

Muscle tissue

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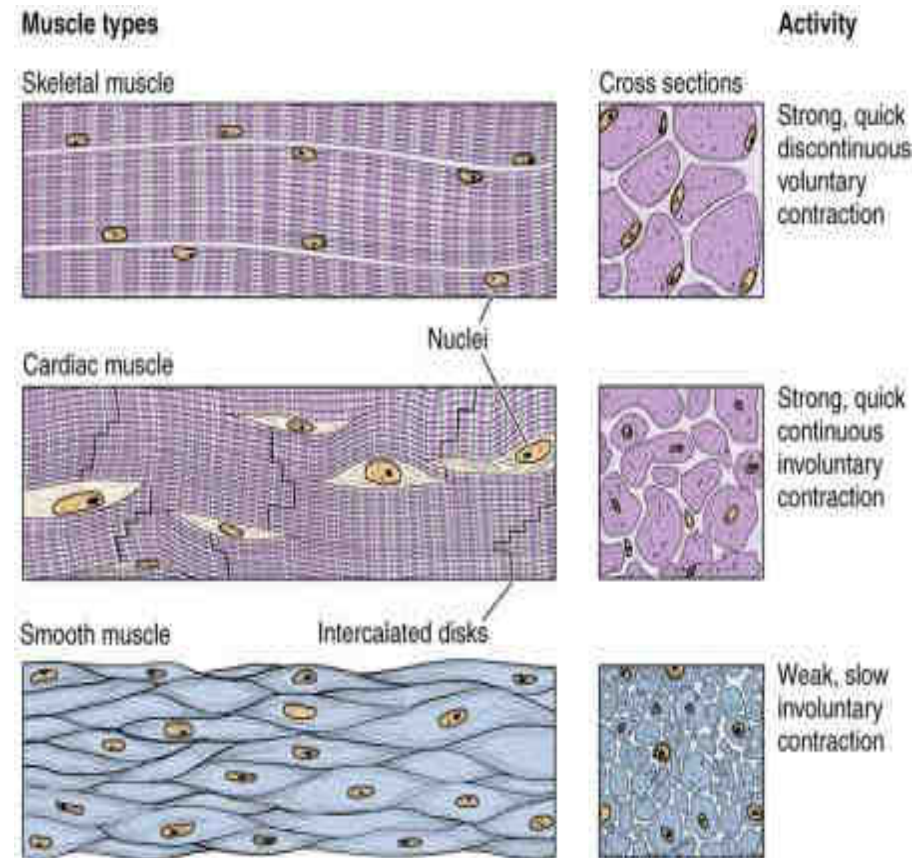
General characteristic of muscle tissue

Hallmarks

- Unique cell architecture
- Excitability and contraction
- Mesodermal origin

Muscle tissue

- Skeletal
- Cardiac
- Smooth



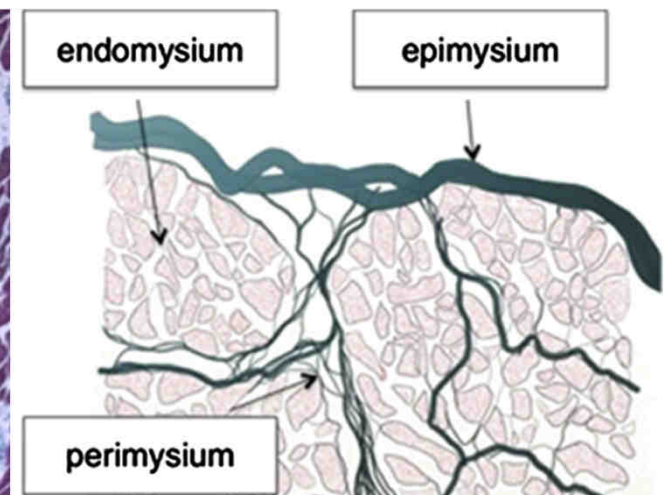
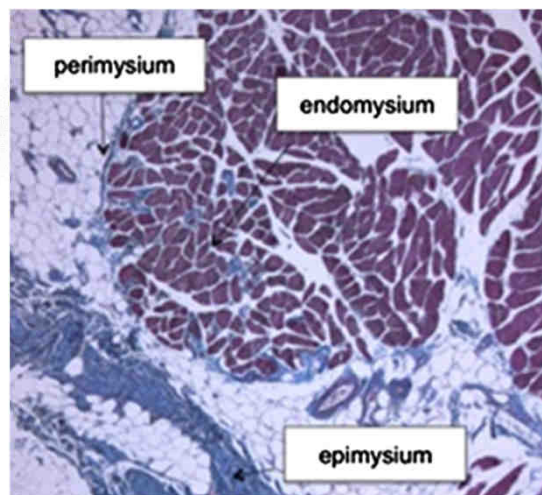
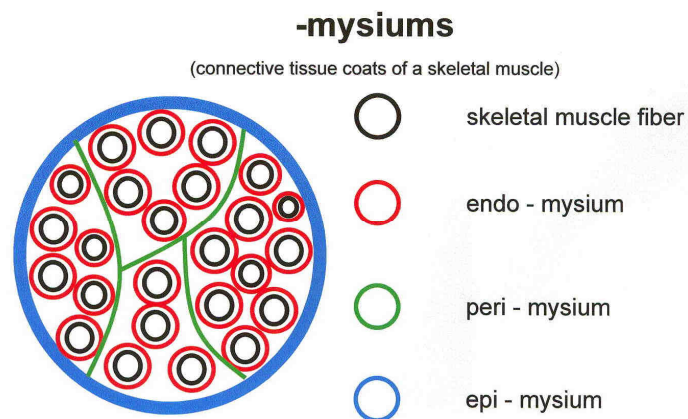
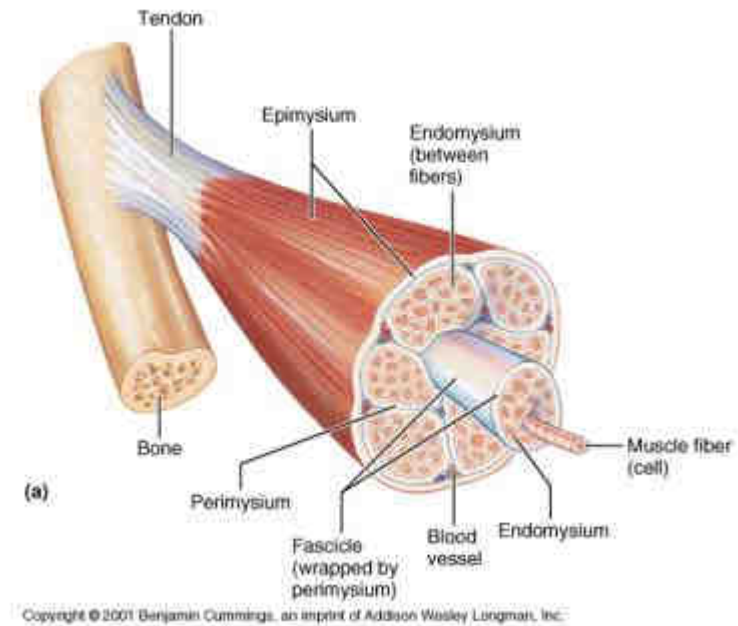
Histology of skeletal muscle tissue

- Composition: muscle cells + connective tissue, blood vessels
- Unique cell architecture – long multinuclear cells – muscle fibers (rhabdomyocytes)
- Long axis of cells is oriented parallel with direction of contraction
- Specific terminology:
 - cell membrane = sarcolemma
 - cytoplasm = sarcoplasm
 - sER = sarcoplasmic reticulum

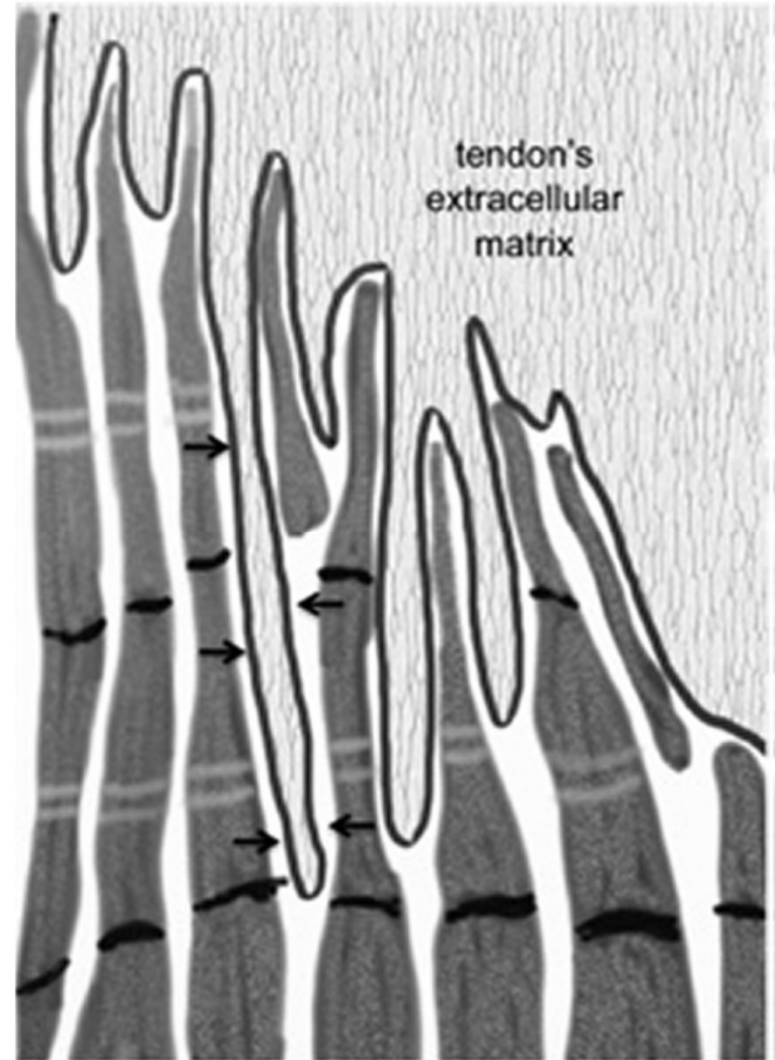
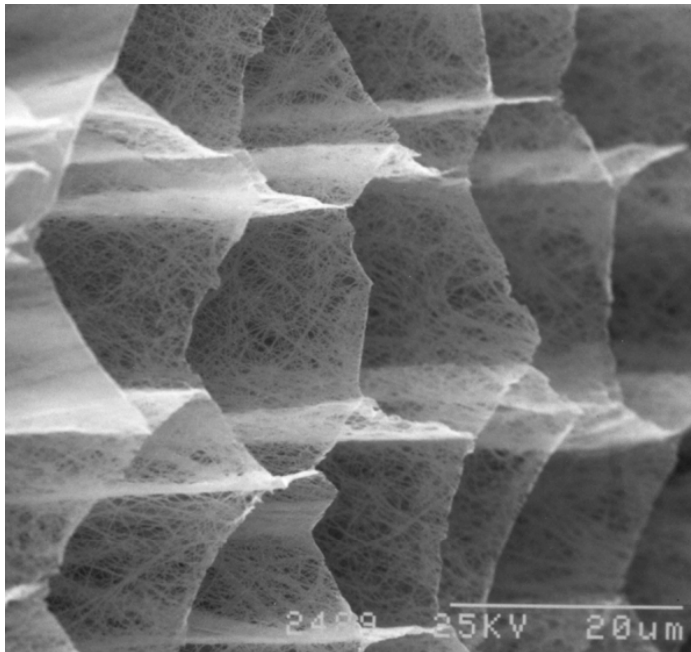
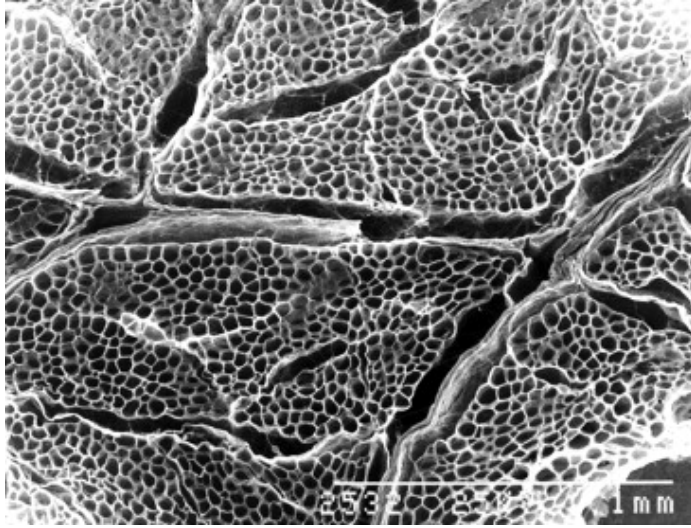
 - Muscle fiber – microscopic unit of skeletal muscle
 - Myofibril – LM unit – myofilaments – unit of muscle fibers
 - Myofilaments – filaments of actin and myosin (EM)

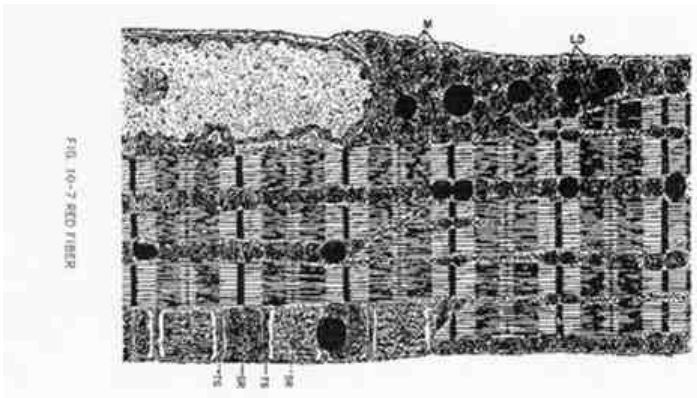
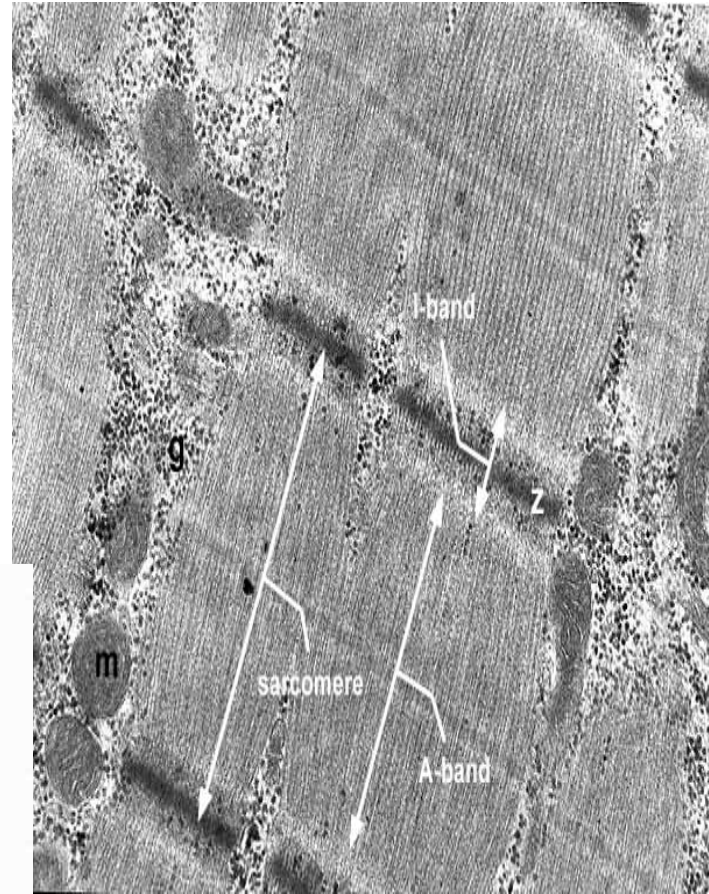
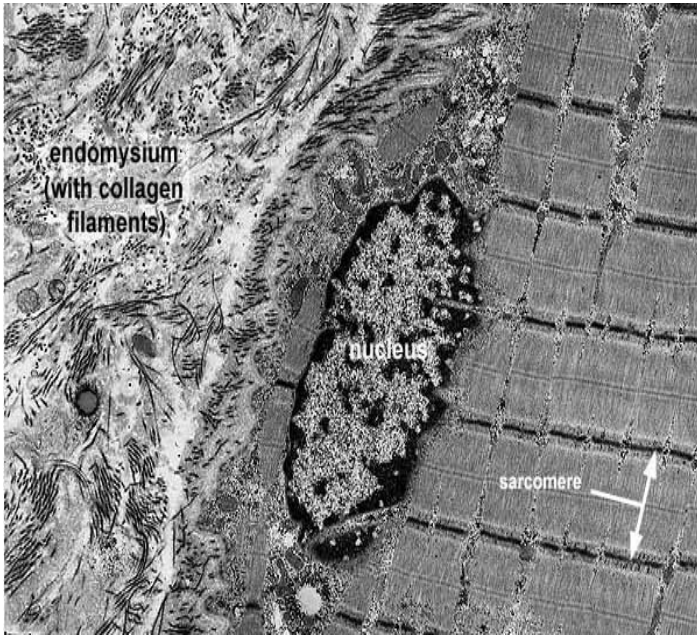
Connective tissue of skeletal muscle

- Containment
- Limit of expansion of the muscle
- Transmission of muscular forces
- **Endomysium** – around each muscle cell (fiber)
- **Perimysium** – around and among the primary bundles of muscle cells
- **Epimysium** – dense irregular collagen c.t., continuous with tendons and fascia
- Fascia – dense regular collagen c.t.

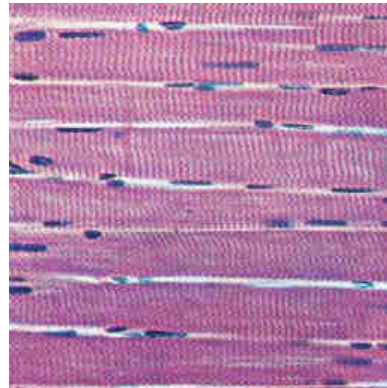
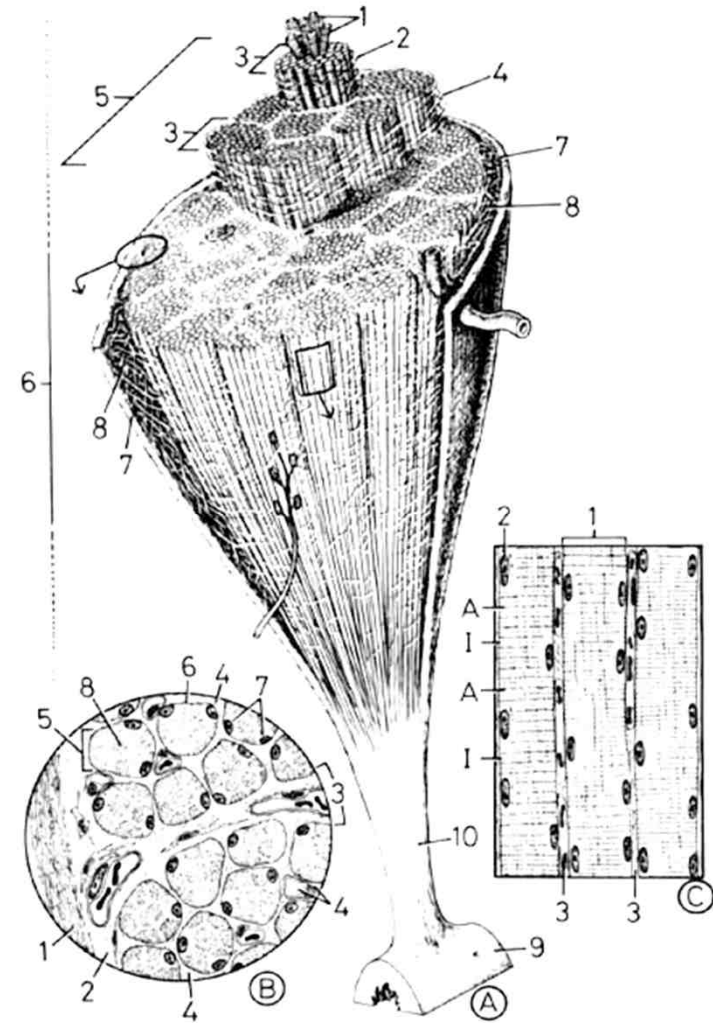
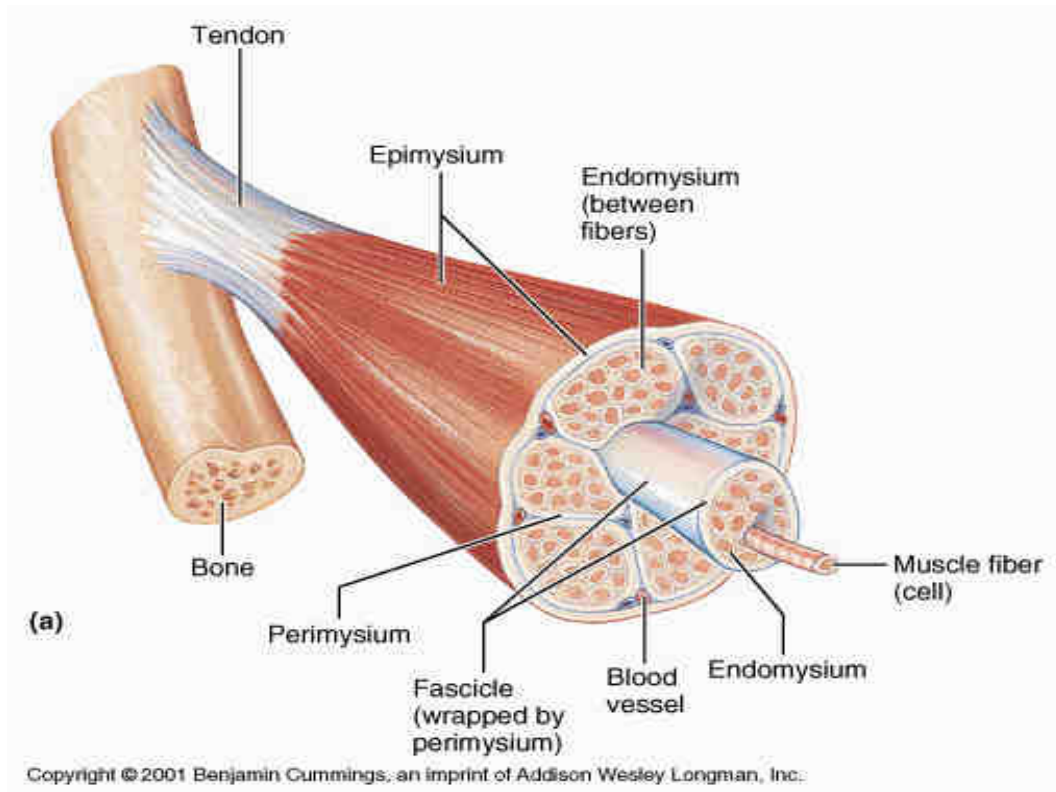


Connective tissue of skeletal muscle



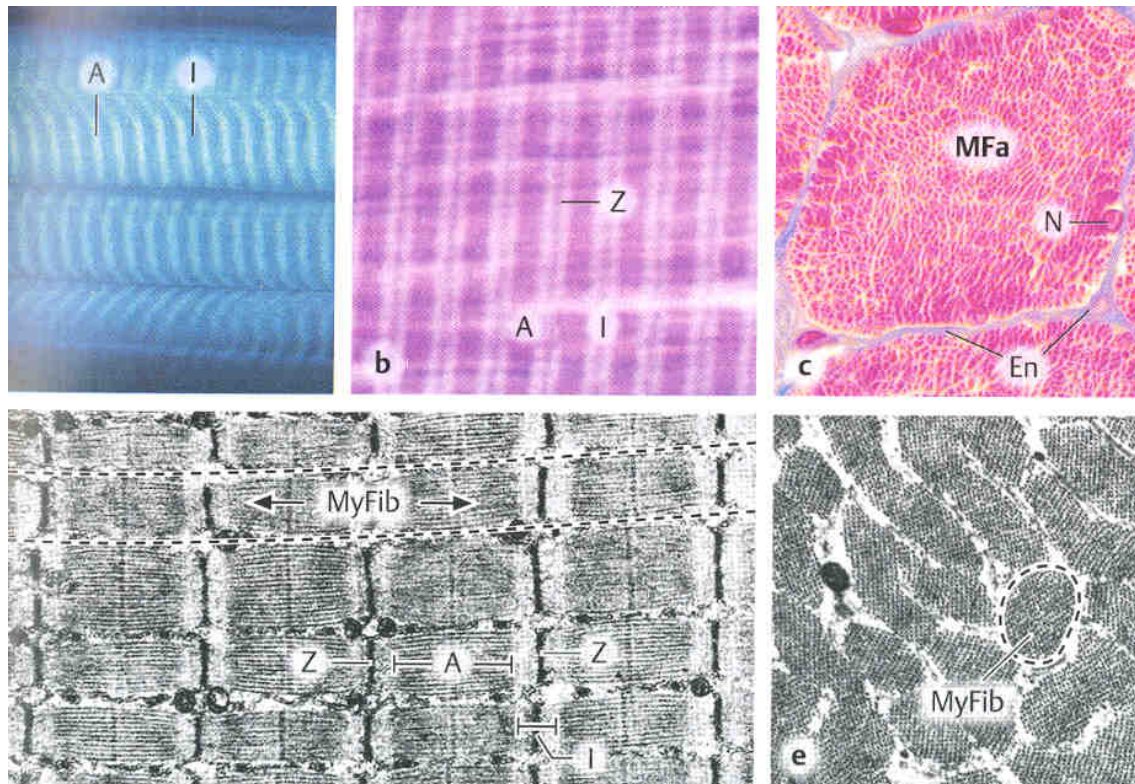


Structure of skeletal muscle



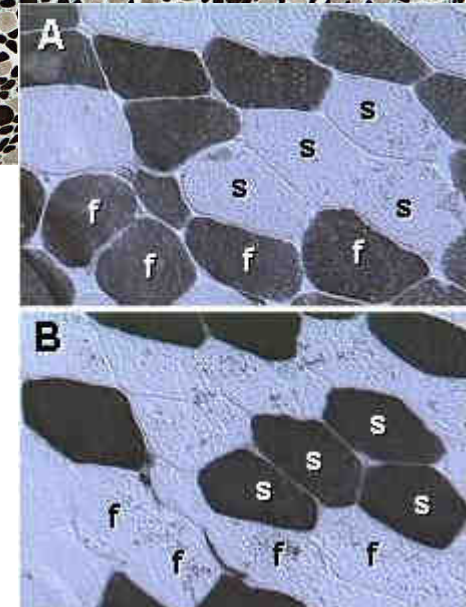
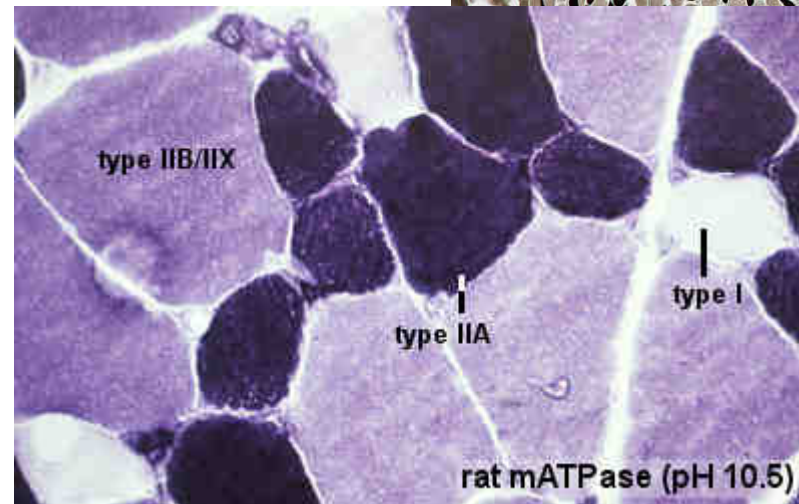
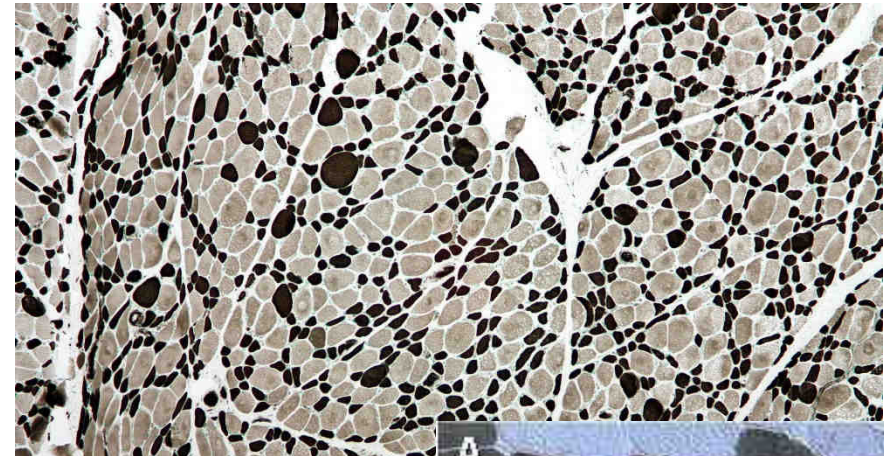
Structure of skeletal muscle

- morphological and functional unit: **muscle fiber (rhabdomyocyte)** – elongated, cylindrical-shaped, multinucleated cell (syncytium)
- nuclei are located at the periphery (under sarcolemma)
- **myofibrils** show cross striation
- diameter of muscle fiber: 25-100 μm
- length: millimeters - centimeters (up to 15)



Classification of skeletal muscle fibers

- **Myosin heavy chain (MHC) type I and II**
 - distinct metabolic, contractile, and motor-unit properties
 - ATPase activity
- **Twitch type**
 - Fast vs. slow
- **Fiber color**
 - Red vs. white
- **Myoglobin content**
- **Glycogen content**
- **Energy metabolism**
- **Endurance**



Classification of skeletal muscle fibers

Fast and slow twitch fibers

1. Type I fibers

"red" or "slow twitch", small diameter muscle fibers with high resistance to fatigue, higher concentration of ATPase, relatively low glycogen content and lower concentration of SDH (succinate dehydrogenase) as well as - besides the above mentioned high myoglobin content - a large number of mitochondria. They are mainly found in the "red" musculature and possess a good energy supply due to being well capillarized. They are employed in long-lasting movements with limited development of force.

2. Type II fibers

"white" or "fast twitch", large diameter muscle fibers

1. Type IIA fibers:

"fast" or "fast twitch" fibers with a high fatigue tendency, high content of glycolytic and oxidative enzymes that are needed with longer lasting contractions with relatively higher development of force.

2. Type IIB fibers:

fast, easily fatigued fibers with high glycogen and low mitochondria content. Their energy supply occurs very rapidly, mainly via glycolysis, which is important for short or intermittent strain with a high amount of force development.

3. Type IIC fibers:

so-called intermediary fibers, which can be ordered between types I and II and, depending on the training, develop more type I or more type II characteristics.

Properties	Type I fibers	Type IIA fibers	Type IIX fibers
Motor Unit Type	Slow Oxidative (SO)	Fast Oxidative/Glycolytic (FOG)	Fast Glycolytic (FG)
Twitch Speed	Slow	Fast	Fast
Twitch Force	Small	Medium	Large
Resistance to fatigue	High	High	Low
Glycogen Content	Low	High	High
Capillary Supply	Rich	Rich	Poor
Myoglobin	High	High	Low
Red Color	Dark	Dark	Pale
Mitochondrial density	High	High	Low
Capillary density	High	Intermediate	Low
Oxidative Enzyme Capacity	High	Intermediate-high	Low
Z-Line Width	Intermediate	Wide	Narrow
Alkaline ATPase Activity	Low	High	High
Acidic ATPase Activity	High	Medium-high	Low

Ultrastructure of rhabdomyocyte

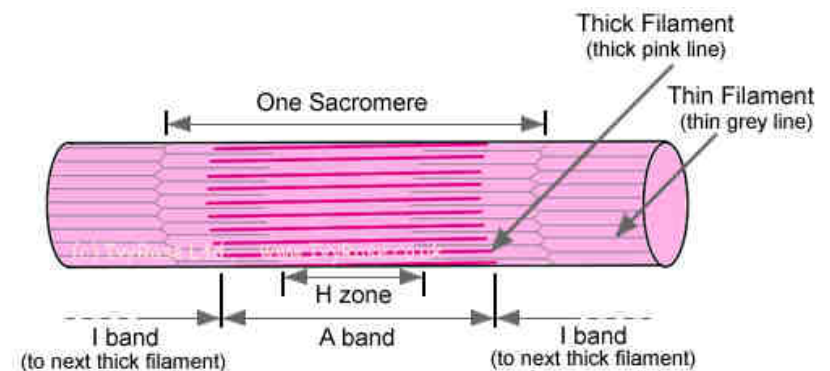
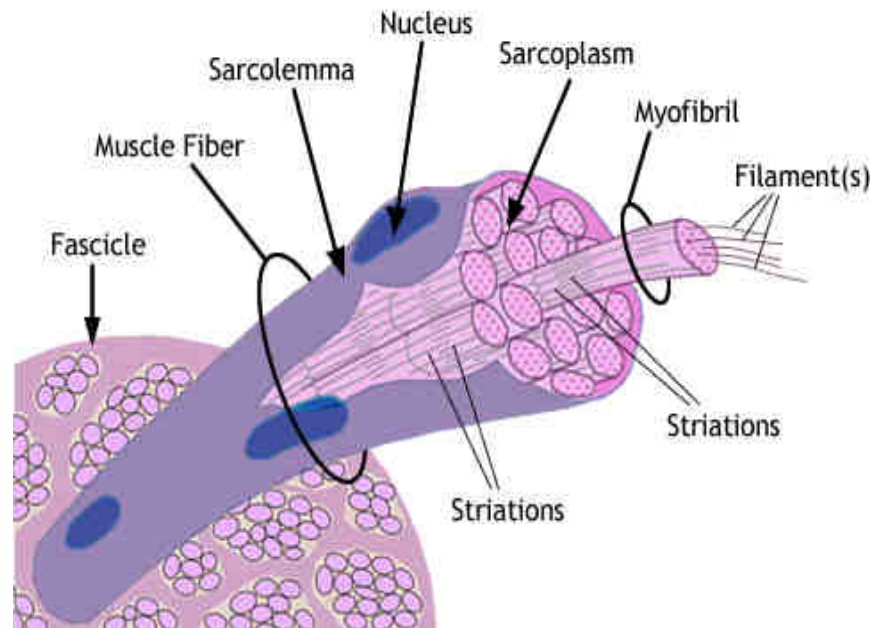
Muscle fiber = myofiber = syncitium = rhabdomyocyte

Muscle fiber – morphologic and functional unit of skeletal muscle [Ø 25 – 100 µm]

Myofibrils – compartment of fiber sarcoplasm [Ø 0.5 – 1.5 µm]

Sarcomere – the smallest contractile unit [2.5 µm], serial arrangement in myofibrils

Myofilaments – actin and myosin, are organized into sarcomeres [Ø 8 and 15 nm]



Ultrastructure of rhabdomyocyte

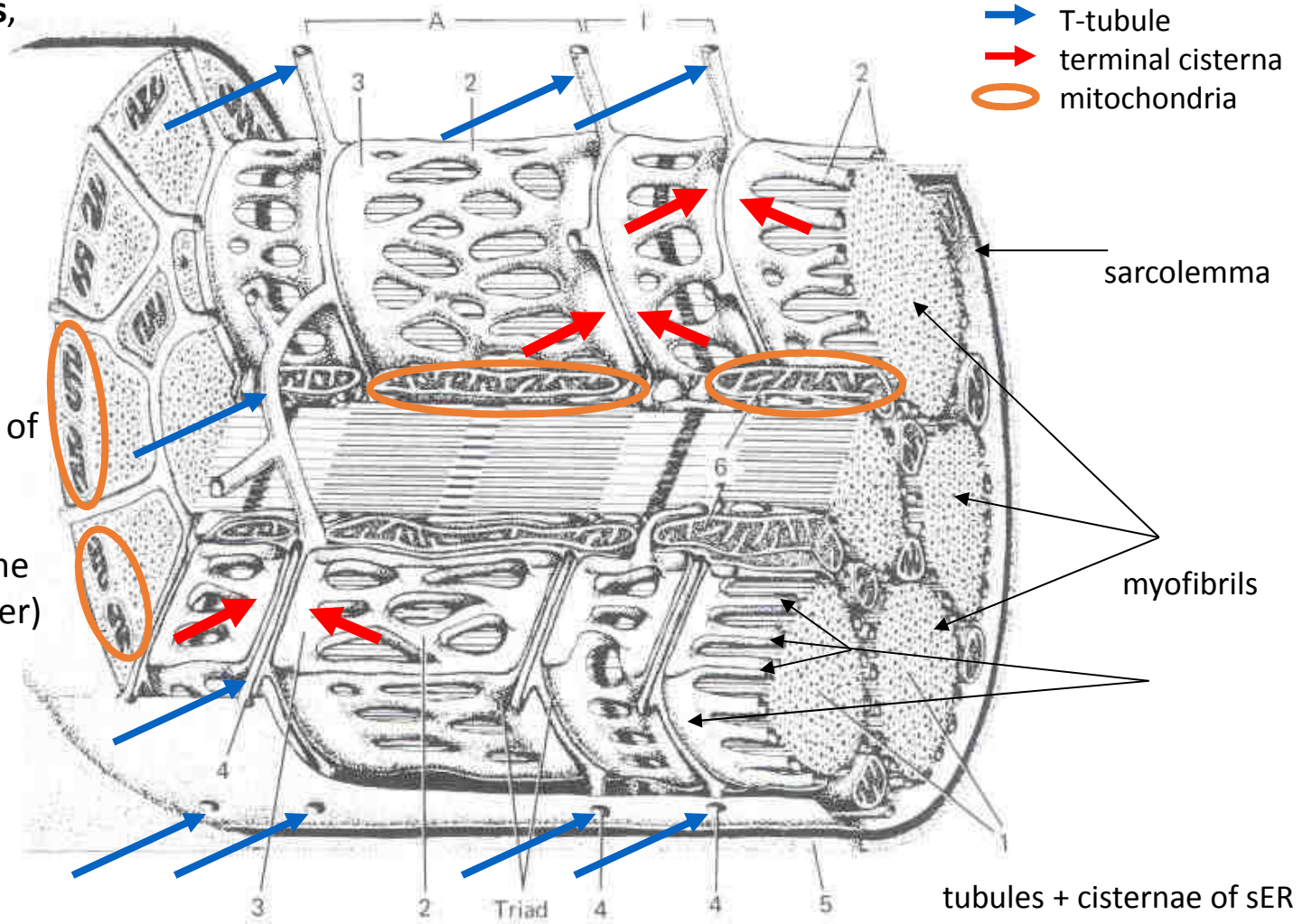
Sarcolemme + t-tubules,

Sarcoplasm:

Nuclei,
Mitochondria,
Golgi apparatus,
Glycogen (β granules)

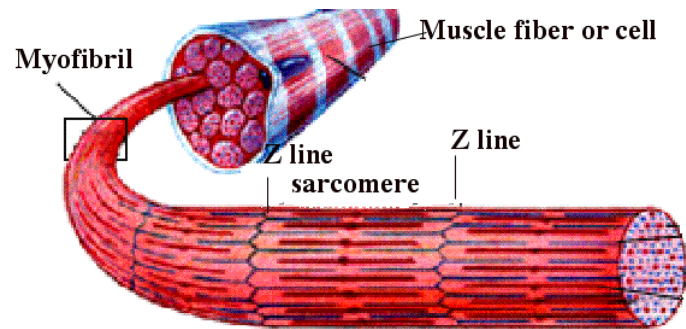
Sarcoplasmic reticulum
(smooth ER) – reservoir of Ca^{2+}

Myofibrils (parallel to the length of the muscle fiber)

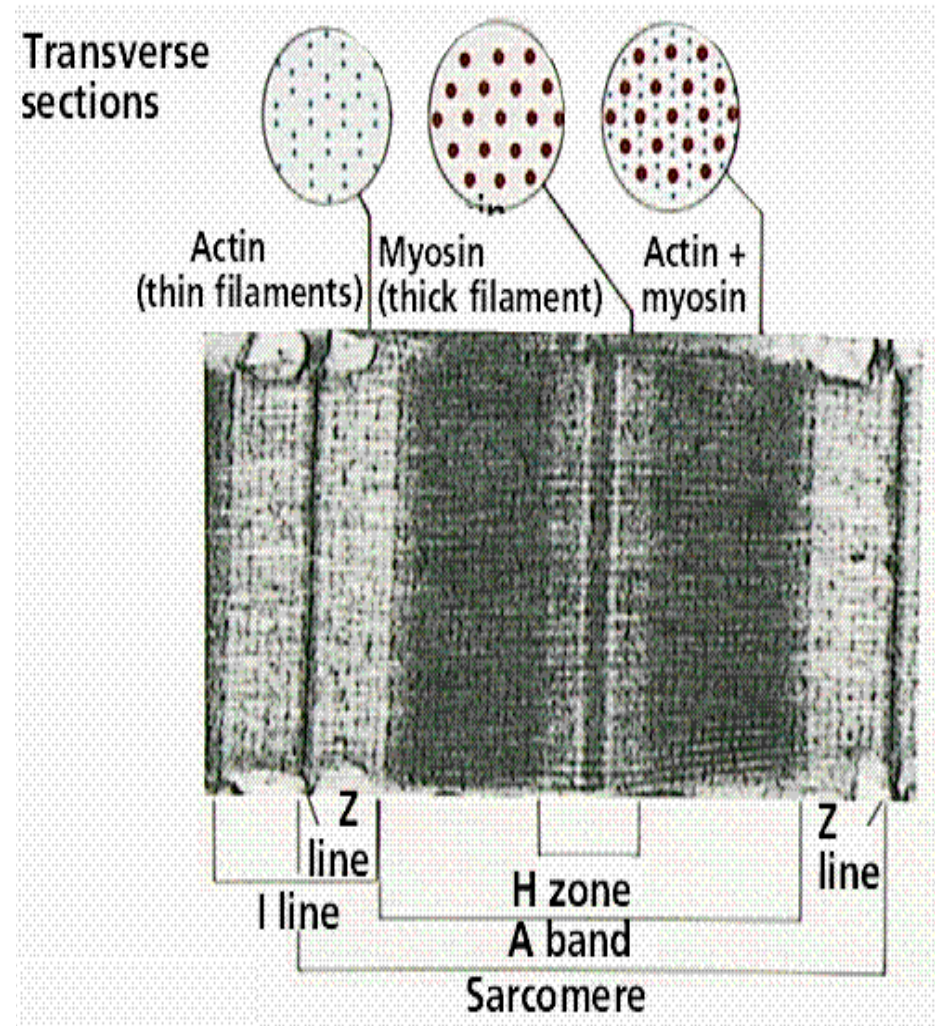
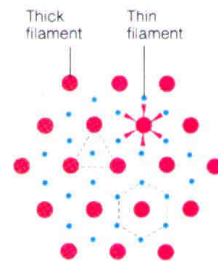


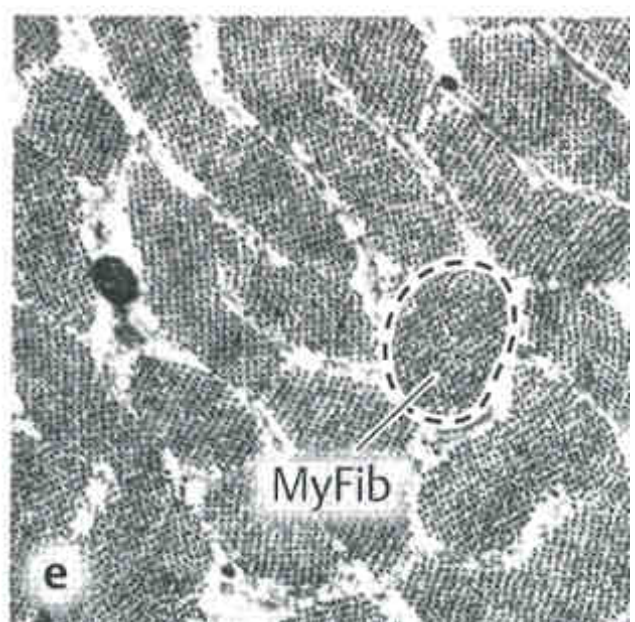
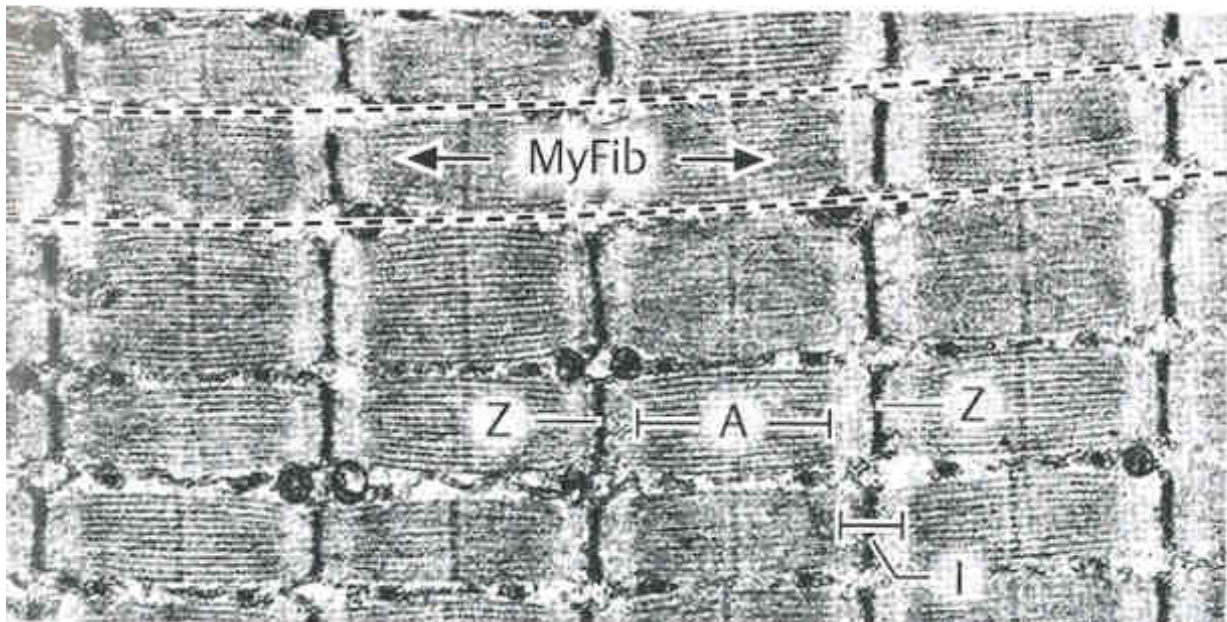
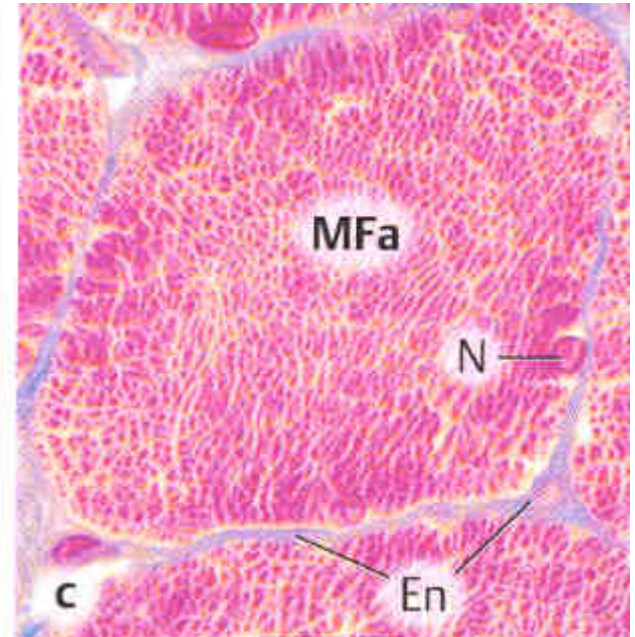
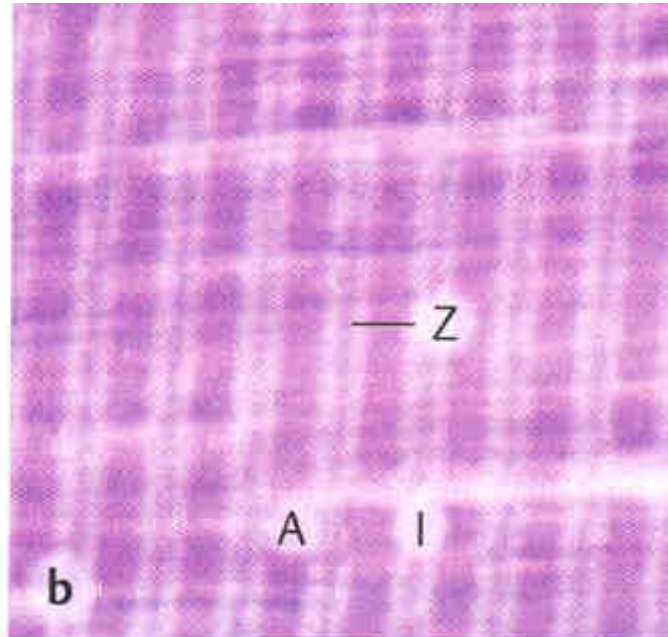
Myofibrils

- elongated structures [\varnothing 0.5 – 1.5 μ] in sarcoplasm of muscle fiber oriented in parallel to the length of the fiber,

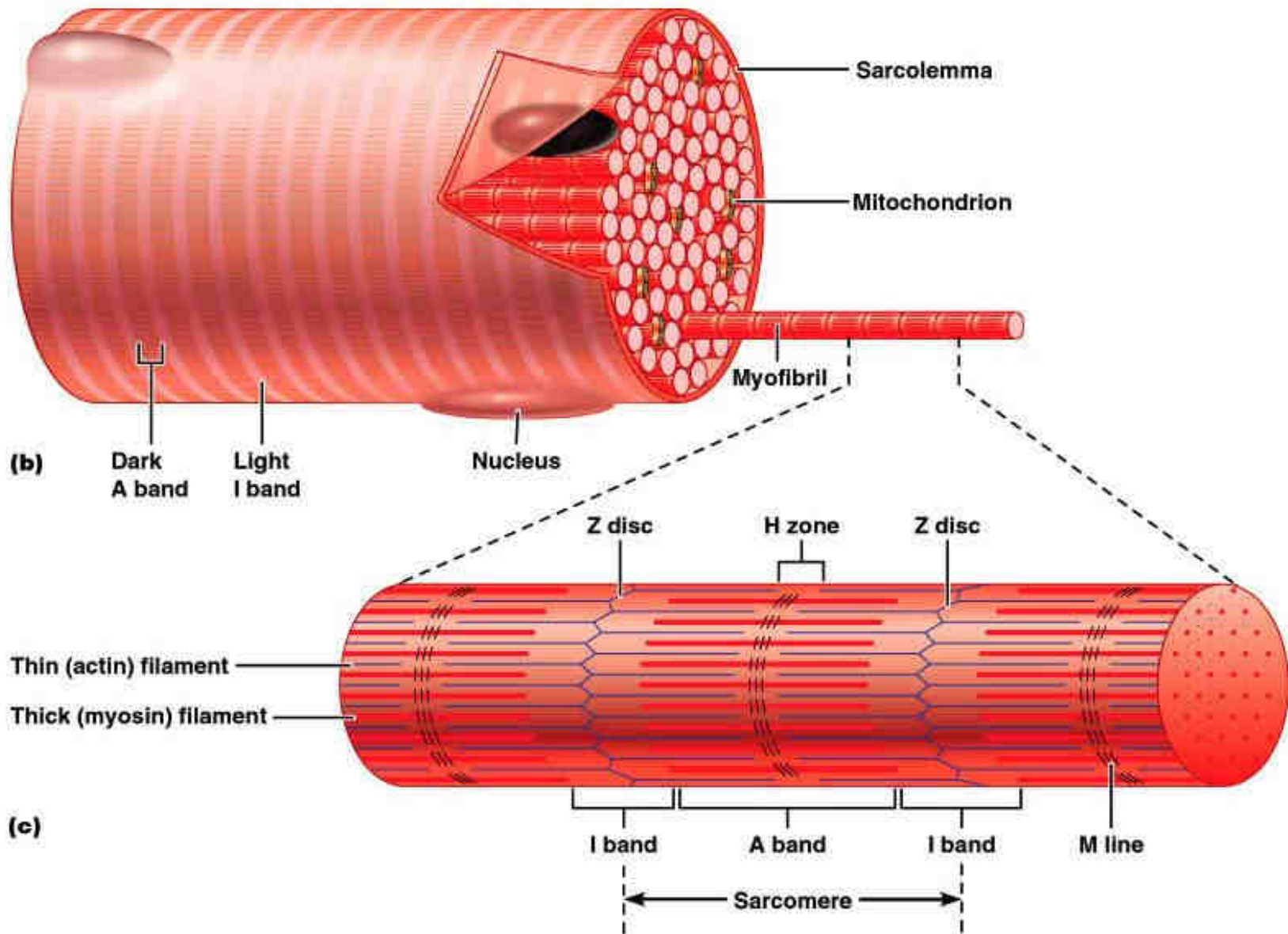


- Actin + myosin myofilaments
- Sarcomere
- Z-line
- M-line and H-zone
- I-band, A-band

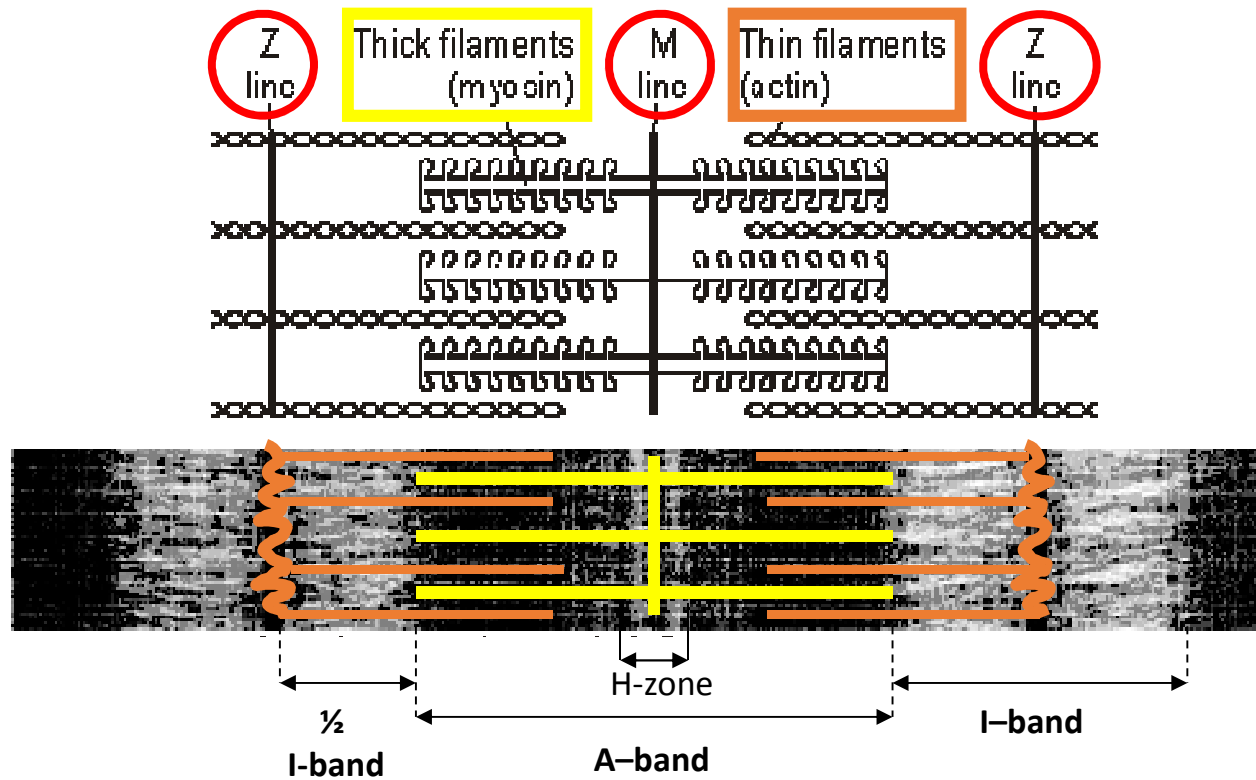




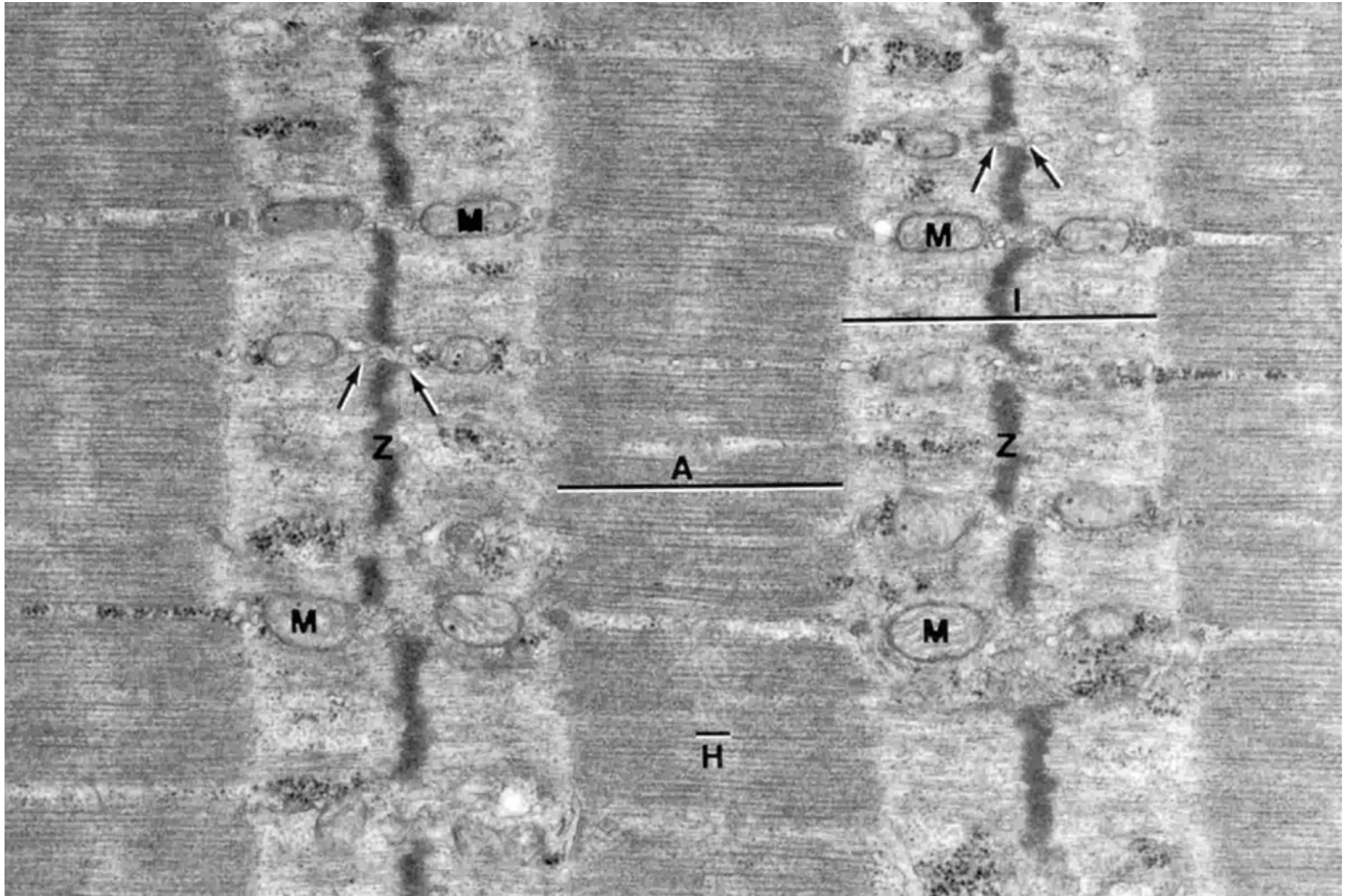
Sarcomere



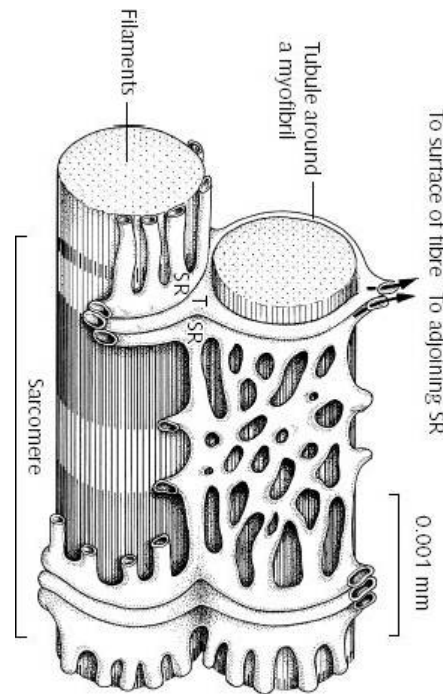
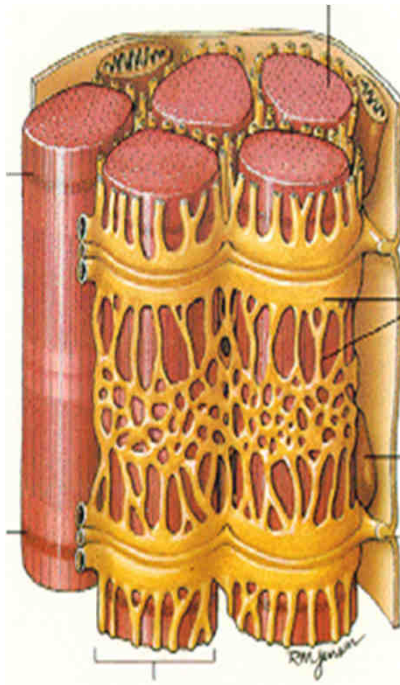
Sarcomere



Sarcomere



Sarcoplasmic reticulum, t-tubule

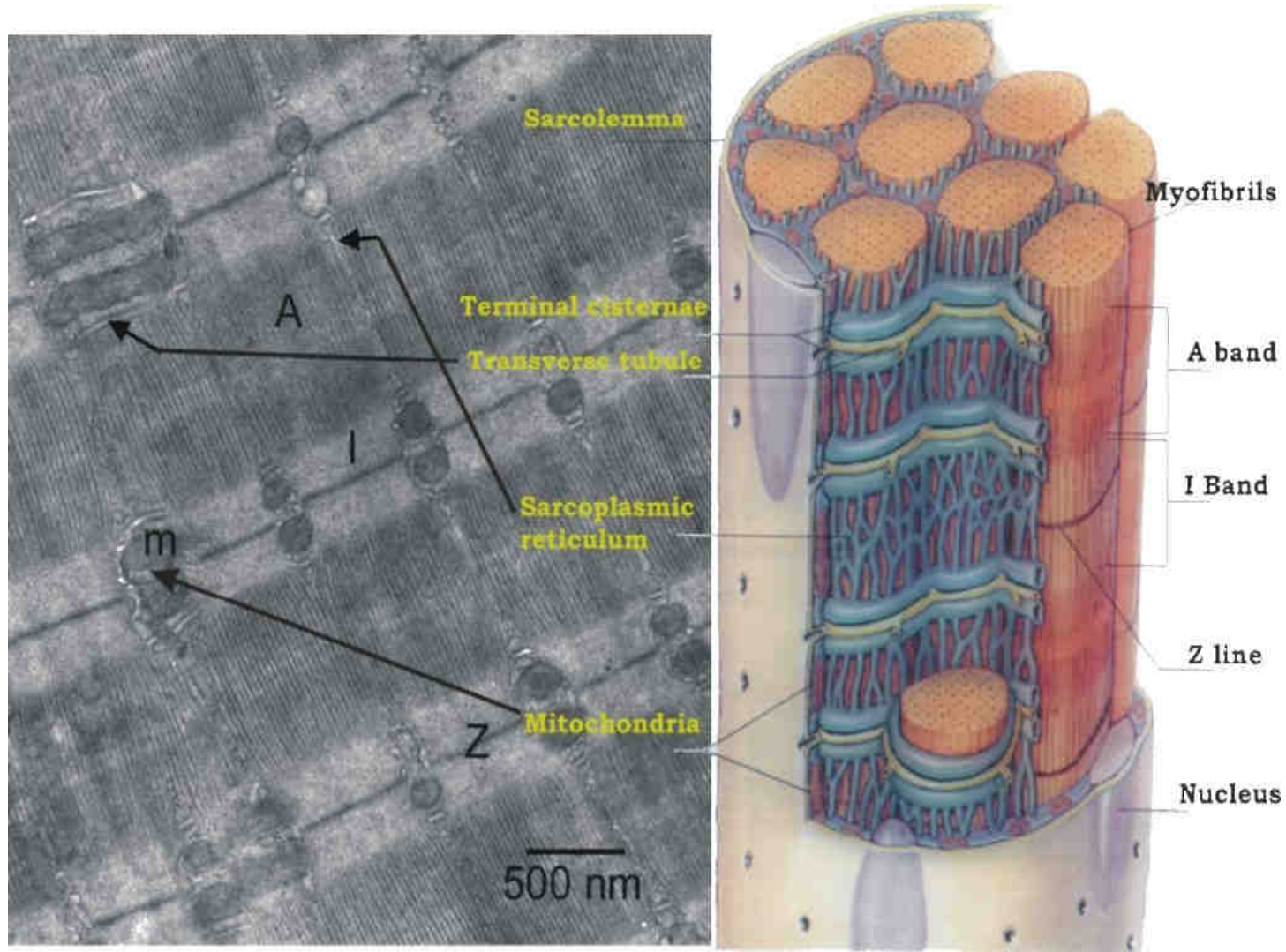


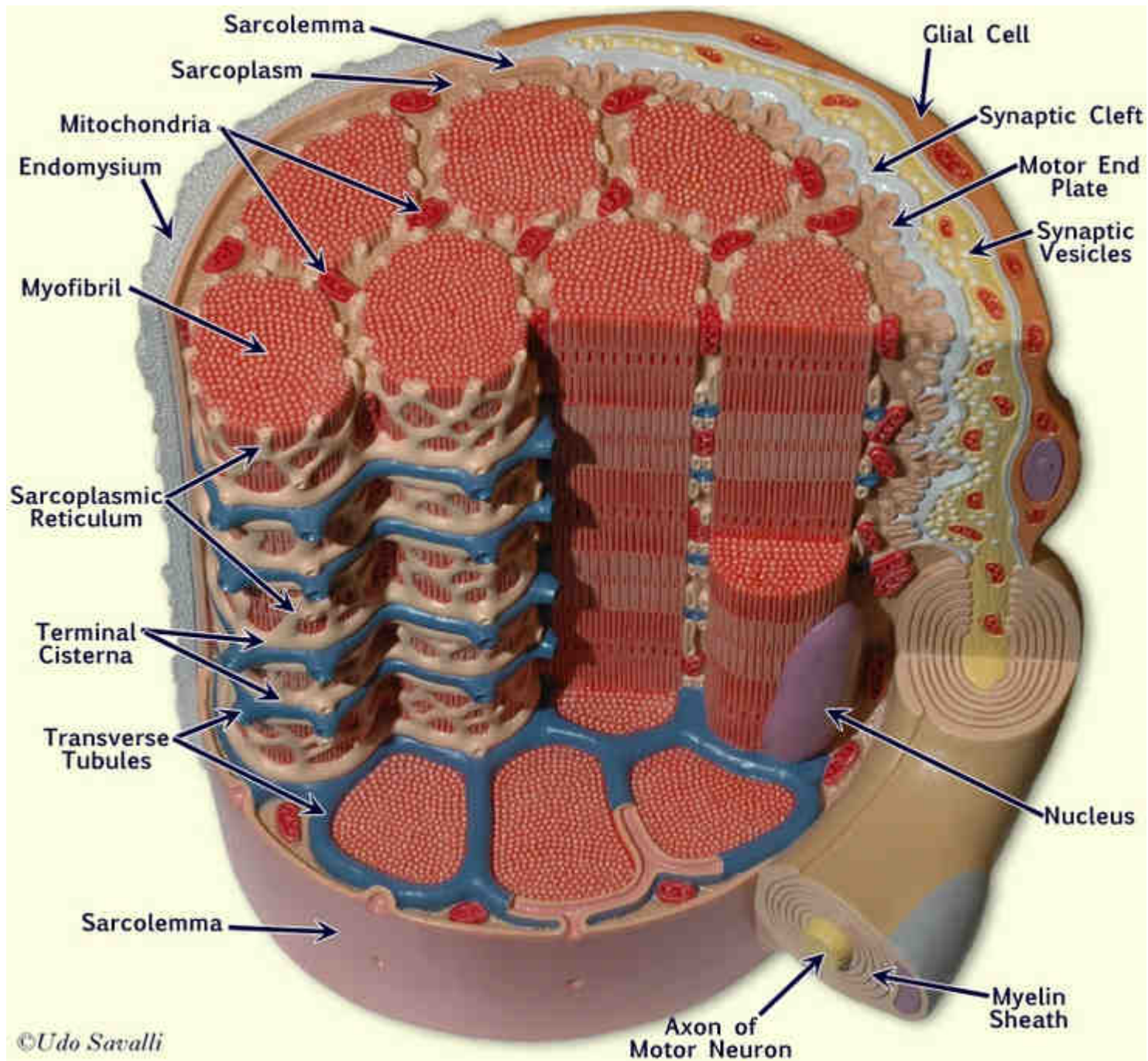
Terminal cisterna
T-tubule
Terminal cisterna } **TRIAD**

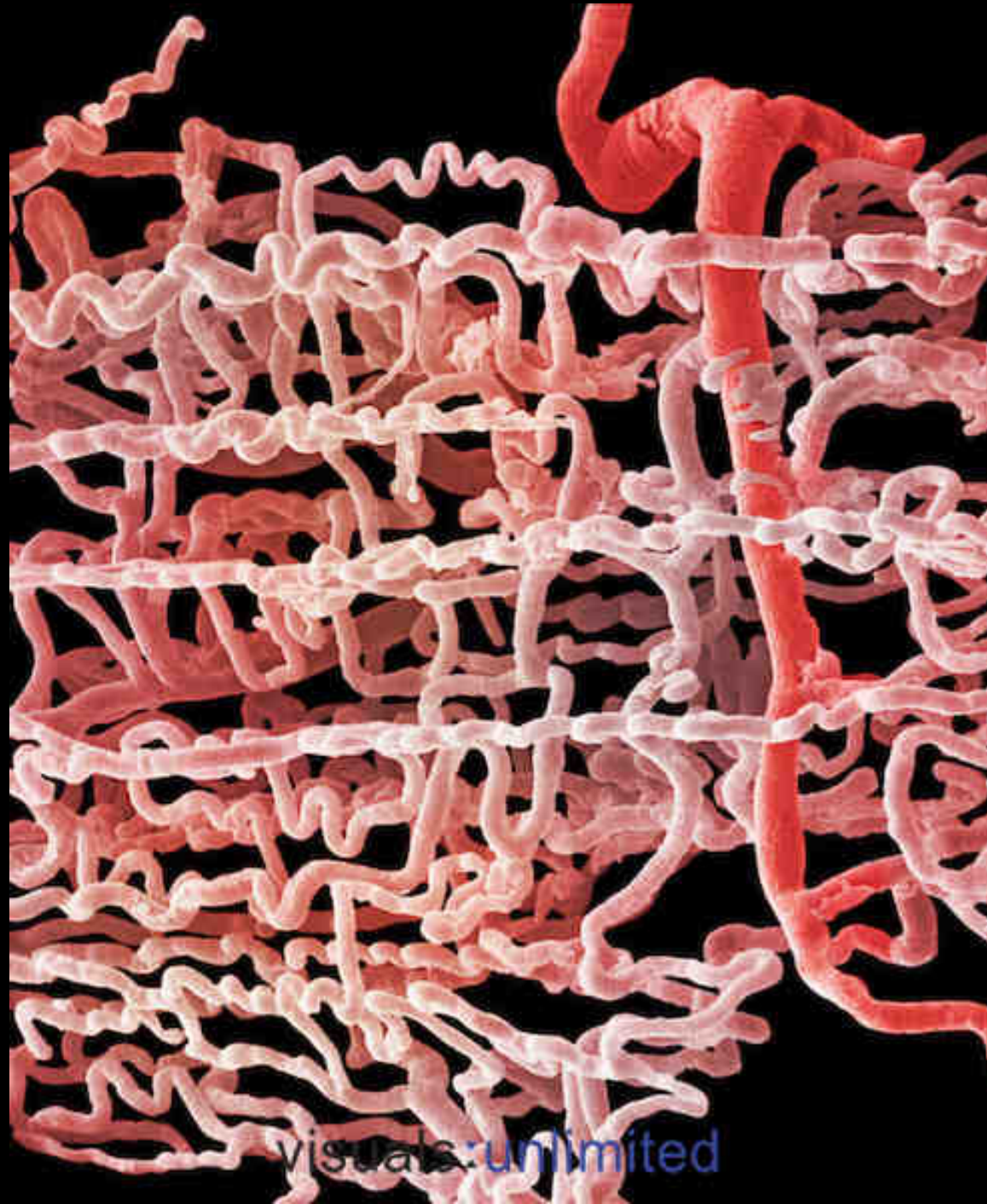
communicating intracellular cavities around myofibrils, separated from cytosol
terminal cisternae (“junction”) and **longitudinal tubules** (“L” system).
reservoir of Ca ions

T-tubules (“T” system) are invaginations of sarcoplasm and bring action potential to terminal cisternae change permeability of membrane for Ca ions

Sarcoplasmic reticulum, t-tubule



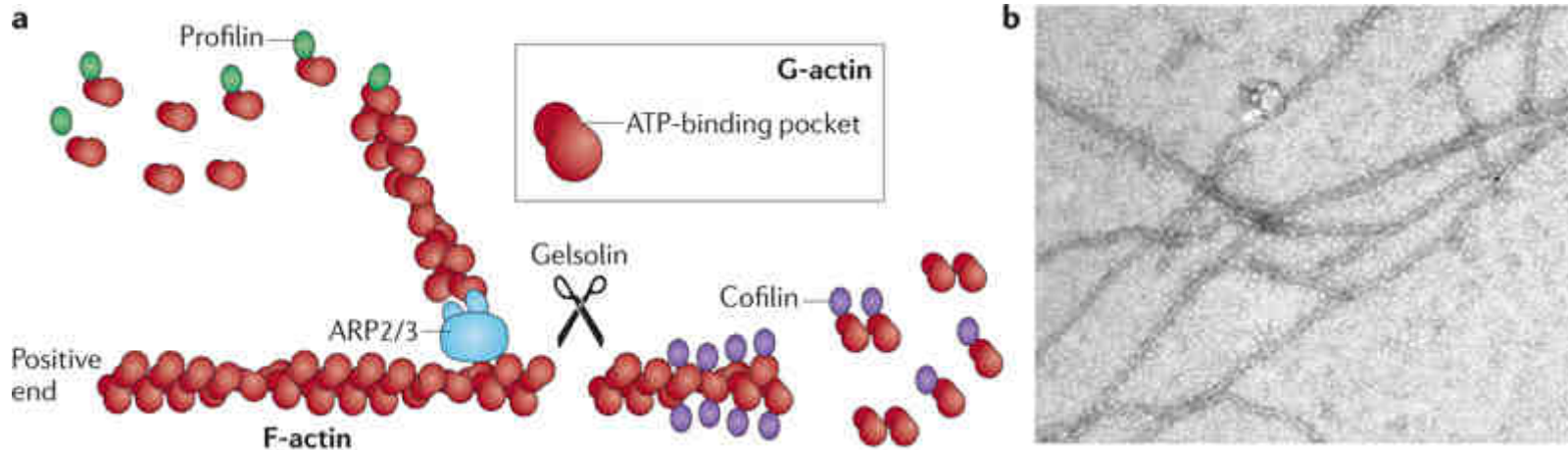




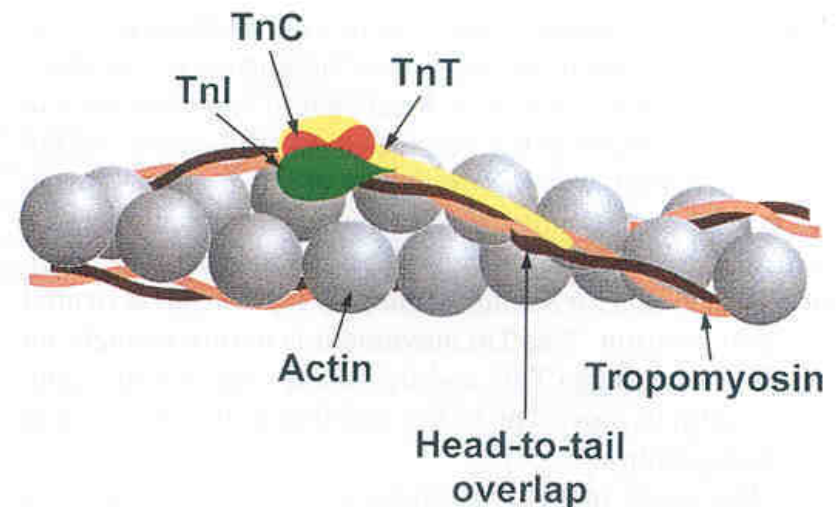
visuals:unlimited

Thin myofilaments

- **Fibrillar actin (F-actin)**

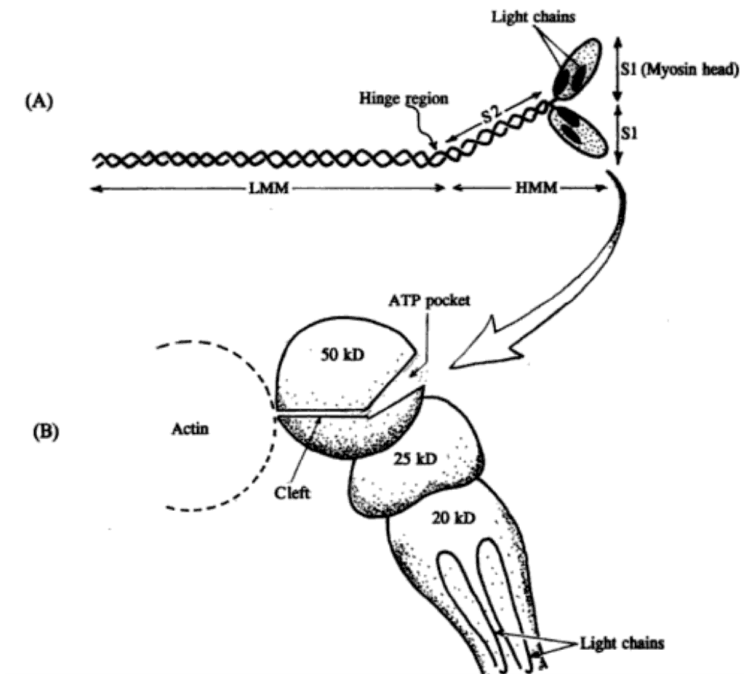
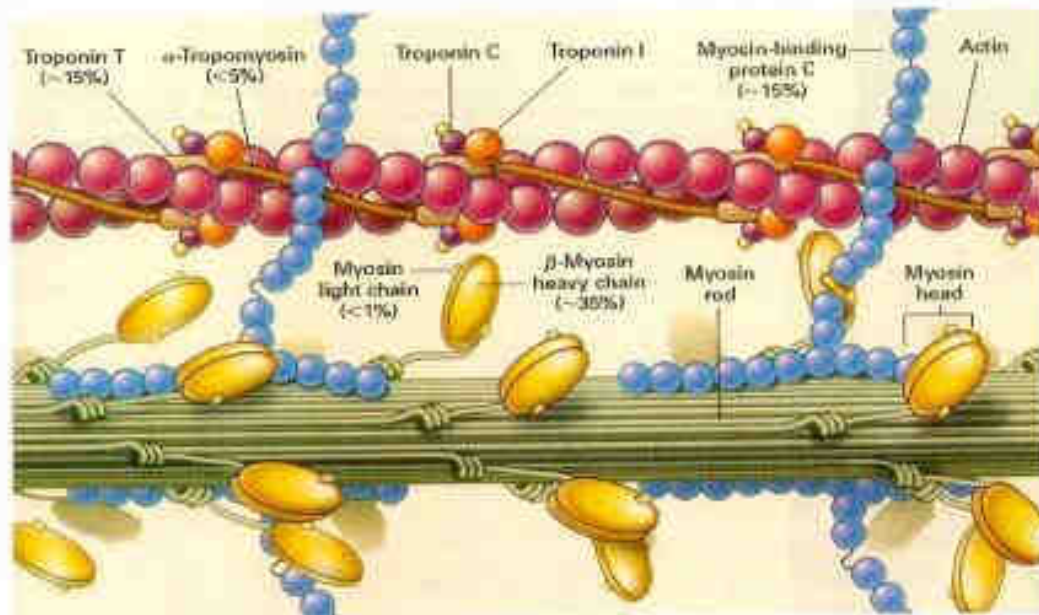
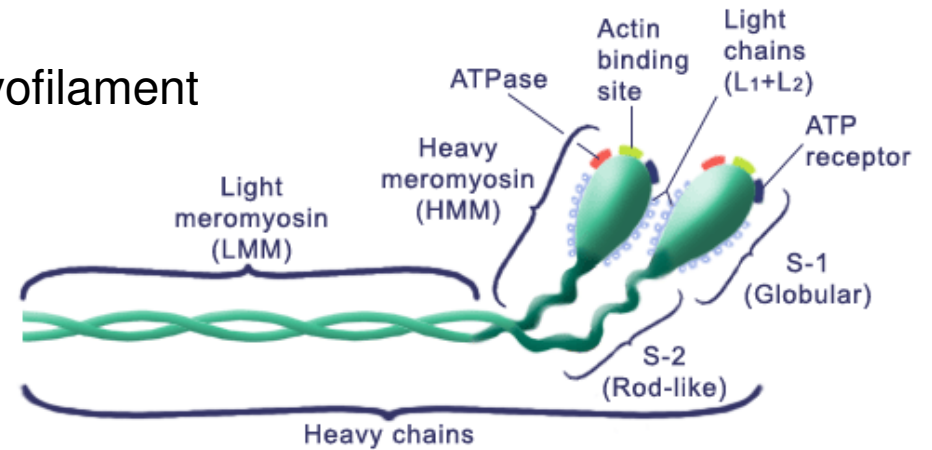
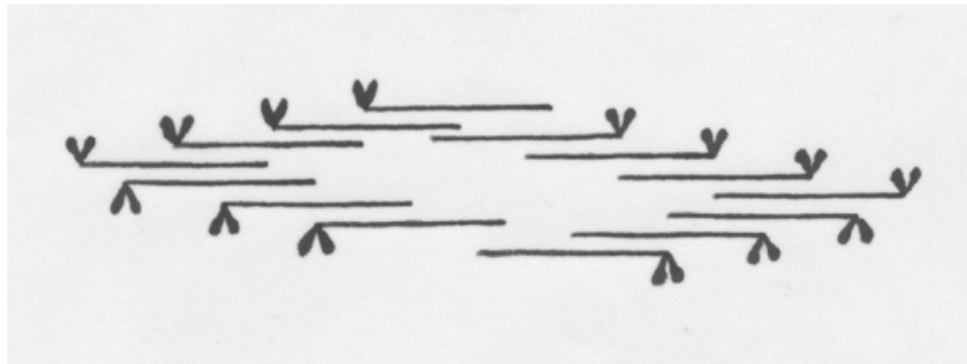


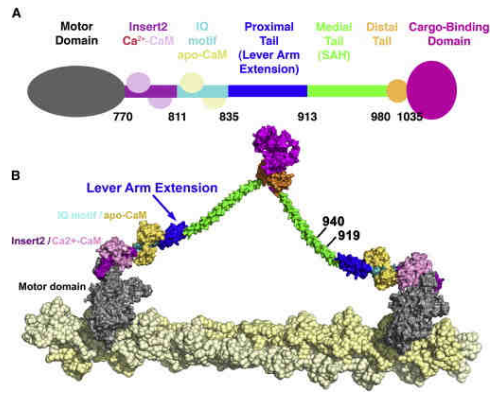
- Tropomyosin – thin double helix in groove of actin double helix, spans 7 monomers of G-actin
- Troponin – complex of 3 globular proteins
 - TnT (Troponin T) – binds tropomyosin
 - TnC (Troponin C) – binds calcium
 - TnI (Troponin I) inhibits interaction between thick and thin filaments



Thick myofilaments

- Myosin
 - Large polypeptide, golf stick shape
 - Bundles of myosin molecules form thick myofilament





(a) Structure of kinesin

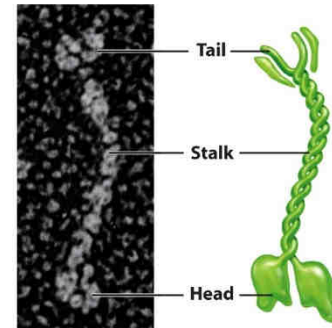
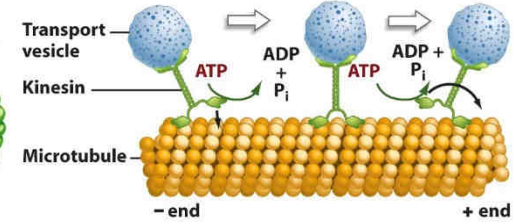
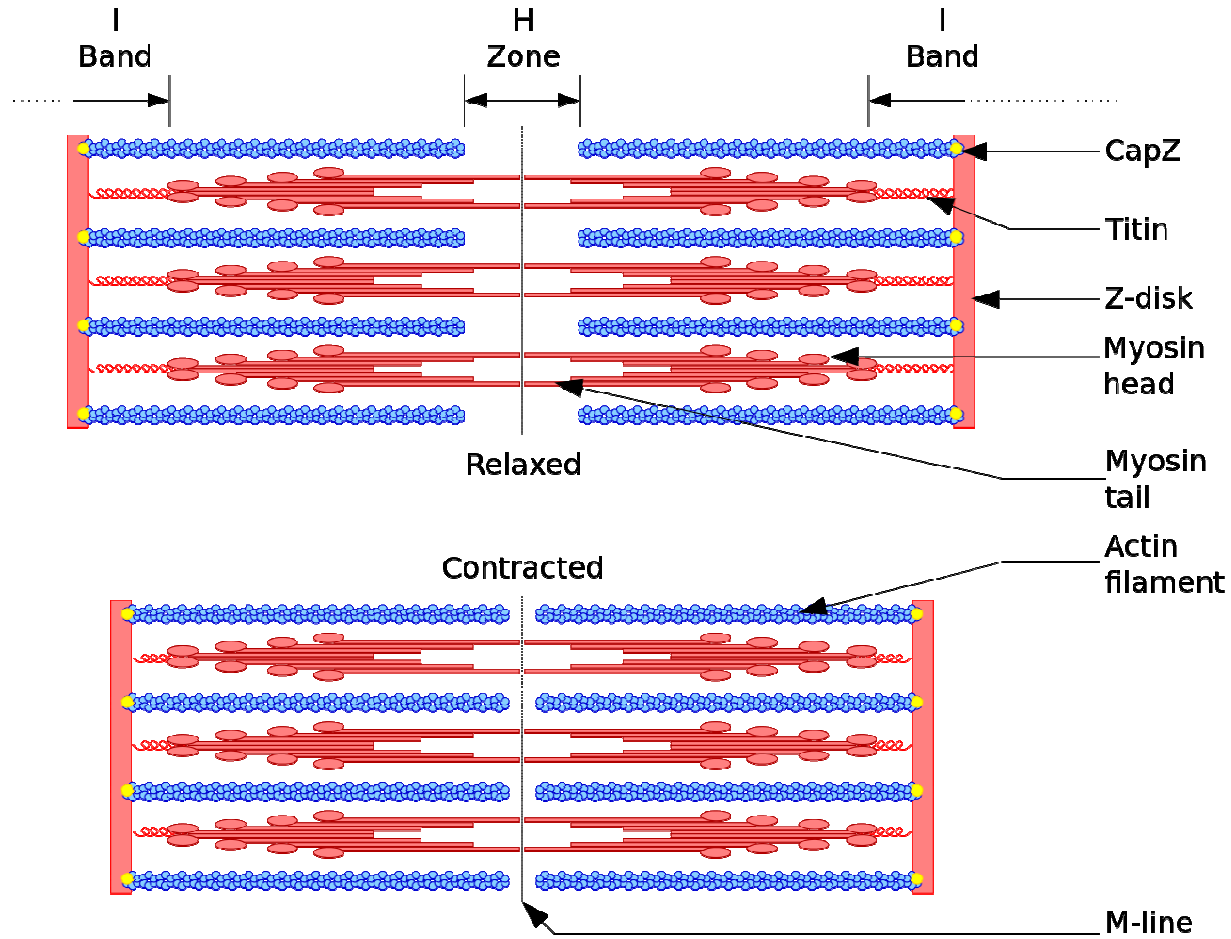


Figure 7-37 Biological Science, 2/e

(b) Kinesin "walks" along a microtubule track.



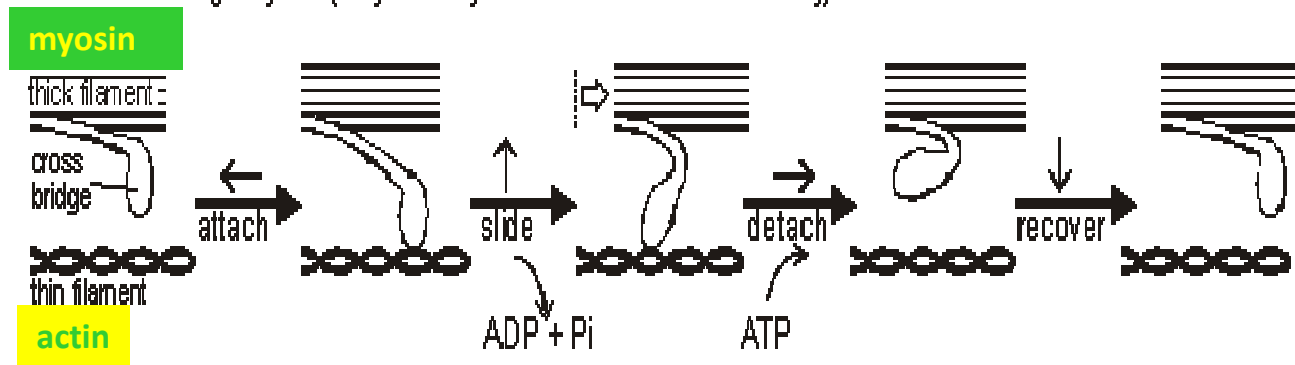
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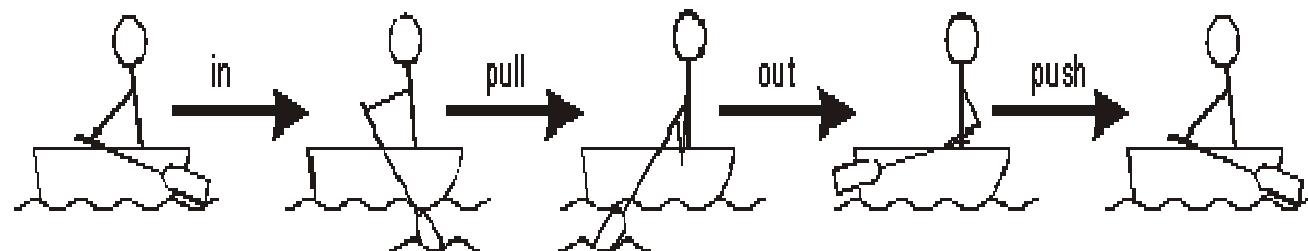
Contraction

- Propagation of action potential (depolarization) via T-tubule (= invagination of sarcolemma)
- Change of terminal cisternae permeability – releasing of Ca^+ ions increases their concentration in sarcoplasm
- Myosin binds actin - sarcomera then shortens by sliding movement – contraction
- Relaxation: repolarization, decreasing of Ca^{2+} ions concentration, inactivation of binding sites of actin for myosin

The Cross Bridge Cycle. (only one myosin head is shown for clarity)



The Rowing Cycle



Contraction

Impulse along motor neuron axon

Depolarization of presynaptic membrane (Na^+ influx)

Synaptic vesicle fuse with presynaptic membrane

Acetylcholine exocytosed to synaptic cleft

Acetylcholine diffuse over synaptic cleft

Acetylcholine bind to receptors in postsynaptic membrane

Depolarization of postsynaptic membrane and sarcolemma (Na^+ influx)

T-tubules depolarization

Depolarization of terminal cisternae of sER

Depolarization of complete sER

Release of Ca^{2+} from sER to sarcoplasm

Ca^{2+} binds TnC

Troponin complex changes configuration

TnI removed from actin-myosin binding sites

Globular parts of myosin bind to actin

ATPase in globular parts of myosin activated

Energy generated from $\text{ATP} \rightarrow \text{ADP} + \text{P}_i$

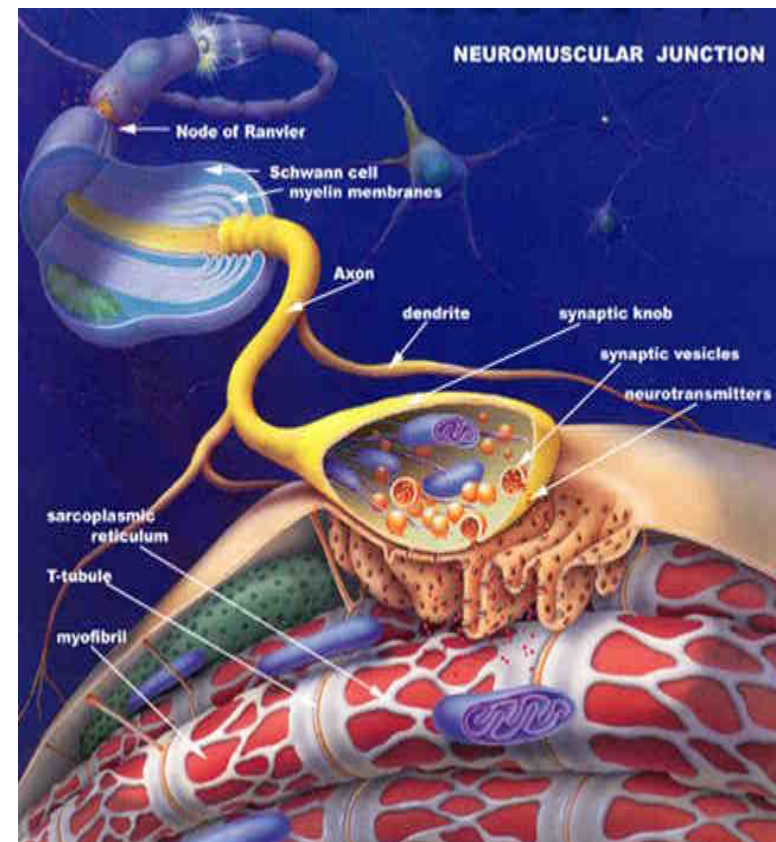
Movement of globular parts of myosin

Actin myofilament drag to the center of sarcomere

Sarcomere contracts (I-band shortens)

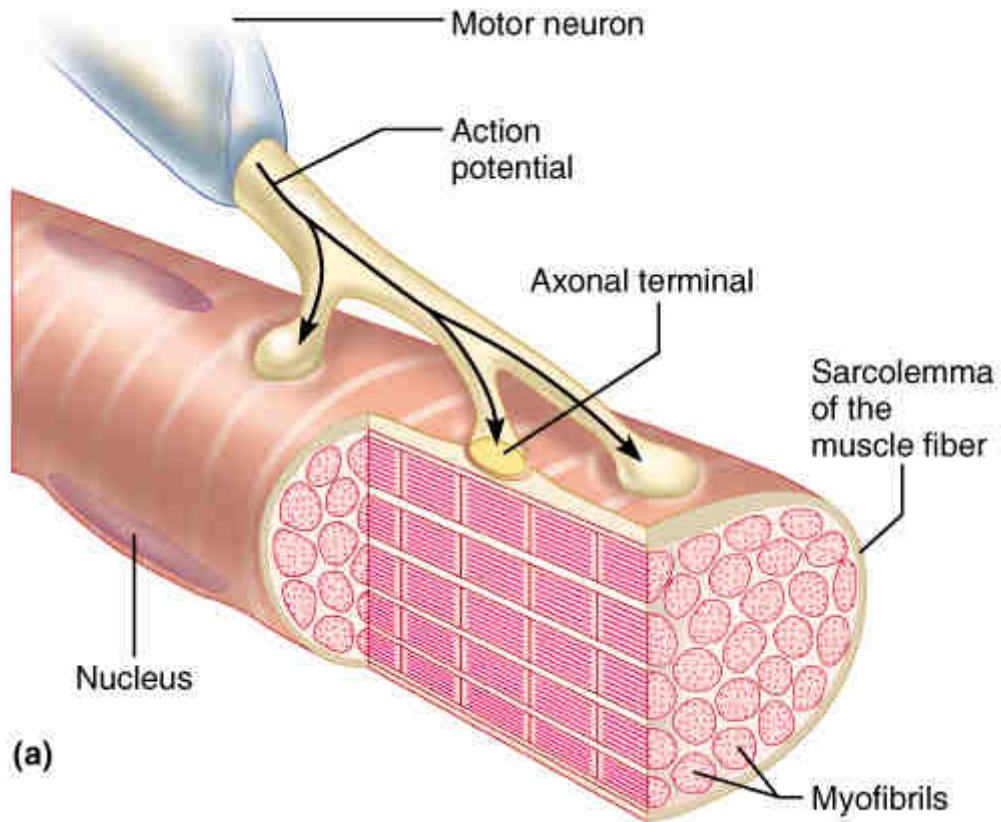
Myofibrils contracted

Muscle fiber contracted

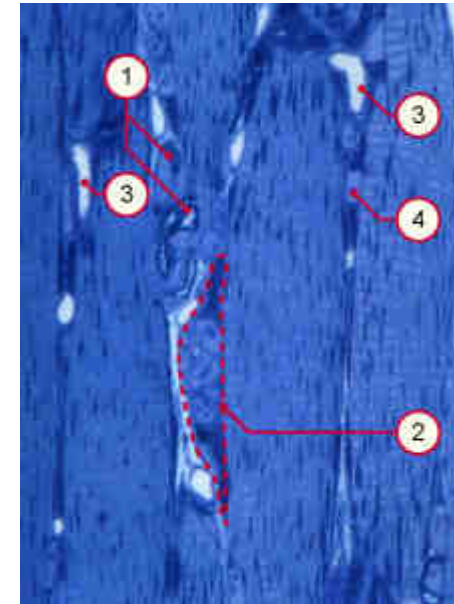


http://highered.mheducation.com/sites/0072495855/student_view0/chapter10/animation__breakdown_of_atp_and_cross-bridge_movement_during_muscle_contraction.html

Neuromuscular junction



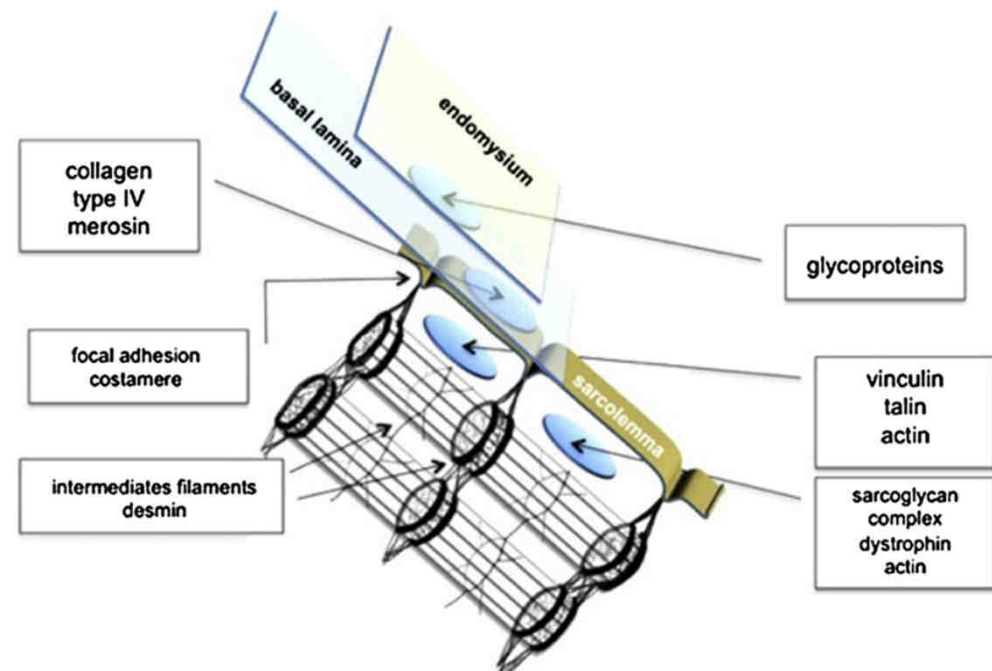
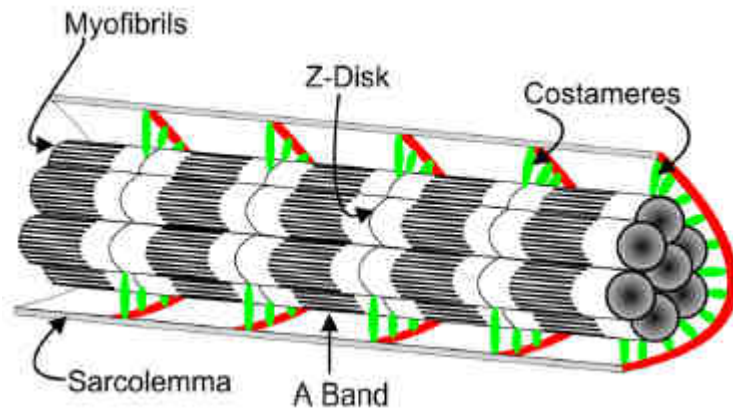
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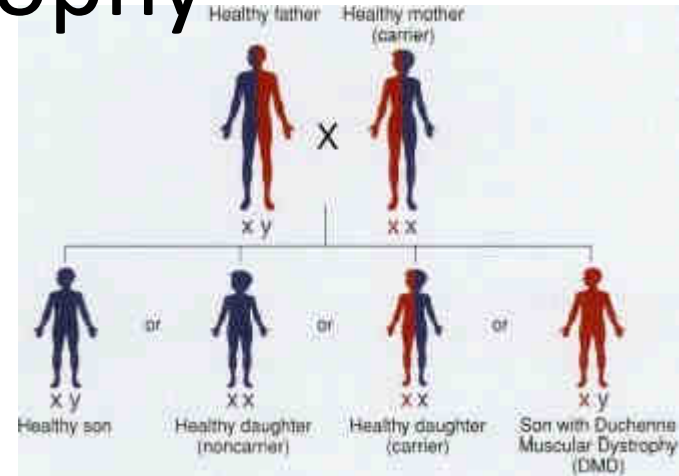
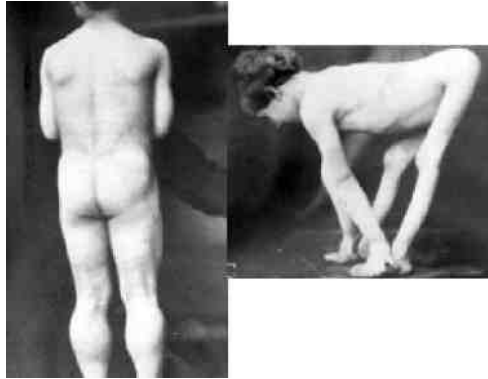
- 1 Myelinated axons
- 2 Neuromuscular junction
- 3 Capillaries
- 4 Muscle fiber nucleus

Costameres

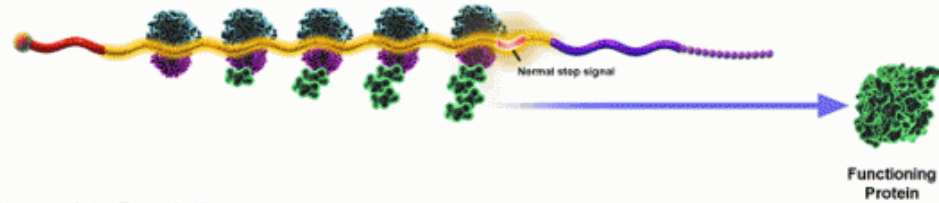
- Structural components linking myofibrils to sarcolemma
- Circumferential alignment
- **dystrophin-associated glycoprotein (DAG) complex**
 - links internal cytoskeleton to ECM
 - Integrity of muscle fiber



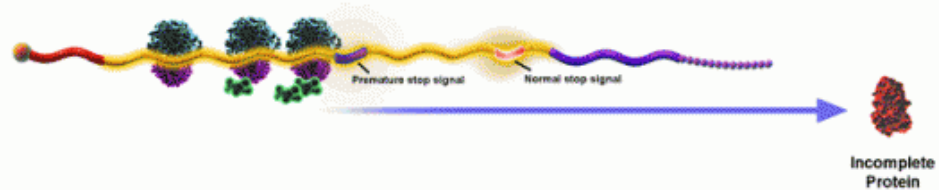
Duchenne muscular dystrophy



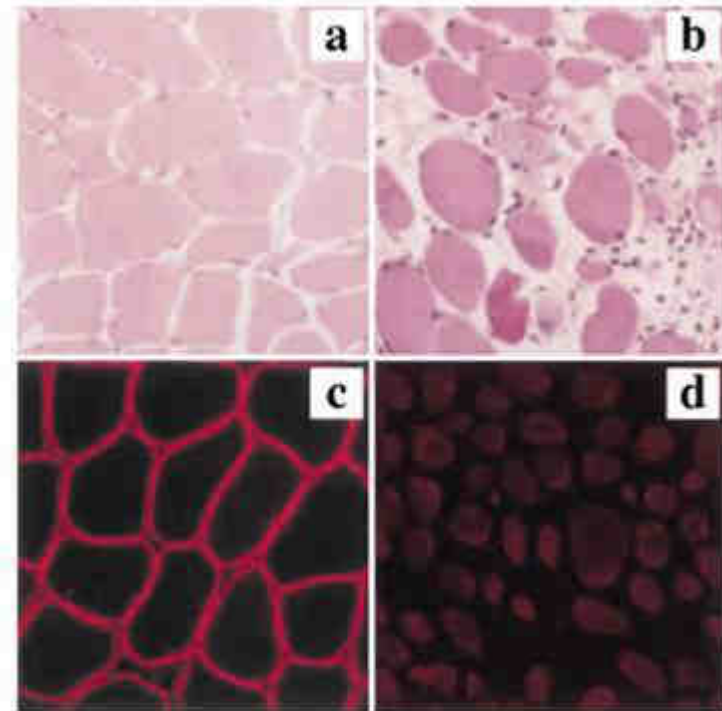
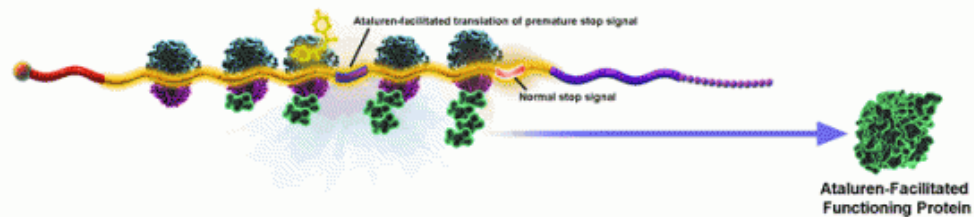
Normal Translation

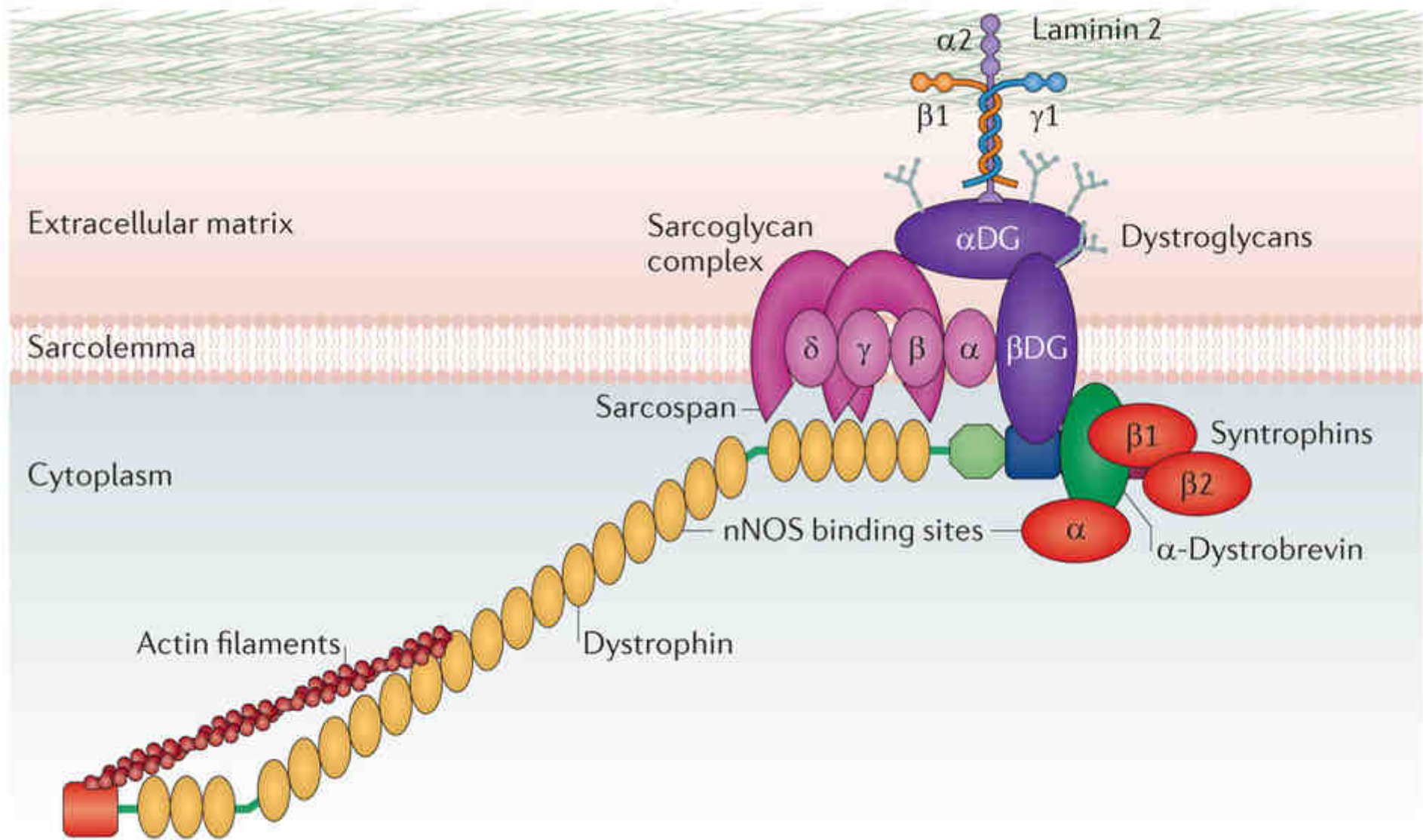


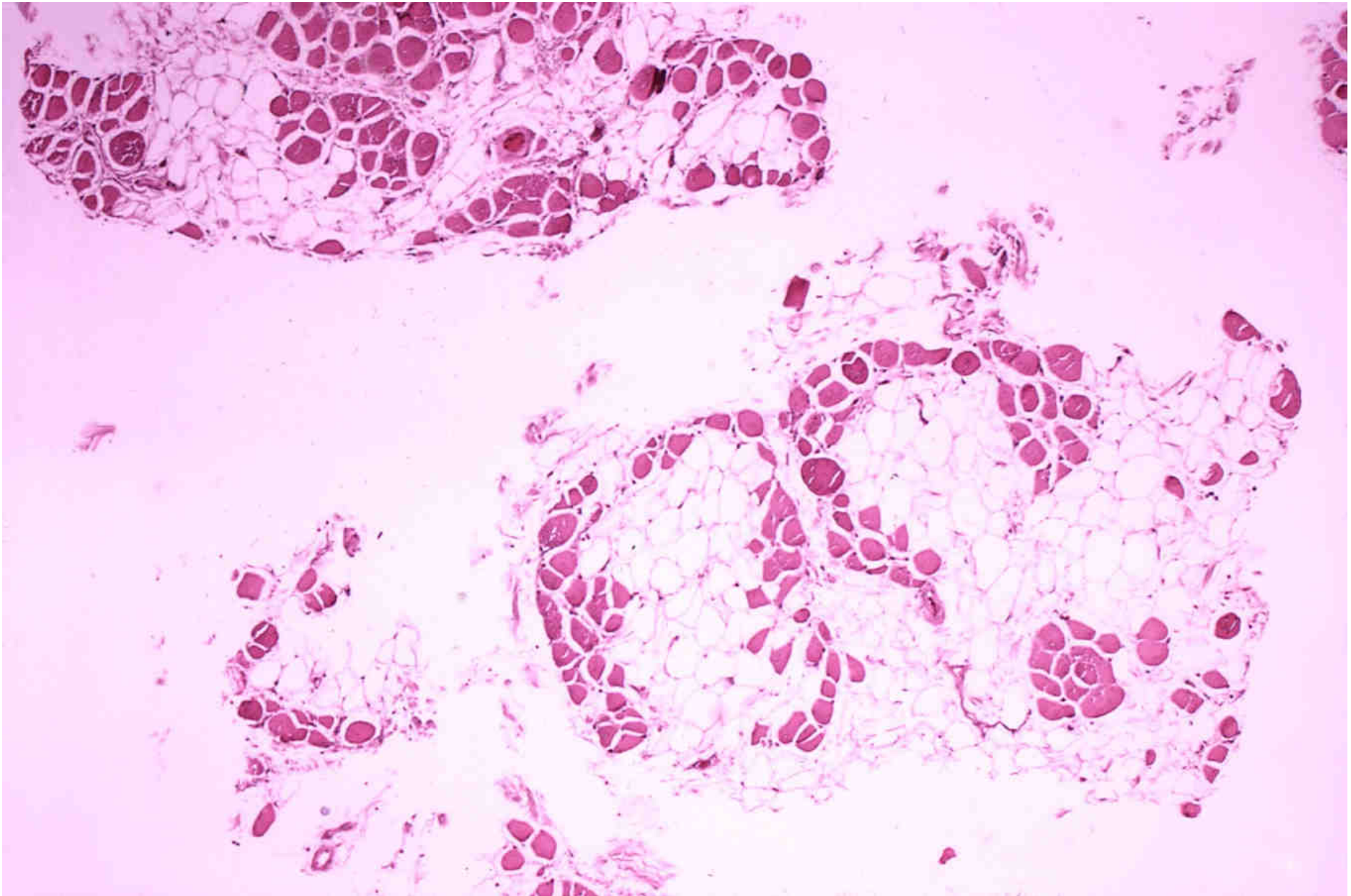
Incomplete Translation



Ataluren-Facilitated Translation





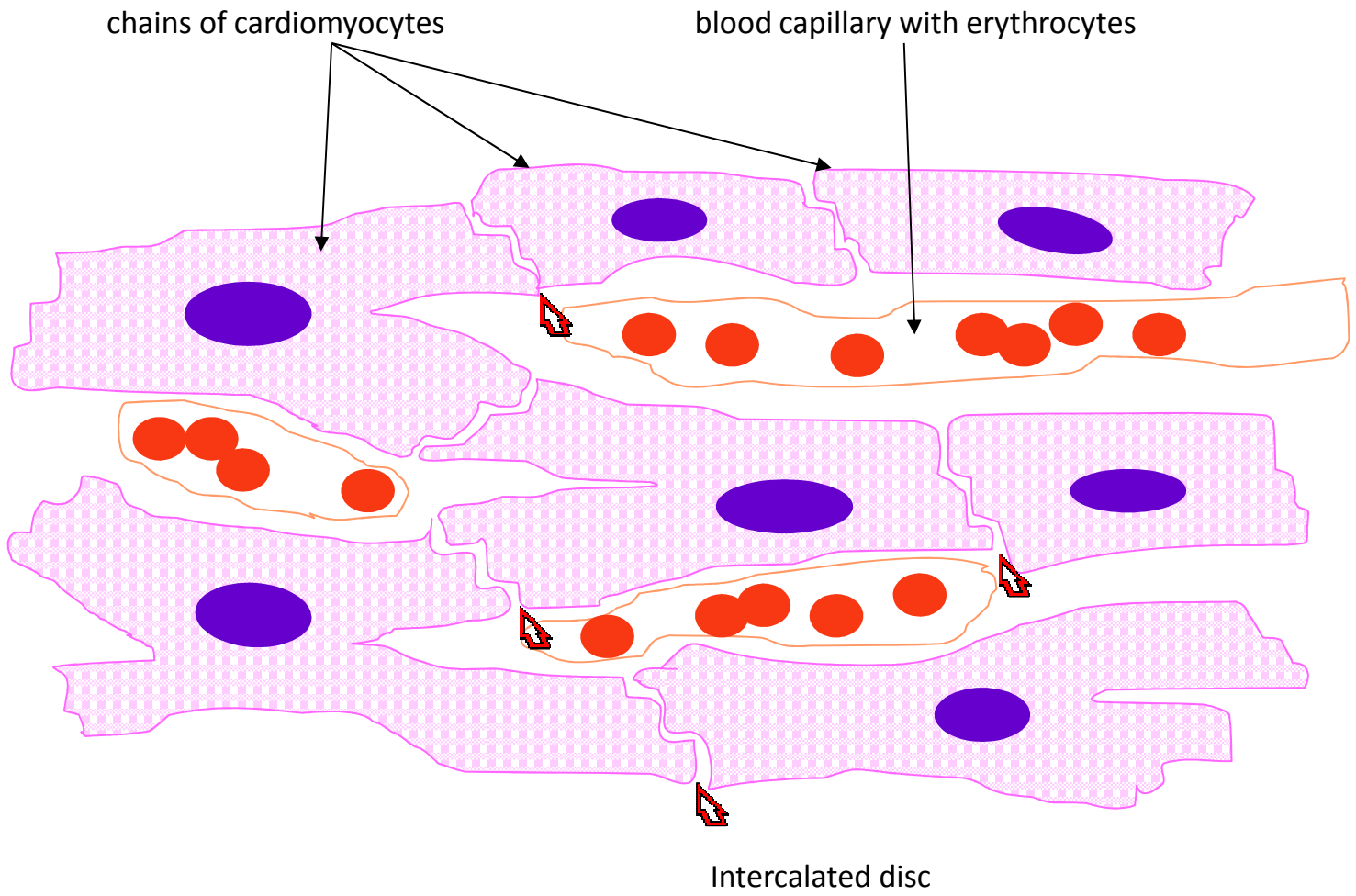


BREAK

Histology of skeletal muscle tissue - myocardium

made up of long branched fiber (cells) – **cardiomyocytes**,

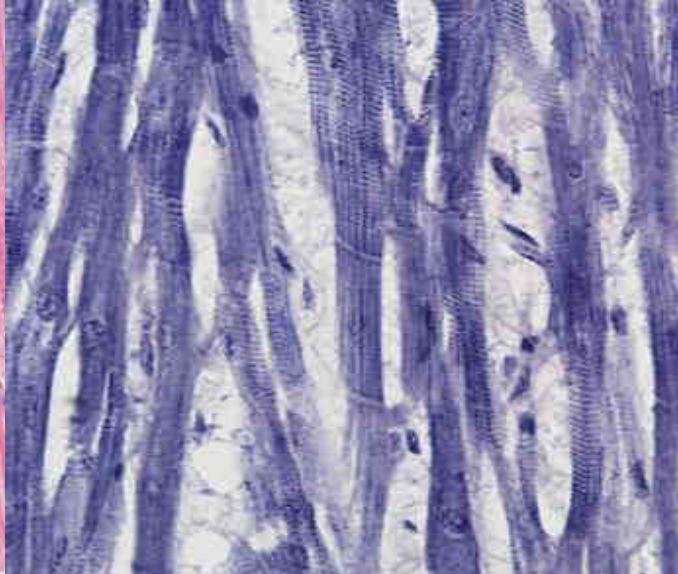
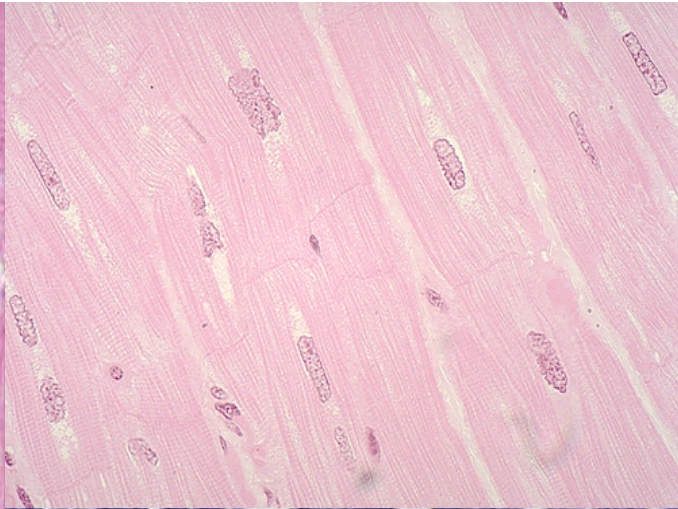
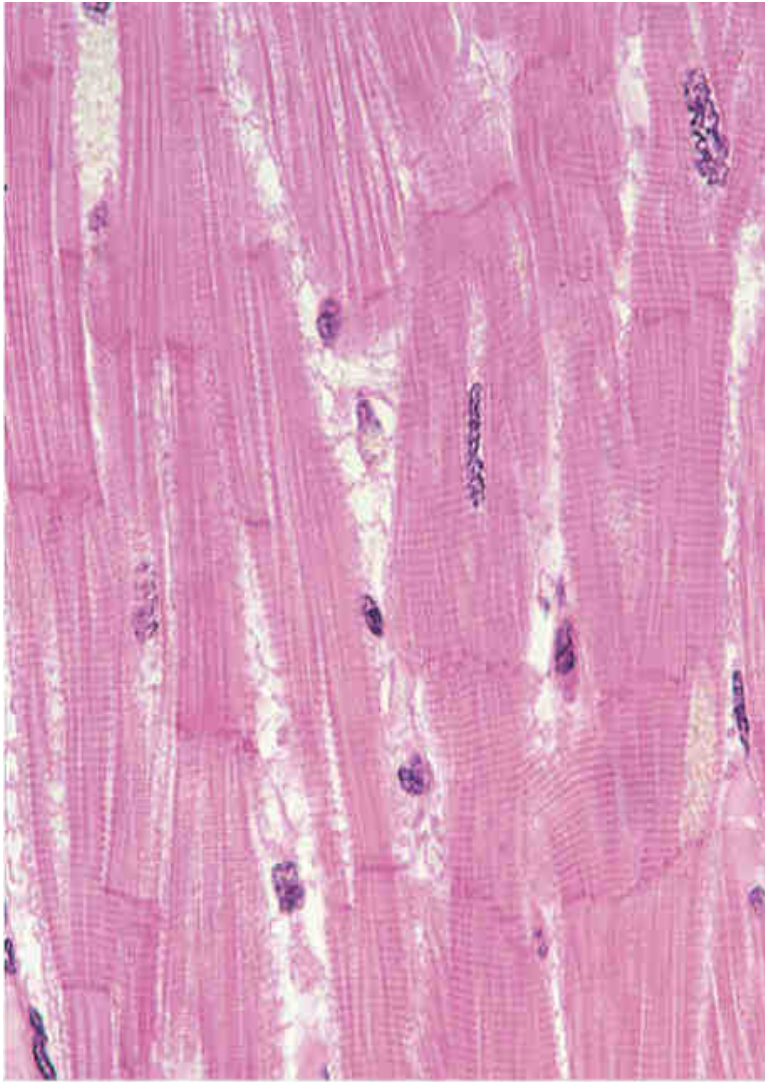
- cardiomyocytes are cylindrical cells, branched on one or both ends (Y, X shaped cells),
- Sarcoplasm: single nucleus in the center of cell, striated myofibrils, numerous mitochondria,
- cells are attached to one another by end-to-end junctions – intercalated discs.



chains of cardiomyocytes

blood capillary with erythrocytes

Intercalated disc



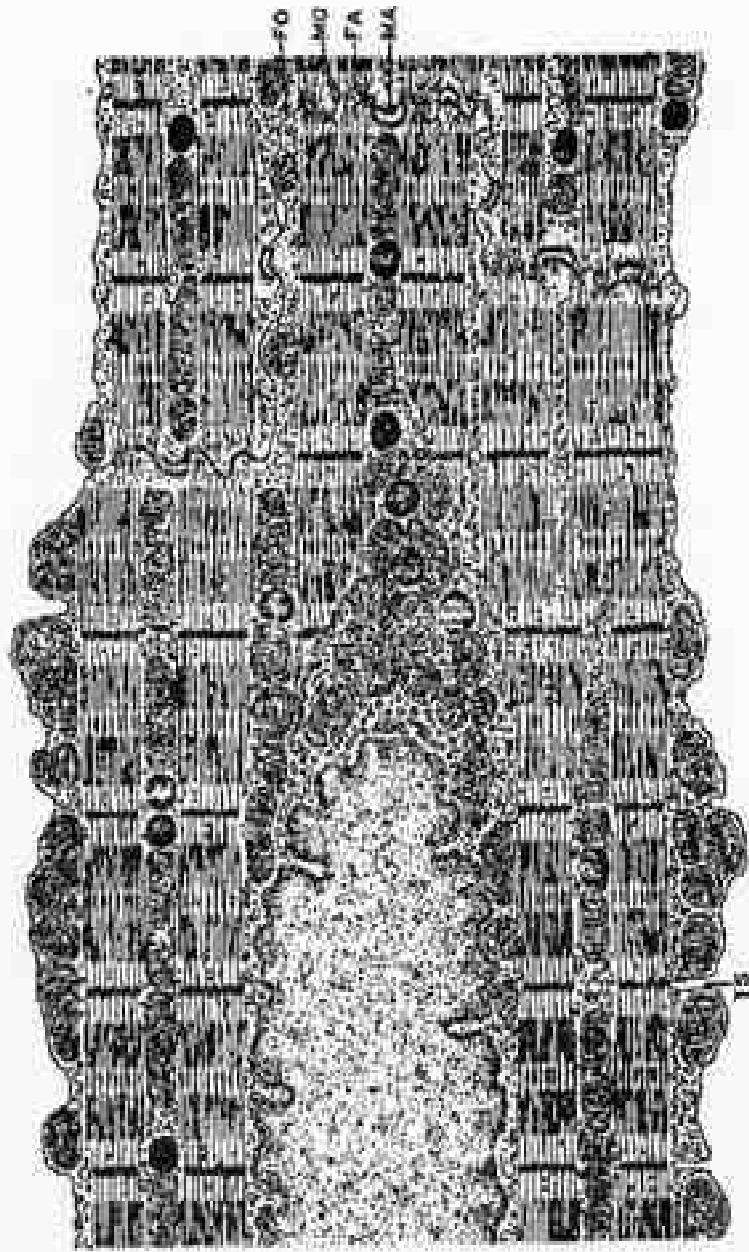
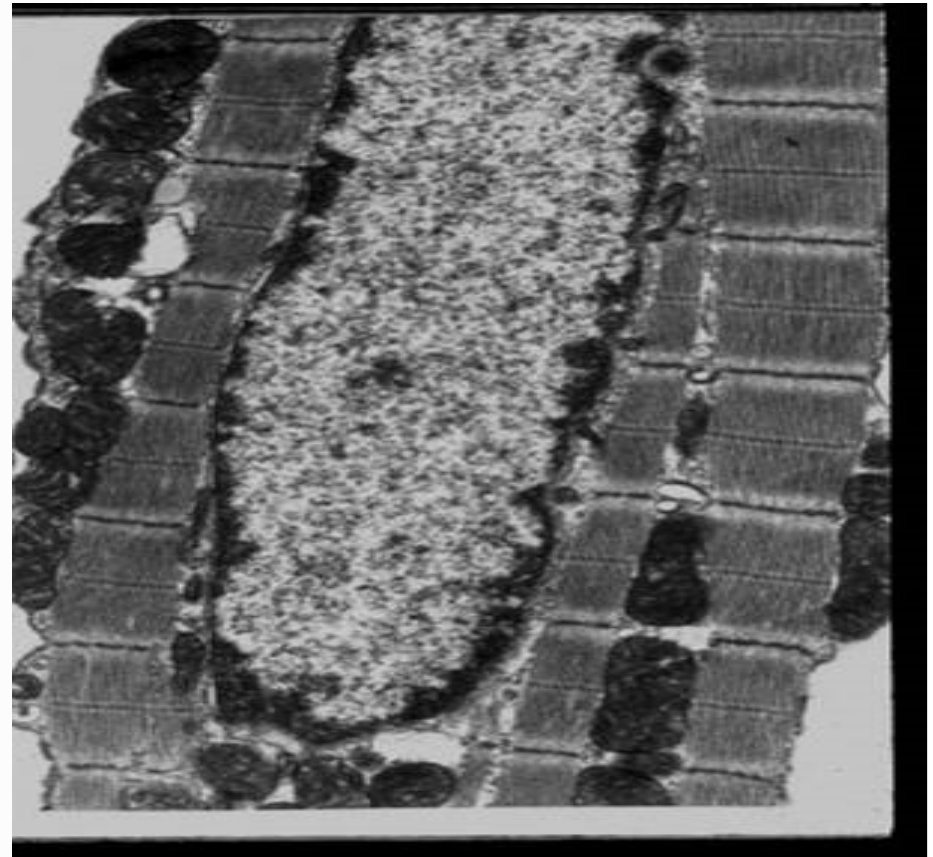
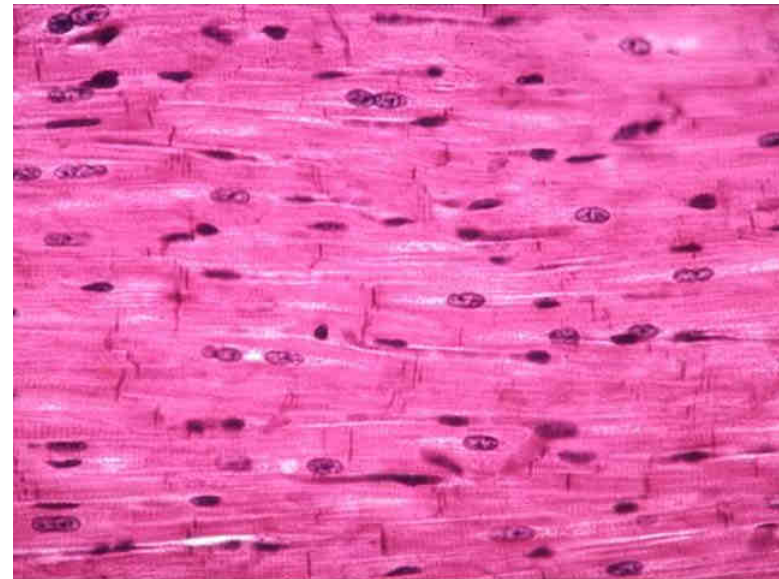
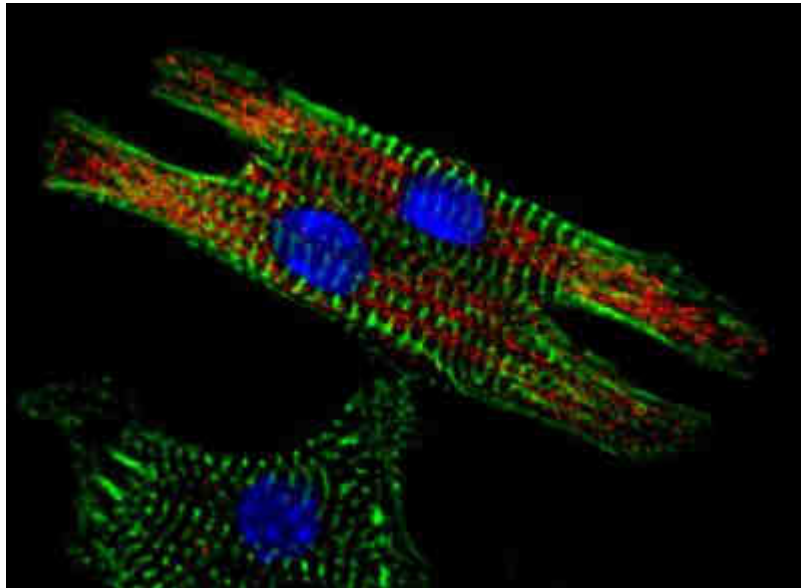


FIG. 10-10 CARDIAC MUSCLE



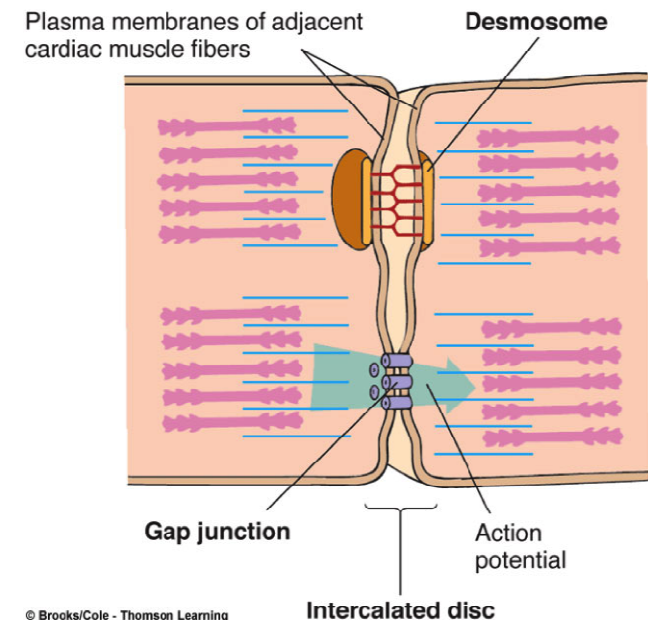
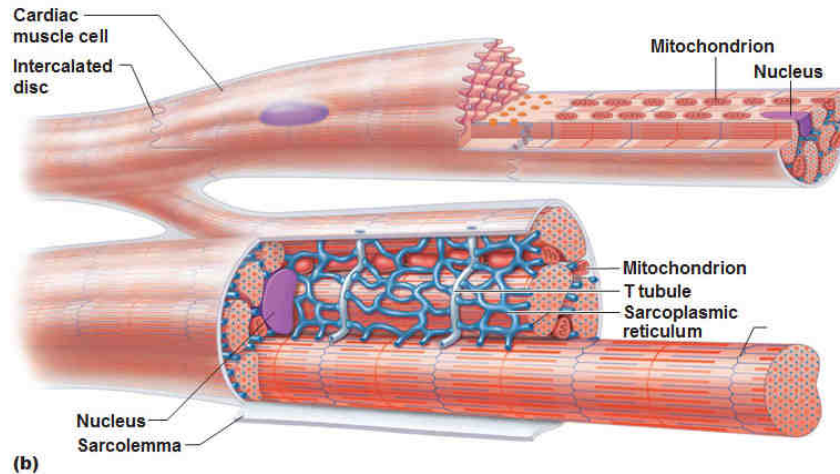
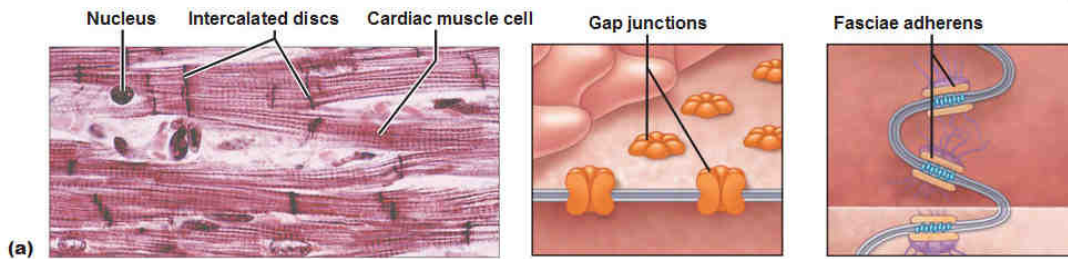
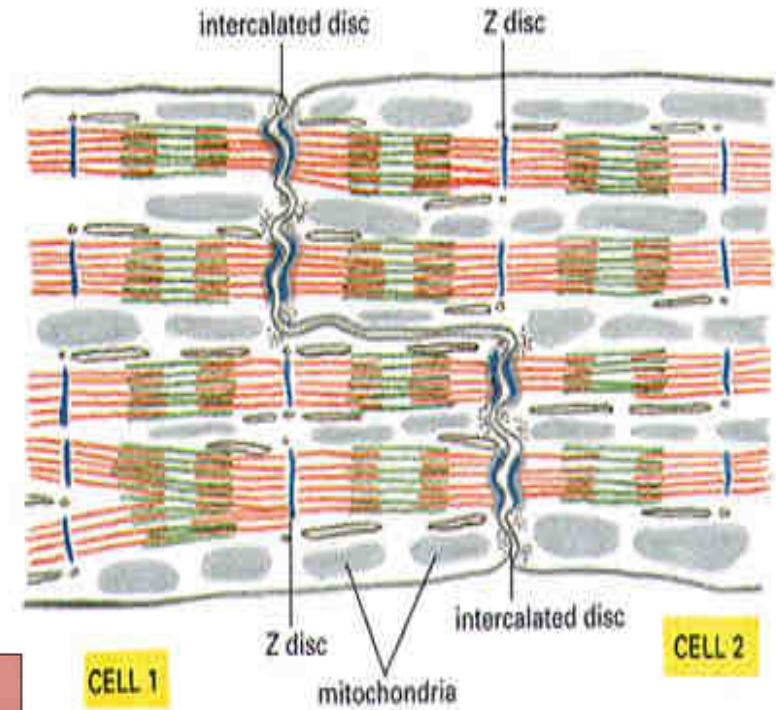
CARDIAC MUSCLE TISSUES COMPARED TO SKELETAL

- no triads, but diads: 1 t-tubule + 1 cisterna
- t-tubules around the sarcomeres at the Z lines rather than at the zone of overlap
- sarcoplasmic reticulum via its tubules contact sarcolemma as well as the t-tubules
- cardiac muscle cells are totally dependent on aerobic metabolism to obtain the energy
- large numbers of mitochondria in sarcoplasm and abundant reserves of myoglobin (to store oxygen)
- abundant glycogen and lipid inclusions



Intercalated disc

- „scariform“ shape of cell ends
- fasciae adherentes (*adhesion of cells*)
- Nexus (quick intercellular communication – transport of ions, electric impulses, information)





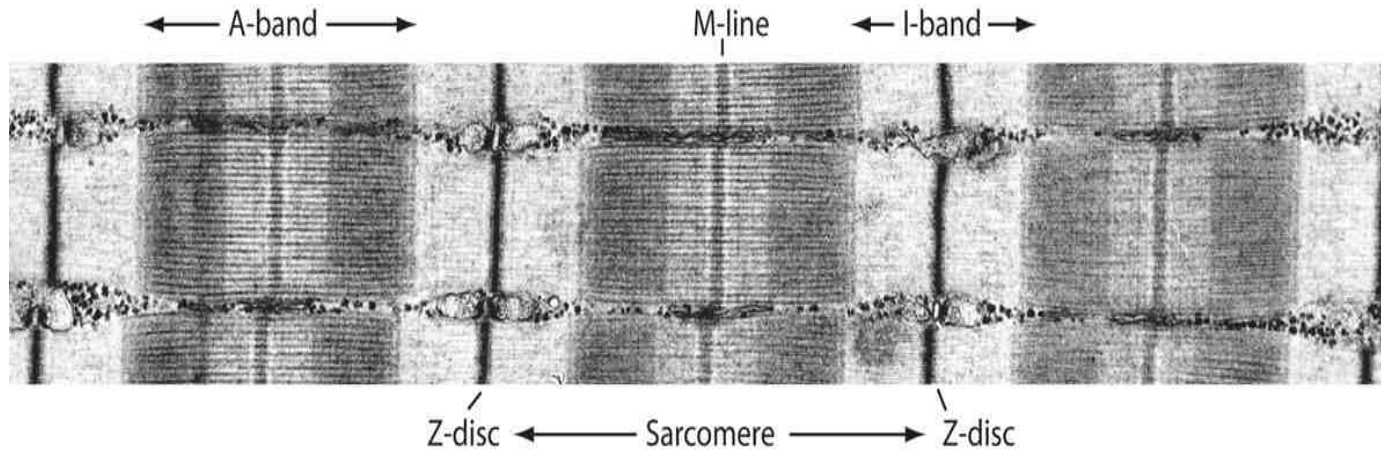
Intercalated disc:

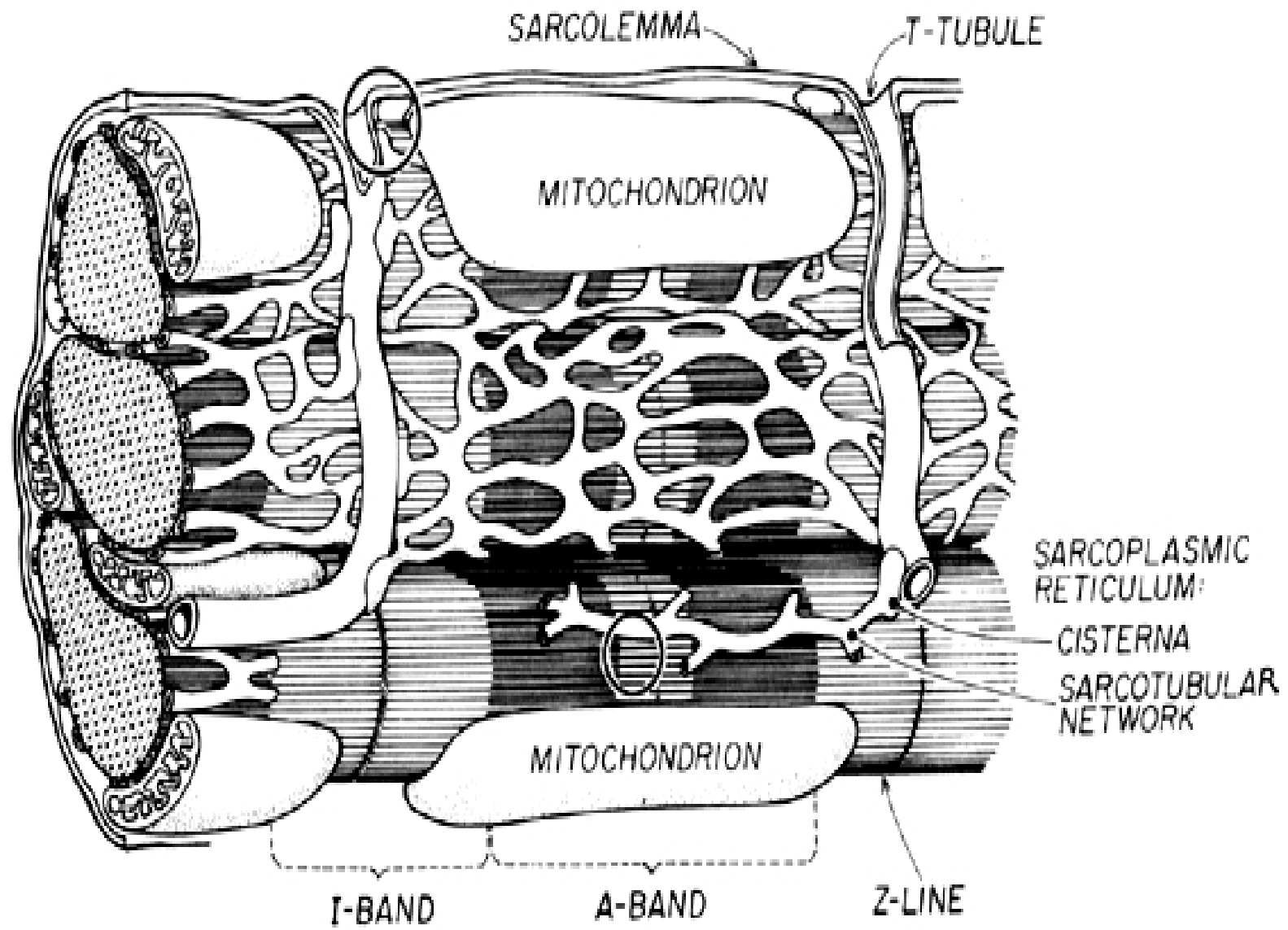
nexus

fascia adherens

Myofibril of cardiomyocyte

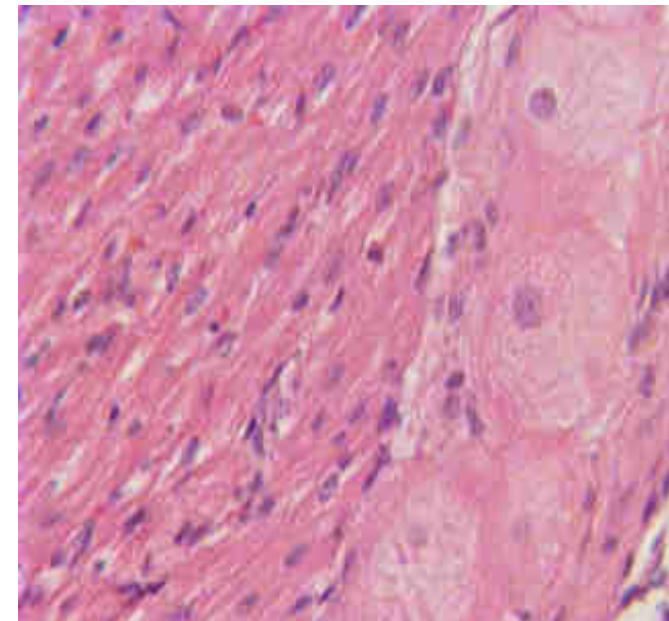
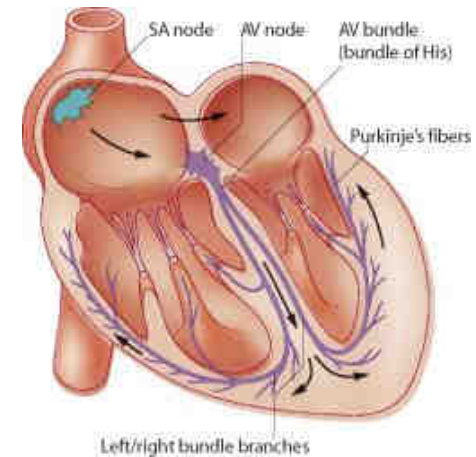
- Actin + myosin myofilaments
- Sarcomere
- Z-line
- M-line and H-zone
- I-band, A-band
- T-tubule + 1 cisterna = diad (around Z-line)



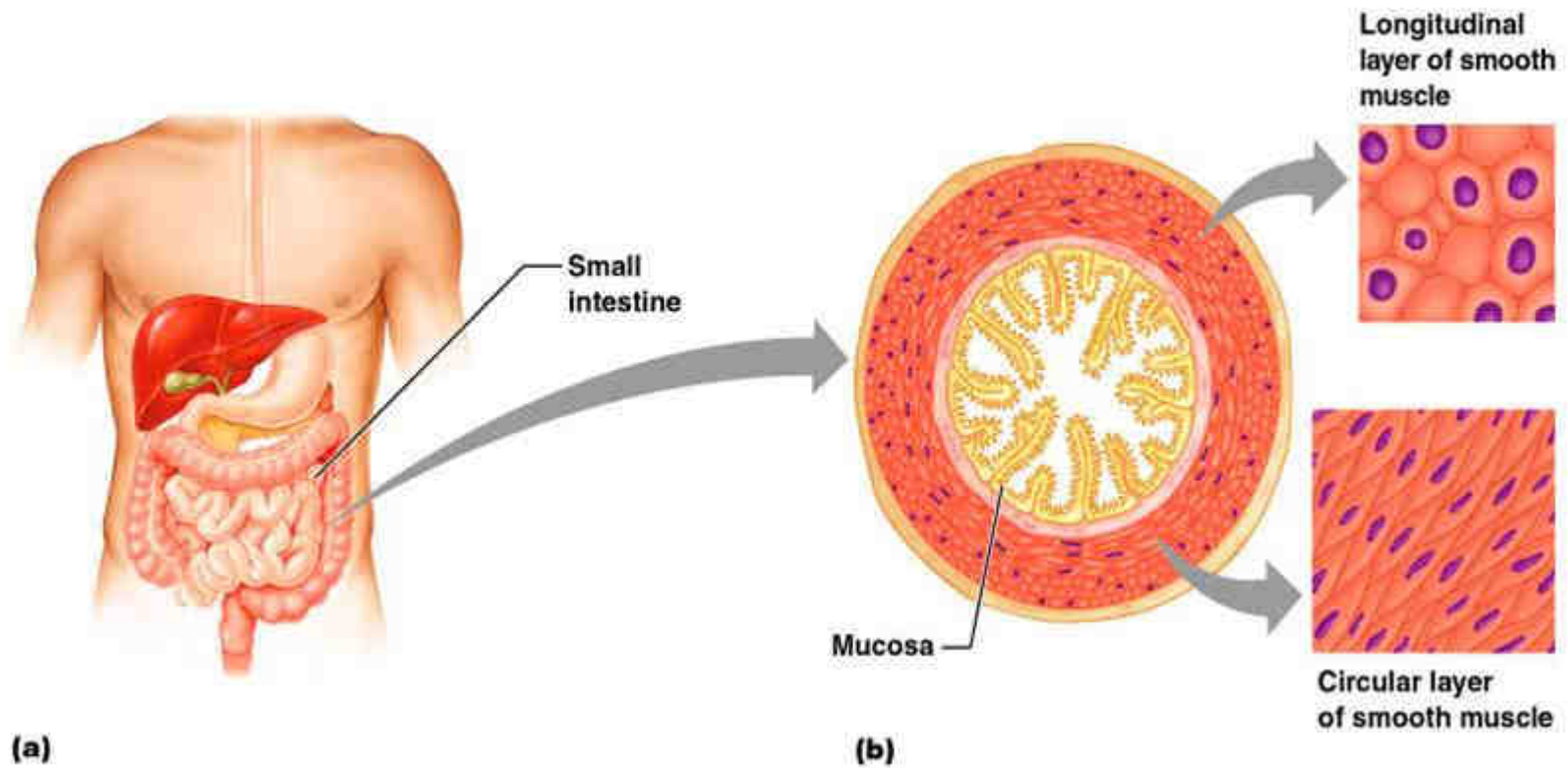


Purkinje fibers

- are located in the inner layer of heart ventricle wall
- are specialized cells fibers that conduct an electrical stimuli or impulses that enables the heart to contract in a coordinated fashion
- numerous sodium ion channels and mitochondria, fewer myofibrils



Smooth muscle tissue

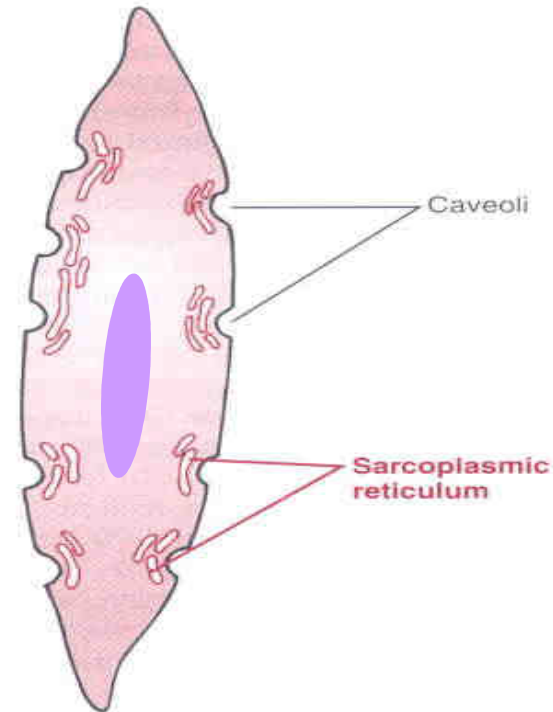
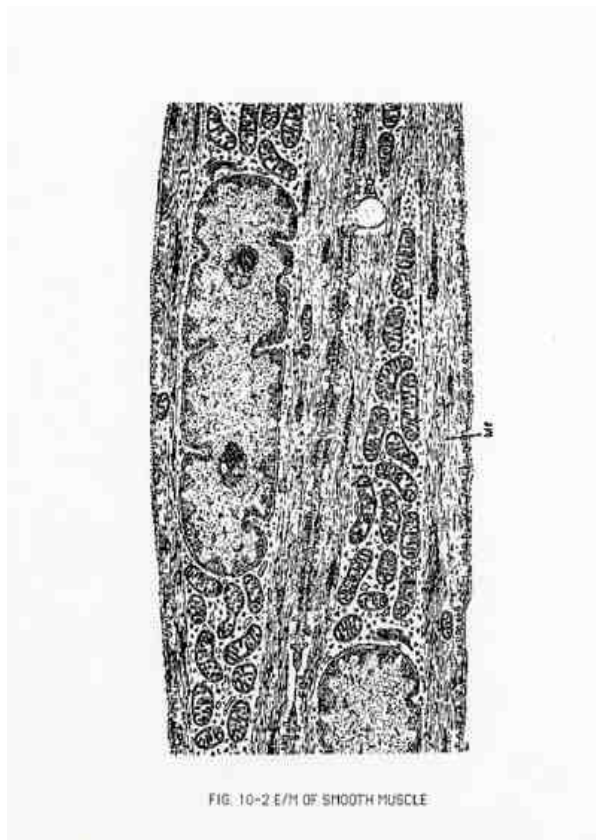


Smooth muscle tissue

- spindle shaped cells (leiomyocytes) with myofilaments not arranged into myofibrils (no striation), 1 nucleus in the centre of the cell
- myofilaments form bands throughout the cell
- actin filaments attach to the sarcolemma by focal adhesions or to the dense bodies substituting Z-lines in sarcoplasm
- calmodulin
- sarcoplasmic reticulum forms only tubules, Ca ions are transported to the cell via pinocytotic vesicles
- zonulae occludentes and nexuses connect cells

Smooth muscle tissue

Caveolae are equivalent to t-tubule and in their membrane ions channel are present to bring Ca needed for contraction.
Caveolae are in contact with sarcoplasmic reticulum.



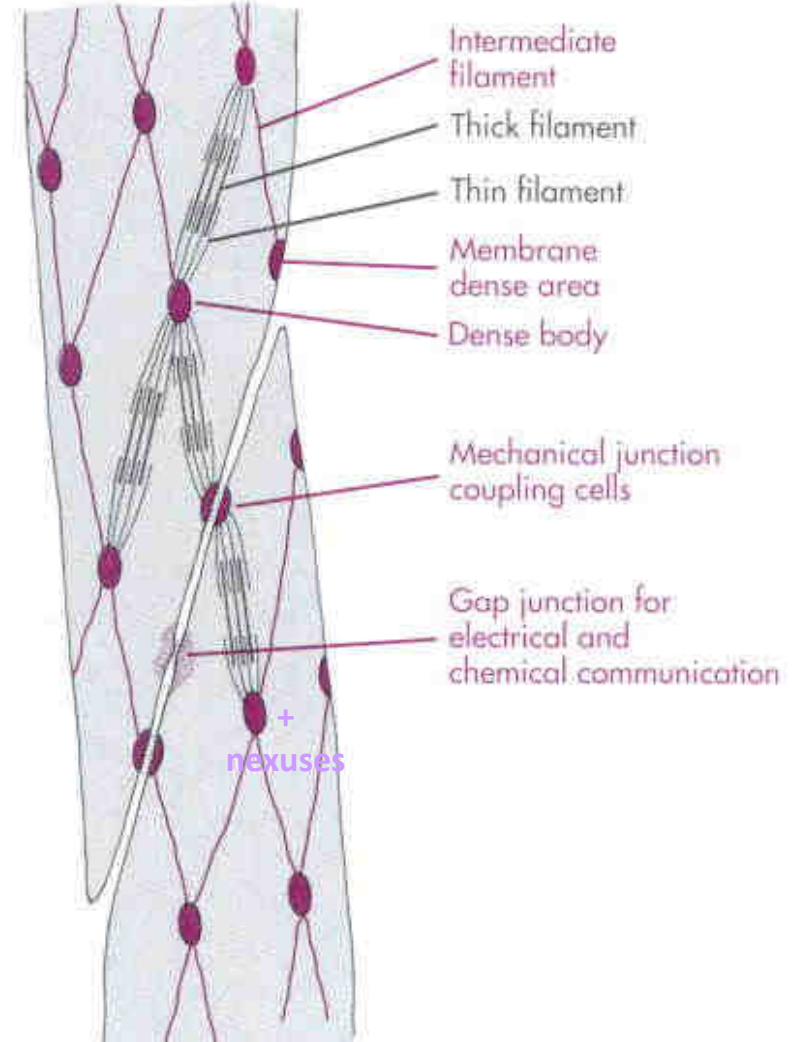
Smooth muscle tissue



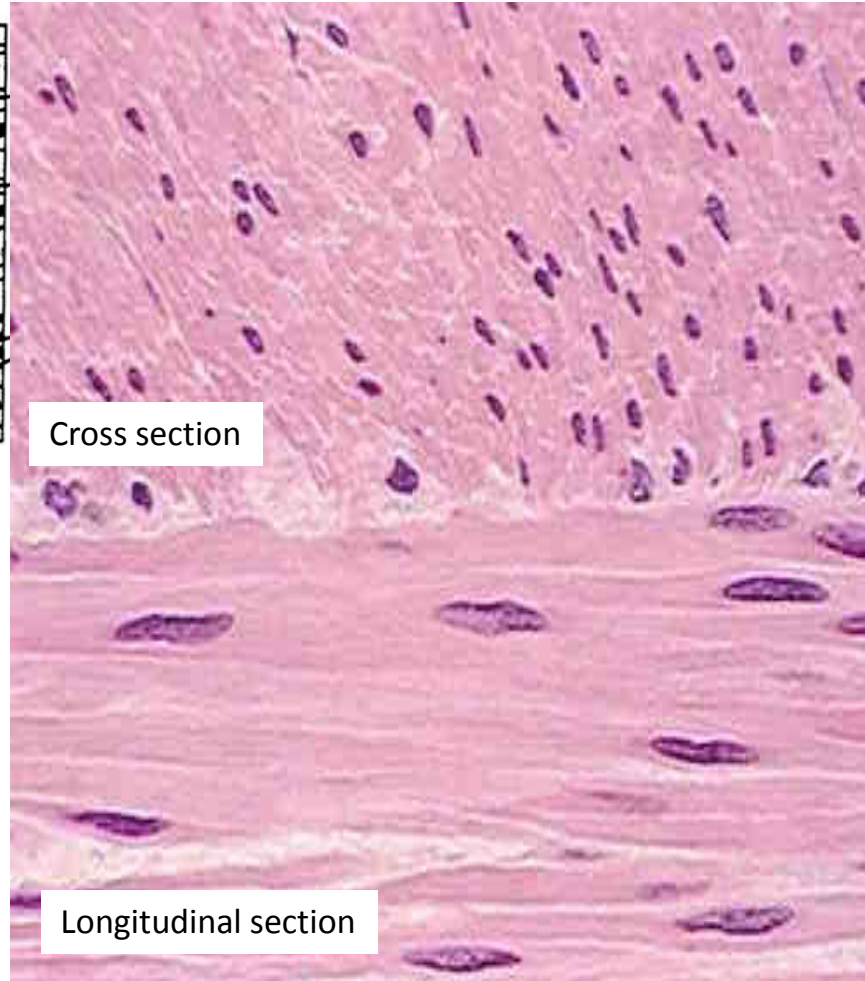
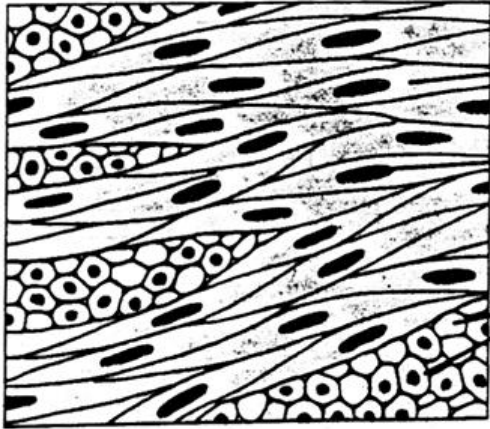
Relaxed smooth muscle cell



Contracted smooth muscle cell

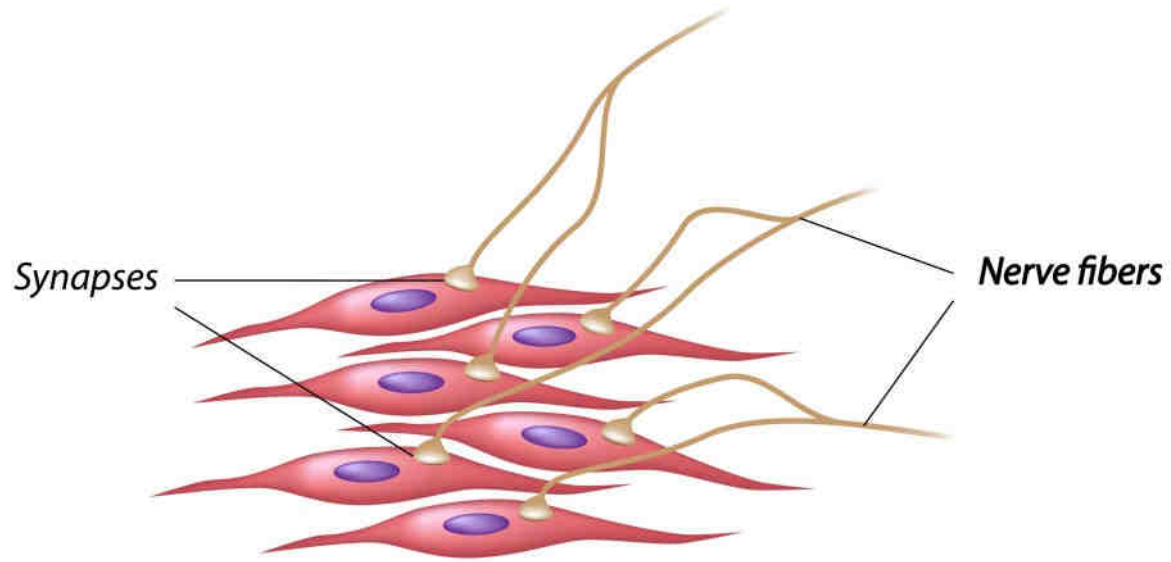


Leiomycocytes are arranged into layers in walls of hollow (usually tubular) organs

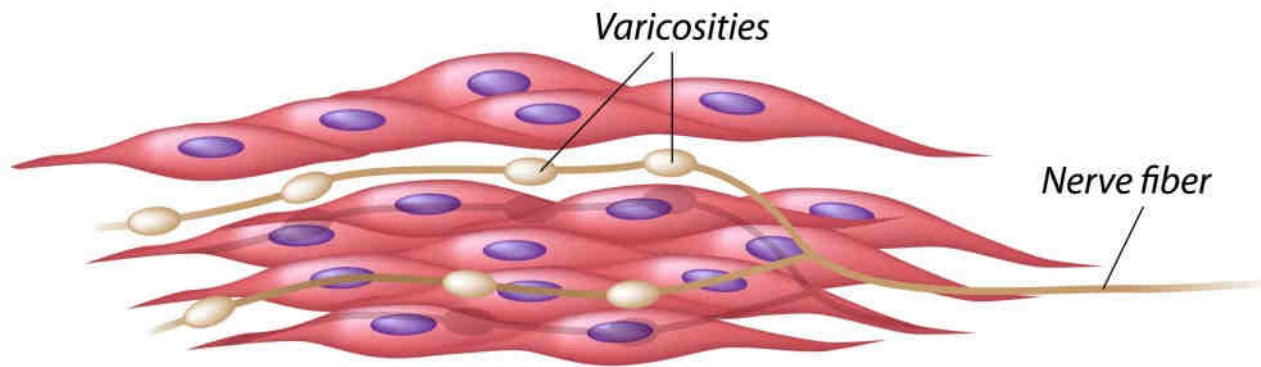


Cross section

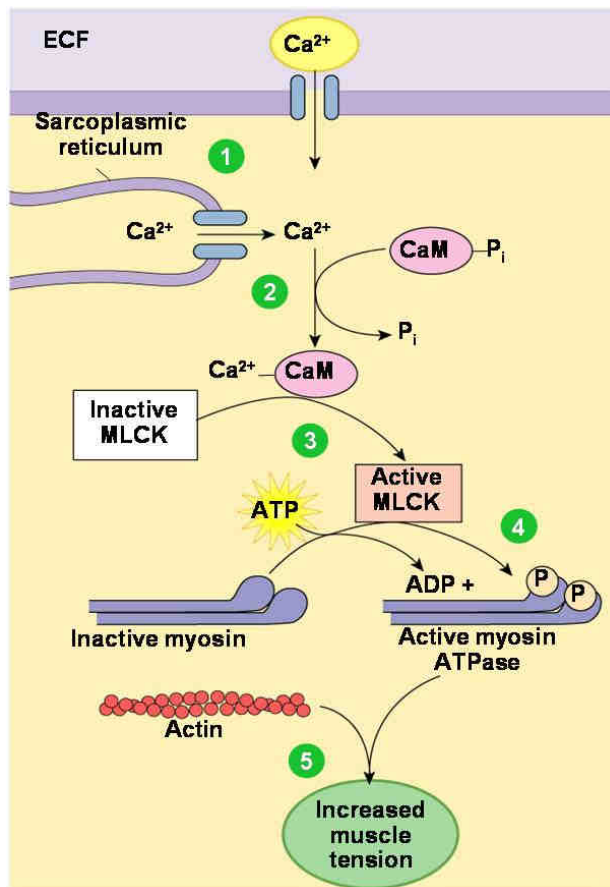
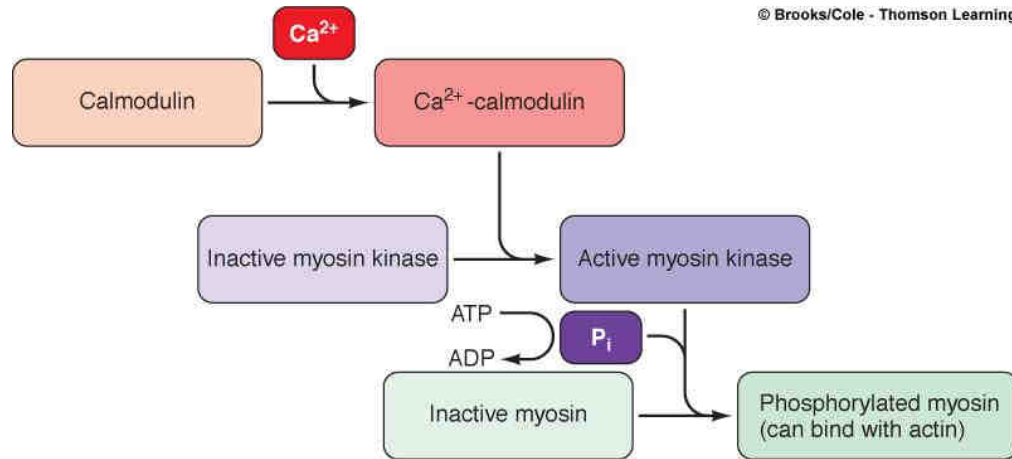
Longitudinal section



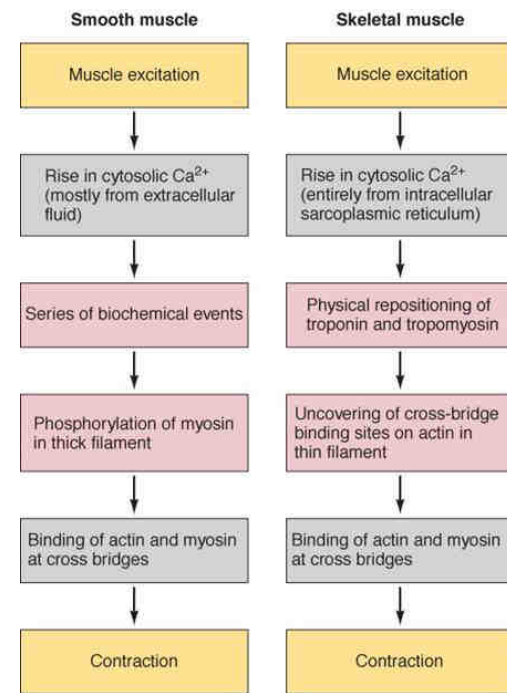
Multiunit Smooth Muscle



Single-unit Smooth Muscle



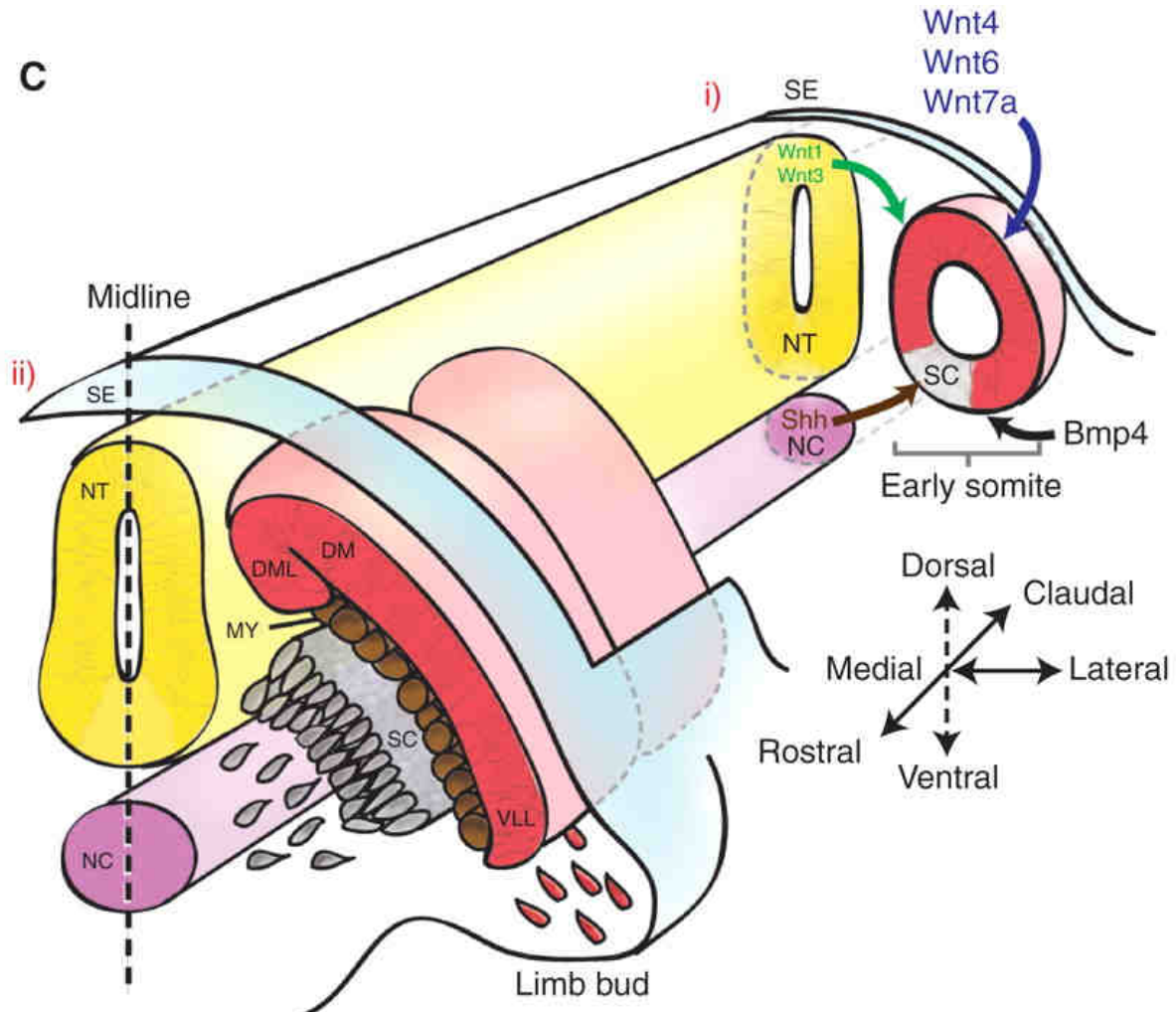
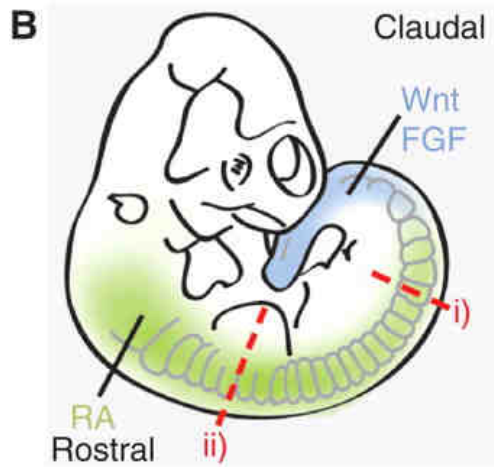
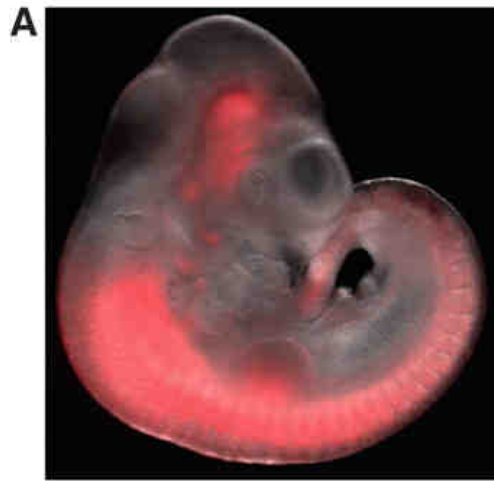
- 1 Intracellular Ca^{2+} concentrations increase when Ca^{2+} enters cell and is released from sarcoplasmic reticulum.
- 2 Ca^{2+} binds to calmodulin (CaM).
- 3 Ca^{2+} -calmodulin activates myosin light chain kinase (MLCK).
- 4 MLCK phosphorylates light chains in myosin heads and increases myosin ATPase activity.
- 5 Active myosin crossbridges slide along actin and create muscle tension.

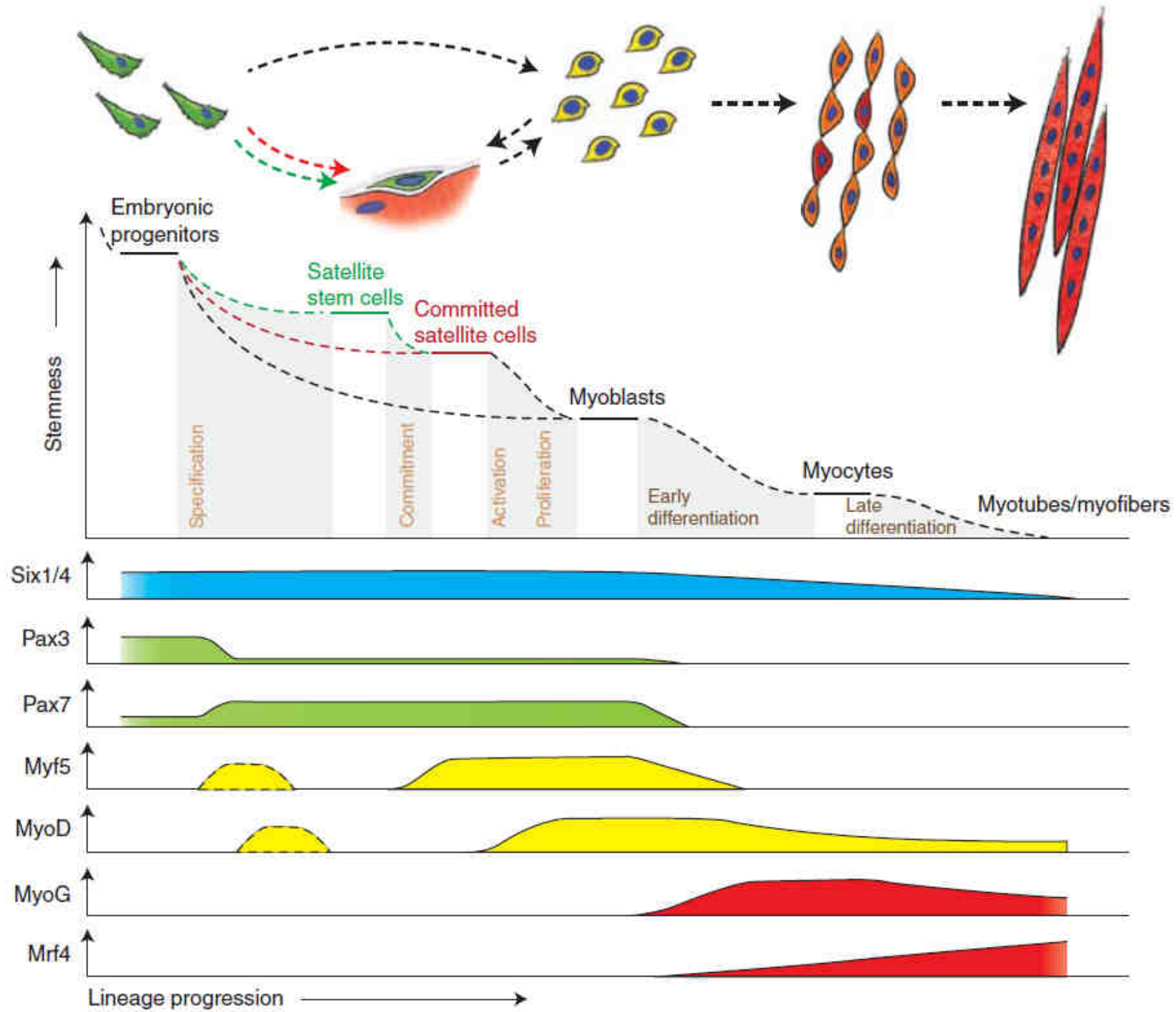


Summary

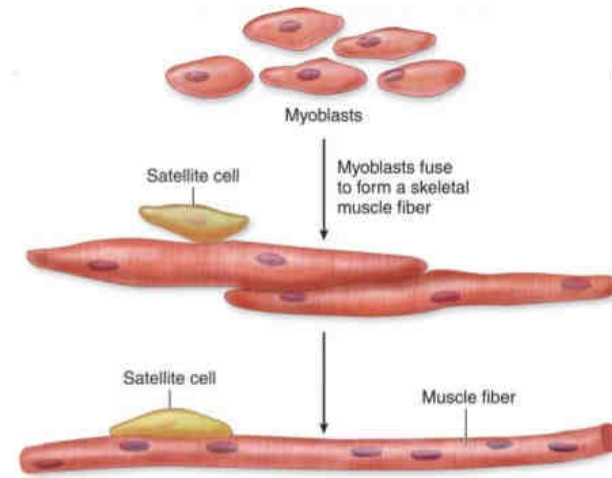
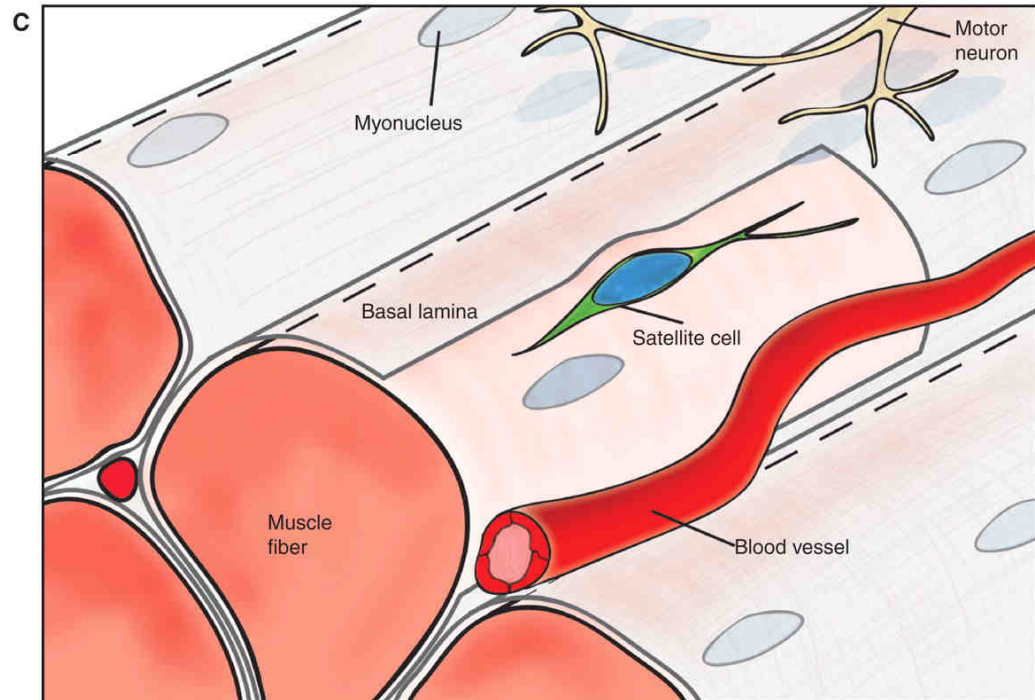
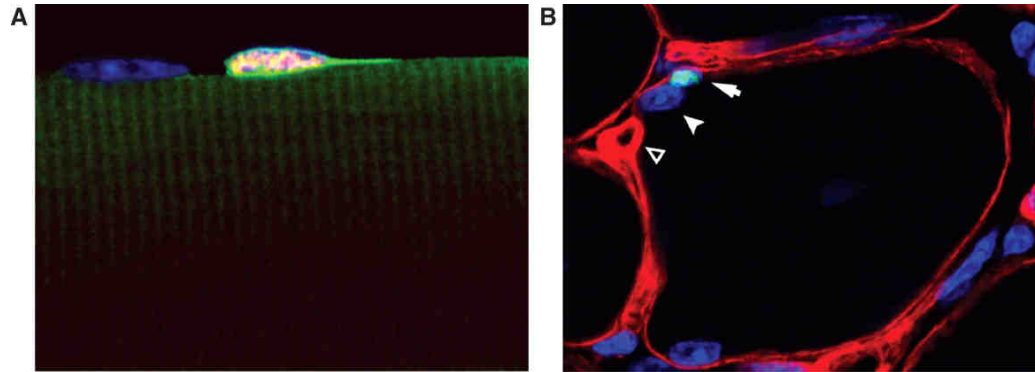
Hallmark	Skeletal muscle	Cardiac muscle	Smooth muscle
Cells	Thick, long, cylindrical, non-branched	Branched, cylindrical	Small, spindle-shaped
Nuclei	Abundant, peripherally	1-2, centrally	1, centrally
Filaments ratio (thin:thick)	6:1	6:1	12:1
sER and myofibrils	Regular sER around myofibrils	Less regular sER, myofibrils less apparent	Less regular sER, myofibrils not developed
T tubules	Between A-I band, triads	Z lines, diads	Not developed
Motor end plate	Present	Not present	Not present
Motor regulation	Voluntary control	No voluntary control	No voluntary control
Other	Bundles, c.t.	Intercalated discs	Caveoli, overlapping cells

Embryonic development

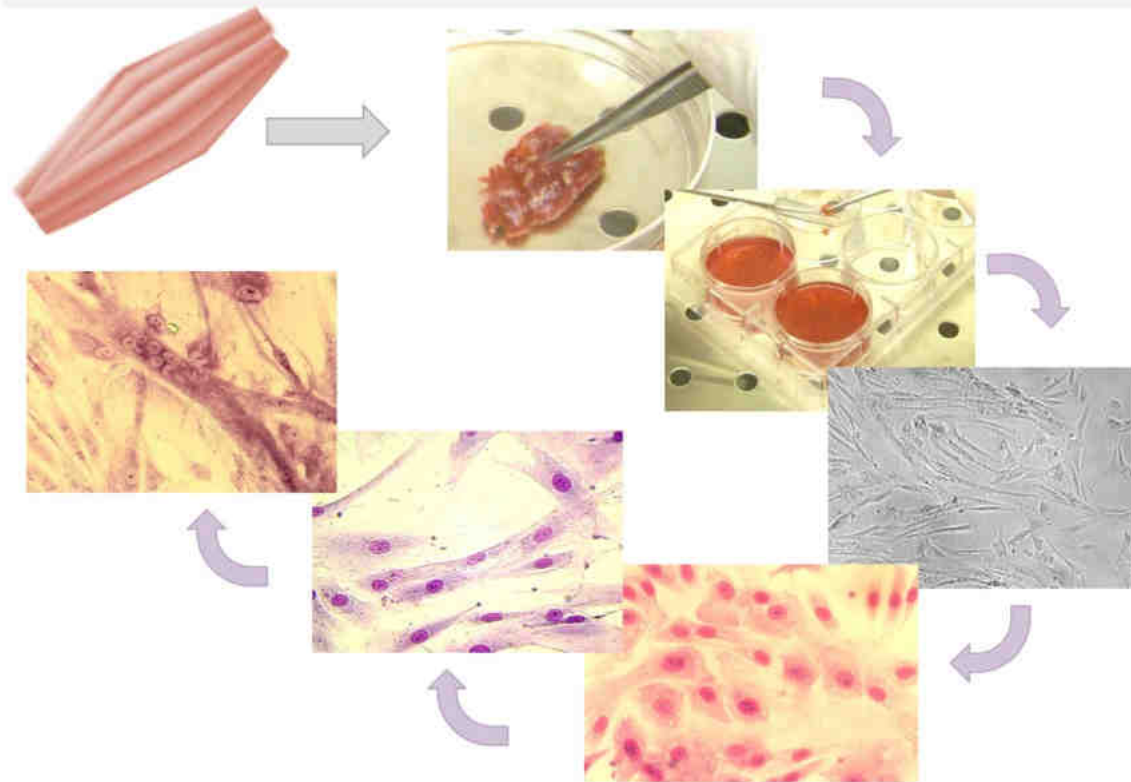
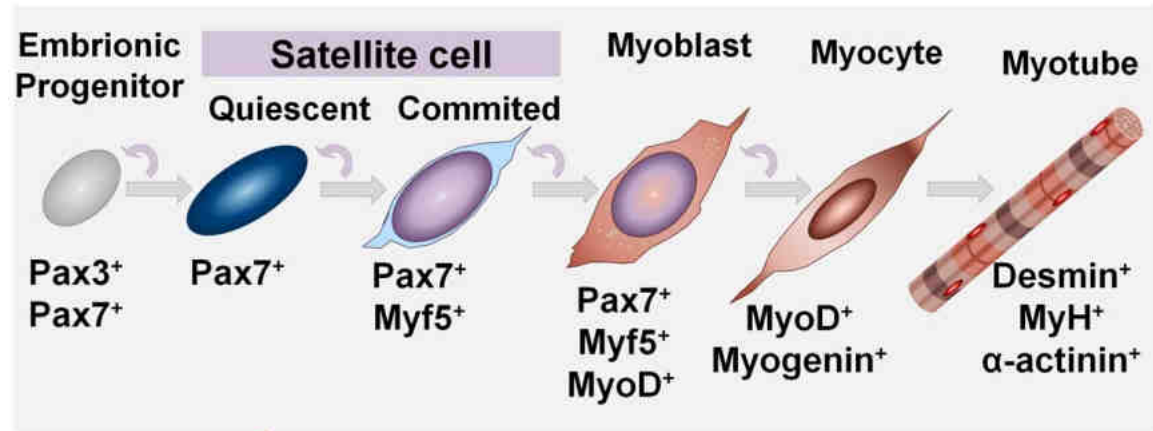


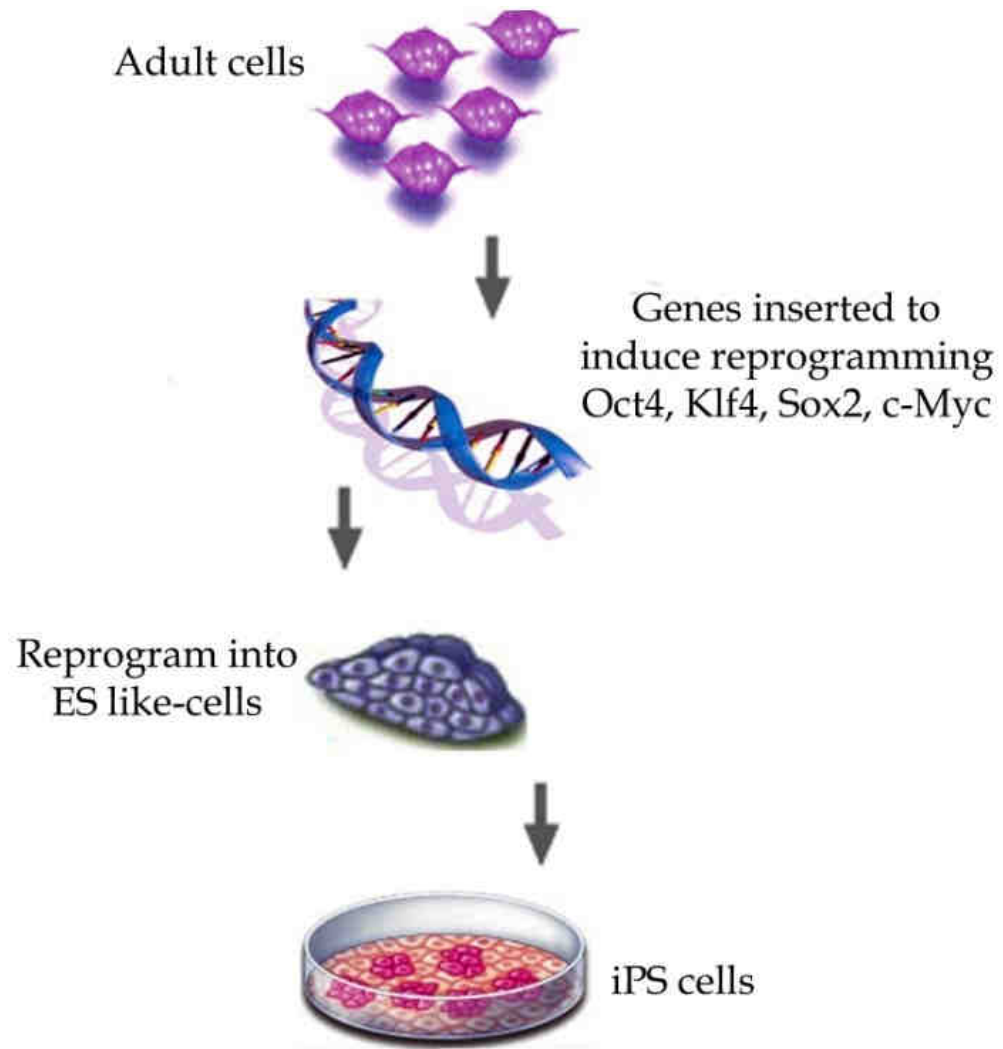


Regeneration



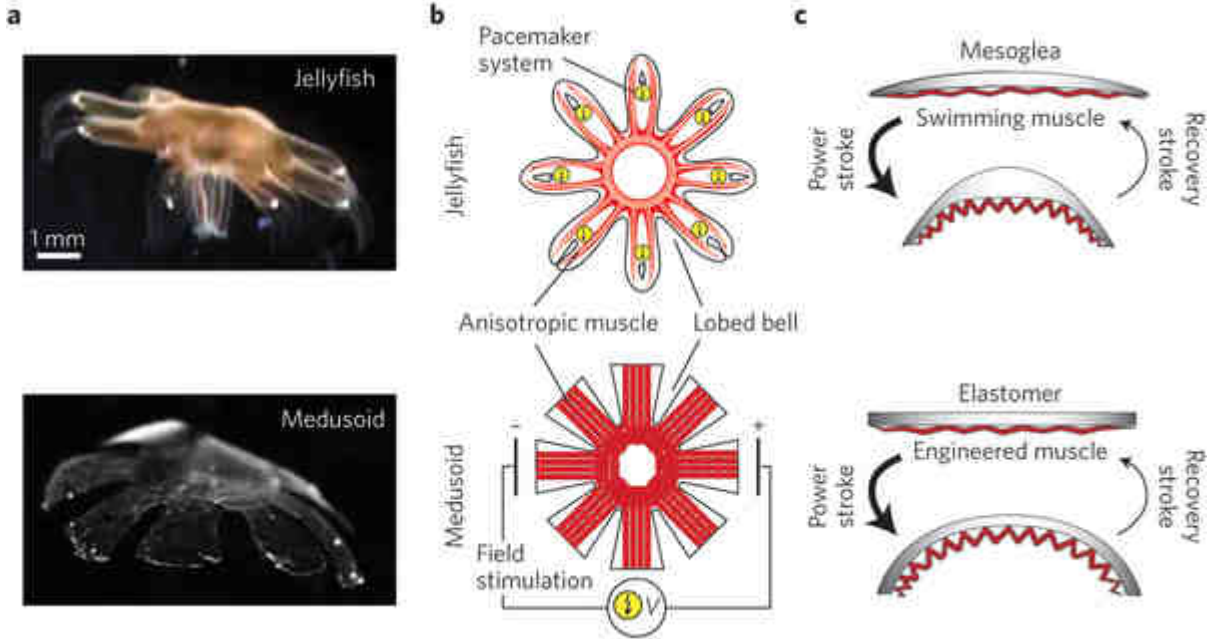
Regeneration





<https://www.youtube.com/watch?v=b1WD564sjWw>

Tissue engineering



Thank you for attention

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<http://www.med.muni.cz/histology>

