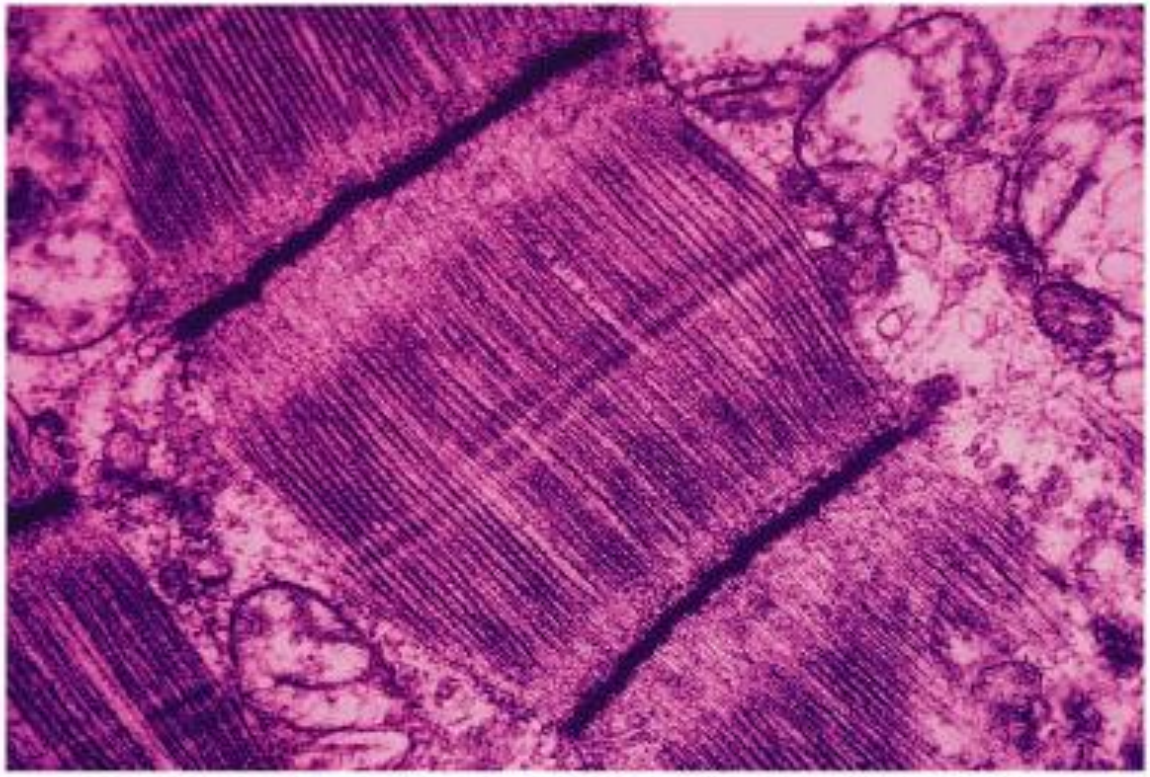
Muscle Histology



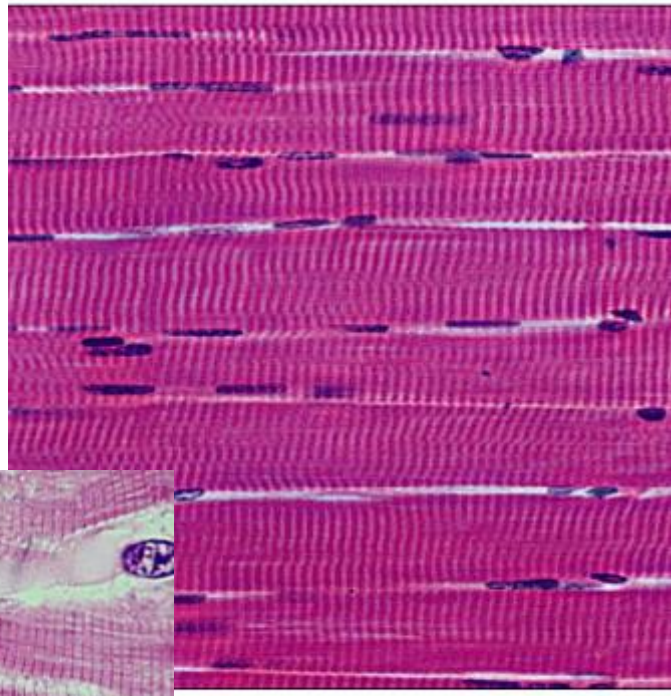
Dr. Heba Kalbouneh

Functions of muscle tissue

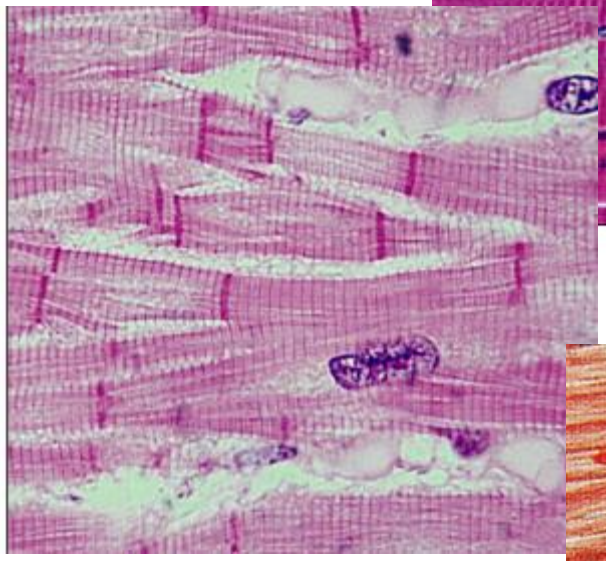
- Movement
- Maintenance of posture
- Joint stabilization
- Heat generation

Types of Muscle Tissue

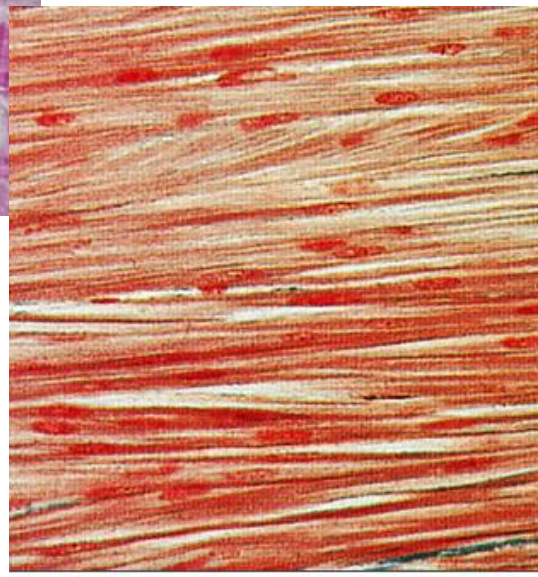
- Skeletal muscle



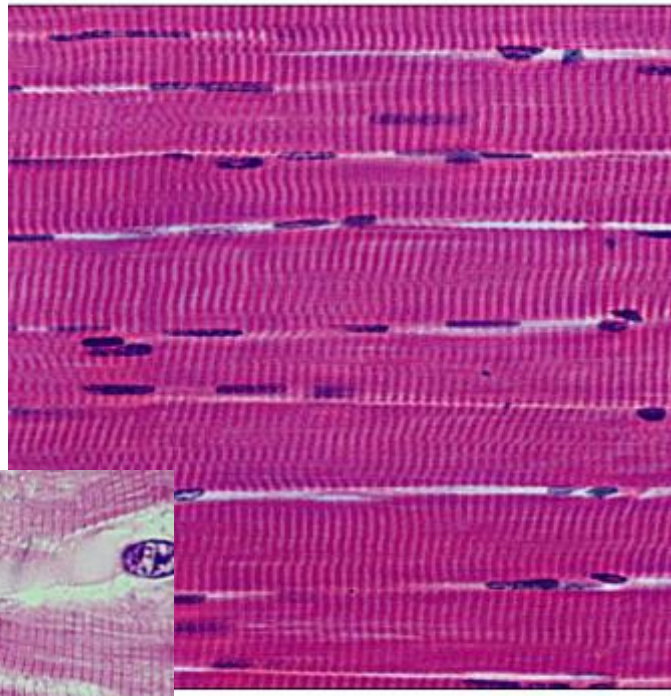
- Cardiac muscle



- Smooth muscle

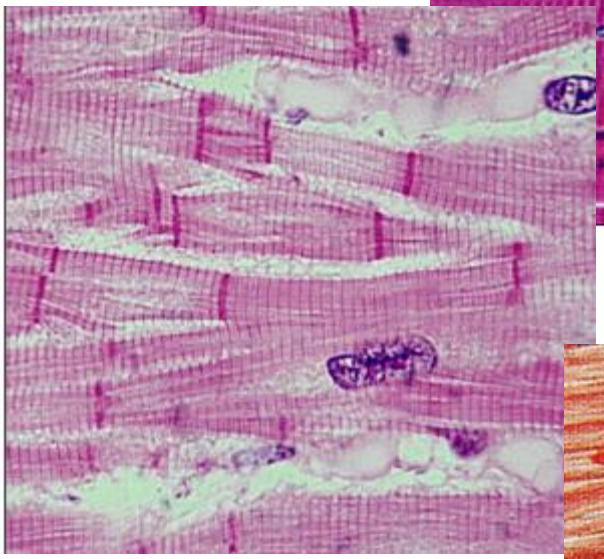


Types of Muscle Tissue



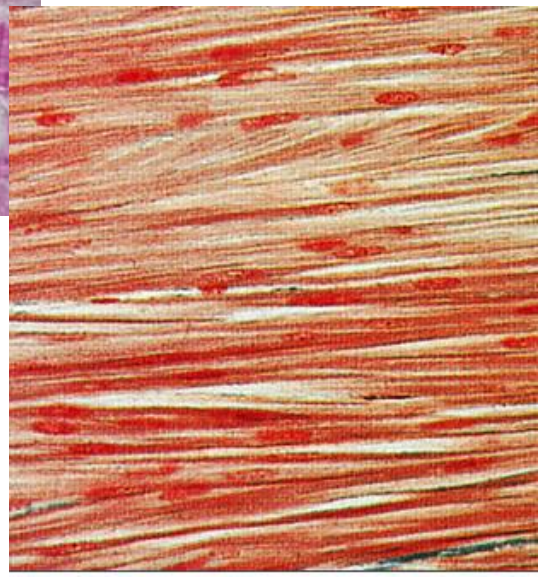
Skeletal

- Attach to and move skeleton
- 40% of body weight
- Fibers = multinucleate cells (embryonic cells fuse)
- Cells with obvious striations
- Contractions are voluntary



Cardiac: *only in the wall of the heart*

- Cells are striated
- Contractions are involuntary (*not* voluntary)



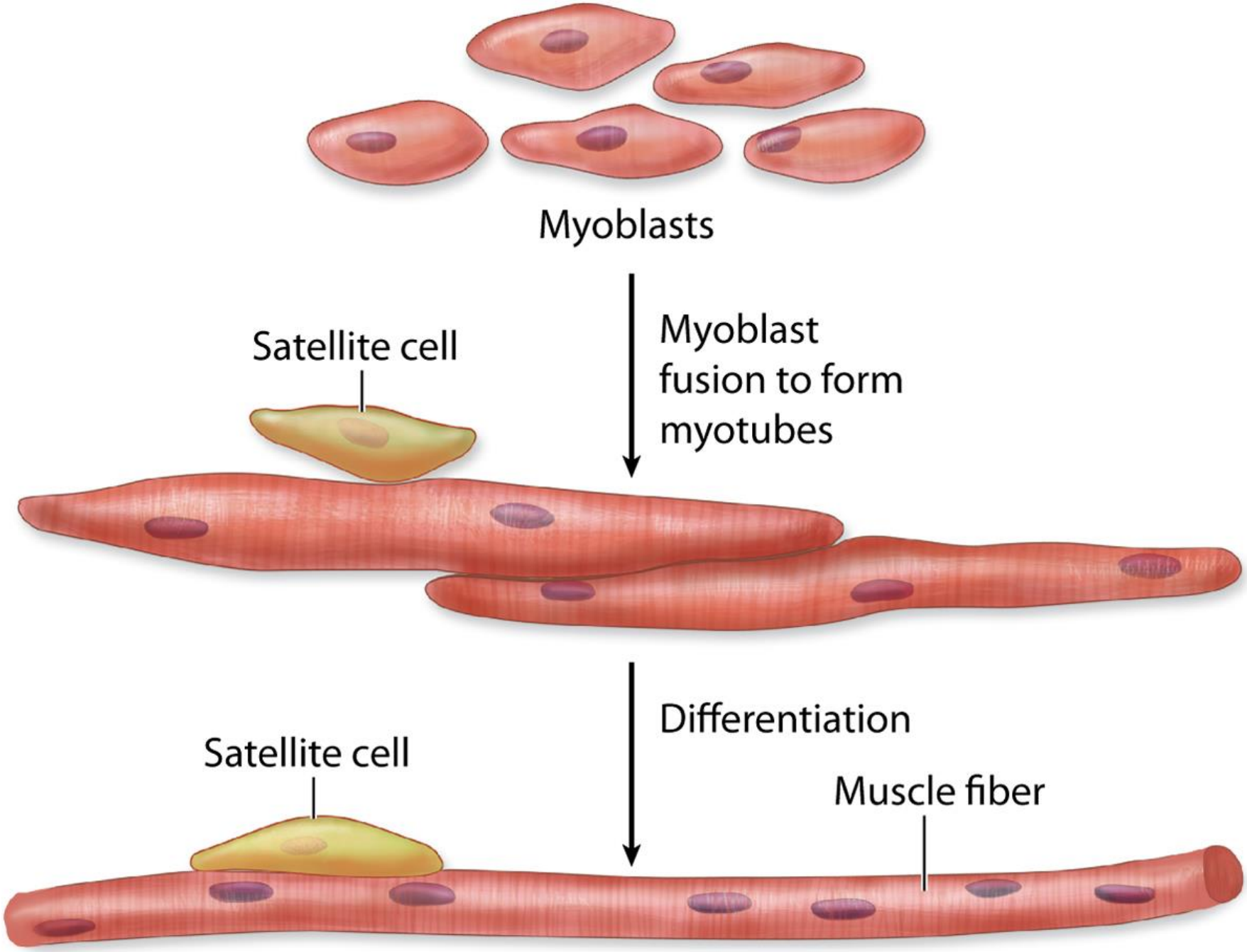
Smooth: *walls of hollow organs*

- Lack striations
- Contractions are involuntary (*not* voluntary)

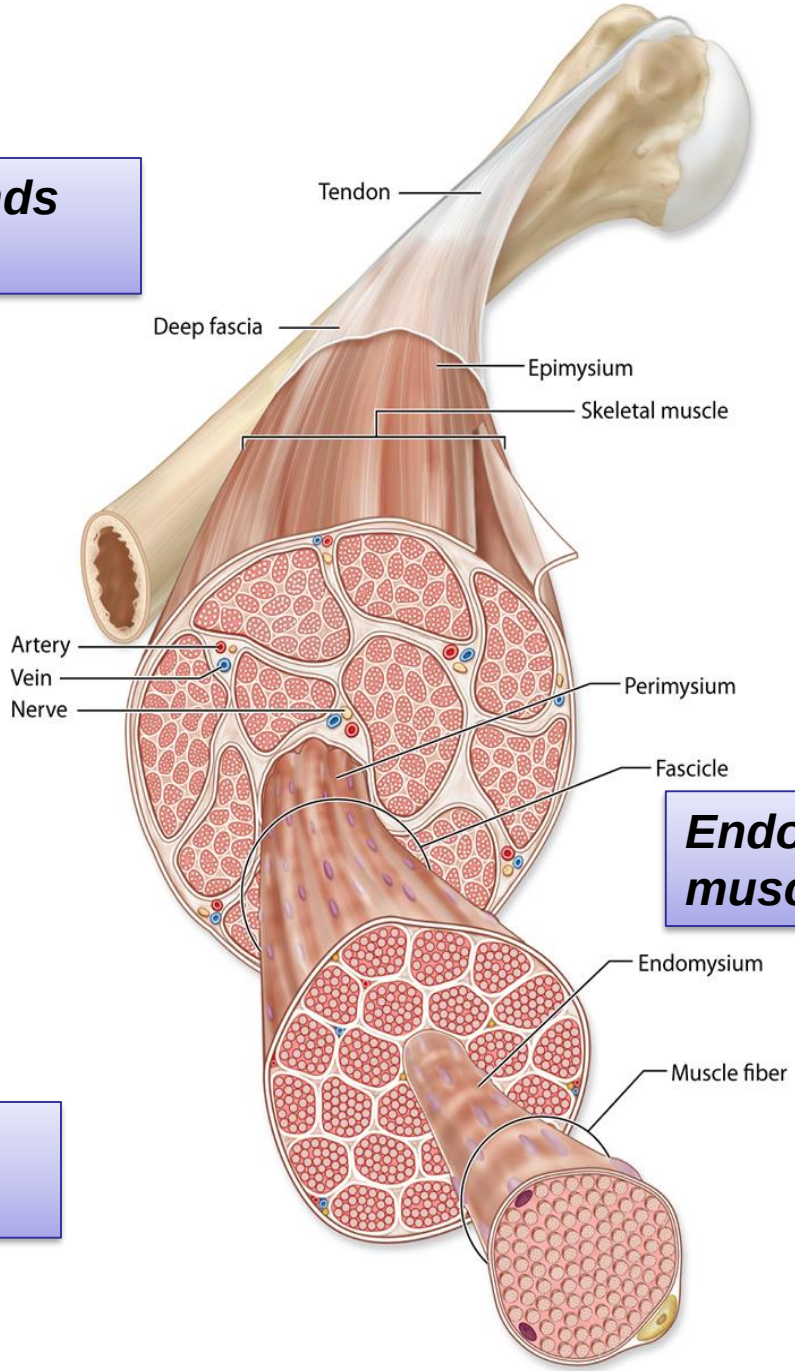
Similarities…

- Their cells are called *fibers* because they are elongated
- Contraction depends on *myofilaments*
  - *Actin*
  - *Myosin*
- Plasma membrane is called *sarcolemma*
  - *Sarcos* = flesh
  - *Lemma* = sheath

SKELETAL MUSCLES

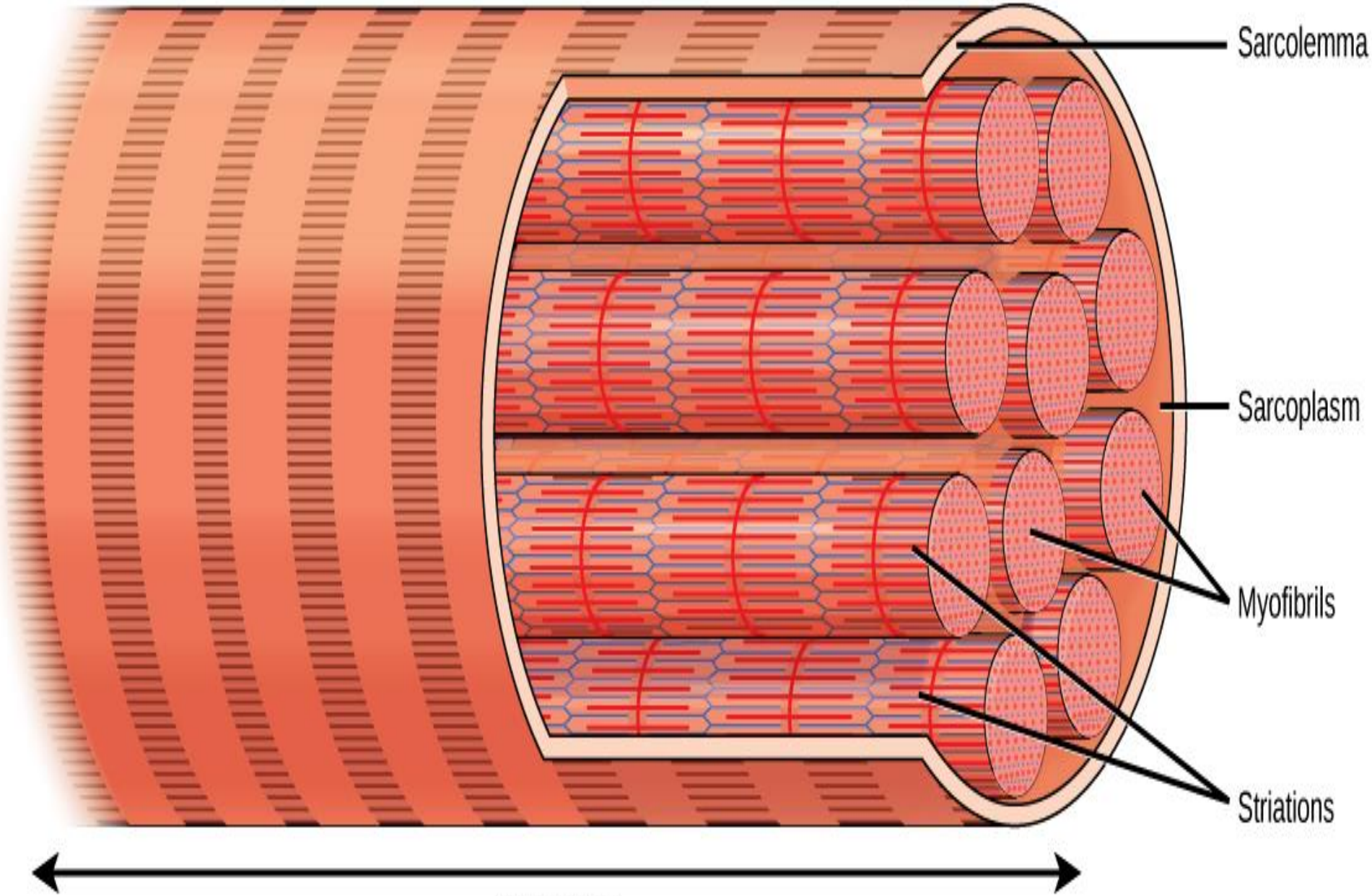

Myoblasts
Myoblast fusion to form myotubes
Satellite cell
Differentiation
Satellite cell
Muscle fiber

Epimysium: surrounds whole muscle



Endomysium is around each muscle fiber

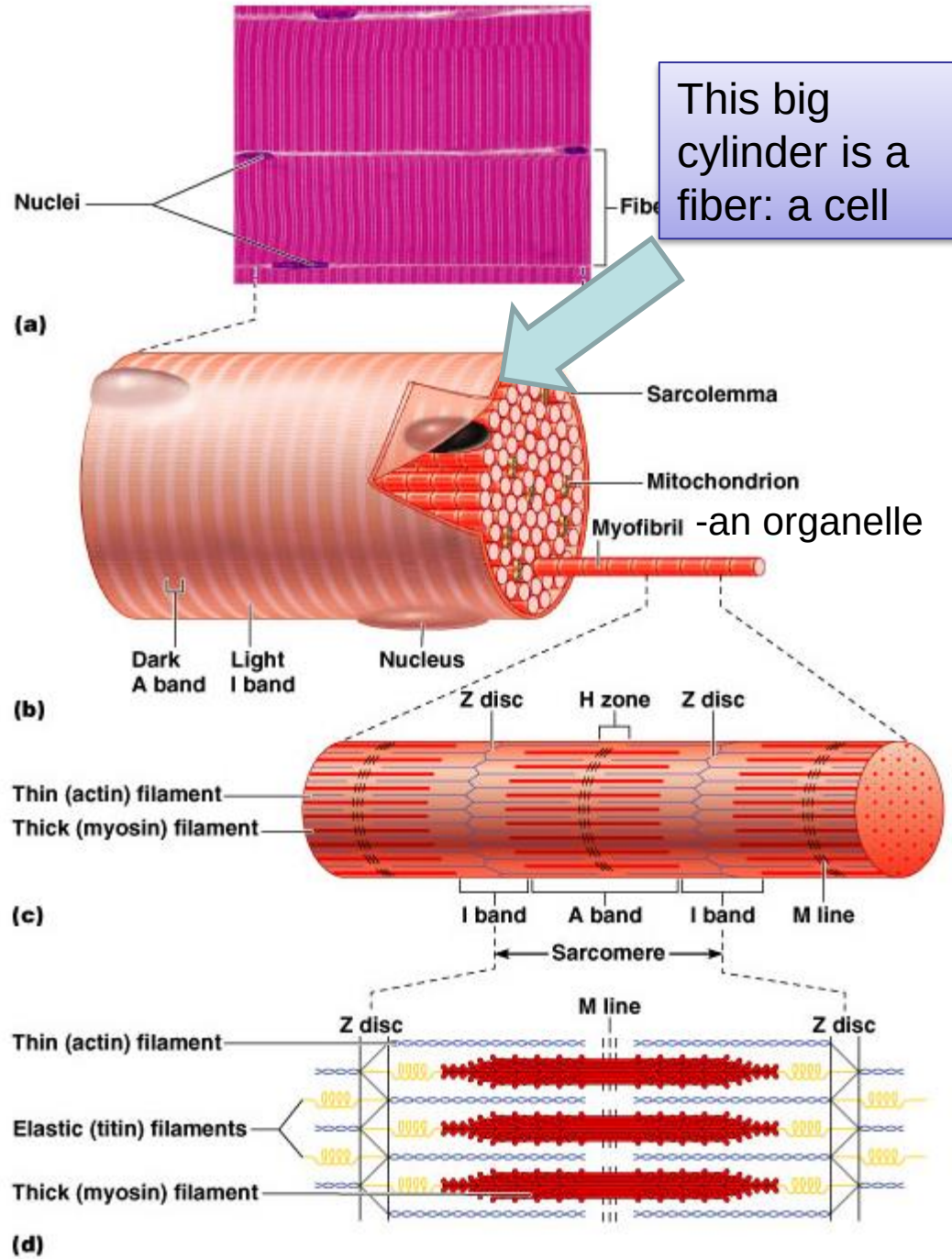
Perimysium is around fascicle

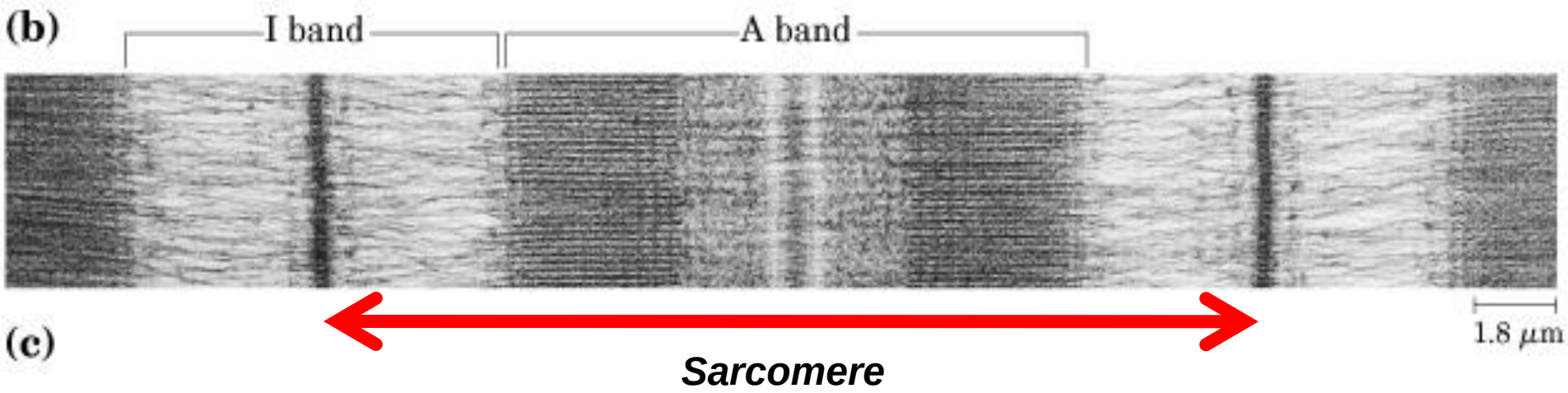


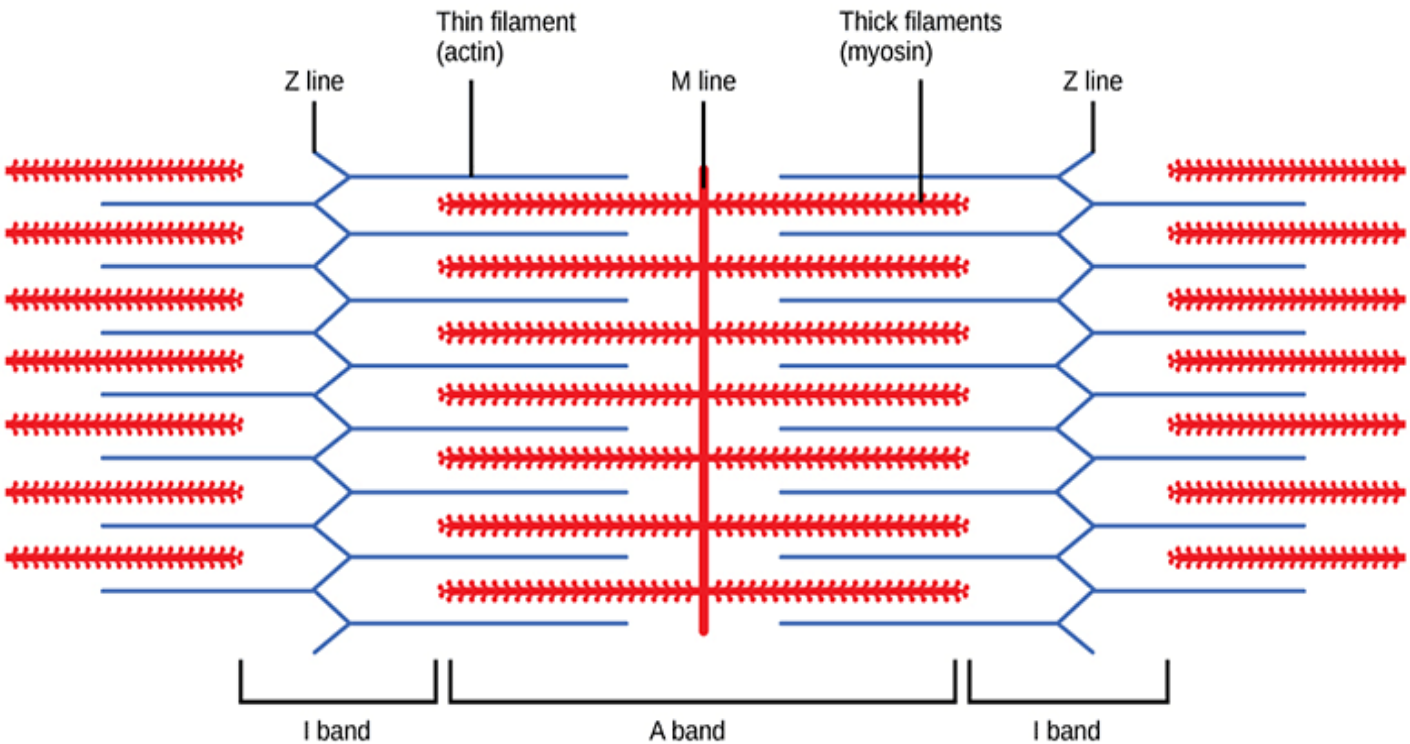
= muscle cell= myofiber

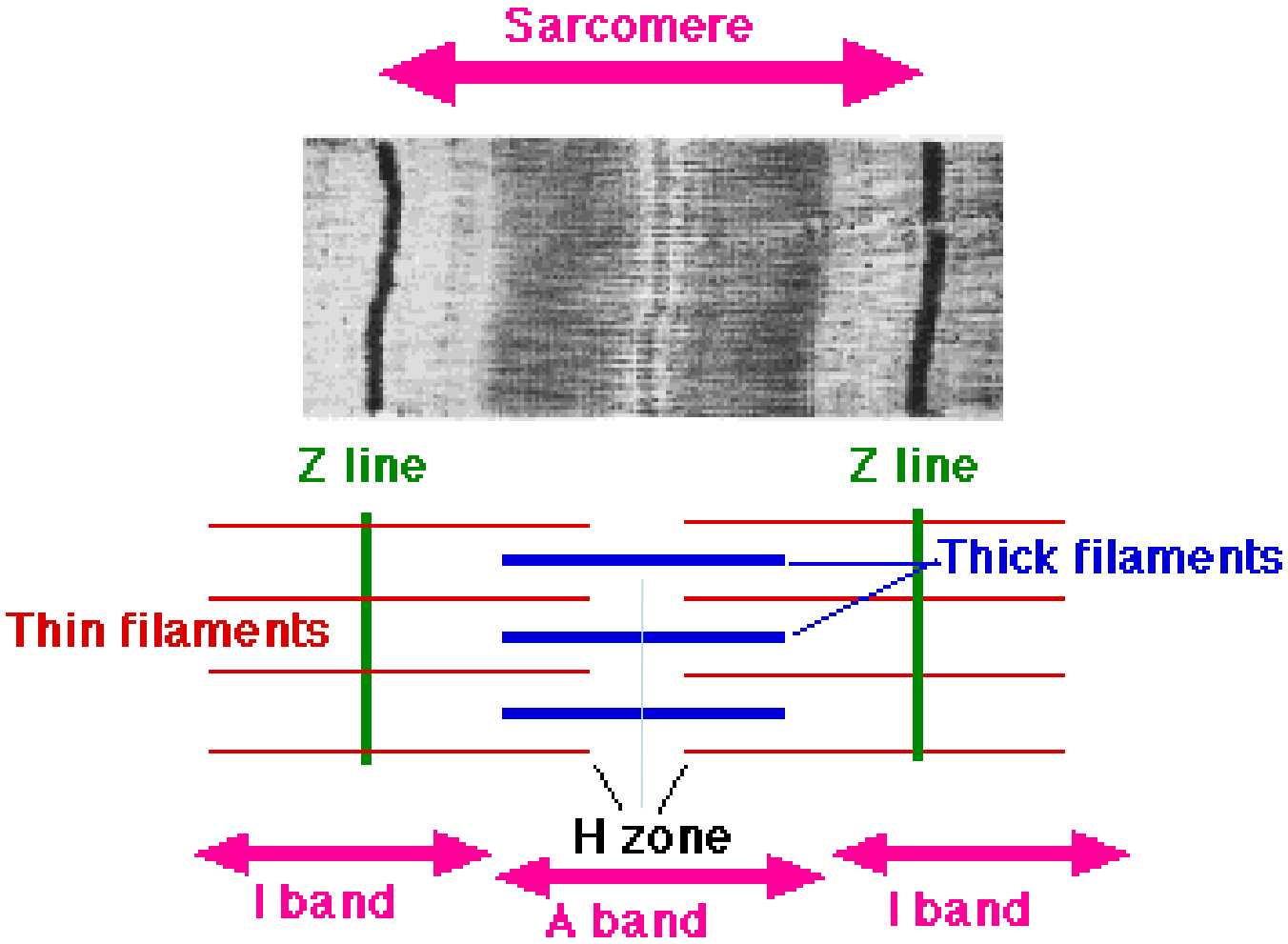
Skeletal muscle

- ***Fibers*** (each is one cell) have striations
- ***Myofibrils*** are organelles of the cell: these are made up of ***myofilaments***
- ***Sarcomere***
  - Basic unit of contraction
  - ***Myofibrils*** are long rows of repeating sarcomeres
  - Boundaries: ***Z discs*** (or lines)




(b)
I band
A band
(c)
1.8 μm
Sarcomere


Thin filament
(actin)
Thick filaments
(myosin)
Z line
M line
Z line
I band
A band
I band



M line provides an attachment to myosin filaments
Z line provides an attachment to actin filaments

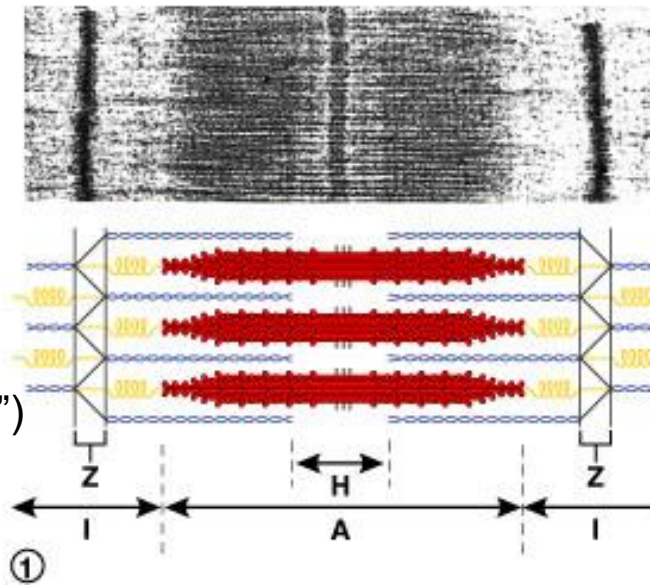
A band is the darker band of the myofibril containing myosin filaments

H band is the lighter section in the middle of the A band where only myosin is present

I band is the lighter band containing only the actin filaments

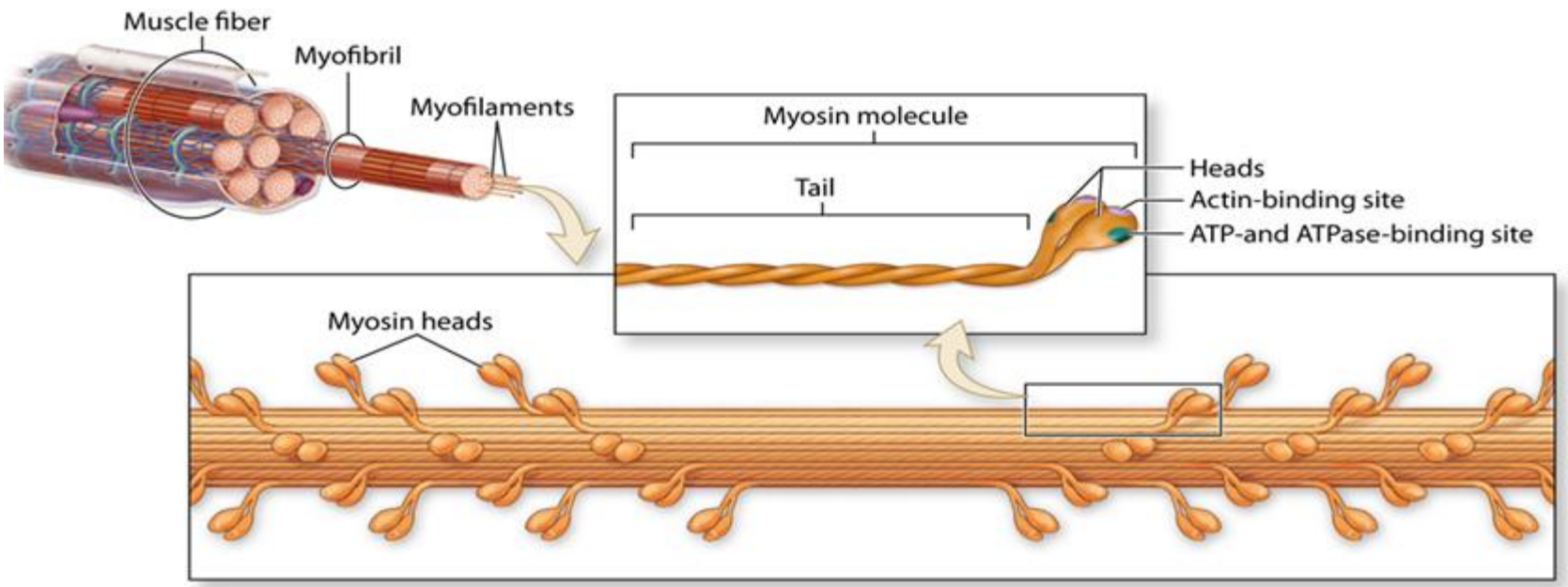
Myofibrils

- Made of ***myo*filaments**:



Contractile unit of striated muscle

- Structures between Z lines
  - 2 halves of I bands
  - A band
  - H zone
  - M line (*mittelscheibe*, Ger. “middle of the disc”)
  - Myofilaments
    - Actin
    - Myosin
  - Other structural proteins
    - **Titin (myosin-associated) <u>supports myosin filaments and anchor them to Z line (elastic)</u>**
    - Nebulin (actin-associated)- <u>binds actin filaments to α actinin</u>
    - Myomesin (at M line)
    - α actinin (at Z line)
    - Desmin (Z line)
    - Vimentin (Z line)
    - Dystrophin (cell membrane)

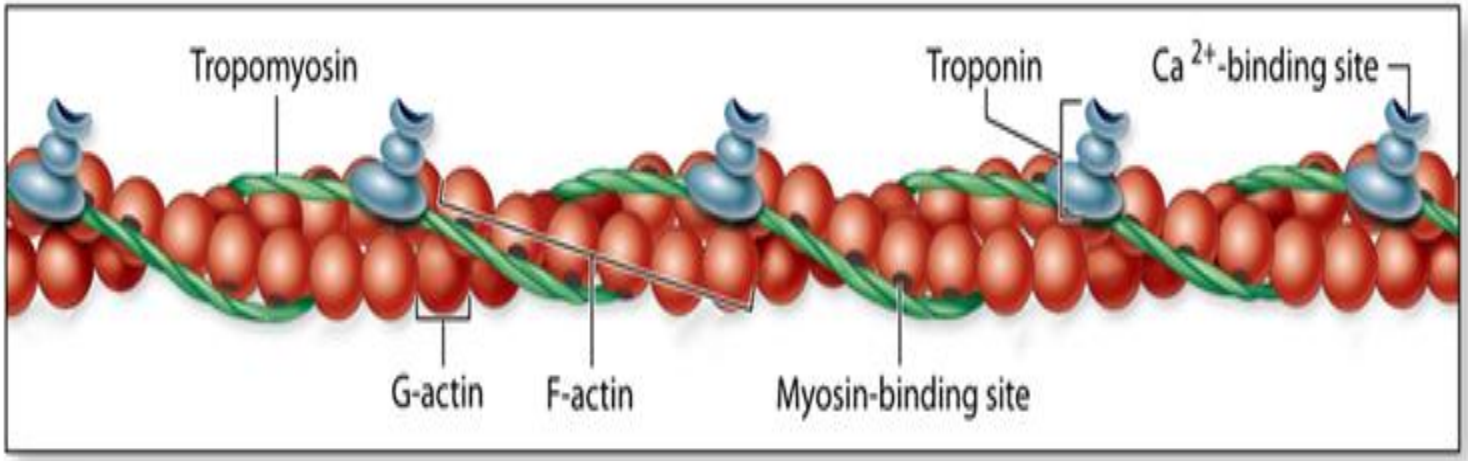


a Thick filament

Myosin is composed of 2 identical heavy chains and two pairs of light chains

heavy chains are twisted together as tail

The four light chains form a head at one end of each heavy chains



b Thin filament

- Actin filaments are composed of two thin helical twisted strands composed of G-actin monomers
- Contain a myosin binding site
- Are anchored to the Z line by alpha-actinin
- Associated with:

A- **Tropomyosin**: coil of two peptide chains located in the groove between the two twisted actin strands

B- **Troponin** a complex of 3 subunits :

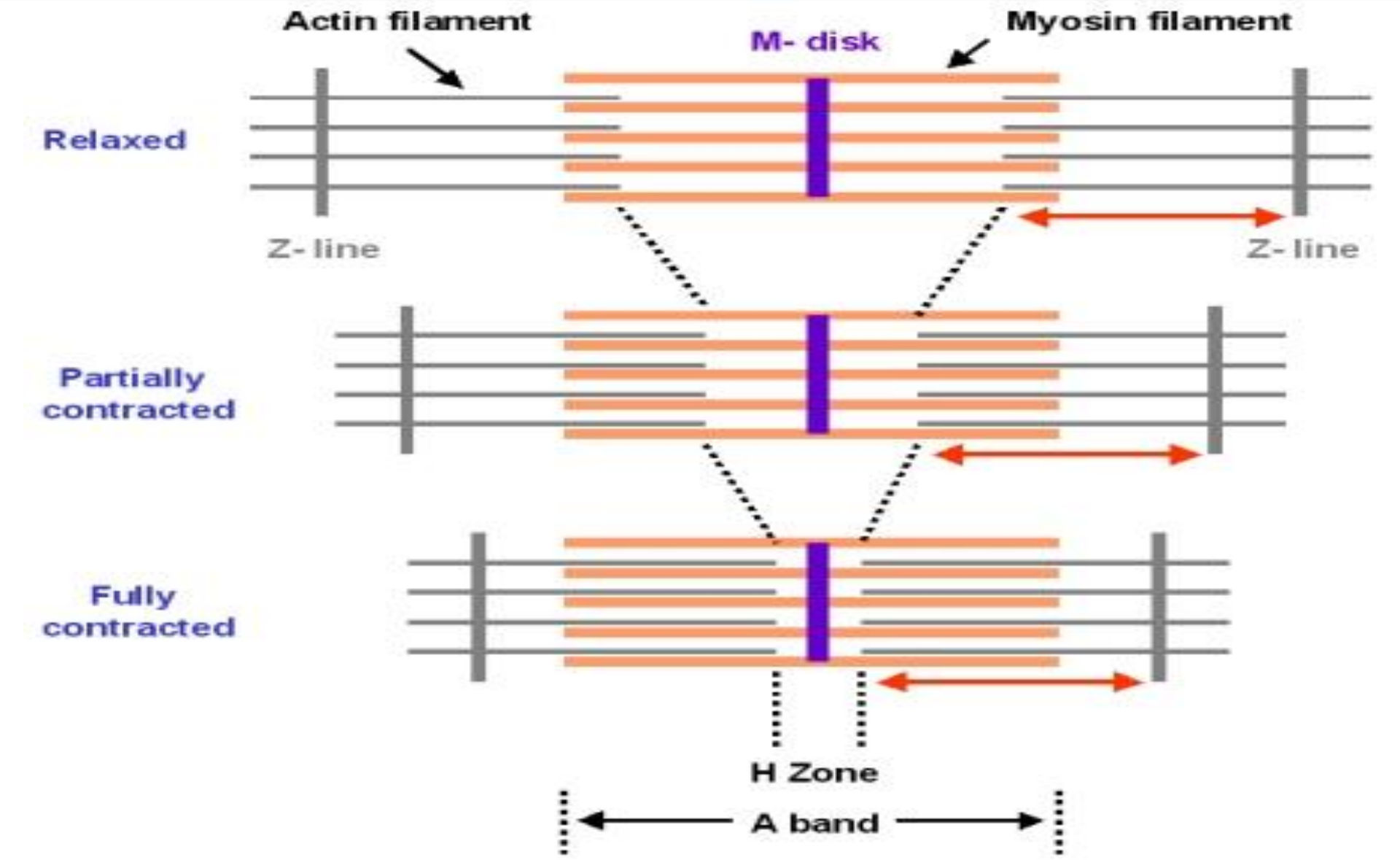
Tropomyosin

Calcium ion

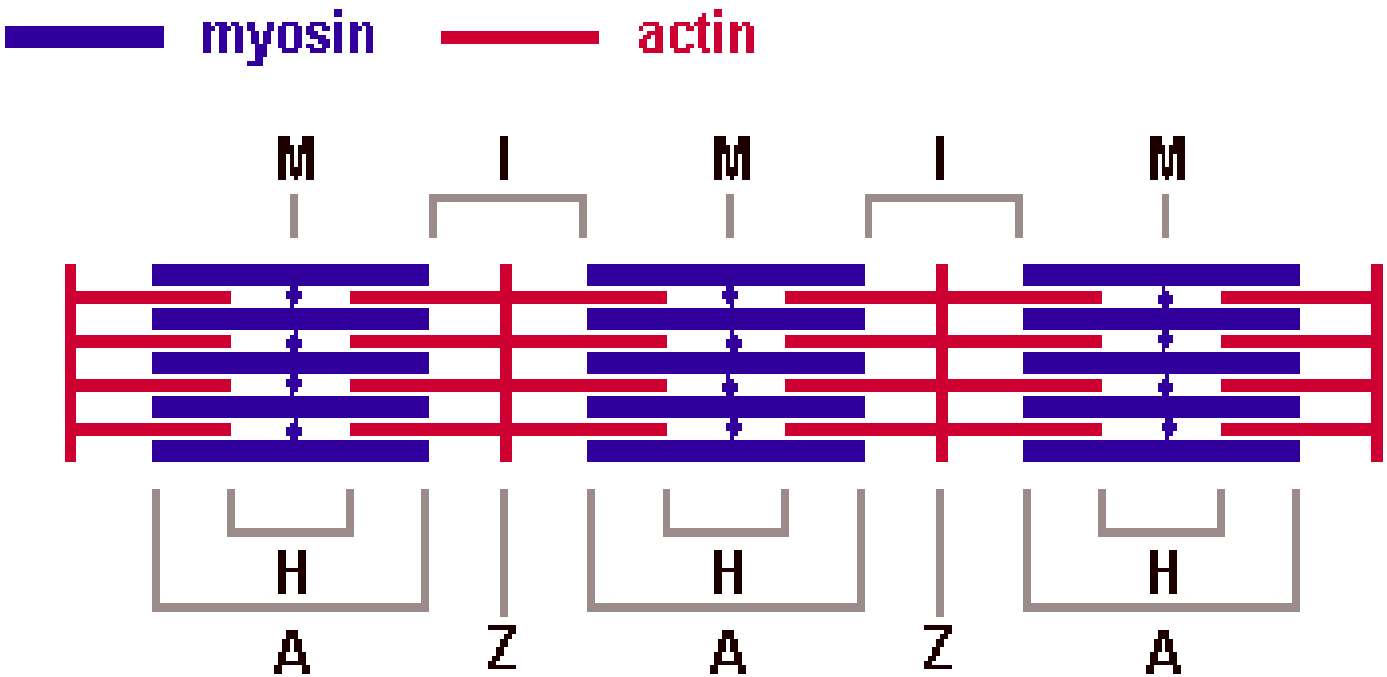
Regulatory subunit

Sliding Filament Model

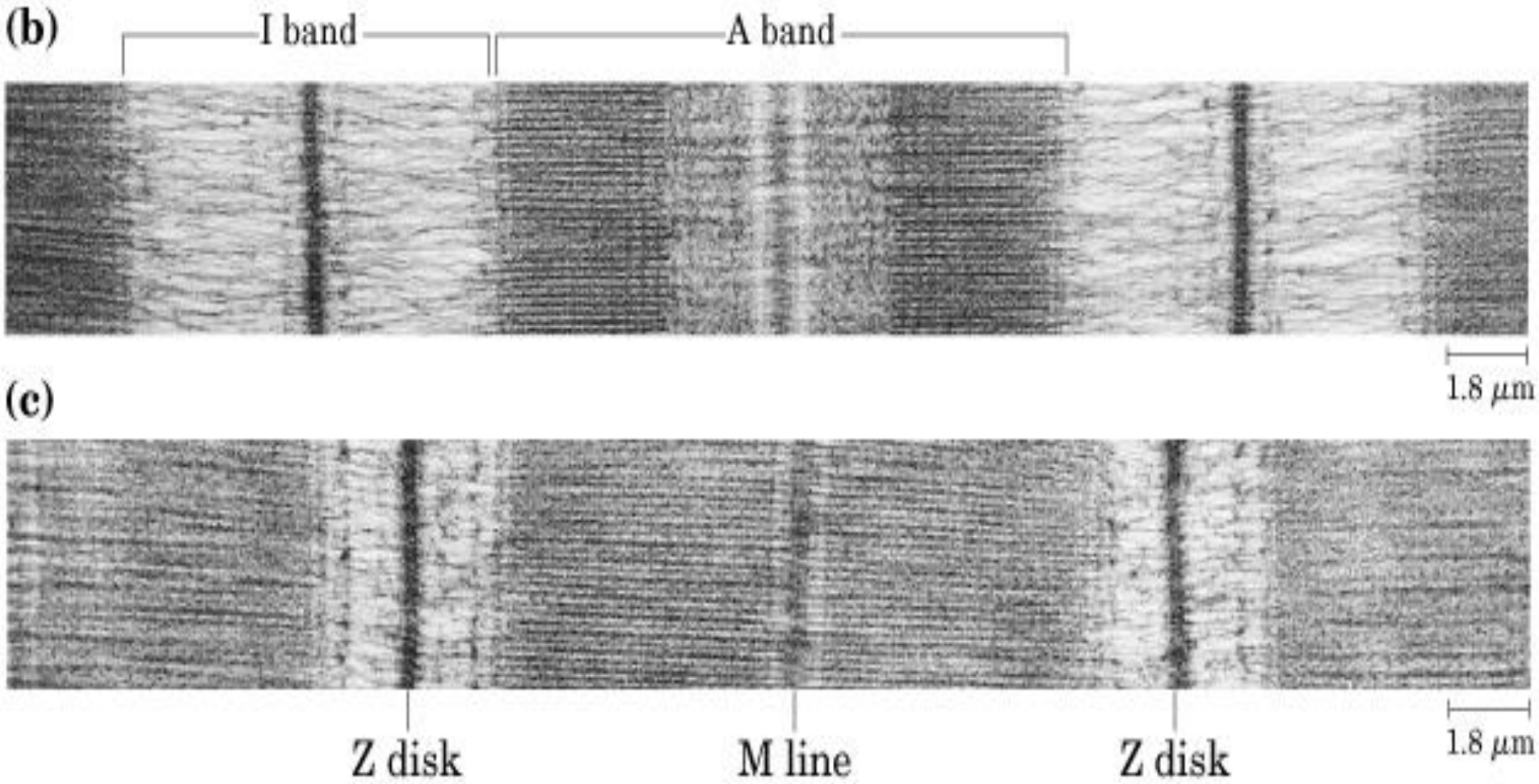
<u>Note</u>: Z lines move closer together; I **band** and **H band** become smaller during contraction



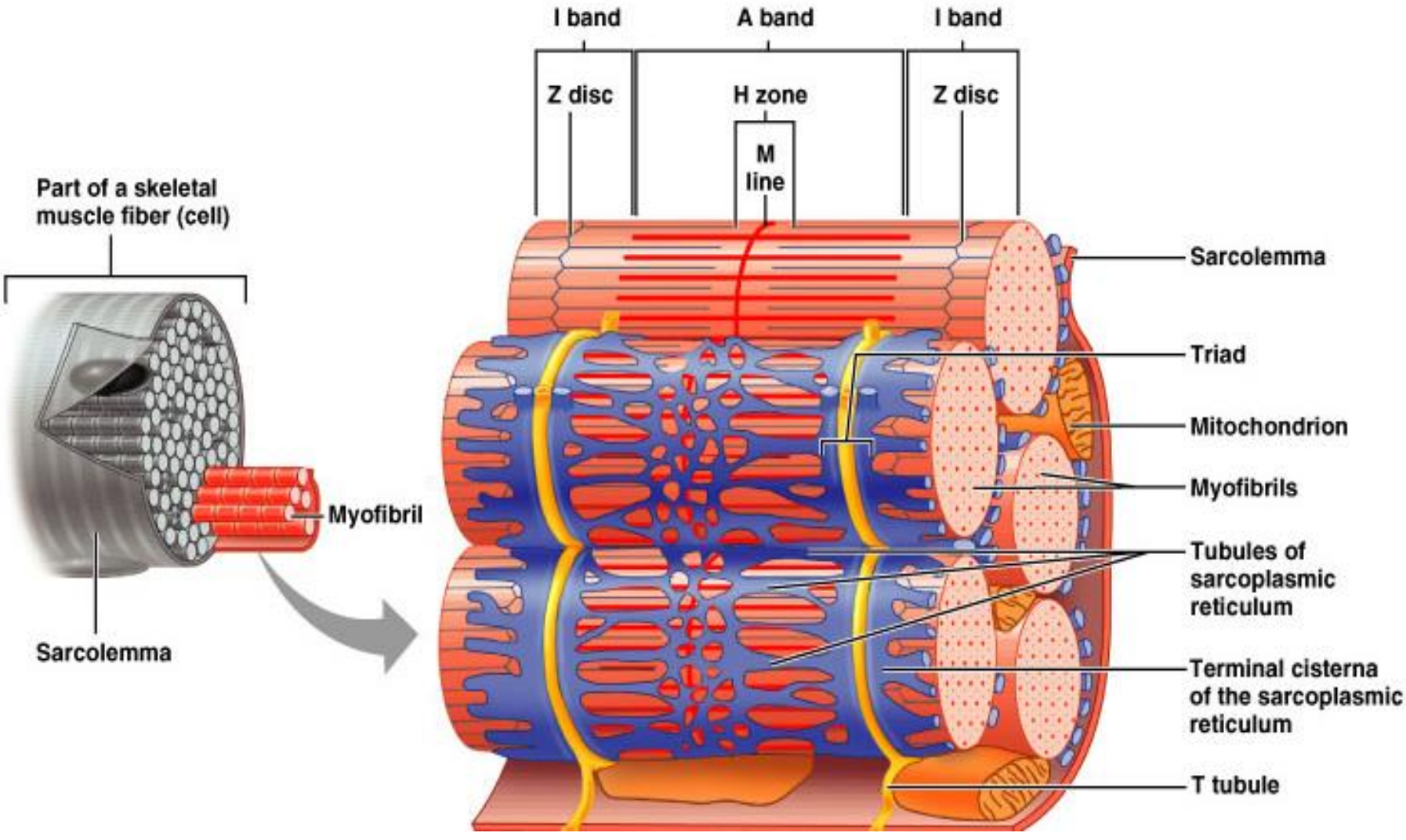
Sarcomere shortens because actin pulled towards its middle by myosin cross bridges



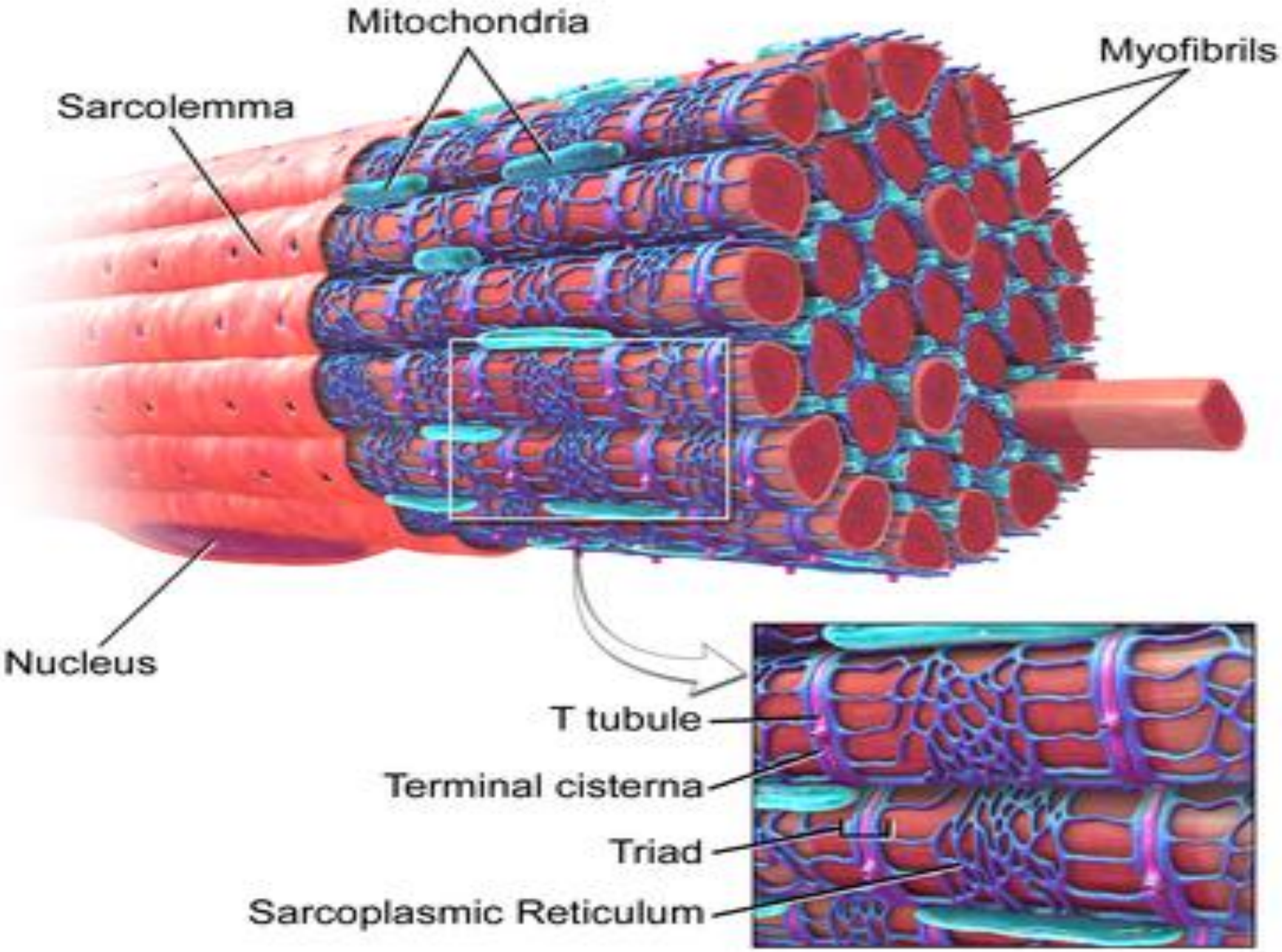
Bands and lines in the contractile apparatus of skeletal muscle


(b)
I band
A band
1.8 μm
(c)
Z disk
M line
Z disk
1.8 μm

- Sarcoplasmic reticulum is smooth ER
  - Tubules surround myofibrils
  - T tubules are continuous with sarcolemma, therefore whole muscle (deep parts as well) contracts simultaneously



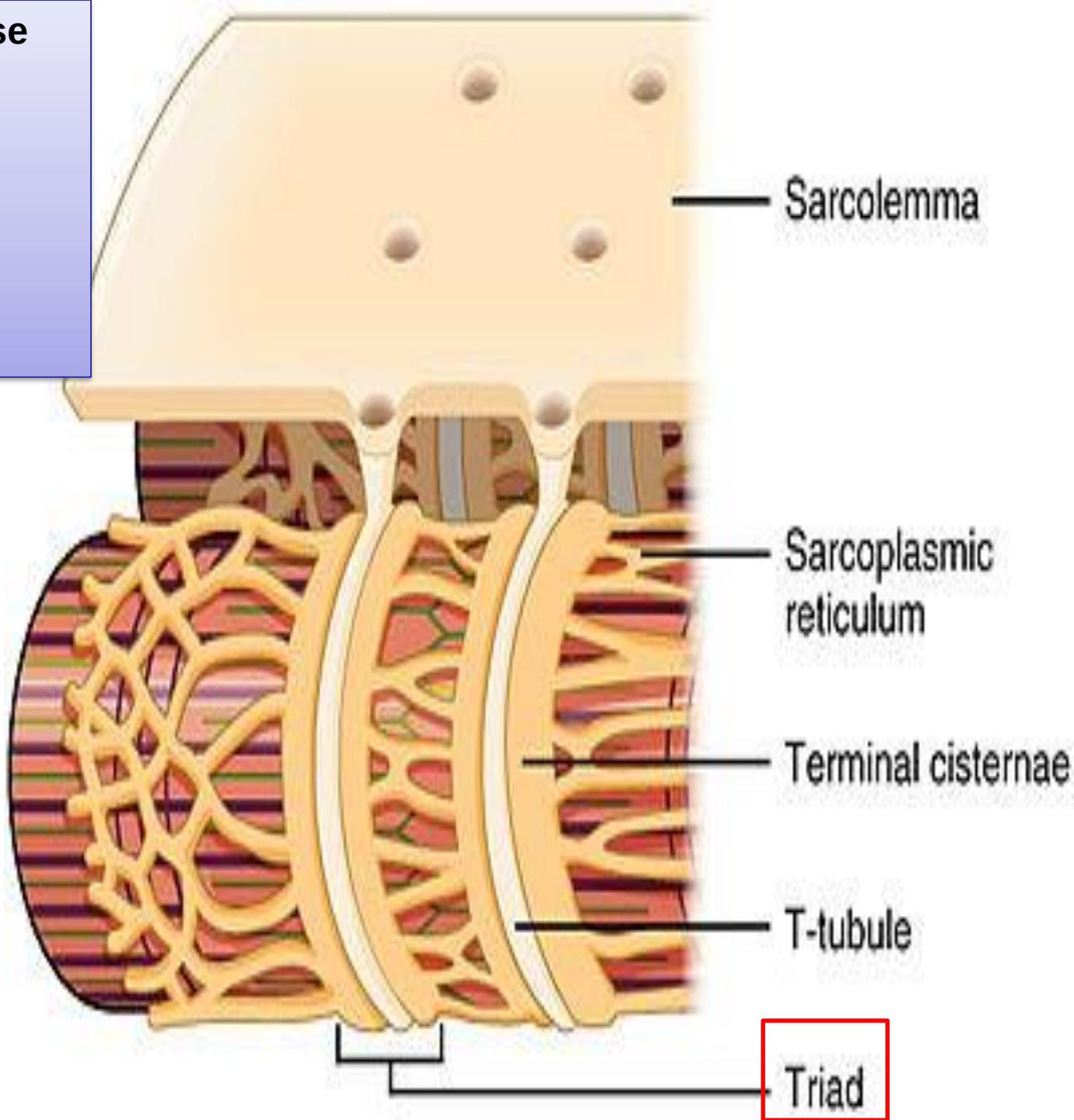
Skeletal Muscle Fiber

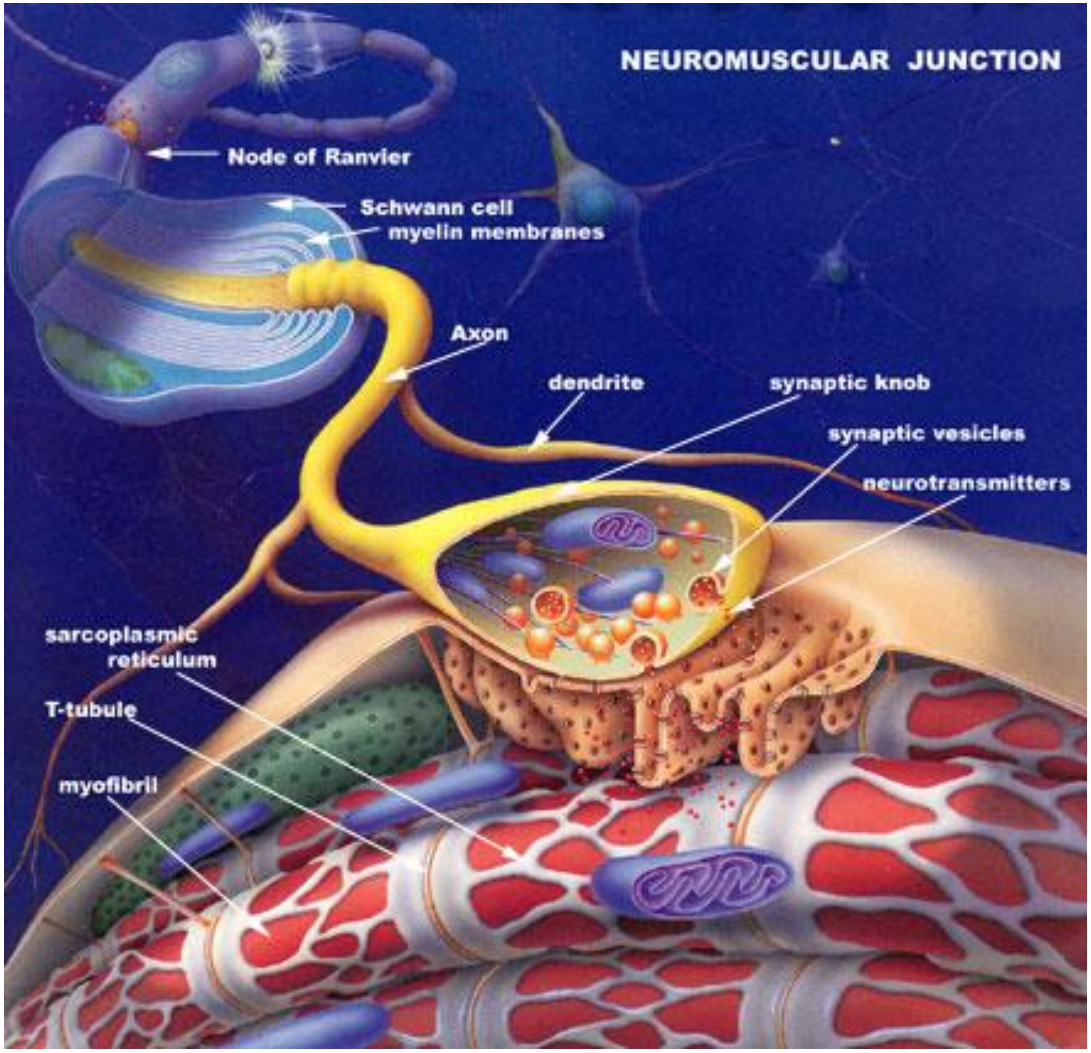


A **T-tubule** (or **transverse tubule**) is a deep invagination of the sarcolemma

T-tubules permit the conduction of electrical impulses

Terminal cisternae are enlarged areas of the sarcoplasmic reticulum surrounding the transverse tubules.
They store calcium and release it when an action potential courses down the transverse tubules, eliciting muscle contraction





Neuromuscular Junction

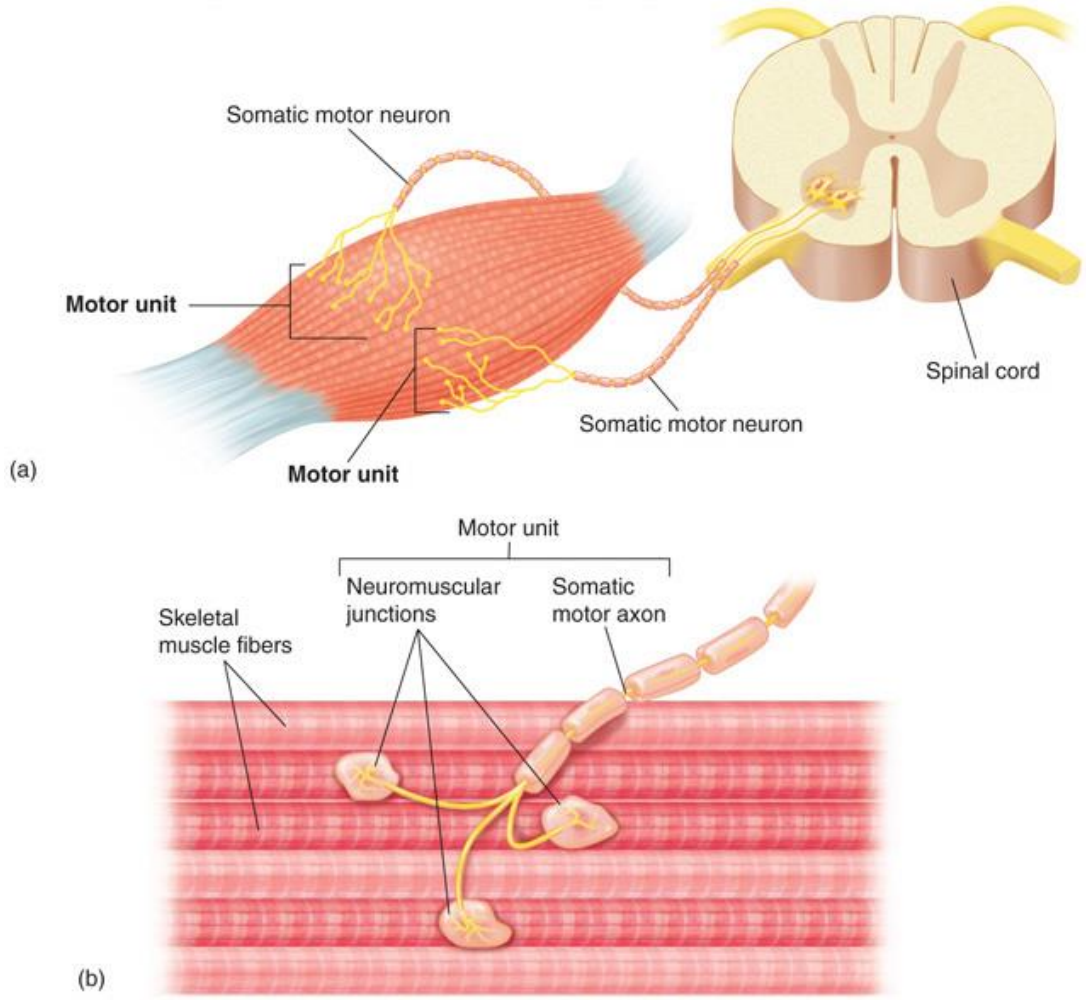
Motor neurons innervate muscle fibers
Motor end plate is where they meet
Neurotransmitters are released by nerve signal: this initiates calcium ion release and muscle contraction

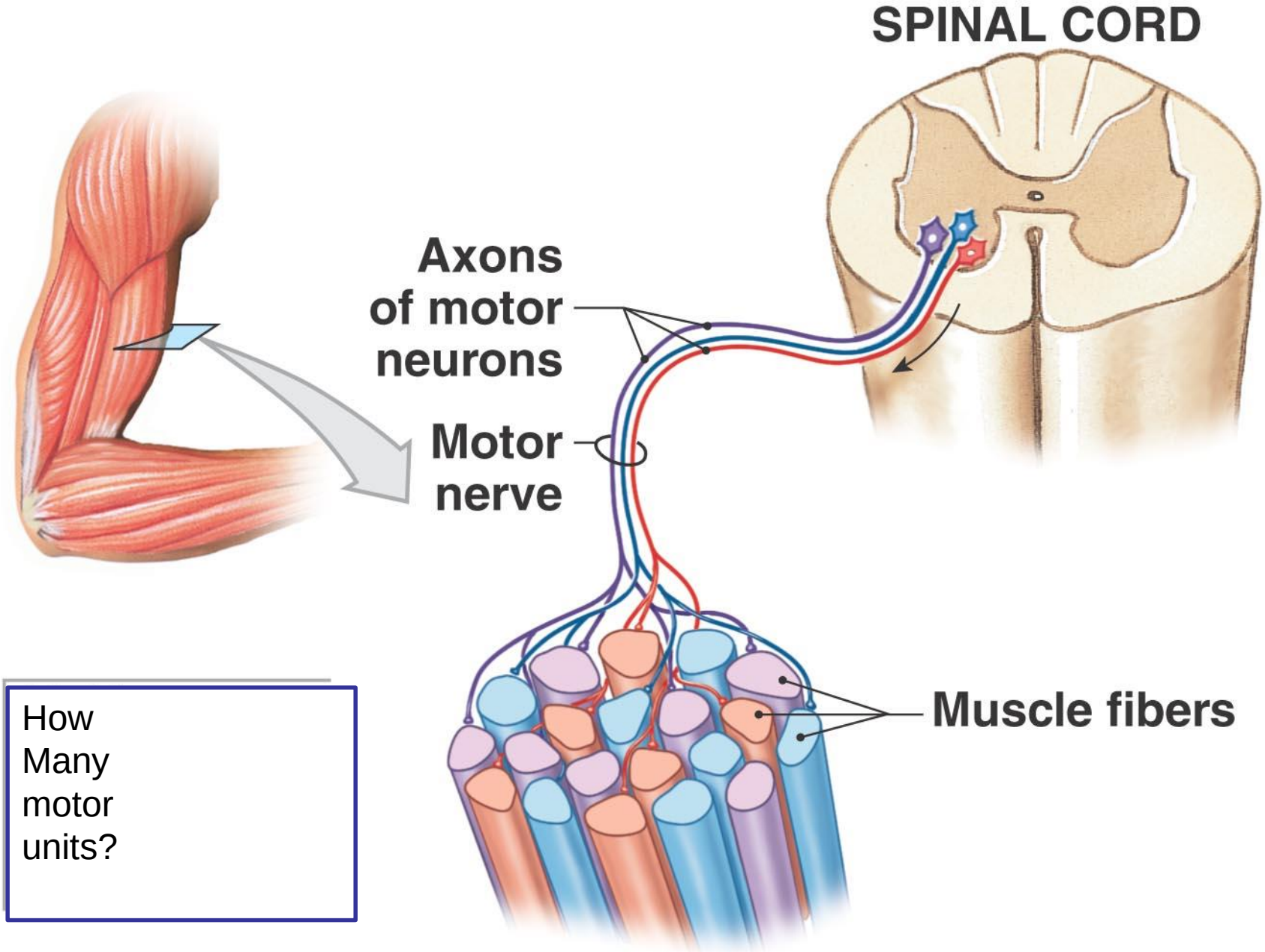
Motor Unit: a motor neuron and all the muscle fibers it innervates (these all contract together)

- Average is 150, but range is one to several hundred muscle fibers in a motor unit
- The finer the movement, the fewer muscle fibers /motor unit
- The fibers are spread throughout the muscle, so stimulation of a single motor unit causes a weak contraction of the entire muscle

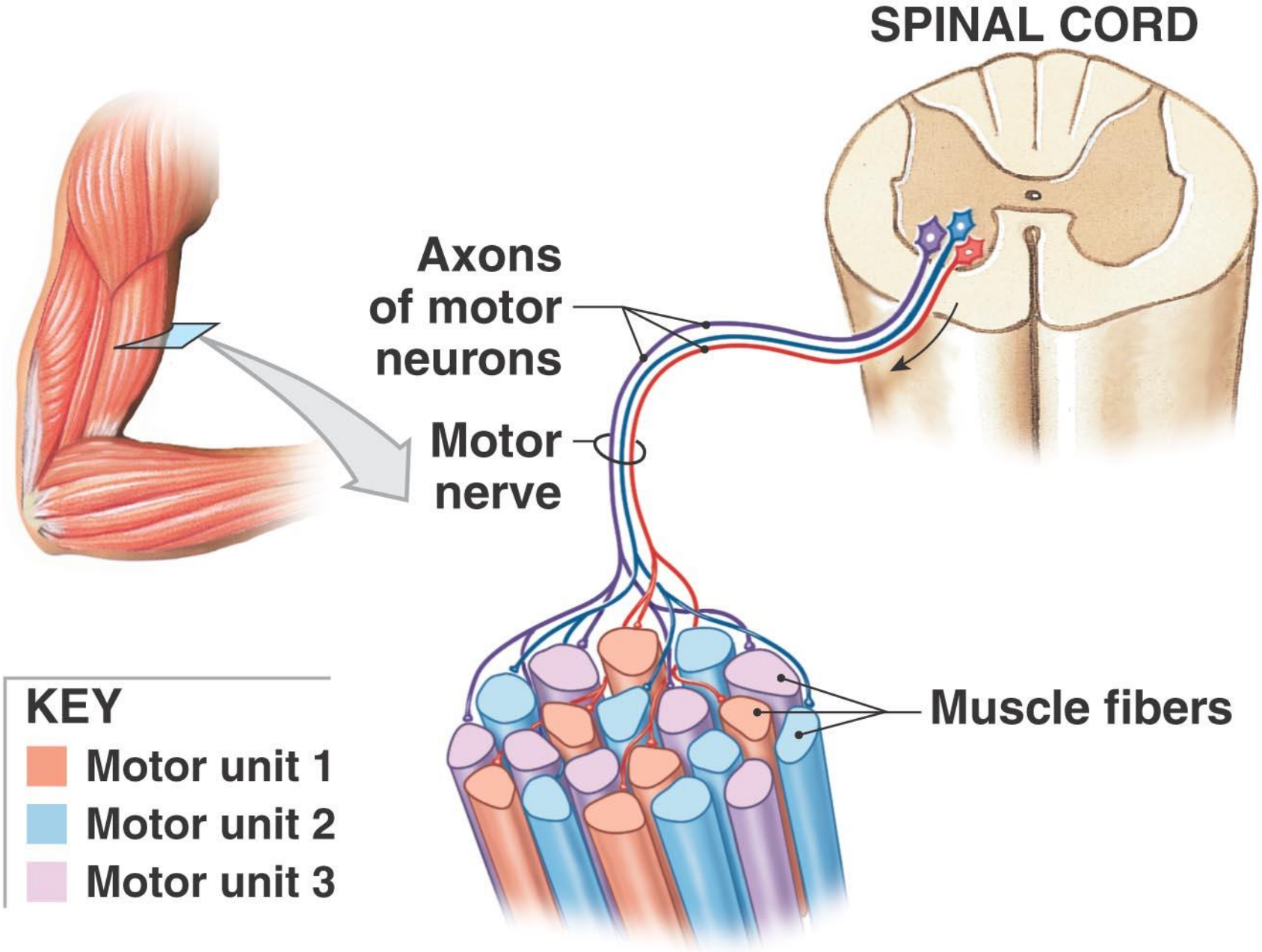
Motor Unit

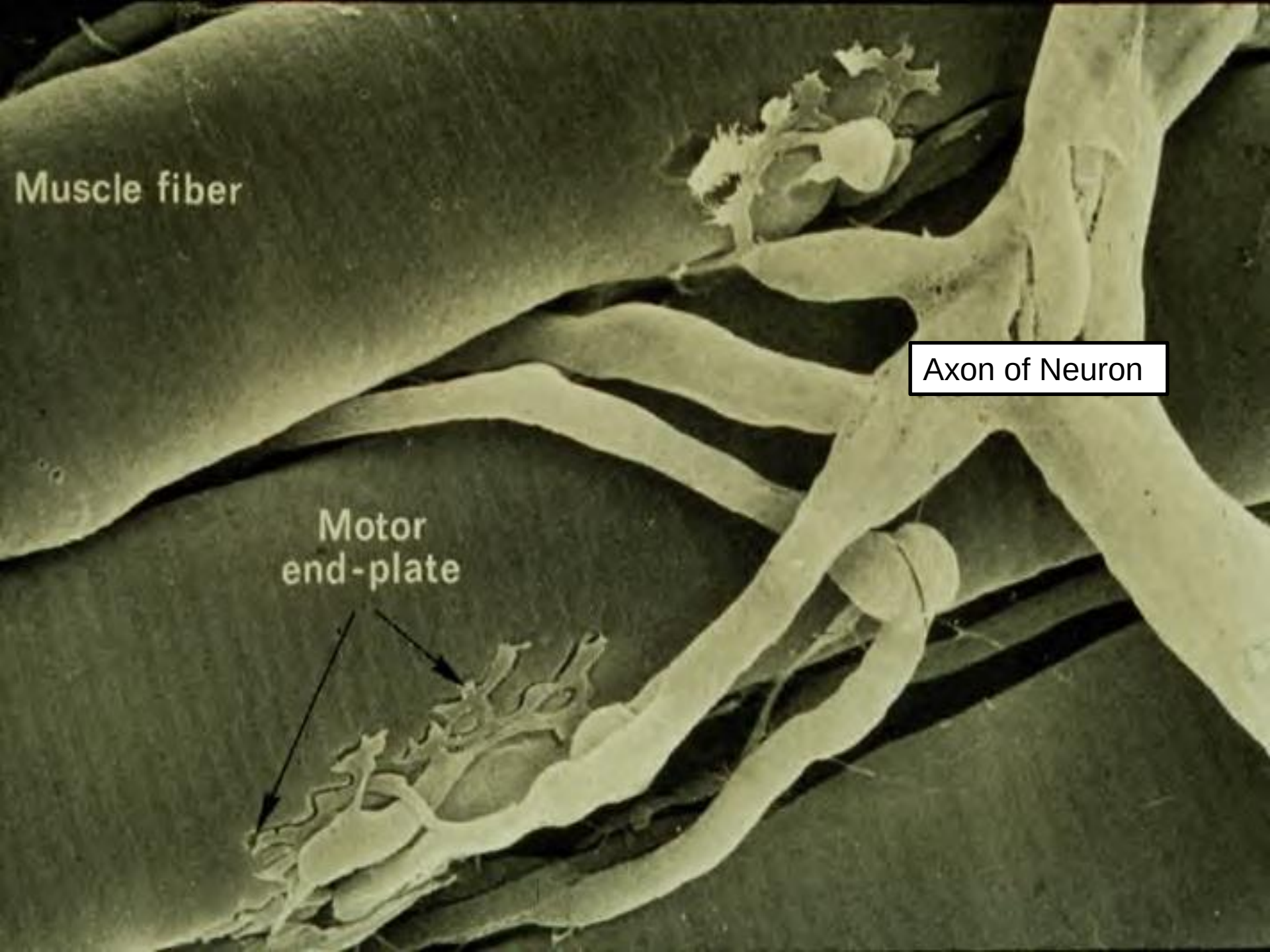
- Each motor neuron branches to innervate a variable # of muscle fibers
- A motor unit includes each motor neuron and all fibers it innervates





How Many motor units?




Muscle fiber
Axon of Neuron
Motor
end-plate

Types of skeletal muscle fibers

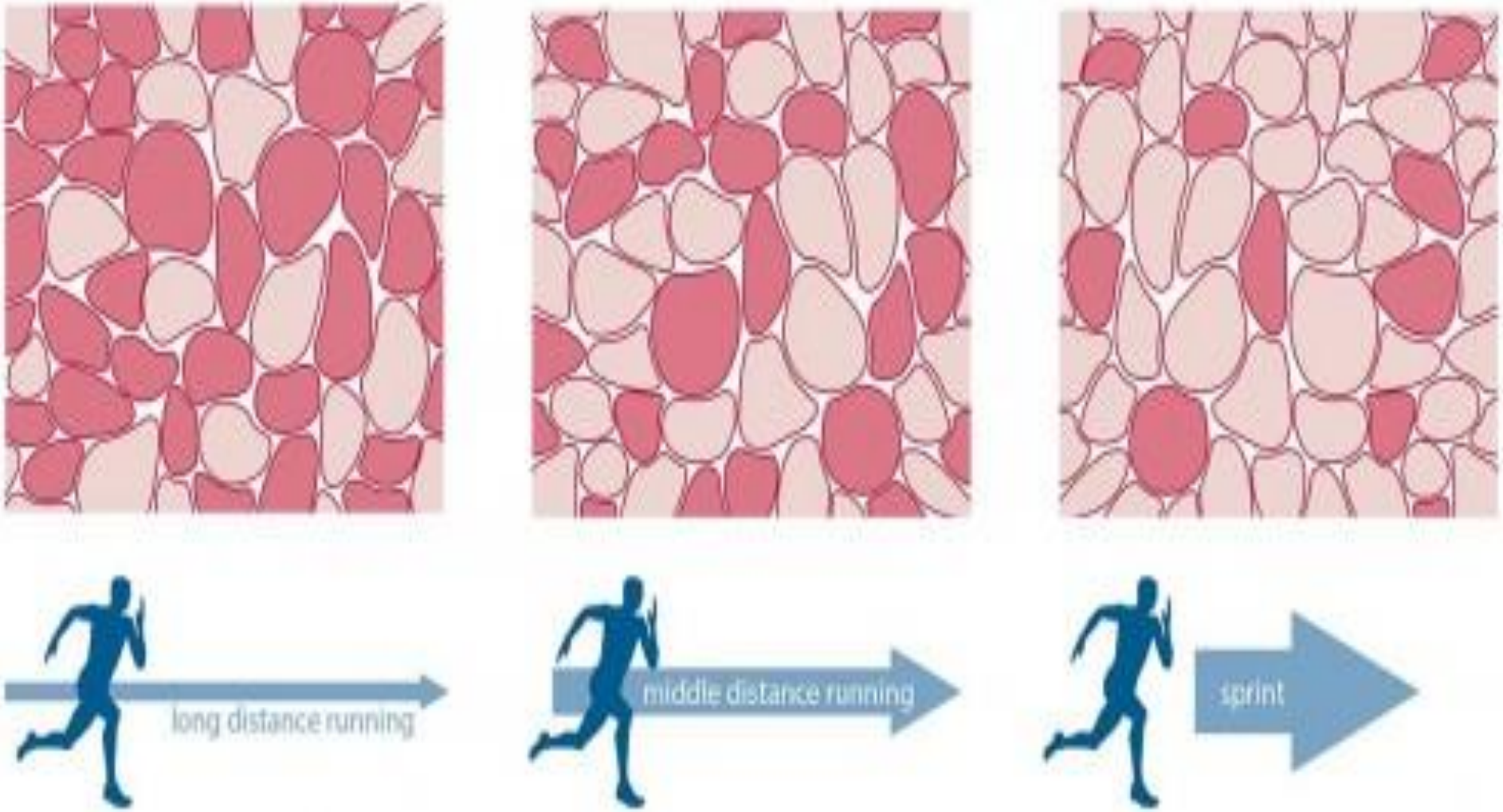
- Fast, slow and intermediate
- Whether or not they predominantly use oxygen to produce ATP
  - Oxidative – aerobic (use oxygen)
  - Glycolytic – make ATP by glycolysis (break down of sugars without oxygen=anaerobic)
- Fast fibers: “white fibers” – large, predominantly anaerobic, fatigue rapidly (rely on glycogen reserves); most of the skeletal muscle fibers are fast
- Slow fibers: “red fibers” – half the diameter, 3X slower, but can continue contracting; aerobic, more mitochondria, myoglobin
- Intermediate: in between

SLOW TWITCH VS FAST TWITCH MUSCLE FIBRES

By: Chirag Navadia @Me

FEATURES	TYPE I MUSCLE FIBER	TYPE II MUSCLE FIBER
FORCE OF CONTRACTION	Slow	Fast
RED COLOR	High (aka Red Fibers)	Low (aka White Fibers)
MITOCHONDRIA & MYOGLOBIN	High	Low
OXIDATIVE CAPACITY	High	Low
CAPILLARY DENSITY & FATIGUE RE-SISTANCE	High	Low
MAIN SOURCE OF ENERGY	Triglycerides	Glycogen & Creatine Phosphate
DURATION OF USE	Long	Short
GLYCOGEN & GLYCOLYTIC CAPACITY	Low	High
POWER	Stamina	Strength
HIGH AMOUNT IN...	Postural Muscles (Axial)	Peripheral Muscles
INCREASED IN...	Marathon Runner (Gastrocnemius) Swimmer (Post. Deltoid)	Sprinter (Gastrocnemius) Pole Vaulting, Shot Putter


Red Turtle



Left – Red Fiber Dominant, Marathoner
Right – White fiber Dominant, Sprinter,
Middle – Perfect, Bodybuilder

All muscle fibers of a motor unit are of the same type.

- A skeletal muscle contracts when its motor units are stimulated
- Amount of tension depends on
  1. the frequency of stimulation
  2. the number of motor units involved
- All or none principle: each muscle fiber either contracts completely or not at all
- Amount of force: depends on how many motor units are activated
- Muscle tone
  - Even at rest, some motor units are active: tense the muscle even though not causing movement: “resting tone”

- Muscle hypertrophy
  - Weight training (repeated intense workouts): increases diameter and strength of “fast” muscle fibers by increasing production of
    - Mitochondria
    - Actin and myosin protein
    - Myofilaments containing these contractile proteins
    - The myofibril organelles these myofilaments form
  - Fibers enlarge (hypertrophy) as number and size of myofibrils increase

    [*Muscle fibers (=muscle cells) don’t increase in number but increase in diameter producing large muscles]*

- Endurance training (aerobic): doesn’t produce hypertrophy

- Muscle atrophy: loss of tone and mass from lack of stimulation
  - Muscle becomes smaller and weaker

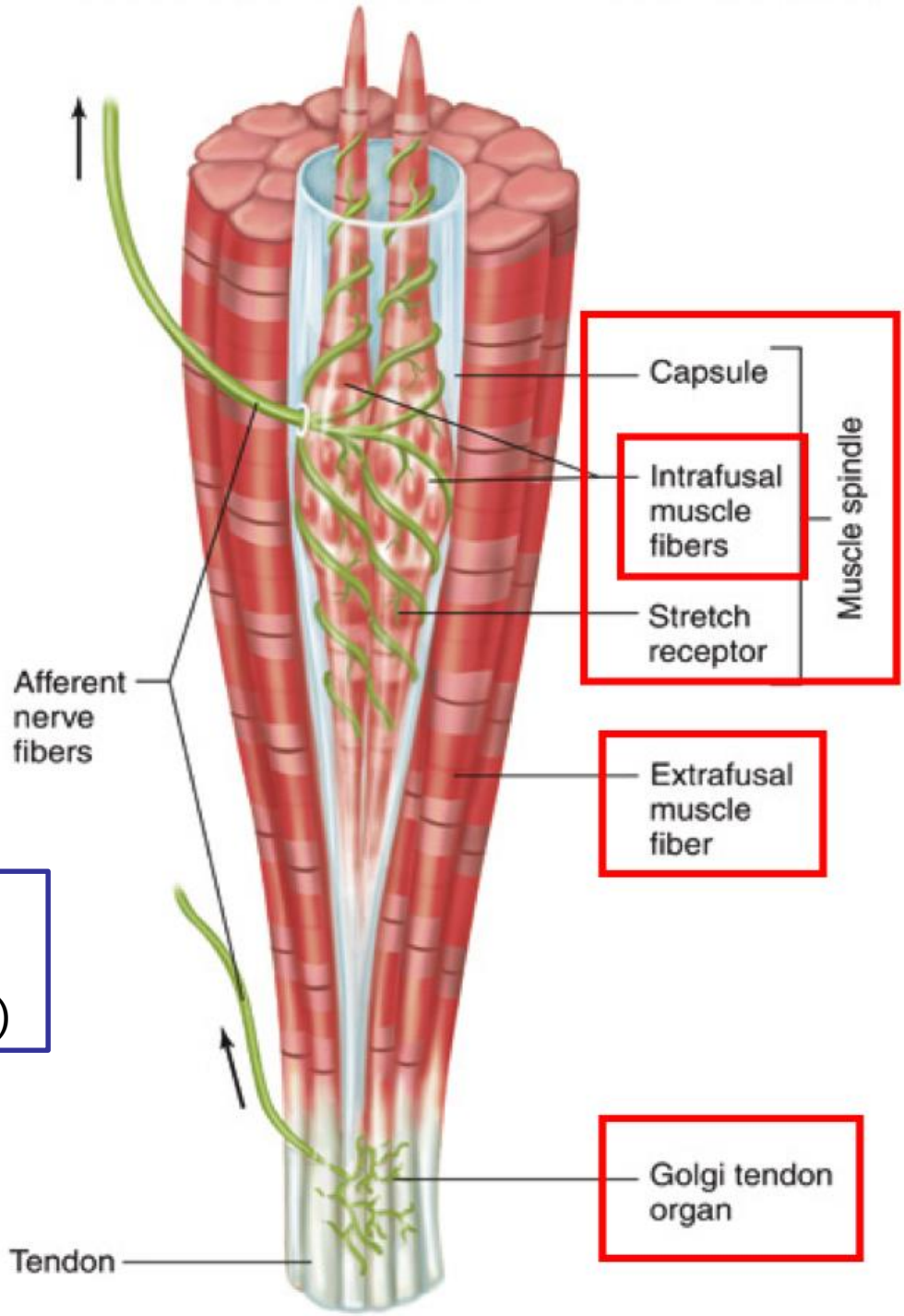
Note on terminology: in general, increased size is *hypertrophy;* increased number of cells is *hyperplasia*

Muscle spindles are sensory receptors within the belly of a muscle that primarily detect changes in the length of this muscle.

They convey length information to the central nervous system via sensory neurons

This information can be processed by the brain to determine the position of body parts

Each muscle spindle consists of an encapsulated cluster of small striated muscle fibers ("**intrafusal muscle fibers**")



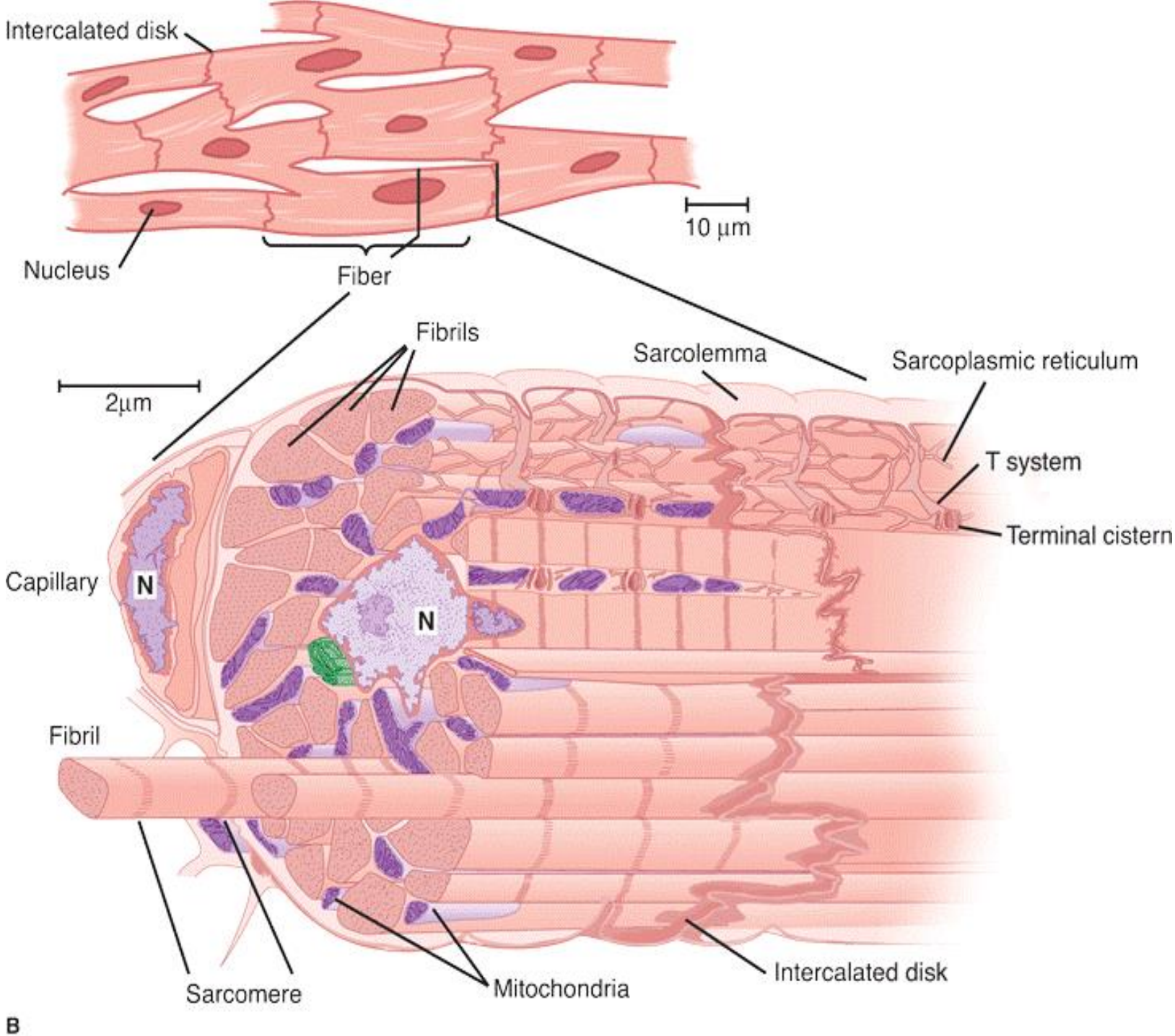
Cardiac Muscle

Tissue Features:

- Striated (same contractile machinery)
- Self-excitatory and electrically coupled
- Rate of contractions modulated by autonomic nervous system

Cell Features:

- 1 or 2 centrally placed nuclei
- Branched fibers with intercalated discs

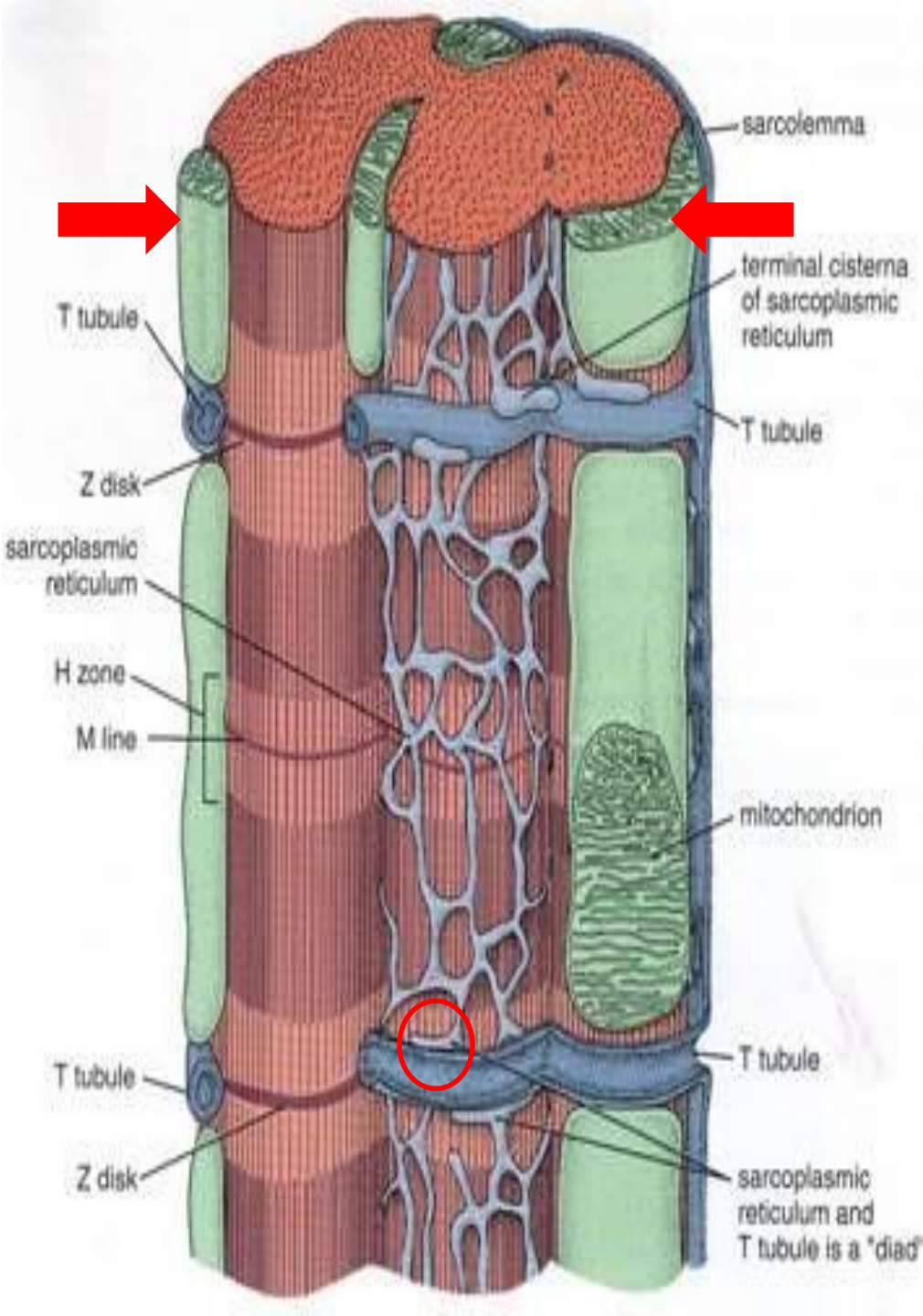

Intercalated disk
10 µm
Nucleus
Fiber
Fibrils
Sarcolemma
Sarcoplasmic reticulum
2µm
T system
Terminal cistern
Capillary
N
N
Fibril
Sarcomere
Mitochondria
Intercalated disk
B

The **diad** is a located at the sarcomere Z-line.

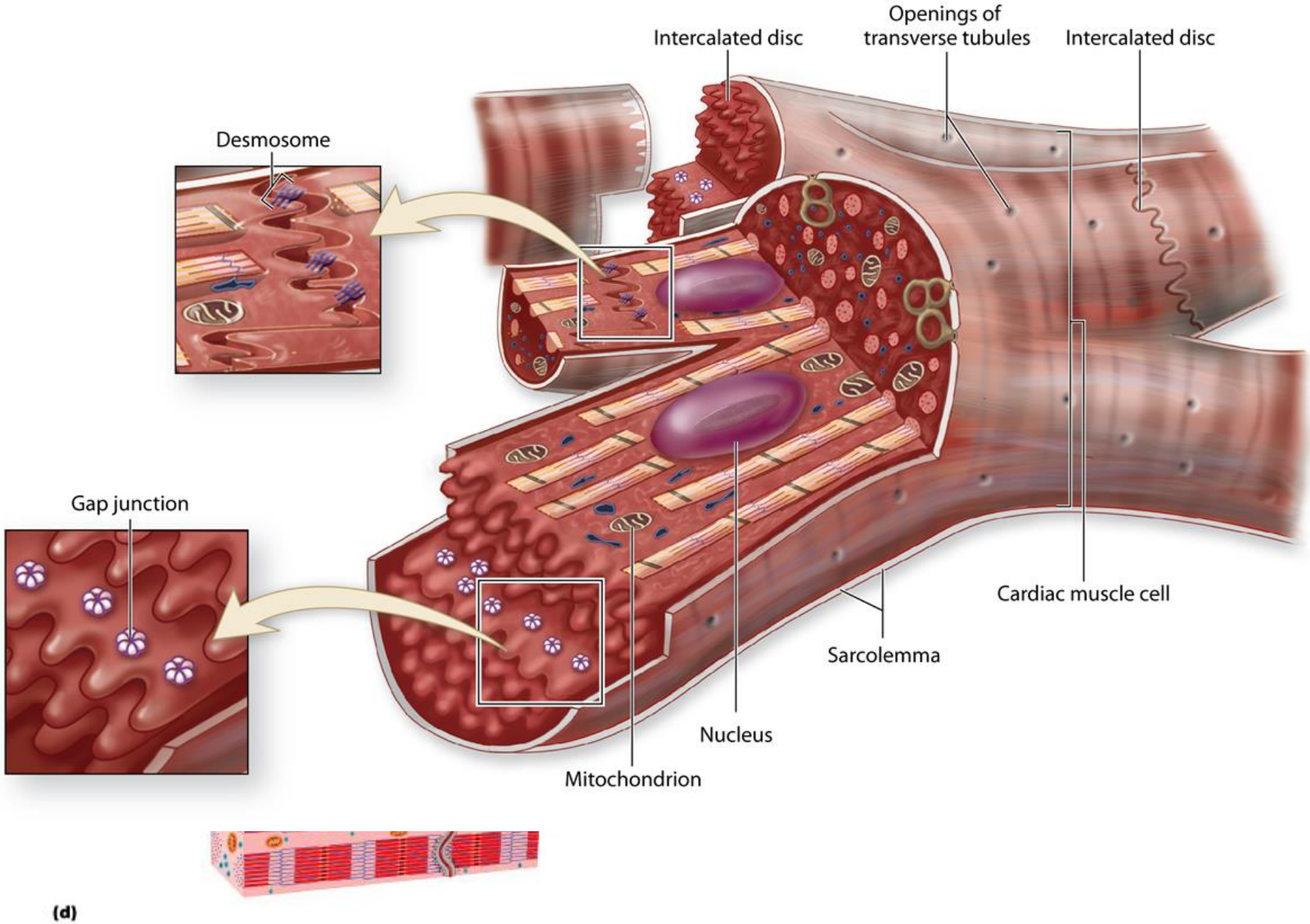
It is composed of a single t-tubule paired with a terminal cisterna of the sarcoplasmic reticulum

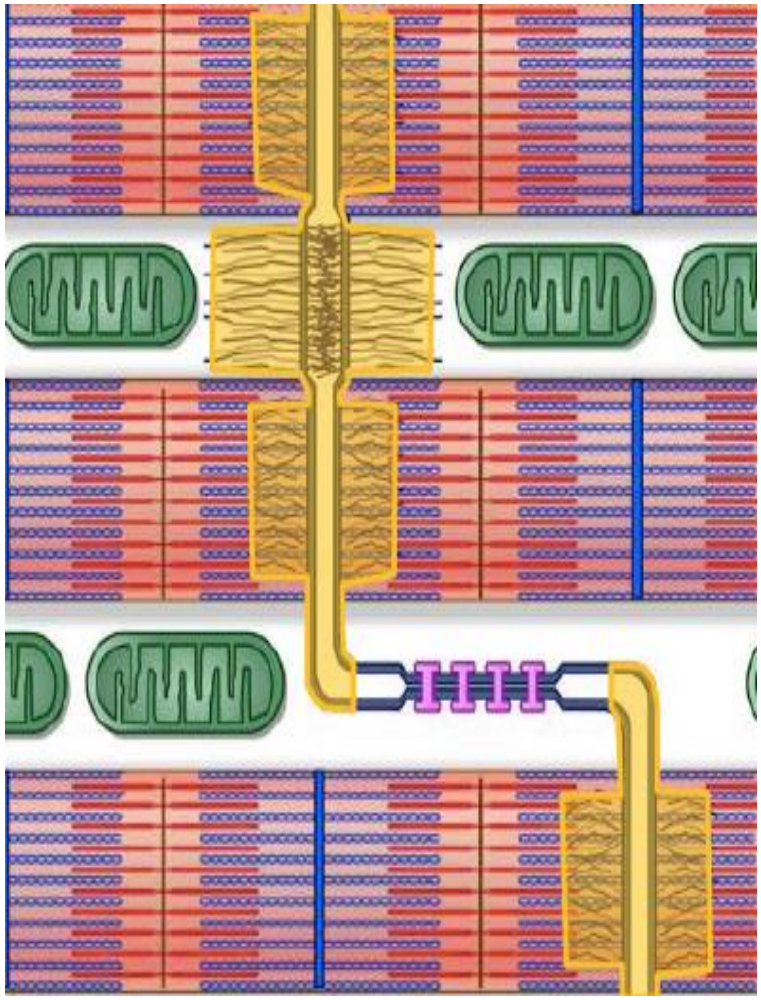
T tubules are about 2x larger in diameter than in skeletal muscle

Numerous mitochondria (up to 40% of cell volume)



Intercalated





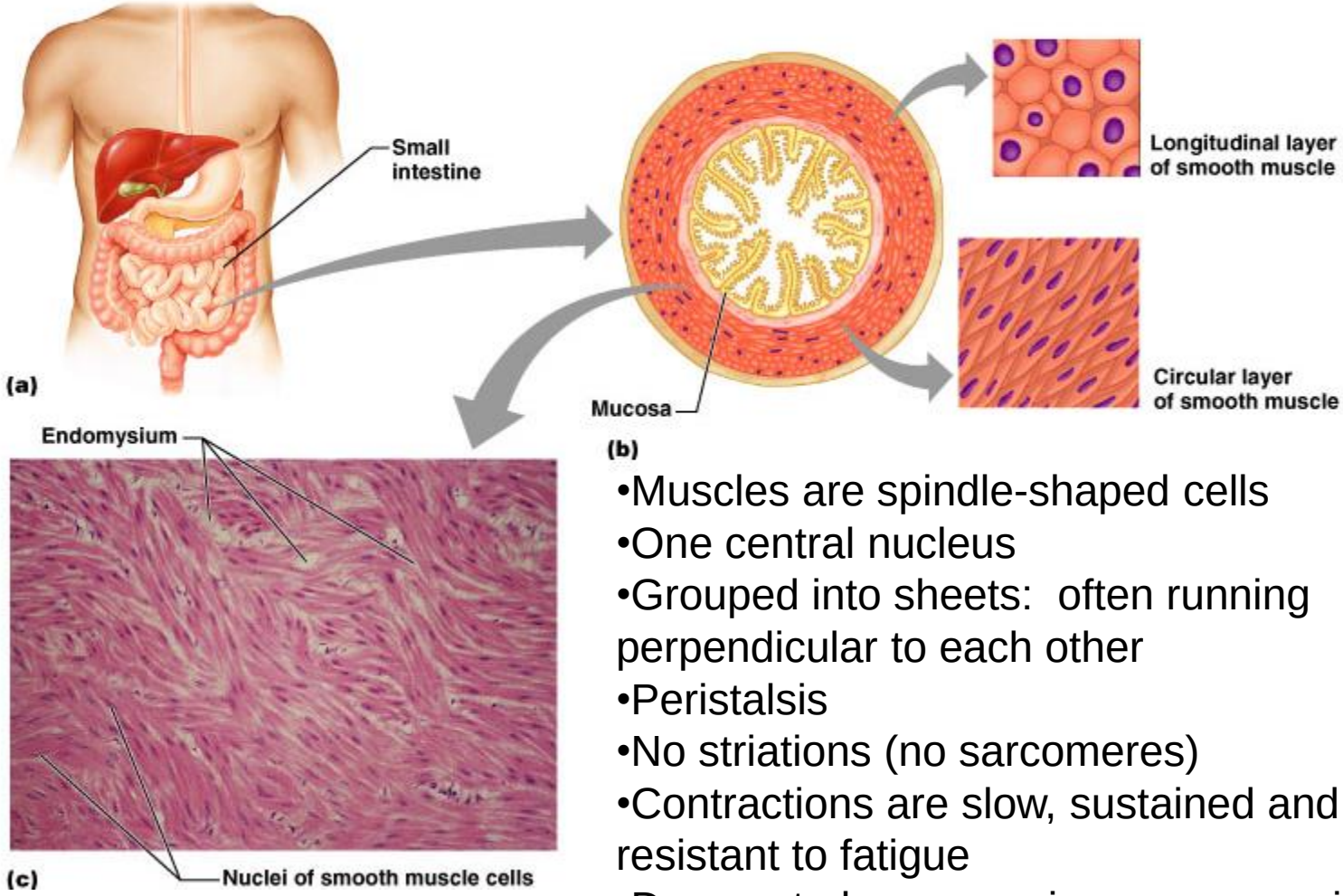
Intercalated discs - junctions between cells where force is delivered. It is a fascia adherens like site (like zonula adherens-disc).

Macula adherens (desmosomes) - anchor intermediate filaments in the same orientation as the fascia adherens

Gap junctions - allow cells to contract simultaneously. Lined up side by side

Cardiac muscle does not contain cells equivalent to the satellite cells of skeletal muscle. Therefore cardiac muscle <u>cannot regenerate</u>

Smooth muscle



- Muscles are spindle-shaped cells
- One central nucleus
- Grouped into sheets: often running perpendicular to each other
- Peristalsis
- No striations (no sarcomeres)
- Contractions are slow, sustained and resistant to fatigue
- Does not always require a nervous signal: can be stimulated by stretching or hormones
- Gap junctions

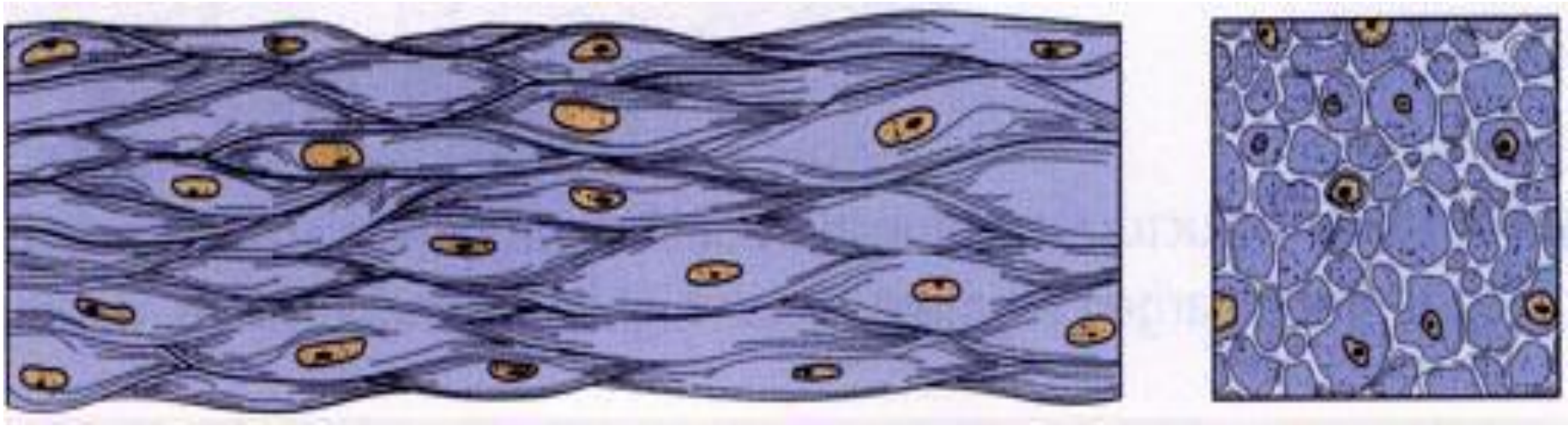
6 major locations:

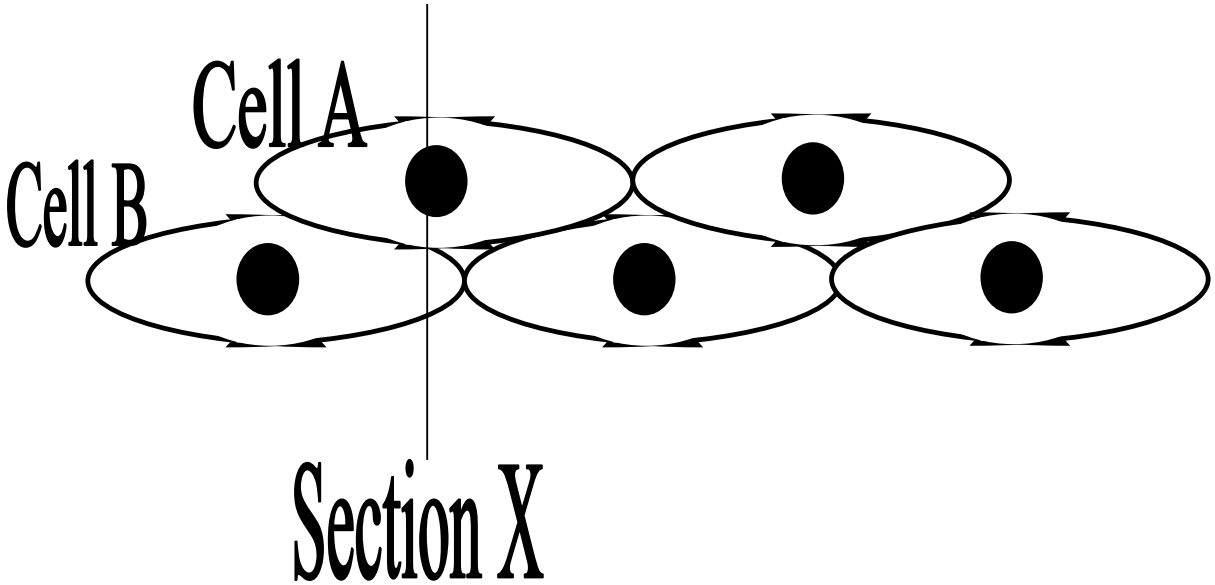
1. inside the eye 2. walls of vessels 3. respiratory tubes
4. digestive tubes 5. urinary organs 6. reproductive organs

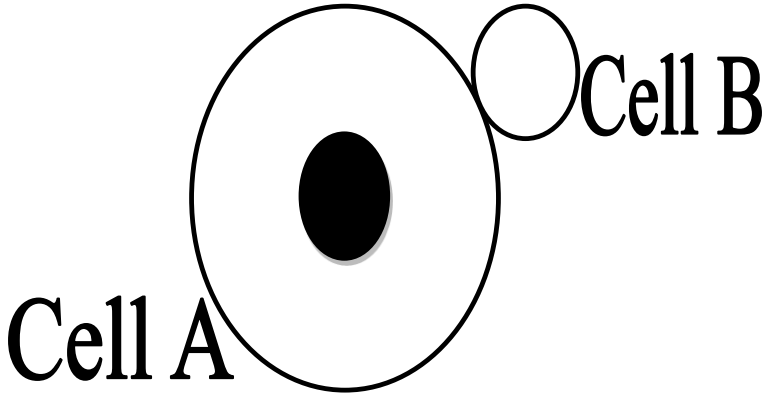
Smooth Muscle

Longitudinal section

Cross section

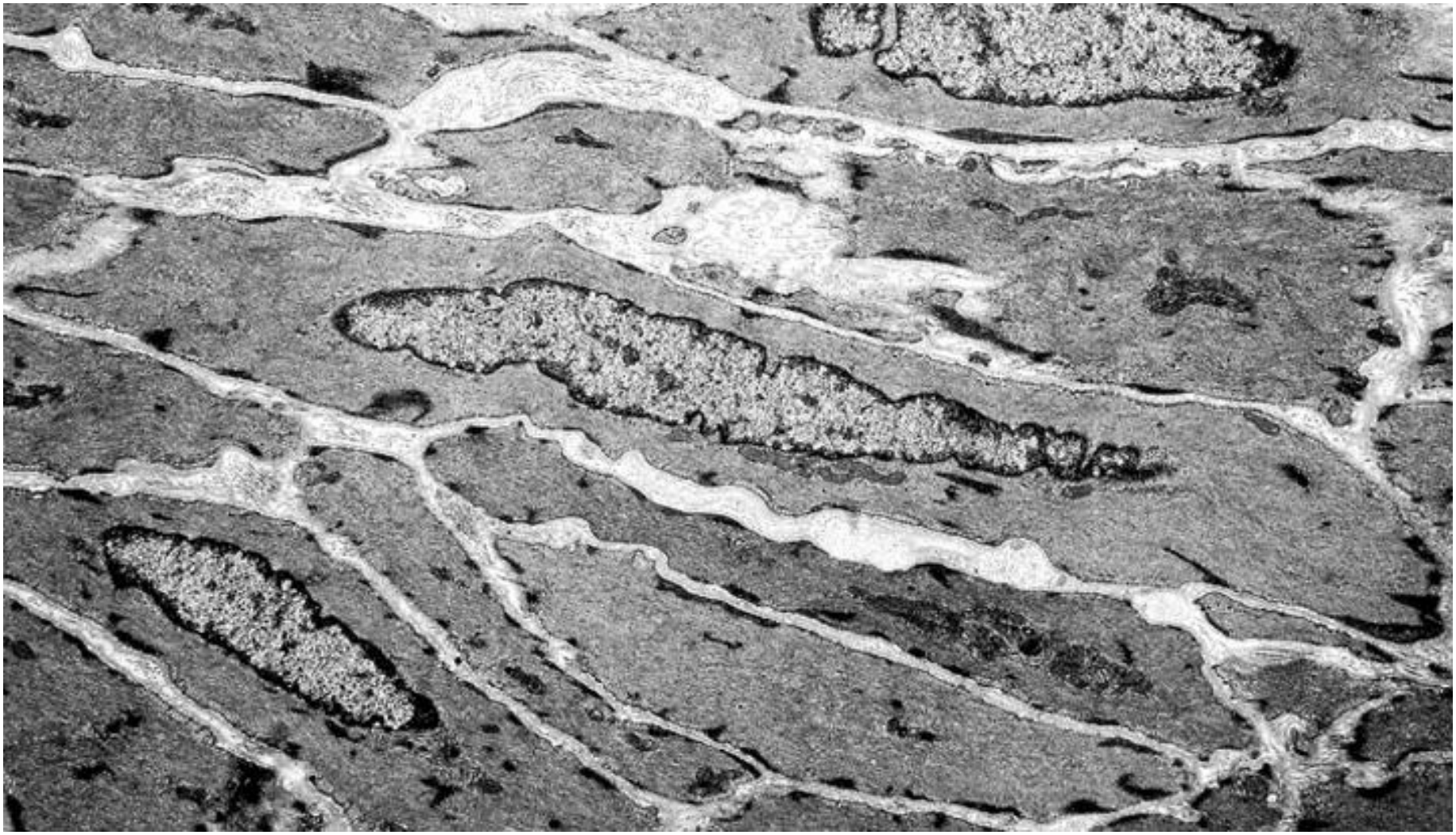



Cell A
Cell B
Section X


Cell B
Cell A

Ultrastructure of Smooth Muscle:

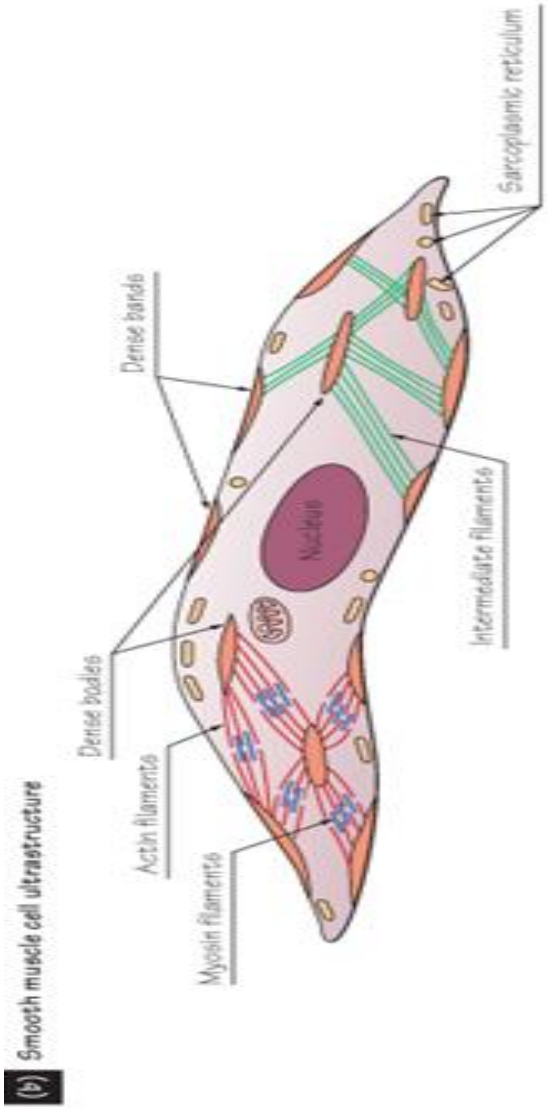
- actin and myosin filaments
- intermediate filaments of desmin (also vimentin in vascular smooth muscle)
- membrane associated and cytoplasmic dense bodies containing α actinin (similar to Z lines)
- relatively active nucleus (smooth muscle cells make collagen, elastin, and proteoglycans)



The myofilaments of smooth muscle are arranged differently and appear less organized

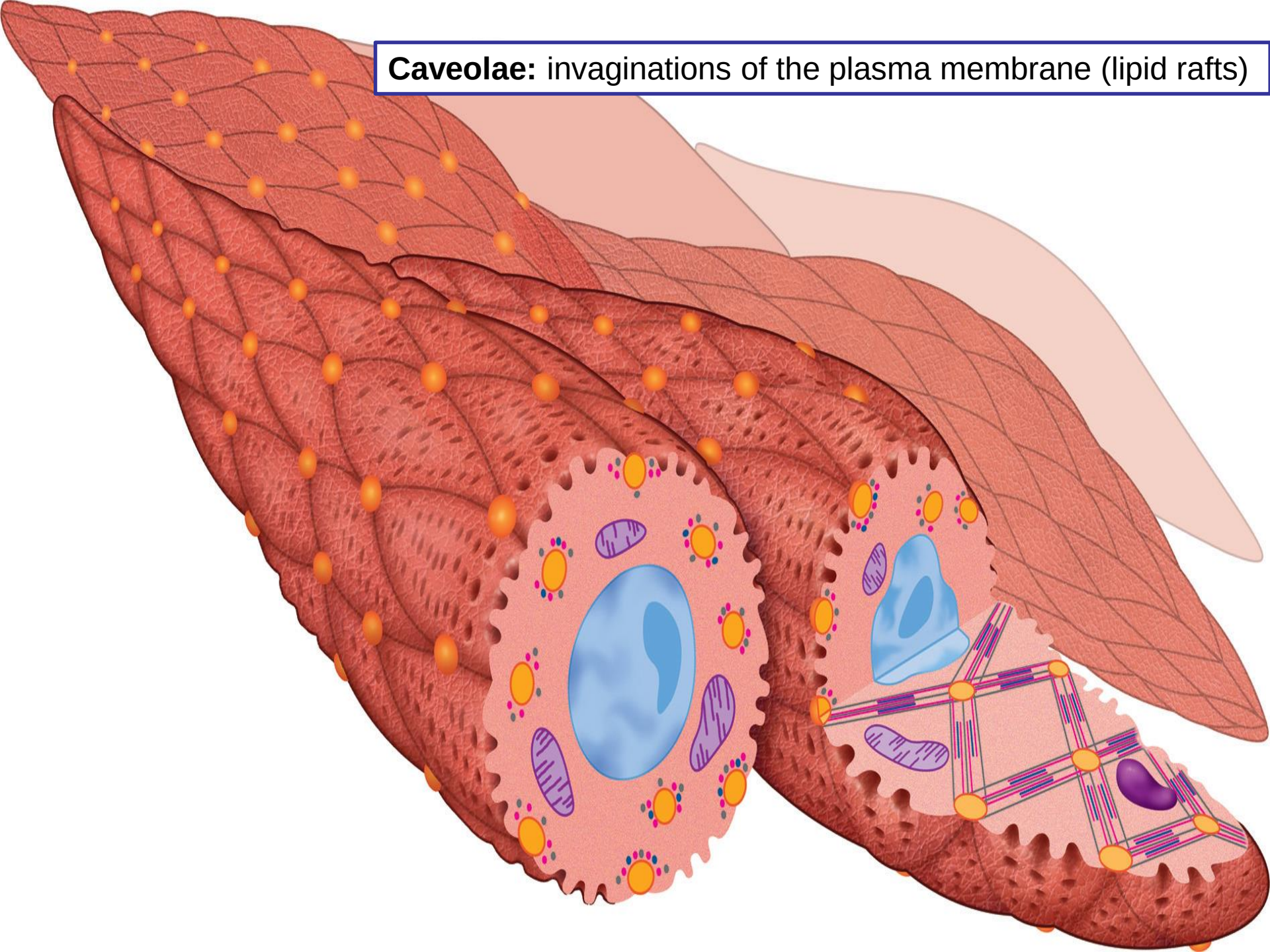
Thin filaments attach to **dense bodies** located on the cytoplasmic surface of the plasma membrane and deep in the cytoplasm (intracytoplasmatic dense bodies)

Dense bodies contain α-actinin for thin filament attachment

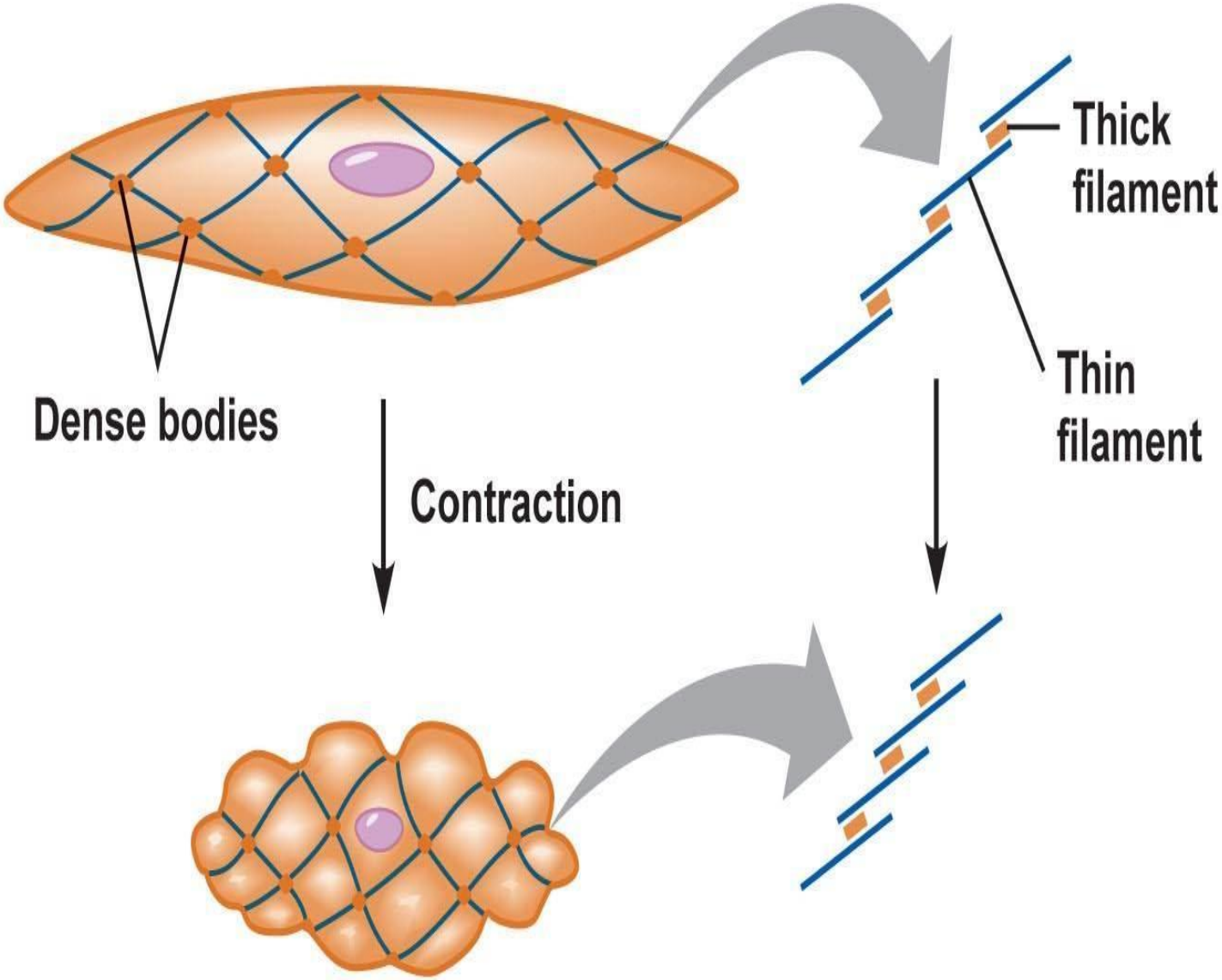


Dense bodies at the membrane are also attachment sites for intermediate filaments and for adhesive junctions between cells. This arrangement of both the cytoskeleton and contractile apparatus allows the multicellular tissue to contract as a unit, providing better efficiency and force

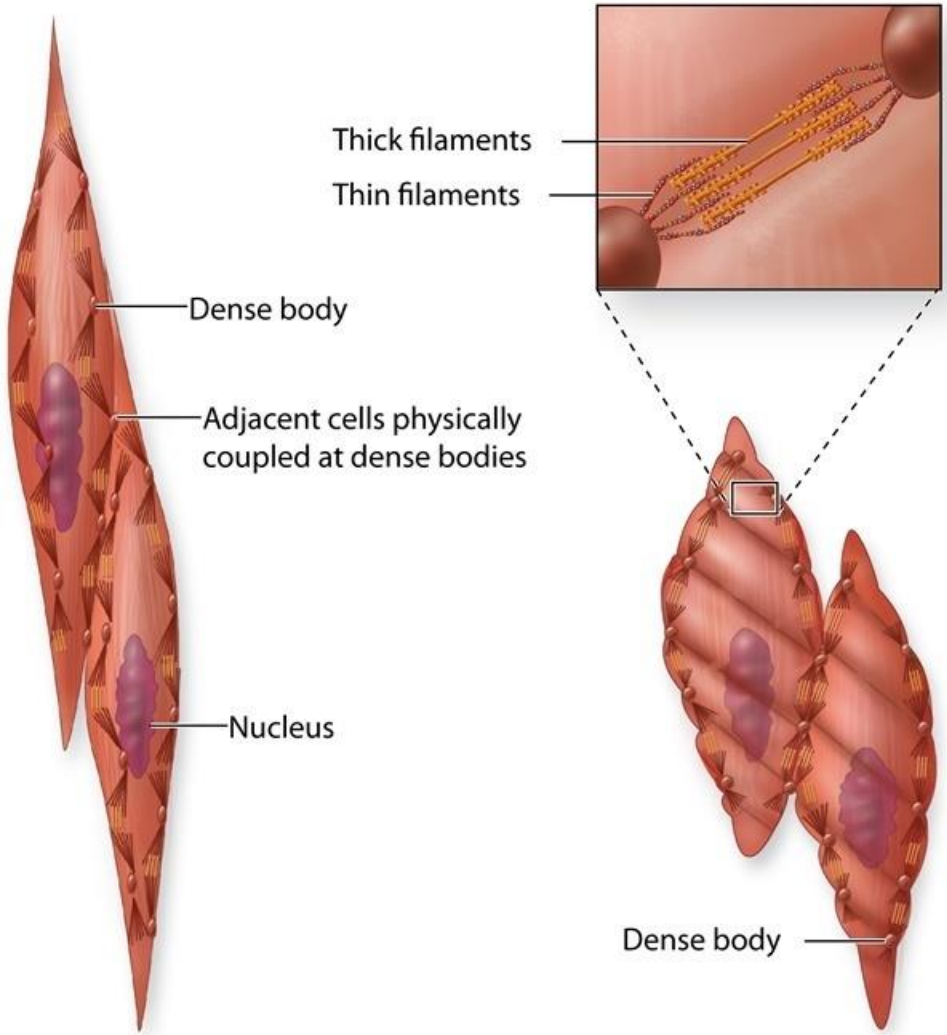
Caveolae: invaginations of the plasma membrane (lipid rafts)



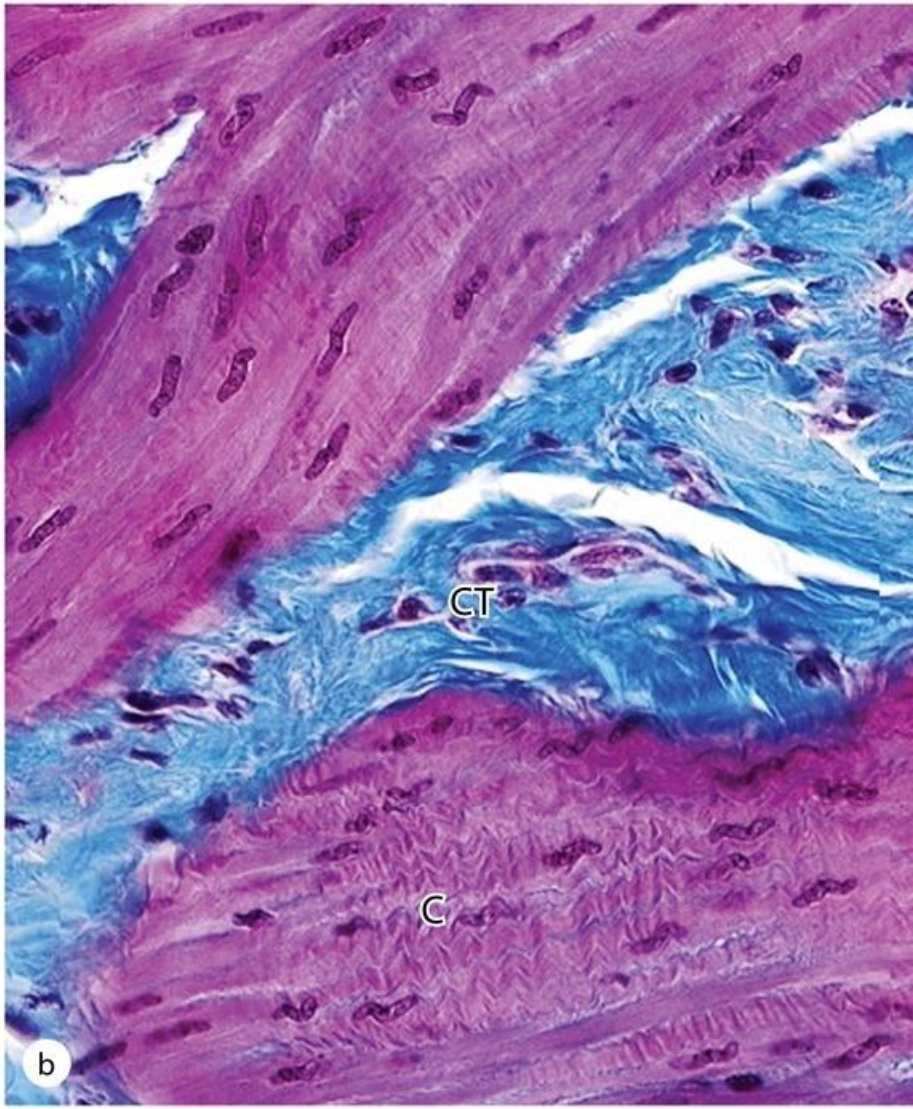
Relaxed



Contracted

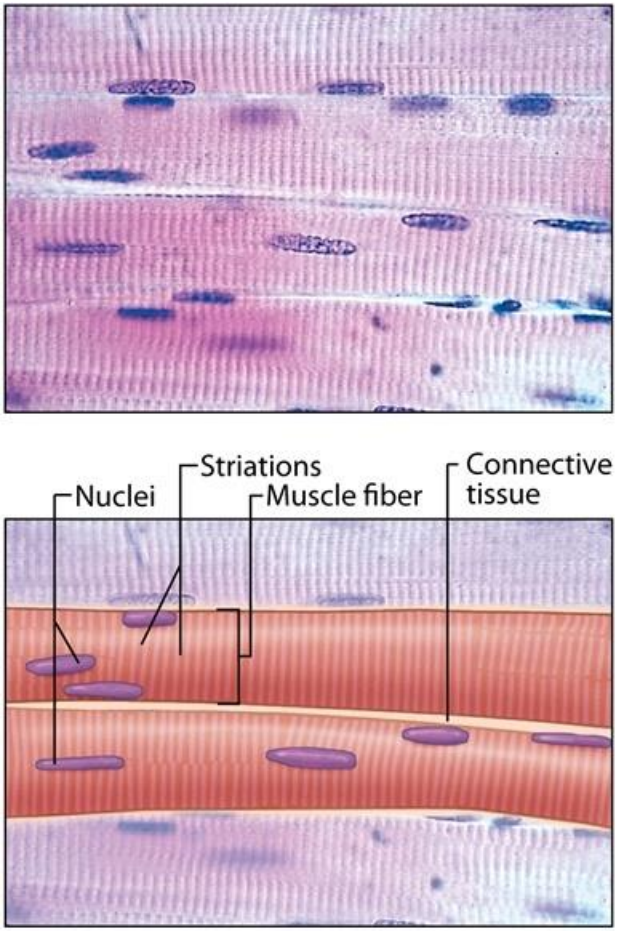

Thick filaments
Thin filaments
Dense body
Adjacent cells physically coupled at dense bodies
Nucleus
Dense body

a

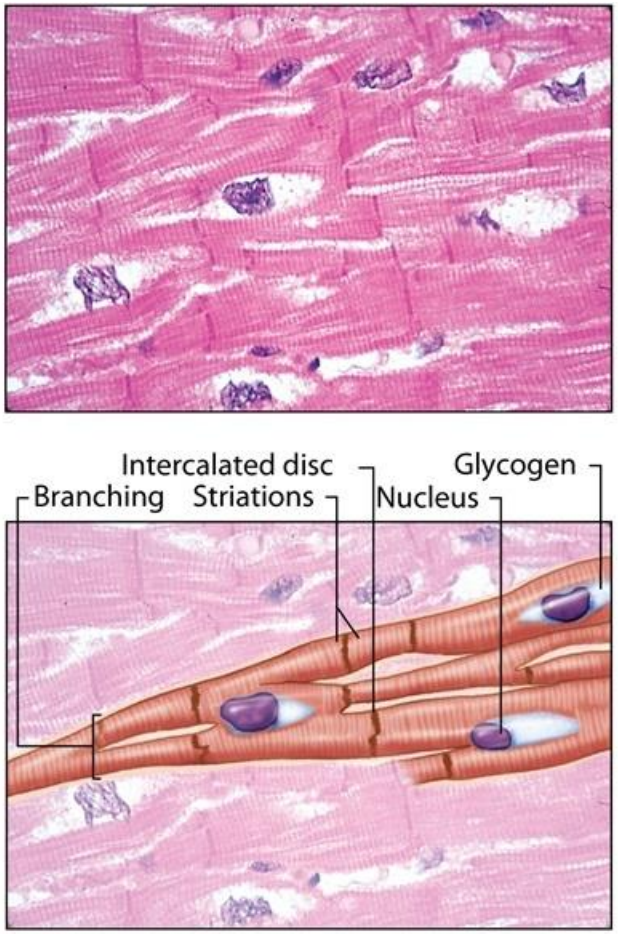

CT
C

b

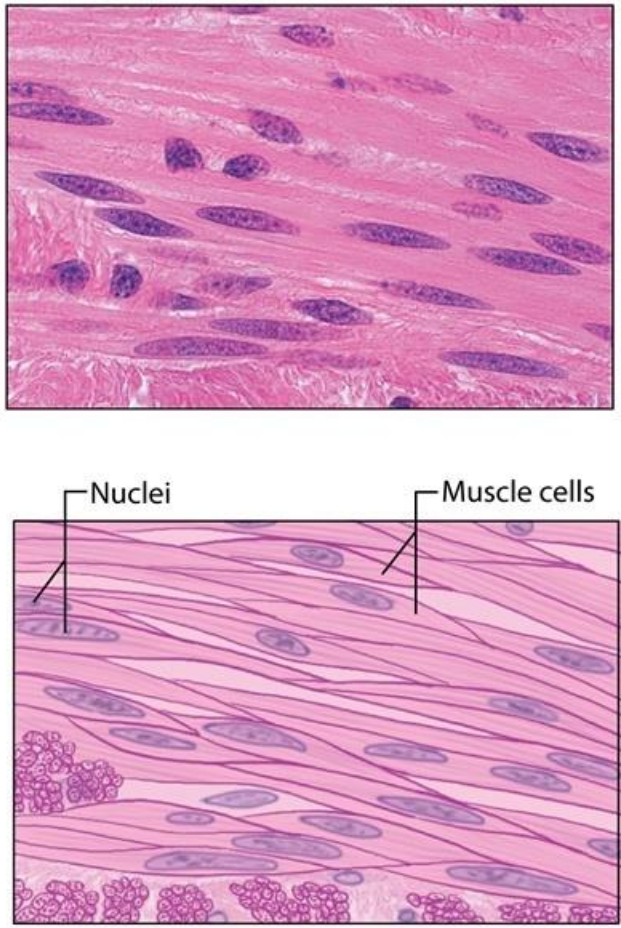
Smooth muscles can undergo **Hypertrophy** and **Hyperplasia**



a Skeletal muscle



b Cardiac muscle



c Smooth muscle