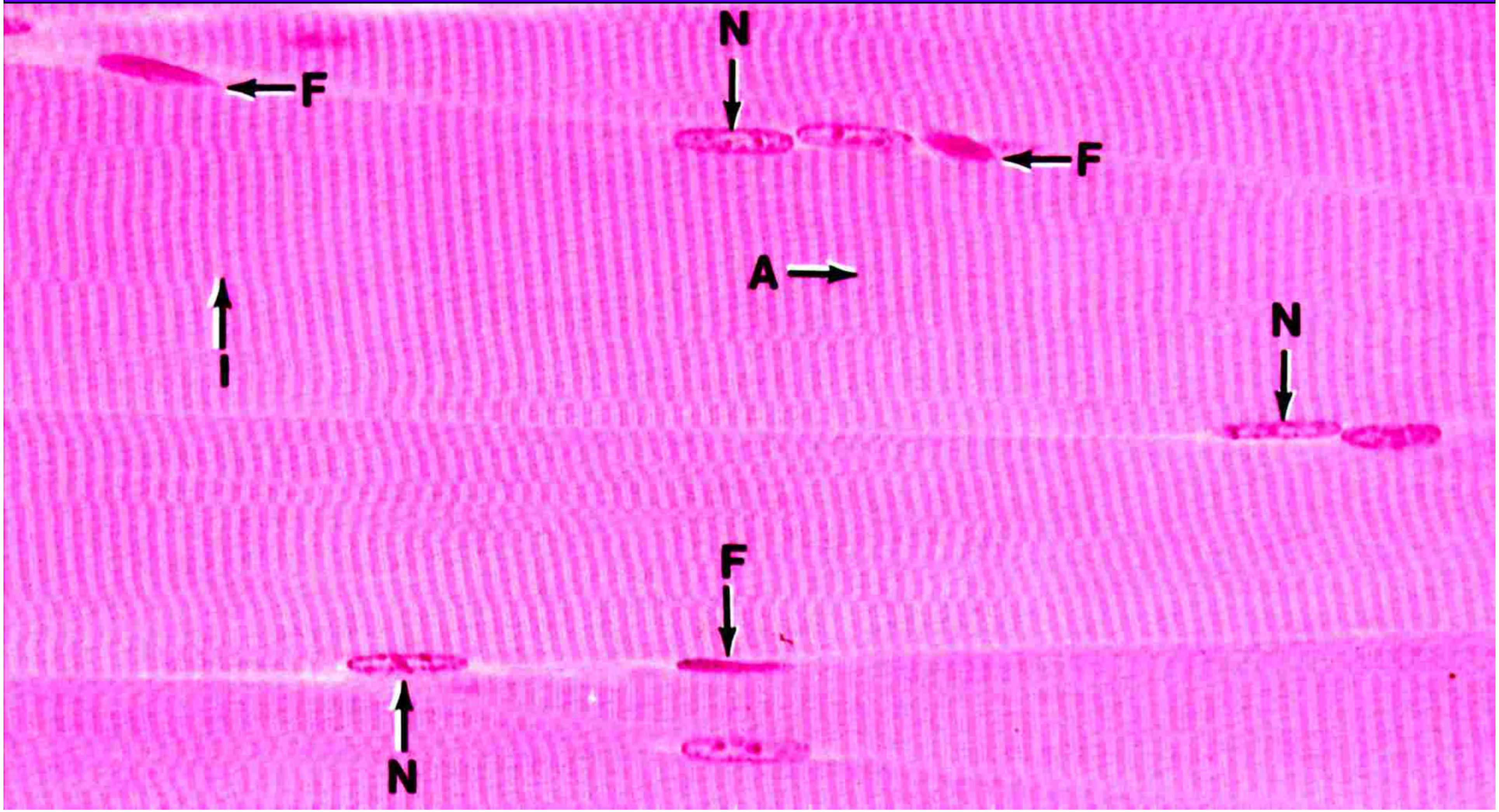
Table 9.1b

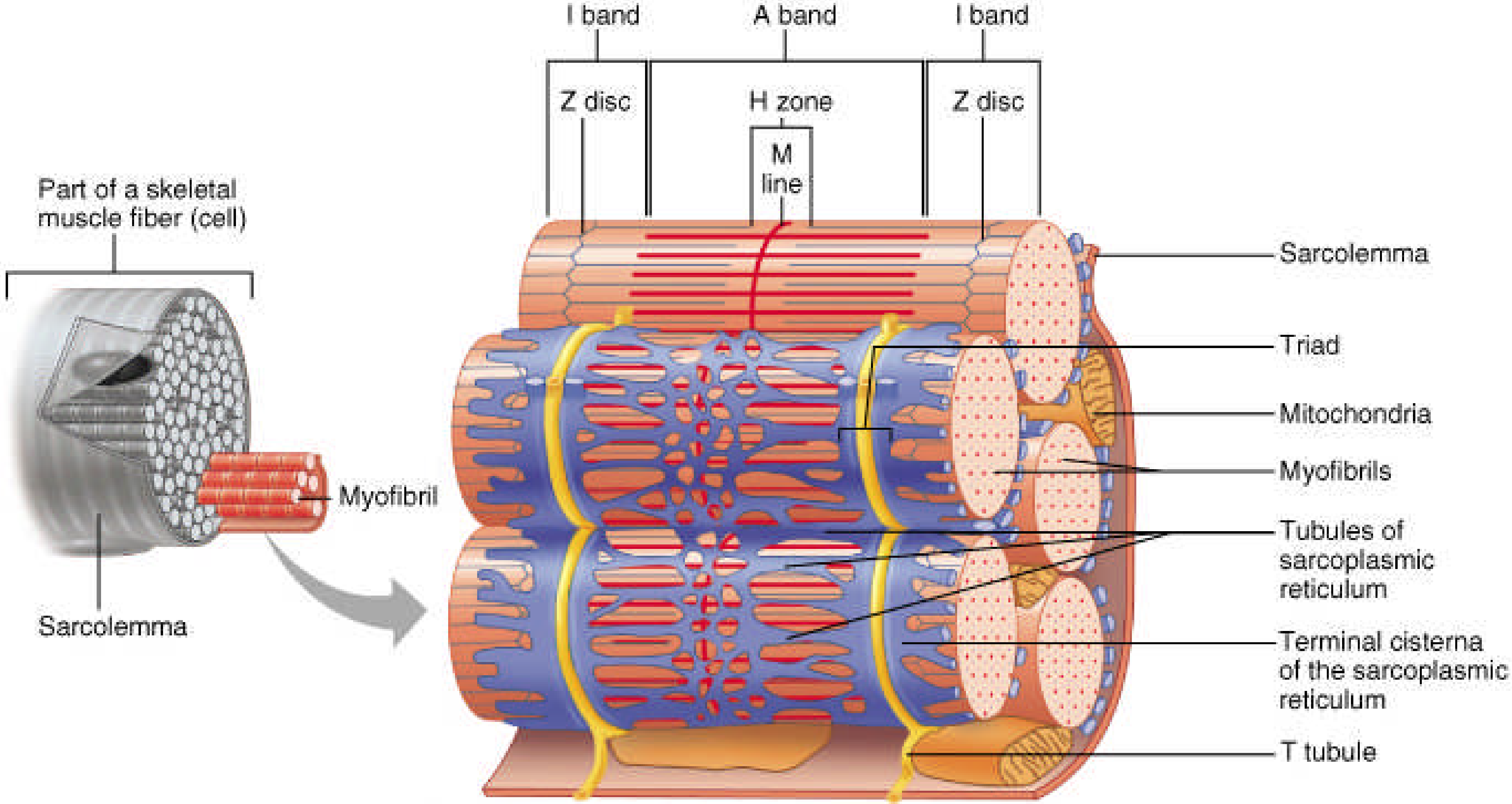


Bands and lines in the contractile apparatus of skeletal muscle


T Tubule
I Band
A Band
Terminal Cisternae
Sarcotubules
Sarcolemma
T Tubule
Myofibril
LUMEN
KB

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?

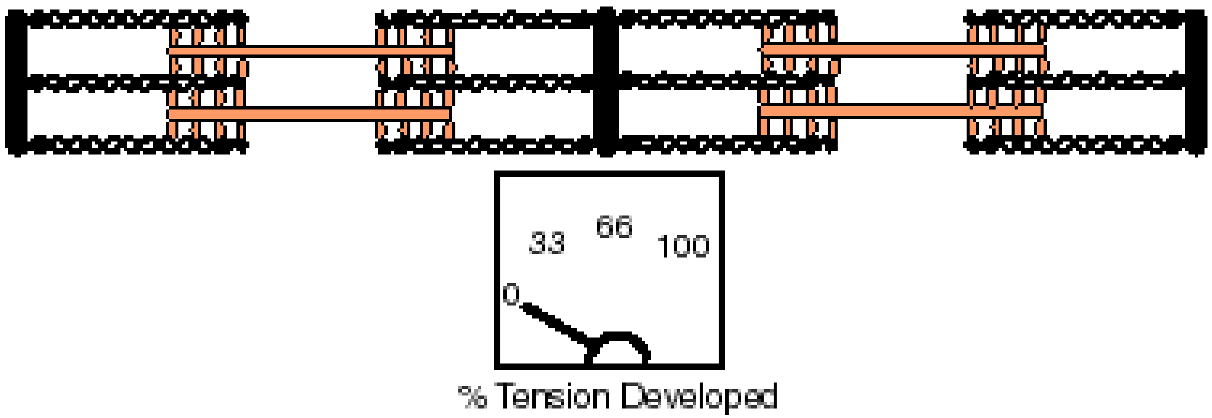




Part of a skeletal muscle fiber (cell)
Myofibril
Sarcolemma
I band
A band
I band
Z disc
H zone
Z disc
M line
Sarcolemma
Triad
Mitochondria
Myofibrils
Tubules of sarcoplasmic reticulum
Terminal cisterna of the sarcoplasmic reticulum
T tubule

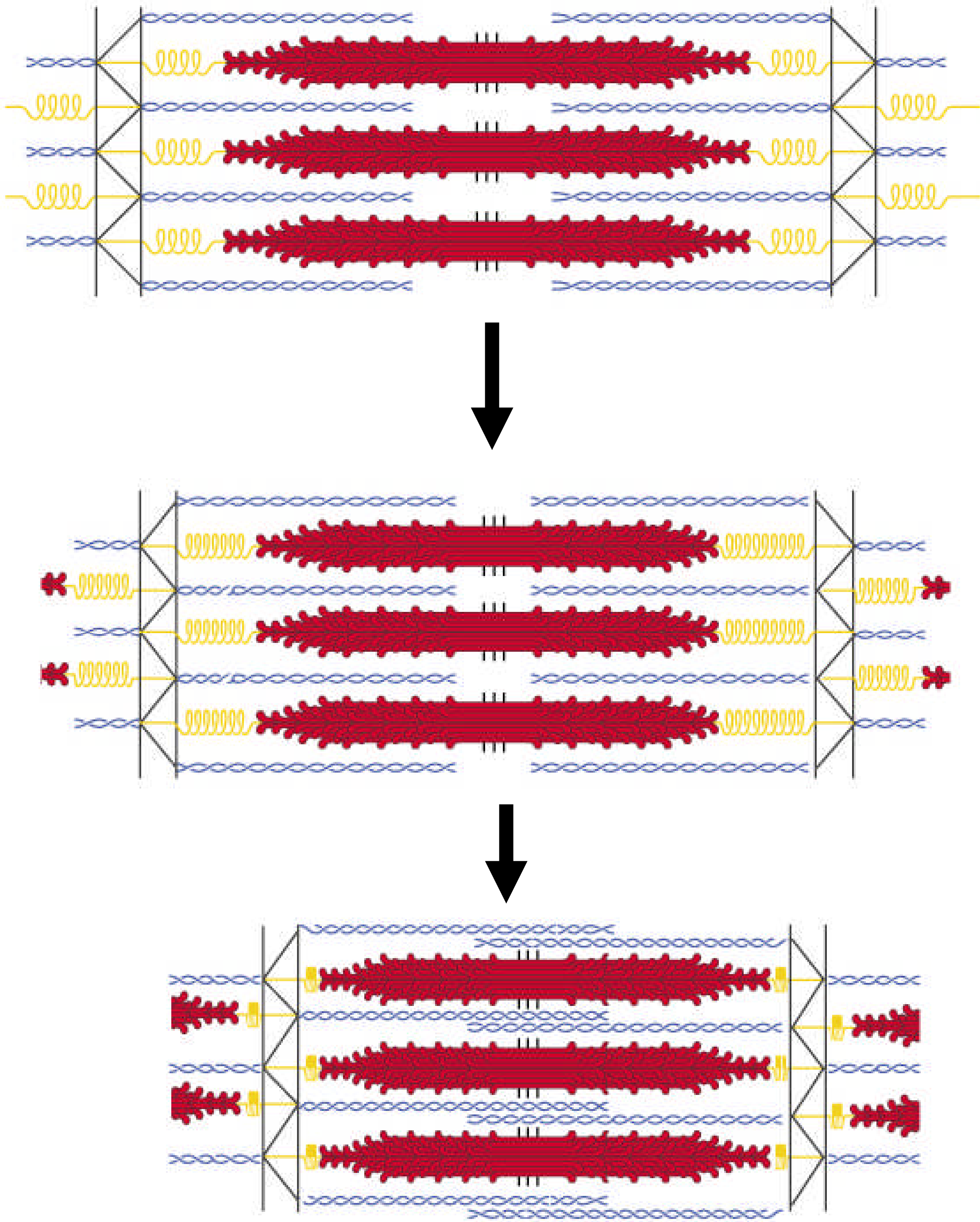
Muscle Contraction: The Sliding Filament Hypothesis

- 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 b

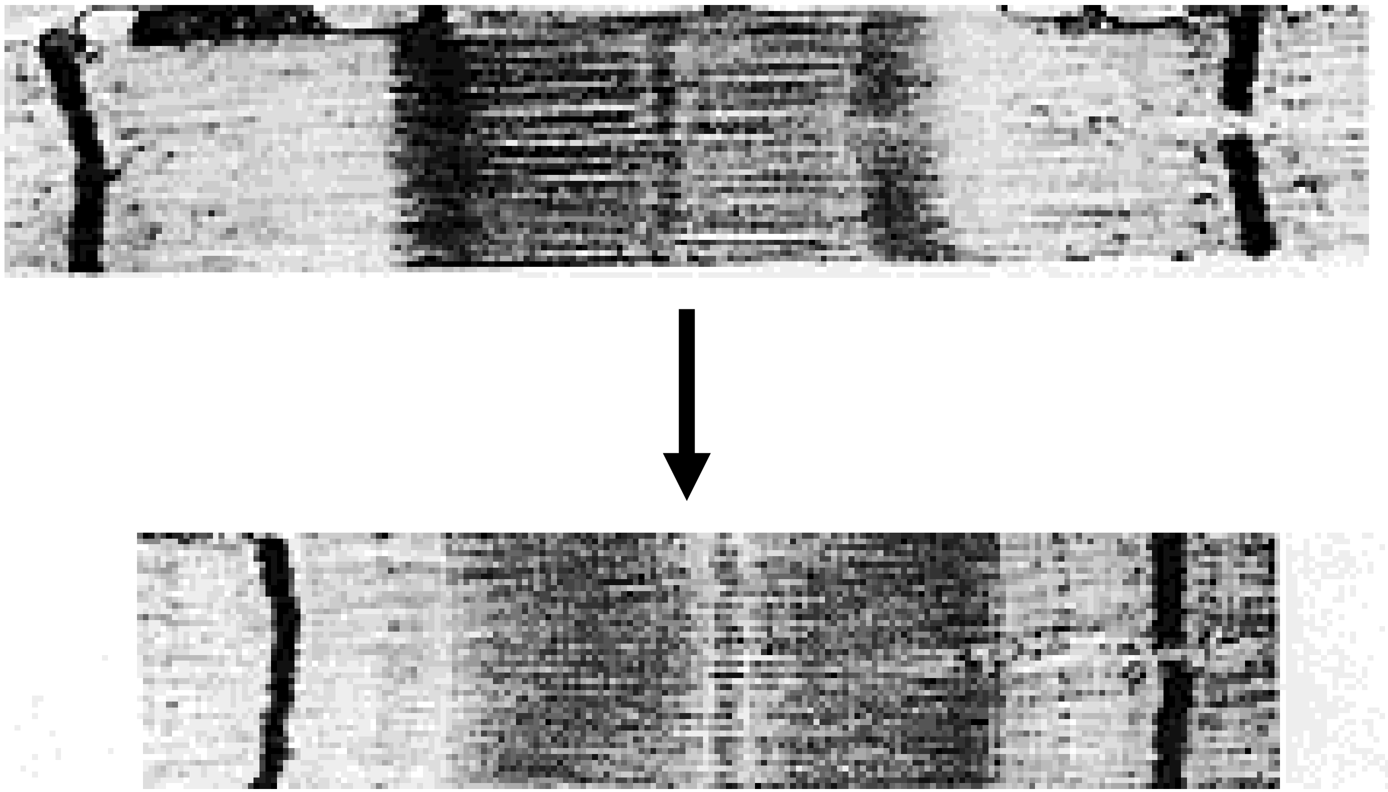


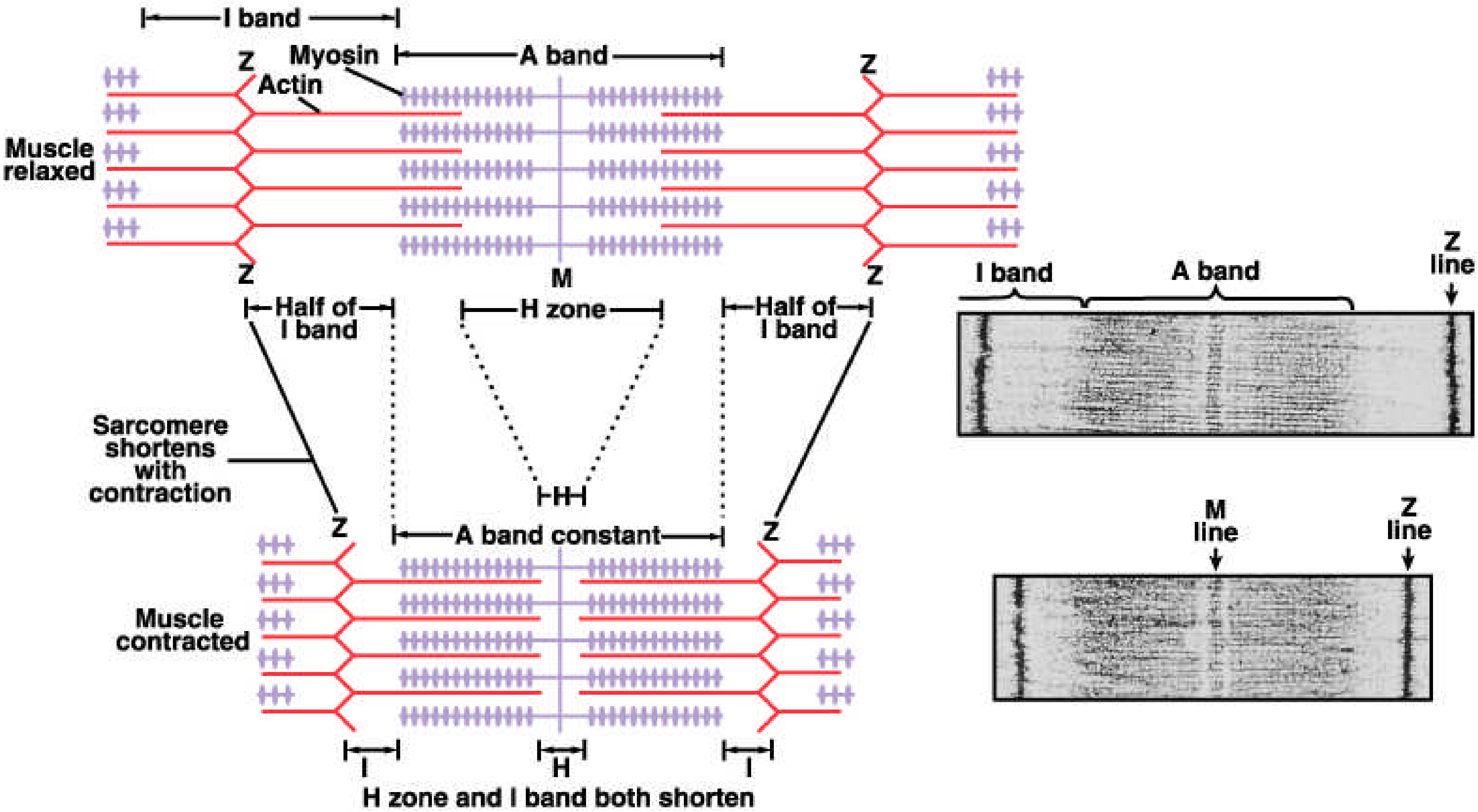
Here is what happens as the filaments slide and the sarcomere and the muscle fiber shortens.
In the process of contraction,
what happens to the:

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?



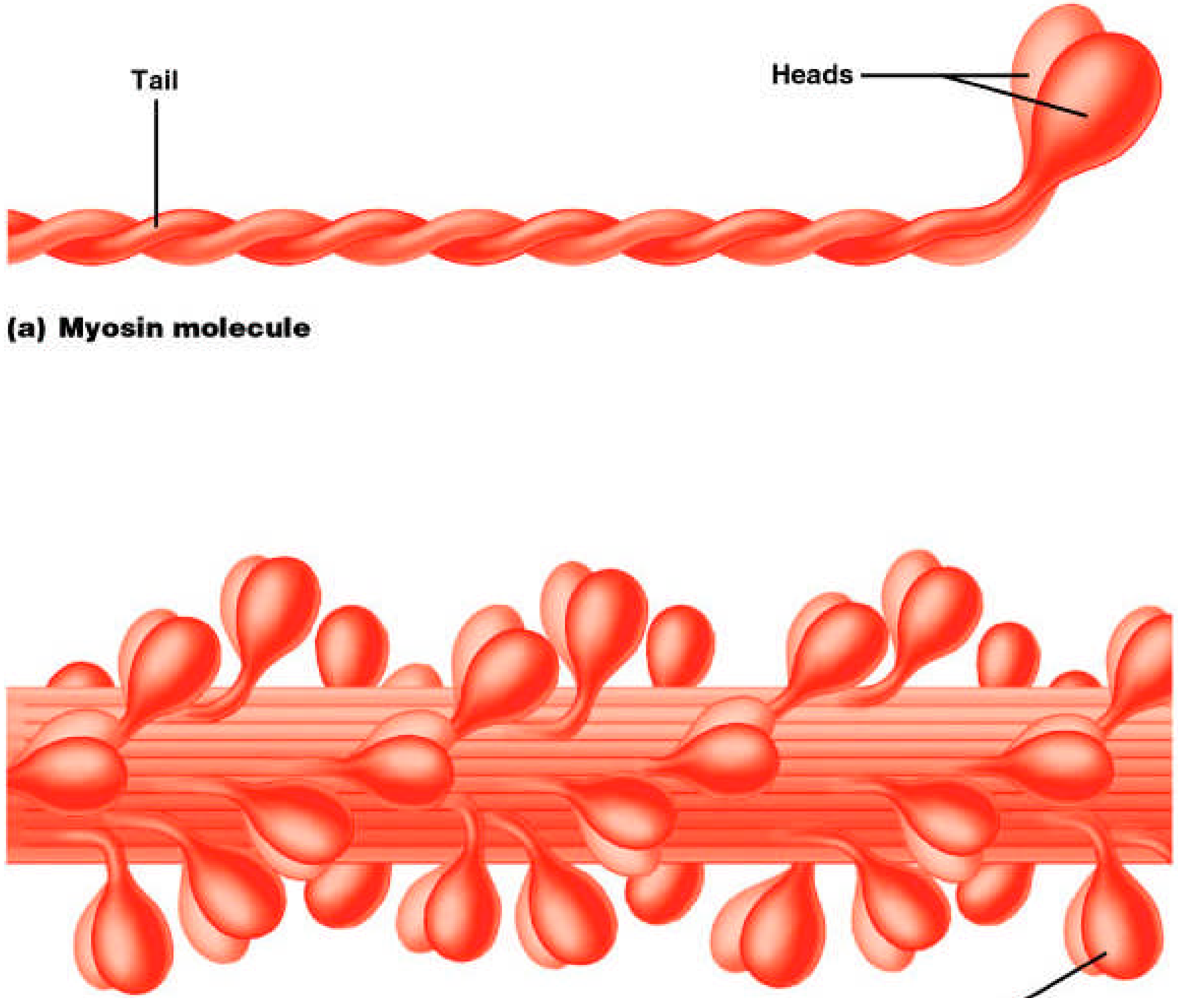


I band
Z
Myosin
A band
Actin
Z
Muscle relaxed
Z
M
Z
Half of I band
H zone
Half of I band
Sarcomere shortens with contraction
H
Z
A band constant
Z
Muscle contracted
I
H
I
H zone and I band both shorten
I band
A band
Z line
M line
Z line

Ultrastructure of Myofilaments: Thick Filaments

- Thick filaments are composed of the protein myosin
- Each myosin molecule has a rod-like tail and two globular heads
  - Tails – two interwoven, heavy polypeptide chains
  - Heads – two smaller, light polypeptide chains called cross bridges

Ultrastructure of Myofilaments:



(a) Myosin molecule

(b) Portion of a thick filament

Figure 9.4a,b

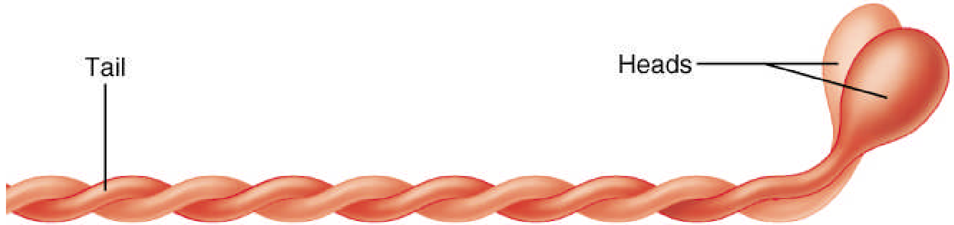
Ultrastructure of Myofilaments: Thin Filaments

- 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

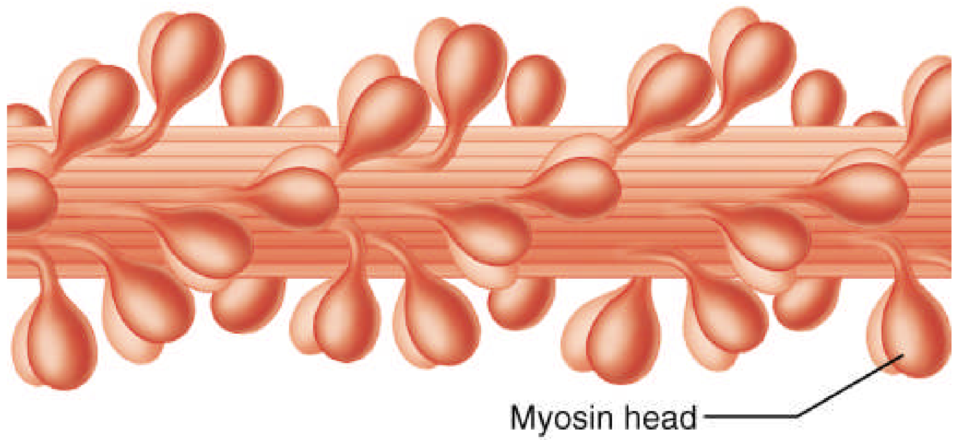
Myofilaments

- 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

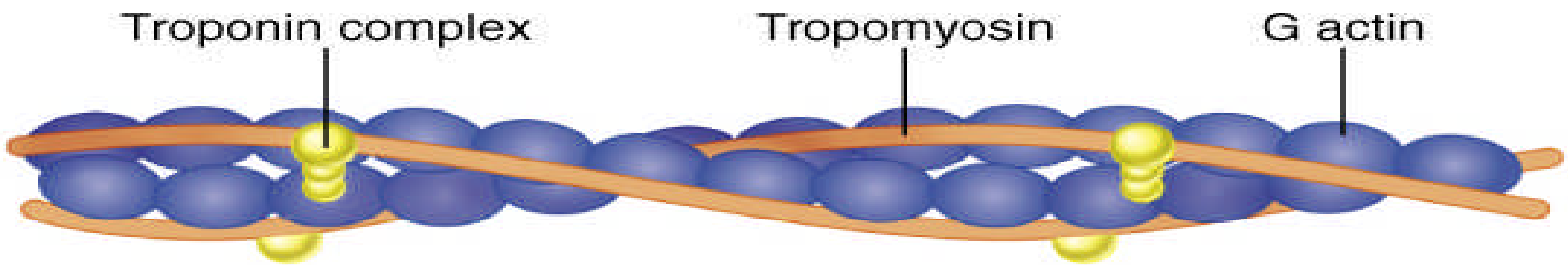


About 300 of these myosin molecules are joined together to form a single thick filament

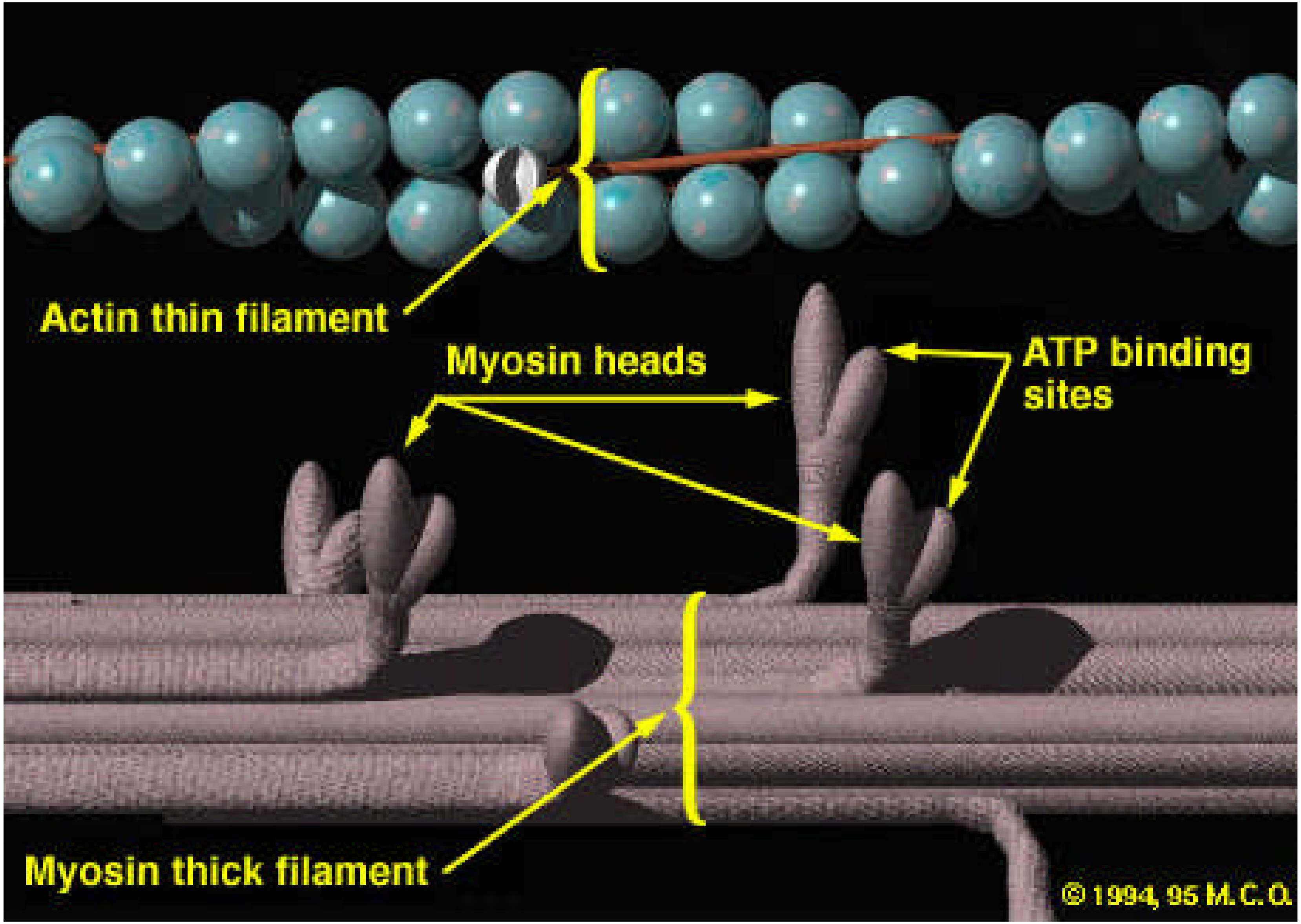


Portion of a thick filament

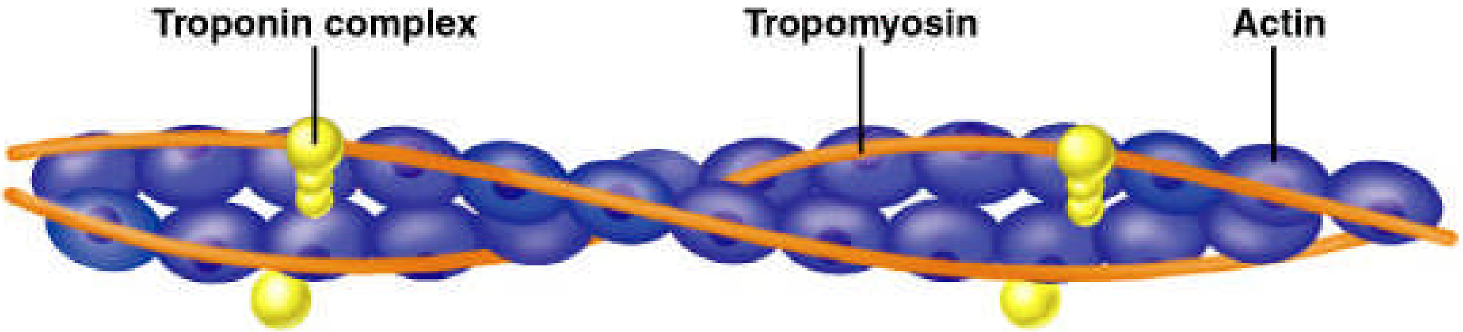
- Each thin filament is made up of 3 different types of protein: actin, tropomyosin, and troponin.
  - Each thin filament consists of a long helical double strand. This strand is a polymer that resembles a string of beads. Each “bead” is the globular protein actin. On each actin subunit, there is a myosin 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.



Note the relationship between the thin and thick filaments



Ultrastructure of Myofilaments: Thin Filaments

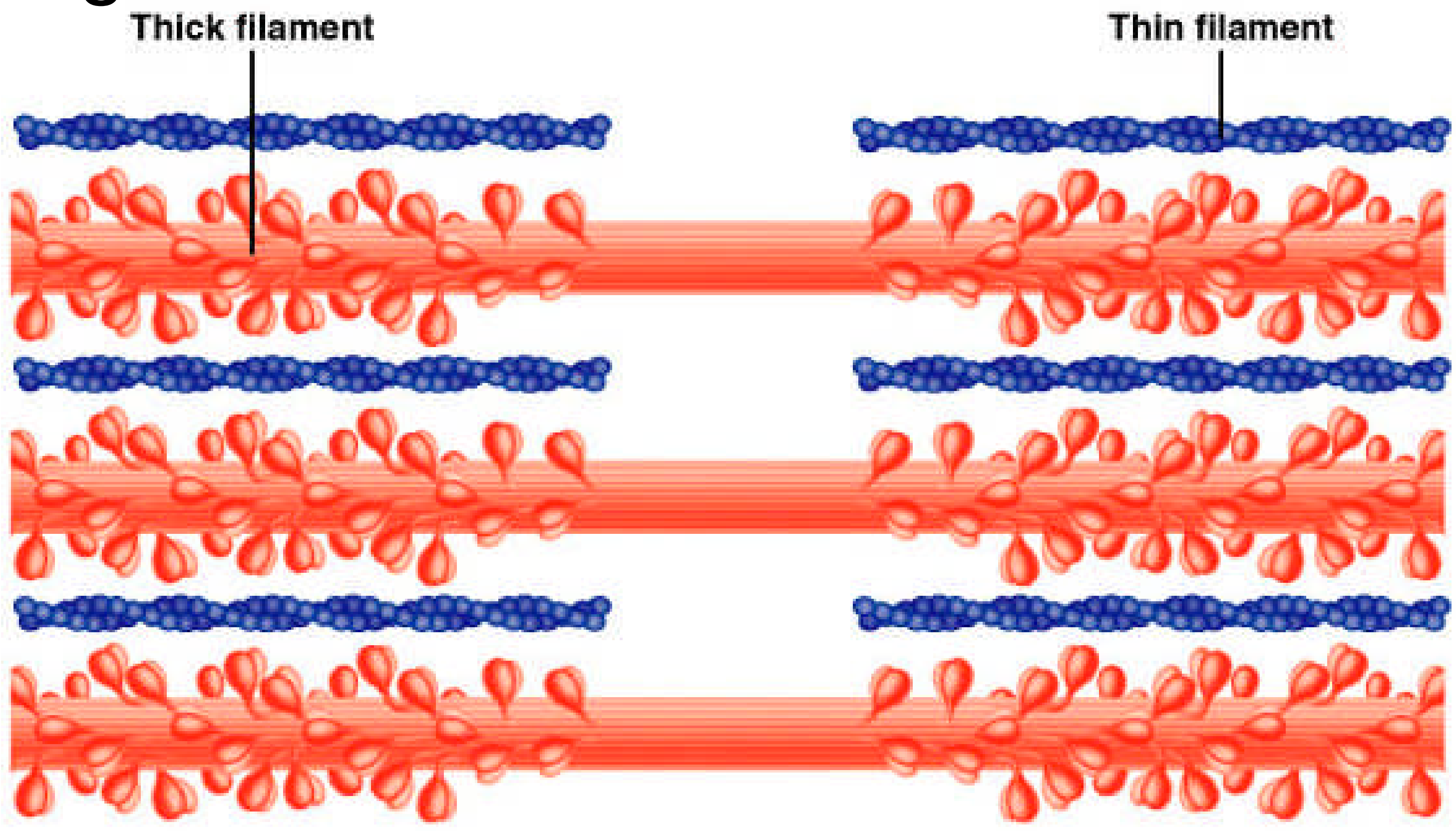


(c) Portion of a thin filament

Figure 9.4c

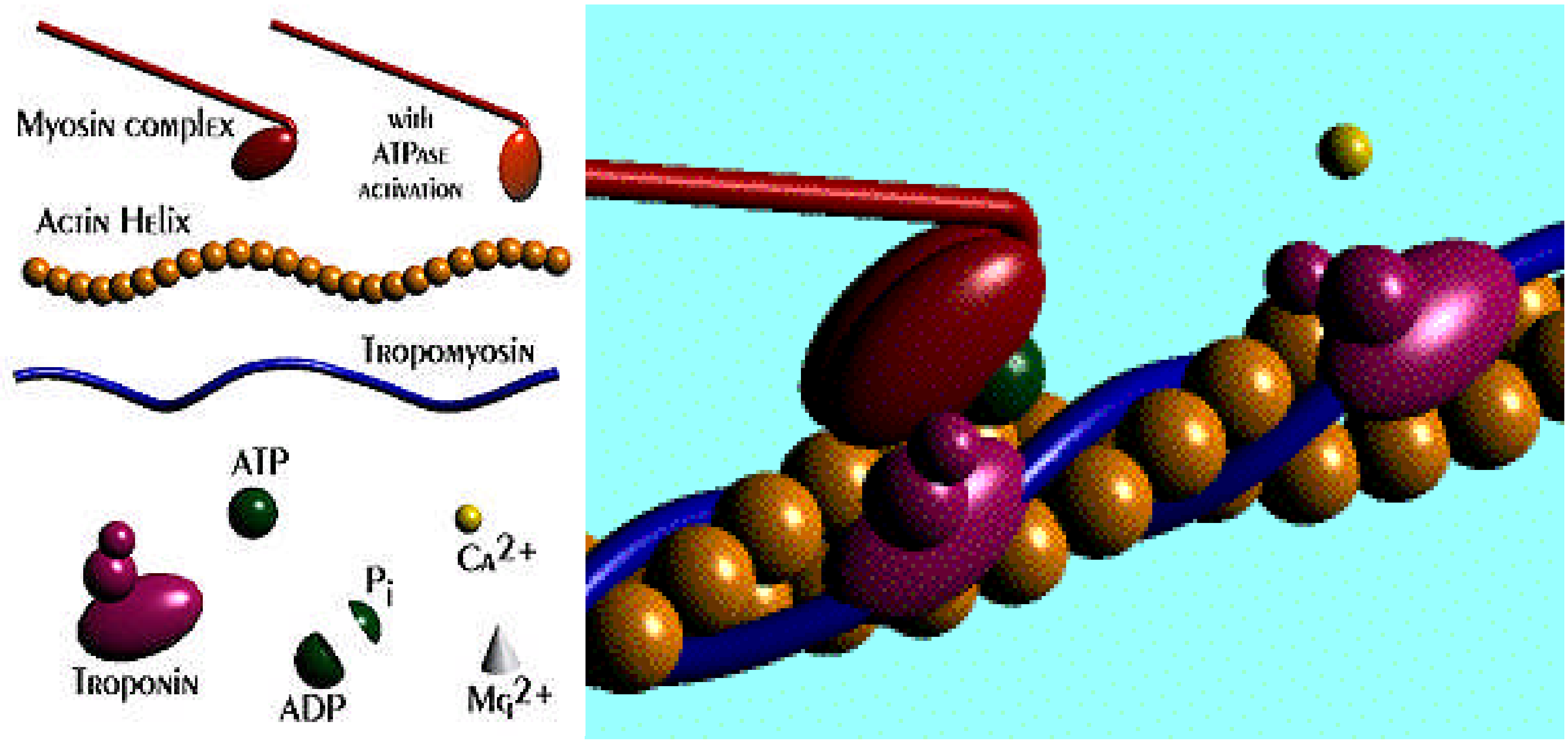
Arrangement of the Filaments in a Sarcomere

- Longitudinal section within one sarcomere



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

Figure 9.4d



Actin Myosin Crossbridge 3D Animation

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

Sarcoplasmic Reticulum (SR)

- 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)

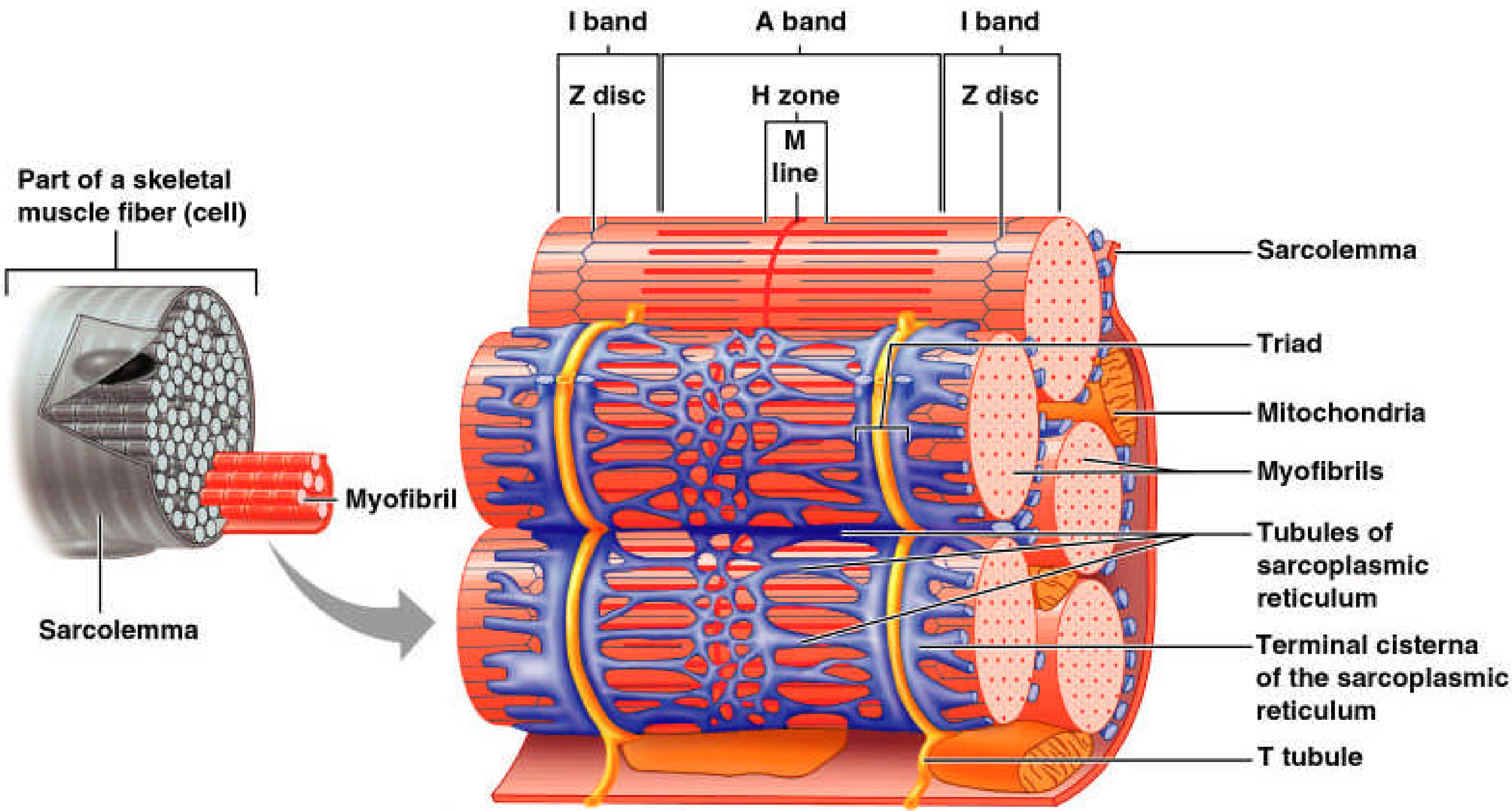


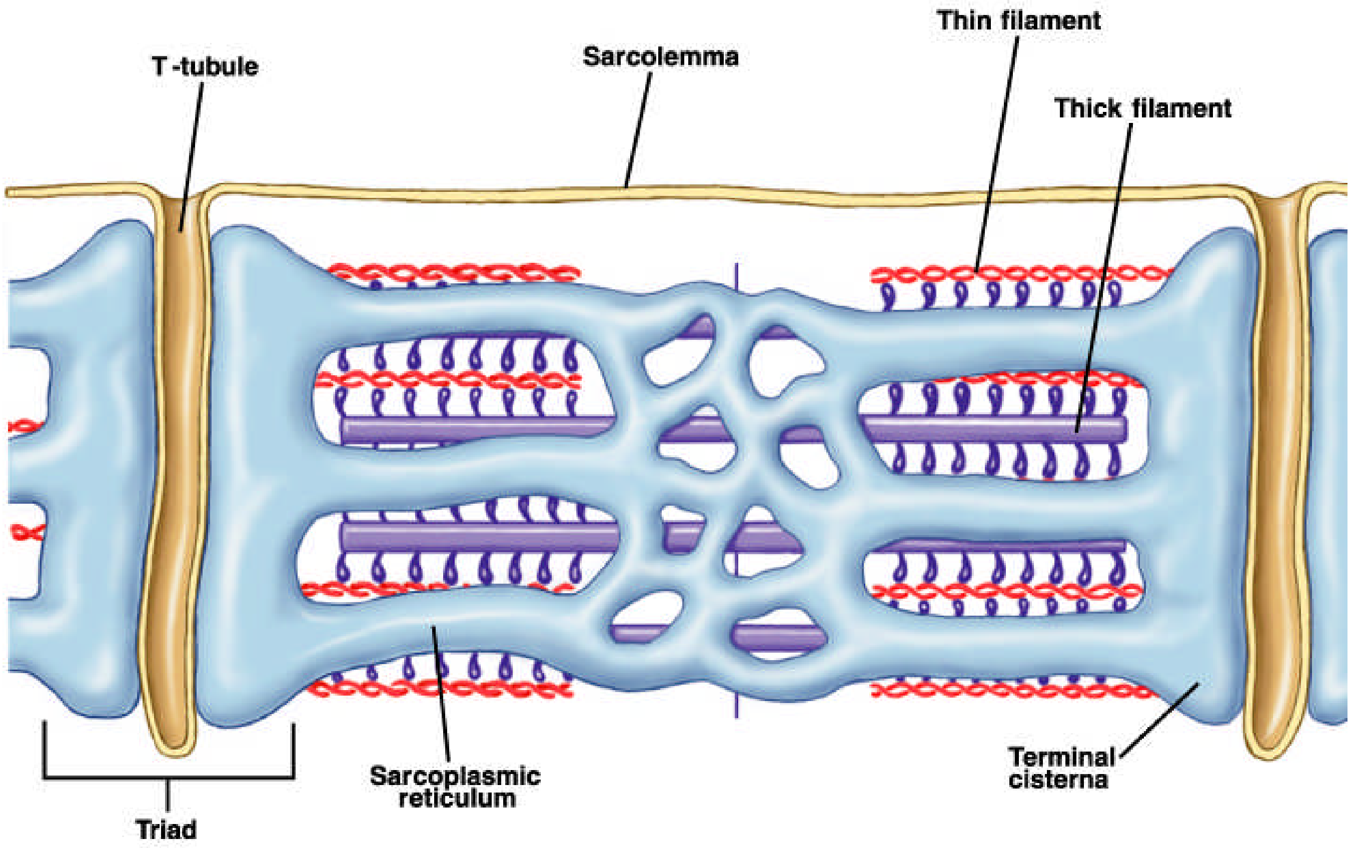
Figure 9.5

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.

Triad Relationships

- T tubules and SR provide tightly linked signals for muscle contraction
- A double zipper of integral membrane proteins protrudes into the intermembrane space
- T tubule proteins act as voltage sensors
- SR foot proteins are receptors that regulate Ca^{2+} release from the SR cisternae

PLAY

InterActive Physiology ®:
Anatomy Review: Skeletal Muscle Tissue, page 10

Sliding Filament Model of Contraction

- Thin filaments slide past the thick ones so that the actin and myosin filaments overlap to a greater degree
- In the relaxed state, thin and thick filaments overlap only slightly
- Upon stimulation, myosin heads bind to actin and sliding begins

SKELETAL MUSCLE

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 tobone.

•Most moveable attachment is **insertion**

•Least moveable attachment is **origin**

•**Aponeurosis**is a flattened sheet like muscle attachment.

•Four principal fiber patterns in skeletal muscle

1.Parallel fibers [rectus abdominus]
2.Convergent fibers [pectoralismajor]
3.Circular fibers [orbicularis oris]
4.Pennatefibers [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.

SKELETAL MUSCLE

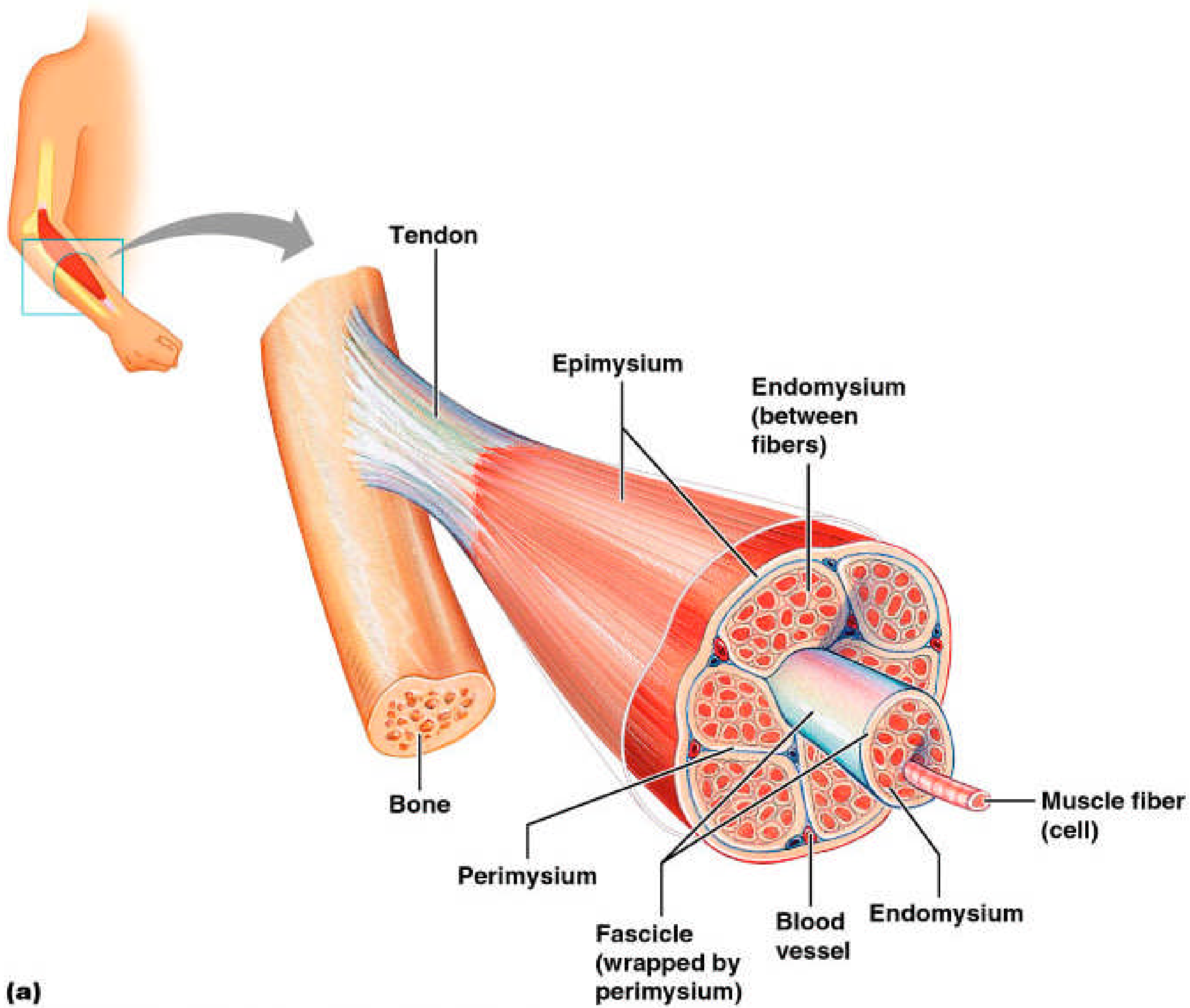
I. CELLS (FIBERS)
1) Very long compared with most other cells, up to several cm long, 10-100 micrometers in diameter
2) Multinucleate, nuclei are located peripherally
3) Development:
Mesenchymal cell ---> Myoblast (proliferative) ---> Myotubule ---> Muscle Cell

II. ARRANGEMENT OF FIBERS - similar to tendon arrangement
- Blood vessels, lymph vessels, and nerves penetrate muscle with perimysium
- Endomysium contains capillaries and nerve fibers

III. STRIATION ULTRASTRUCTURE (Fibers ---> Myofibrils ---> Myofilaments)
- Proteins are *actin* (thin filaments) and myosin (thick filaments), also tropomyosin and troponin are associated with thin filaments

Skeletal Muscle

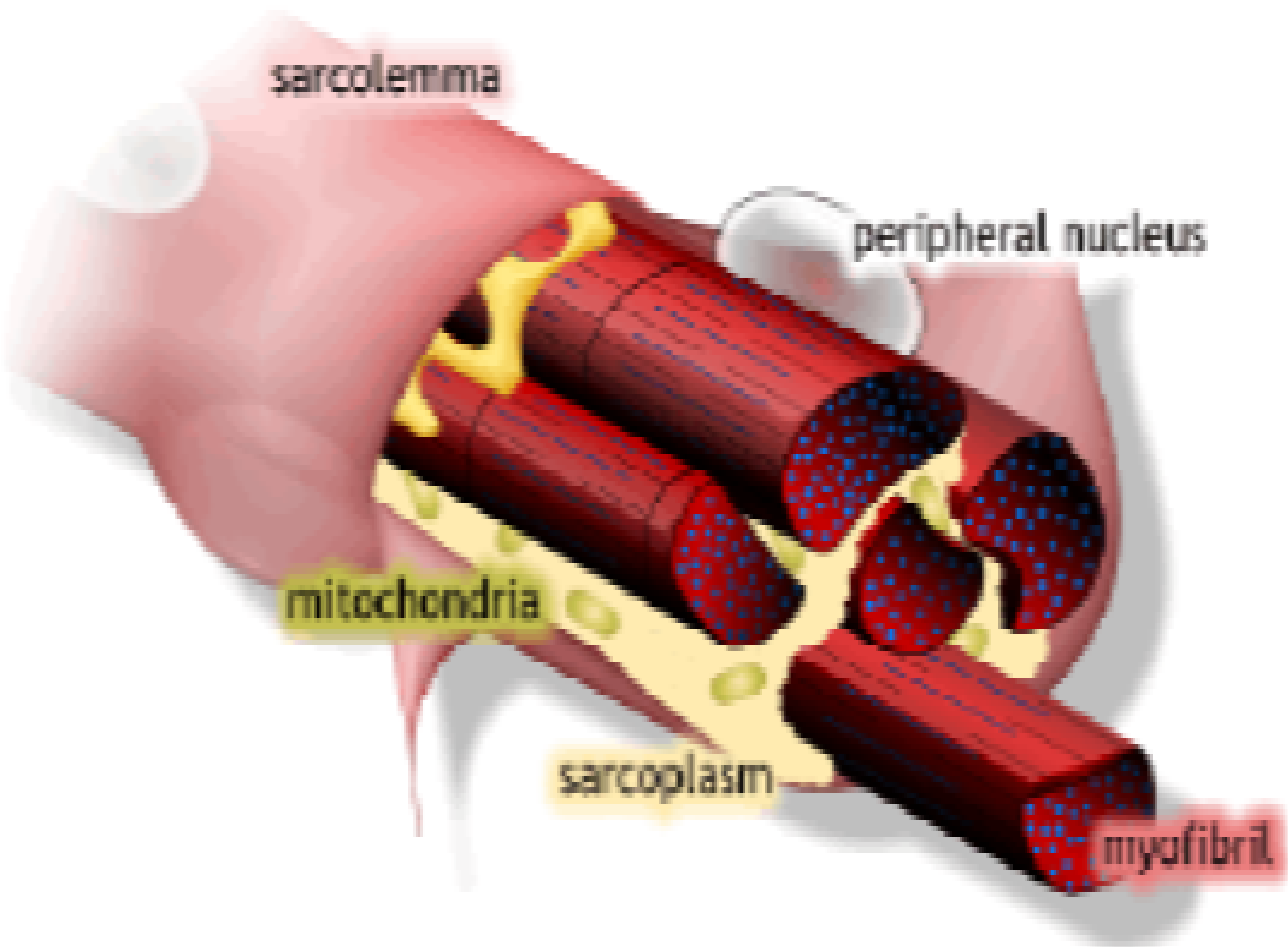
- The three connective tissue sheaths are:
  - Endomysium – fine sheath of connective tissue composed of reticular fibers surrounding each muscle fiber
  - Perimysium – fibrous connective tissue that surrounds groups of muscle fibers called fascicles
  - Epimysium – an overcoat of dense regular connective tissue that surrounds the entire muscle

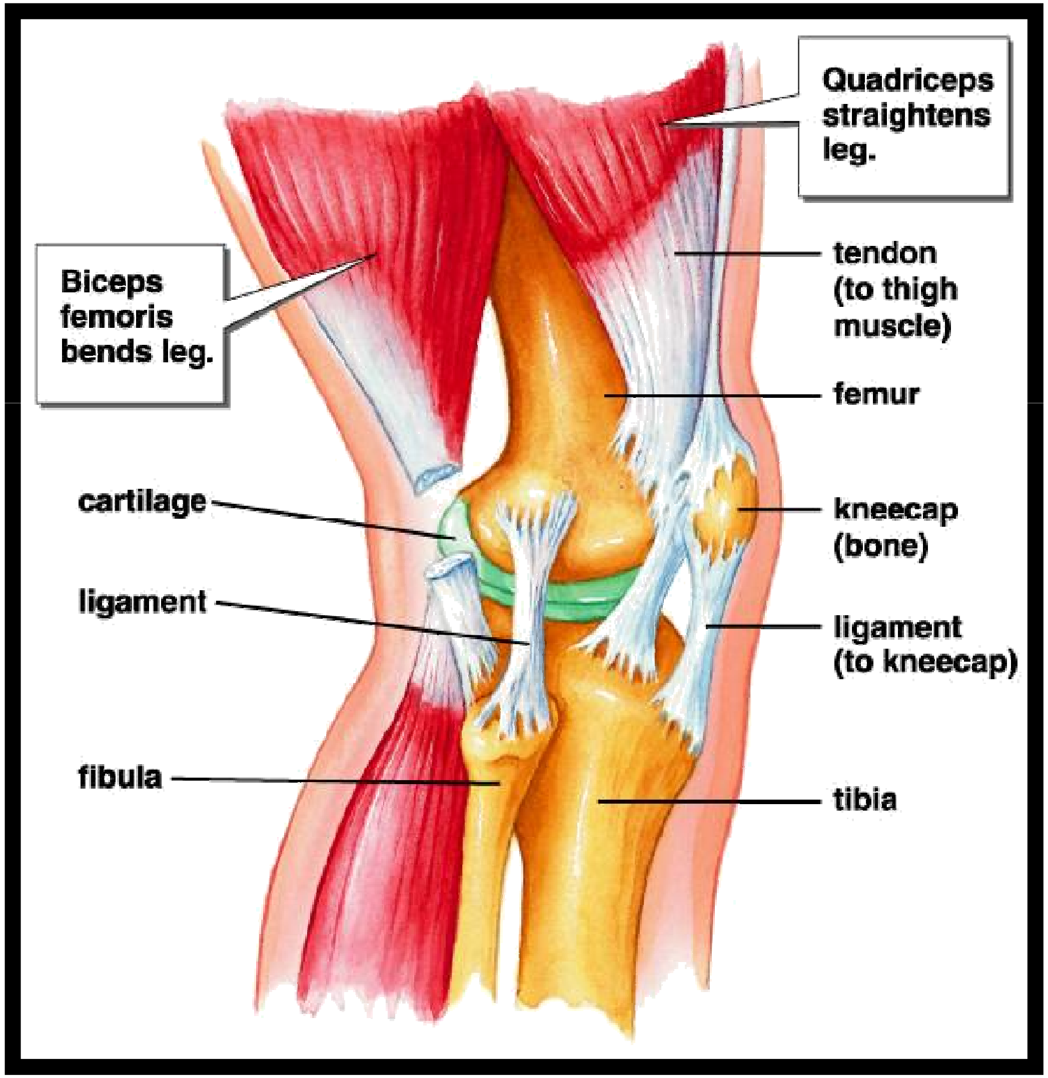


PLAY

InterActive Physiology ®:
Anatomy Review: Skeletal Muscle Tissue, pages 4-6

Figure 9.2a


sarcolemma
peripheral nucleus
mitochondria
sarcoplasm
myofibril


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

Skeletal Muscle

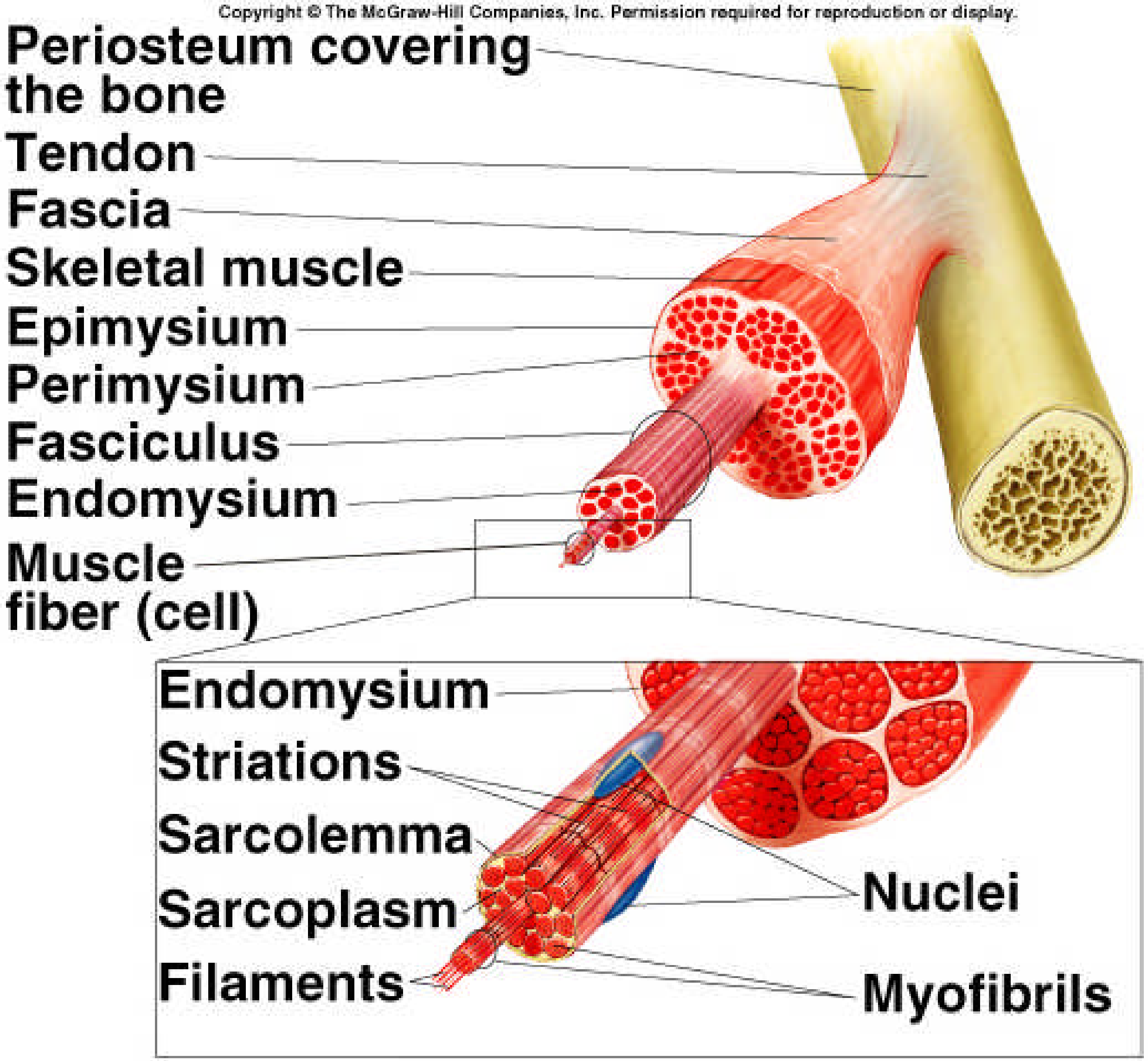
- Skeletal muscle is attached to bone on each end by tendons.
  - <u>Insertion:</u>
    - More movable attachment.
  - <u>Origin:</u>
    - Are pulled towards it.

- Surrounded by <u>connective tissues</u> (around each muscle, subsets, and muscle cell).

Skeletal Muscle: Attachments

- Muscles attach:
  - Directly – epimysium of the muscle is fused to the periosteum of a bone
  - Indirectly – connective tissue wrappings extend beyond the muscle as a tendon or aponeurosis

Skeletal Muscle



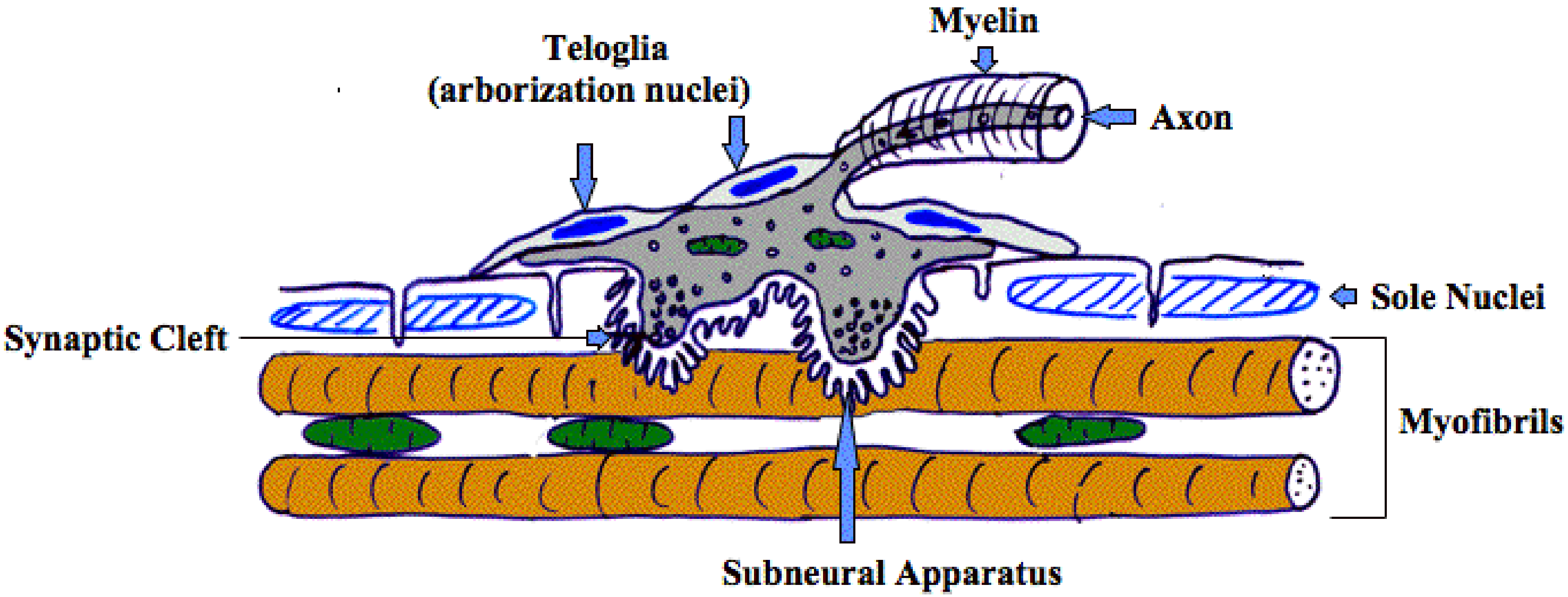
Skeletal Muscle

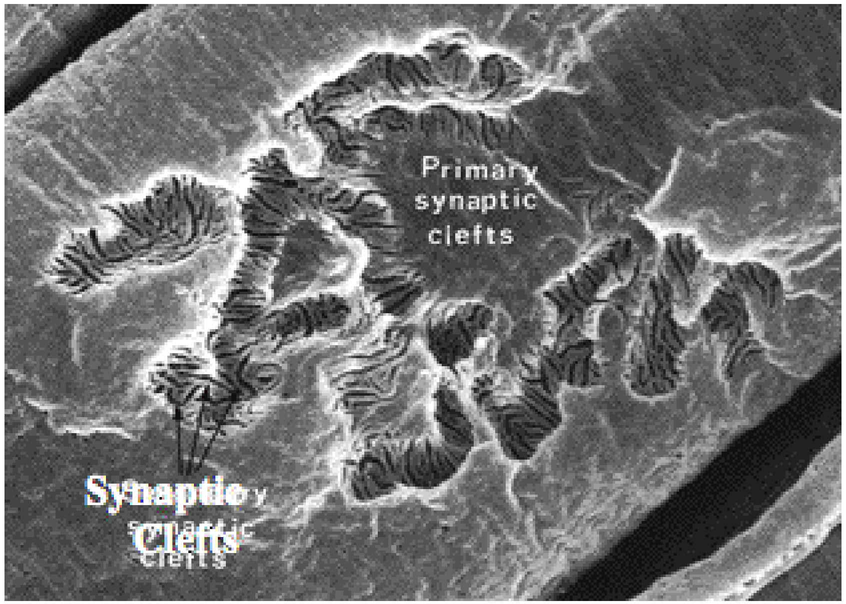
- Motor end plate= sarcolemma at neuromuscular junction

Skeletal Muscle

- **Motor unit**= myofibers innervated by same motor neuron
- Muscles:
  - –Graded contractions by how many motor units contract.

MYONEURAL JUNCTION





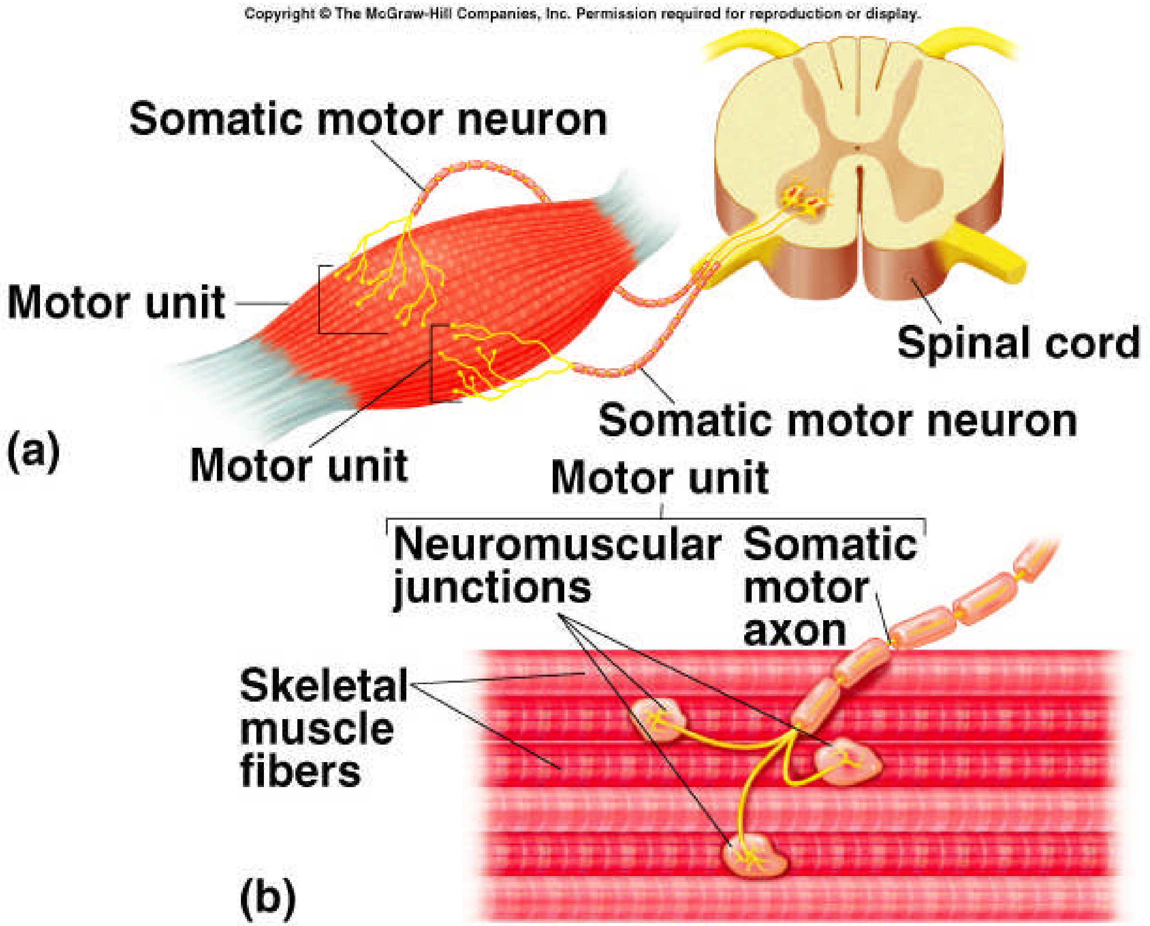
Microscopic Anatomy of a Skeletal Muscle Fiber

- Each fiber is a long, cylindrical cell with multiple nuclei just beneath the sarcolemma
- Each cell is a syncytium produced by fusion of embryonic cells

Microscopic Anatomy of a Skeletal Muscle Fiber

- Sarcoplasm has numerous glycosomes and a unique oxygen-binding protein called myoglobin
- Fibers contain the usual organelles, myofibrils, sarcoplasmic reticulum, and T tubules

Motor Unit



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

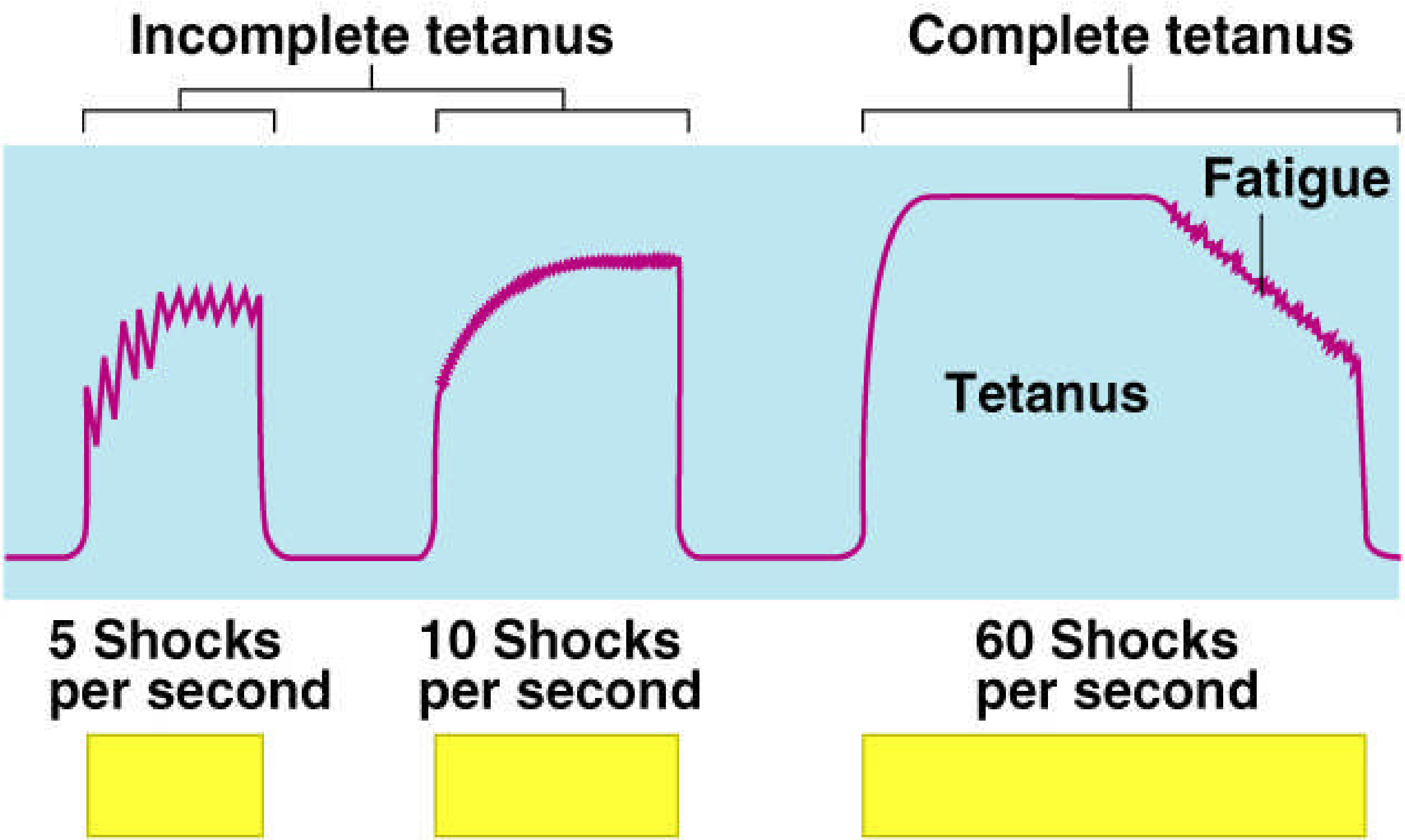
Muscles

- **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.

Muscles


Incomplete tetanus
Complete tetanus
Fatigue
Tetanus
5 Shocks per second
10 Shocks per second
60 Shocks per second

Muscles

- **Treppe**:
  - –Second stimulus elicits a stronger response
    - Perhaps due to increase in intracellular Ca^{2+}.

Contractions

- **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
  –

Tendons

- **Tendons:**
  - Have elasticity.
  - Display recoil.
    - Spring back to resting length.

Metabolism

•During some exercise: ATP used faster than can be renewed through cell respiration.

•So: **Phosphocreatine reservoir**!

•ADP + phosphocreatine -> ATP + creatine

Skeletal muscle

- Contraction speed:
  - Slow-twitch.
  - Fast-twitch.
- due to different myosins.

- Red/white meat…!

Individual Fiber Types

Fast fibers

- **Type IIb**
  - Fast Fast-twitch fibers twitch fibers
  - Fast Fast-glycolytic glycolytic fibers fibers

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

Slow fibers

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

Myofibers

- **Slow-twitch:**
  - Red fibers.
  - High oxidative capacity for aerobic respiration.
  - Many: mitochondria, capillaries
  - Myoglobin (like hemoglobin) for oxygen.
  - Postural muscles

Myofibers

- **Fast-twitch** (type IIX fibers):
  - White fibers.
  - respire anaerobically.
  - much glycogen.
- Fast-twitch oxidative (type IIA fibers):
  - Also white fibers.
- People vary genetically in proportion of fast- and slow-twitch fibers in their muscles.

Exercise

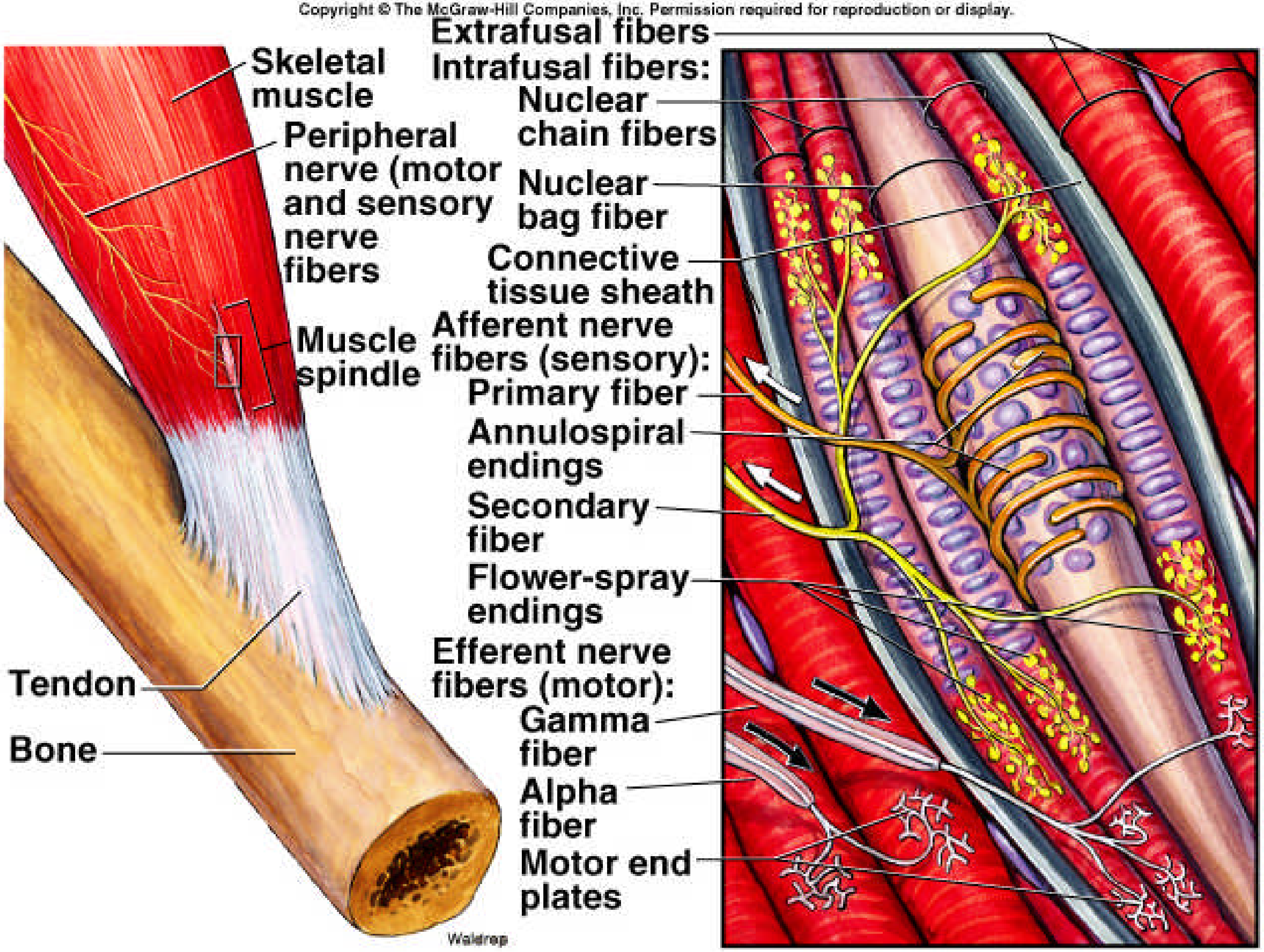
- <u>Weight lifting</u>: hypertrophy.
- <u>Endurance training</u>: more mitochondria.

Muscle Spindle Apparatus

- **<u>Muscle spindle apparatus</u>**
  - Length detector.
  - Contains thin muscle cells called intrafusal fibers.
  - Reflex contraction in response to rapid stretch.
  - Stimulated by γ motor neurons from spinal cord.
  - Helps maintain muscle tone (resting muscle length and state of tension).

  - Extrafusal fibers (rest of muscle!): stimulated by α motor neurons from spinal cord.

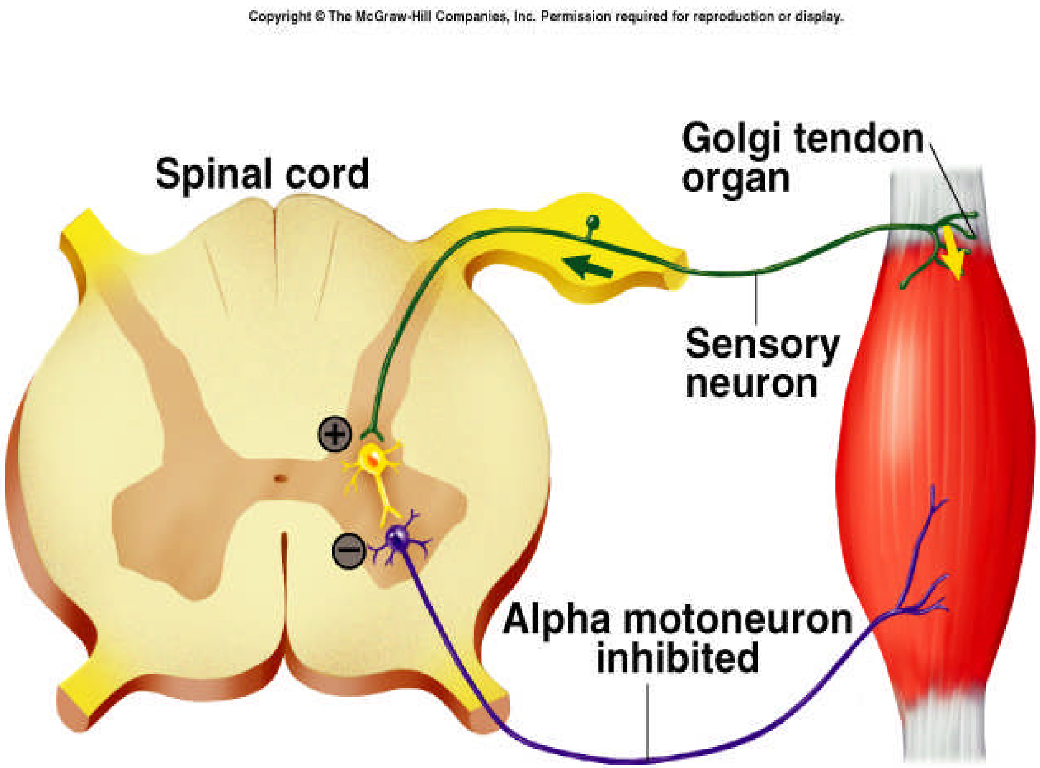
Spindle apparatus



Golgi Tendon Organ

- **<u>Golgi tendon organ</u>**

- Helps prevent excessive muscle contraction or excessive passive muscle stretching.
- A reflex.



Skeletal Muscles

- **Agonist** muscle:
  - Prime mover.

- **Antagonist** muscle:
  - Flexors and extensors that act on the same joint to produce opposite actions.

Reciprocal Innervation

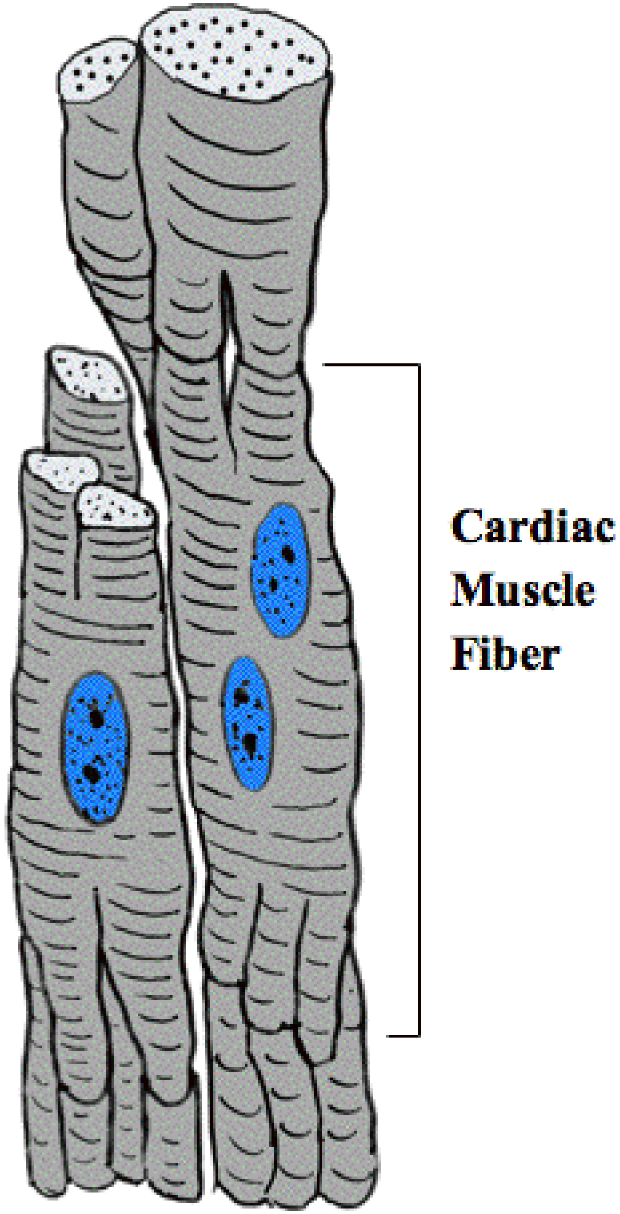
•**Reciprocal innervation:**

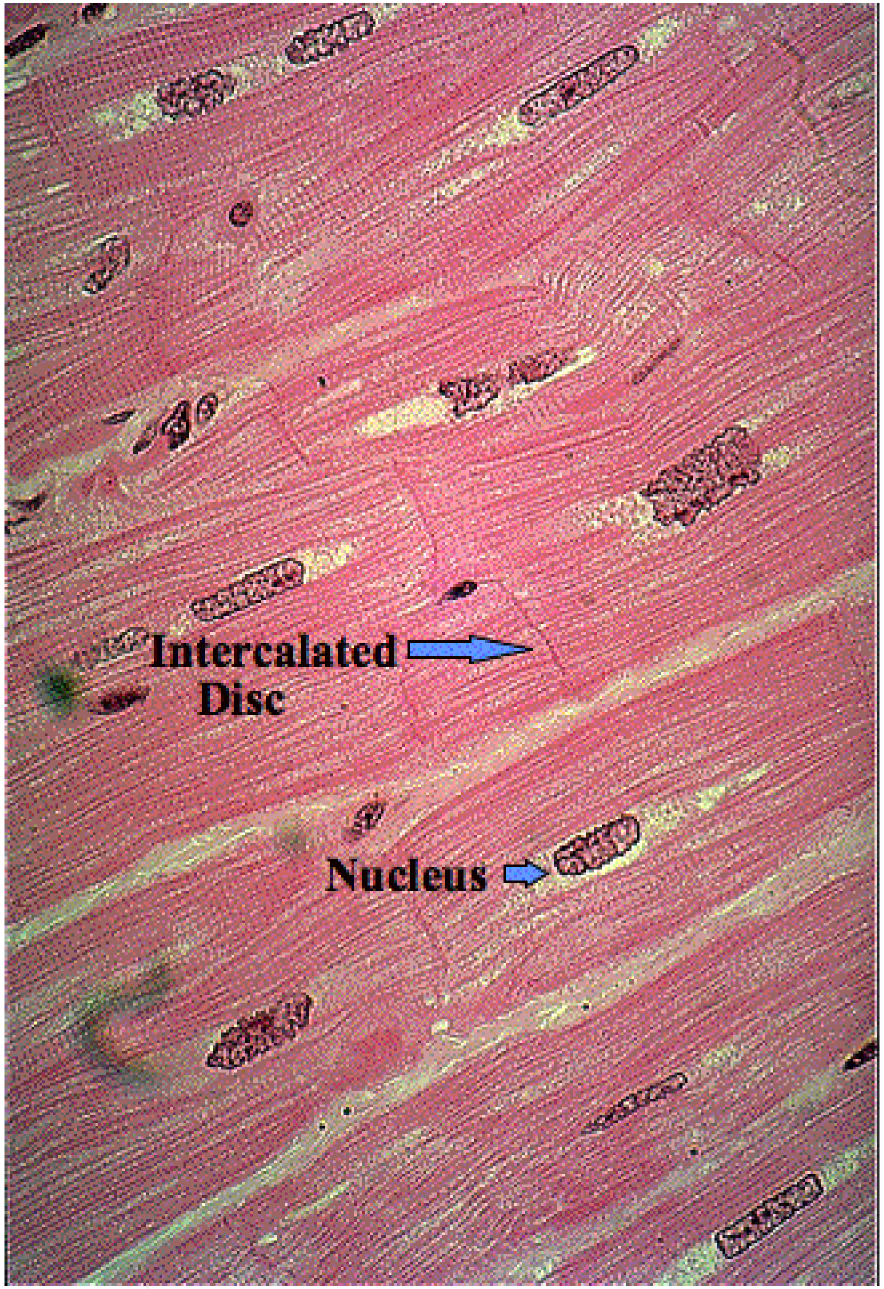
•motor neurons of antagonistic muscles inhibit each other (through interneurons) so they don't both contract simultaneously.

•When limb is flexed, antagonistic extensor muscles are passively stretched.

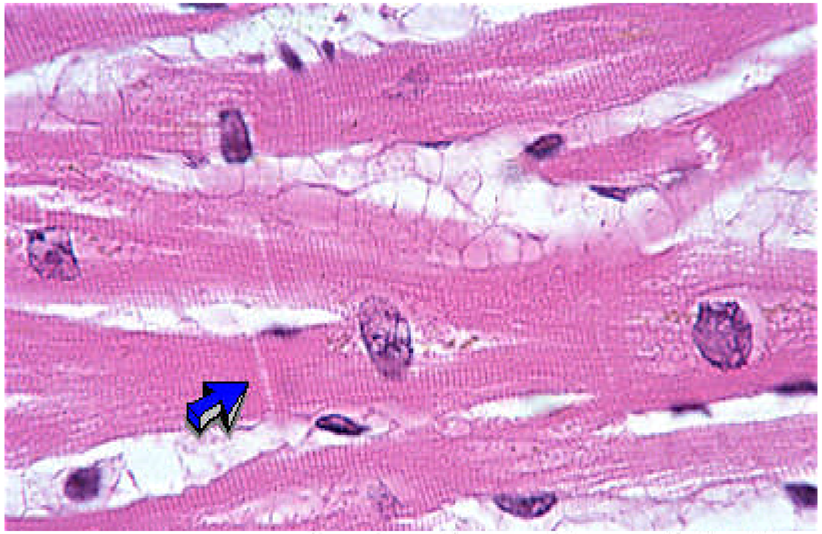
CARDIAC MUSCLE

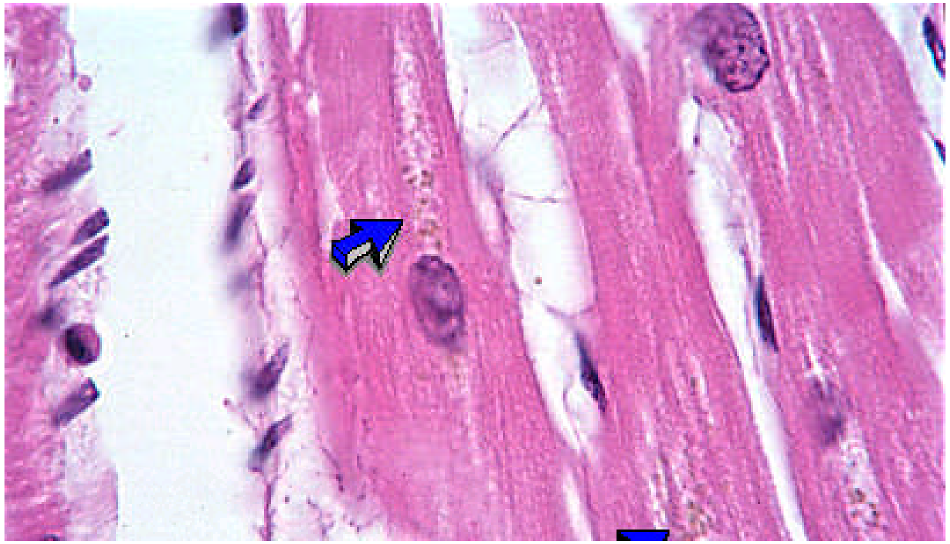
CARDIAC MUSCLE

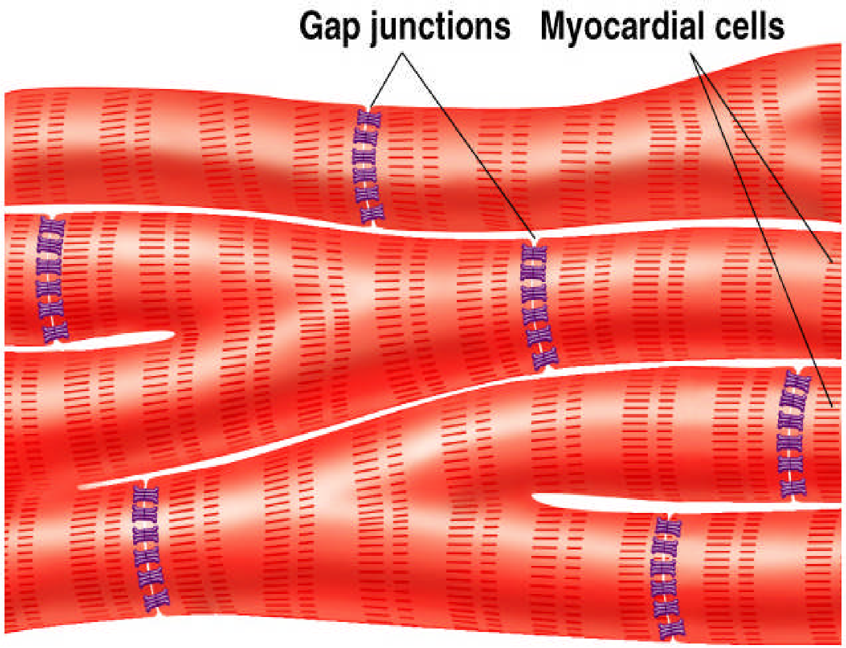




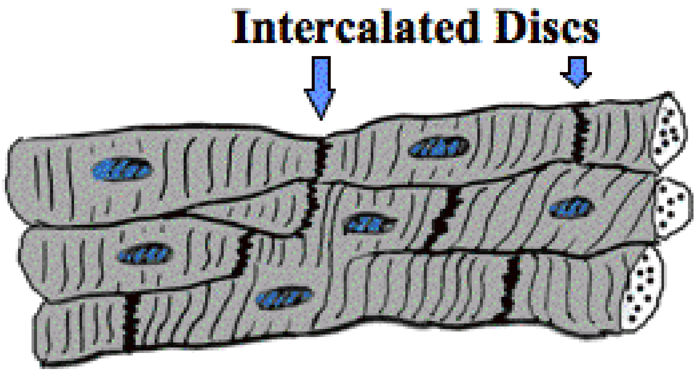
Cardiac Muscle

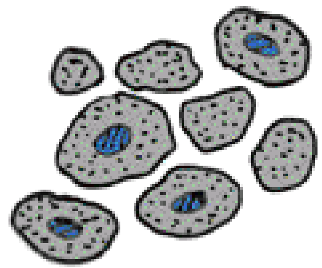




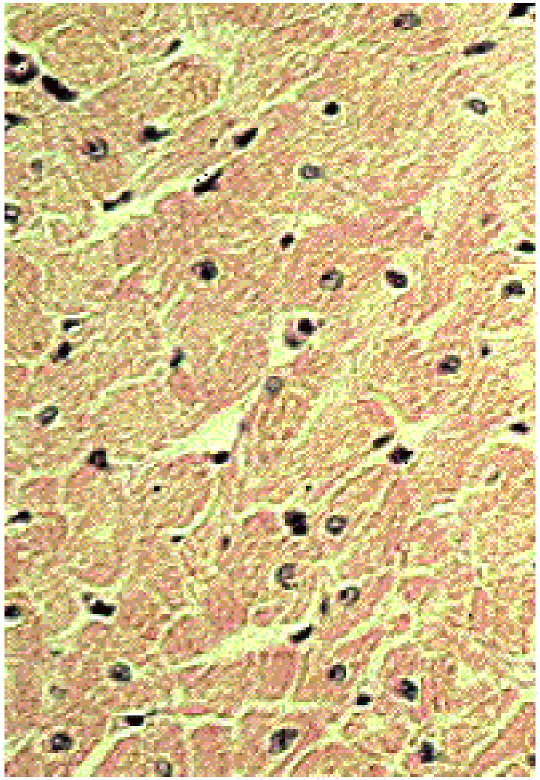


INTERCALATED DISCS

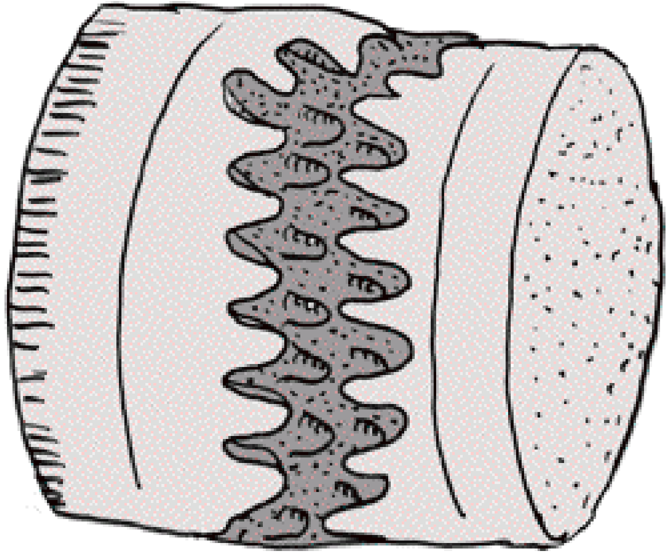


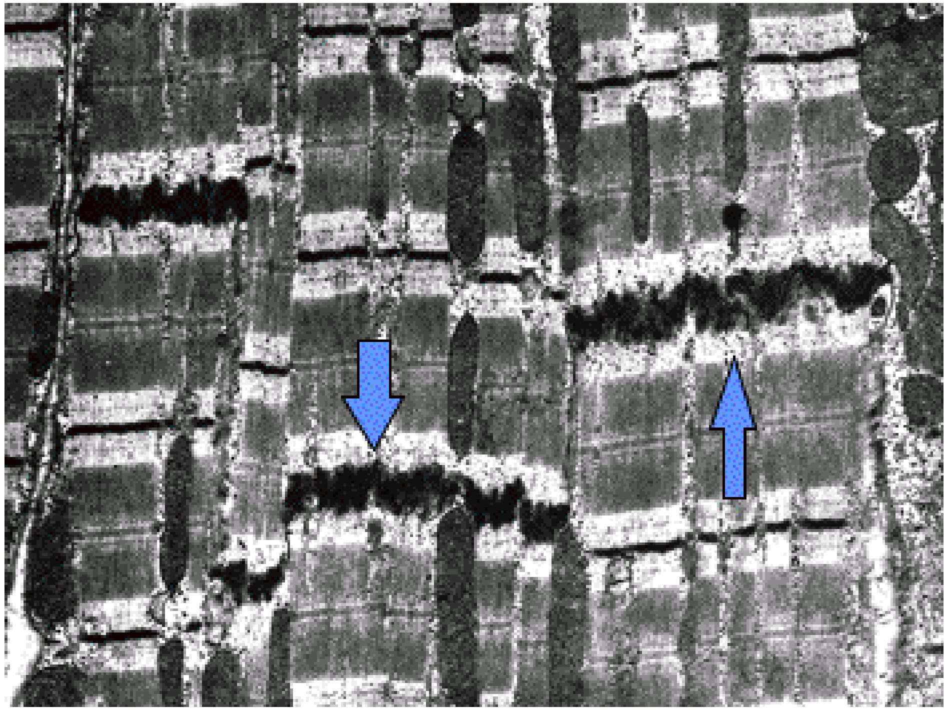


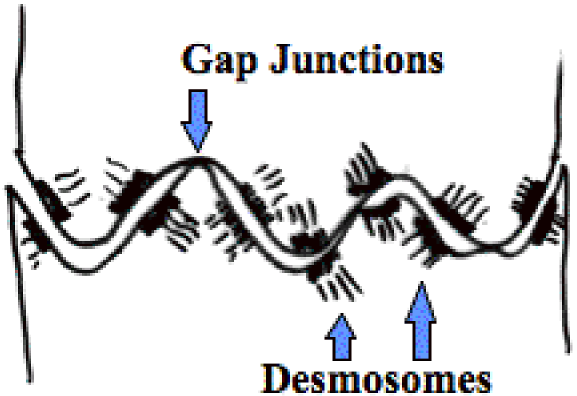
Cardiac Muscle Fibers
(transverse section)

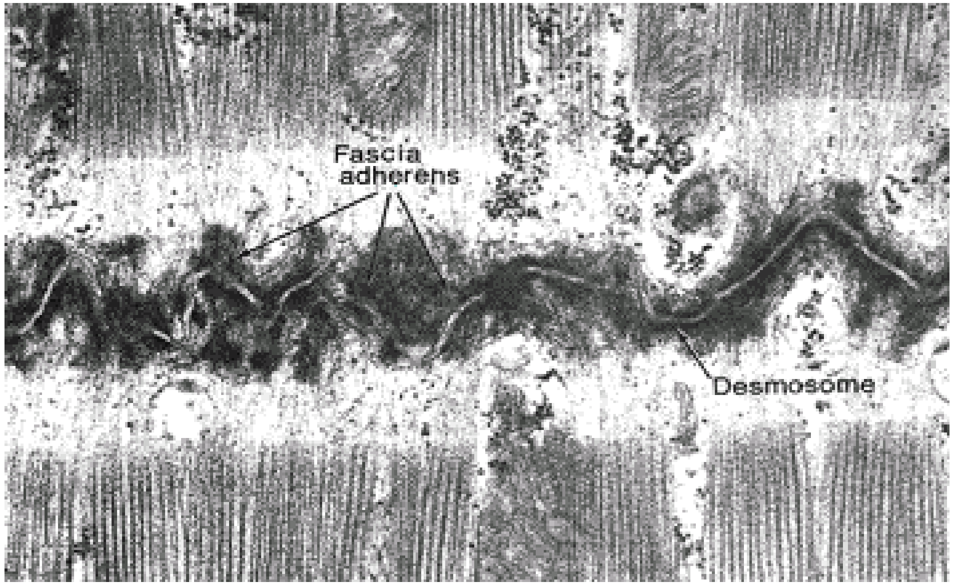


INTERCALATED DISCS



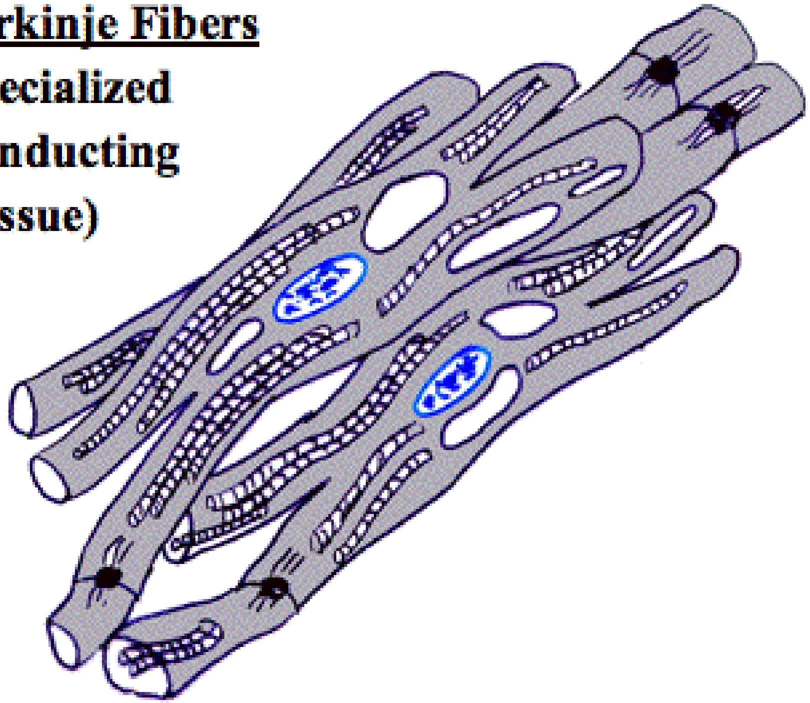




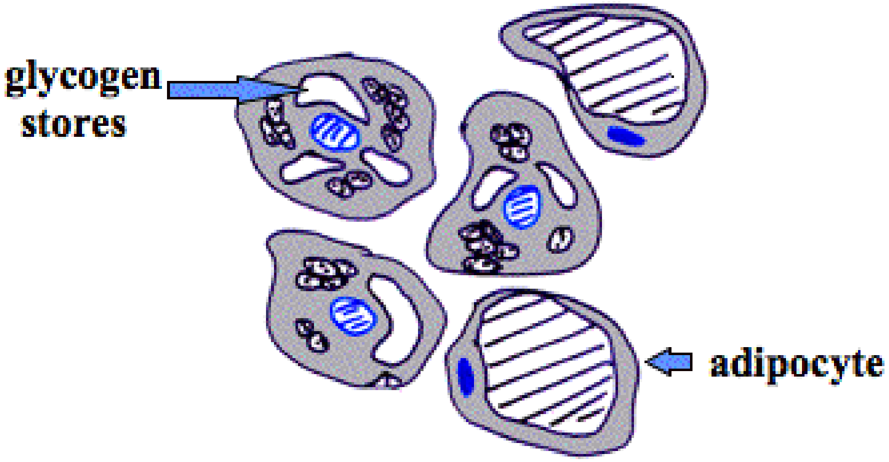


PURKINJE FIBERS

Purkinje Fibers
(specialized conducting tissue)



Purkinje Fibers (trans. section)



Cardiac Muscle

•Like skeletal muscle:

•- striated: actin and myosin in <u>sarcomeres.</u>

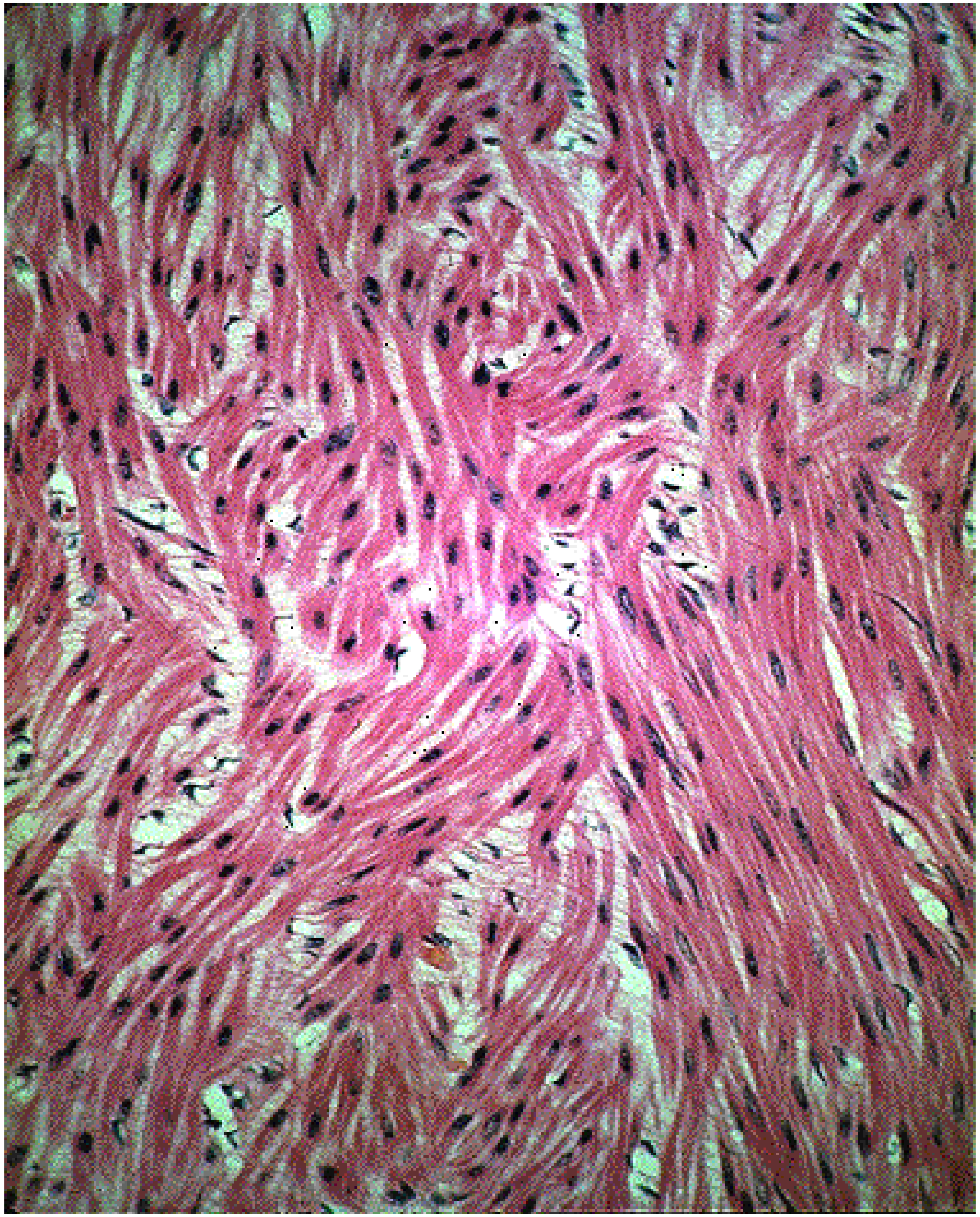
•- contract via sliding-filament mechanism.

•Unique to cardiac muscle:

•- Adjacent <u>myocardial </u>cells joined by gap junctions= intercalated discs=electrical synapse.

SMOOTH MUSCLE

LOCATIONS OF SMOOTH MUSCLE



DIGESTIVE TRACT

DUCTS OF GLANDS

RESPIRATORY PASSAGES

URINARY & GENETAL TRACT

ARTERIES AND VEINS

PILIERECTOR MUSCLES

IRIS & CILIARY BODY

UTERUS

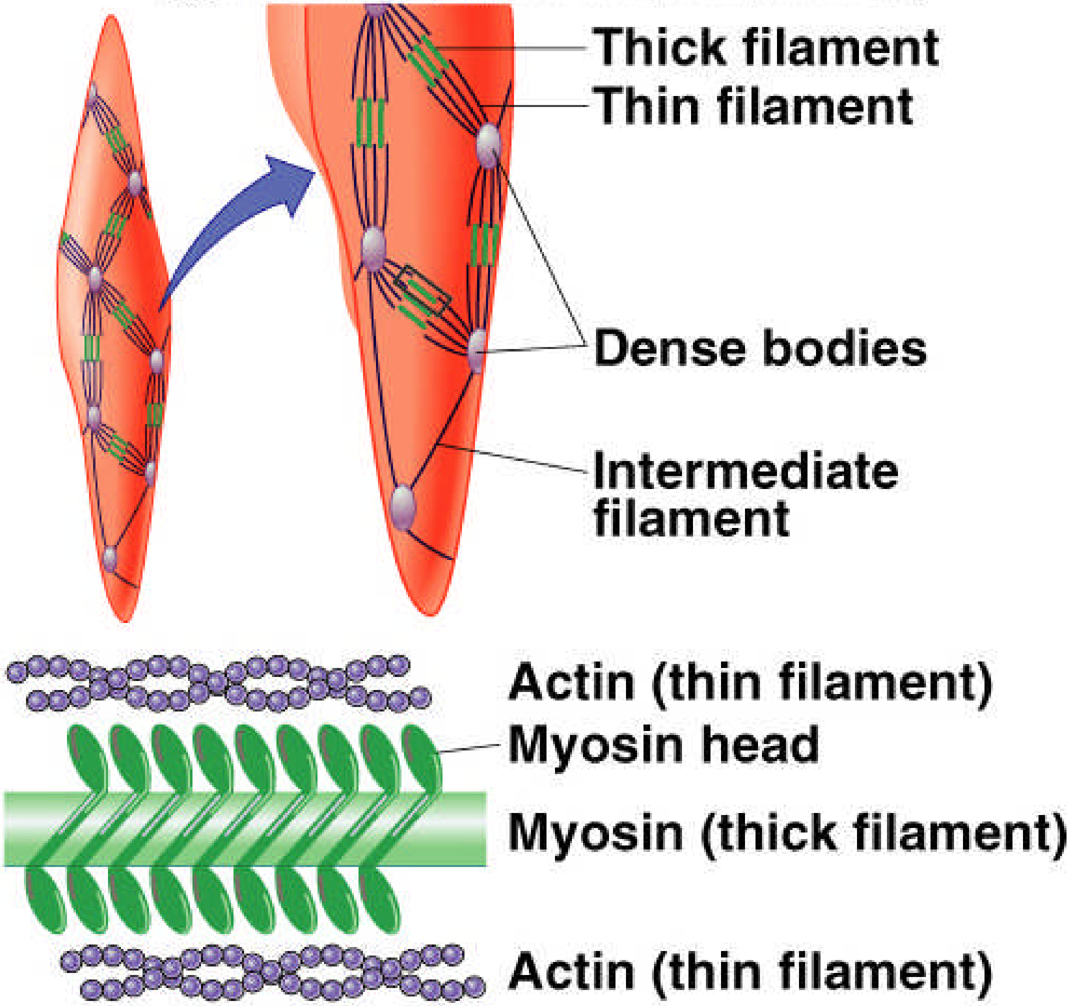
BLADDER

STOMACH

Smooth Muscle

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

Smooth Muscle



Smooth Muscle

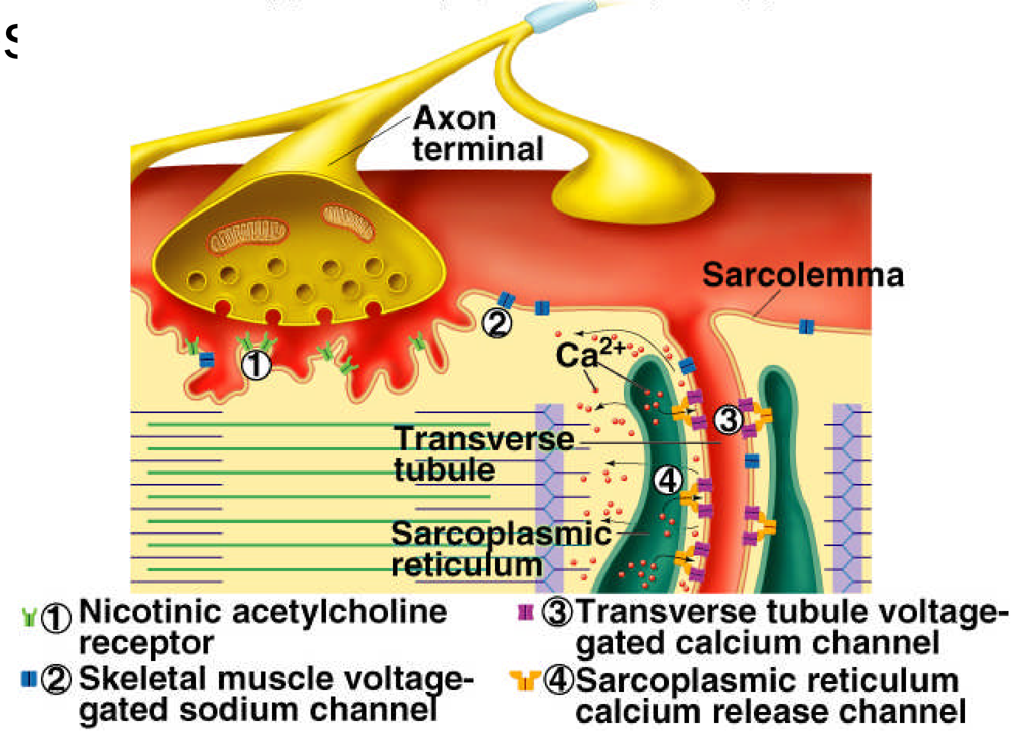
- Actin all over the cell, linked by myosin (web-like pattern, not striations).

- Rise in Ca^{2+} -> Ca^{2+} binds with **calmodulin** -> activates **MLCK (**a kinase) -> Myosin heads are phosphorylated and can bind to actin.

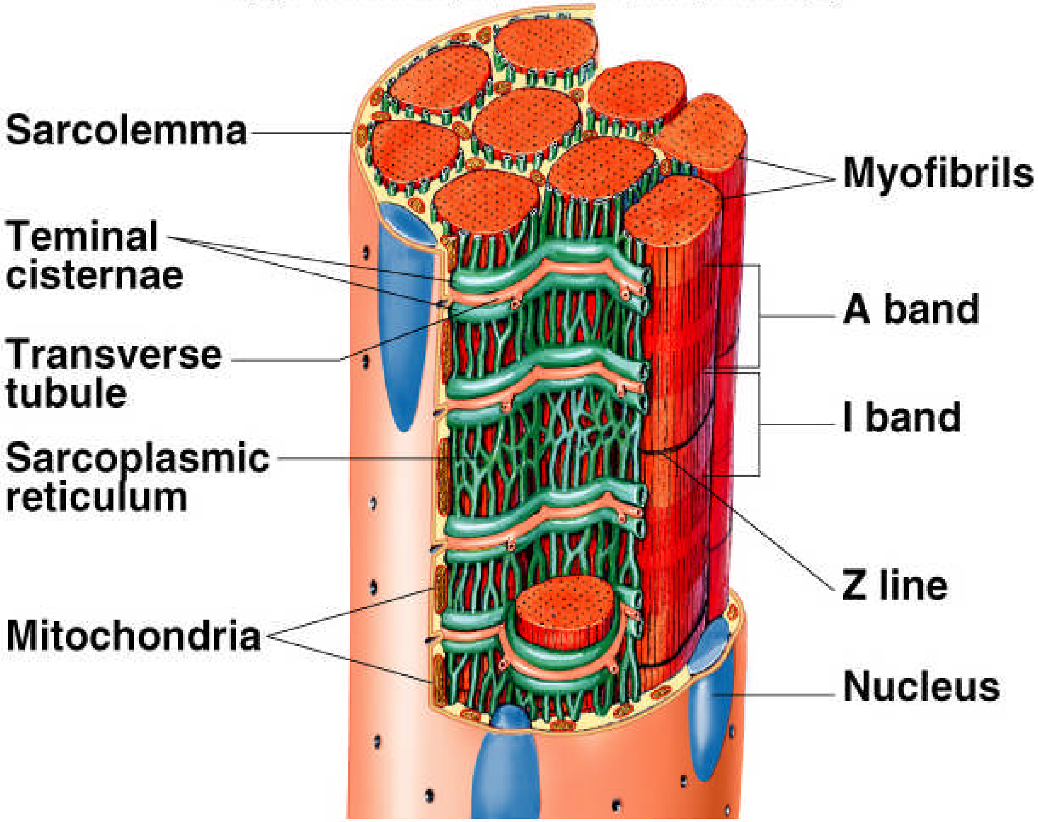
Myofiber anatomy

- Sarcoplasmic reticulum lies next to T tubules.

- Transverse tubules= infoldings of sarcolemma.



Myofiber anatomy



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

Smooth Muscle

- Composed of spindle-shaped fibers with a diameter of 2-10 μm and lengths of several hundred μm
- Lack the coarse connective tissue sheaths of skeletal muscle, but have fine endomysium
- Organized into two layers (longitudinal and circular) of closely apposed fibers

Smooth Muscle

- Found in walls of hollow organs (except the heart)
- Have essentially the same contractile mechanisms as skeletal muscle

Smooth Muscle

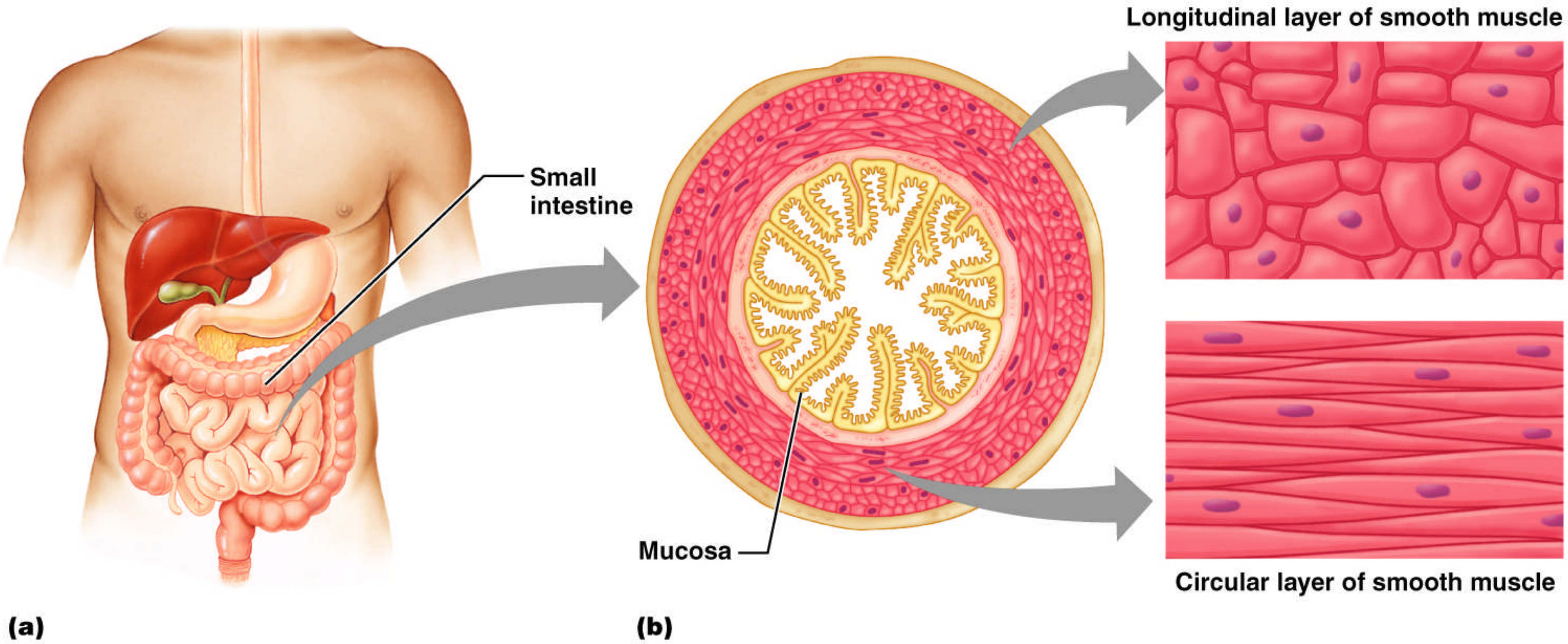


Figure 9.24

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

Innervation of Smooth Muscle

Figure 9.25

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

Microscopic Anatomy of Smooth Muscle

- Ca^{2+} 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

Proportion and Organization of Myofilaments in Smooth Muscle

- 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

Proportion and Organization of Myofilaments in Smooth Muscle

- Thick and thin filaments are arranged diagonally, causing smooth muscle to contract in a corkscrew manner
- Noncontractile intermediate filament bundles attach to dense bodies (analogous to Z discs) at regular intervals

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

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

Types of Smooth Muscle: Multiunit

- 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

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

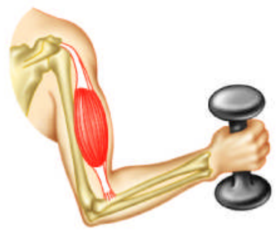
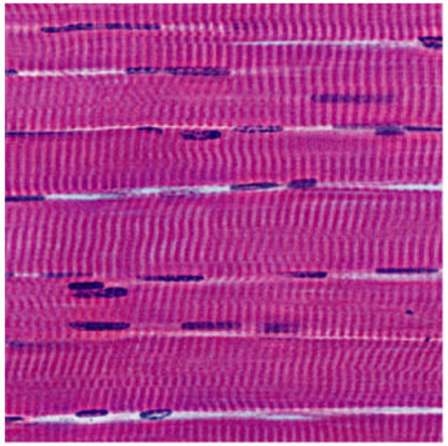
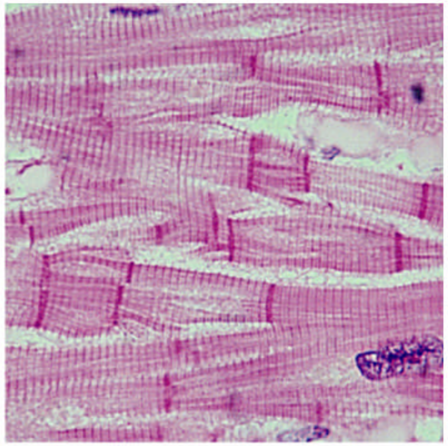
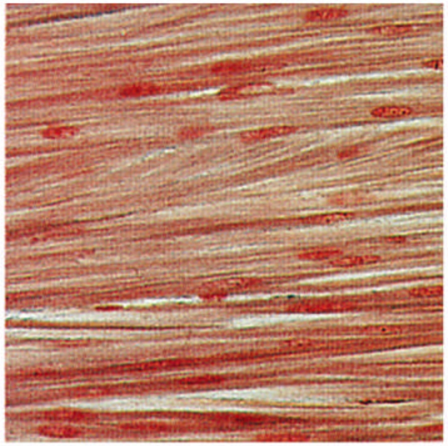
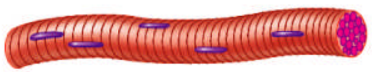
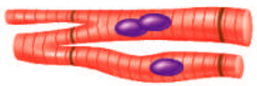
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Body location	Attached to bones or (some facial muscles) to skin	Walls of the heart	Single-unit muscle in walls of hollow visceral organs (other than the heart); multiunit muscle in intrinsic eye muscles, airways, large arteries
			
Cell shape and appearance	Single, 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

Comparison of Skeletal, Cardiac and Smooth Muscle Cells

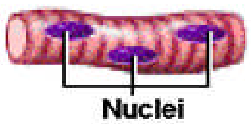
Skeletal Muscle Cell:

Elongated Cells

Multiple Peripheral Nuclei

Visible Striations

Voluntary



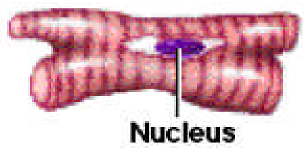
Cardiac Muscle:

Branching Cells

Single Central Nucleus

Visible Striations

Involuntary



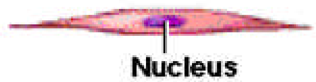
Smooth Muscle Cell:

Spindle-Shaped Cell

Single Central Nucleus

Lack Visible Striations

Involuntary



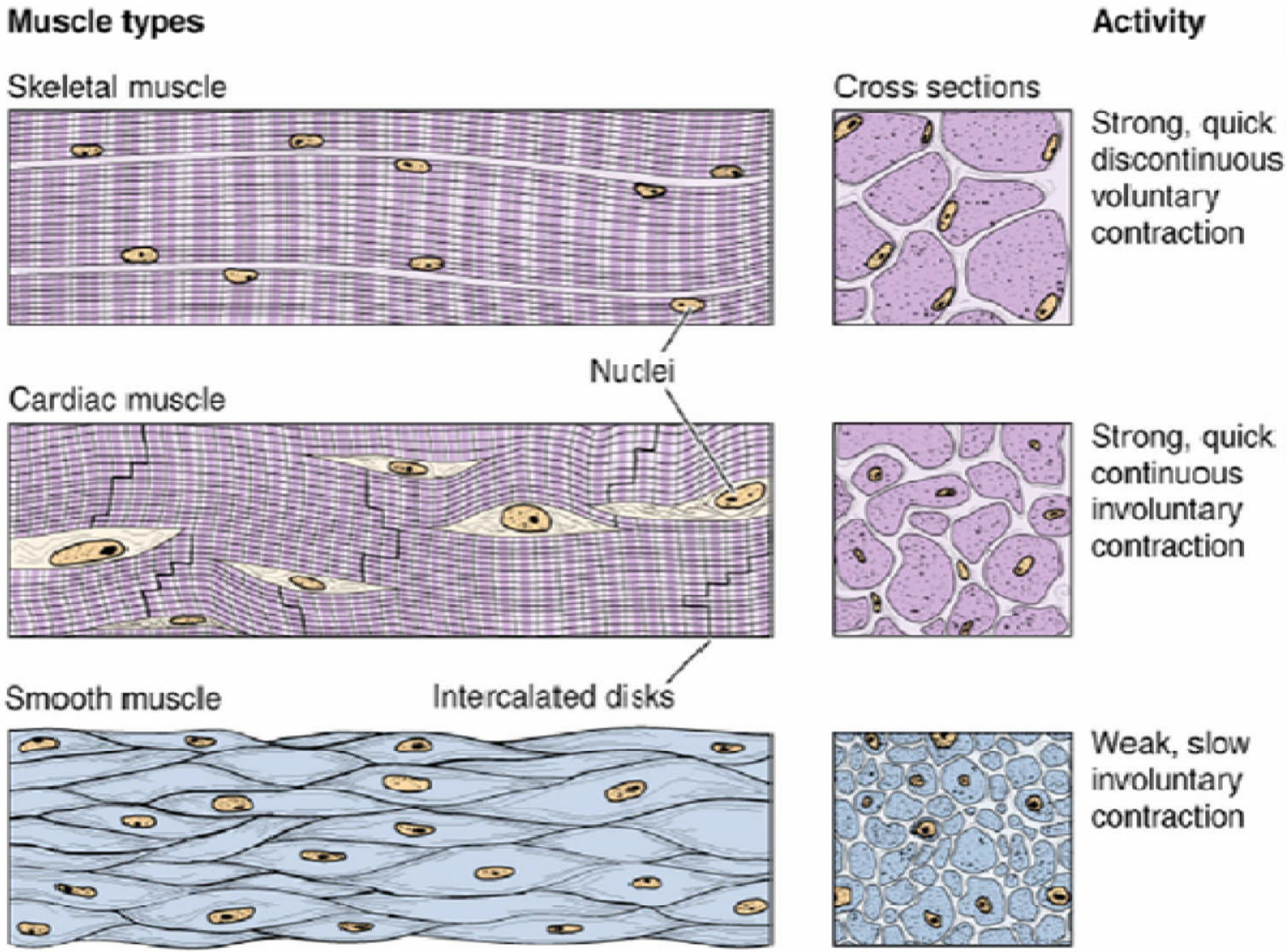

Muscle types
Activity
Skeletal muscle
Cross sections
Strong, quick discontinuous voluntary contraction
Nuclei
Cardiac muscle
Strong, quick continuous involuntary contraction
Smooth muscle
Intercalated disks
Weak, slow involuntary contraction

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

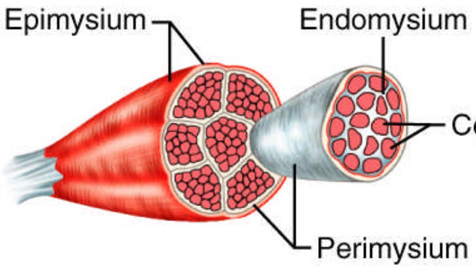
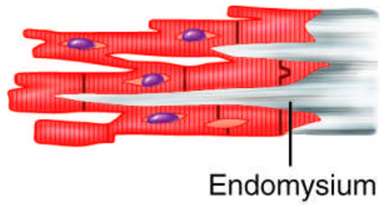
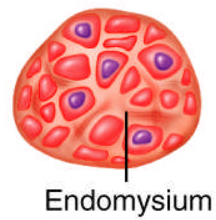
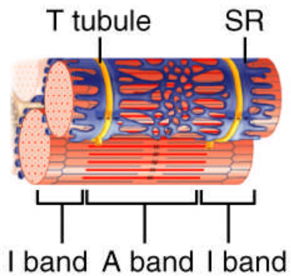
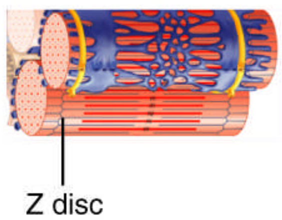
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Connective tissue components	Epimysium, perimysium, and endomysium	Endomysium attached to fibrous skeleton of heart	Endomysium
			
Presence of myofibrils composed of sarcomeres	Yes	Yes, but myofibrils are of irregular thickness	No, but actin and myosin filaments 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 9.3.2

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

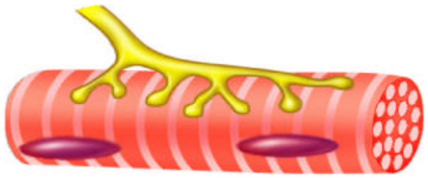
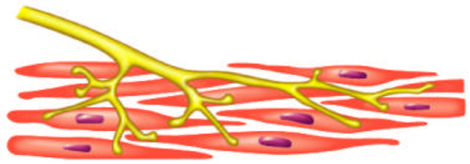
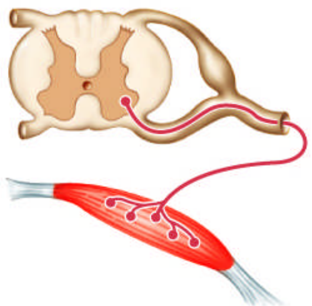
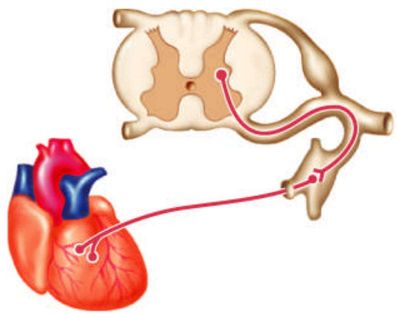
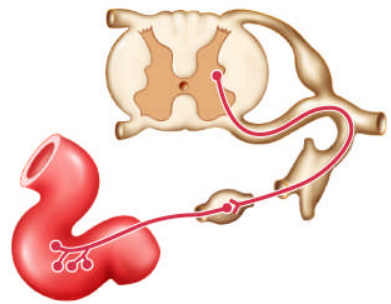
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Presence of gap junctions	No	Yes; at intercalated discs	Yes; in single-unit muscle
Cells exhibit individual neuromuscular junctions	Yes	No	Not in single-unit muscle; yes in multiunit muscle
			
Regulation of contraction	Voluntary via axon terminals of the somatic 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 9.3.3

TABLE 9.3 Comparison of Skeletal, Cardiac, and Smooth Muscle

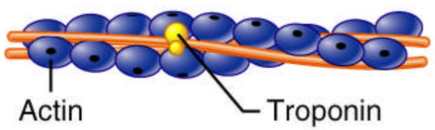
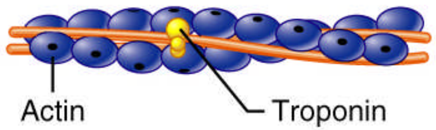
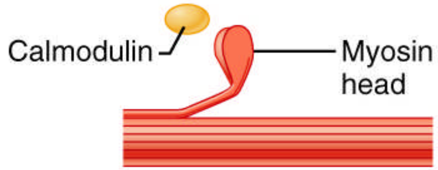
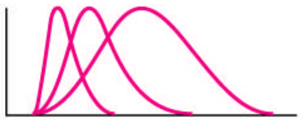
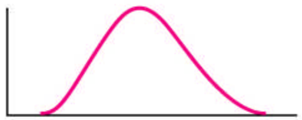
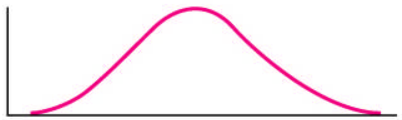
CHARACTERISTIC	SKELETAL	CARDIAC	SMOOTH
Site of calcium regulation	Troponin on actin-containing thin filaments	Troponin on actin-containing thin filaments	Calmodulin in the sarcoplasm
			
Presence of pacemaker(s)	No	Yes	Yes (in single-unit muscle only)
Effect of nervous system stimulation	Excitation	Excitation 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

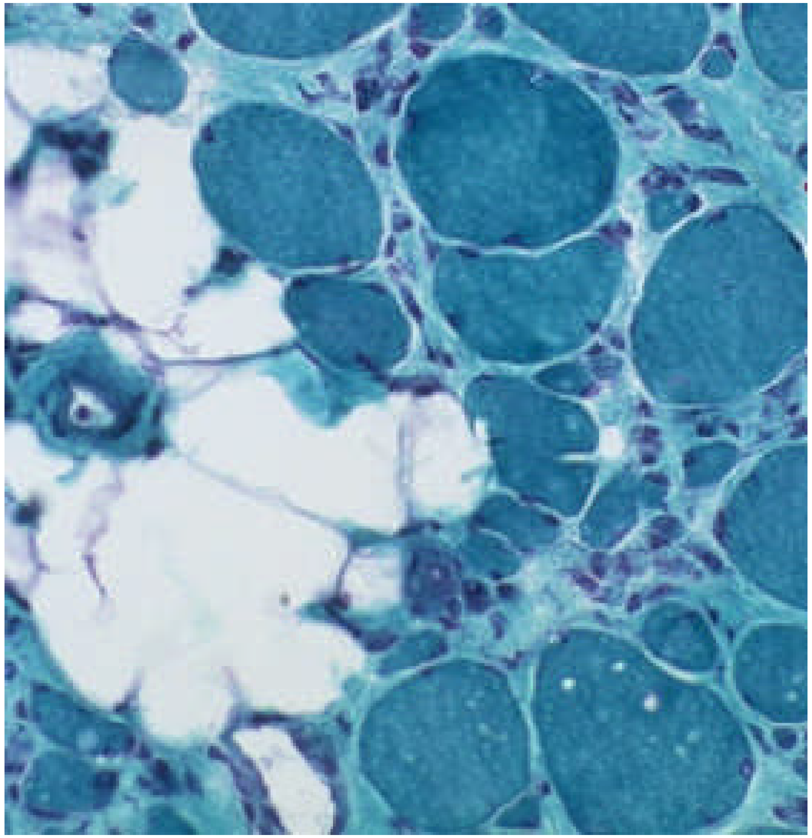
Table 9.3.4

Myasthenia Gravis

- My=muscle, asthen=weakness, gravi=heavy
- Autoimmune disease where antibodies attack the ACh receptors on neuromuscular junctions.
- Results in progressive weakening of the skeletal muscles. Why?
- Treated w/ anticholinesterases such as neostigmine or physostigmine. These decrease the activity of acteylcholinesterase.
  - *Why would this help someone with myasthenia gravis?*

Muscular Dystrophy

- Group of inherited muscle-destroying diseases that generally appear during childhood.
- Dys=faulty; Troph=growth
- Most common is Duchenne muscular dystrophy
  - DMD is caused by an abnormal X-linked recessive gene
  - Diseased muscle fibers lack the protein dystrophin which normally links the cytoskeleton to the ECM and stabilizes the sarcolemma
  - Age of onset is btwn 2 and 10. Muscle weakness progresses. Afflicted individuals usually die of respiratory failure, usually by age 25.



Here is a slide of skeletal muscle from someone with DMD. Look how much connective tissue there is. Lots of adipose tissue too. Why do you think there's so much?

Other Important Terms

- Flaccid paralysis
  - Weakness or loss of muscle tone typically due to injury or disease of motor neurons
- Spastic paralysis
  - Sustained involuntary contraction of muscle(s) with associated loss of function
    - *How do flaccid and spastic paralysis differ?*
- Spasm
  - A sudden, involuntary smooth or skeletal muscle twitch. Can be painful. Often caused by chemical imbalances.

Other Important Terms

- Cramp
  - A prolonged spasm that causes the muscle to become taut and painful.
- Hypertrophy
  - Increase in size of a cell, tissue or an organ.
    - In muscles, hypertrophy of the organ is always due to cellular hypertrophy (increase in cell size) rather than cellular hyperplasia (increase in cell number)
    - Muscle hypertrophy occurs due to the synthesis of more myofibrils and synthesis of larger myofibrils.

Other Important Terms

- Atrophy
  - Reduction in size of a cell, tissue, or organ
    - In muscles, its often caused by disuse. Could a nerve injury result in disuse? Why might astronauts suffer muscle atrophy?
- Fibrosis
  - Replacement of normal tissue with heavy fibrous connective tissue (scar tissue). How would fibrosis of skeletal muscles affect muscular strength? How would it affect muscle flexibility?

Muscular Dystrophy

- Muscular dystrophy – group of inherited muscle-destroying diseases where muscles enlarge due to fat and connective tissue deposits, but muscle fibers atrophy

Muscular Dystrophy

- Duchenne muscular dystrophy (DMD)
  - Inherited, sex-linked disease carried by females and expressed in males (1/3500)
  - Diagnosed between the ages of 2-10
  - Victims become clumsy and fall frequently as their muscles fail

Muscular Dystrophy

- Progresses from the extremities upward, and victims die of respiratory failure in their 20s
- Caused by a lack of the cytoplasmic protein dystrophin
- There is no cure, but myoblast transfer therapy shows promise

Developmental Aspects

- Muscle tissue develops from embryonic mesoderm called myoblasts
- Multinucleated skeletal muscles form by fusion of myoblasts
- The growth factor *agrin* stimulates the clustering of ACh receptors at newly forming motor end plates

Developmental Aspects

- As muscles are brought under the control of the somatic nervous system, the numbers of fast and slow fibers are also determined
- Cardiac and smooth muscle myoblasts do not fuse but develop gap junctions at an early embryonic stage

Developmental Aspects: Regeneration

- Cardiac and skeletal muscle become amitotic, but can lengthen and thicken
- Myoblastlike satellite cells show very limited regenerative ability
- Cardiac cells lack satellite cells
- Smooth muscle has good regenerative ability

Developmental Aspects: After Birth

- Muscular development reflects neuromuscular coordination
- Development occurs head-to-toe, and proximal-to-distal
- Peak natural neural control of muscles is achieved by midadolescence
- Athletics and training can improve neuromuscular control

Developmental Aspects: Male and Female

- There is a biological basis for greater strength in men than in women
- Women’s skeletal muscle makes up 36% of their body mass
- Men’s skeletal muscle makes up 42% of their body mass

Developmental Aspects: Male and Female

- These differences are due primarily to the male sex hormone testosterone
- With more muscle mass, men are generally stronger than women
- Body strength per unit muscle mass, however, is the same in both sexes

Developmental Aspects: Age Related

- With age, connective tissue increases and muscle fibers decrease
- Muscles become stringier and more sinewy
- By age 80, 50% of muscle mass is lost (sarcopenia)

Developmental Aspects: Age Related

- Regular exercise reverses sarcopenia
- Aging of the cardiovascular system affects every organ in the body
- Atherosclerosis may block distal arteries, leading to intermittent claudication and causing severe pain in leg muscles