



# MUSCLE TISSUE

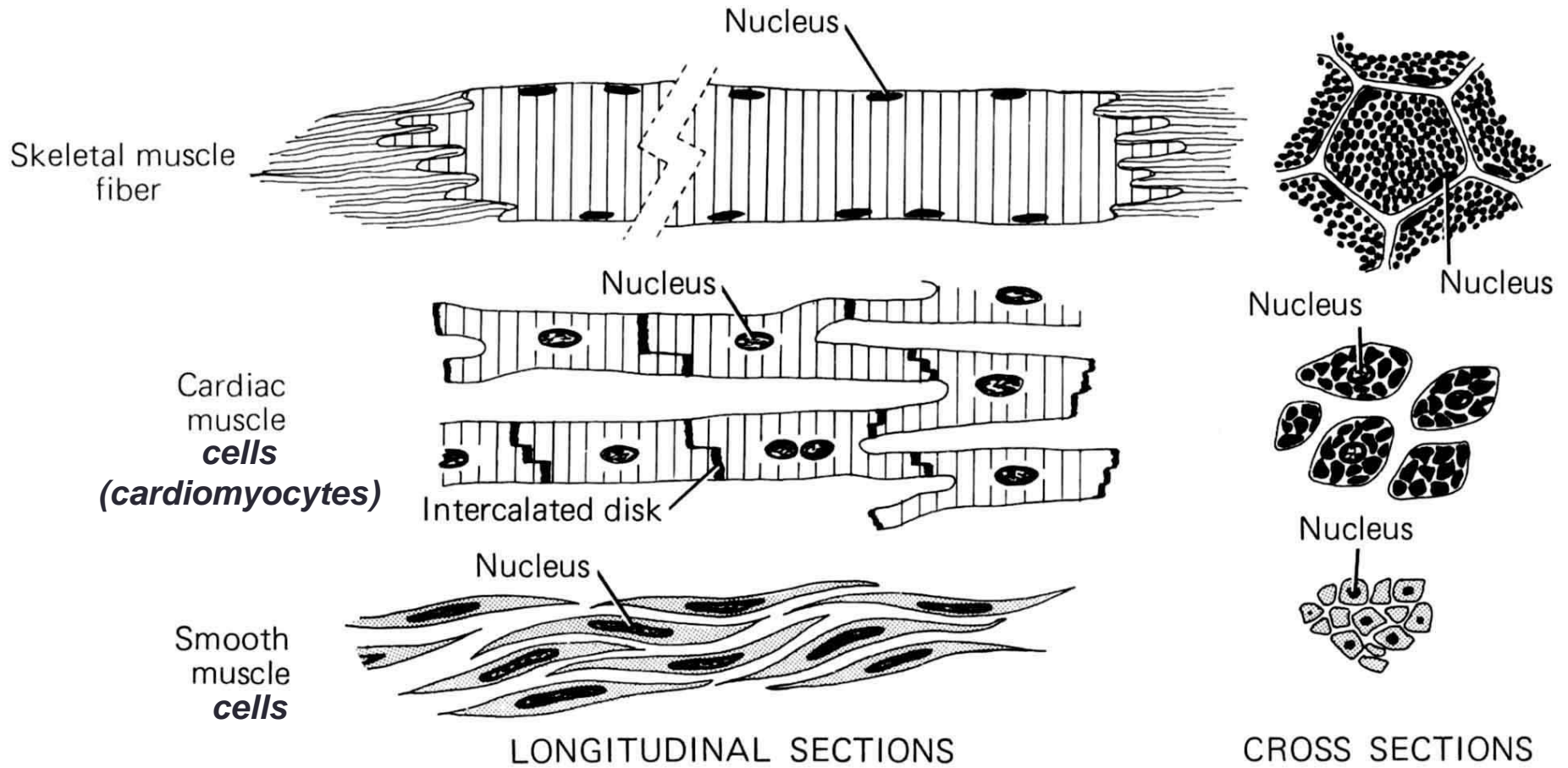
Andrea Felšöová

# Muscle tissue

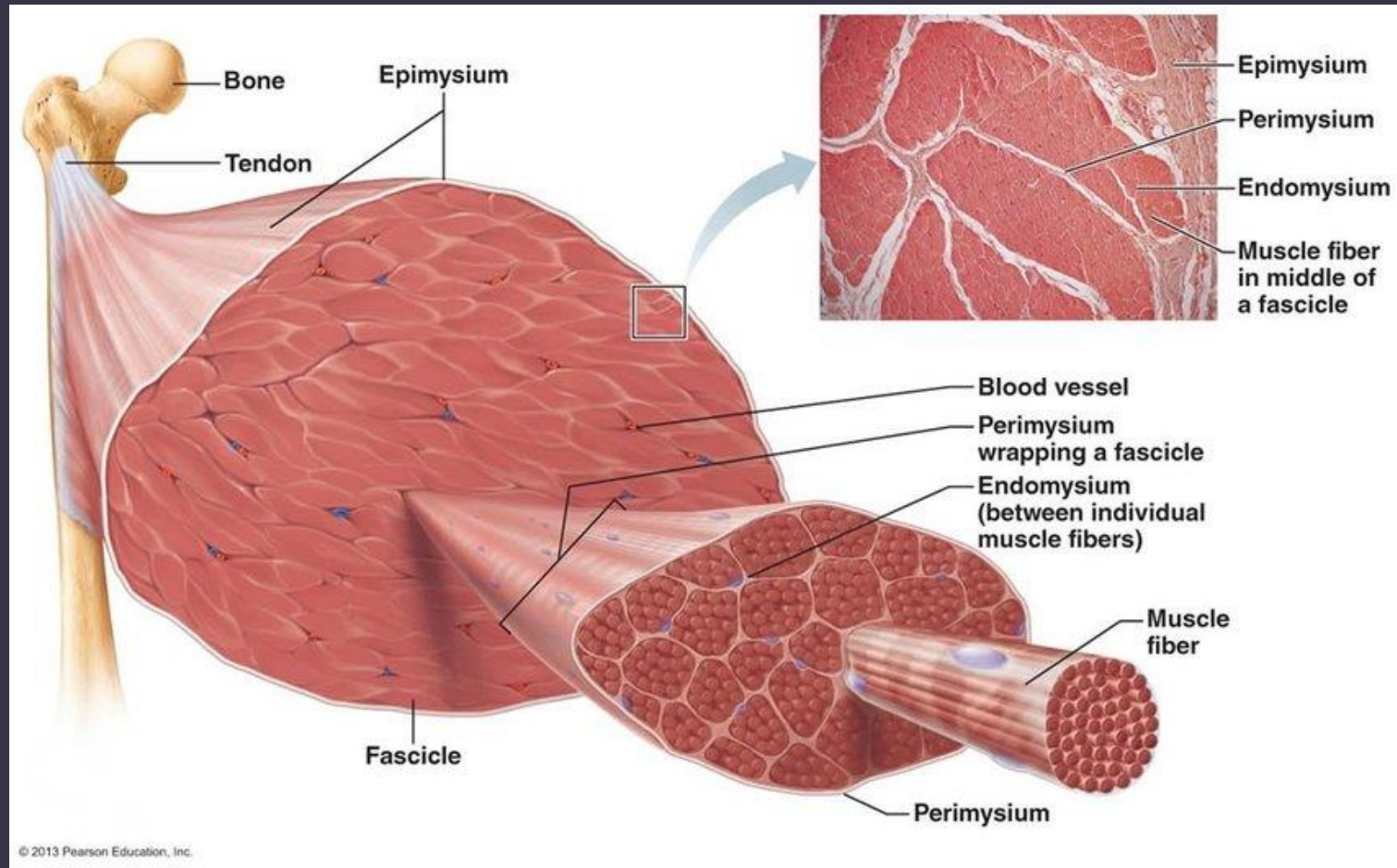
- composed of elongated elements whose basic property is **contractility**
- muscle elements exhibit intercellular contacts
- amount of extracellular matrix is relatively small

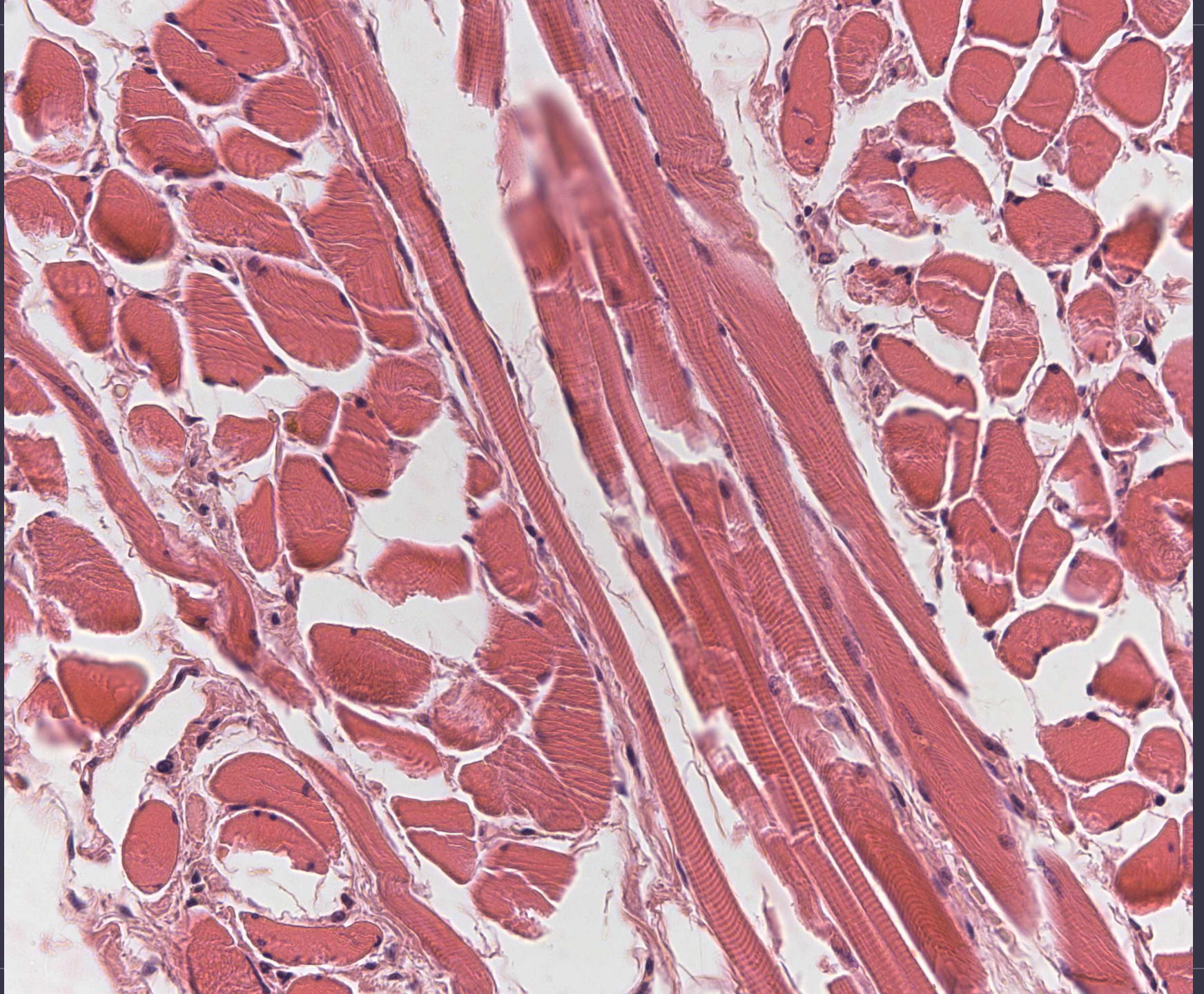
Contraction = interaction of myofilaments

# Muscle elements



# Striated skeletal muscle





# Striated skeletal muscle

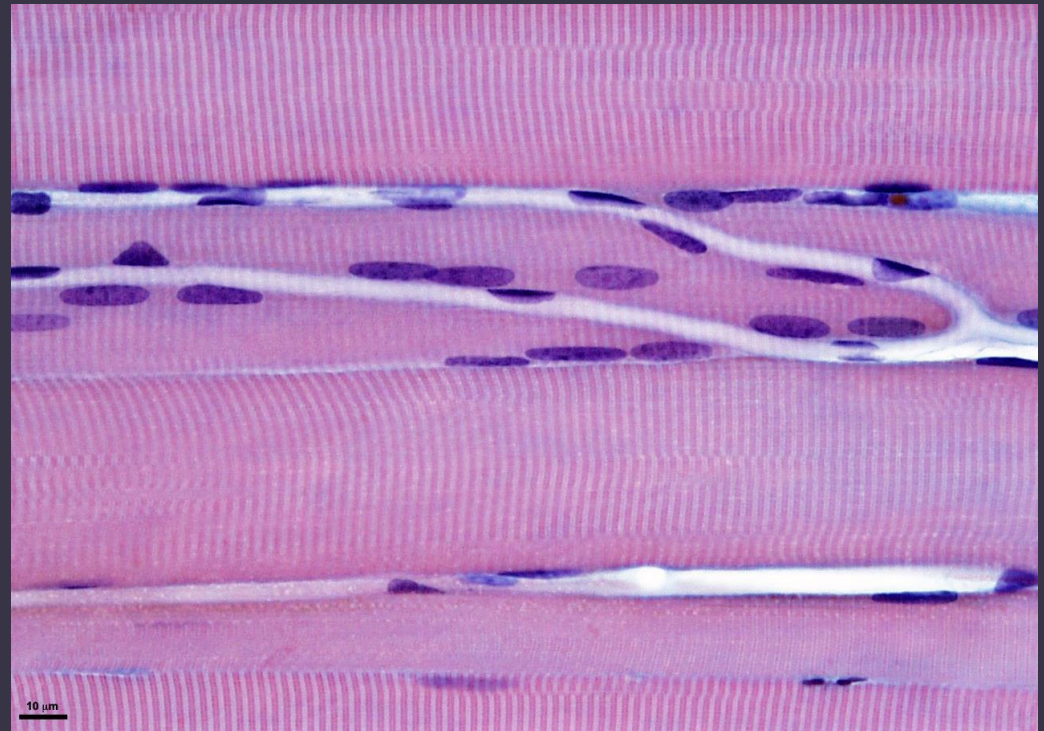
The basic unit is a **muscle fiber** = multinucleated **syncytium**

Various length, diameter 10 to 100  $\mu\text{m}$

Eosinophilic **sarcoplasm**

**Cross-striation** in LM

Nuclei are located **beneath**  
**the sarcolemma**

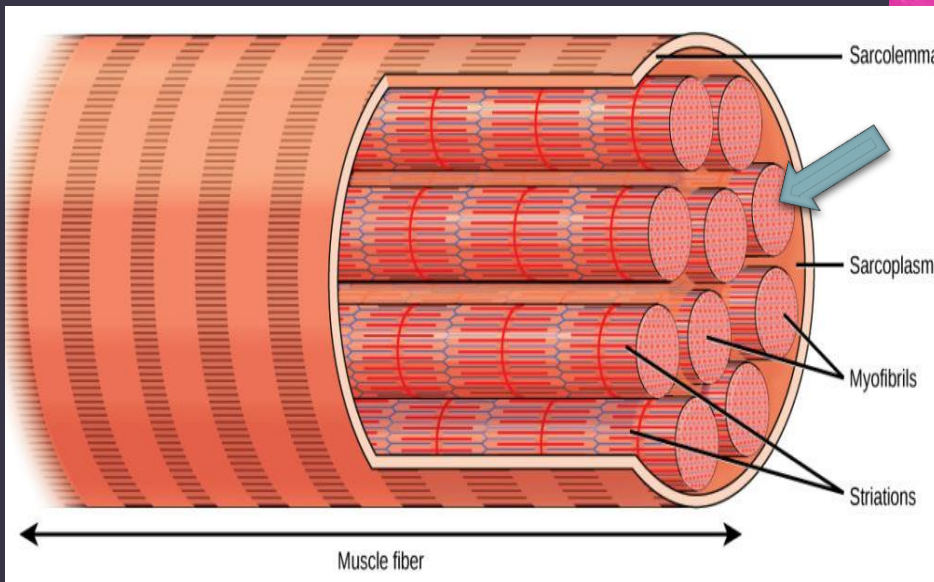


# Striated skeletal muscle

Cytoskeletal functional and structural subunit = **myofibril** ( $\varnothing$  1-2  $\mu\text{m}$ )

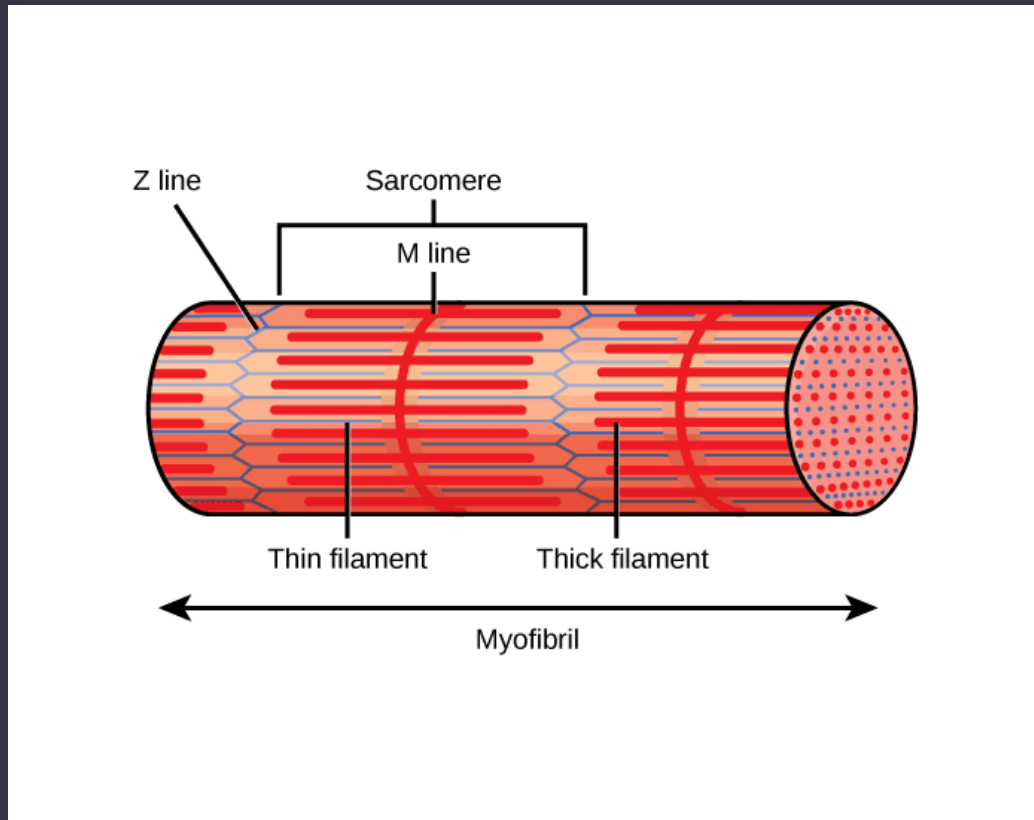
**Muscle fiber** is filled with longitudinally arrayed **myofibrils**

Each **myofibril** is composed of **myofilaments**



# Myofibril and Sarcomere

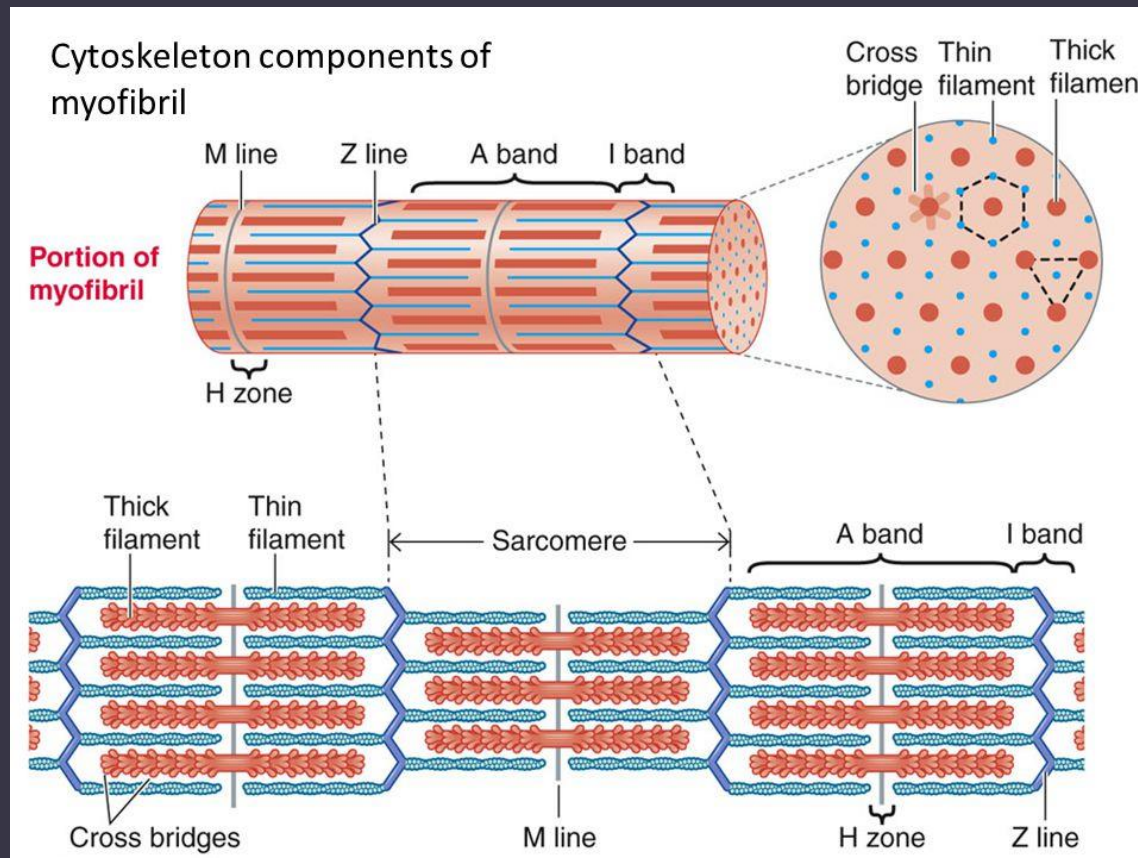
**Sarcomere** is the functional unit of **myofibril**





# Organization of skeletal muscle

[https://www.youtube.com/watch?v=f\\_tZne9ON7c](https://www.youtube.com/watch?v=f_tZne9ON7c)



**M = myofibril**

**A = A band**

**I = I band**

**S = sarcomere**

**Z = Z line (telofragma)**

**H = H band**

**N = nuclei of muscle fibres**

**CT = connective tissue cell**



**A**

**I**

**S**

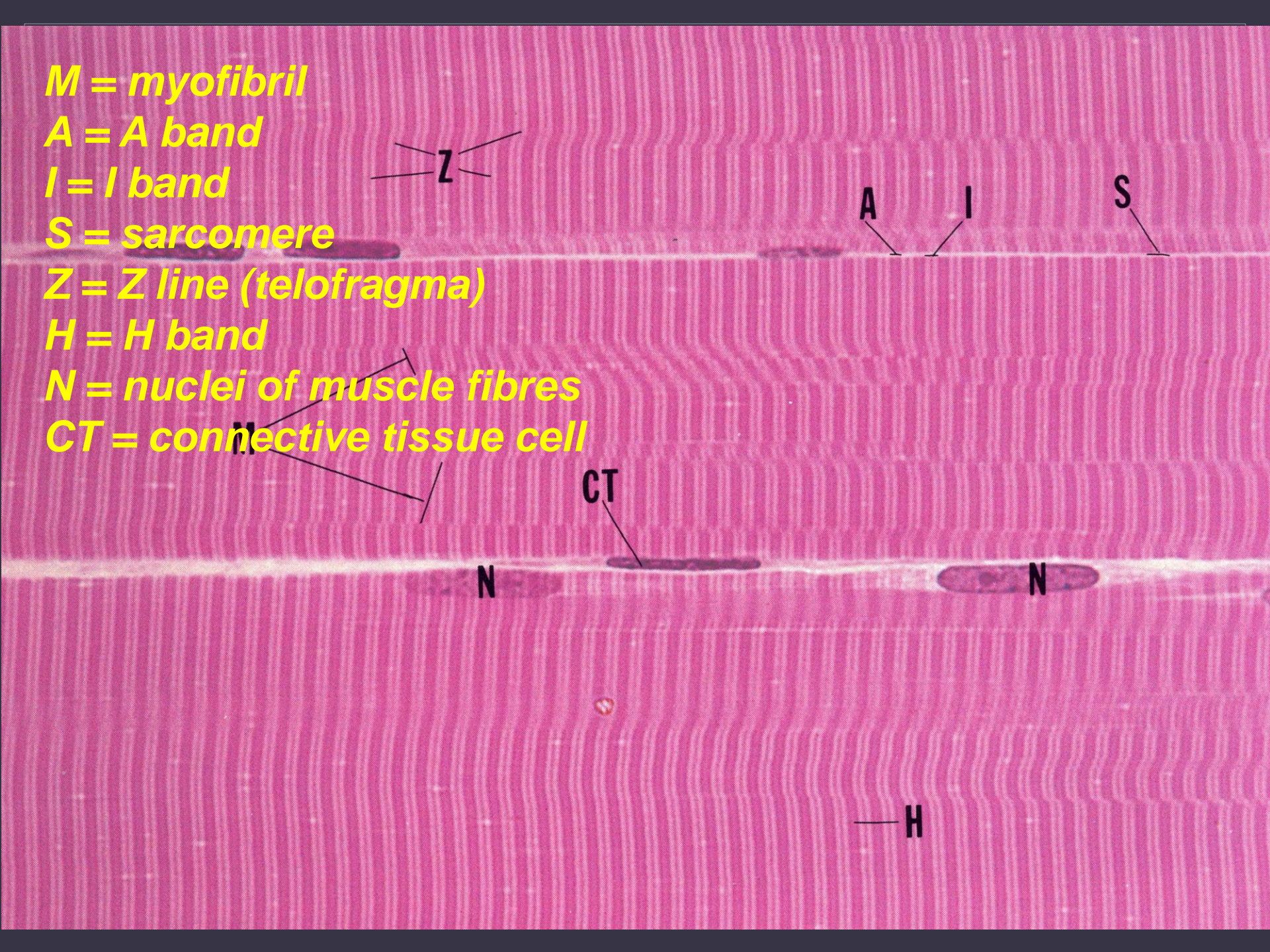
**M**

**CT**

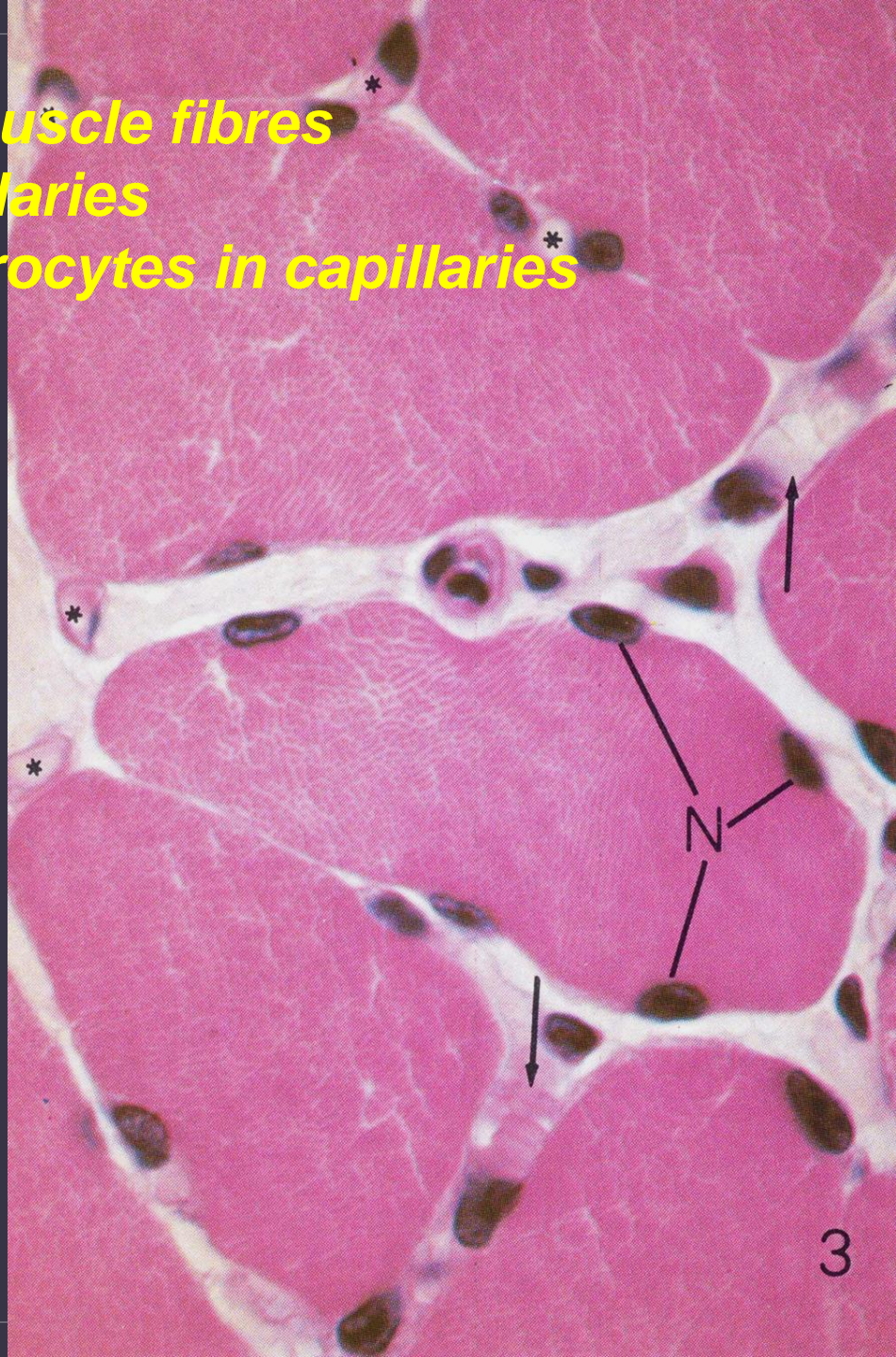
**N**

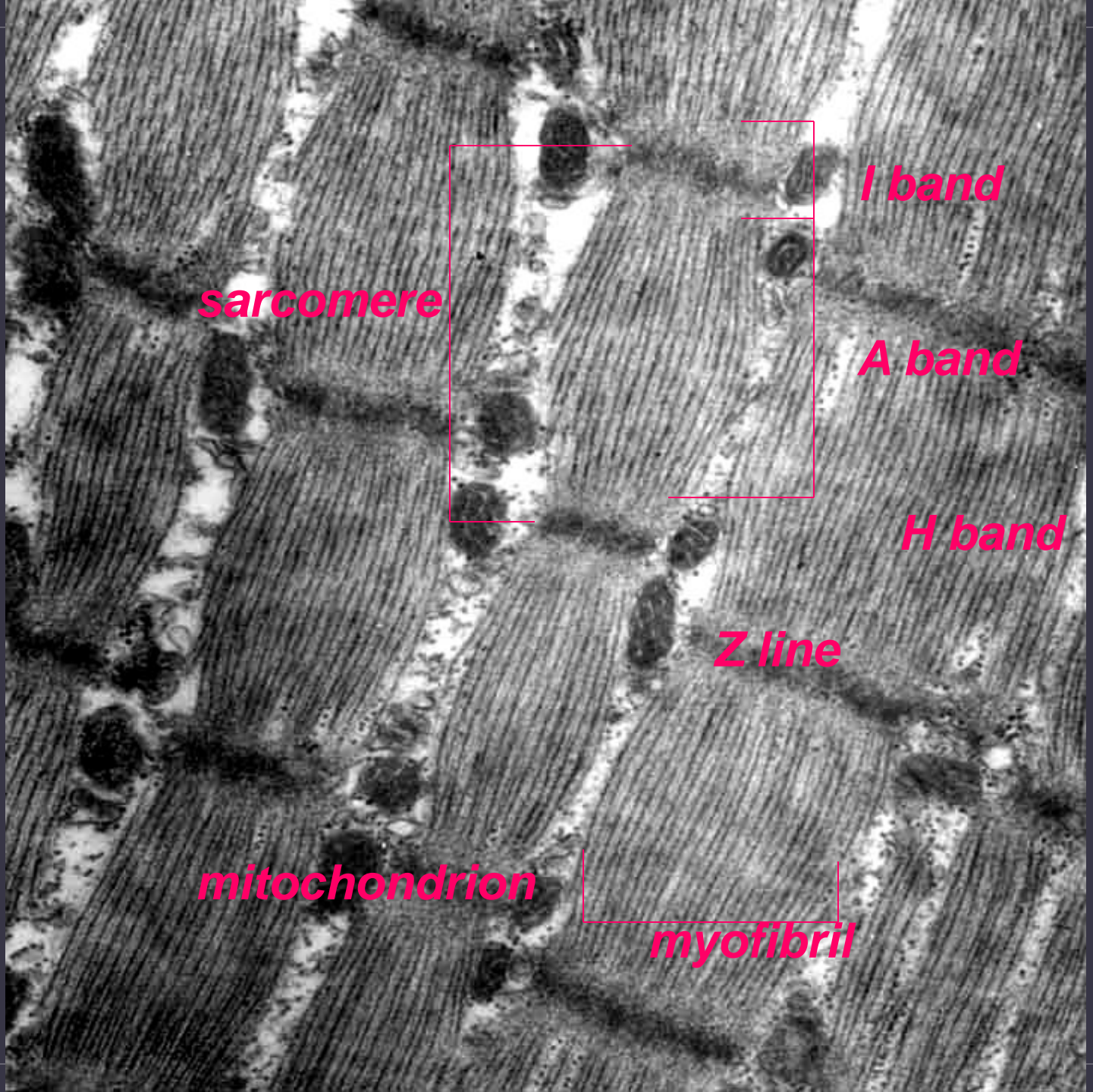
**N**

**H**



***N = nuclei of muscle fibres***  
***\* = empty capillaries***  
***arrows = erythrocytes in capillaries***





**sarcomere**

**I band**

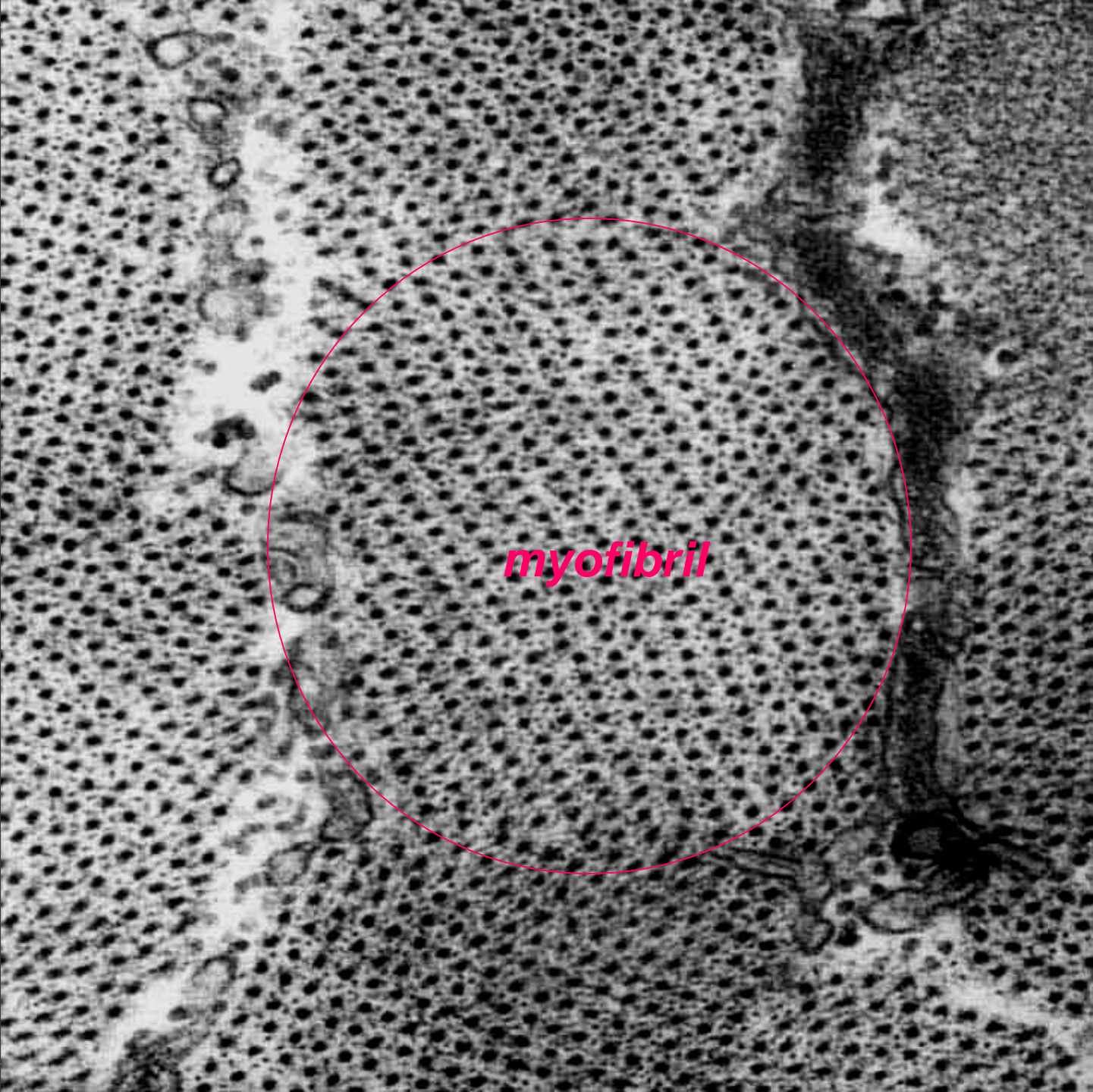
**A band**

**H band**

**Z line**

**mitochondrion**

**myofibril**



*myofibril*

# Other components of muscle fiber

Numerous mitochondria - ATP

Prominent **sarcoplasmic reticulum** – repeating series of network around myofibrils = transverse tubular system

**T tubule**

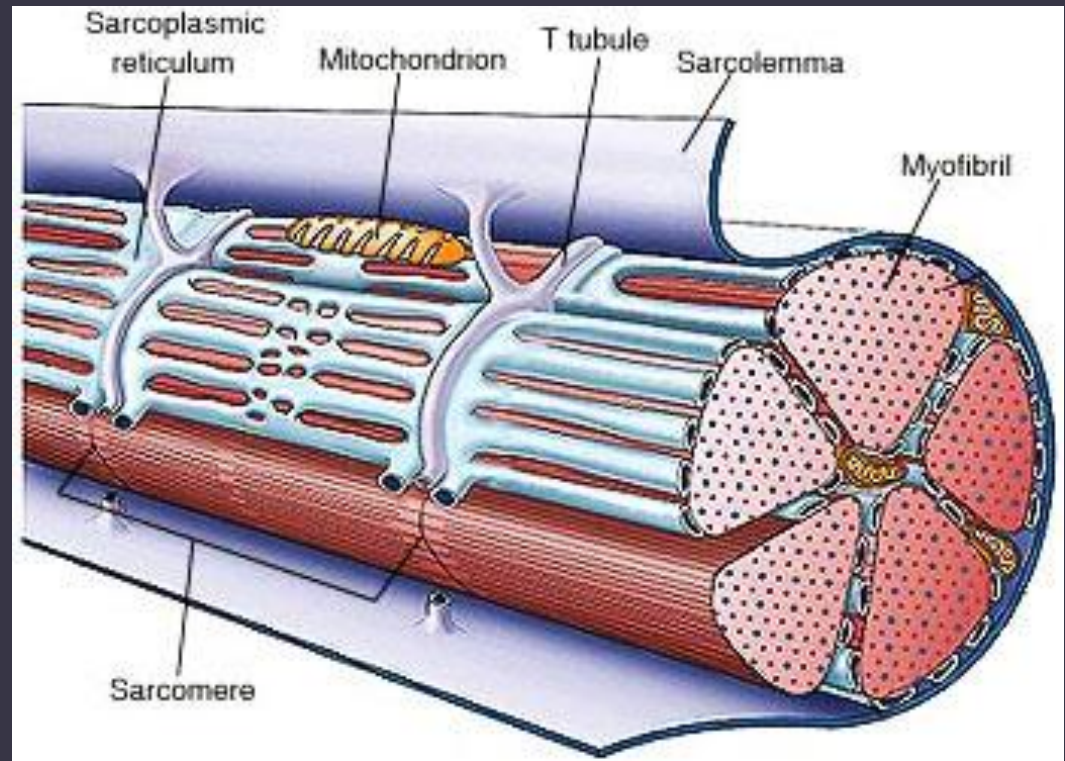
**Terminal cisternae**  
(triad)

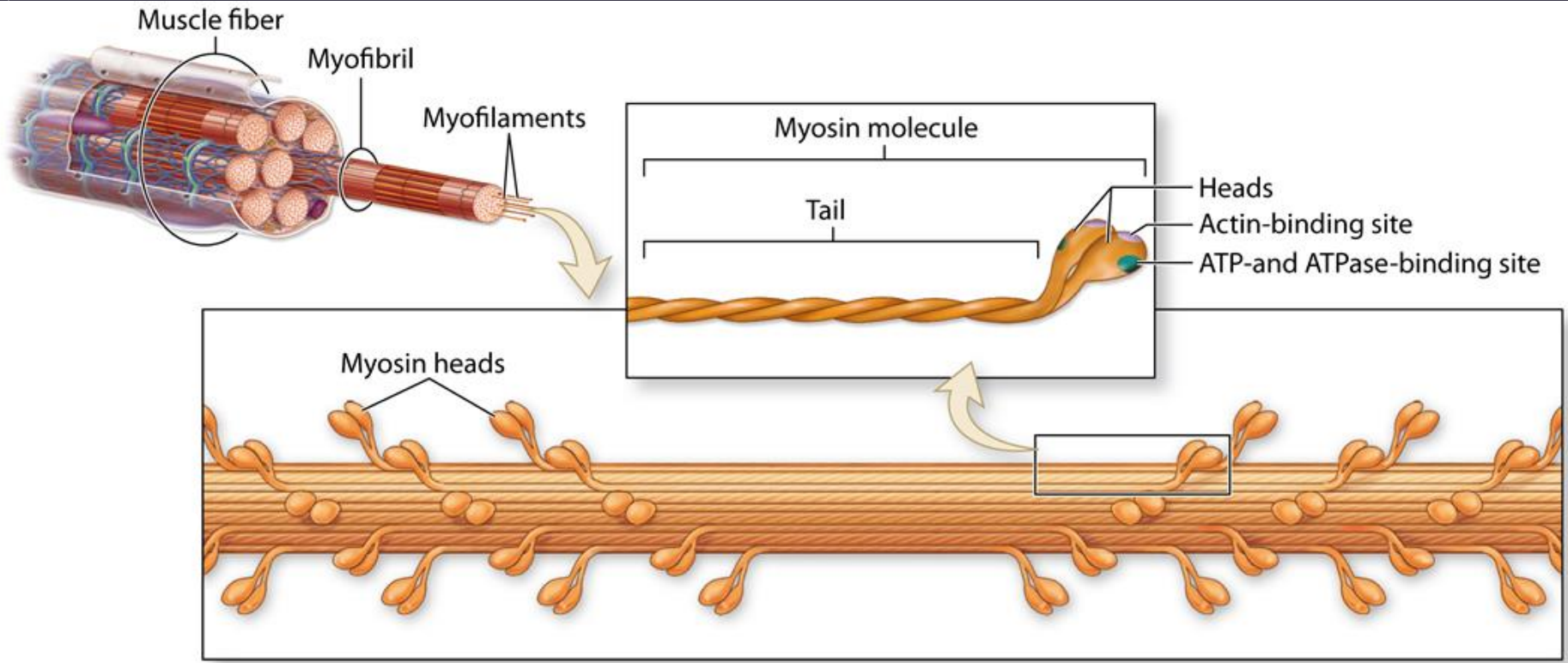
**Myoglobin**

– oxygen binding protein

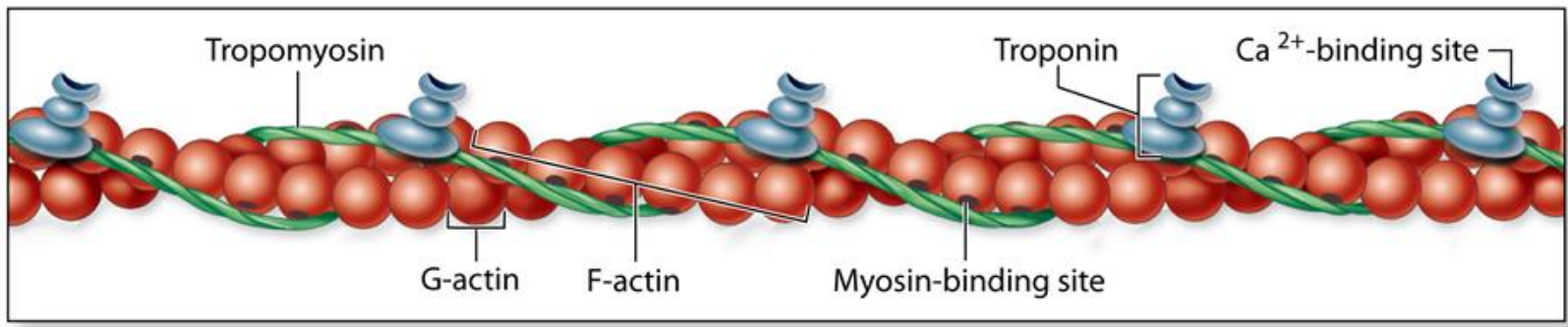
**Glycogen** inclusions

- anaerobic glycolysis



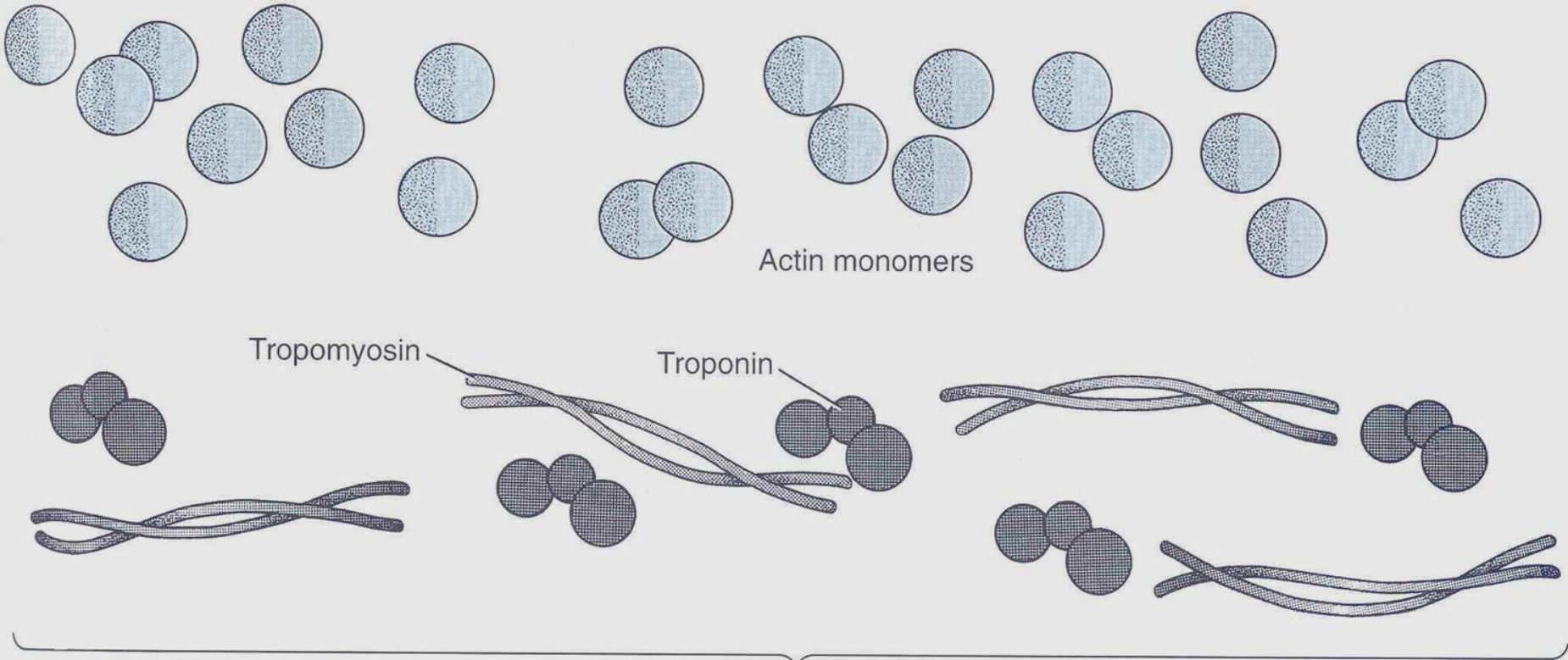


a Thick filament

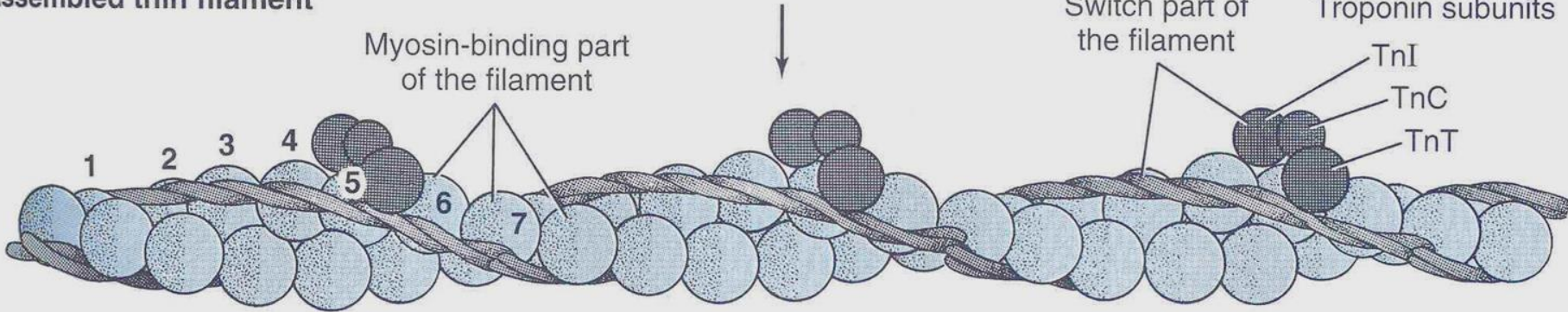


b Thin filament

**Disassembled components of the thin filament**

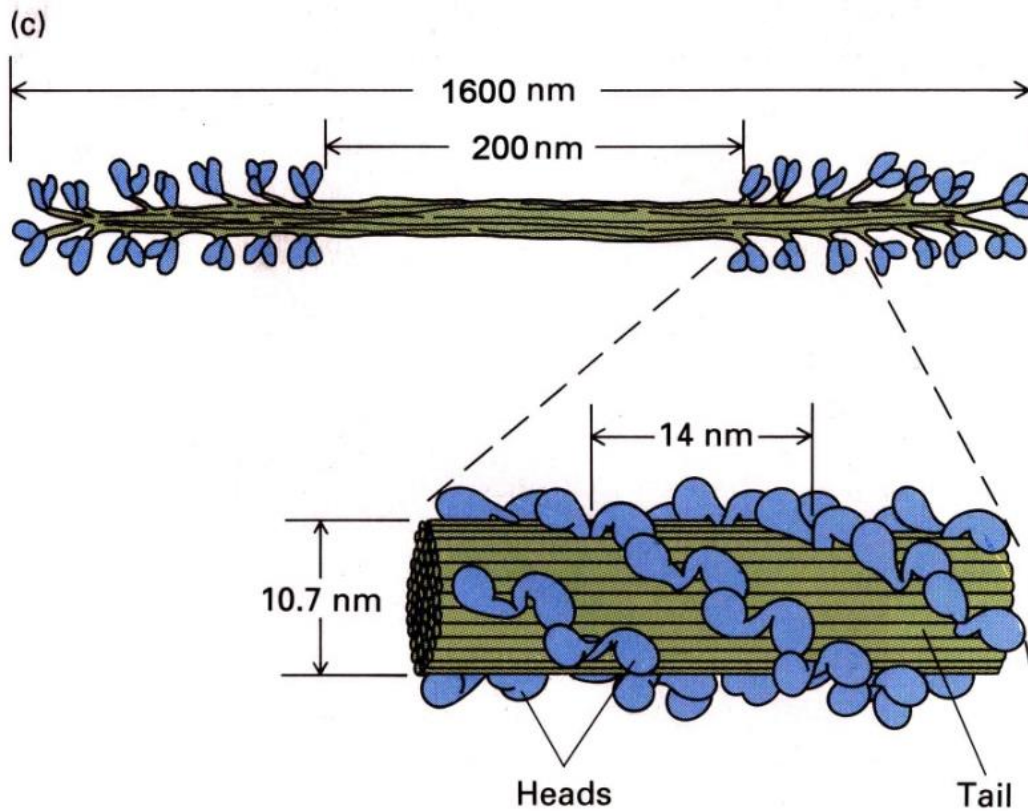
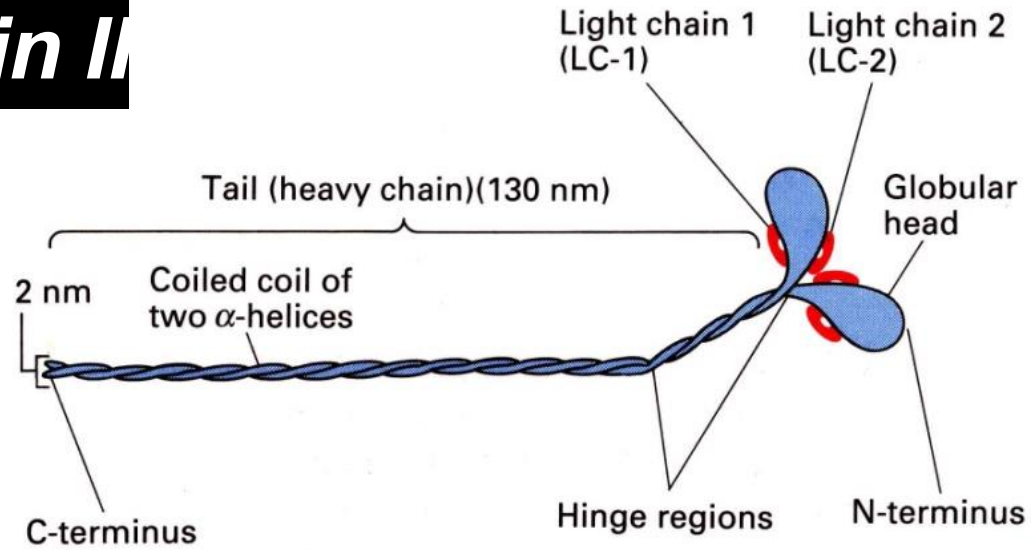


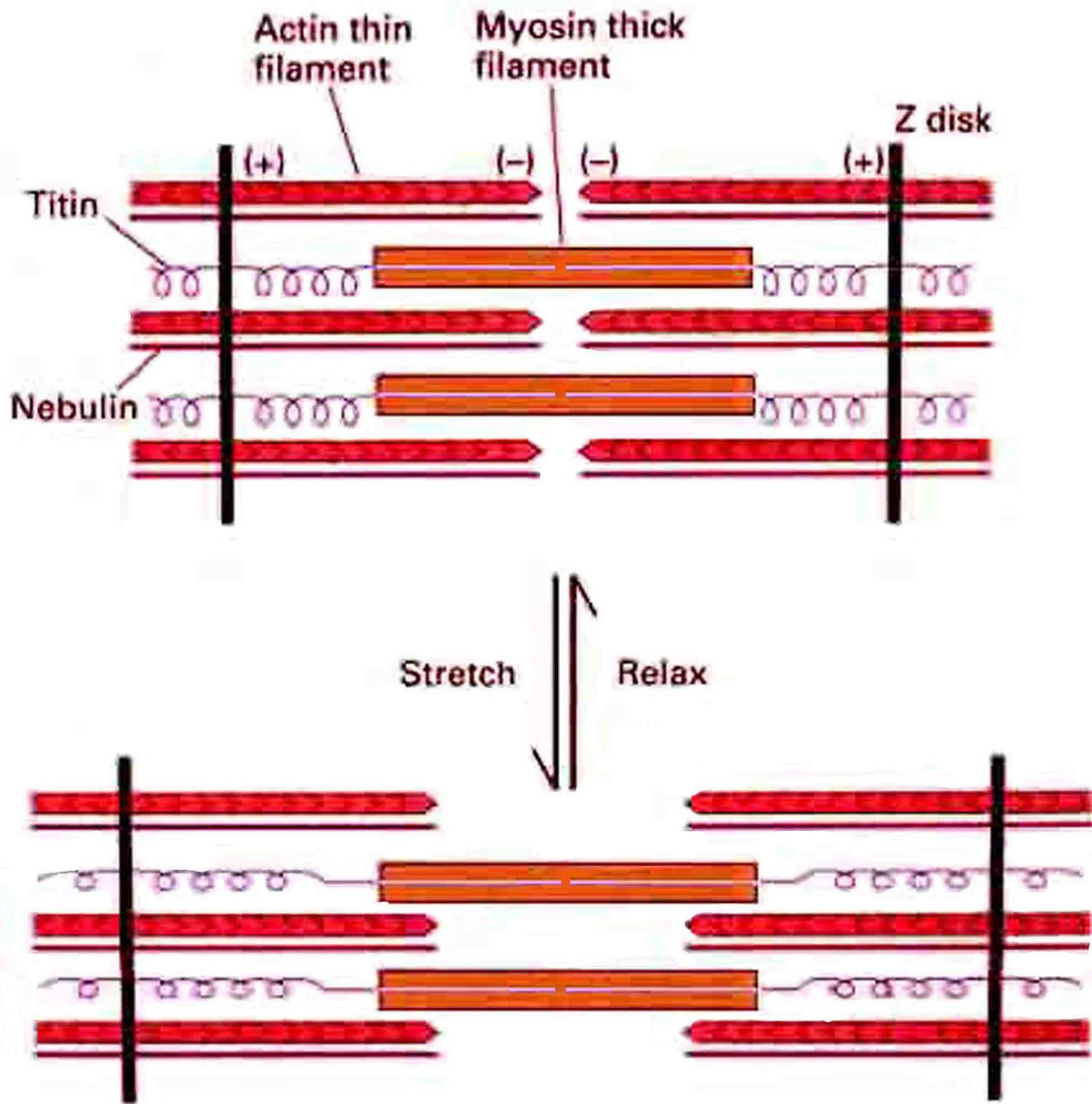
**Assembled thin filament**



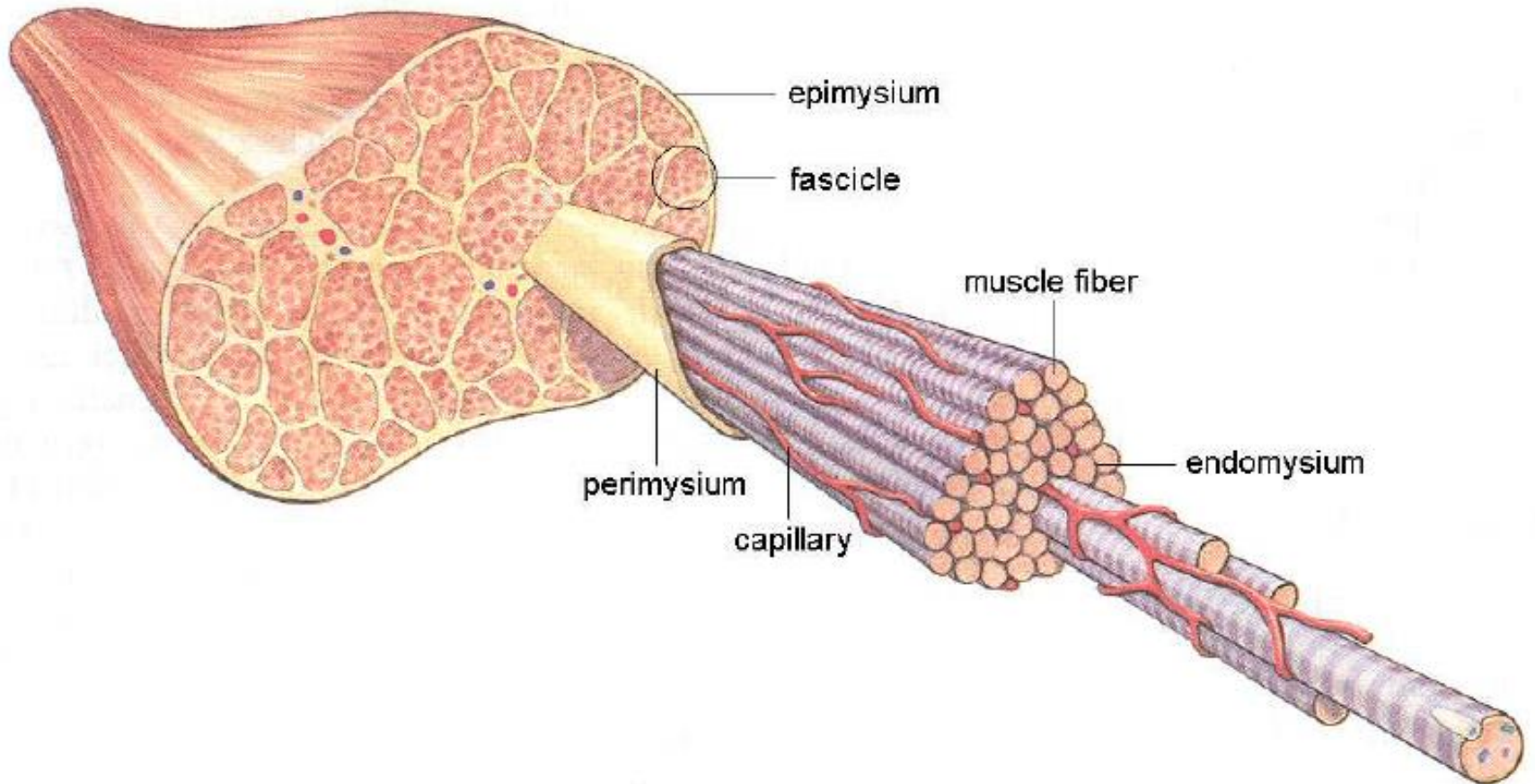


# Myosin II





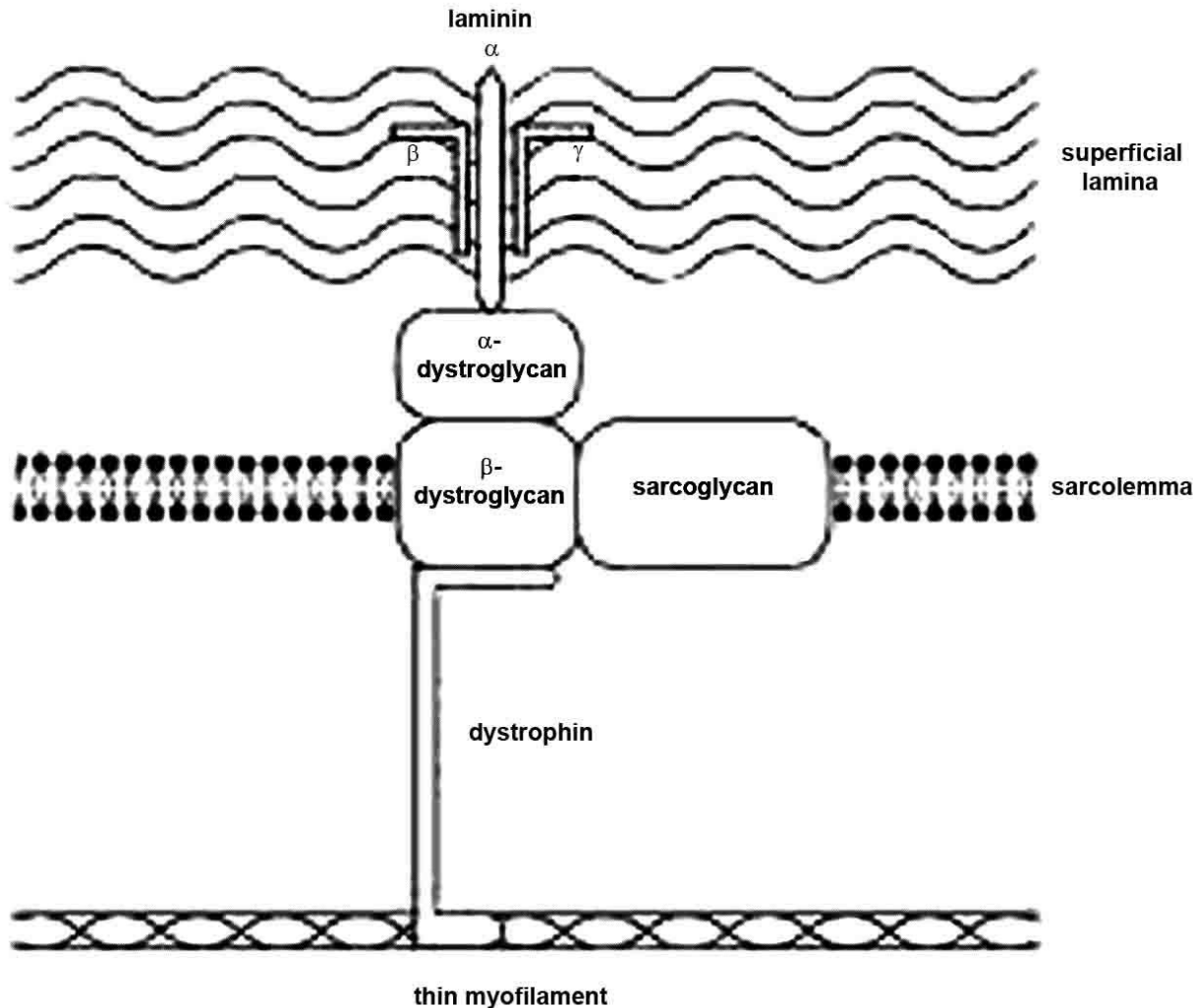
# Muscle sheets



*contraction of myofibrils must be transmitted to sarcolemma and endomysium  
peripheral myofibrils are attached to sarcolemma at Z-line*

ZJEDNODUŠENÉ SCHEMA KOSTAMERY („ŽEBROVÍ“)

SIMPLIFIED SCHEME OF A COSTAMERE



**costamere**  
(„ribbing“)

**dystrophin**  
**dystroglycan**  
**sarcoglycan**  
**synemin**  
**syncoilin**  
**dystrobrevin**  
**sarcospan**

# Types of skeletal muscle fibers

Type I fibers = slow oxidative fibers

Type IIa = fast oxidative glycolytic

Type IIb = fast glycolytic



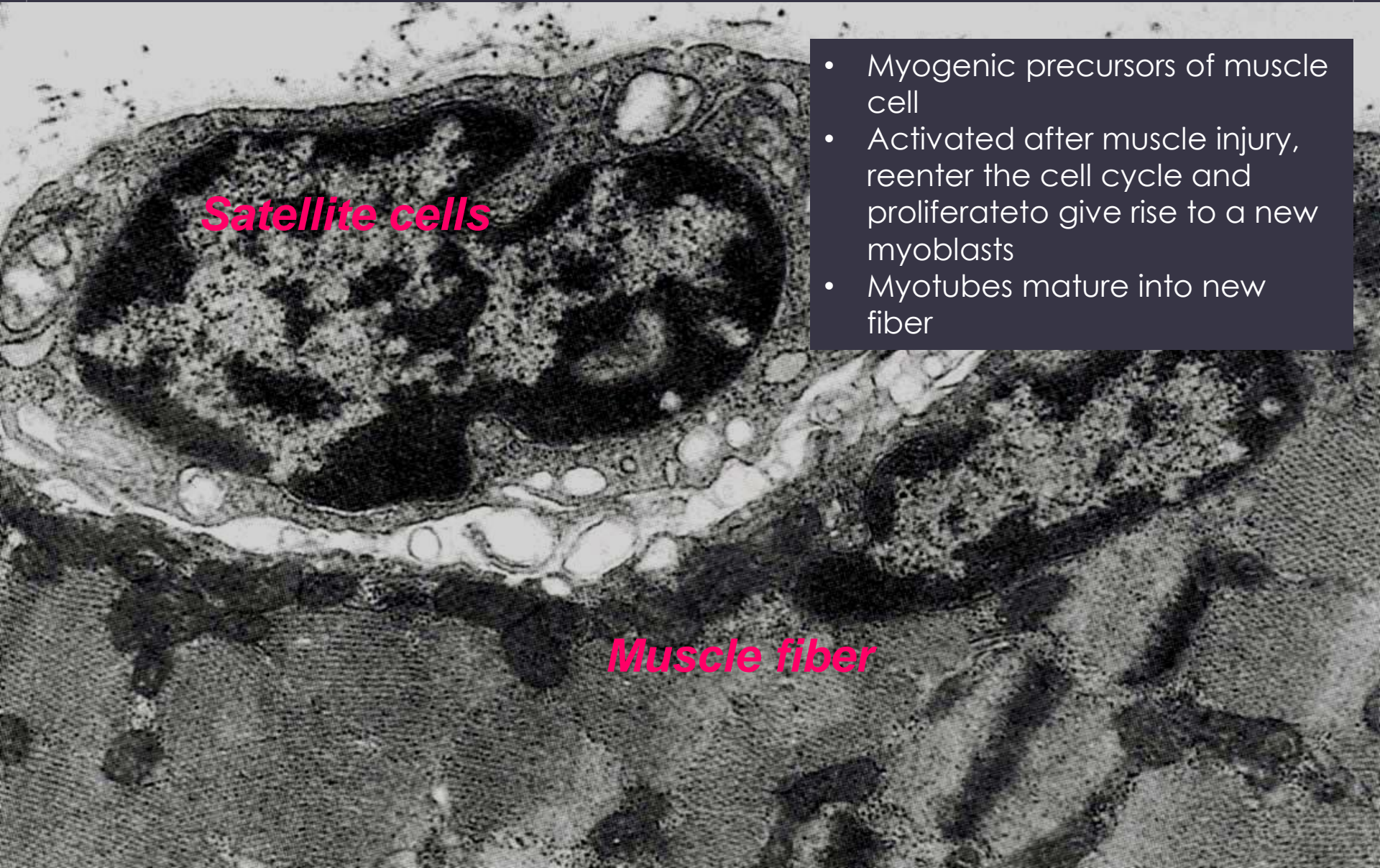


*type IIb*

*type I*

*Histochemical reaction based on oxidative enzyme activity – succinic dehydrogenase*

# Regeneration



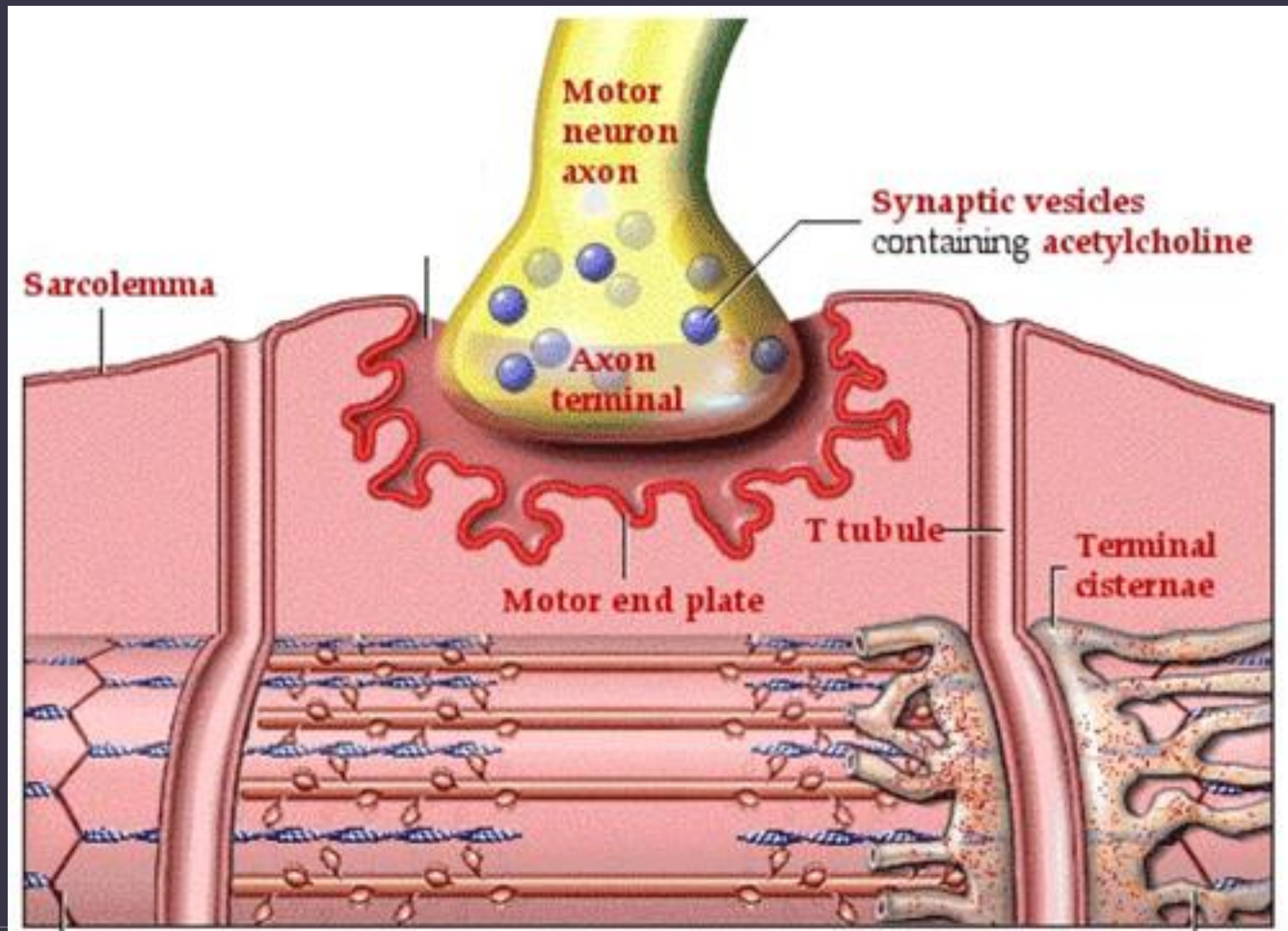
**Satellite cells**

- Myogenic precursors of muscle cell
- Activated after muscle injury, reenter the cell cycle and proliferate to give rise to a new myoblasts
- Myotubes mature into new fiber

**Muscle fiber**

# Neuromuscular junction and contraction

<https://www.youtube.com/watch?v=sZuy356qkPM>





# Cardiac muscle

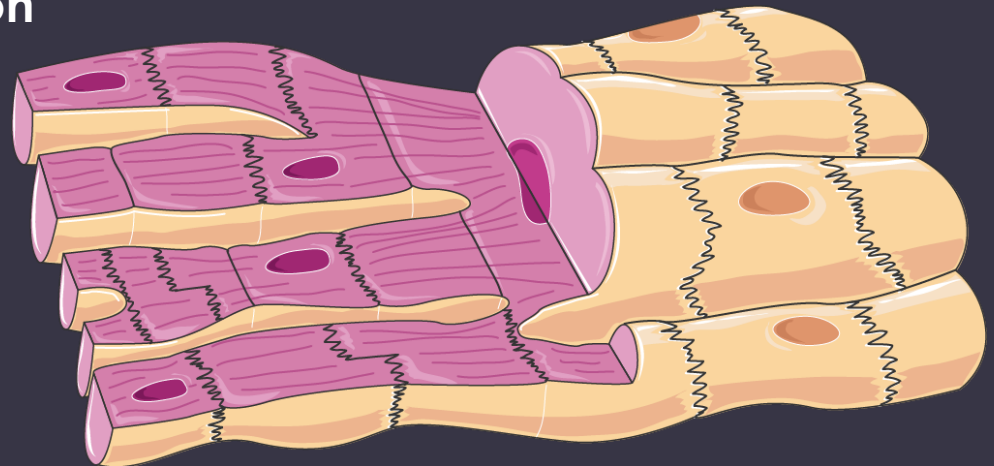
**Cardiomyocytes** – cylindrical cells arranged end to end

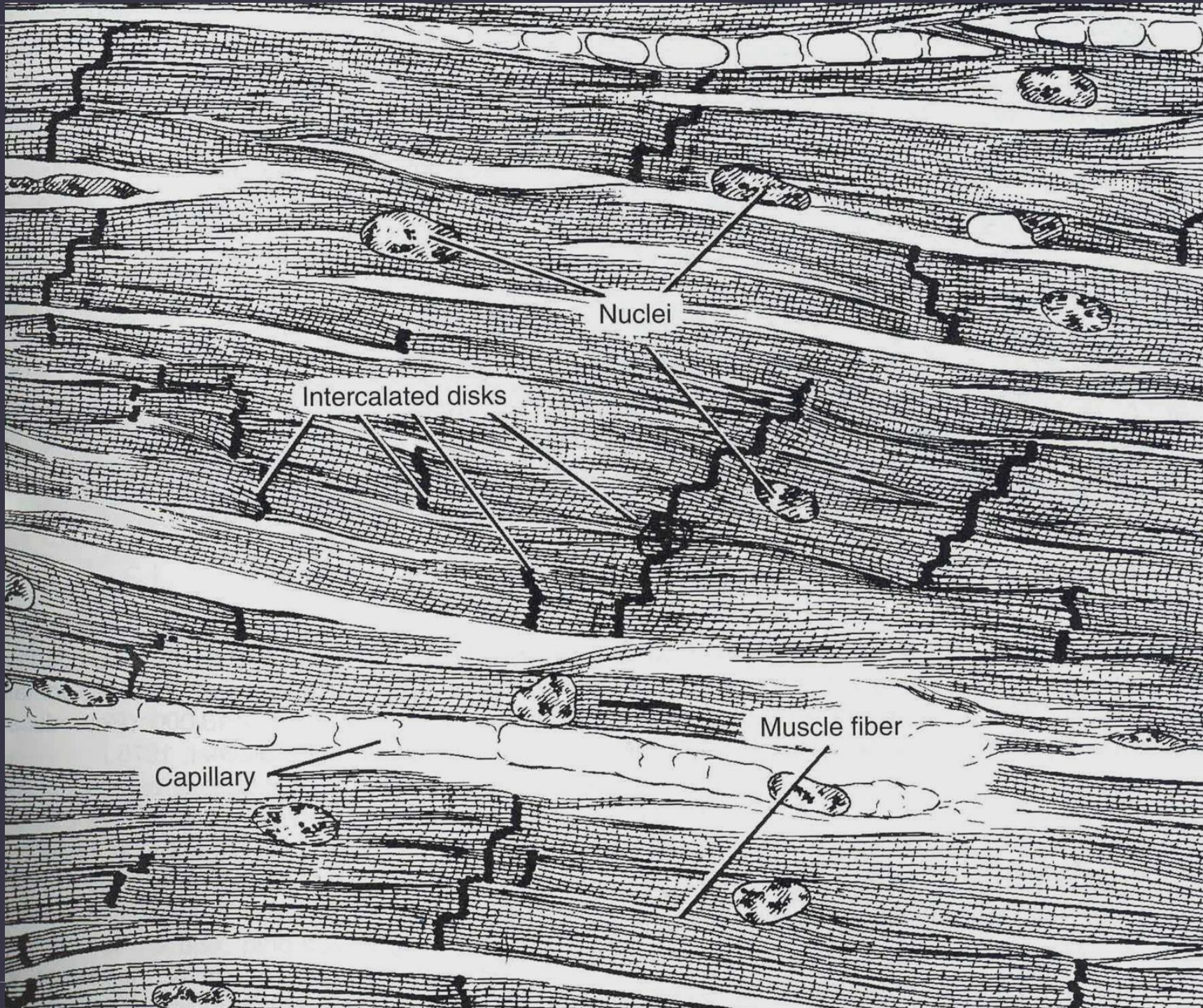
**Intercalated discs** = specialized attachment sites between adjacent cells

**Nucleus** lies in the center of cell

Large **mitochondria** and **glycogen** stores

Spontaneous **rythmic contraction**



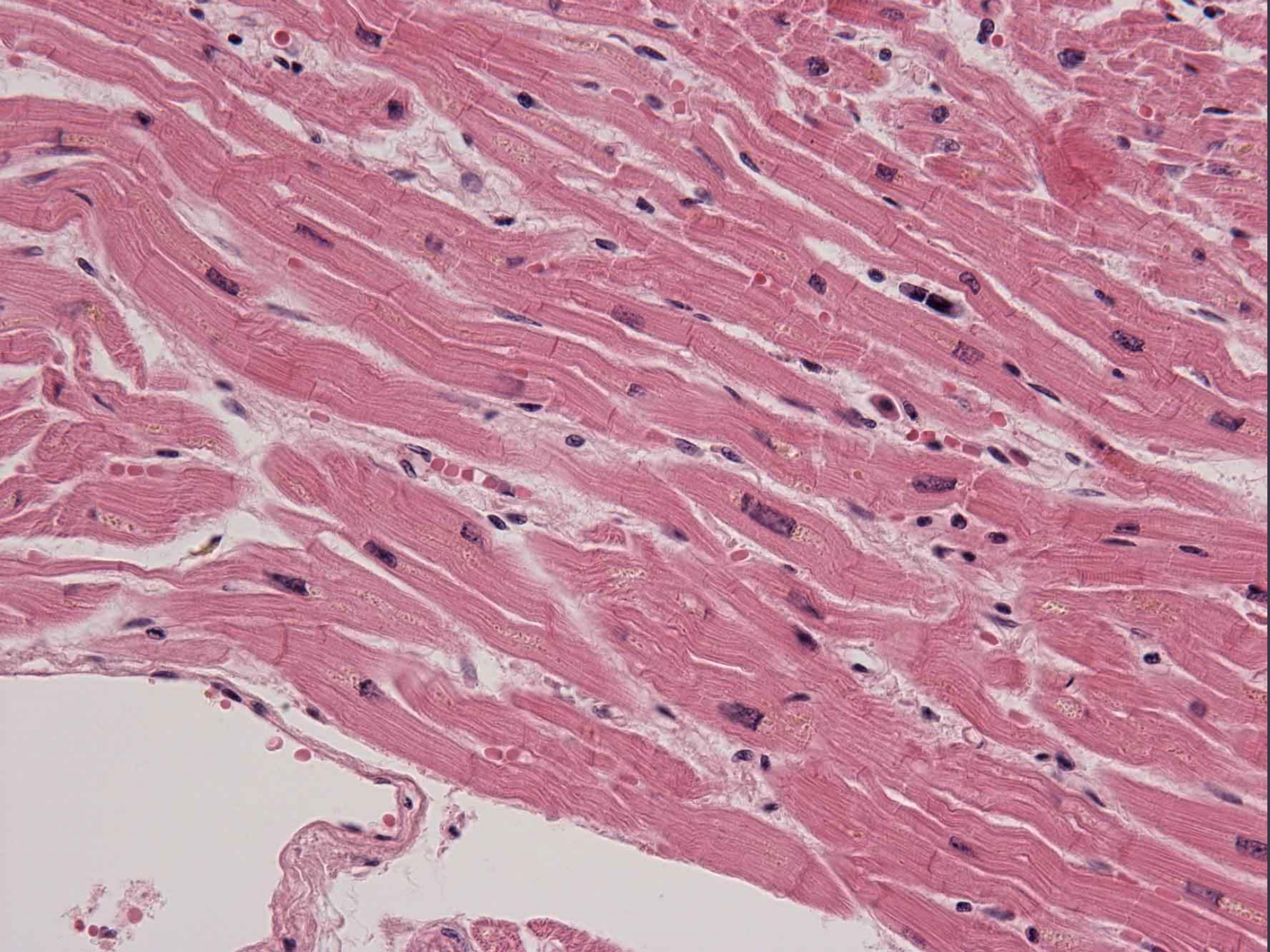


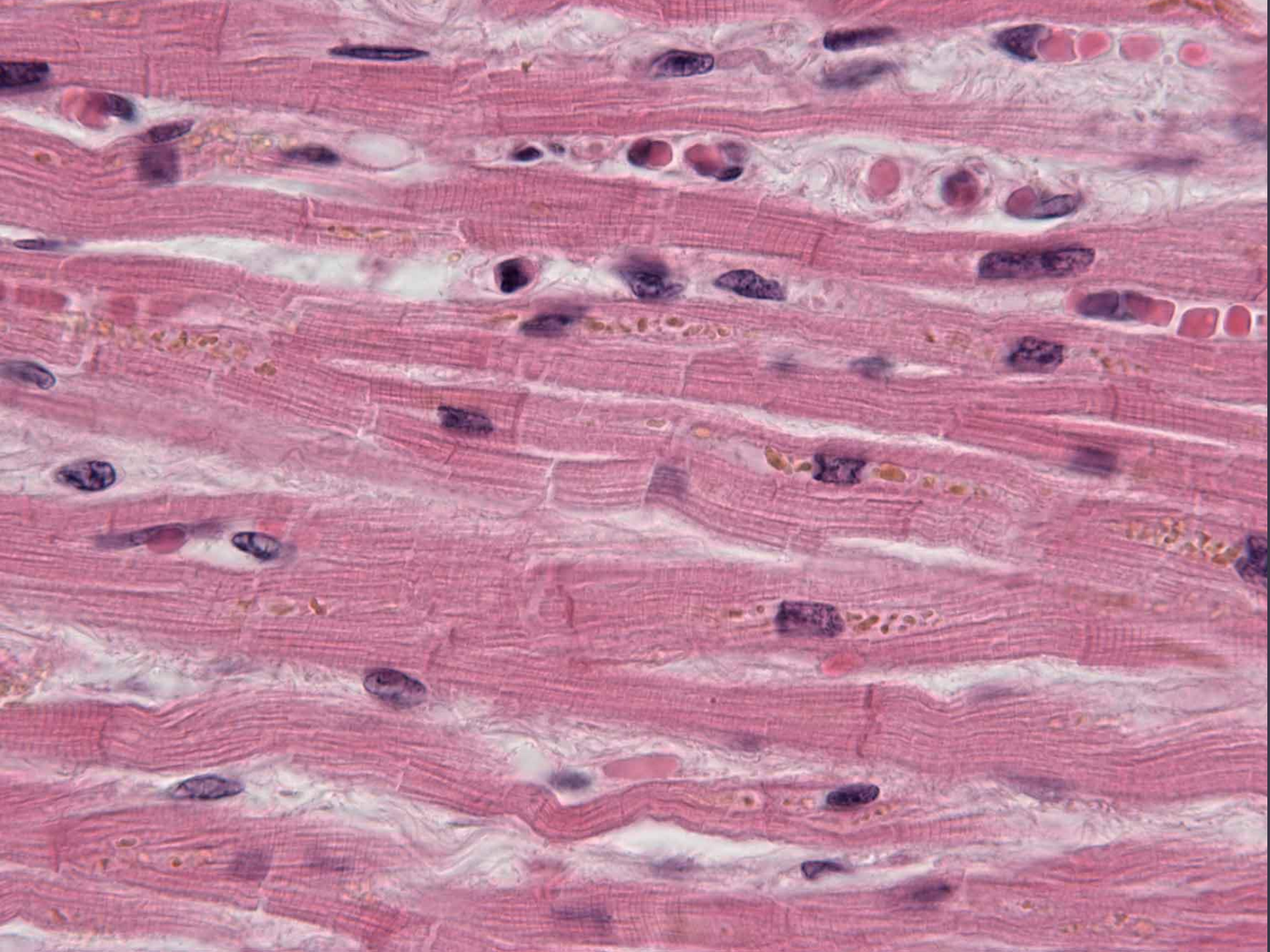
Nuclei

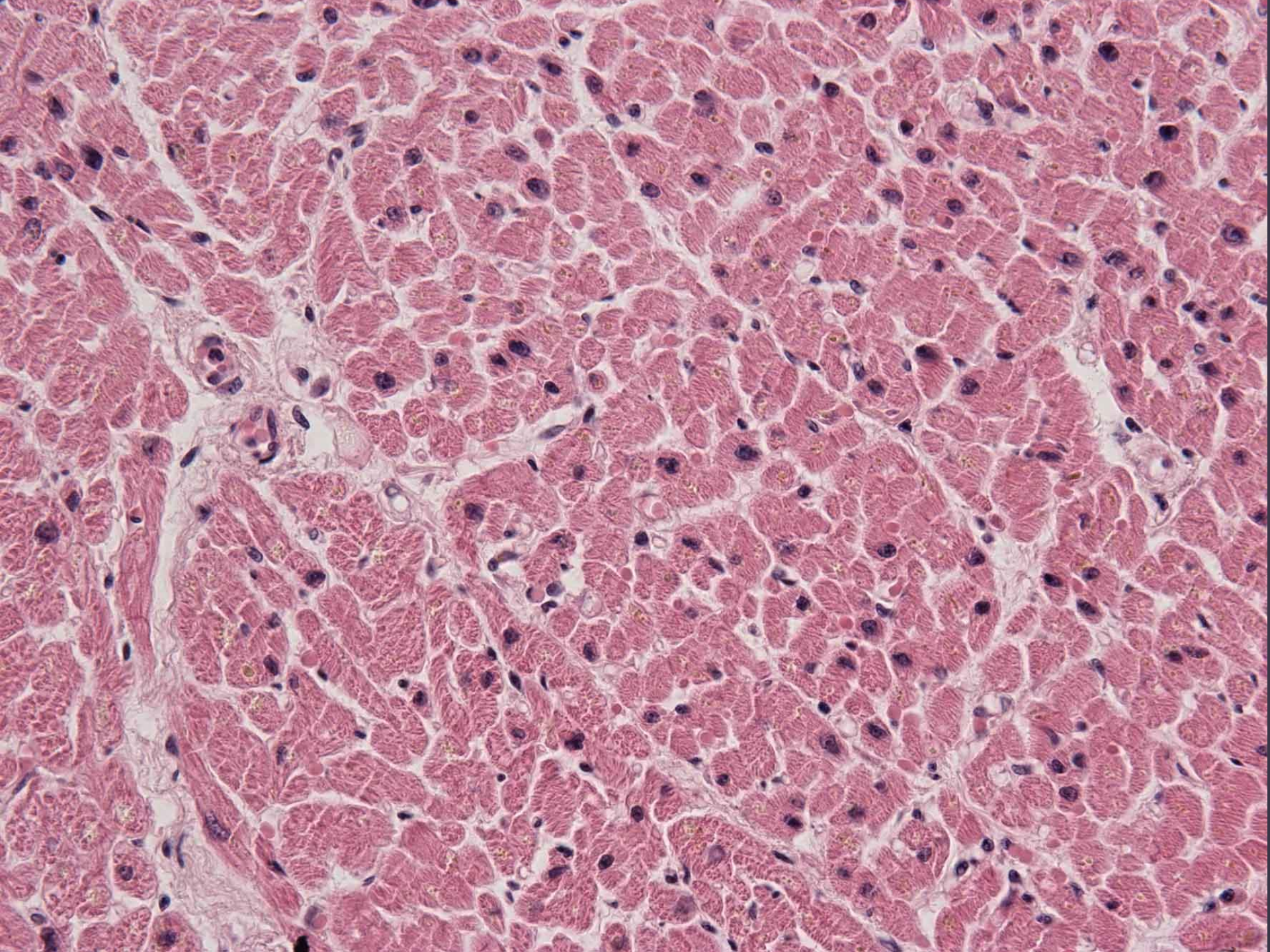
Intercalated disks

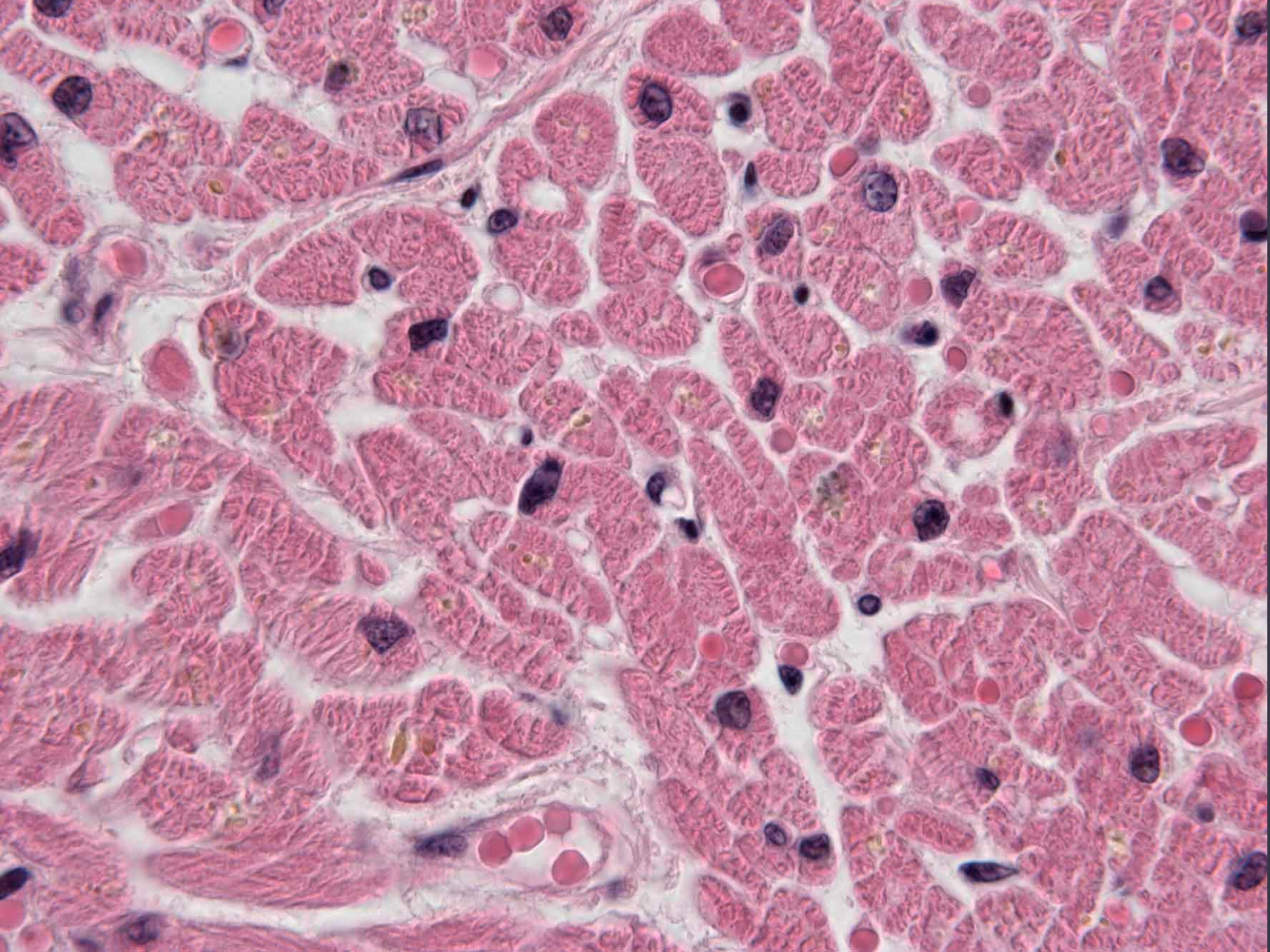
Muscle fiber

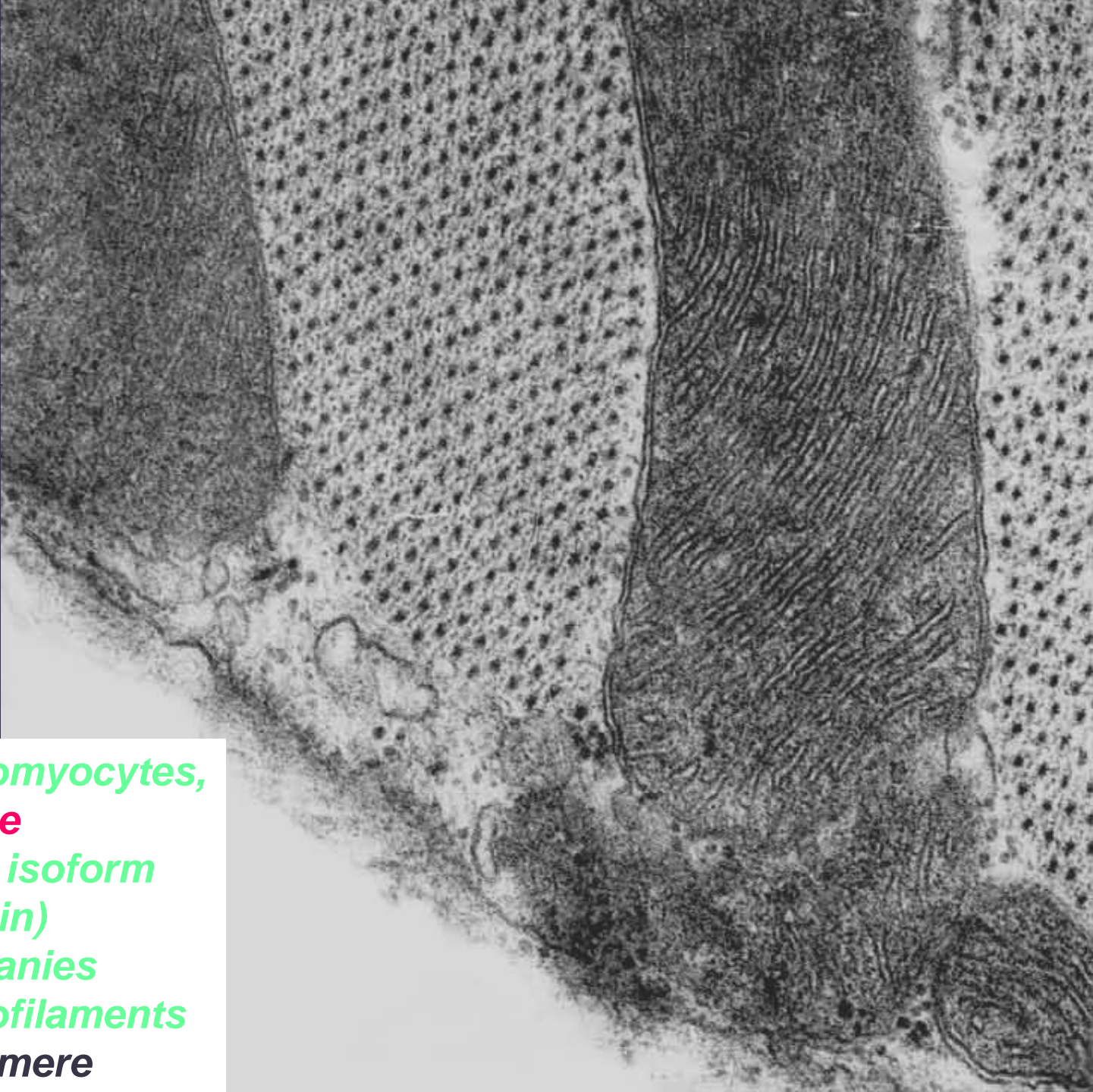
Capillary



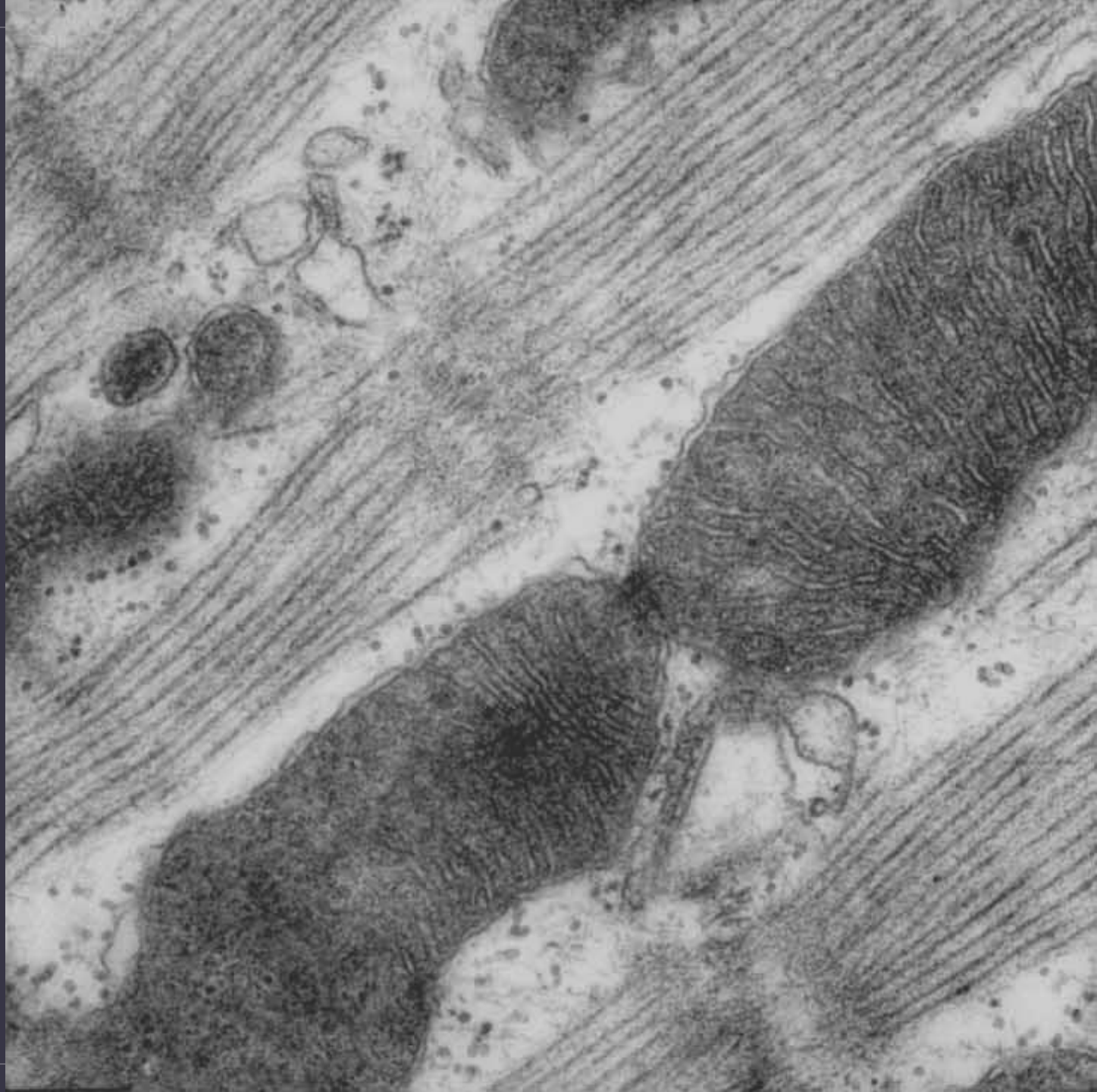








*in cardiomyocytes,*  
**nebullette**  
*(smaller isoform*  
*of nebulin)*  
*accompanies*  
*thin myofilaments*  
**in sarcomere**

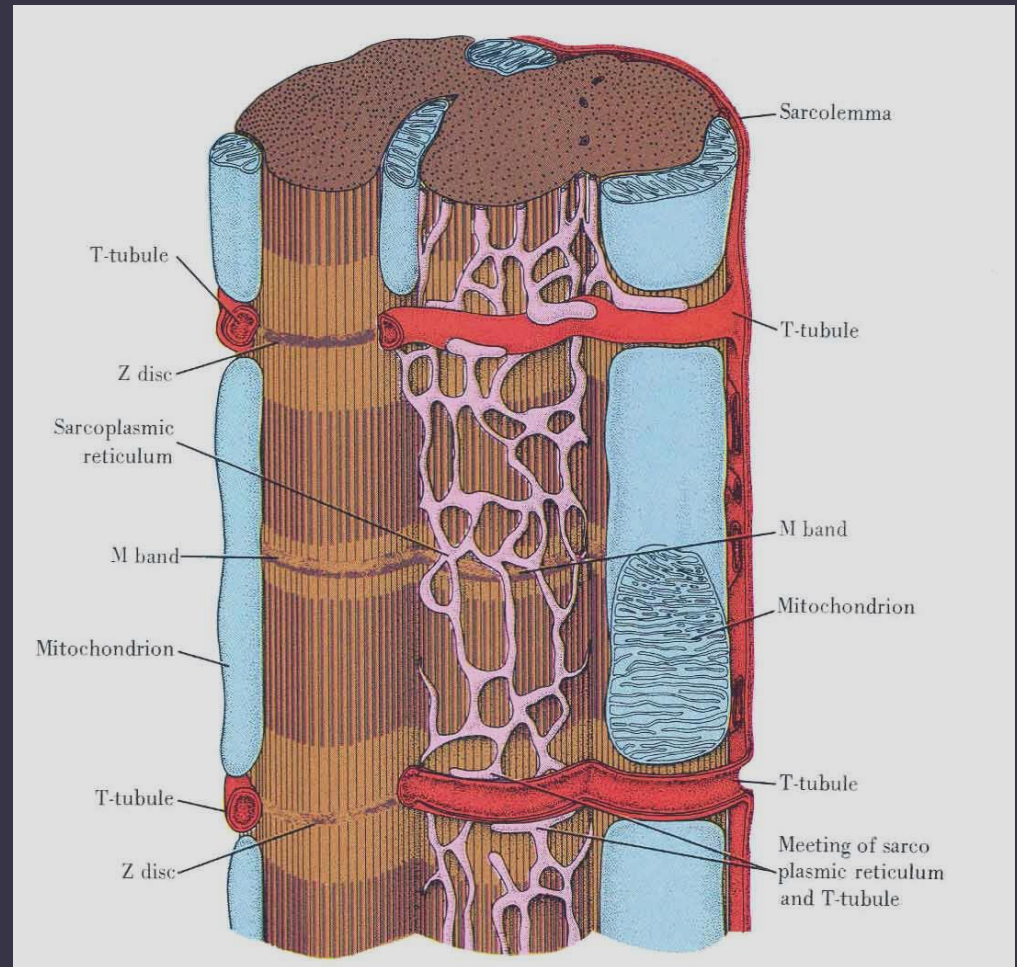




# Sarcoplasmic reticulum

Single network extending between two adjacent Z-lines

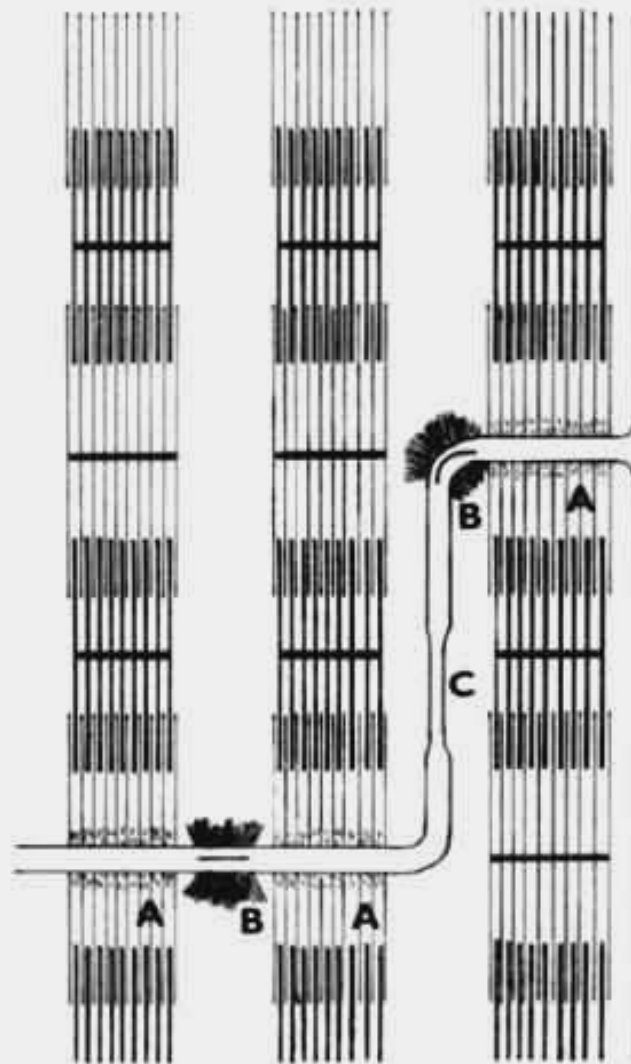
Terminal cisternae form **diad** with T tubules at the level of Z-line





*T tubule*  
*diad*

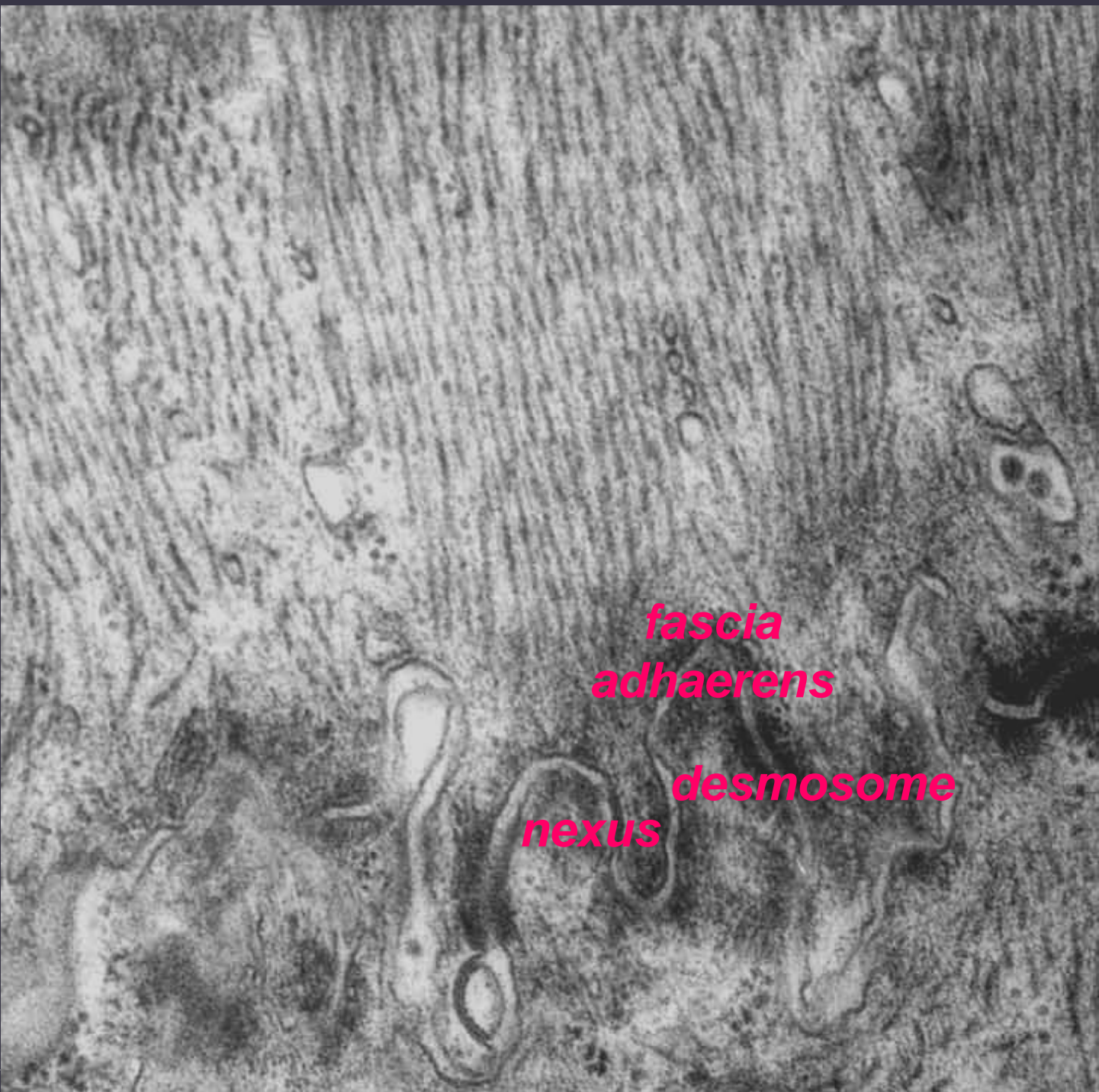
## INTERCALATED DISC



**A – fascia adhaerens**

**B – macula adhaerens (desmosome)**

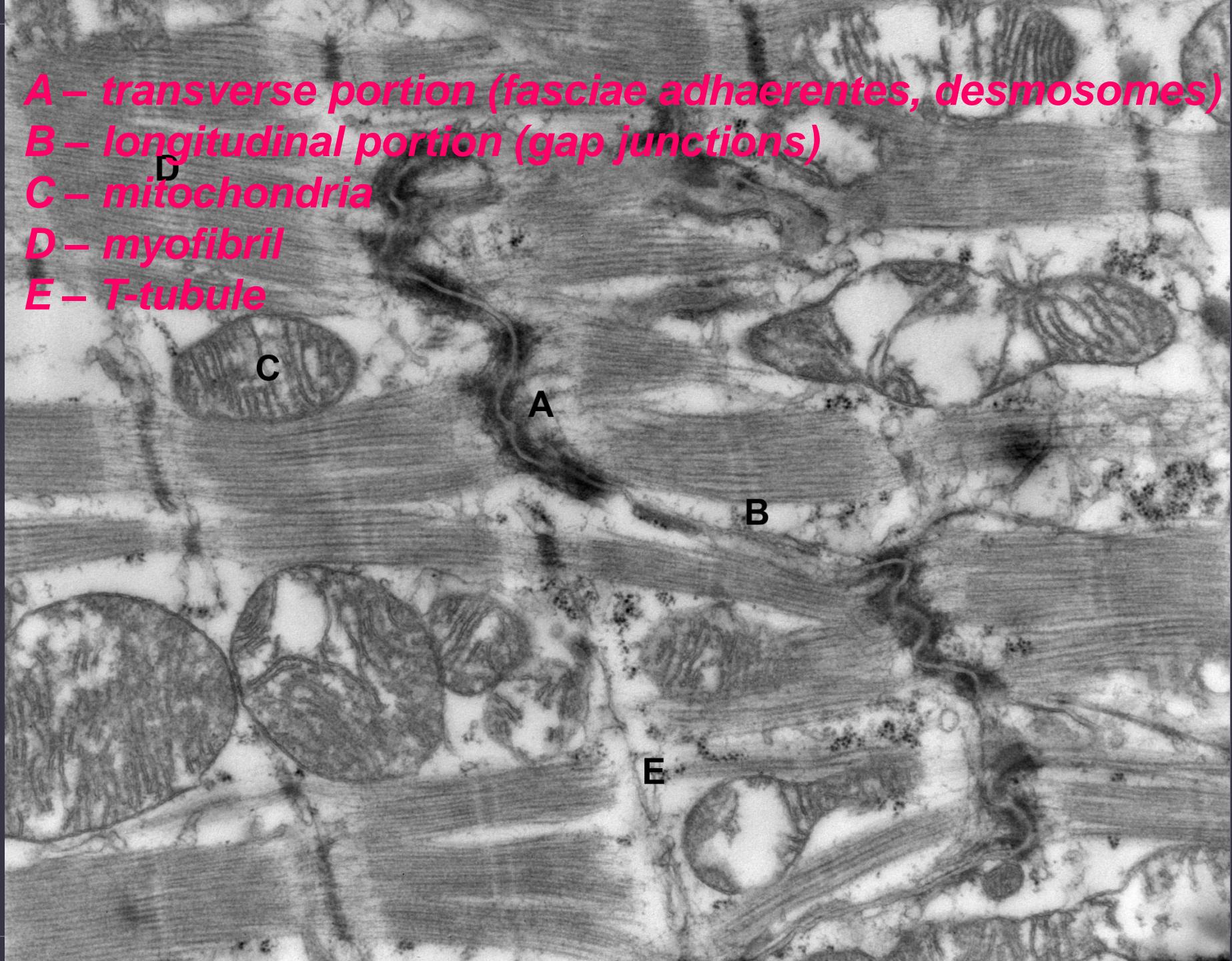
**C – gap junction (nexus)**

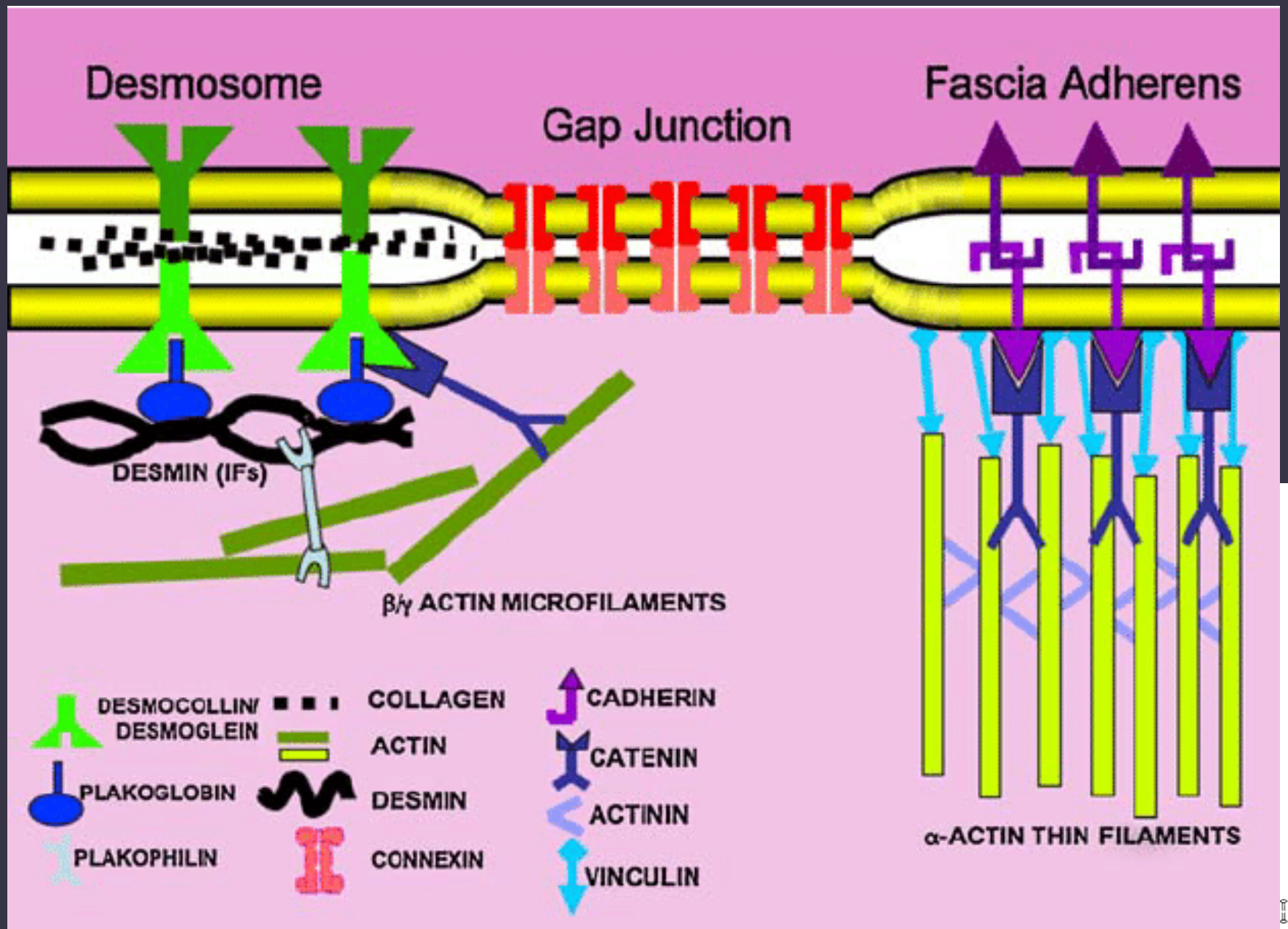


*fascia  
adhaerens*

*desmosome  
nexus*

- A – transverse portion (fasciae adhaerentes, desmosomes)**  
**B – longitudinal portion (gap junctions)**  
**C – mitochondria**  
**D – myofibril**  
**E – T-tubule**





← Long axis of the cell →

Hypothetical  
integral  
membrane  
protein

Intercalated  
disk

Vinculin

Actin  
filaments

$\alpha$ -Actinin

(+)

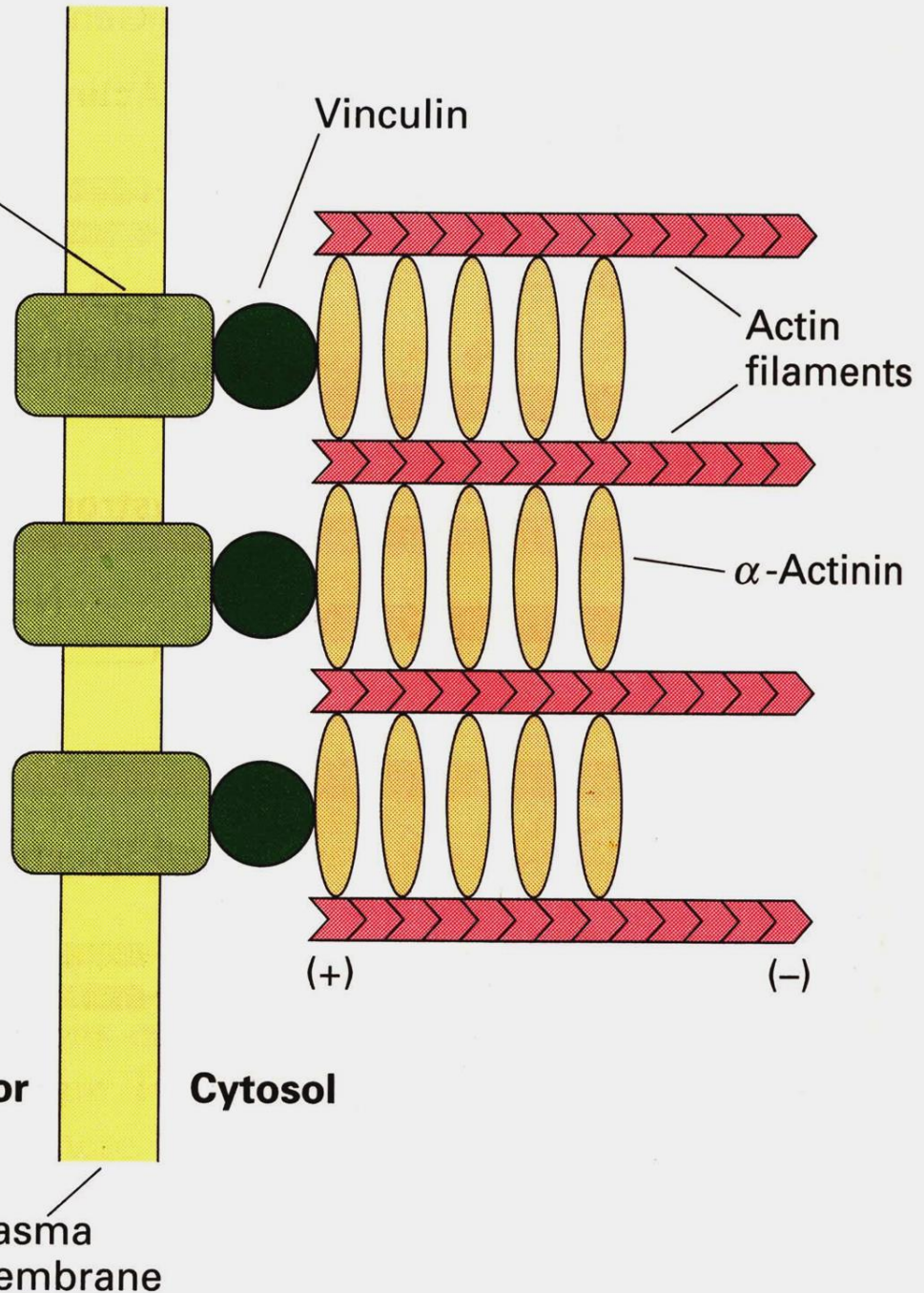
(-)

Exterior

Cytosol

Plasma  
membrane

*in cardiomyocytes,  
vinculin  
shares the role  
with dystrophin  
in the costamere*



# Regeneration





# Smooth muscle

Elongated fusiform cells with **nuclei** located **in the centre**

Gap junctions

**Dense bodies** – cytoplasmic densities

Network of **intermediate filaments** – desmin (and vimentin)

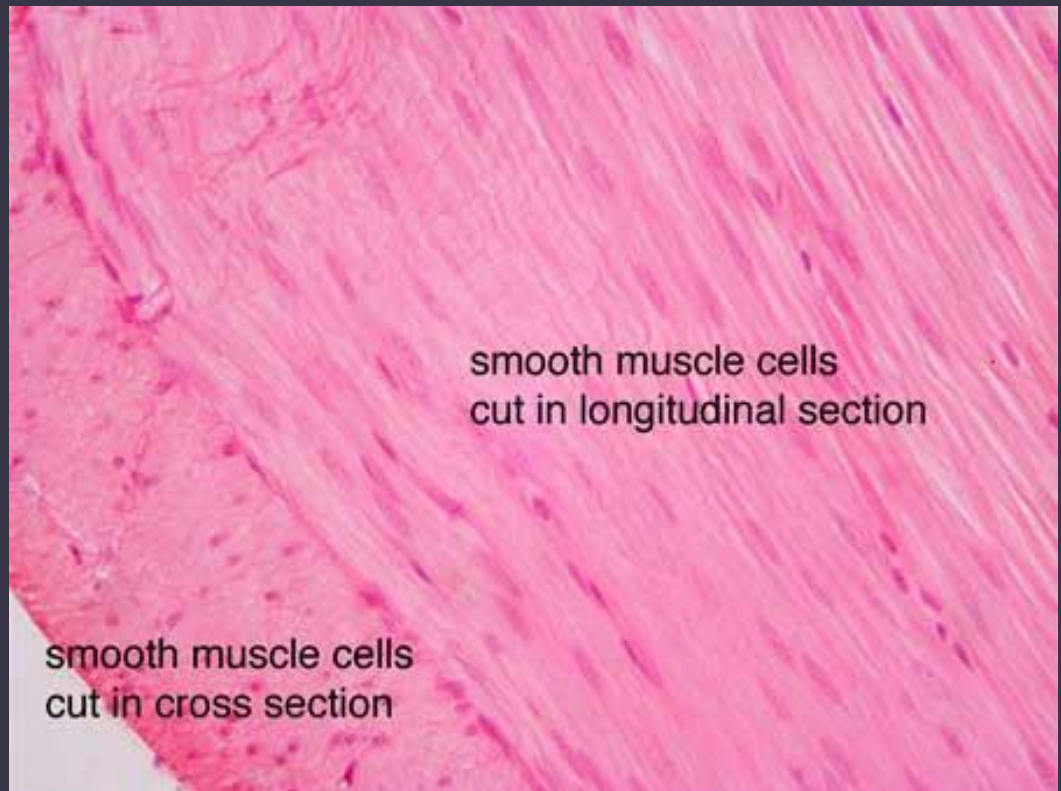
basic unit: **SMOOTH MUSCLE CELL**  
spindle-shaped element with one nucleus  
slow contraction without any voluntary control

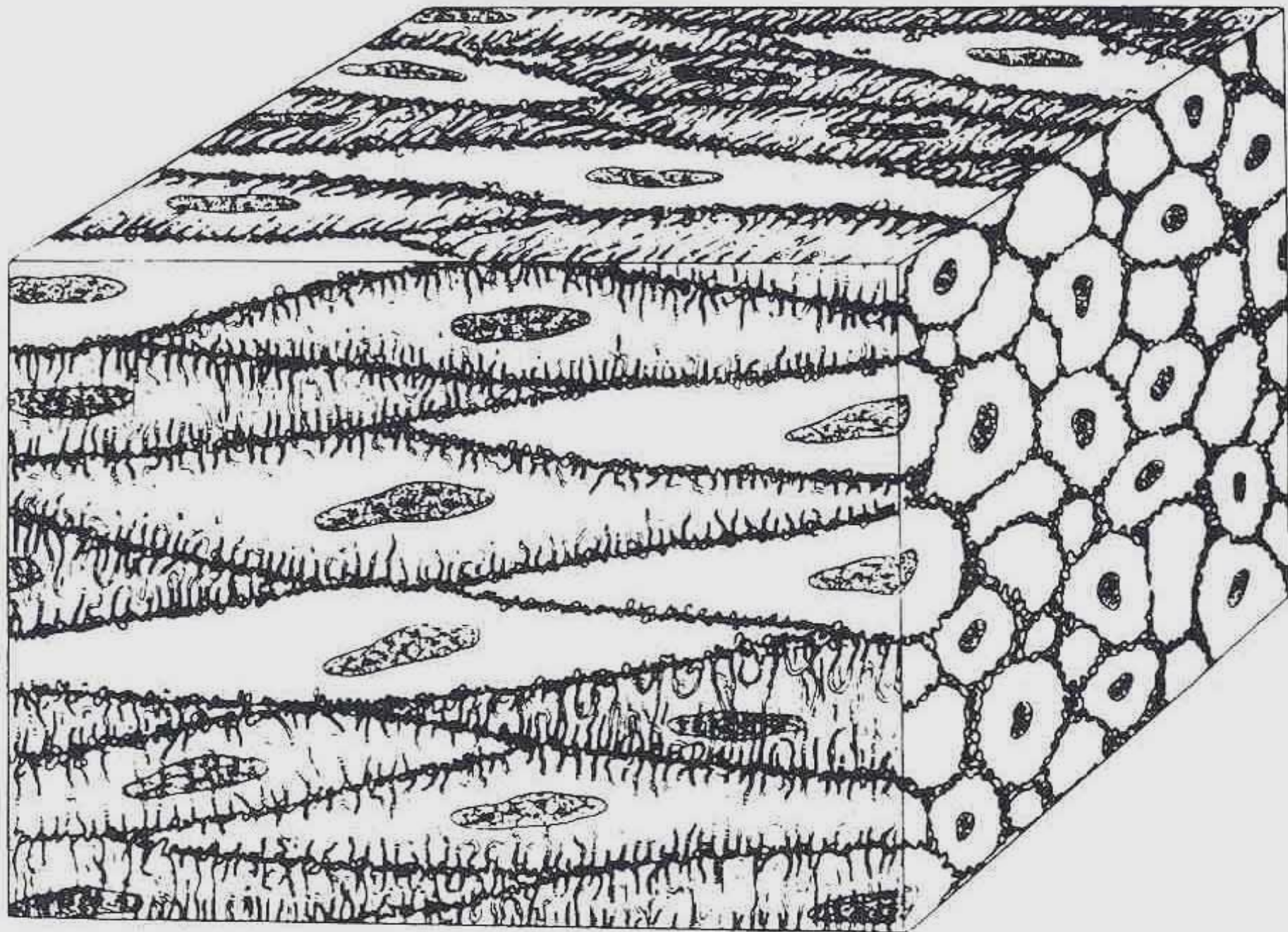
length: 15 to 500 micrometers

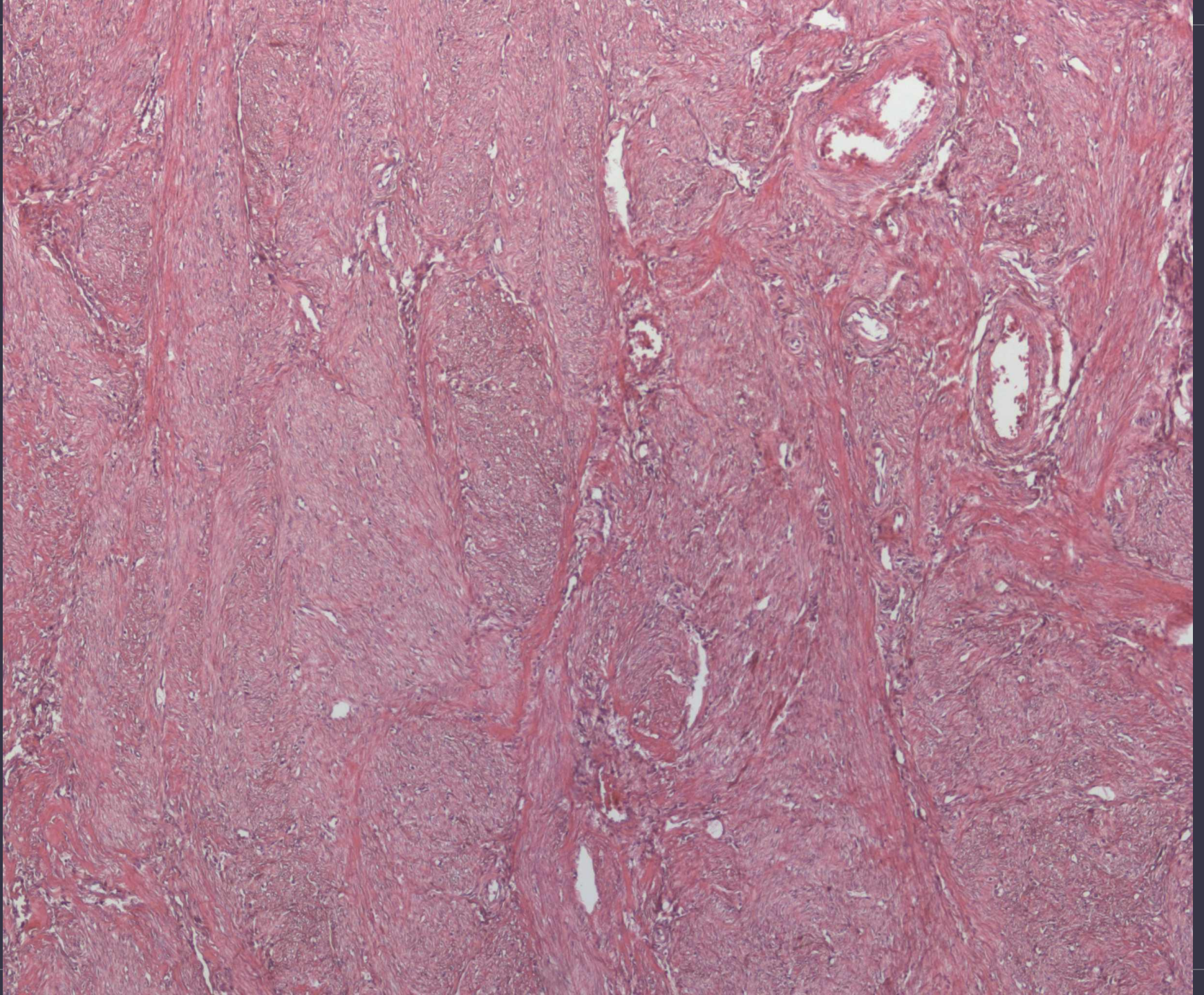
diameter: approx. 6 micrometers

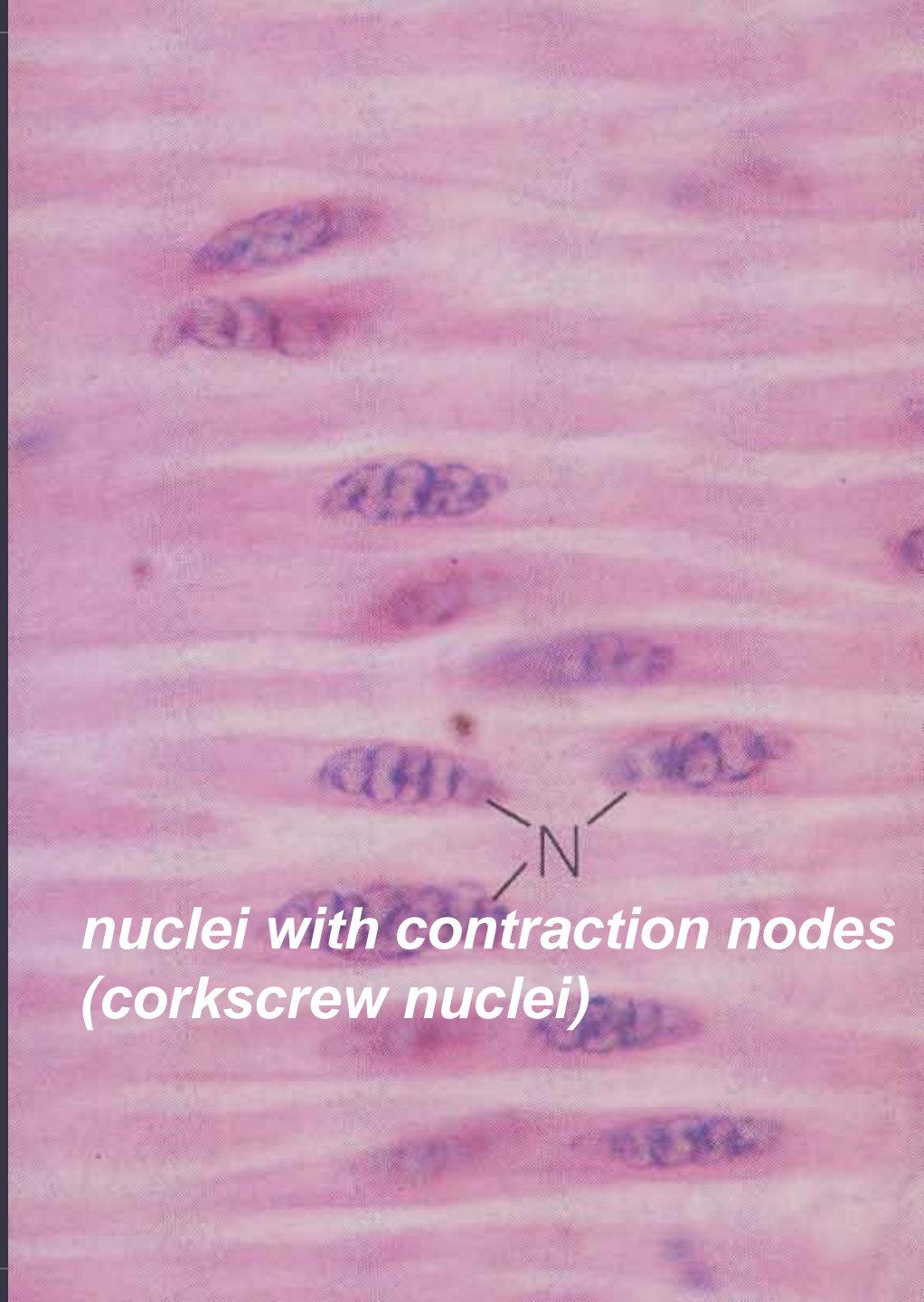
nucleus situated in the centre

myofilaments arranged irregularly (**NO MYOFIBRILS**)

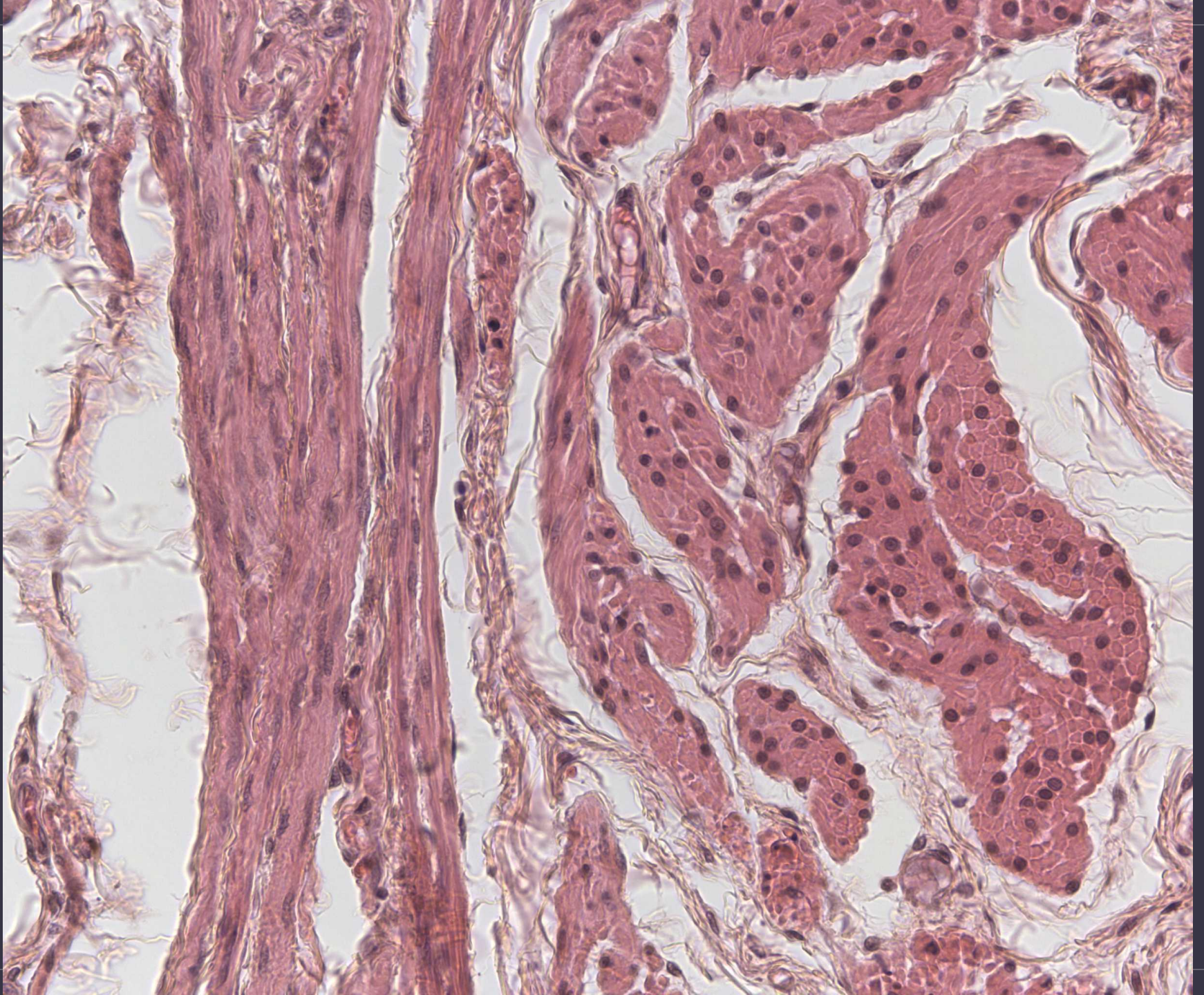








***nuclei with contraction nodes  
(corkscrew nuclei)***

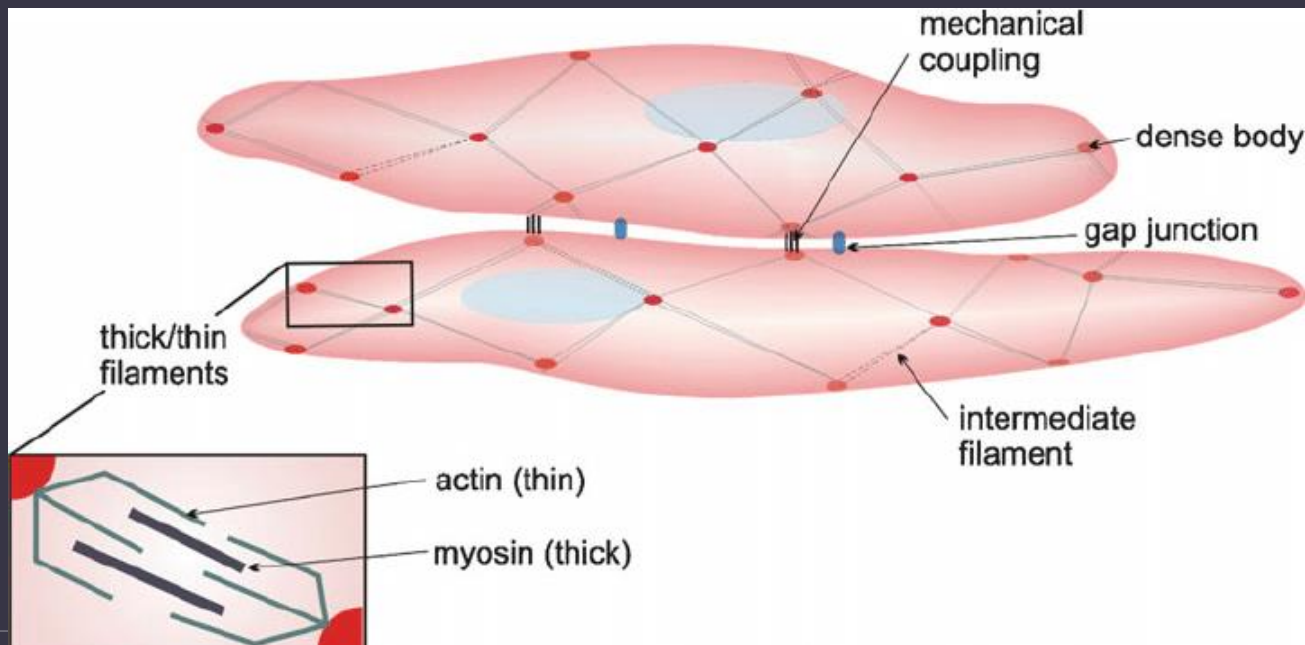


# Dense bodies and contractile network

Thin myofilaments are anchored into dense bodies

Intracellular network of anchoring points is joined to intermediate desmin filaments

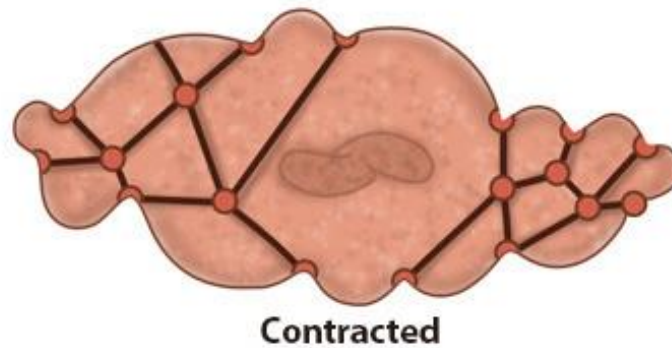
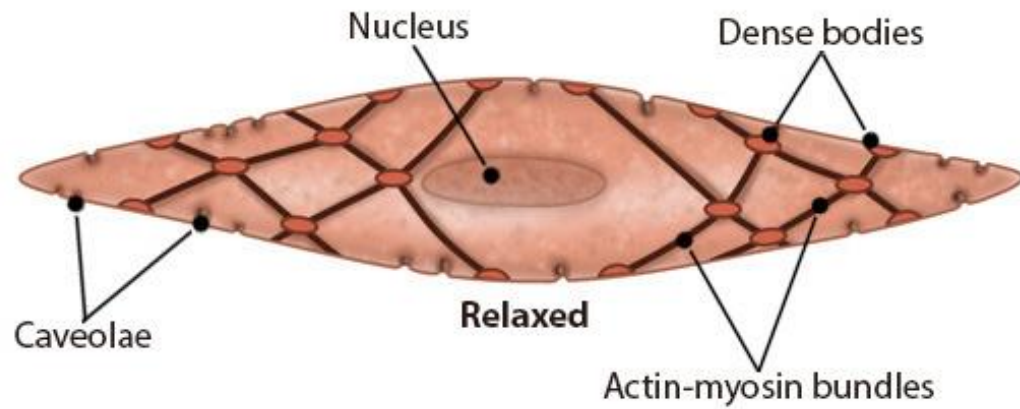
Thin myofilaments have no troponin complex





***dense body***

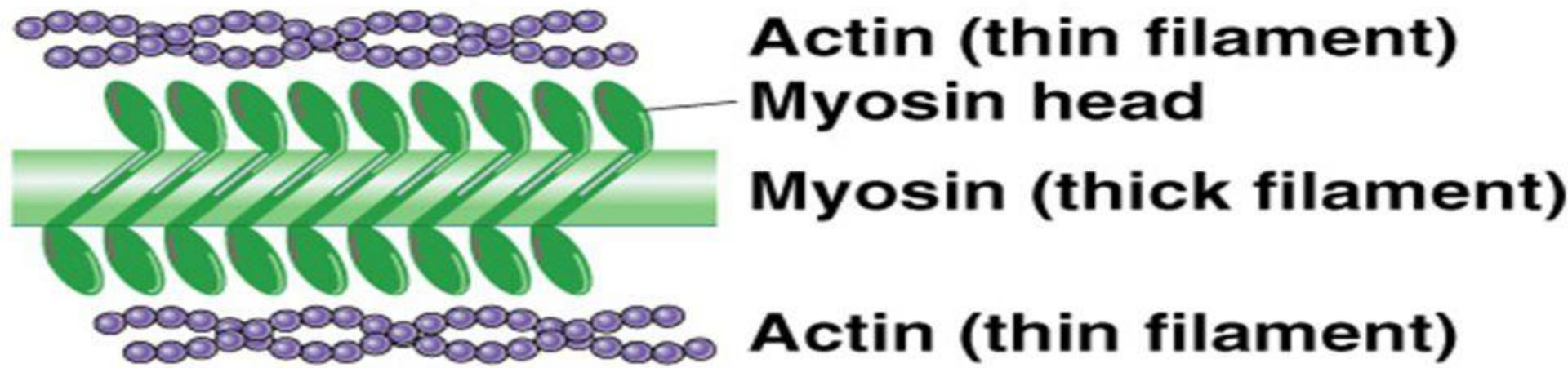
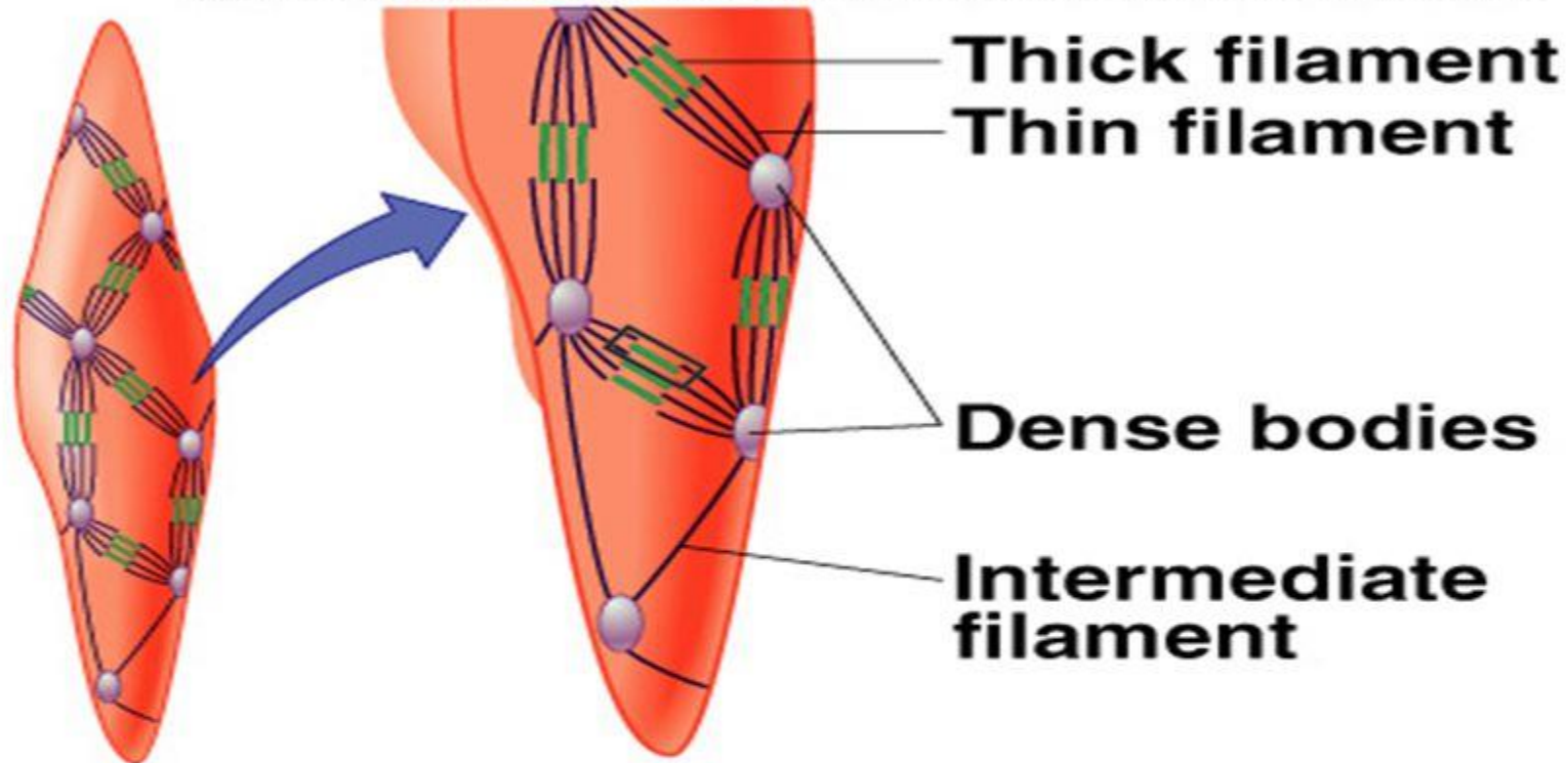
# Contraction





# Structure of Smooth Muscle

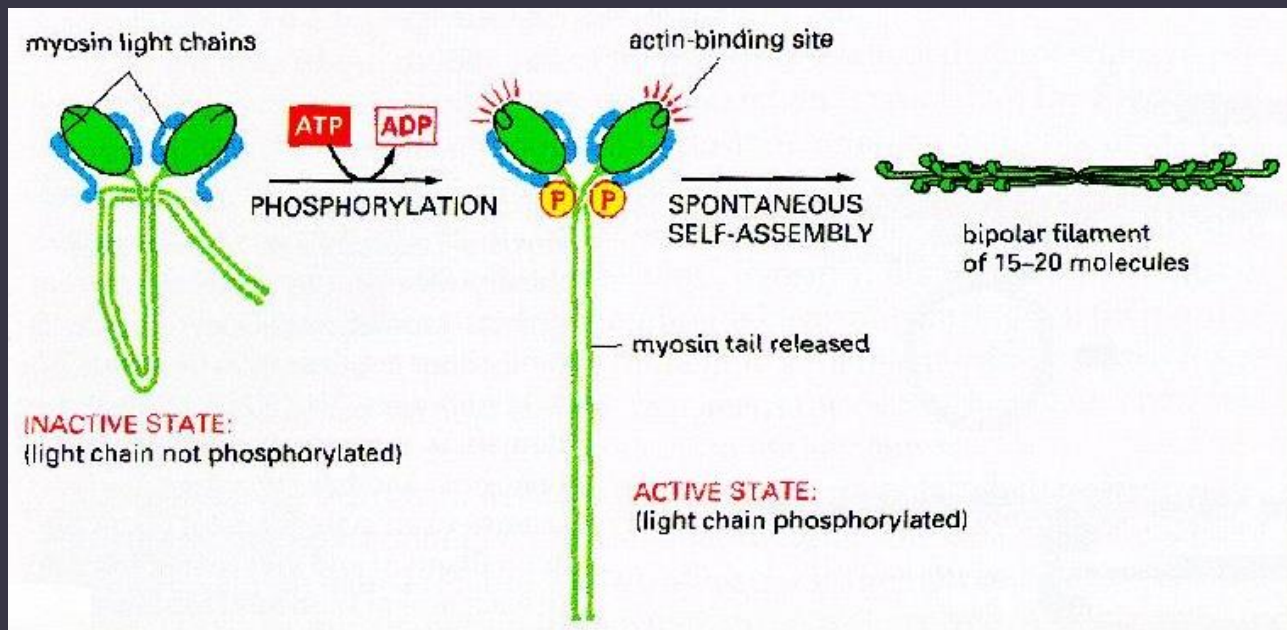
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# Thick filaments – myosin II

In the resting state the actin-binding site is inactivated, myosin II is folded

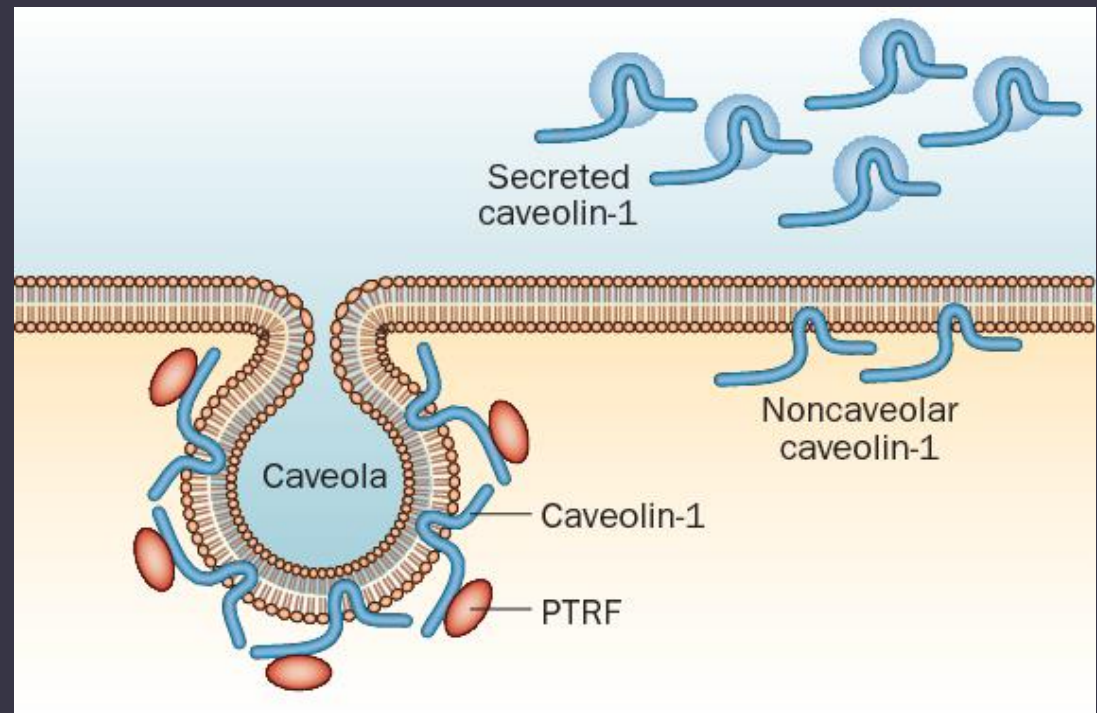
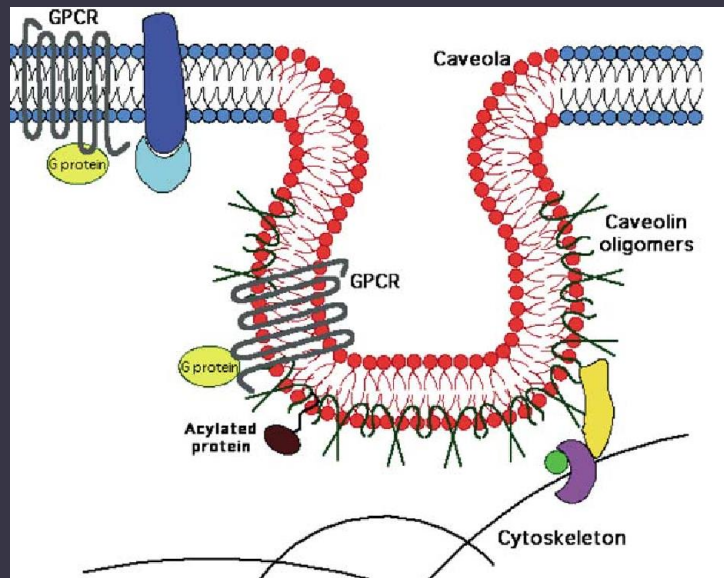
After the phosphorylation by **myosin light chain kinase**, actin-binding site of the myosin head is activated and binds to actin. In the presence of ATP, the myosin head bends and produces a contraction.



# Caveolae

Specialized invaginations of sarcolemma

Role in the **entry of  $Ca_2$  ions** into the cell

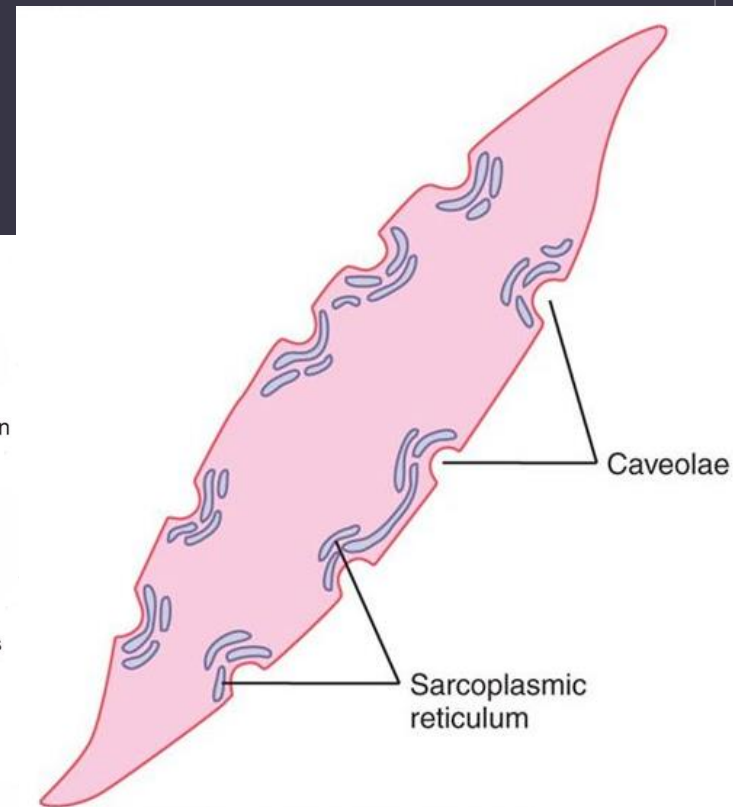
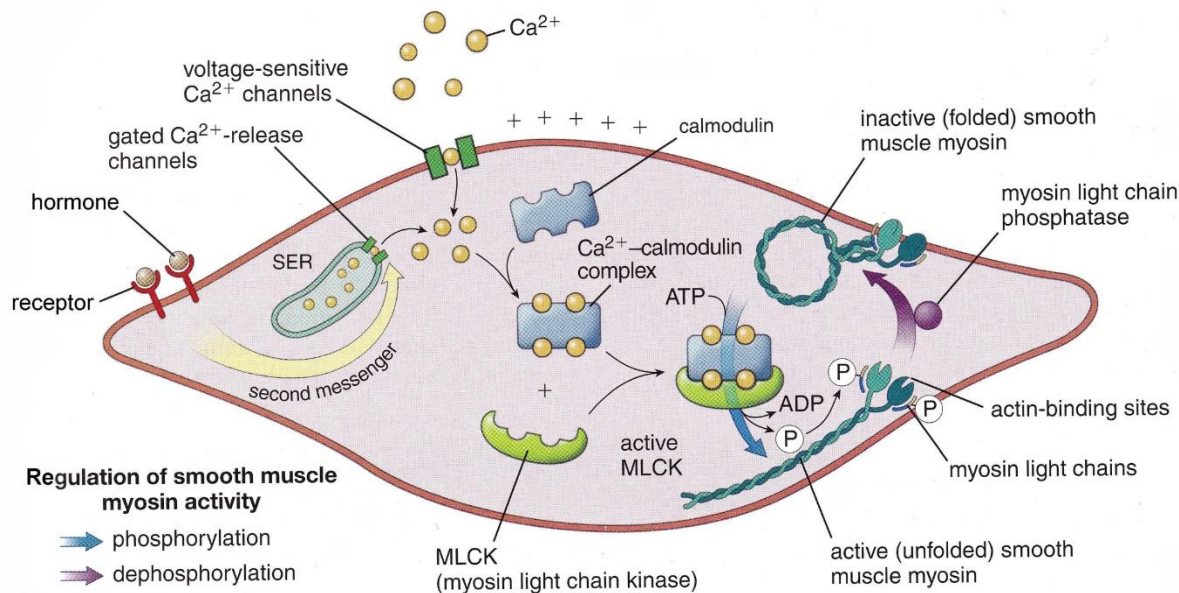


# Organelles

Well-developed smooth endoplasmic reticulum

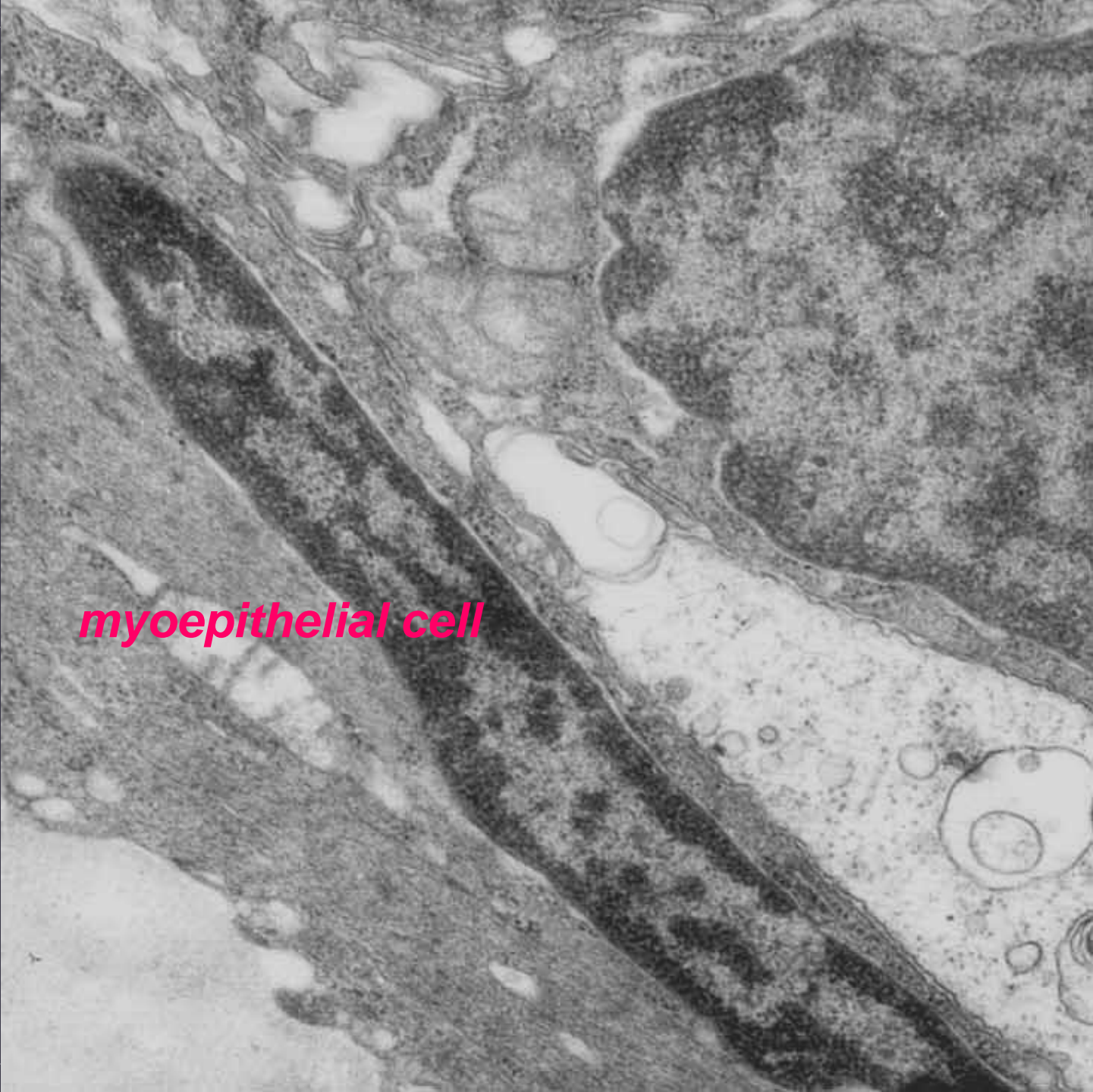
None T tubules!

Well-developed rER and GA –  
production of connective tissue matrix



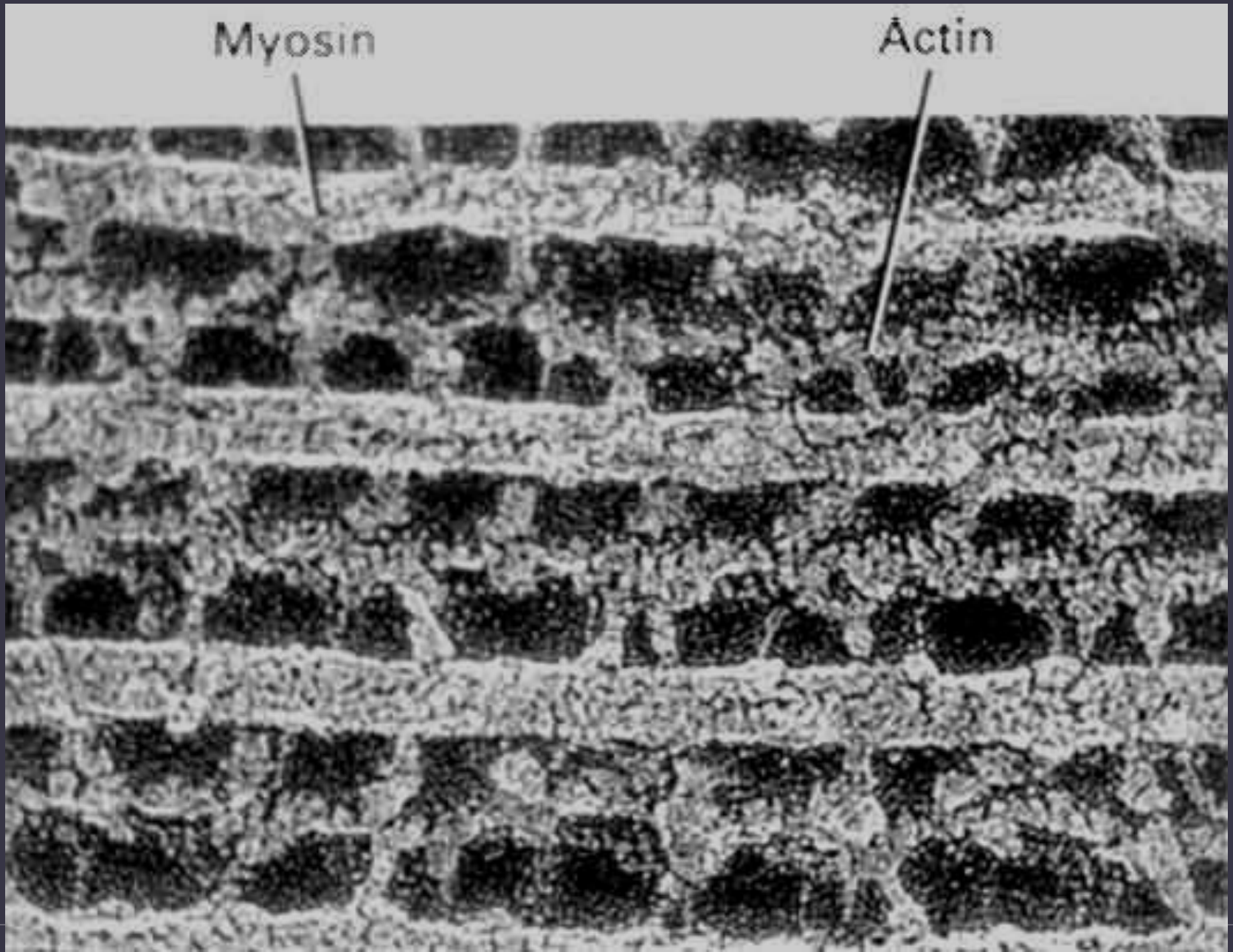
# ***Contractile non-muscle elements***

- *myoepithelial cells (glands)*
- *myofibroblasts (connective tissue proper)*
- *pericytes (capillaries, smallest venules)*
- *mesangial cells (kidneys)*
- *myoid cells (testes)*
- *contractile interstitial cells in alveolar septa (lungs)*

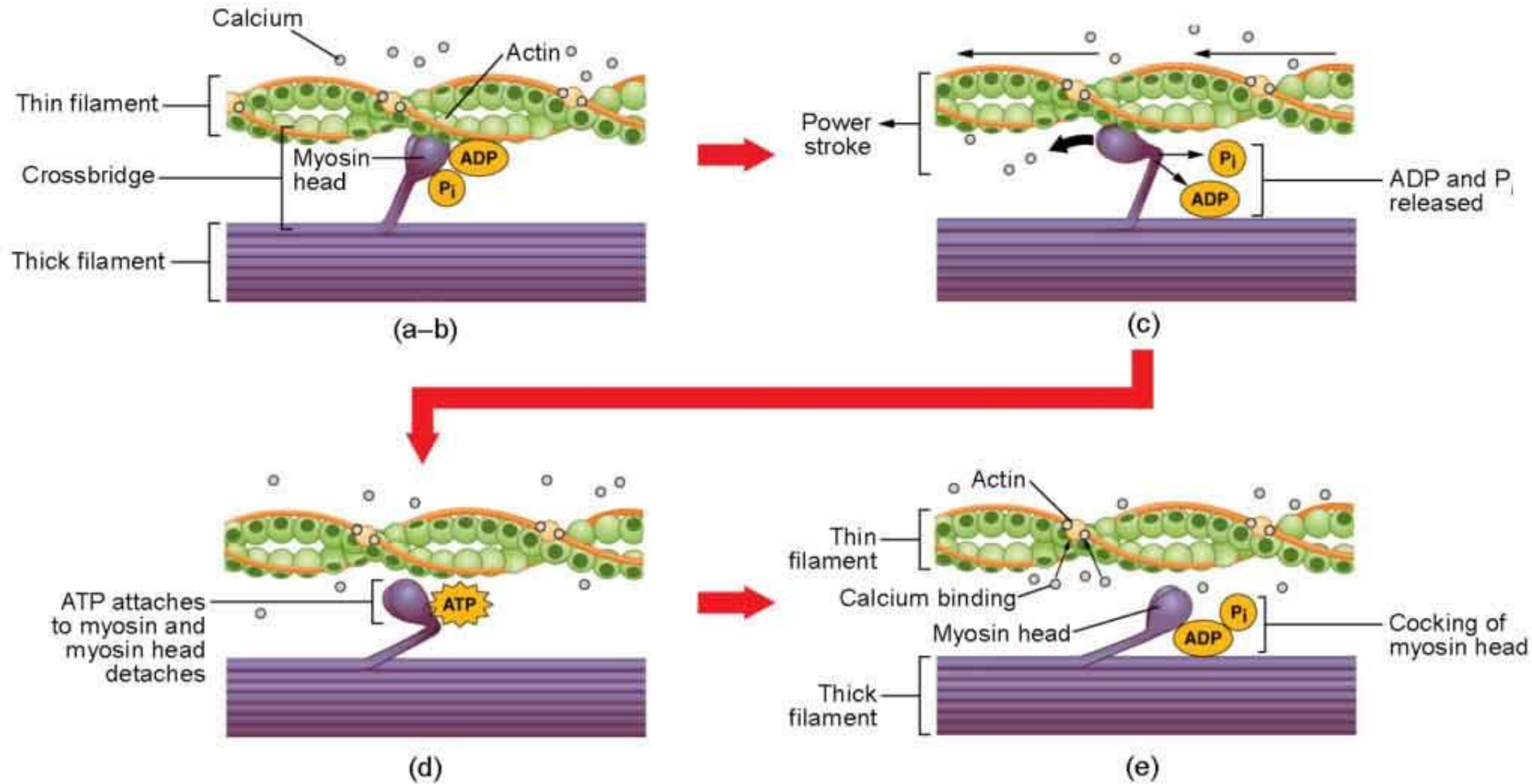


*myoepithelial cell*

# ***Mechanism of muscle contraction***



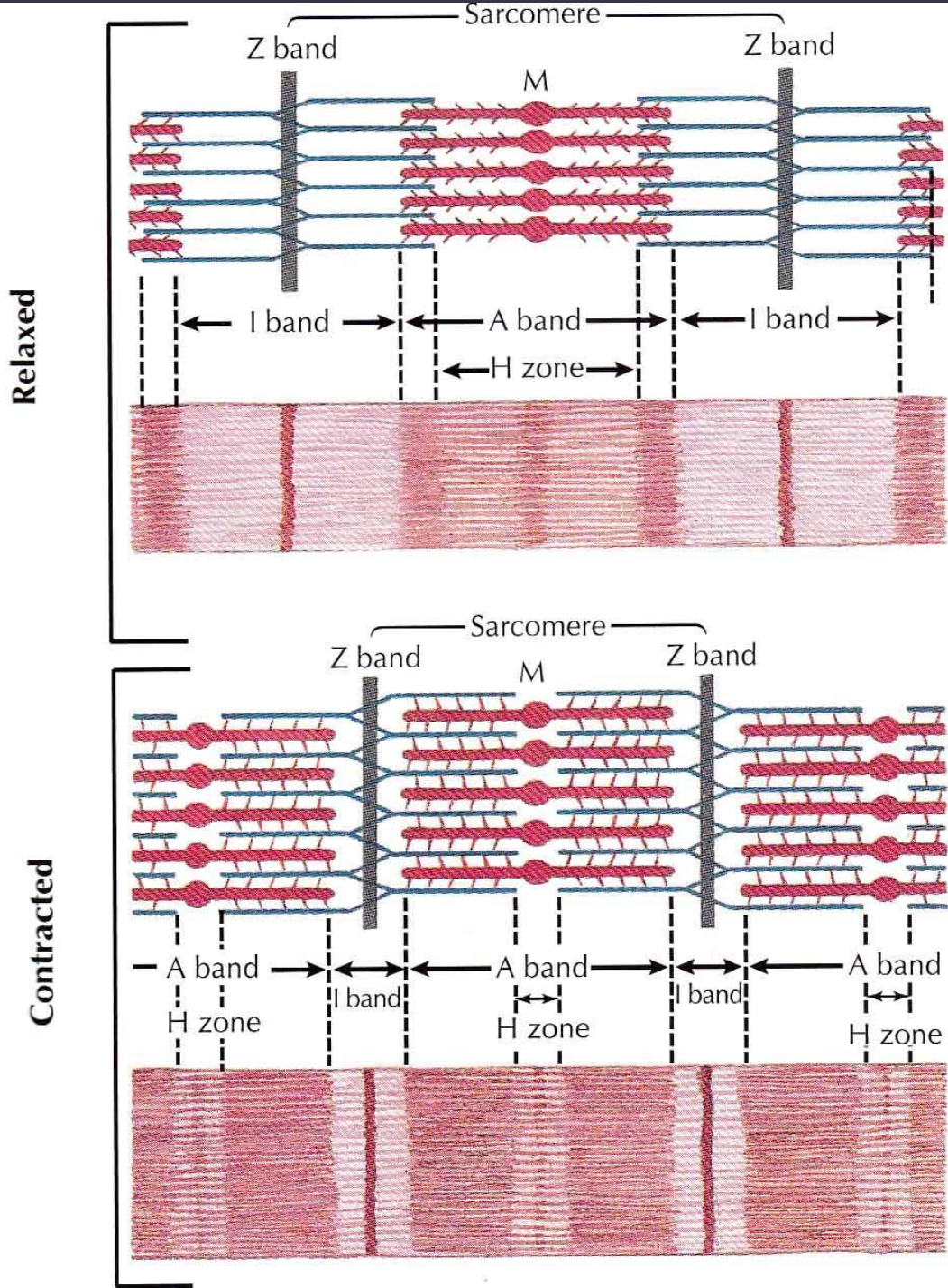
# Striated muscle (skeletal and cardiac)





- 1) ATP available and bound to myosin,  $\text{Ca}^{2+}$  not available – resting state***
- 2) splitting ATP to ADP and Pi without release of splitting products,  $\text{Ca}^{2+}$  available, TnI unlocks binding site and myosin binds to actin (actin is required as a co-factor for release of splitting products)***
- 3) released energy pushes lever arms by nearly 7 nm***
- 4) binding new ATP to myosin weakens actin-myosin bridge, the cycle repeats until  $\text{Ca}^{2+}$  is available***

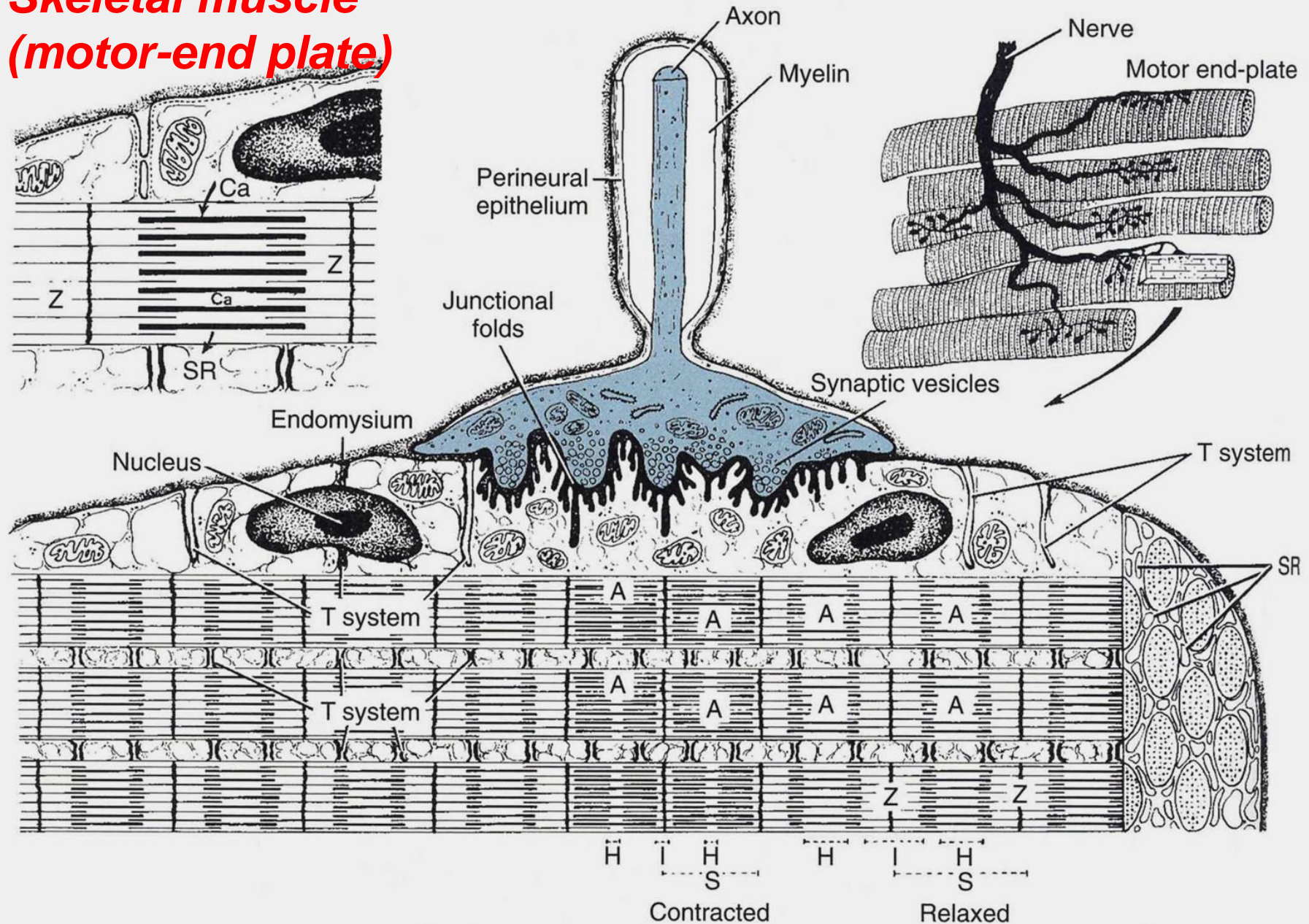
***RIGOR MORTIS: ATP not available,  $\text{Ca}^{2+}$  available - myosin heads remain linked to actin***



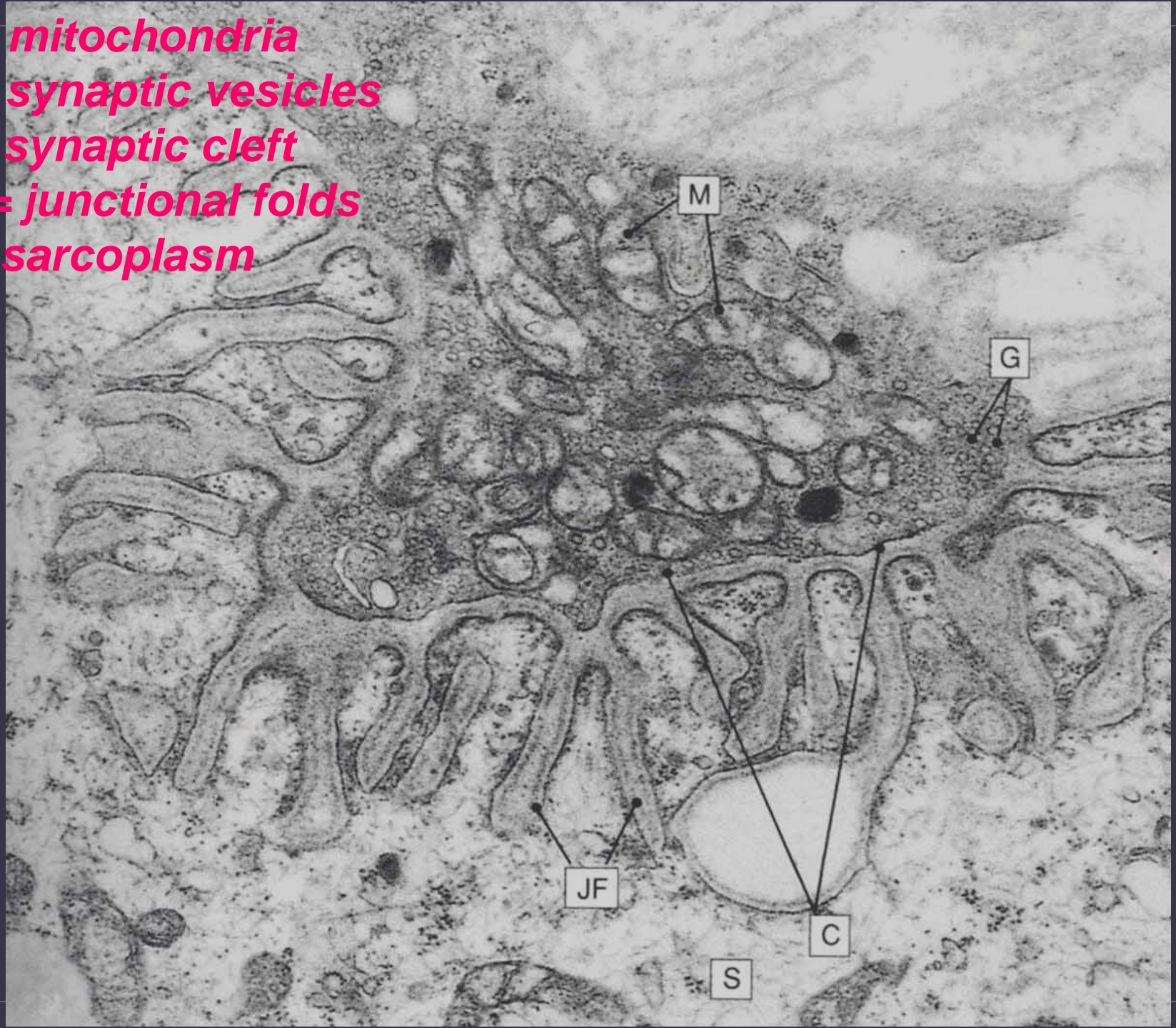
*Ovalle W.K.,  
Nahirney P.C.:  
Netter's Essential  
Histology. 2<sup>nd</sup> Ed.,  
Elsevier 2013*

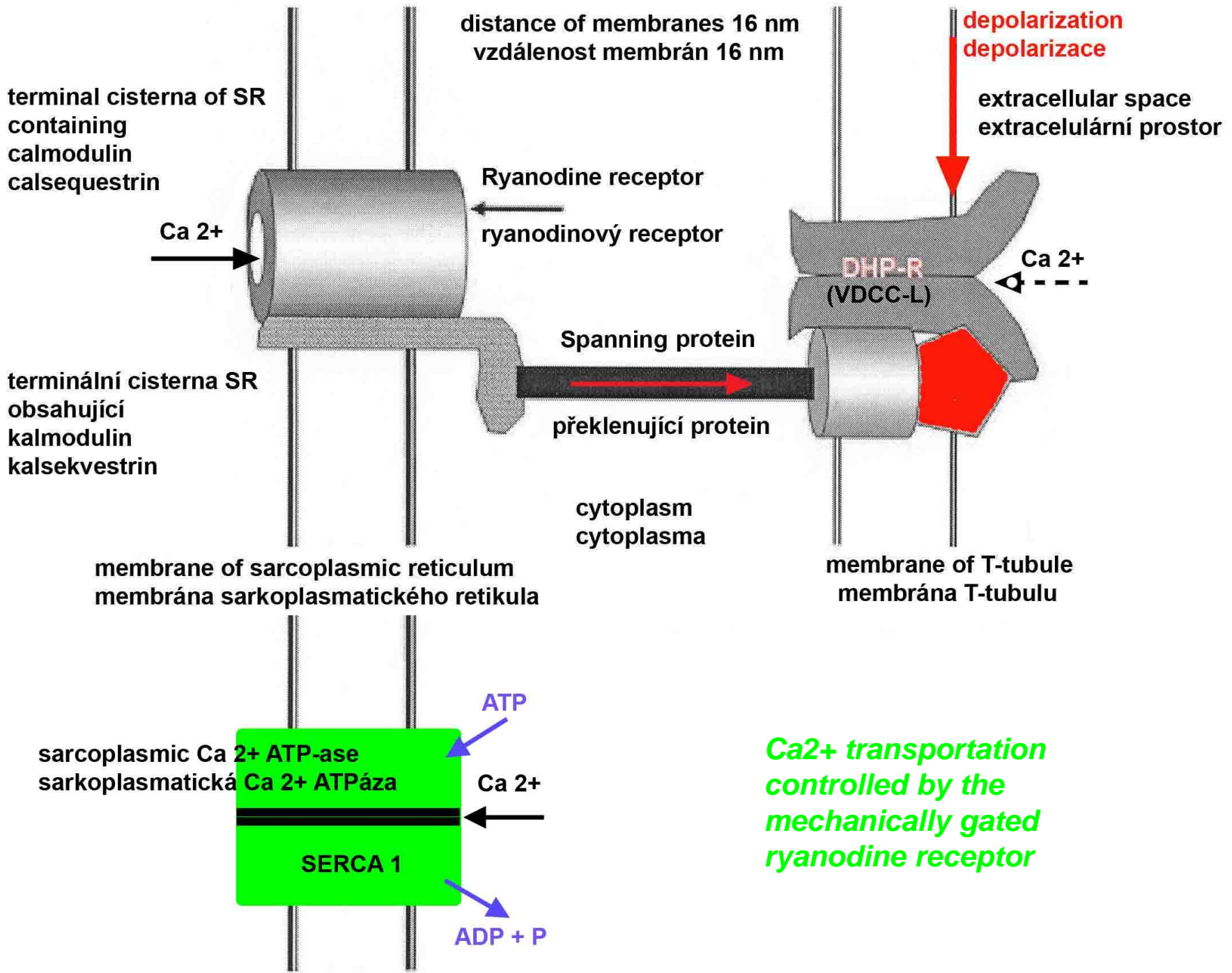
# Regulation of muscle contraction

## Skeletal muscle (motor-end plate)



***M = mitochondria***  
***G = synaptic vesicles***  
***C = synaptic cleft***  
***JF = junctional folds***  
***S = sarcoplasm***





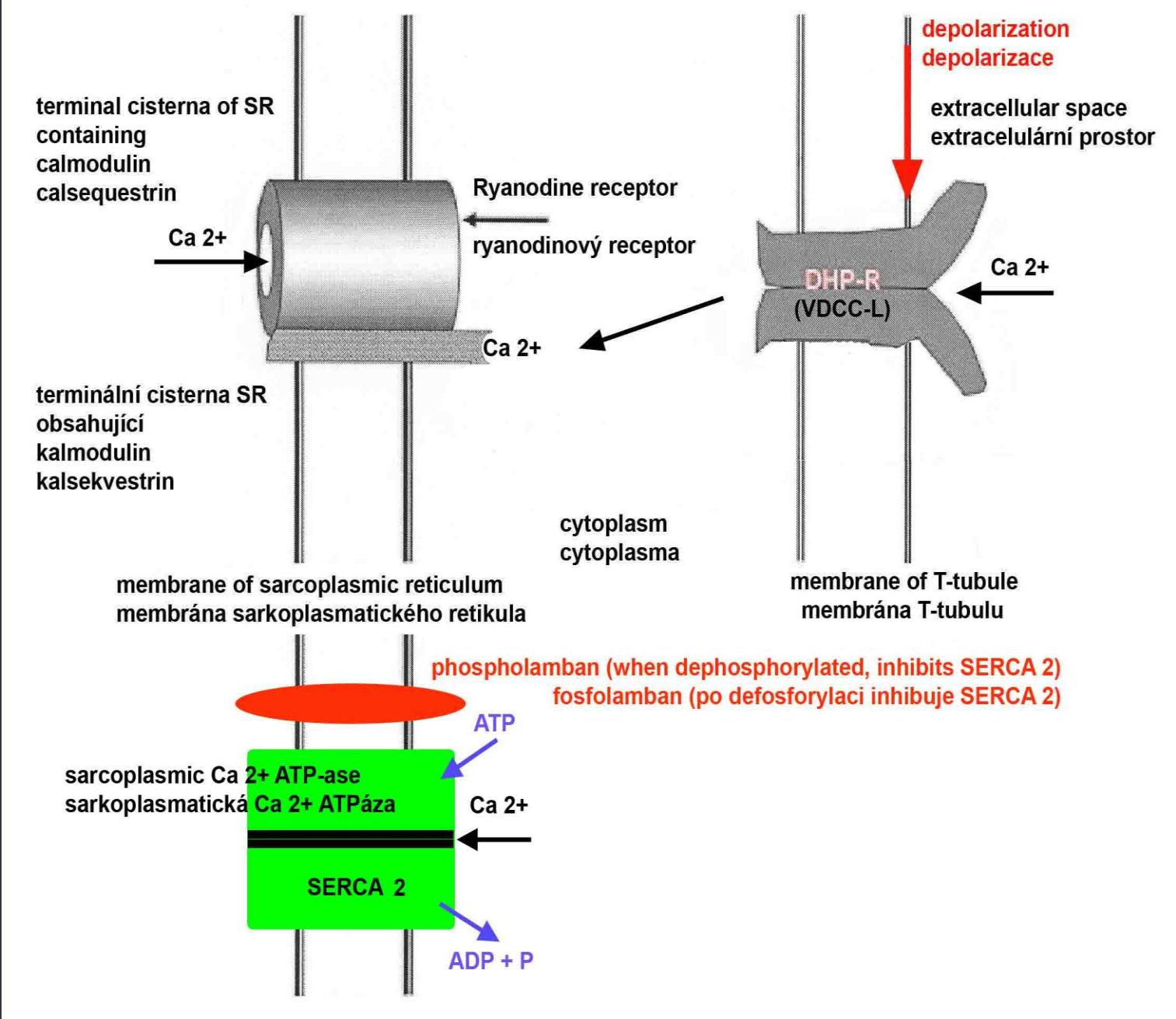
*Ca<sup>2+</sup> transportation controlled by the mechanically gated ryanodine receptor*



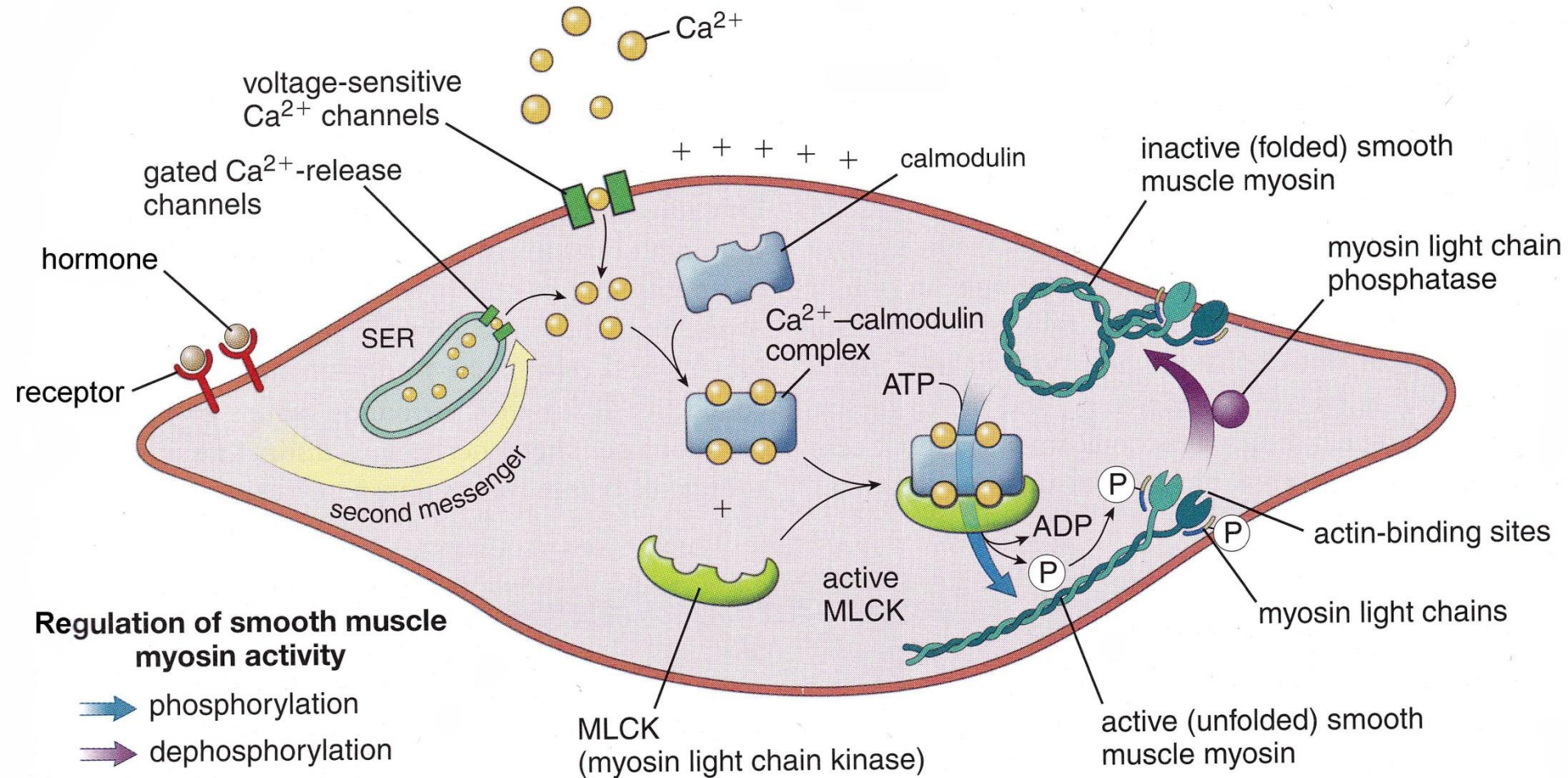
*transport of  $Ca^{2+}$  is controlled by the  $Ca^{2+}$ -gated ryanodine receptor*

*calstabin 2 closes the channel*

*$Ca^{2+}$  "leak" causes an abnormal contraction (arrhythmia)*

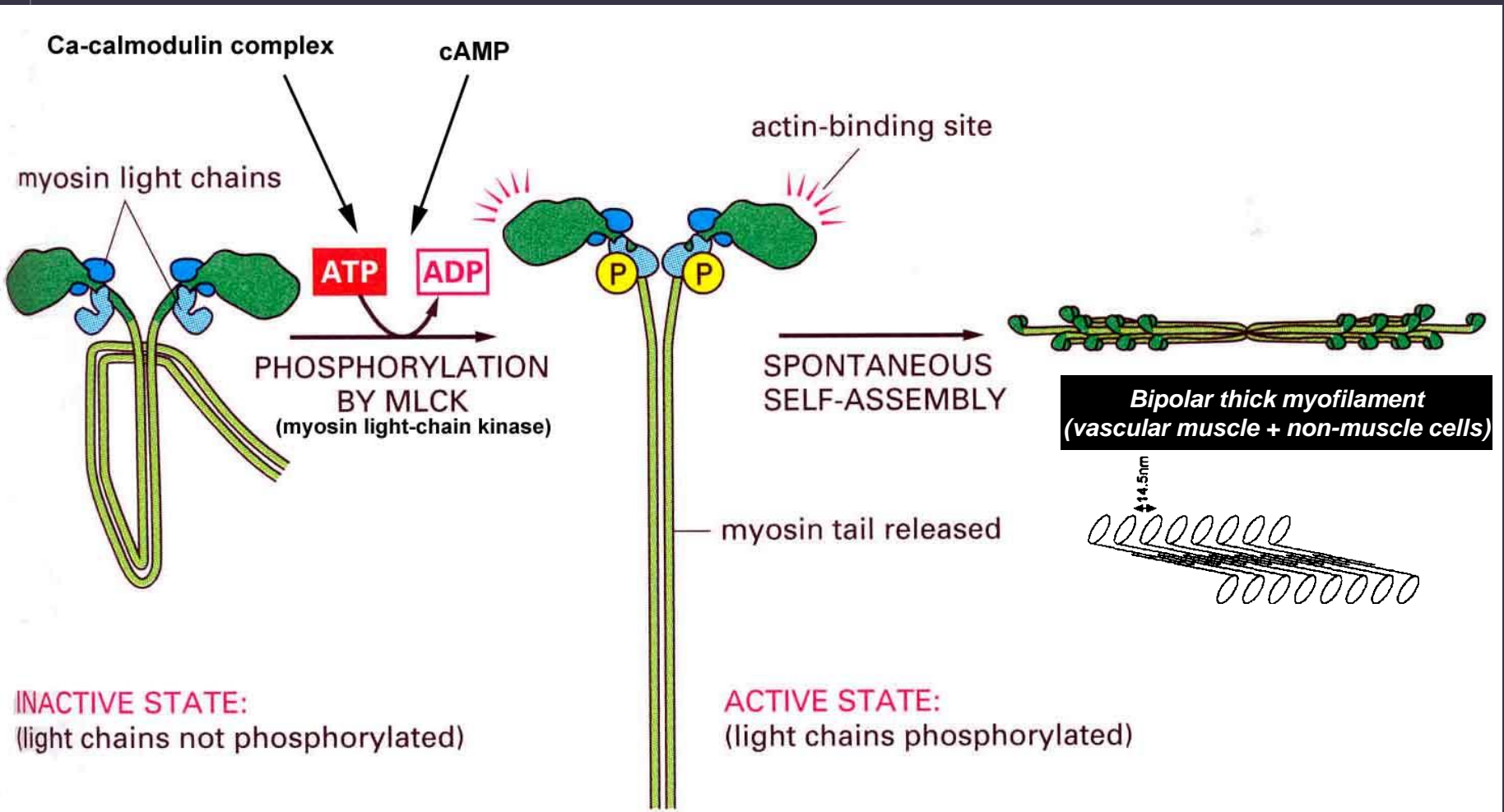


# Smooth muscle

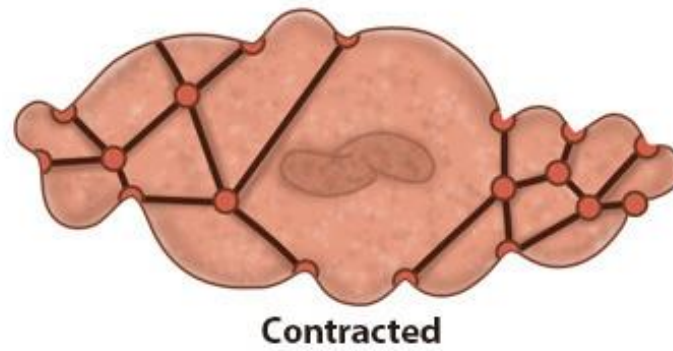
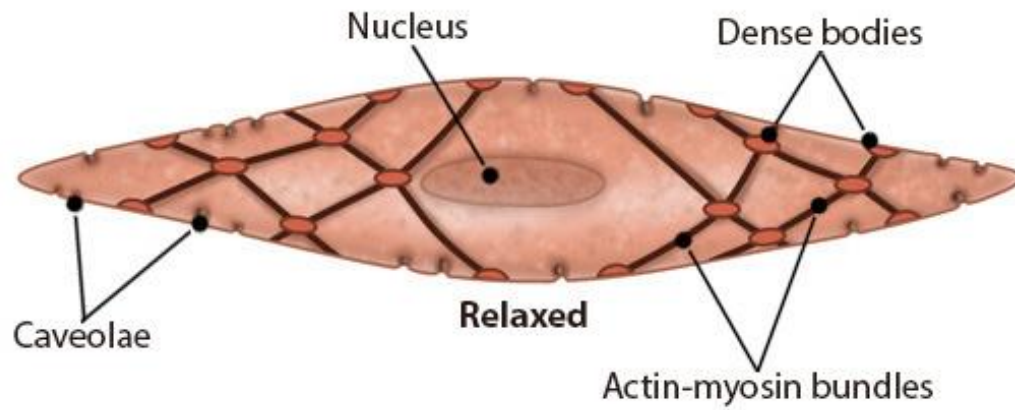




# Contraction of smooth muscle and non-muscle cells



*interaction of actin and myosin then proceeds just as in cross-striated muscle*



# Thank you for your attention

