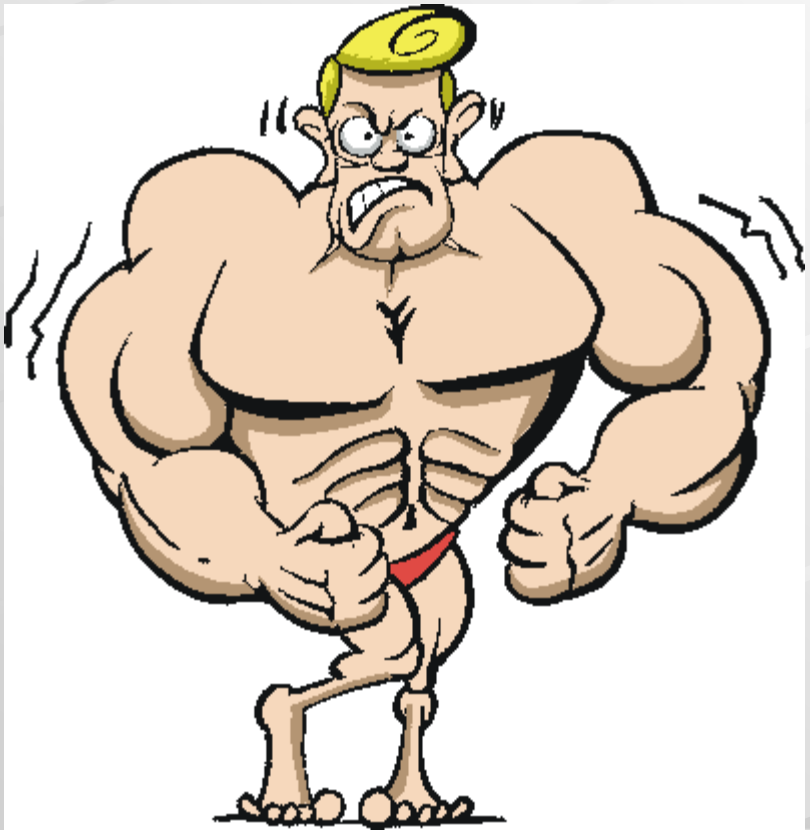
Muscle tissue

1) Striated skeletal muscle tissue.
2) Striated cardiac muscle tissue.
3) Smooth muscle tissue.



General characteristic of muscle tissue

- Origin: mesoderm and mesenchyme
- Excitability
- Contraction + relaxation ⇒ cause movement
- Composition: muscle cells + connective tissue (+blood vessels + nerves)
- contractile proteins in sarcoplasm – actin and myosin
- Long axis of cells is usually oriented paralelly with direction of contraction

Nomenclature

mys/myos (muscle)

myocyte (muscle cell)

sarx/sarcós (meat):

cell membrane = sarcolemma

cytoplasm = sarcoplasm

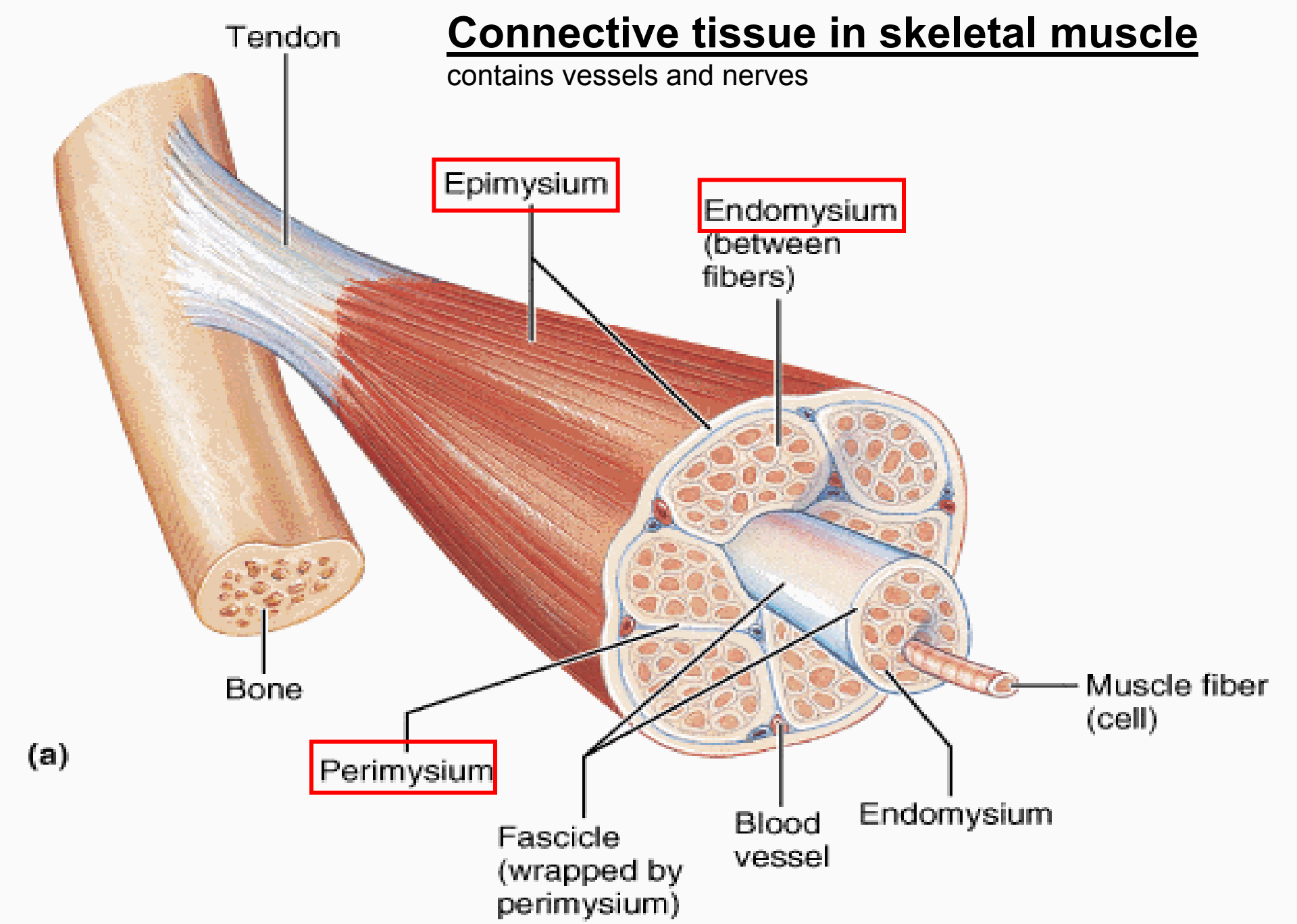
smooth ER = sarcoplasmic reticulum

Connective tissue of muscle

- Endomysium – around each muscle cell (fiber)
- Perimysium – around and among the primary bundles of muscle cells
- Epimysium – connective tissue „capsule“ covering the surface of muscle

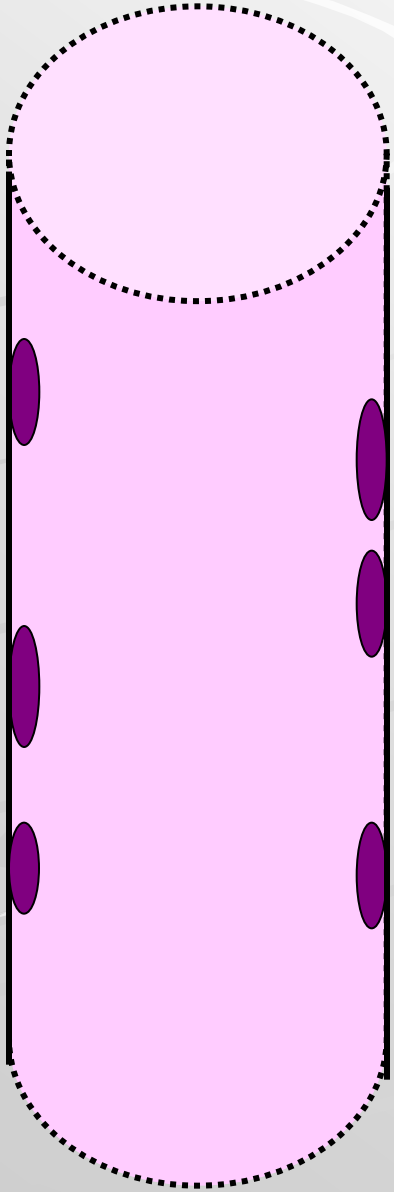
Connective tissue in skeletal muscle

contains vessels and nerves



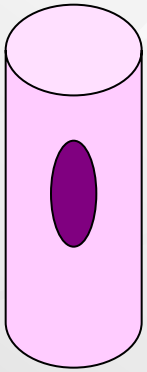
MUSCLE CELLS

rhabdomyocyte

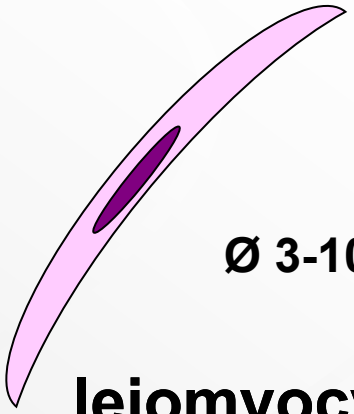


Ø 25-100 µm

cardiomyocyte



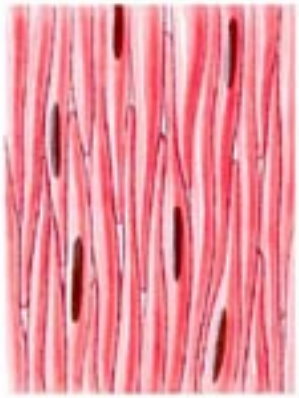
Ø 15 µm



Ø 3-10 µm

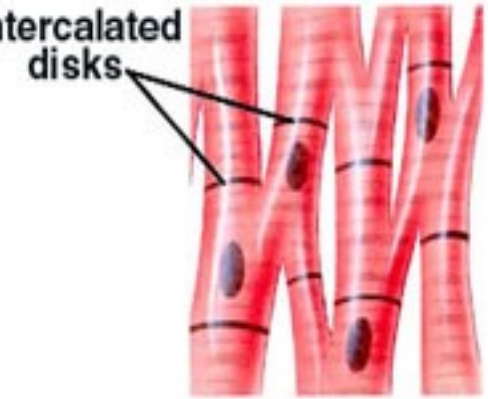
leiomyocyte

Types of Muscle

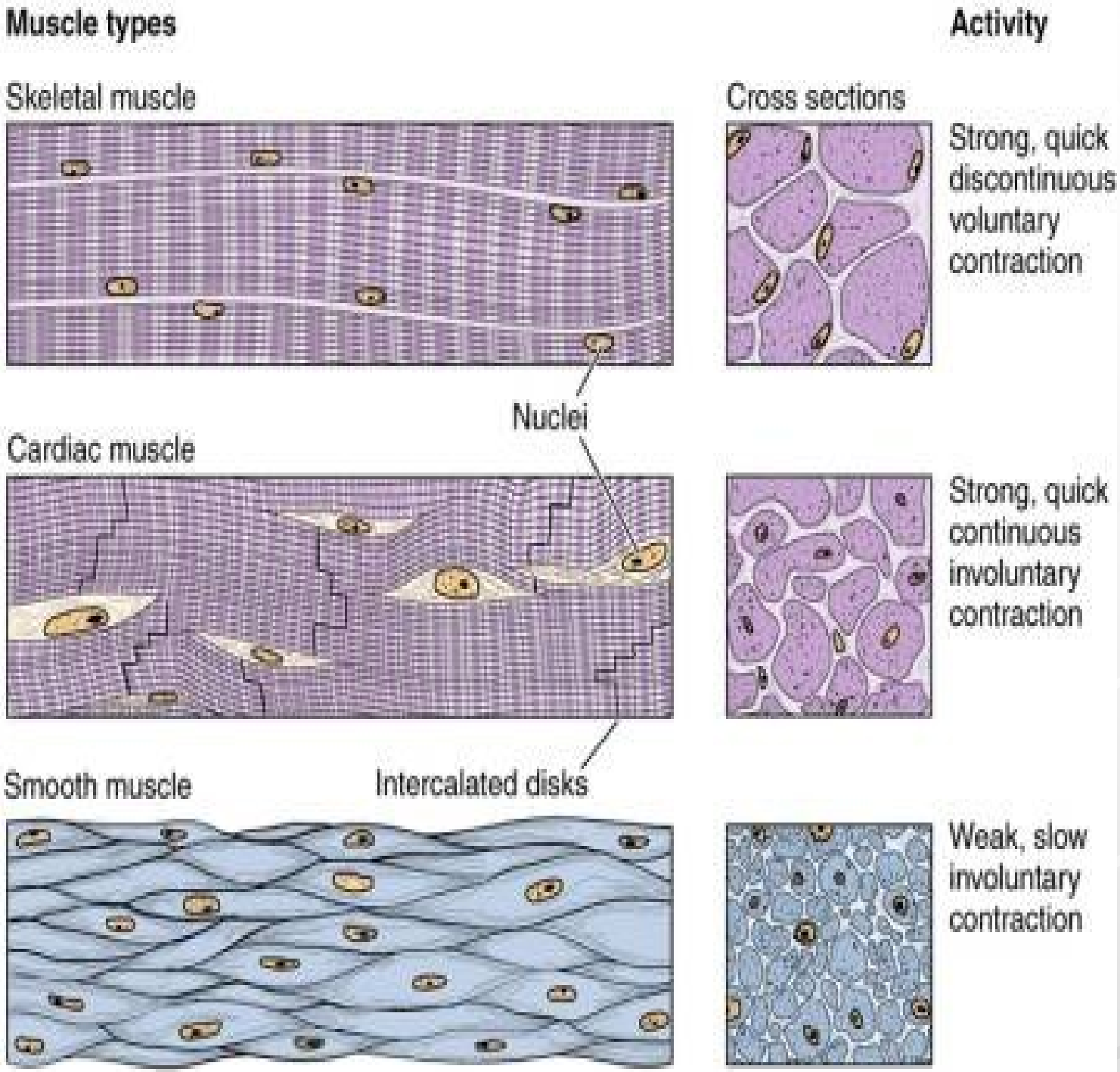


Smooth muscle

Skeletal muscle



Cardiac muscle



Occurrence:

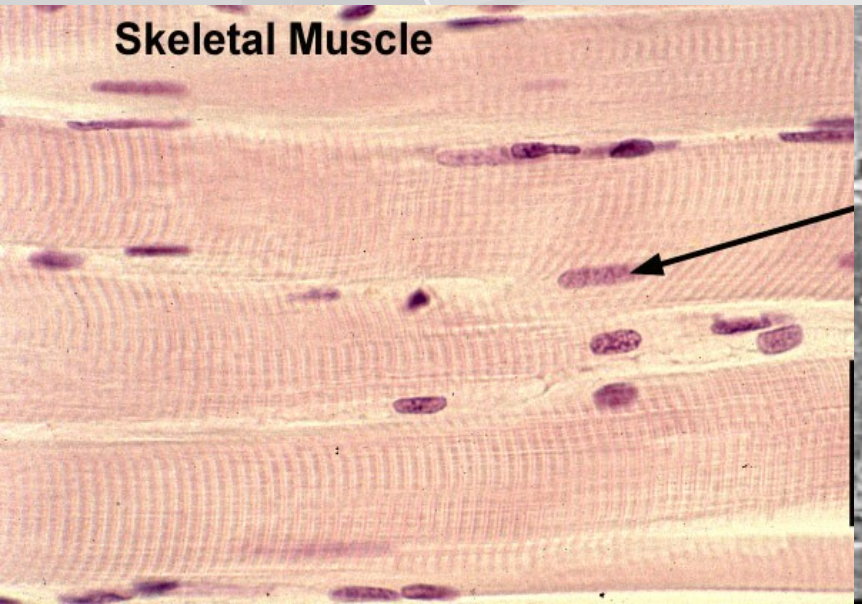
Skeletal muscles

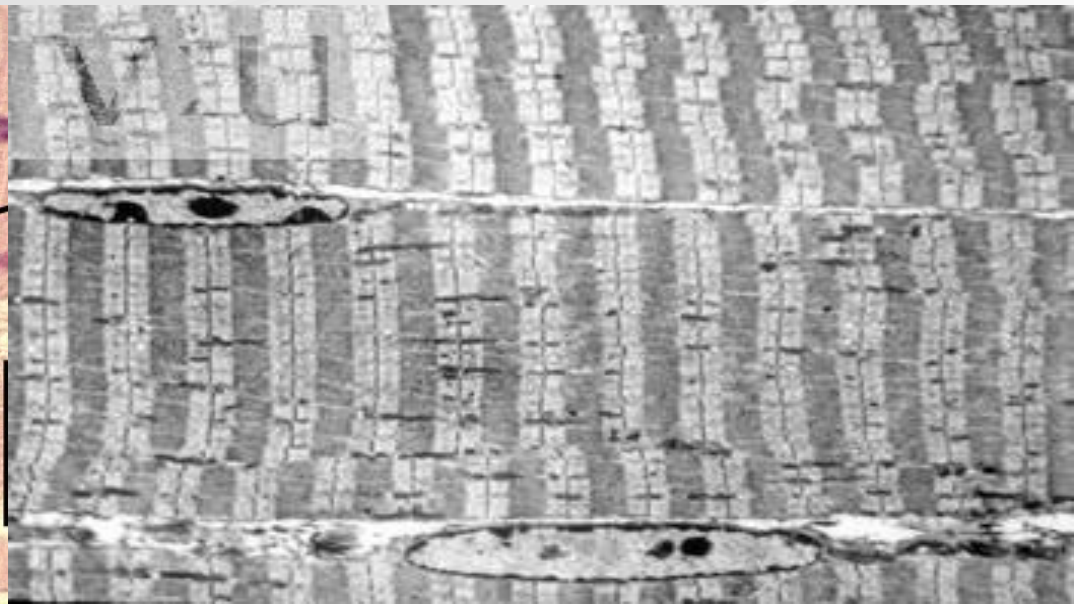
Heart

Inner organs (their wall

Cross-striated skeletal muscle tissue

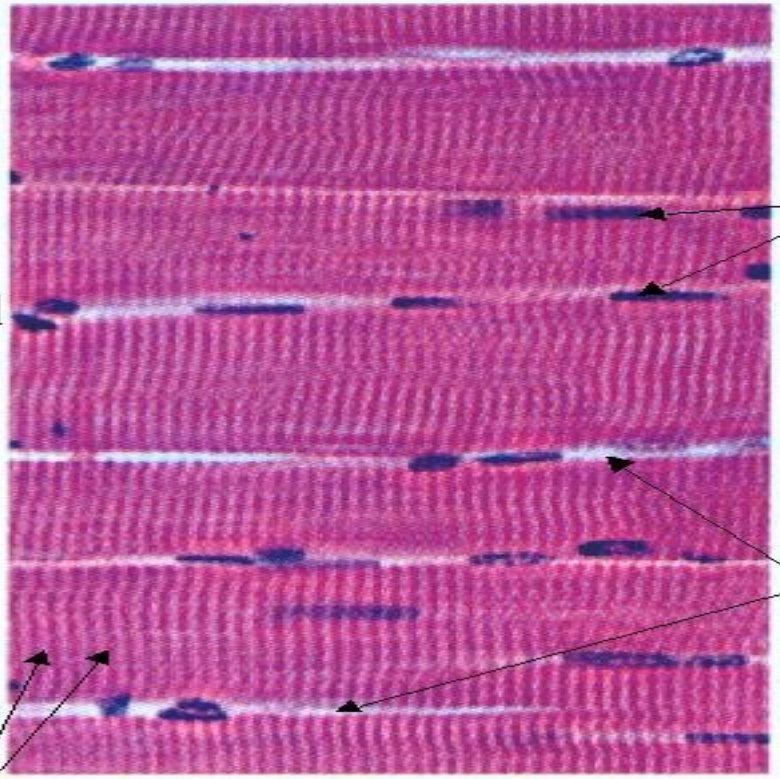
- **morphological and functional unit: muscle fiber (rhabdomyocyte)** – elongated, cylindrical shape, multinucleated cell (=syncytium) – nuclei are located at the periphery (beneath sarcolemma), myofibrils show cross striation
- diameter of muscle fiber: 25-100 μm
- length: milimeters - centimeters (up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





Skeletal Muscle Characteristics

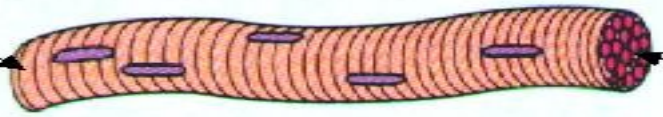
Skeletal muscle cells are long multinucleated cylinders, separated by connective tissue.



nuclei

Connective endomysium separates cells.

Striations are the dark bands perpendicular to cell length

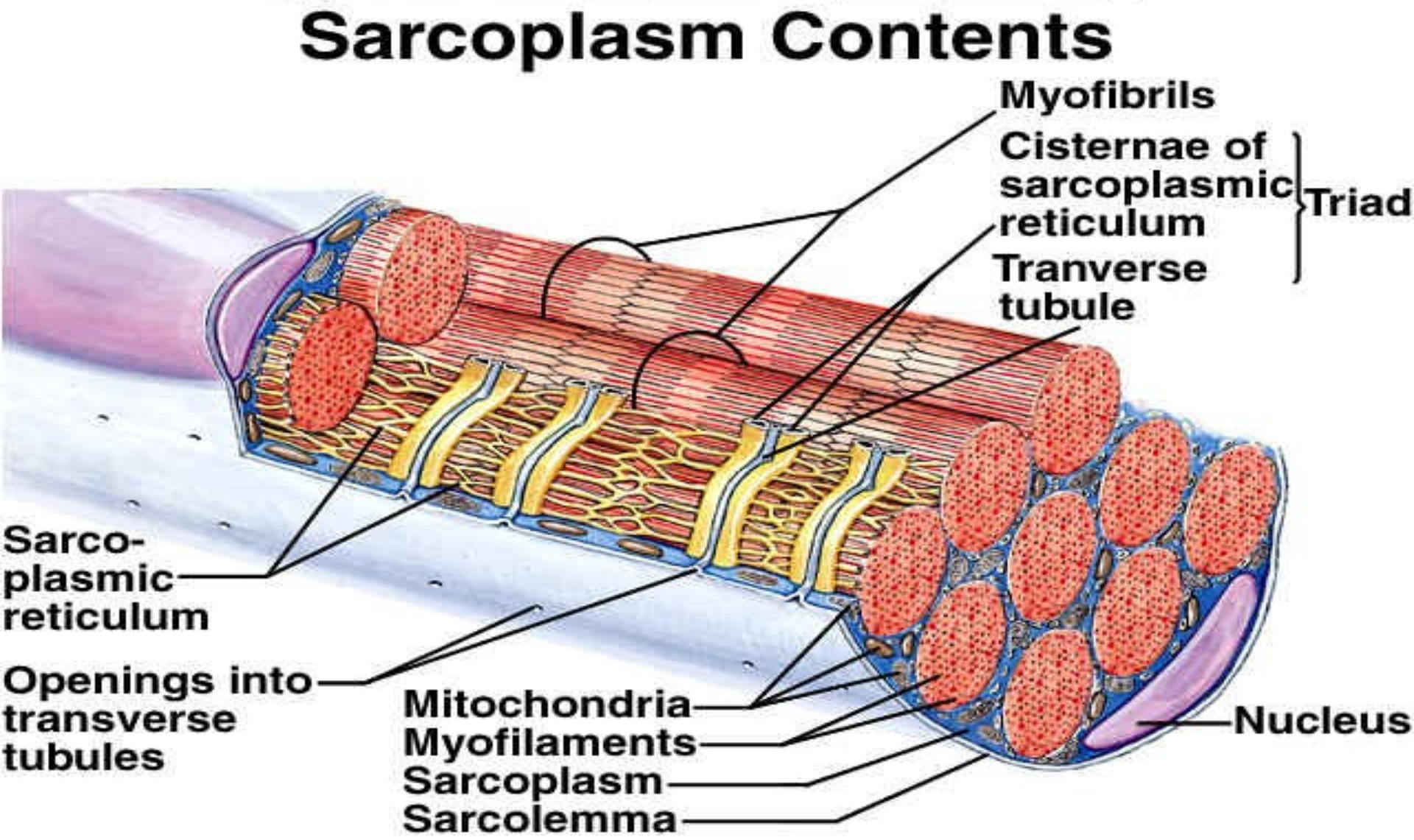


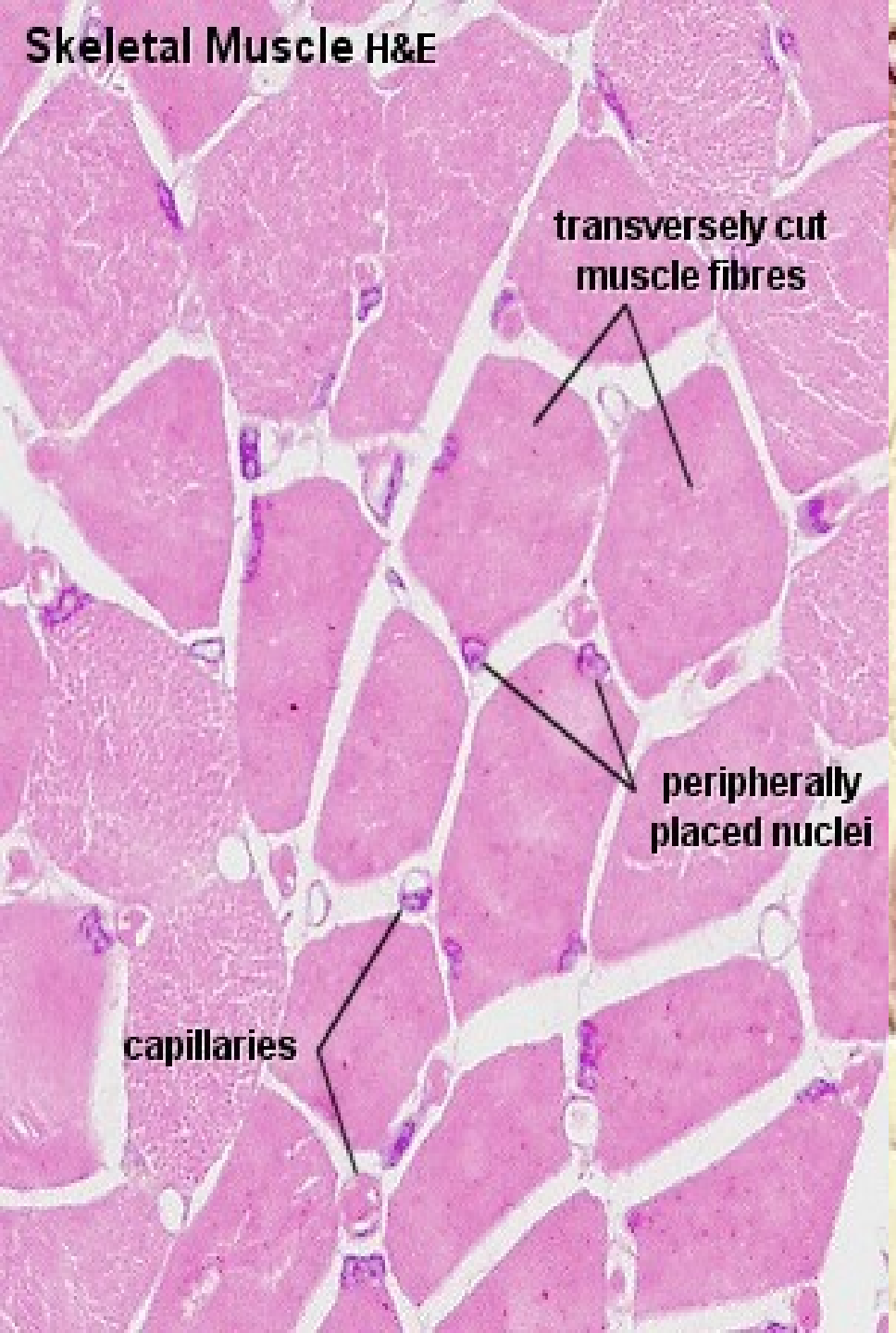
Myofibrils fill cell interior

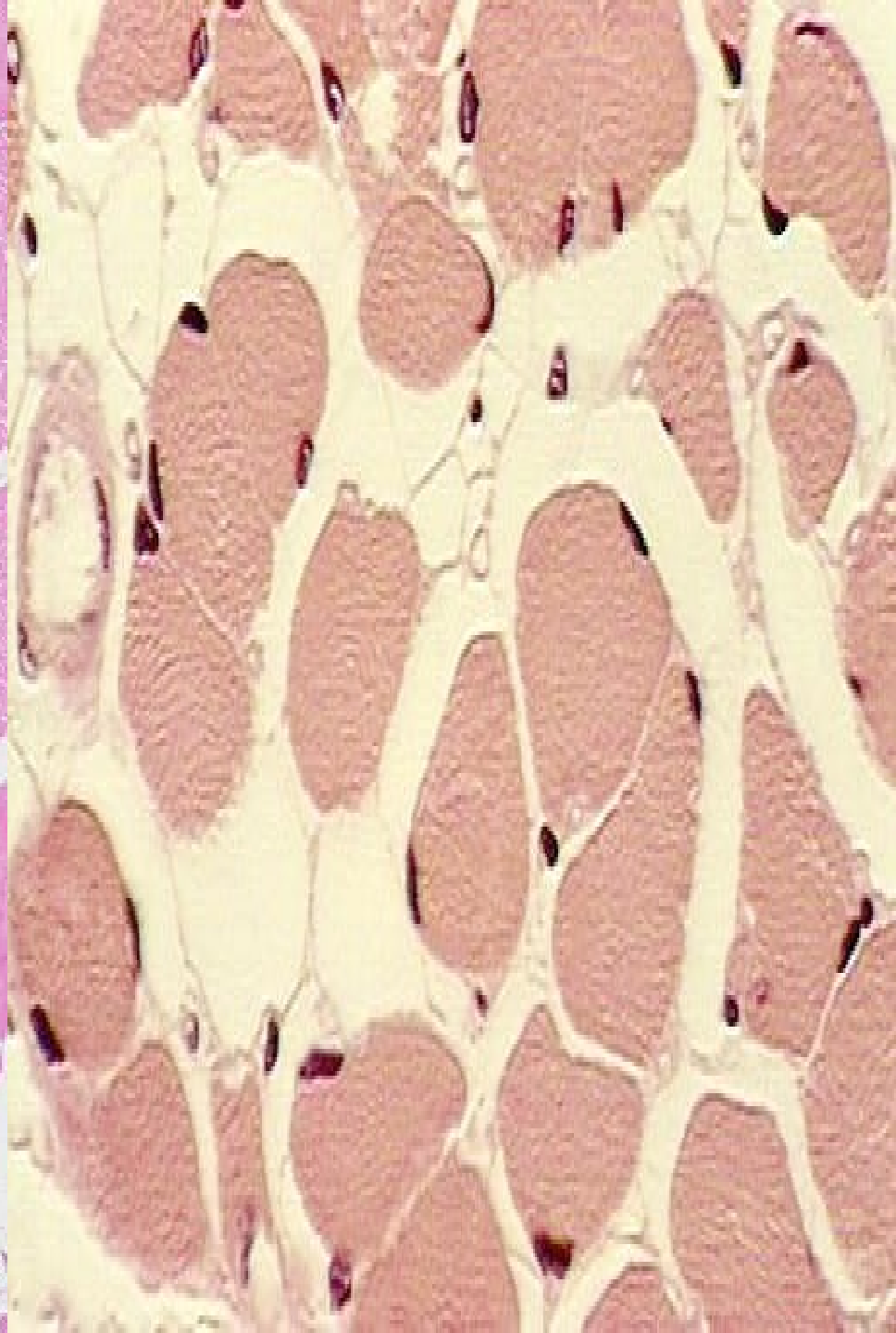
Structure of rhabdomyocyte

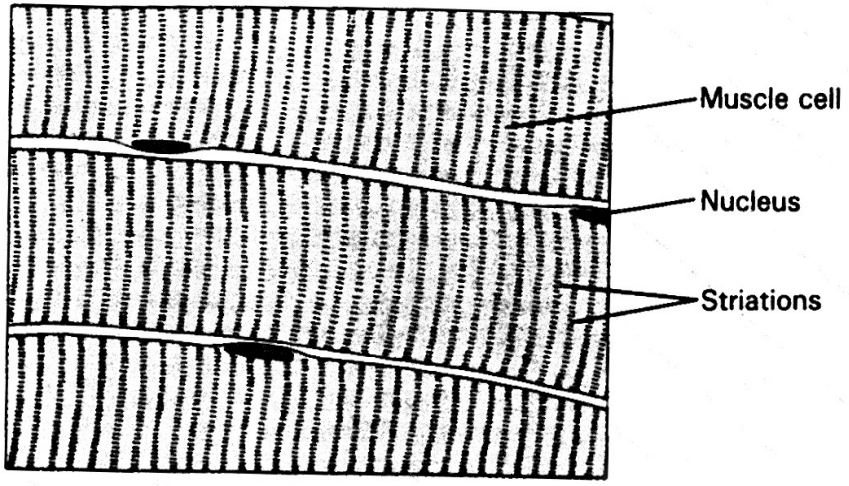
- **sarcolemma + T-tubules**
- **nuclei** (25-40 per 1mm of the length)
- **sarcoplasm:**
  - **myoglobin** (protein with heme (iron-containing porphyrin) prostetic group, and is the primary oxygen-carrying pigment
  - **myofibrils** (cross-striated 1–2 μm thick fibrils)
  - **organelles: mitochondria, Golgi apparatus, sarcoplasmic reticulum** (Ca^{2+} depot , sarcotubules, terminal cisternae)
  - **inclusion (glycogen)**

Rhabdomyocyte




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




Muscle cell
Nucleus
Striations

Skeletal muscle cell (fiber)
< rhabdomyocyte >

Used terms:

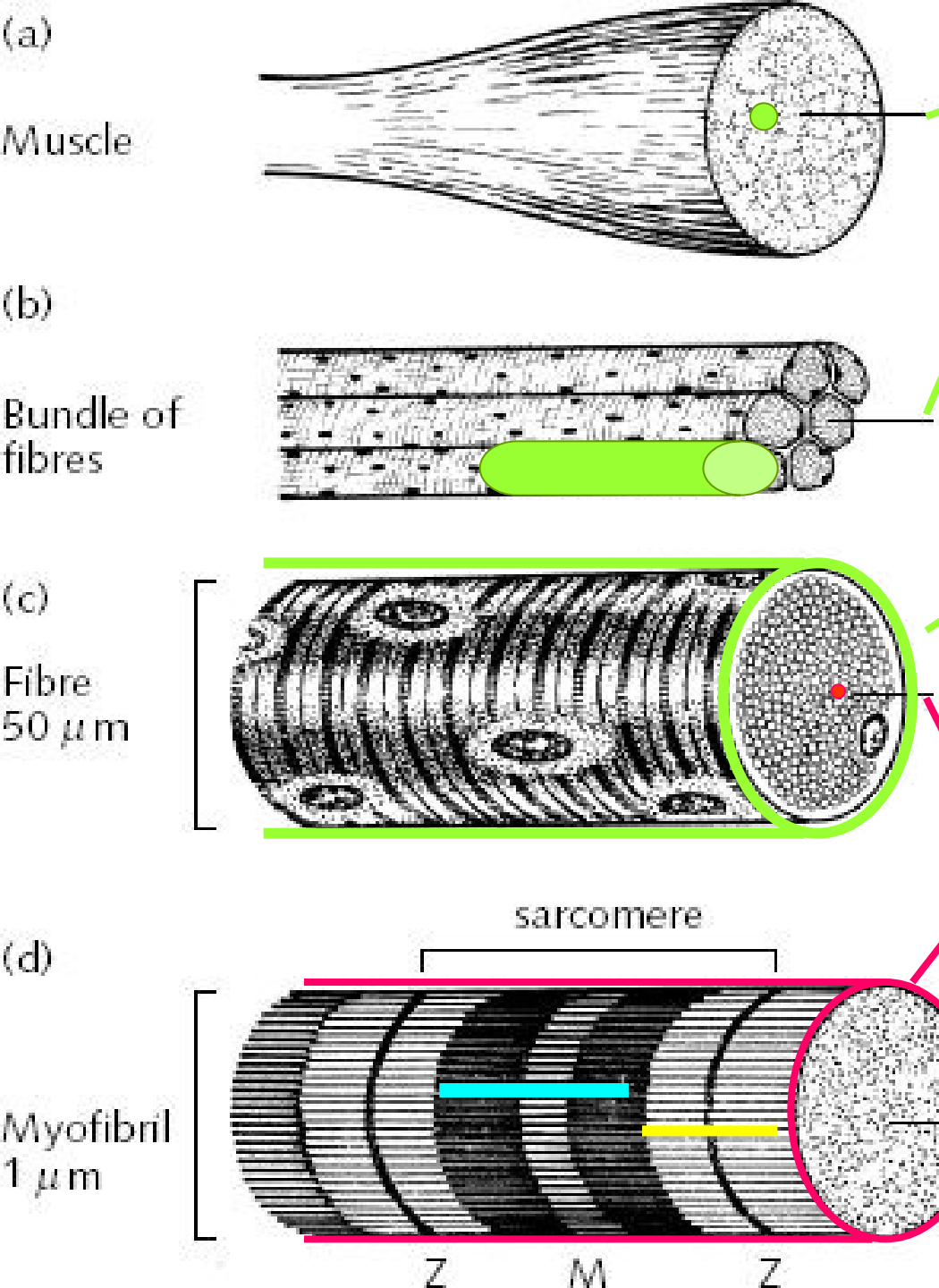
Muscle fiber = myofiber = syncitium = rhabdomyocyte

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

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

Myofilaments – actin and myosin, are organized into sarcomeres (several in the length of myofibril) [Ø 8 and 15 nm]

Sarcomere – the smallest contractile unit [2.5 μm in length]



Bundles of muscle fibrers

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

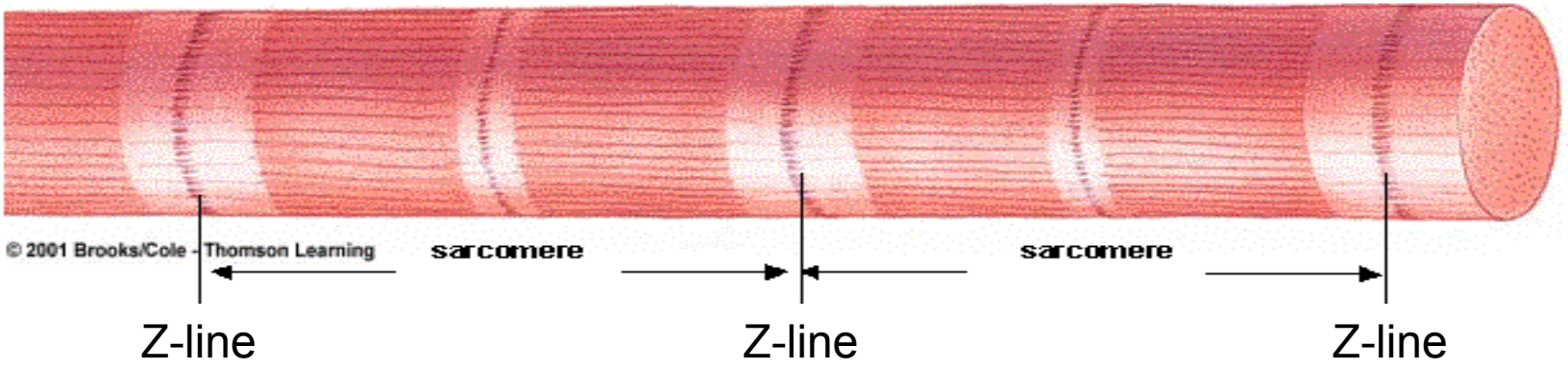
Myofibrils – compartment of fiber sarcoplasm [Ø 0.5 – 1.5 μ]

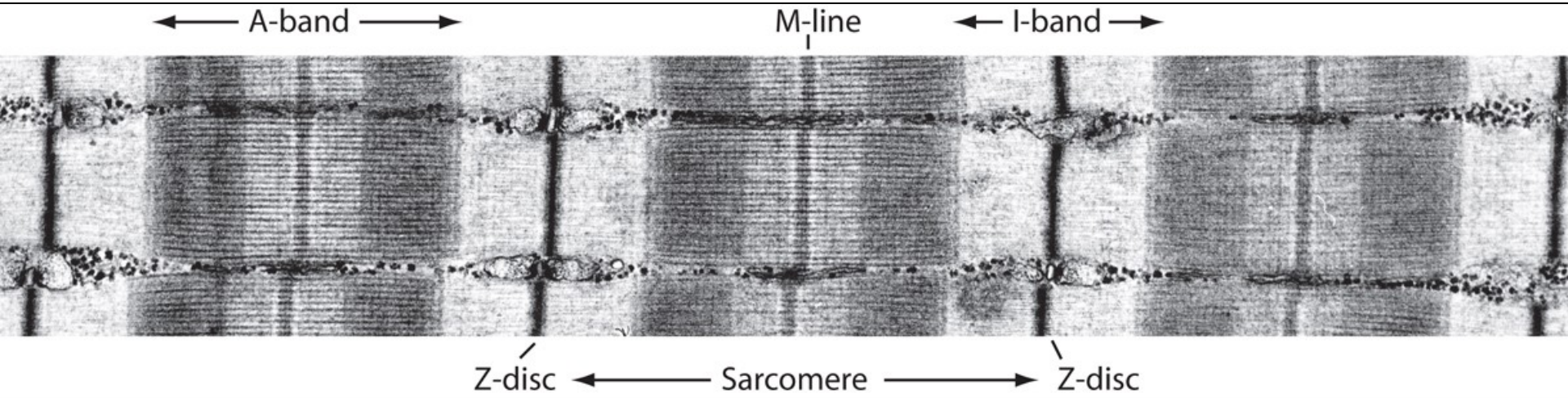
Myofilaments – **actin + myosin** are organized into sarcomeres (several in the length of myofibril) [Ø 8 and 15 nm]

Myofibril [Ø 0.5 – 1.5 μ]: elongated structure in sarcoplasm, oriented paralelly to the length of cell, composed of 2 types of myofilaments – actin and myosin – arranged into:

Sarcomere: the smallest contractile unit between Z-lines on myofibril

(organization of myofilaments causes cross striation of myofibrils)





Myofibril structure

izotropic parts (I-bands) – light, Z-line (telophragma)

anizotropic parts (A-bands) – dark, M-line (mesophragma), H-band

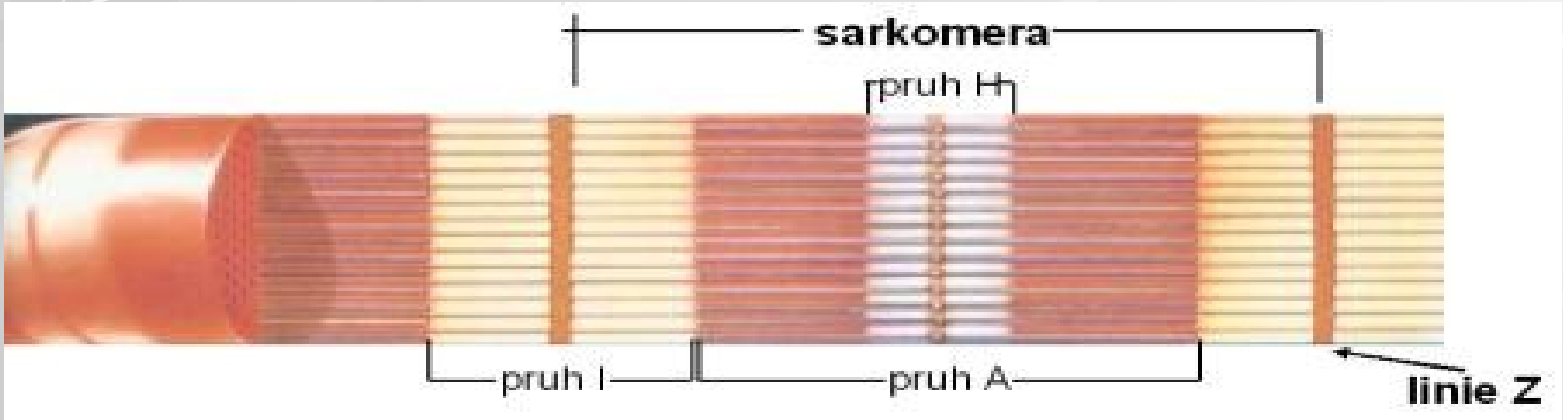
Myofilaments

Thick: only in A-band, **myosin, 15 nm thick, 1.6–1.8 µm long**

Thin: in I-band and at periphery of A-band), **F-actin and regulatory proteins** (troponin, tropomyosin), **6 nm thick, 1.5 µm long**

Principle of myofibril shortening during muscle contraction: sliding mechanism mechanismu

the length of myofilaments does not change during contraction



MYOFIBRIL

SARCOMERE

Z – line

M – line

Z – line

H - zone

Myofilaments:

actin

actin – myosin – actin

actin

I - band

A – band

I - band

Muscle Microfilaments

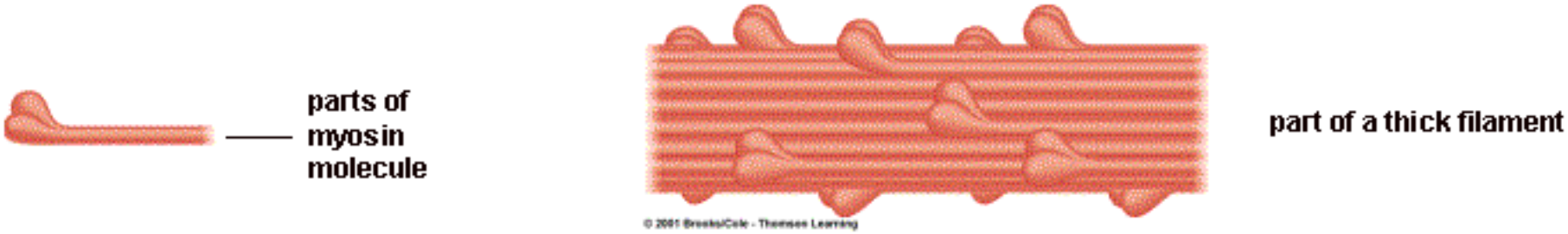
Thin filaments

- Like two strands of pearls twisted together
- Pearls are actin
- Other proteins in grooves in filament

Thick filaments

- Composed of myosin
- Each myosin molecule has tail and a double head

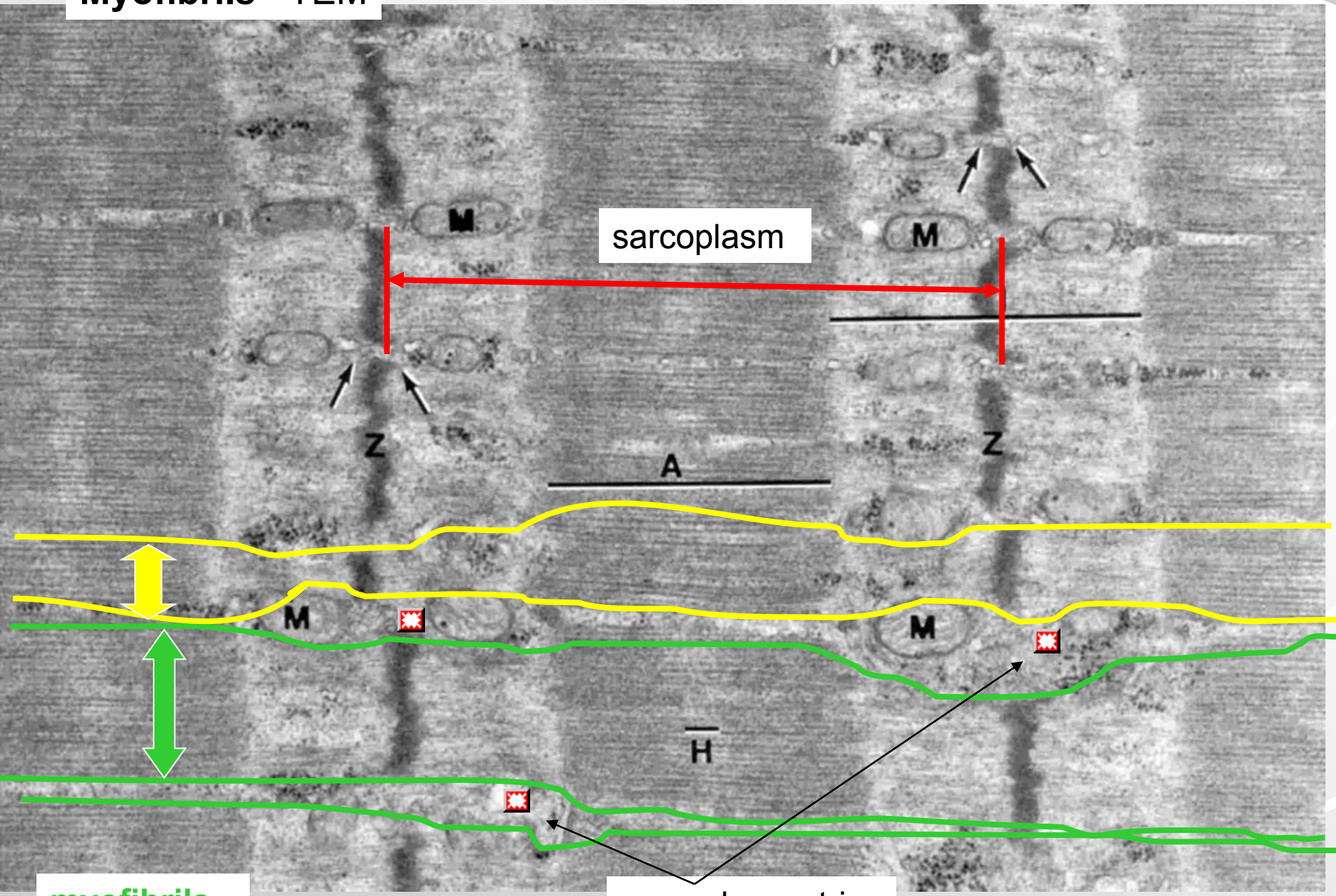
Arrangement of actin molecules in the thin filaments of a sarcomere

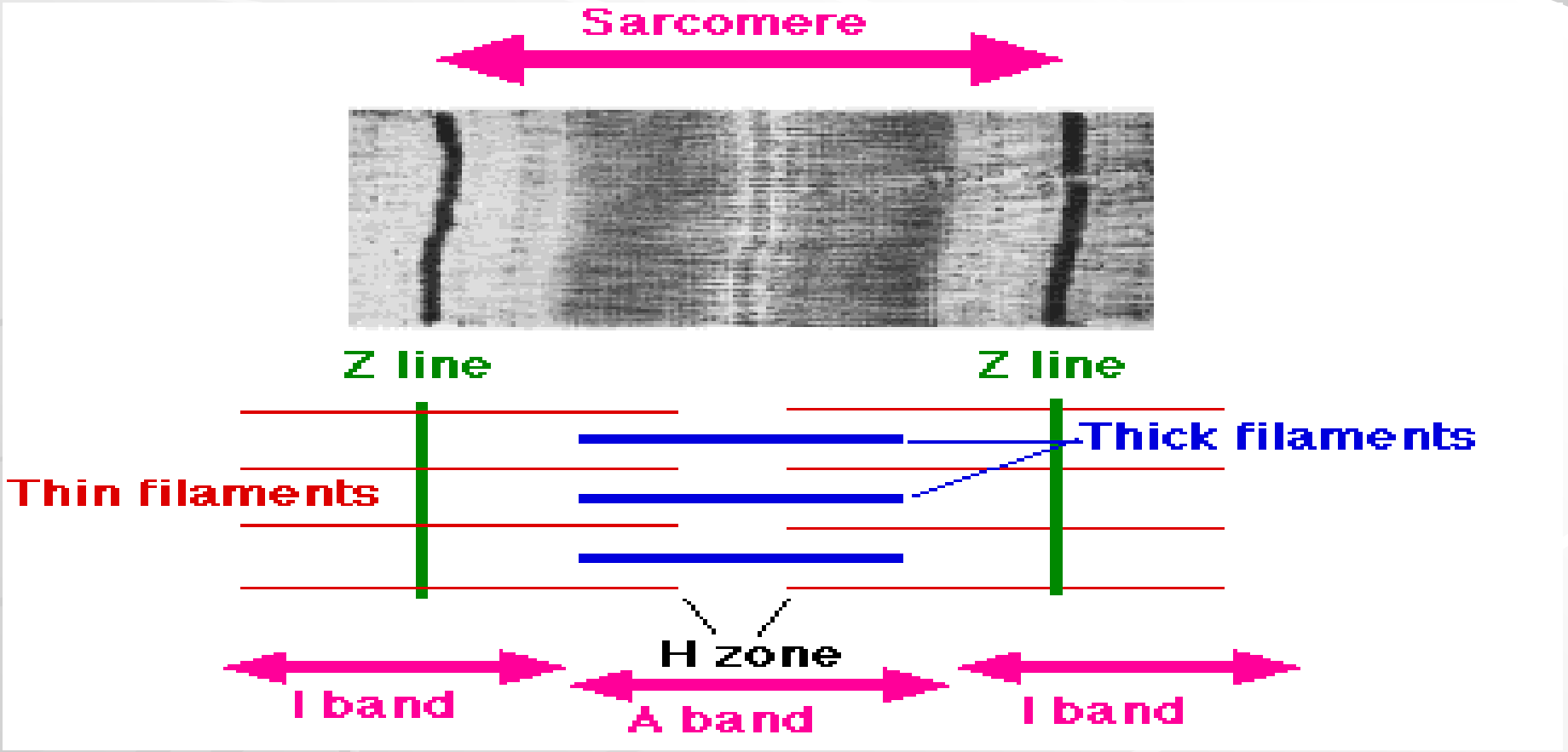


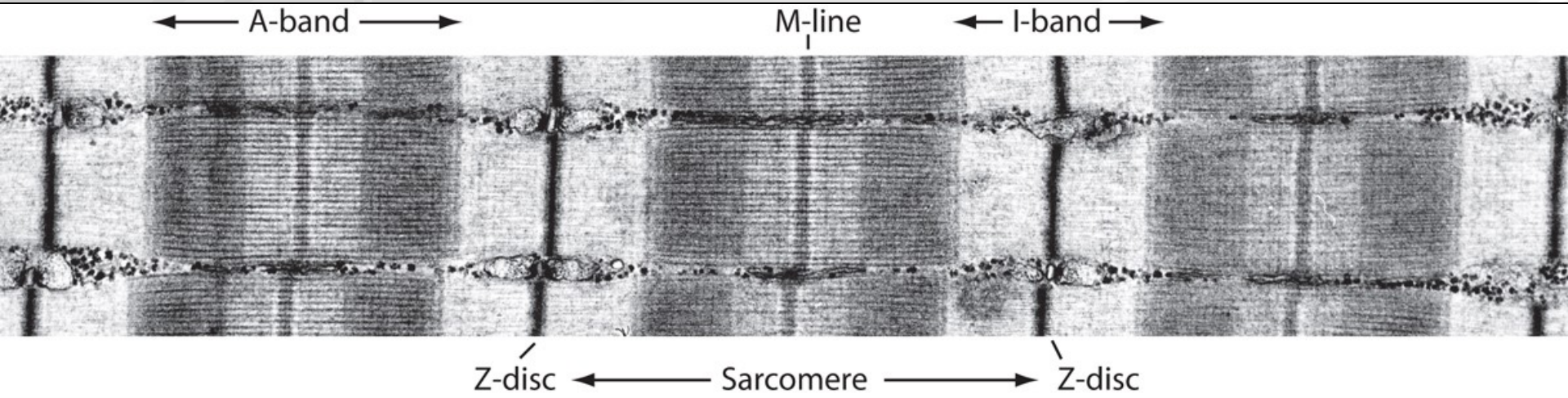
Arrangement of myosin molecules in the thick filaments of a sarcomere


M
I band
A band
I band
Td
Td
TC
T
TC
M
SR
Td
M
Td
SR
0.5 μm

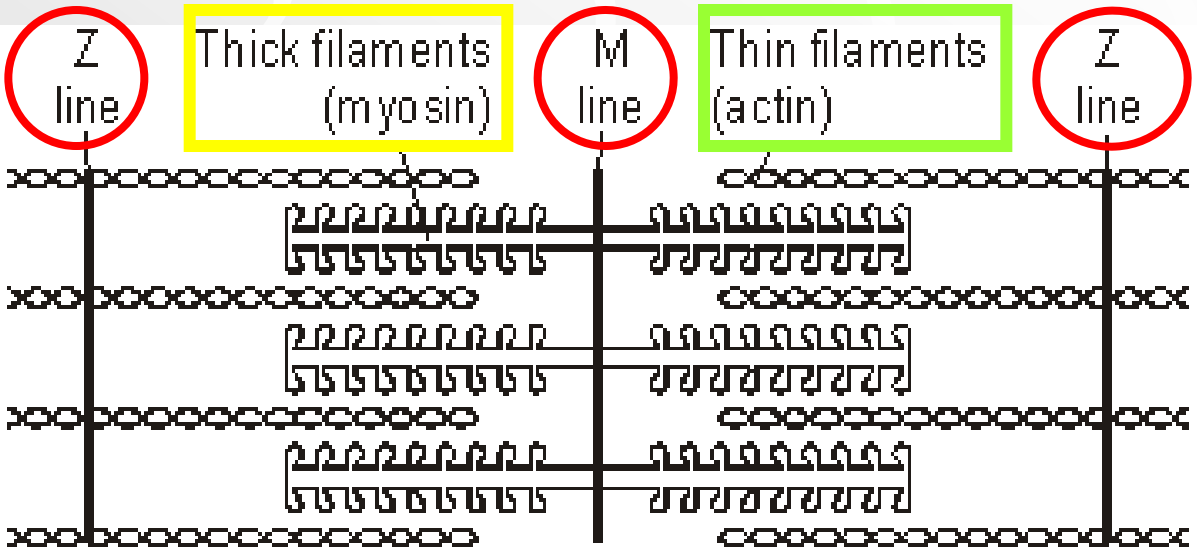
Myofibrils - TEM

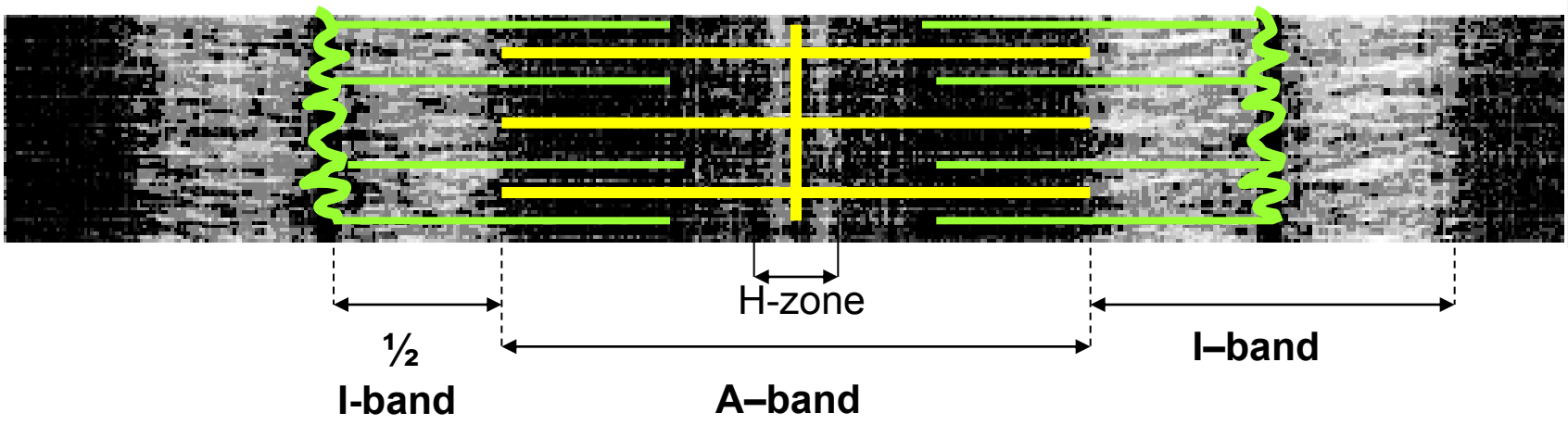


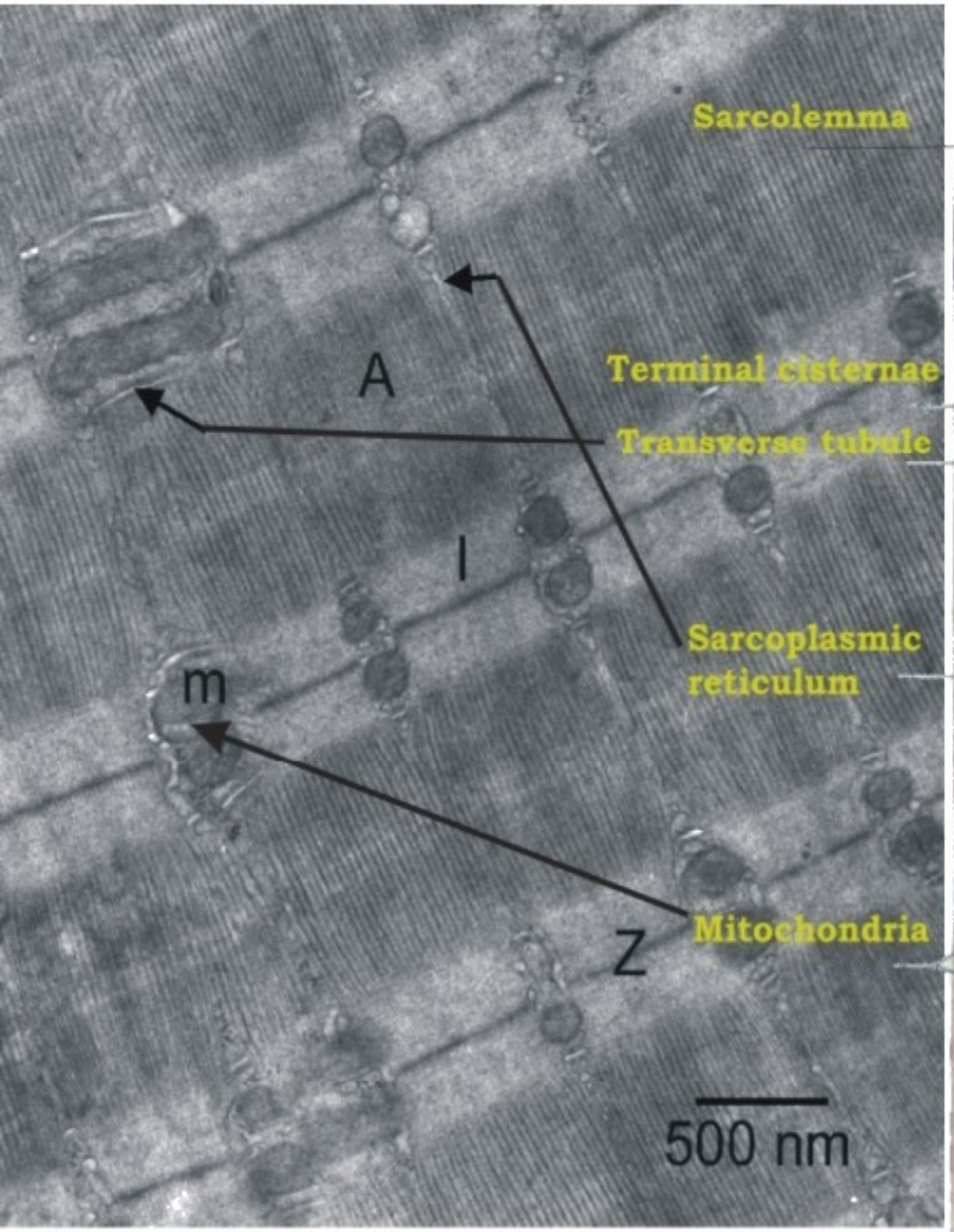

Sarcomere
Z line
Z line
Thick filaments
Thin filaments
H zone
I band
A band
I band

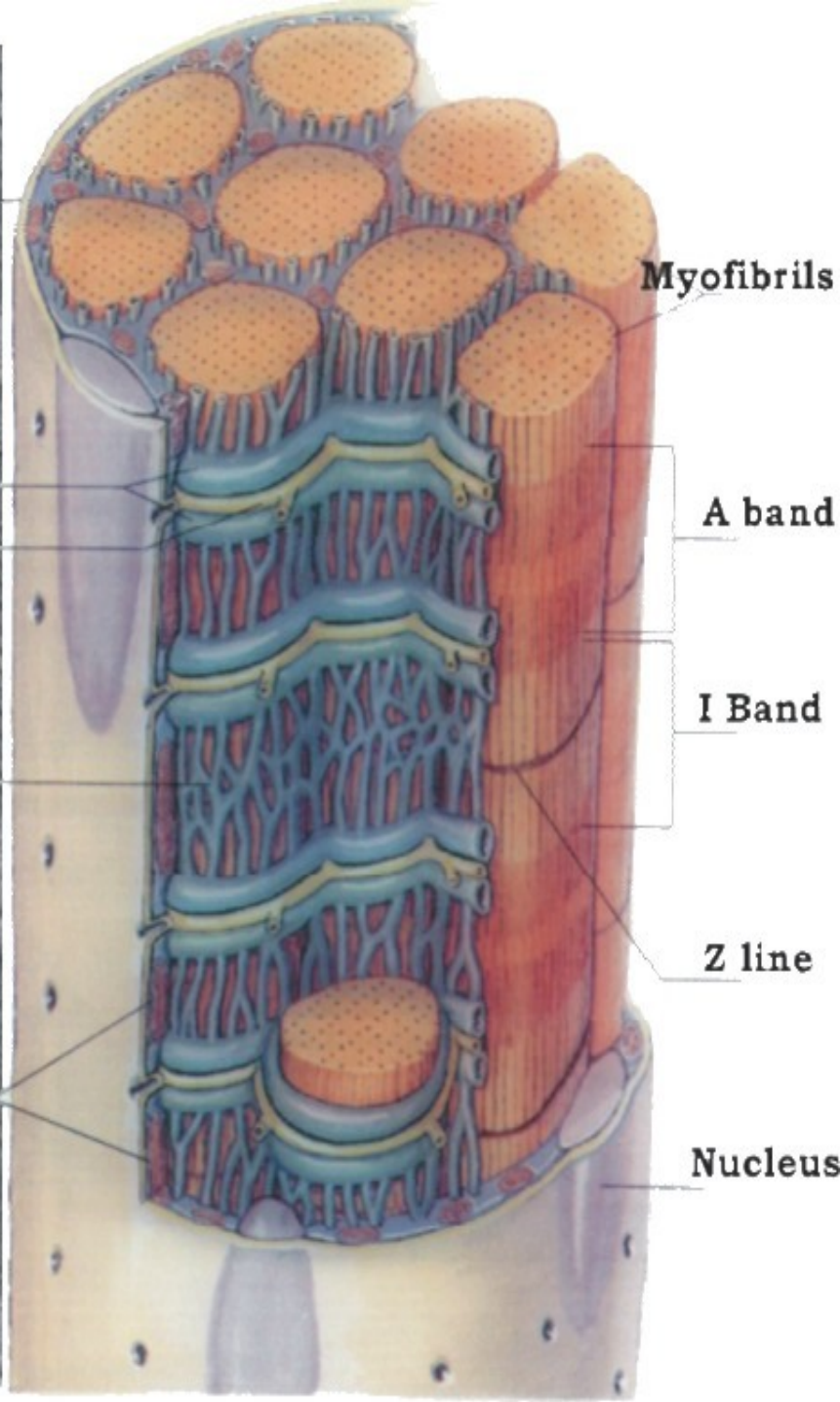

A-band
M-line
I-band
Z-disc
Sarcomere
Z-disc

Sarcomere

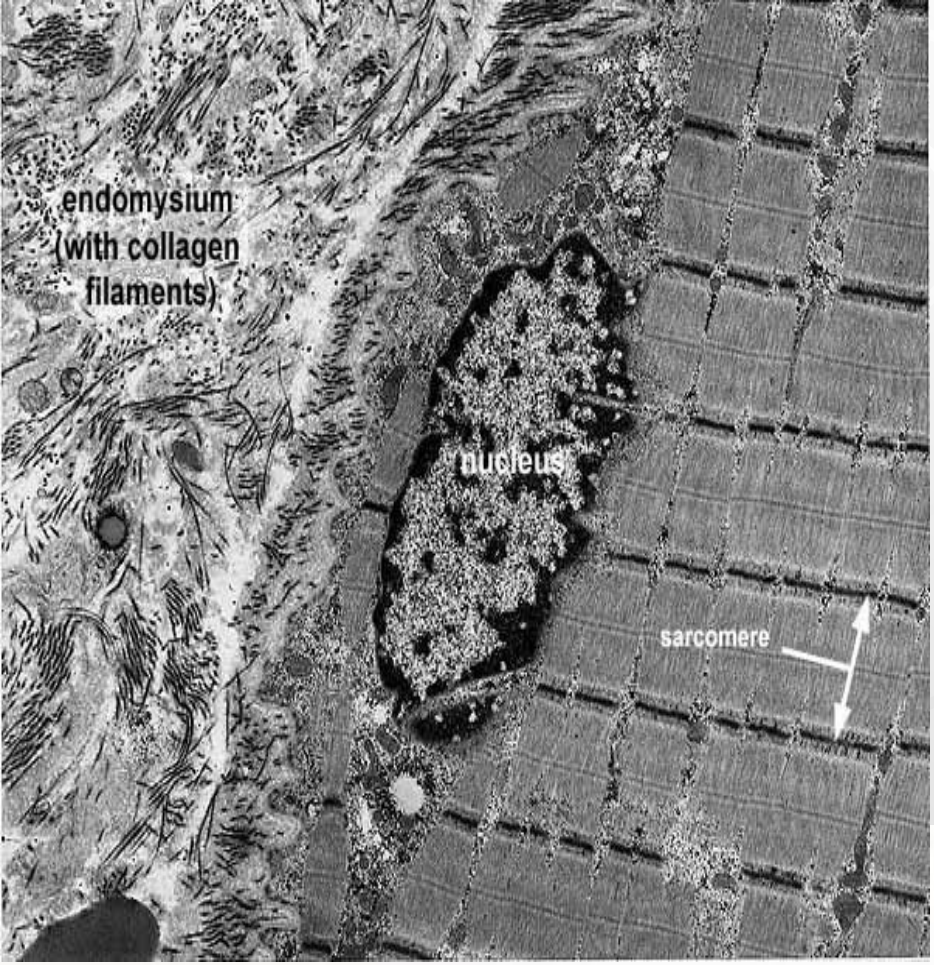

Z line
Thick filaments (myosin)
M line
Thin filaments (actin)
Z line

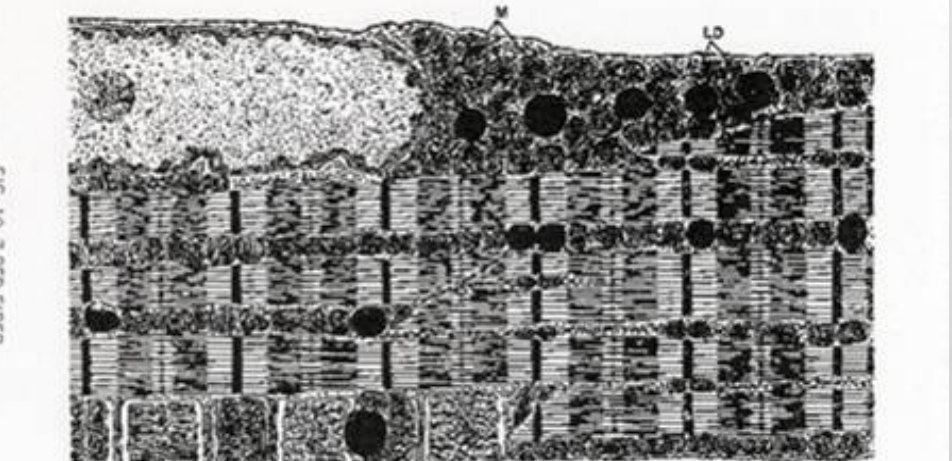

H-zone
½ I-band
A–band
I–band

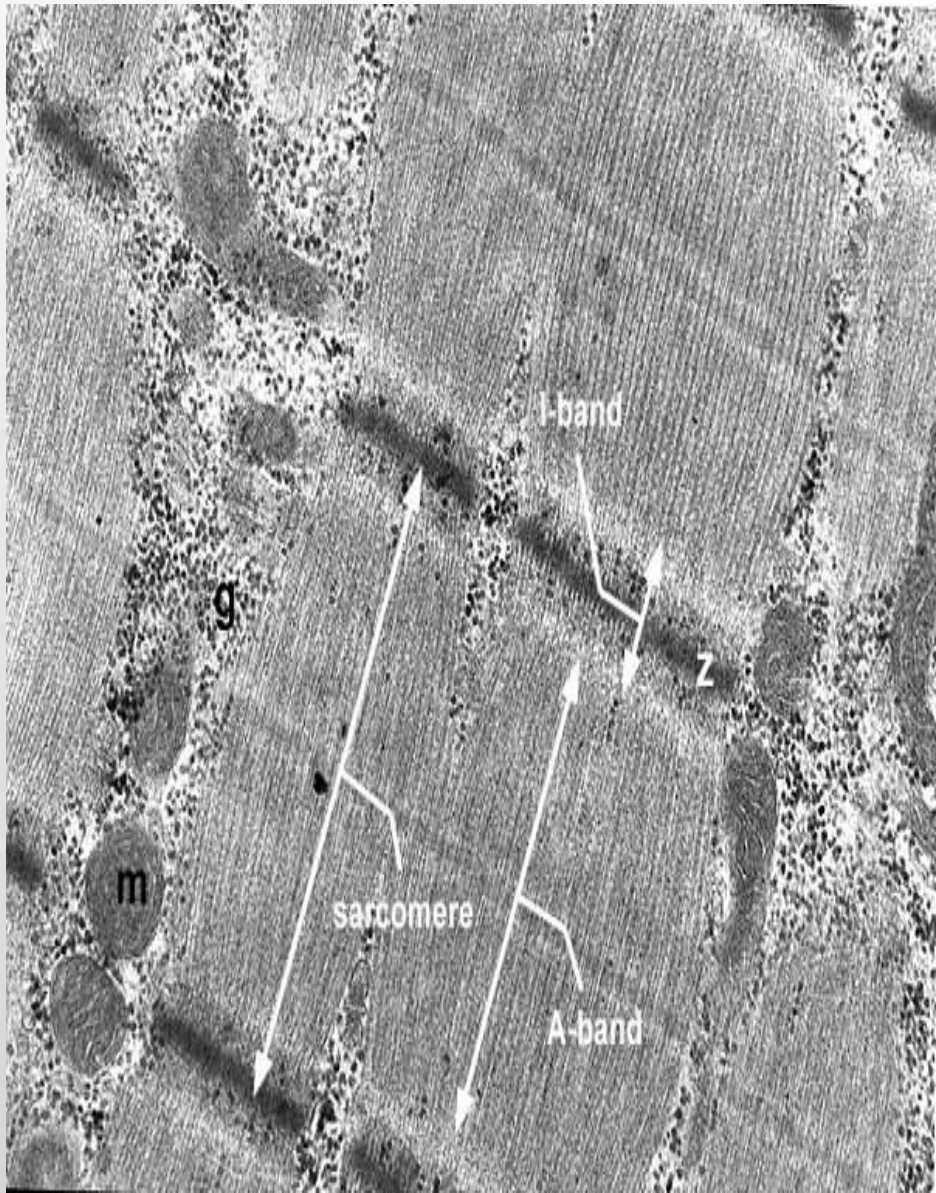

Sarcolemma
A
Terminal cisternae
Transverse tubule
I
Sarcoplasmic reticulum
m
Mitochondria
Z
500 nm


Myofibrils
A band
I Band
Z line
Nucleus

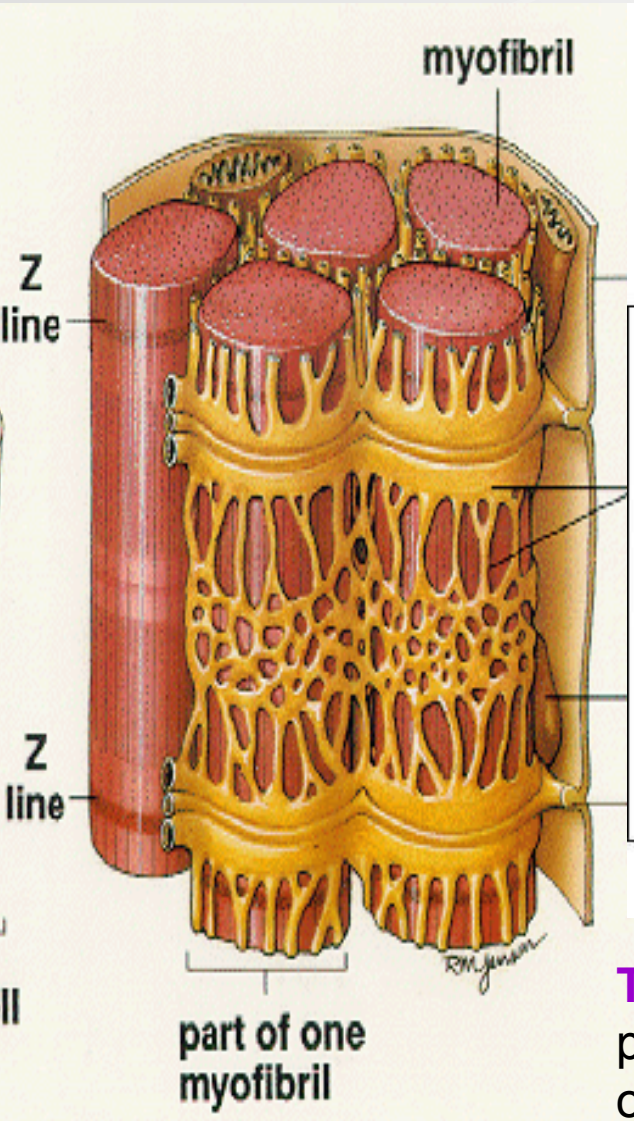
Skeletal muscle in EM

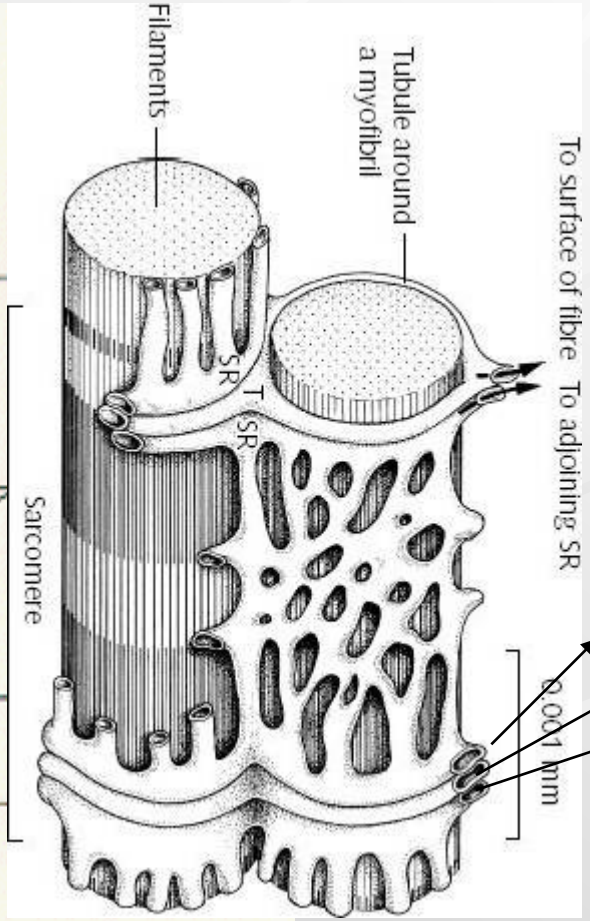






Sarcoplasmic reticulum, t-tubule



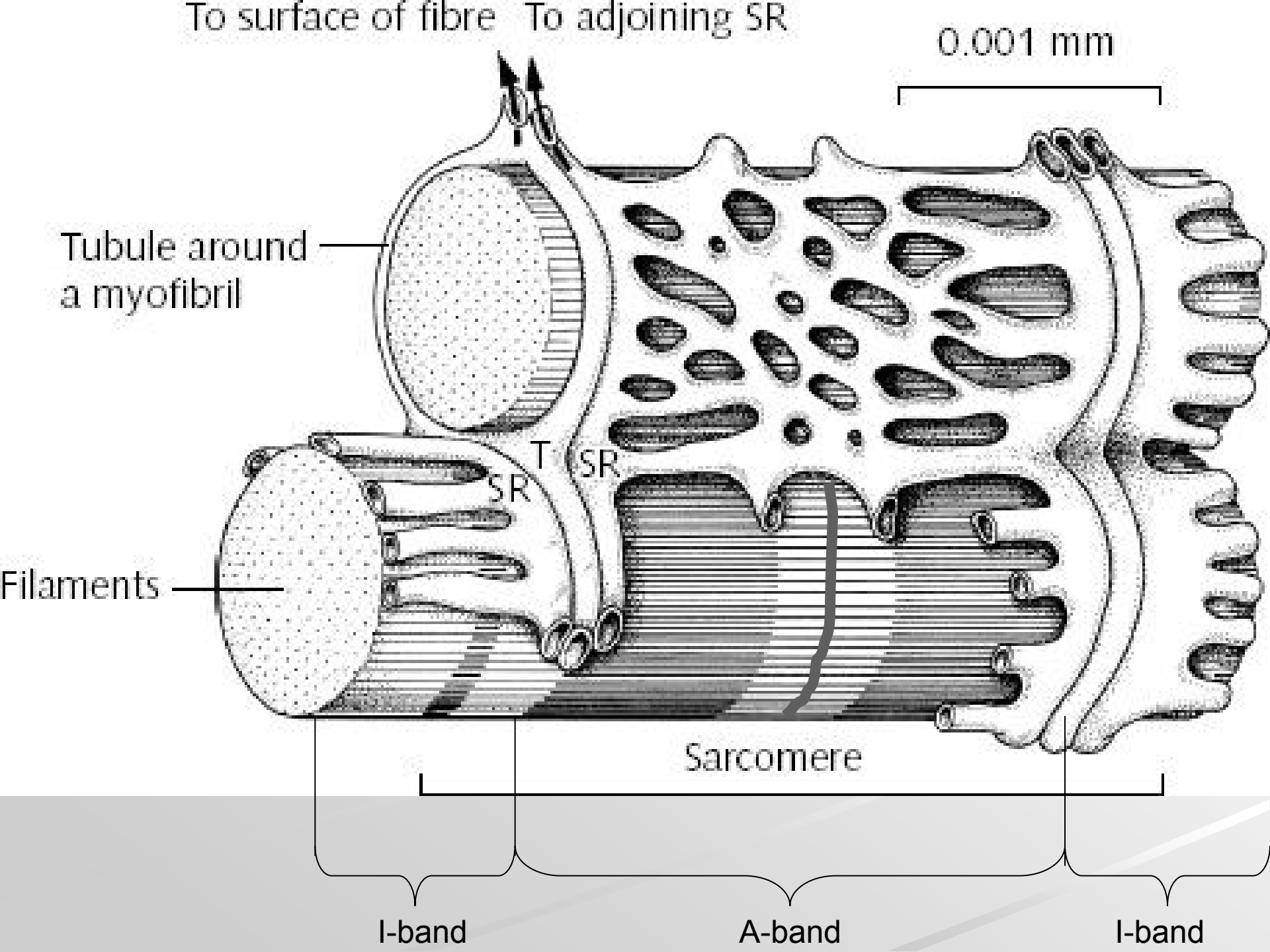


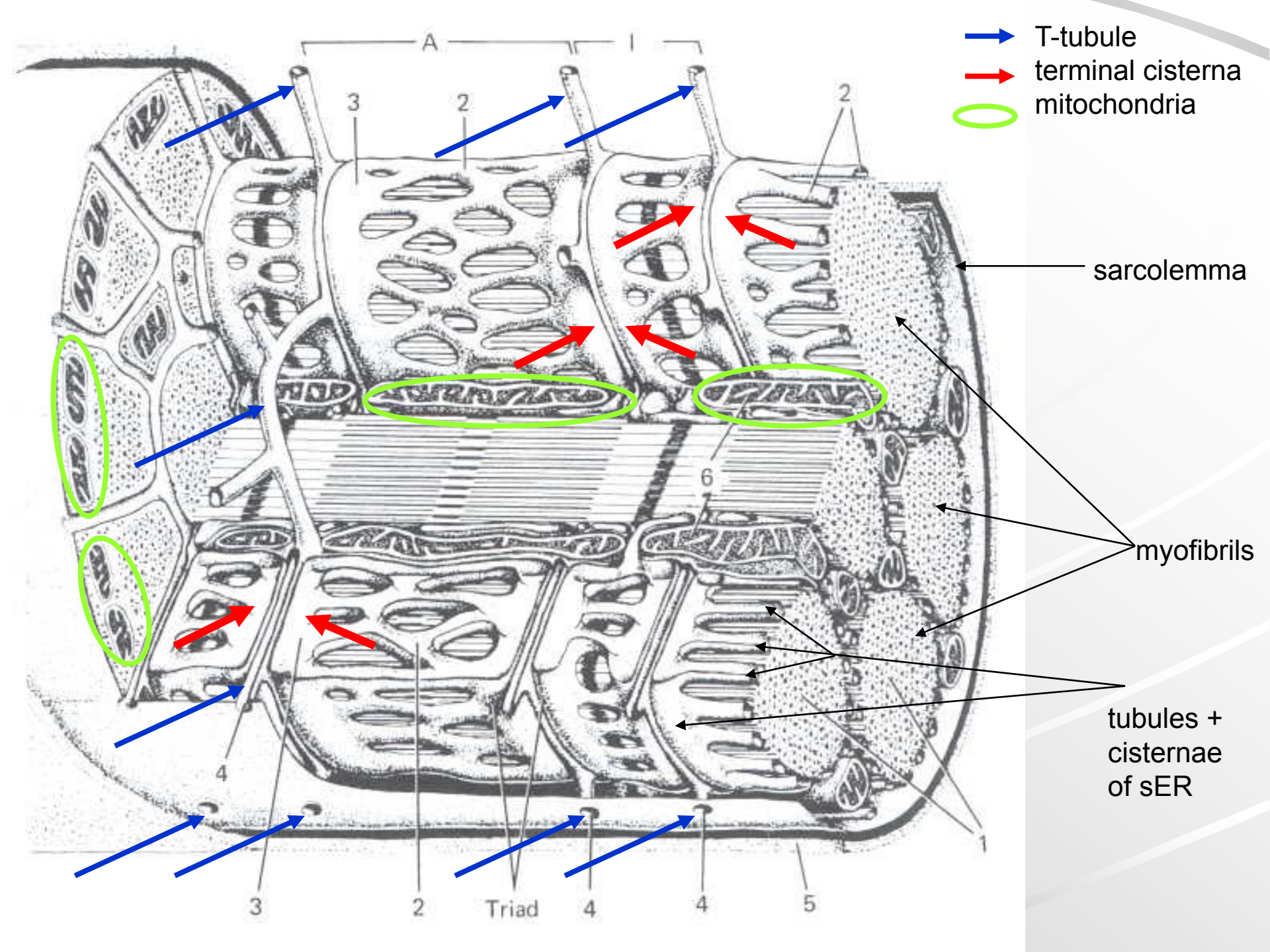
Forms transversal **terminal cisternae** and longitudinal tubules.

Function: reservoir of Ca ions

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

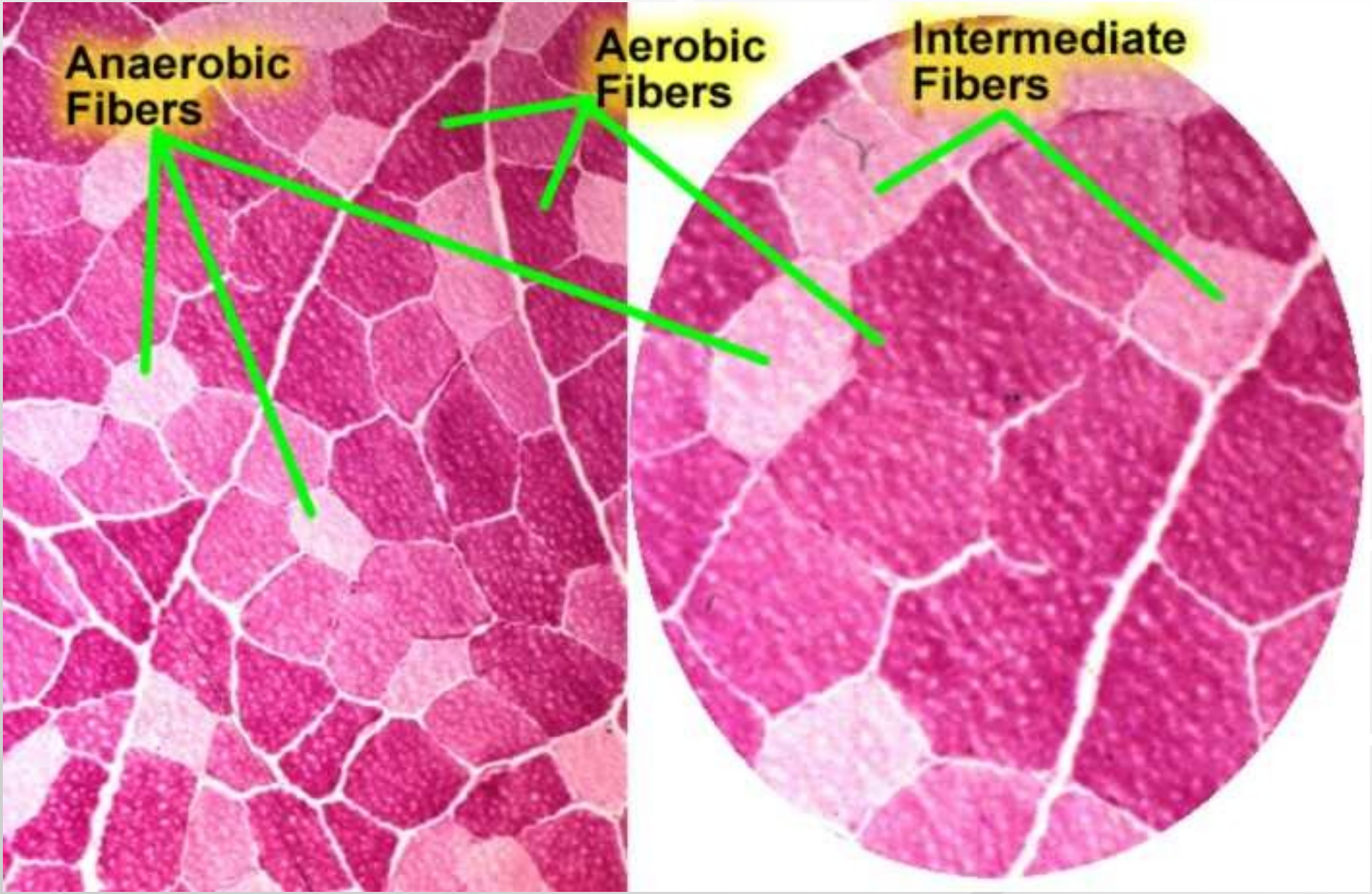
T-tubules are invaginations of sarcoplasm and leads action potential to terminal cisternae (it changes permeability of membrane for Ca ions)


To surface of fibre
To adjoining SR
0.001 mm
Tubule around
a myofibril
T
SR
SR
Filaments
Sarcomere
I-band
A-band
I-band


T-tubule
terminal cisterna
mitochondria
A
I
3
2
2
sarcolemma
6
myofibrils
tubules +
cisternae
of sER
4
1
3
2
Triad
4
4
5

Characteristic of skeletal muscle fiber types

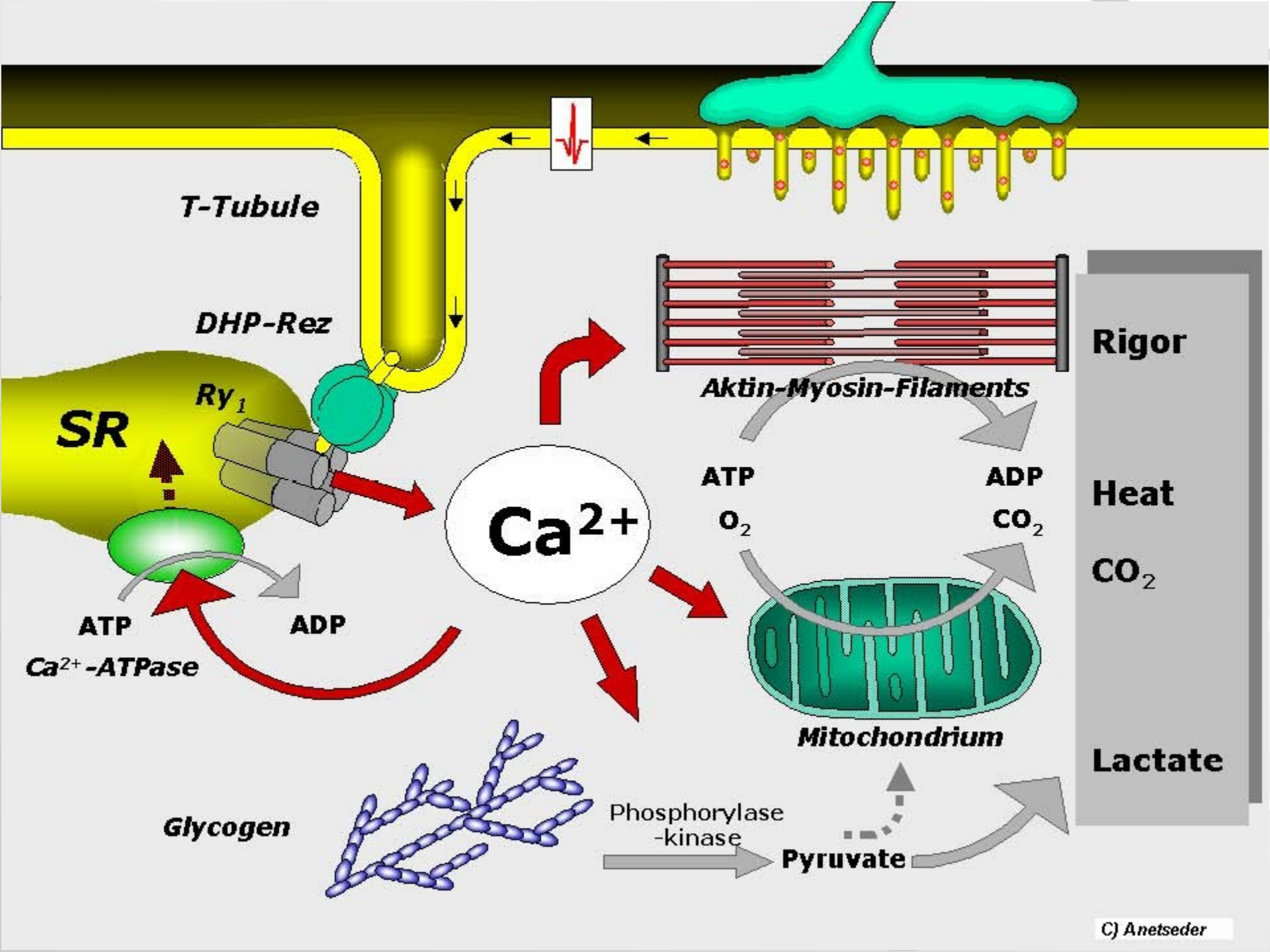
Fibers:	Red	Intermediary	White
Colour	Dark (red)	Dark (red)	Light (white)
Content of myoglobin	High	Intermediate	Low
Number of mitochondria	Many small Mi	Many large Mi	Little small Mi
ATPase activity	Low	High	High
Type of metabolism	Oxidative	Aerobic and anaerobic	Anaerobic
Contraction	Slow	Quick	Quick
Defatigability	Very small	Small	High
Capilary density	High	High	Low


Anaerobic Fibers
Aerobic Fibers
Intermediate Fibers

Contraction

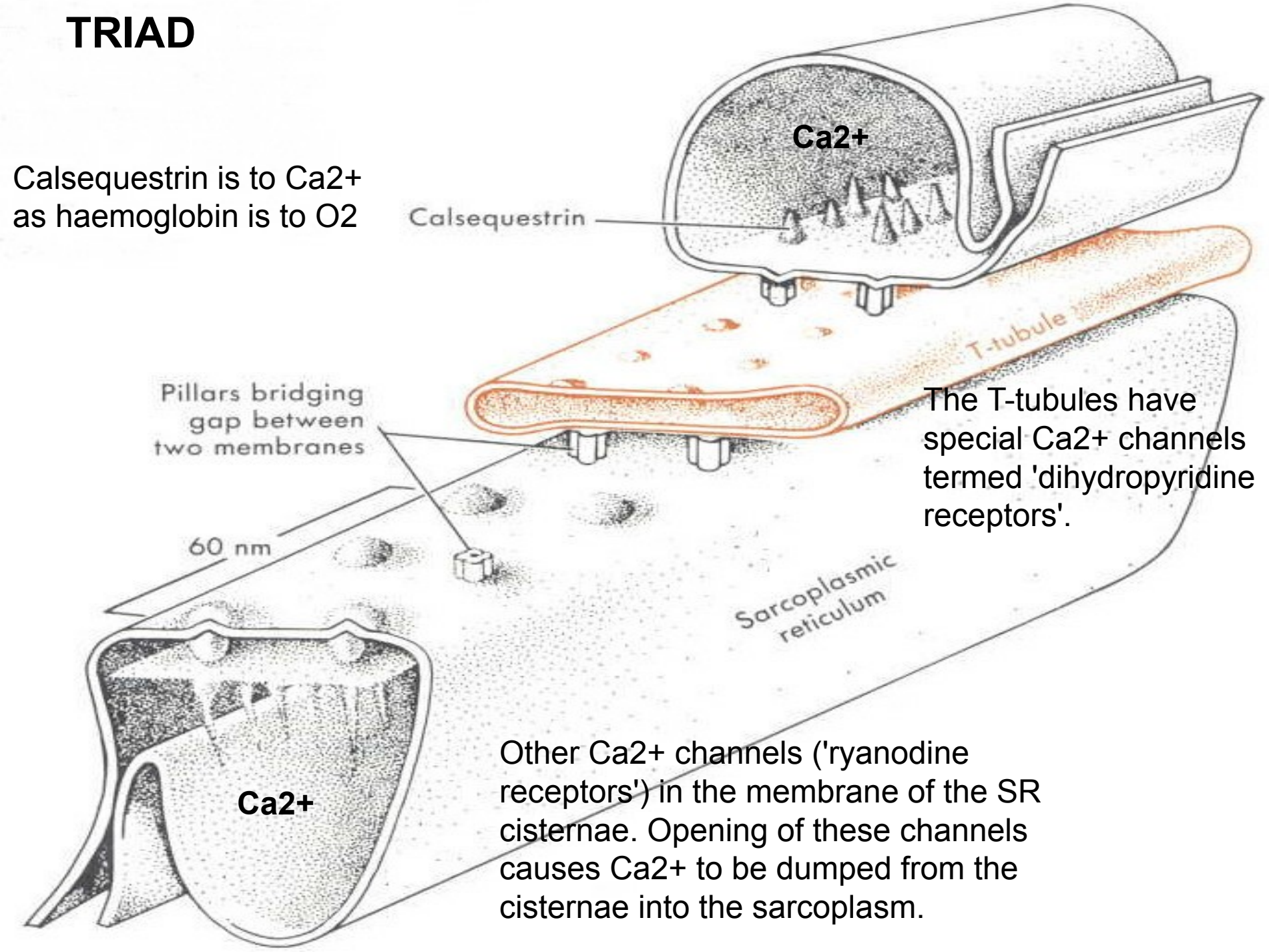
- Propagation of action potential (depolarization) via T-tubule (= invagination of sarcolemma)
- Change of terminal cisternae permeability – releasing of Ca^{+} ions increases their concentration in sarcoplasm
- Myosin contacts actin and sarcomera shortens by sliding movement – contraction
- Relaxation: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

A (ridiculously) simplified model of a sarcomere.


T-Tubule
DHP-Rez
SR
Ry 1
Ca2+
ATP
ADP
Ca2+ -ATPase
Aktin-Myosin-Filaments
ATP
O2
ADP
CO2
Mitochondrium
Rigor
Heat
CO2
Lactate
Glycogen
Phosphorylase
-kinase
Pyruvate
C) Anetseder

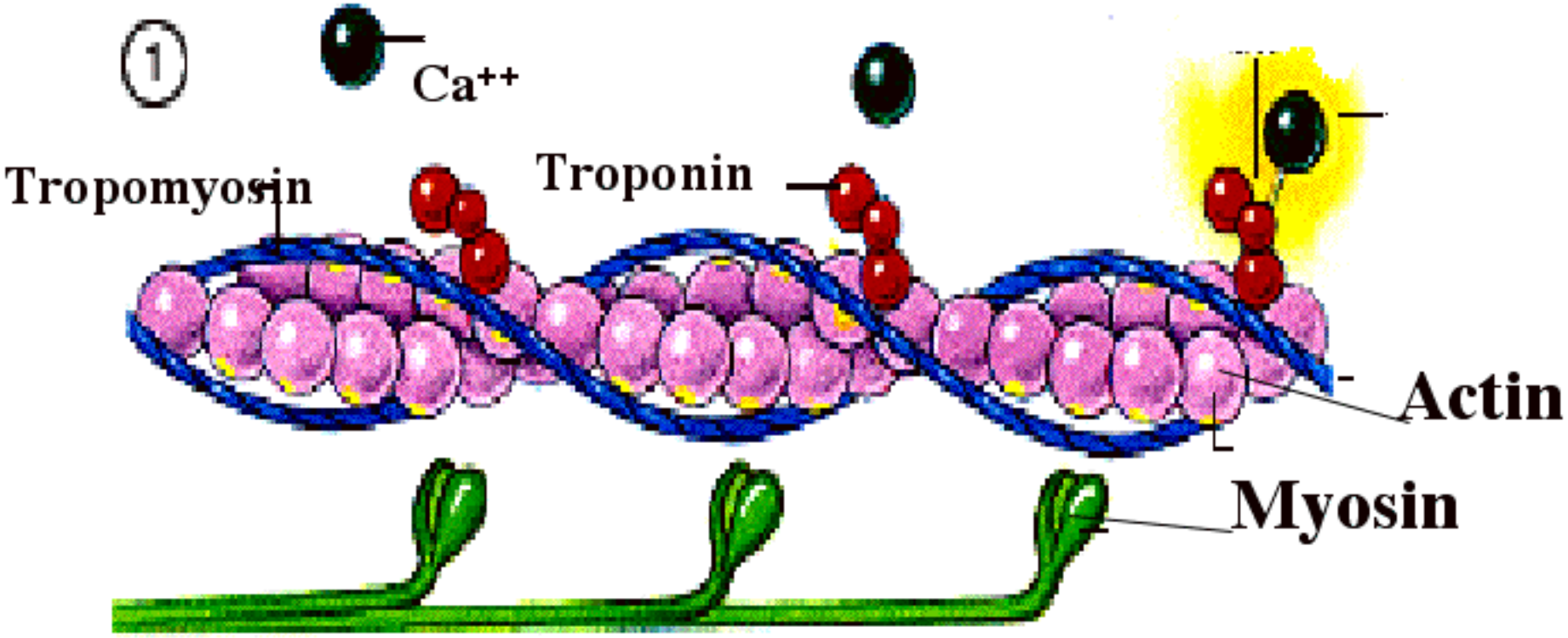
TRIAD

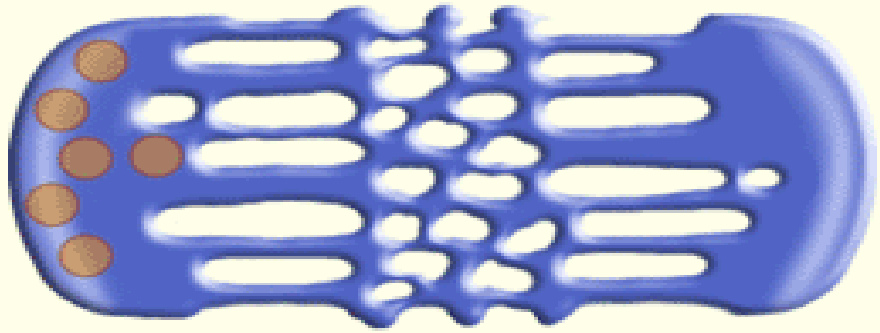
Calsequestrin is to Ca2+ as haemoglobin is to O2

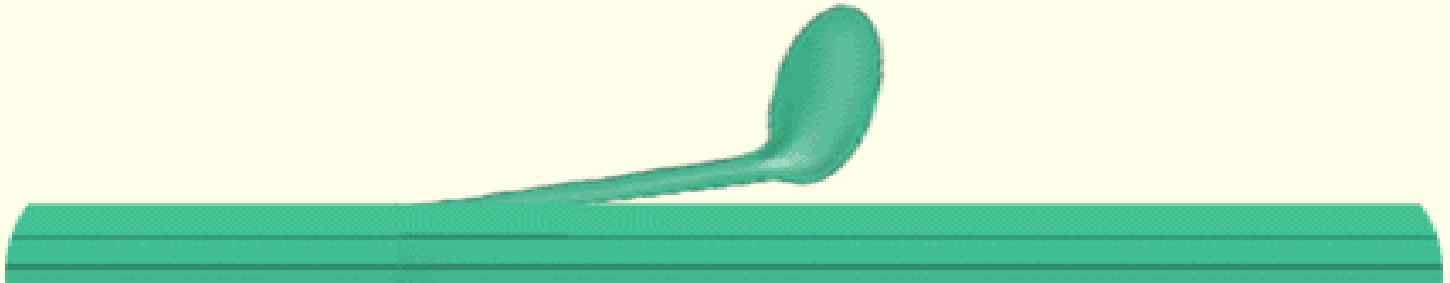


The T-tubules have special Ca2+ channels termed 'dihydropyridine receptors'.

Other Ca2+ channels ('ryanodine receptors') in the membrane of the SR cisternae. Opening of these channels causes Ca2+ to be dumped from the cisternae into the sarcoplasm.

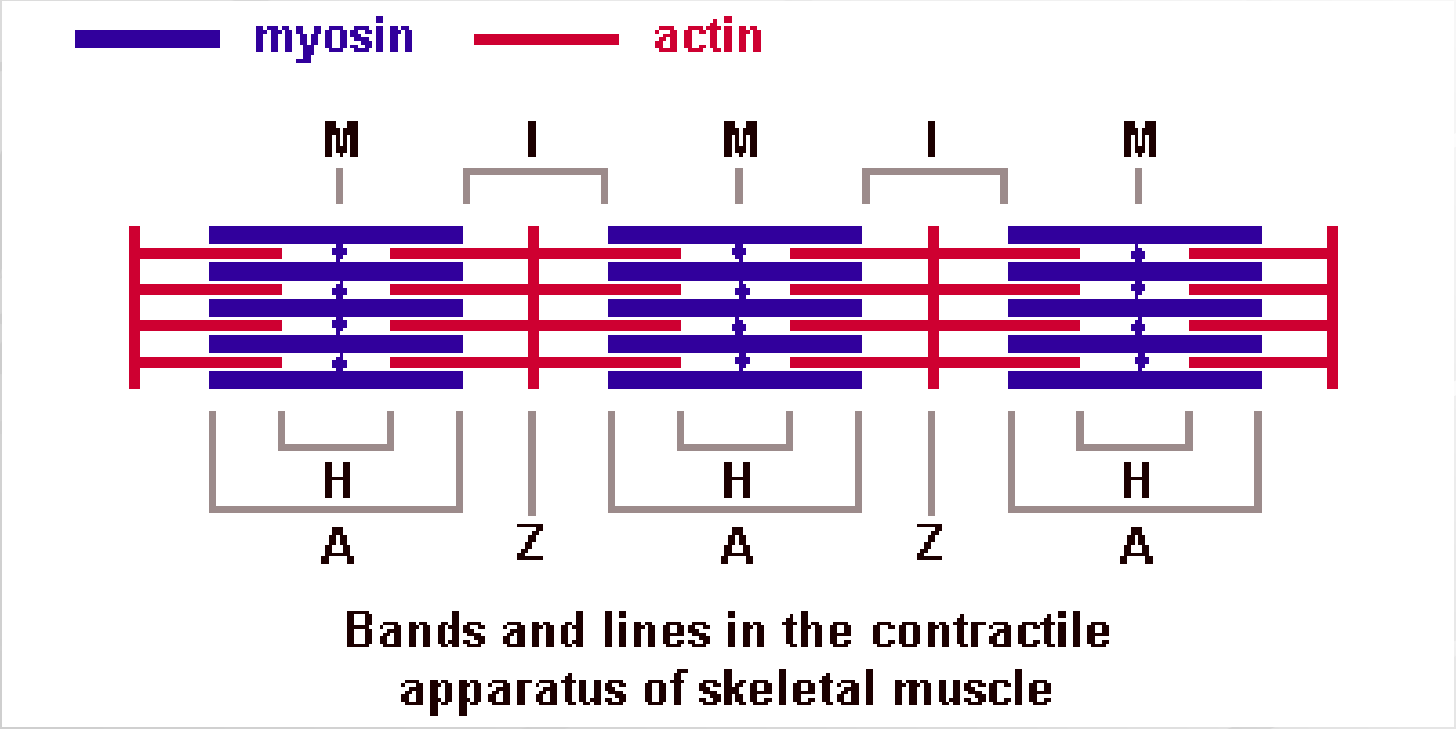

1
Ca++
Tropomyosin
Troponin
Actin
Myosin





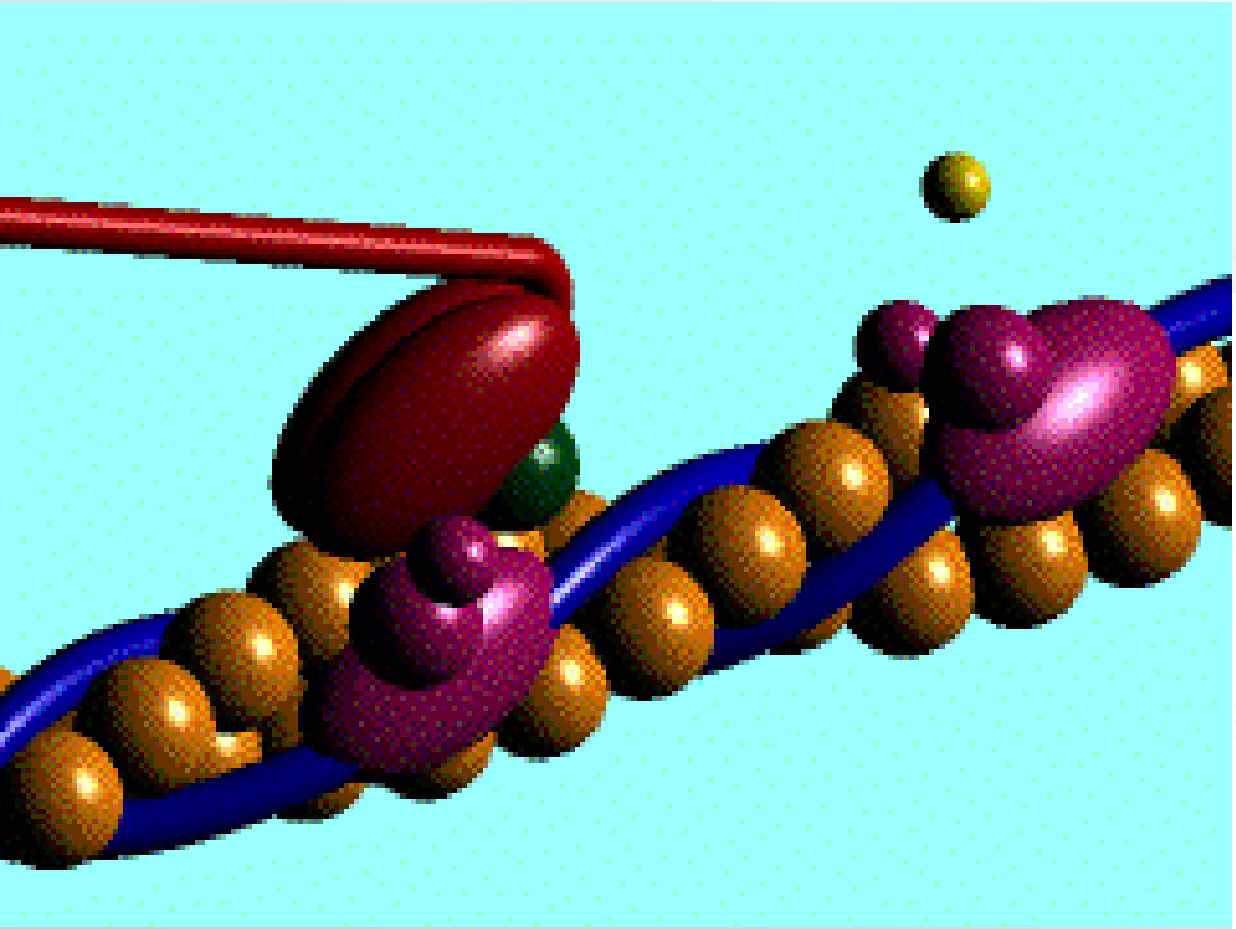
Mechanism of muscle contraction

- During contraction the thick /M/ and thin /A/ slide past each other /sliding filament theory/ and the Z-discs are brought near the ends of the thick filaments.

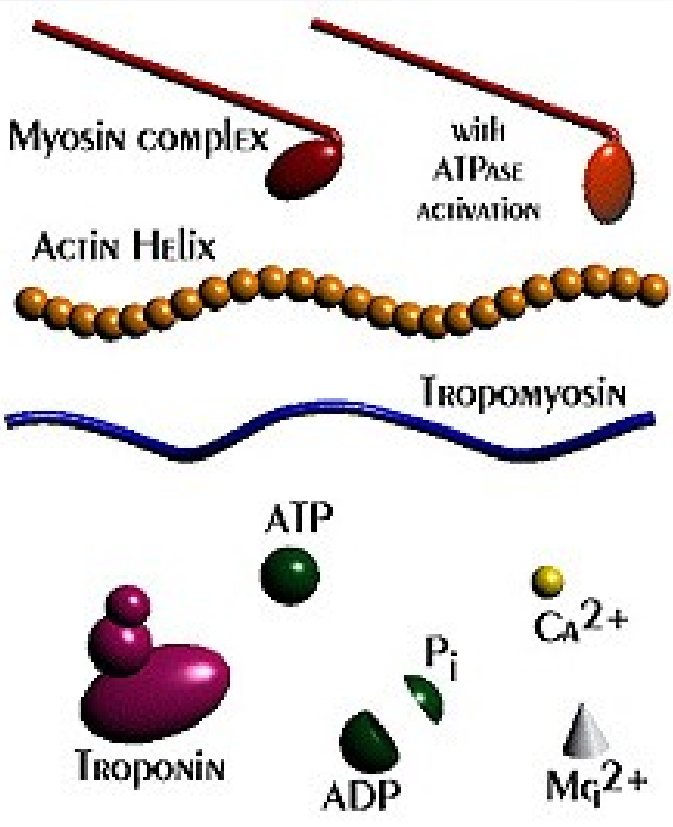


Bands and lines in the contractile apparatus of skeletal muscle

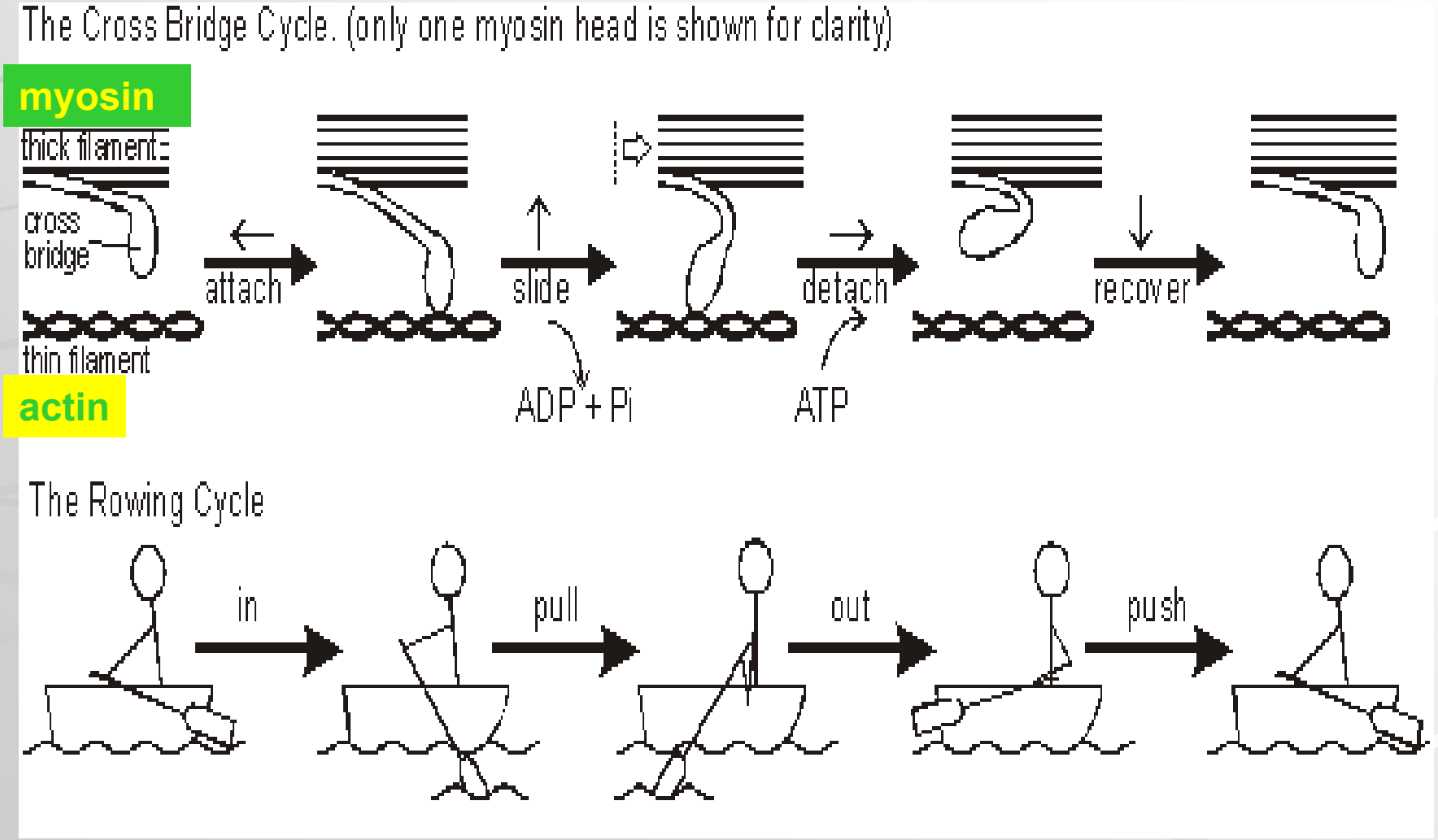
Mechanism of muscle contraction

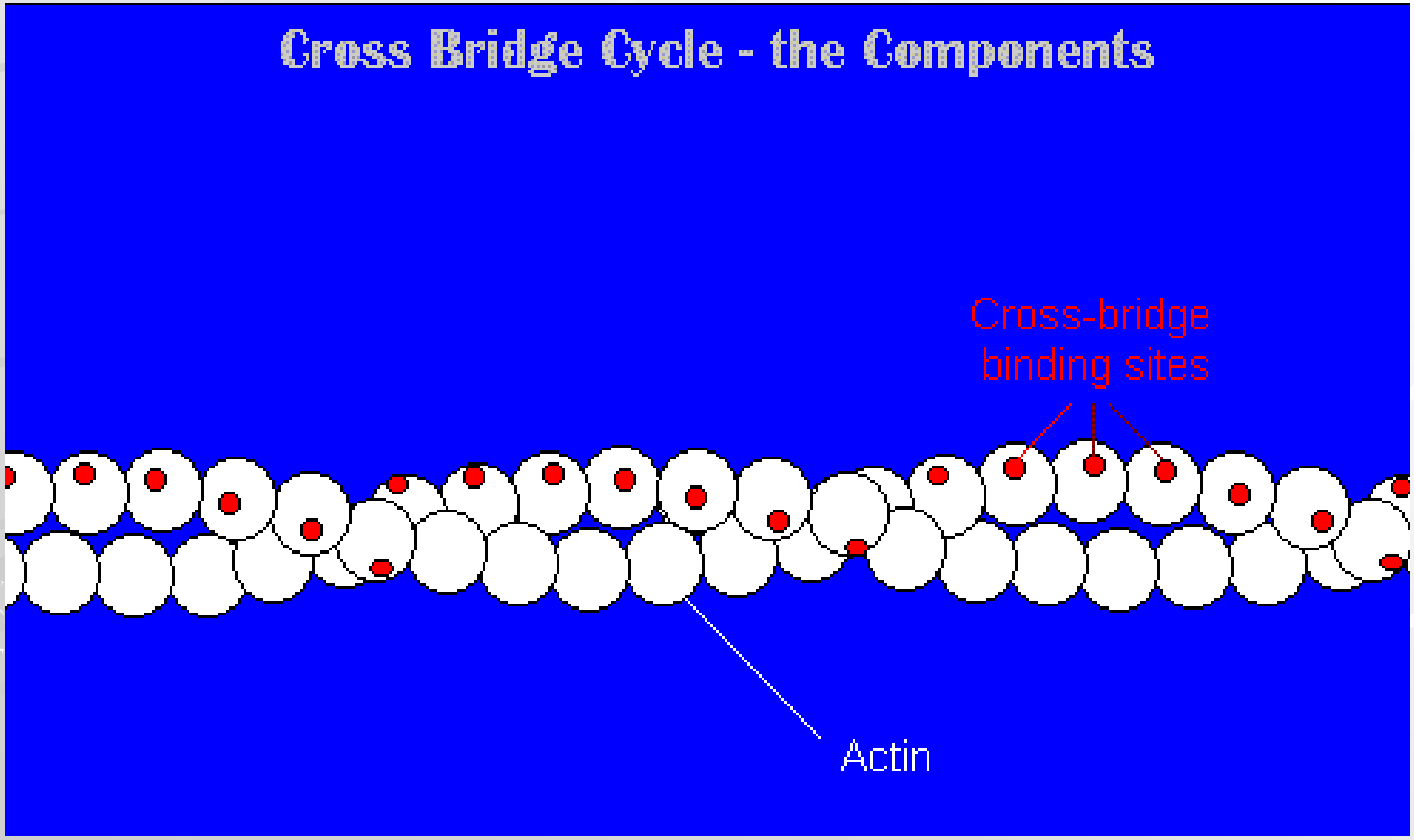


Players:



Mechanism of contraction: sliding of myofilaments

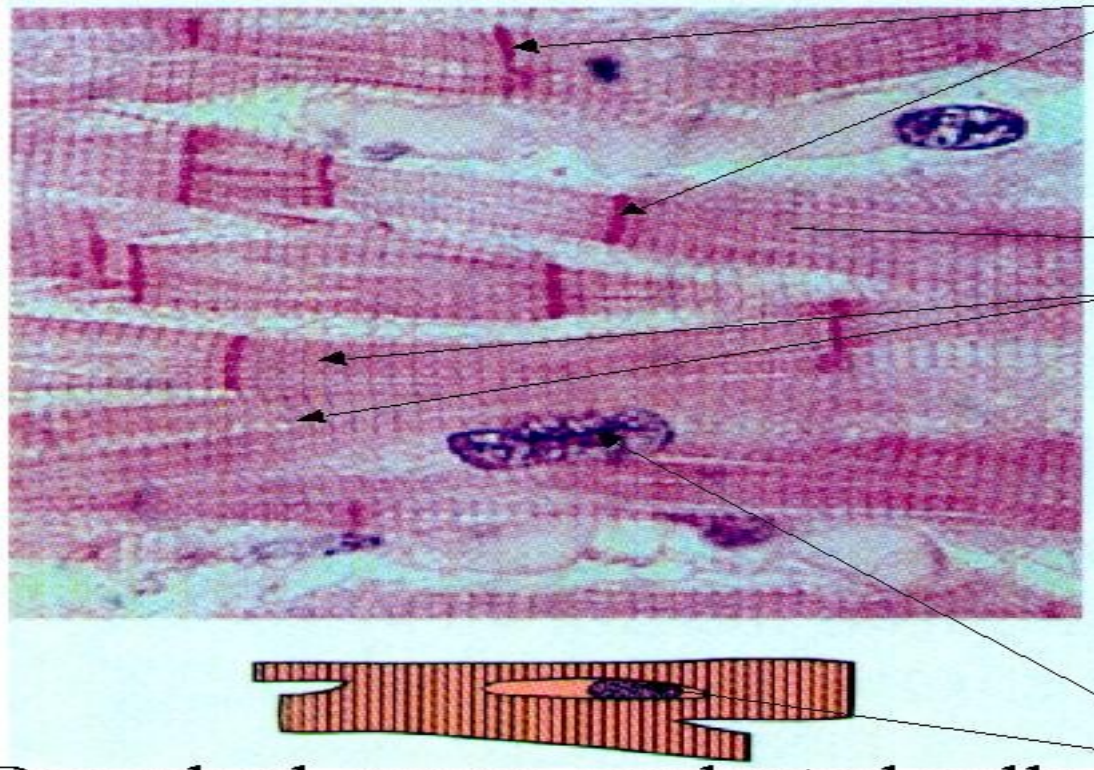



Cross Bridge Cycle - the Components
Cross-bridge
binding sites
Actin

Cardiac muscle - myocardium

- is made up of long branched fibers, composed of cells – **cardiomyocytes**,
- cardiomyocytes are cylindrical cells, which can be branched on one or both ends (Y, X shaped cells),
- Sarkoplasm: 1 nucleus in the center of cell, striated myofibrils, numerous mitochondria,
- cells are attached to one another by end-to-end junctions – intercalated discs.

Cardiac Muscle Characteristics



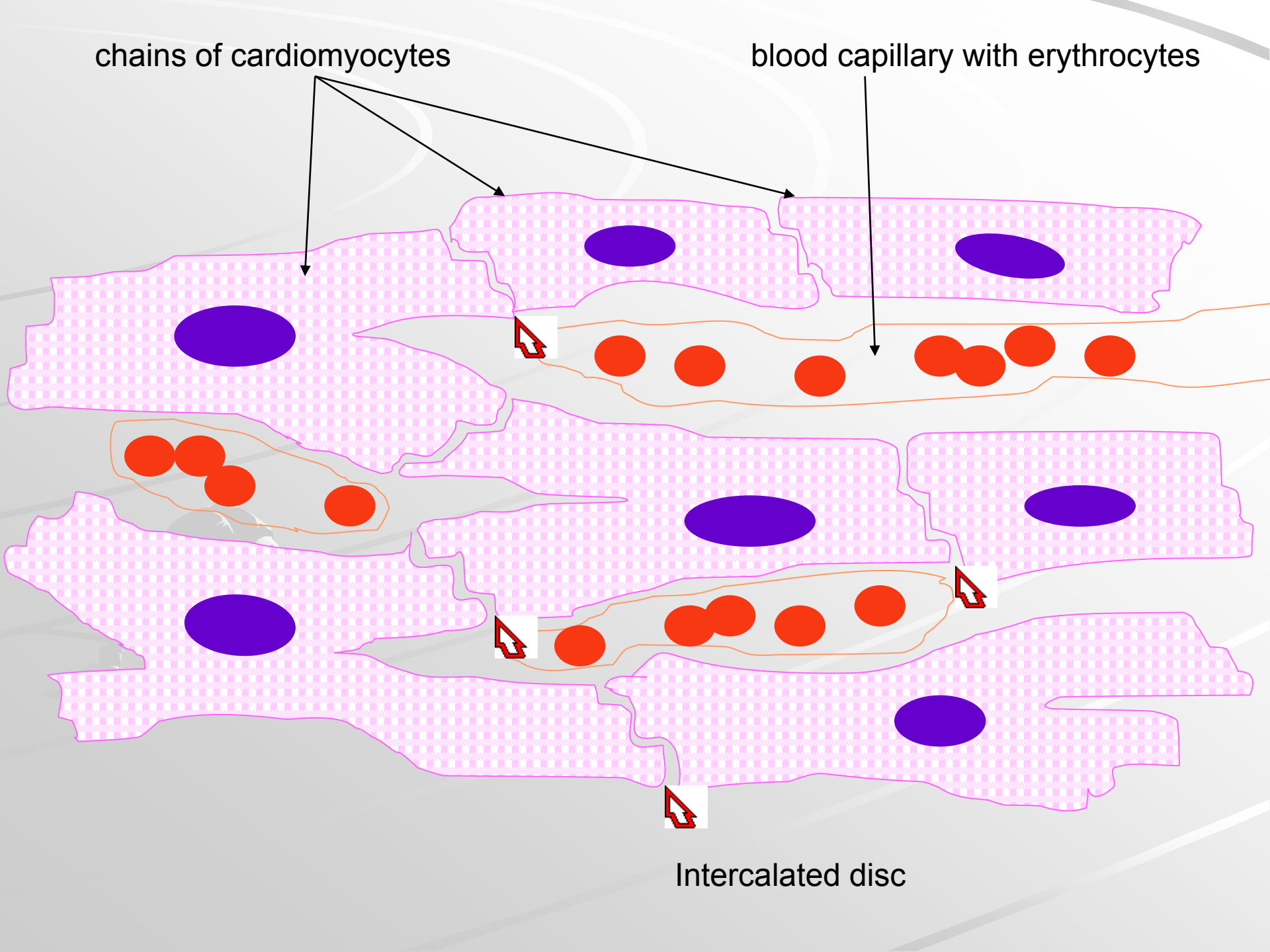
Intercalated disks

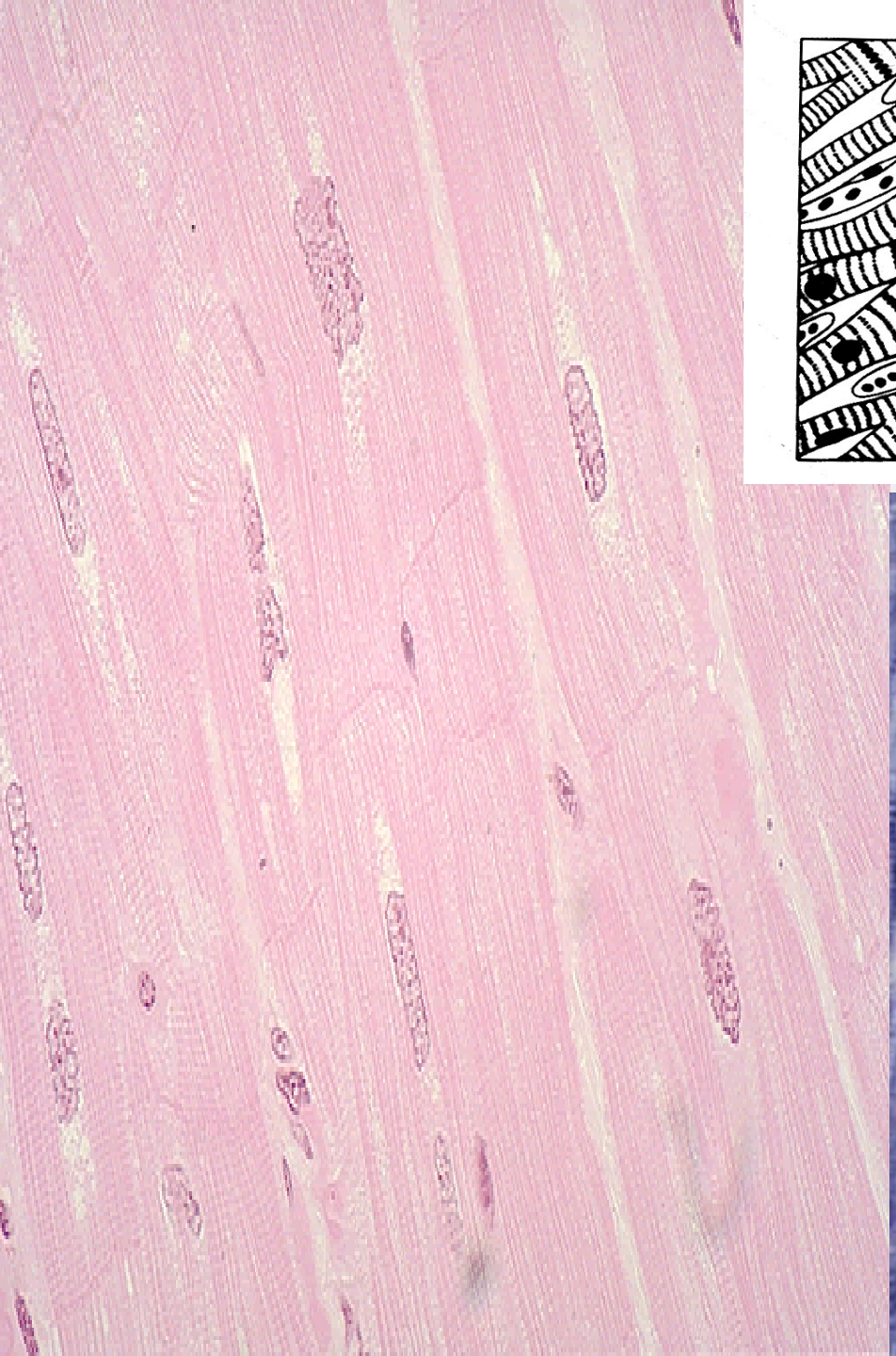
Cardiac muscle cells are faintly striated, branching cells, which connect by means of intercalated disks to form a functional network.

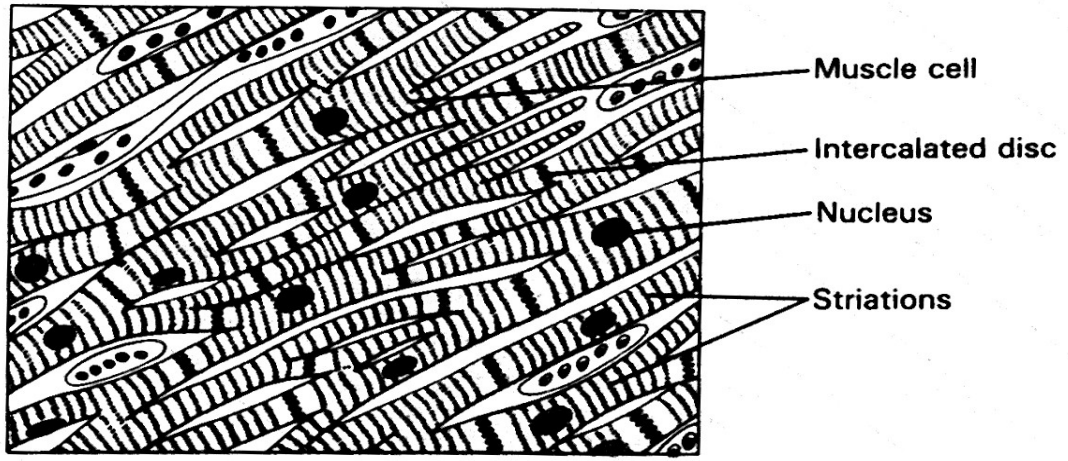
Branched, mono-nucleated cells

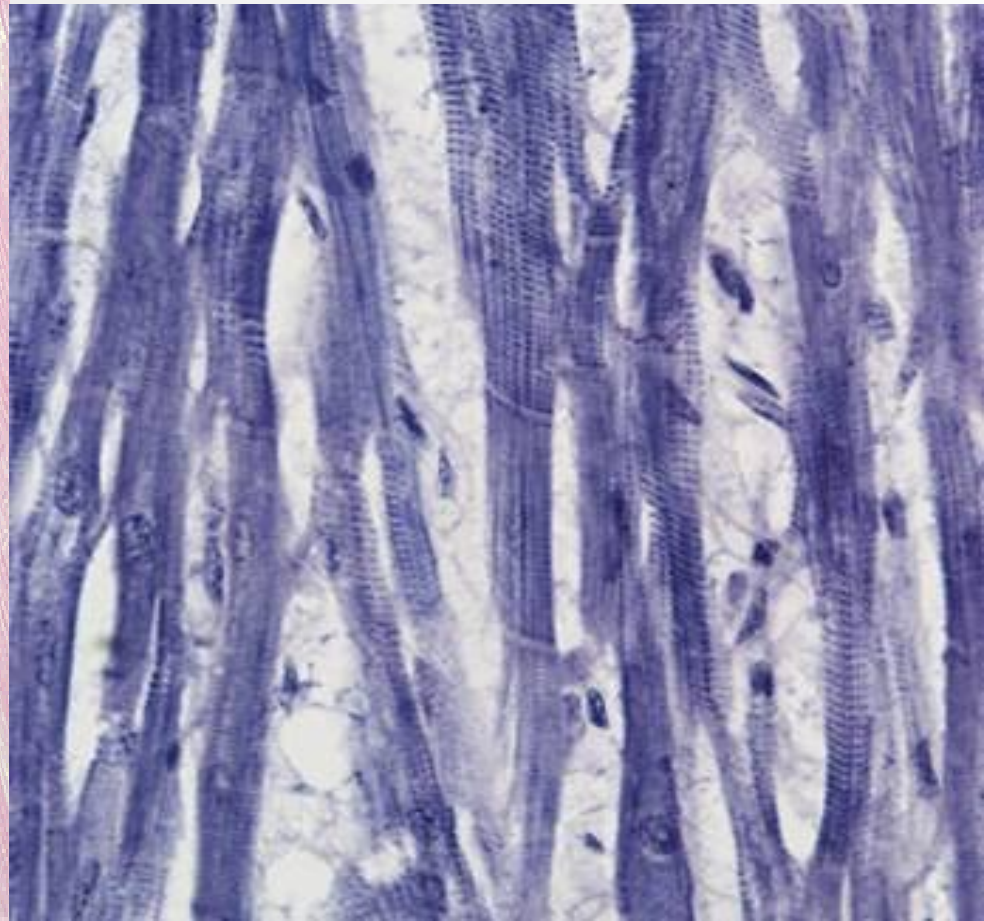
nucleus

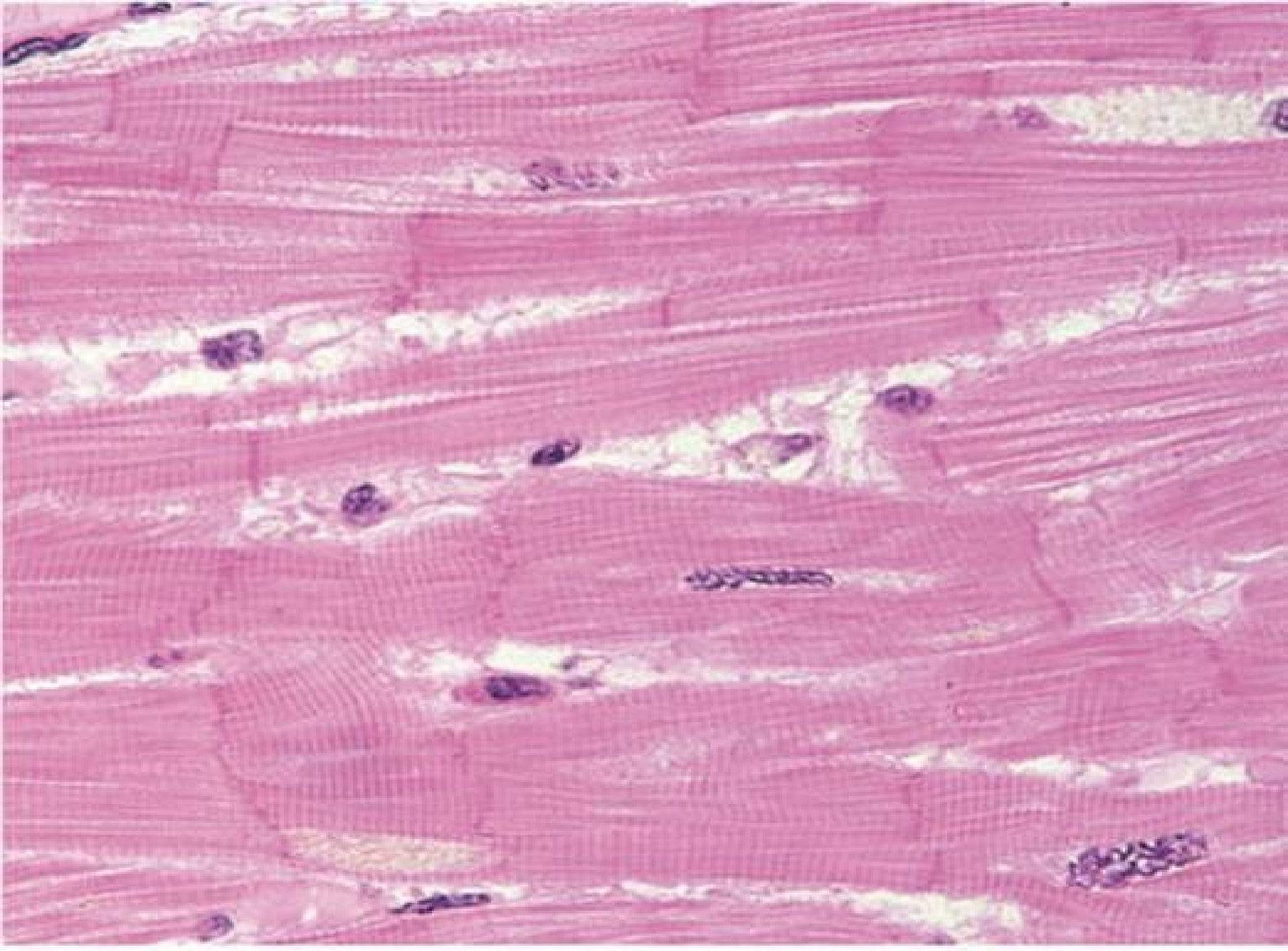
The action potential travels through all cells connected together in the **syncytium** causing them to function as a unit.

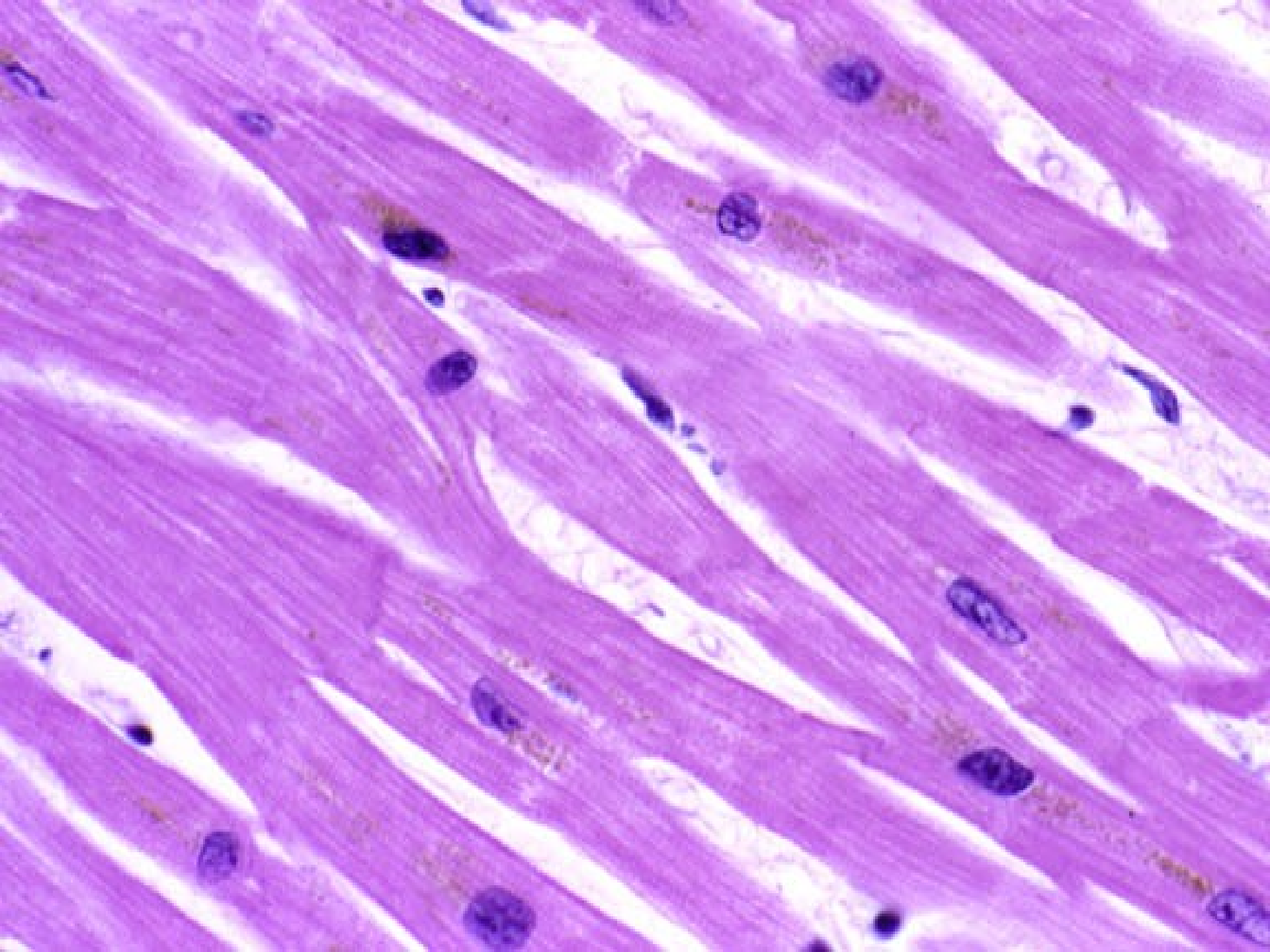

chains of cardiomyocytes
blood capillary with erythrocytes
Intercalated disc

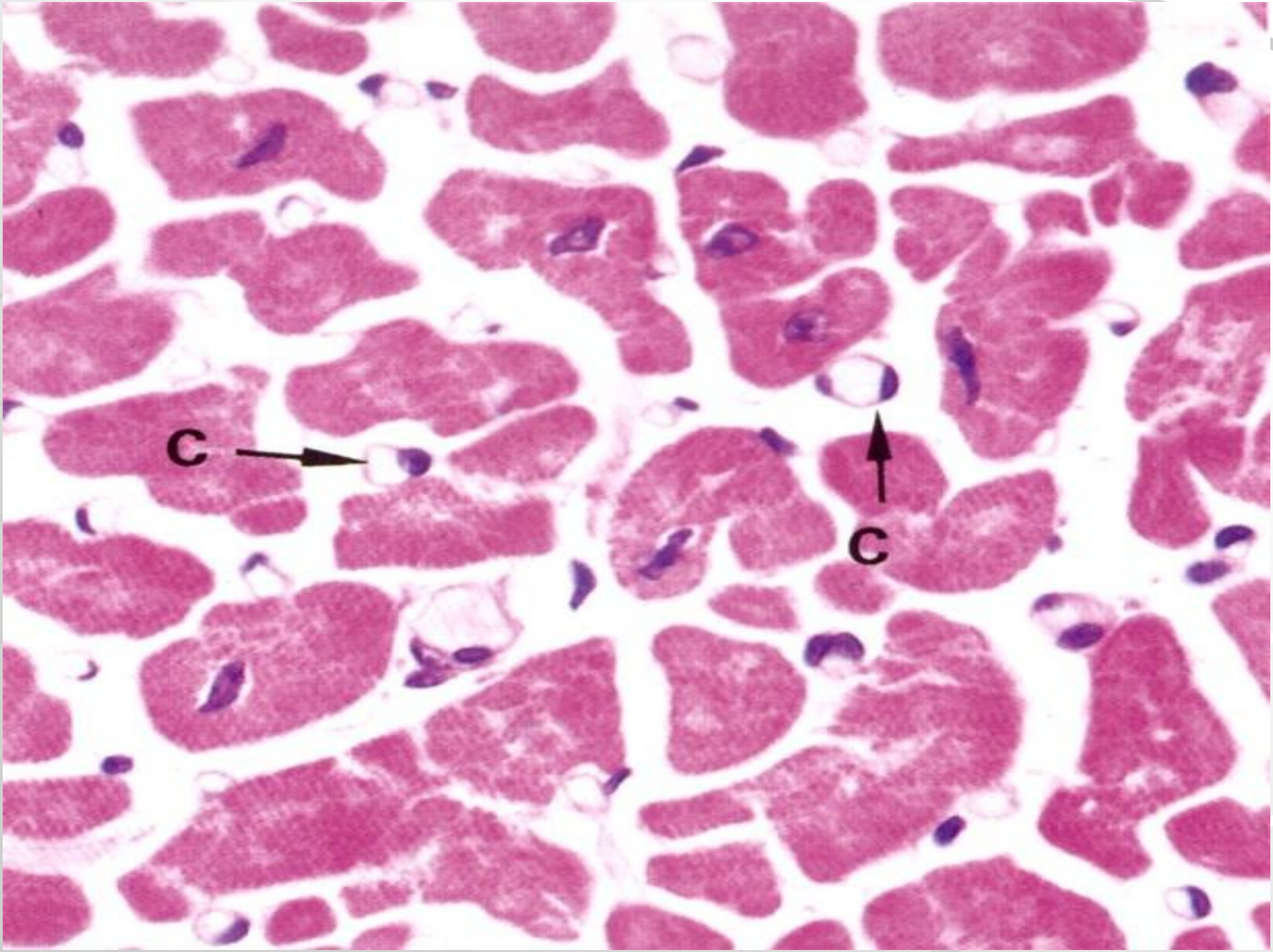



Muscle cell
Intercalated disc
Nucleus
Striations








C
C

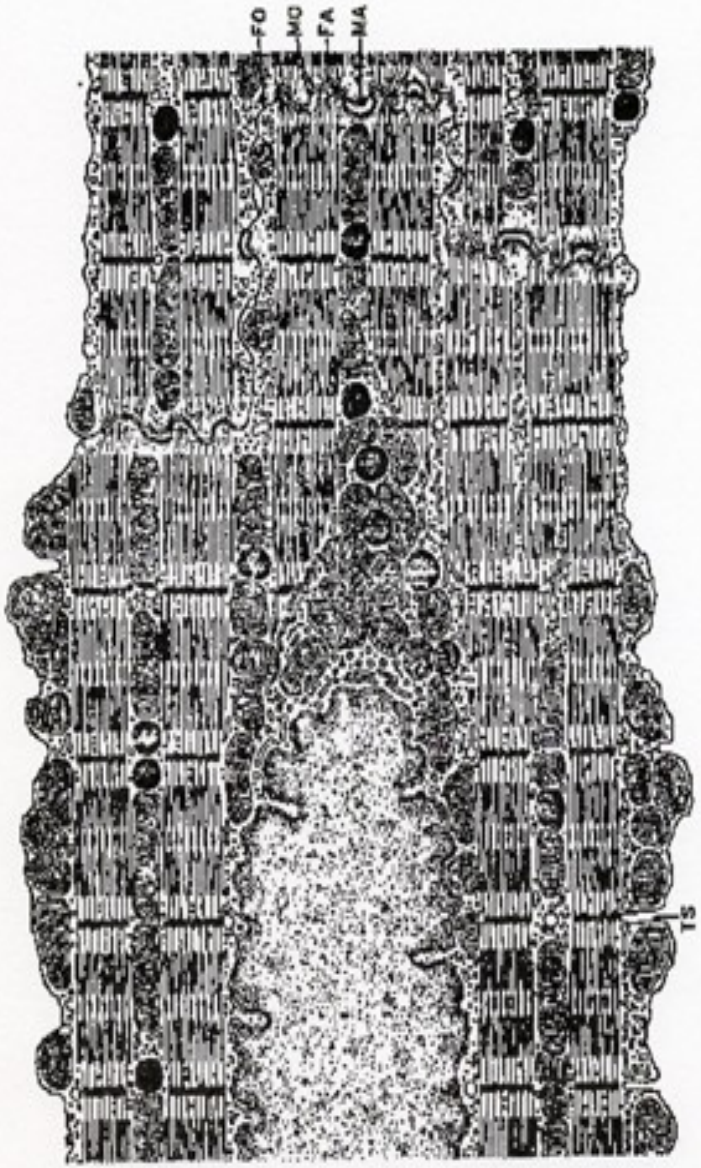
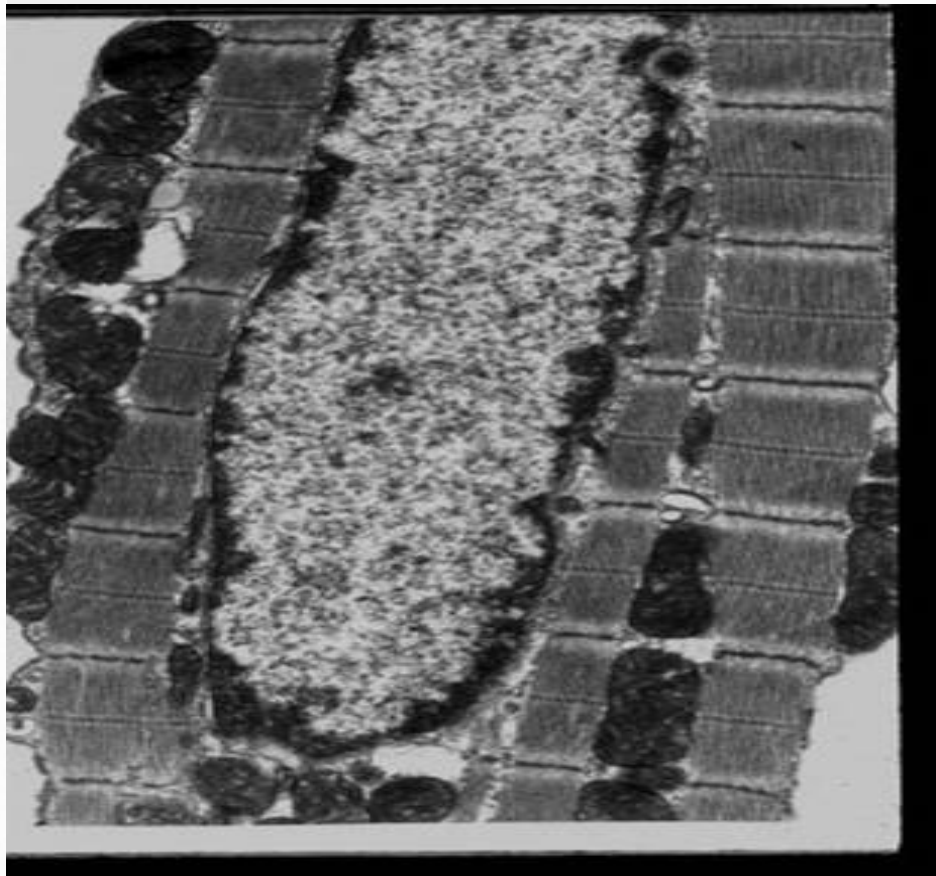


FIG. 10-10 CARDIAC MUSCLE

Diagram and electron micrograph of a part of cardiomyocyte

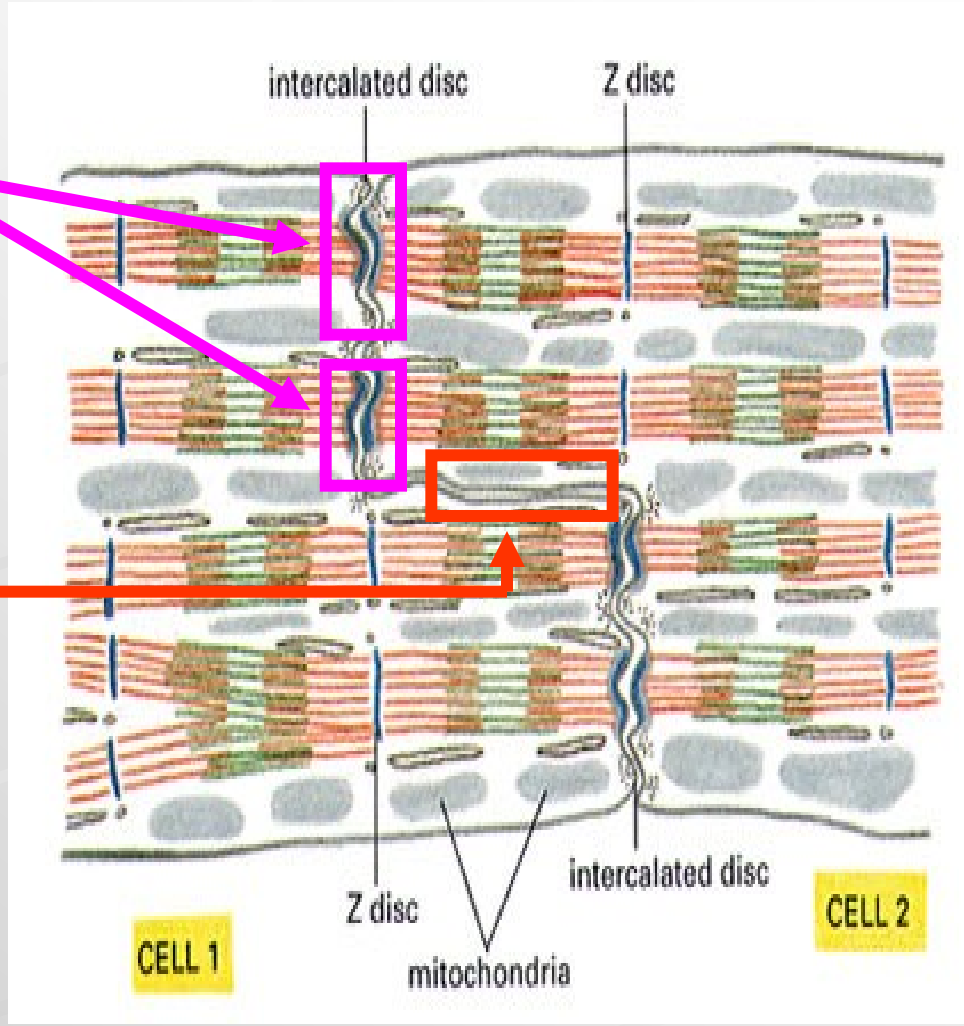


DIFFERENCES BETWEEN CARDIAC AND SKELETAL MUSCLE TISSUES

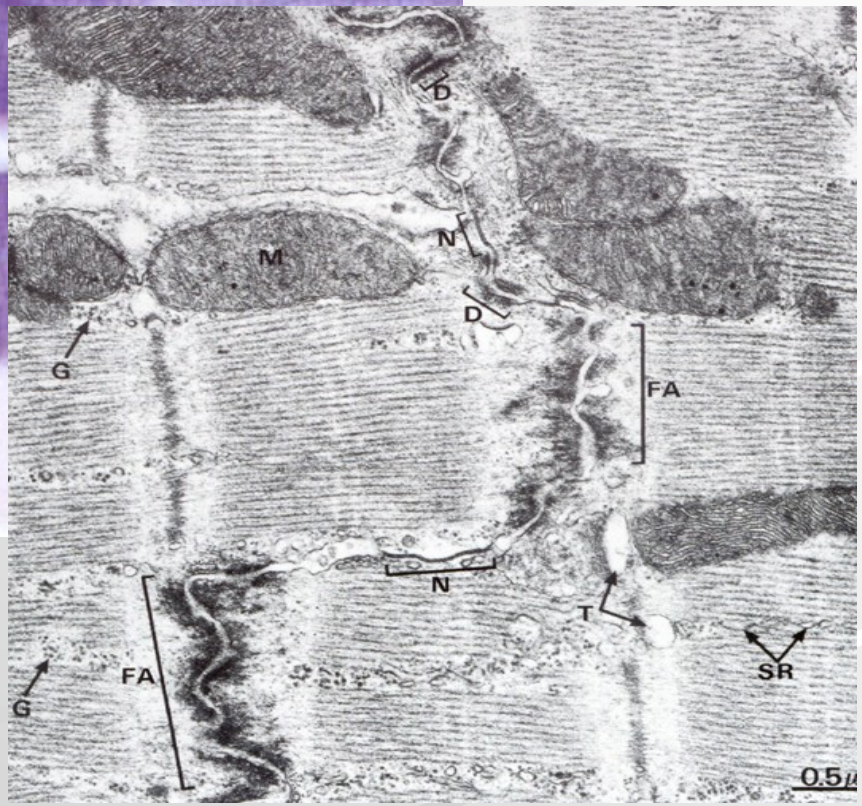
- there are no triads, but diads: 1 t-tubule + 1 cisterna
- t-tubules encircle the sarcomeres at the Z lines rather than at the zone of overlap.
- sarcoplasmic reticulum via its tubules contact sarcolemma as well as the t-tubules
- cardiac muscle cells are totally dependent on aerobic metabolism to obtain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

Intercalated disc

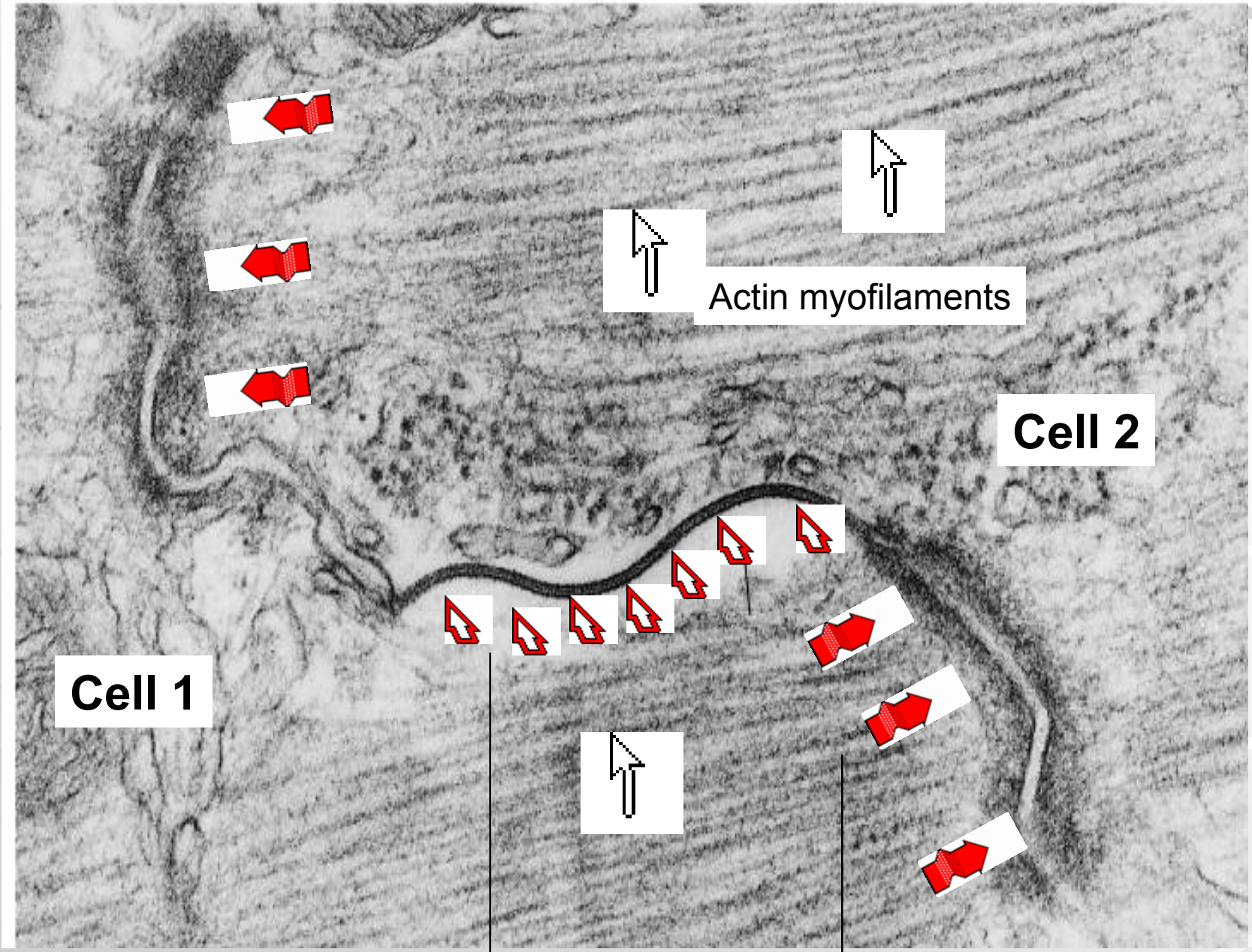
- „scalariform“ shape of cell ends
- fasciae adherentes (*adhesion of cells*)
- Nexus (quick intercellular communication – transport of ions, electric impulses, informations)



striated cardiomyocytes



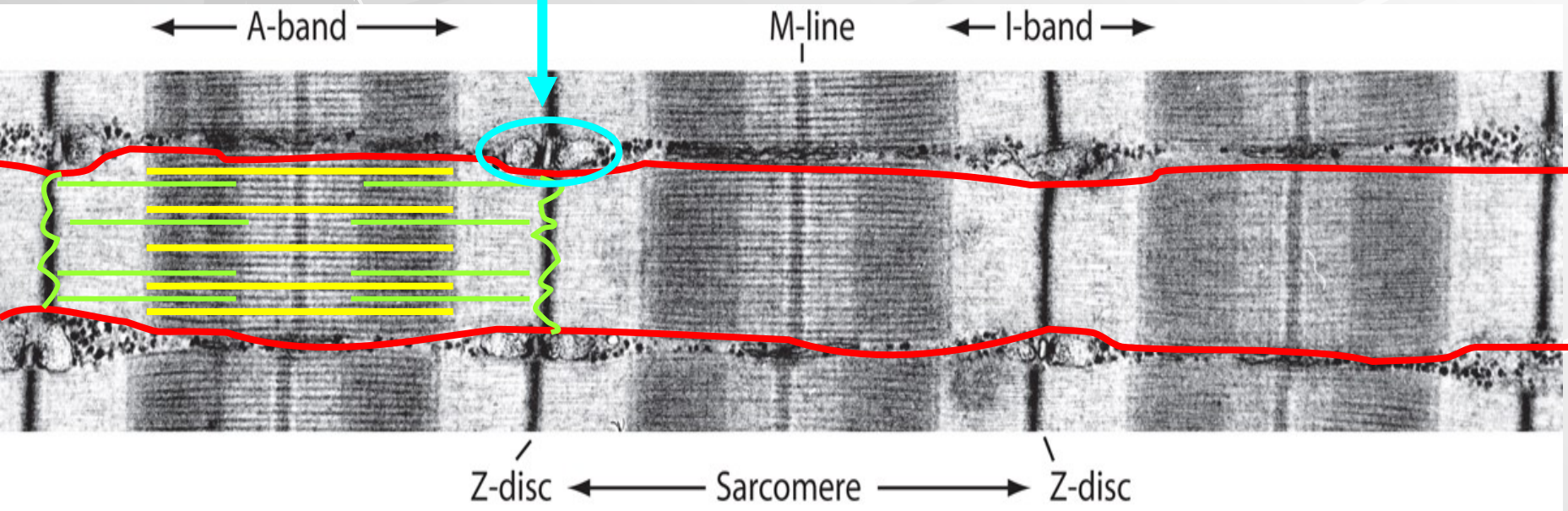
intercalated discs –
desmosomes, fasciae adherentes, nexuses

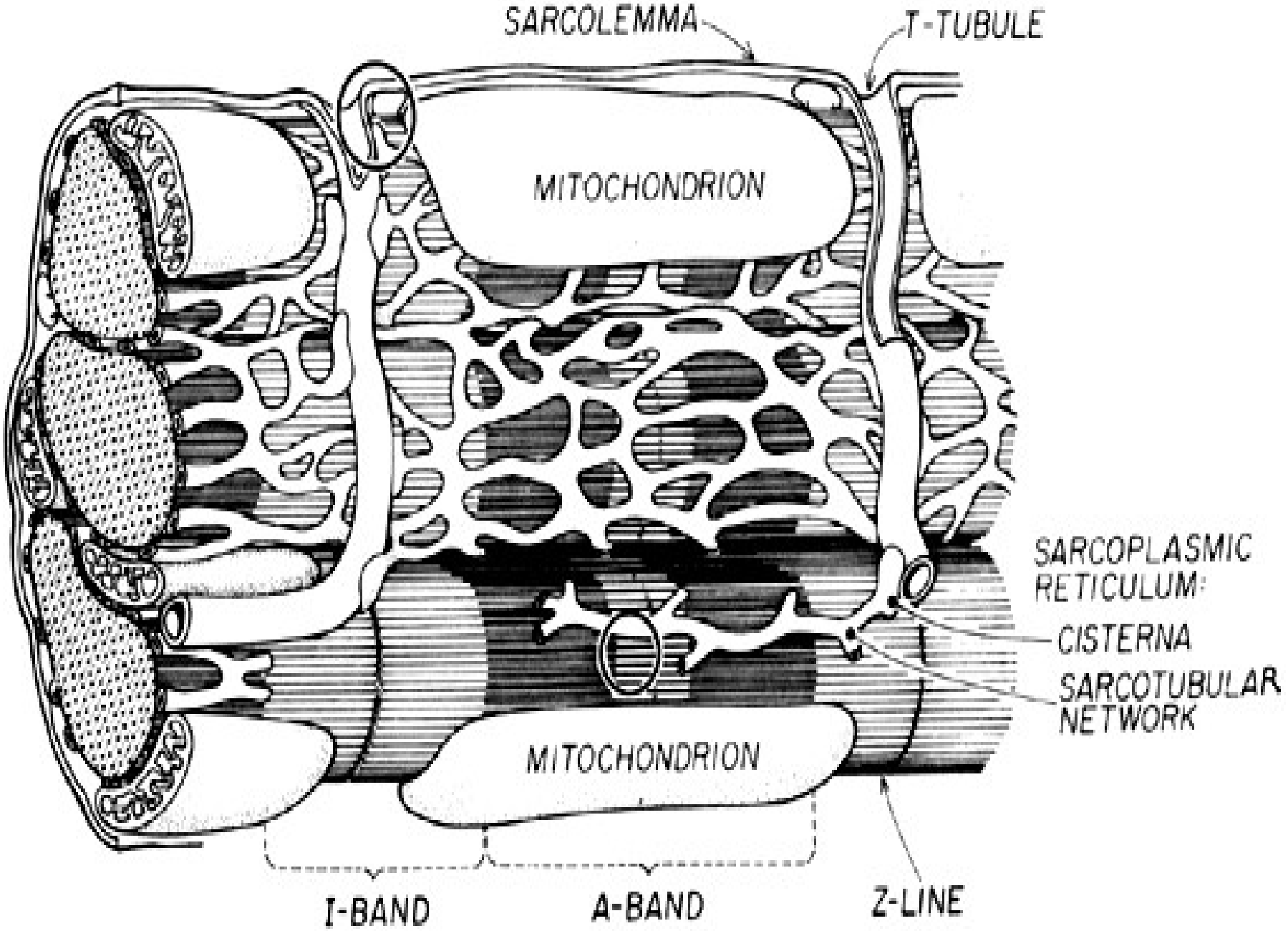


Intercalated disc: nexus fascia adherens

Myofibril of cardiomyocyte

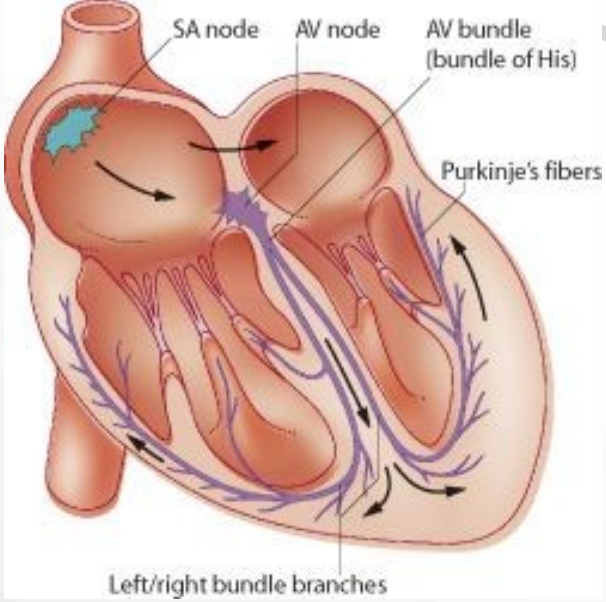
- Actin + myosin myofilaments
- Sarcomere
- Z-line
- M-line and H-zone
- I-band, A-band
- T-tubule + 1 cisterna = diad (around Z-line)

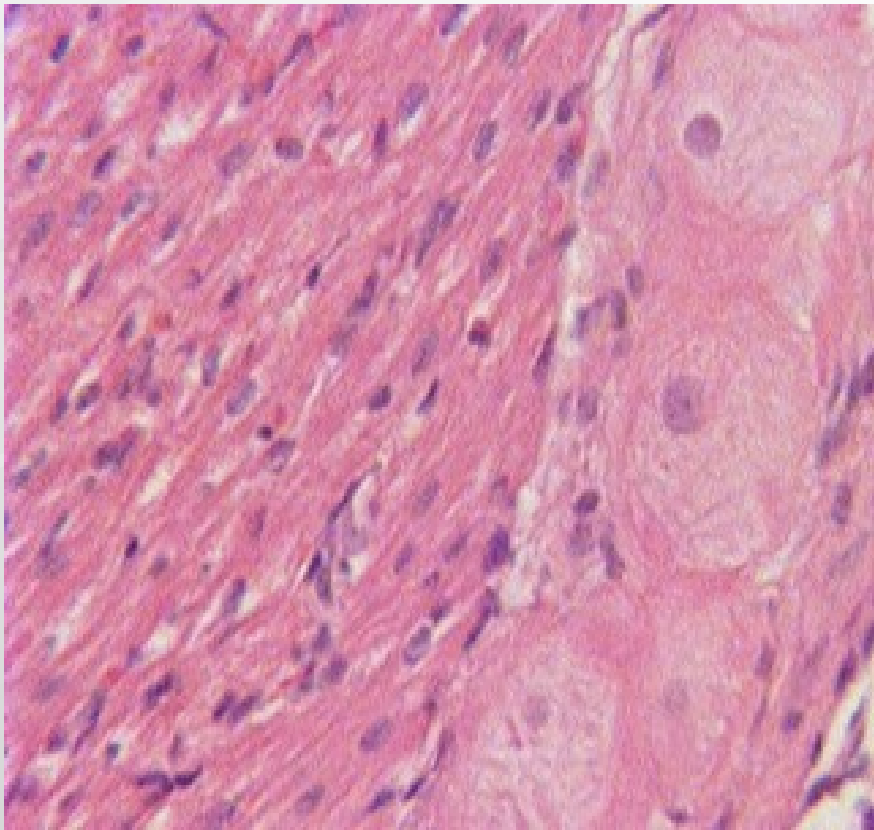



SARCOLEMMA
T-TUBULE
MITOCHONDRION
SARCOPLASMIC RETICULUM:
CISTERNA
SARCOTUBULAR NETWORK
MITOCHONDRION
I-BAND
A-BAND
Z-LINE

Purkinje‘s fibers

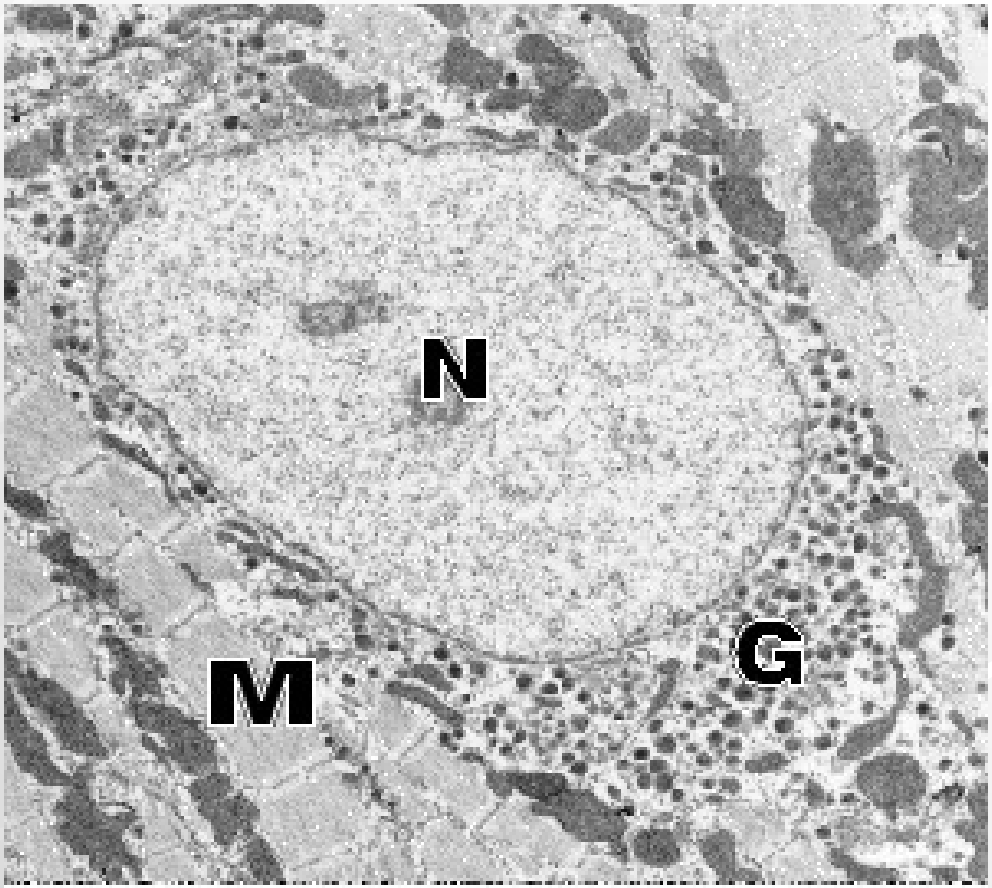
- are located in the inner layer of heart ventricle wall
- are specialized cells fibers that conduct an electrical stimuli or impulses that enables the heart to contract in a coordinated fashion
- numerous sodium ion channels and mitochondria, fewer myofibrils





Natriuretic hormone

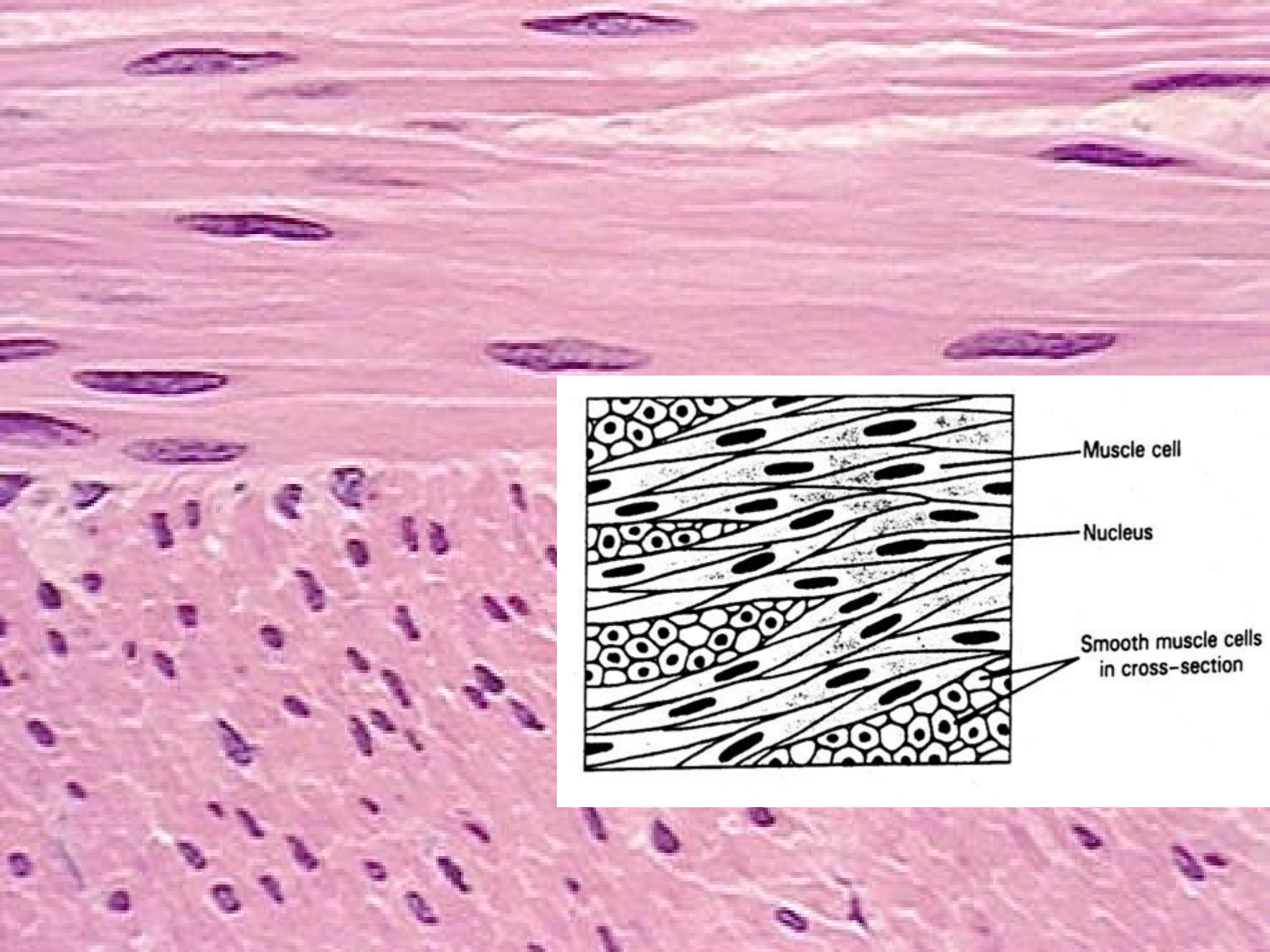
- in atrial granules in sarcoplasm of kardiomyocytes in ventricles
- 300 – 400 nm Ø
- this hormone is involved in regulation of volume of circulating blood

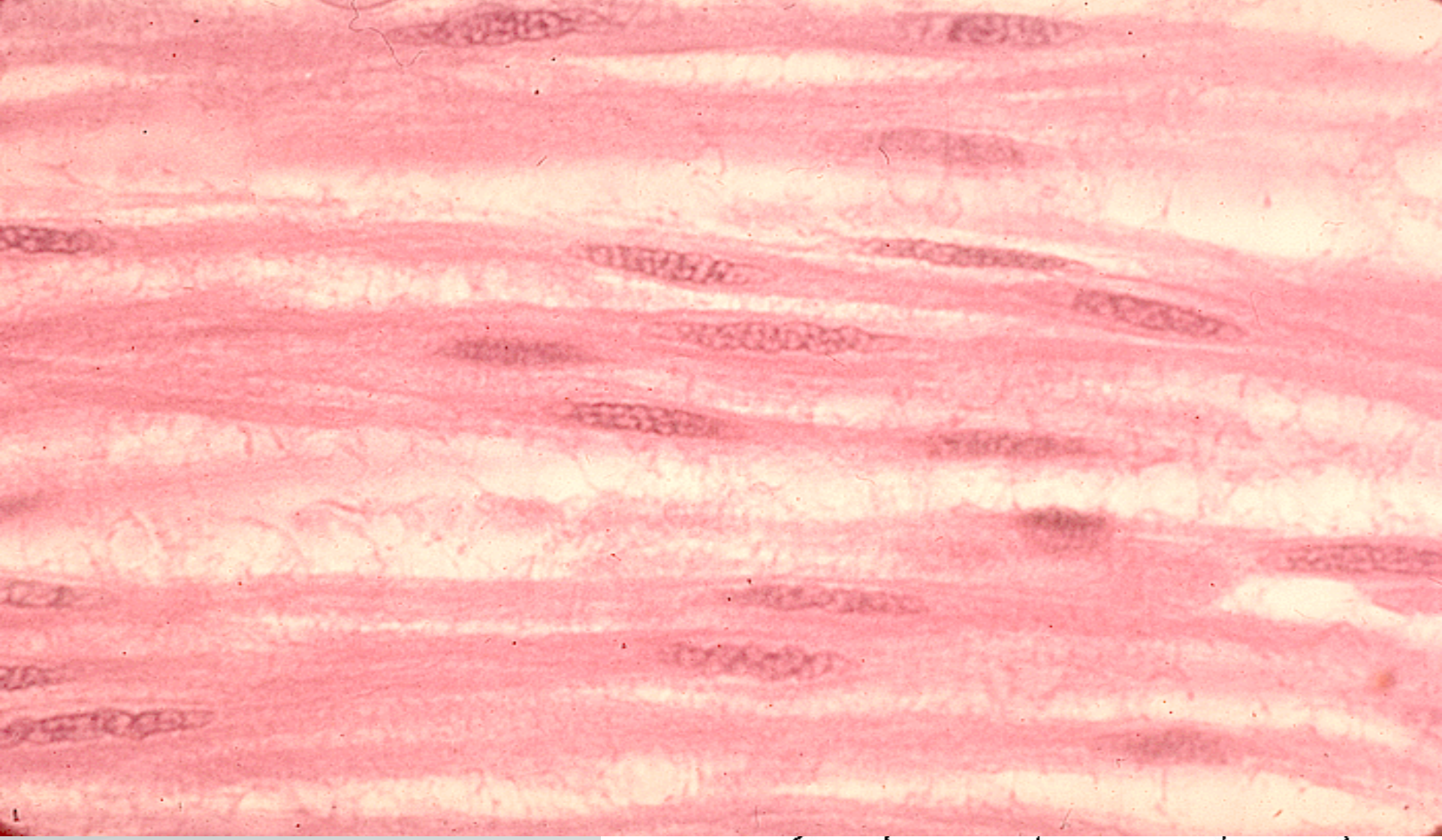


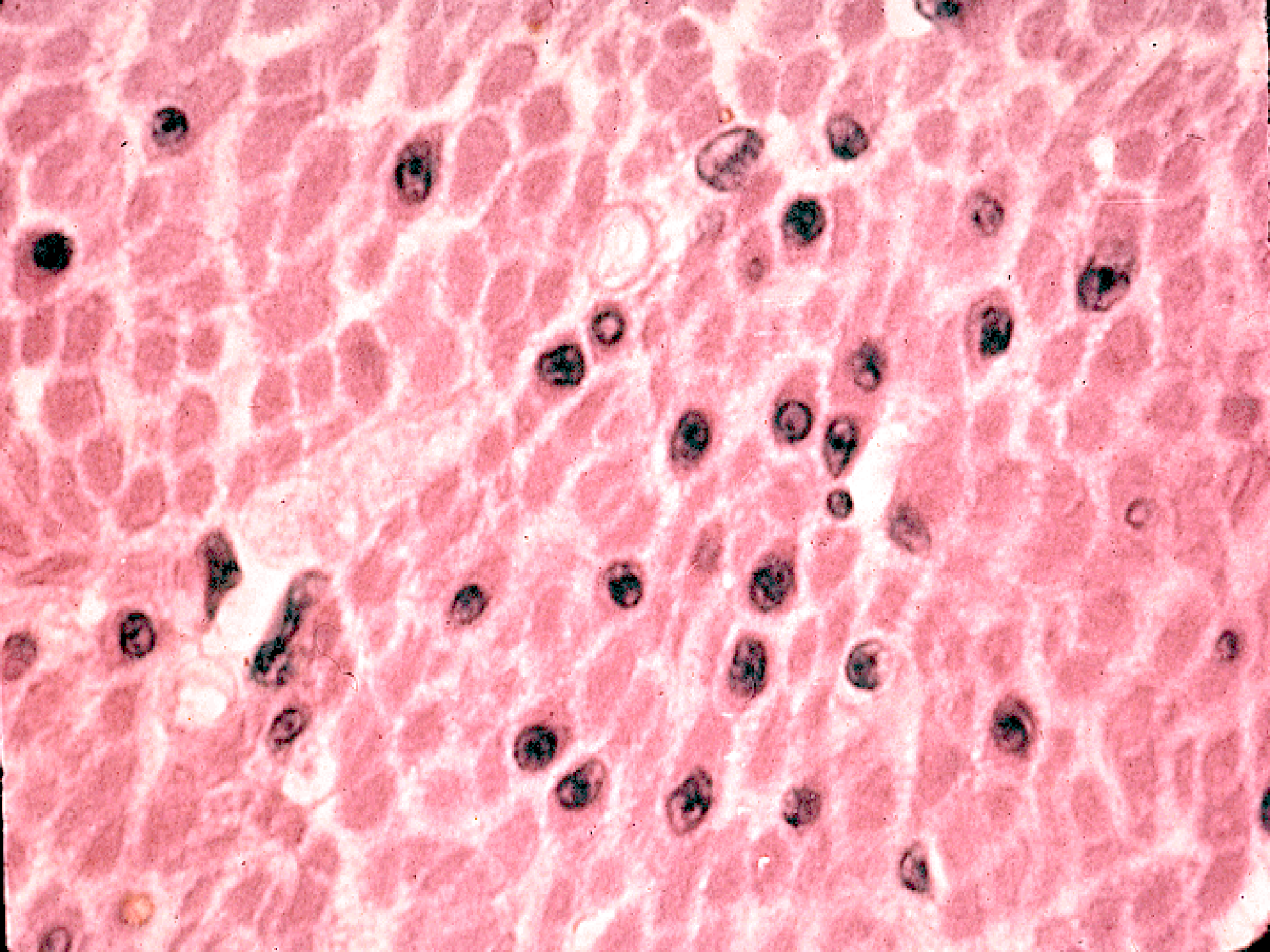
Electron microscopic view of atrial cardiocyte showing nucleus (N), myofibrils (M) and the storage site for ANF and BNP: atrial specific granules (G)

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 substituing Z-lines in sarcoplasm
- calmodulin (has function as troponin)
- sarcoplasmic reticulum forms only tubules
- Caveolae (have function as T-tubules)
- zonulae occludentes and nexuses connect cells


Muscle cell
Nucleus
Smooth muscle cells
in cross-section





Leiomyocyte

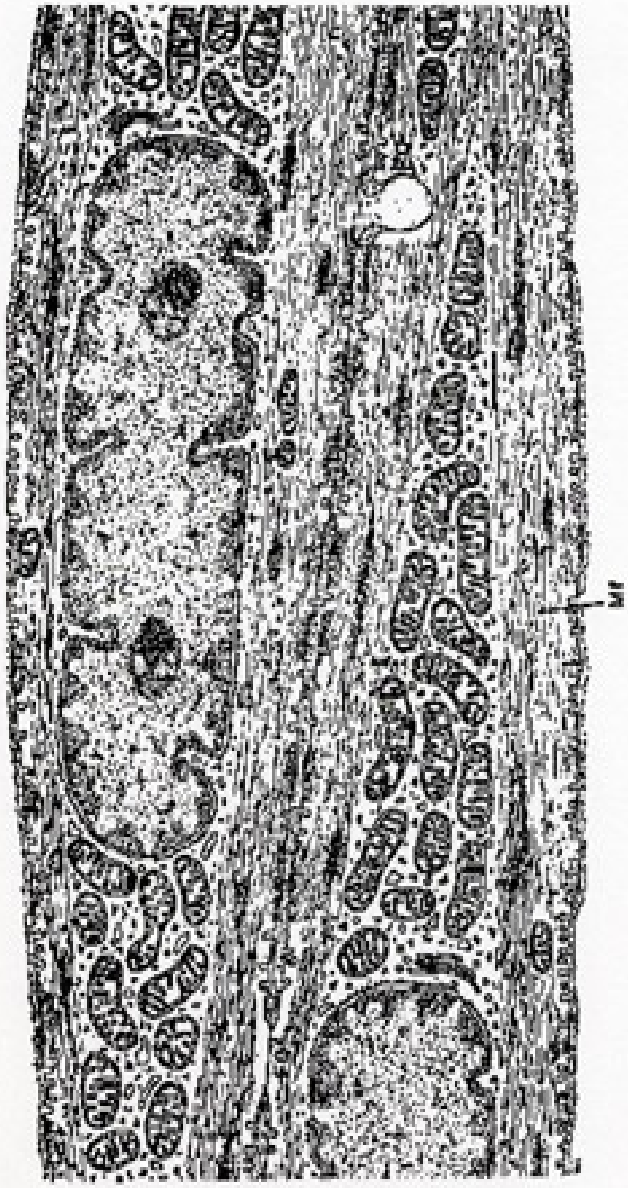
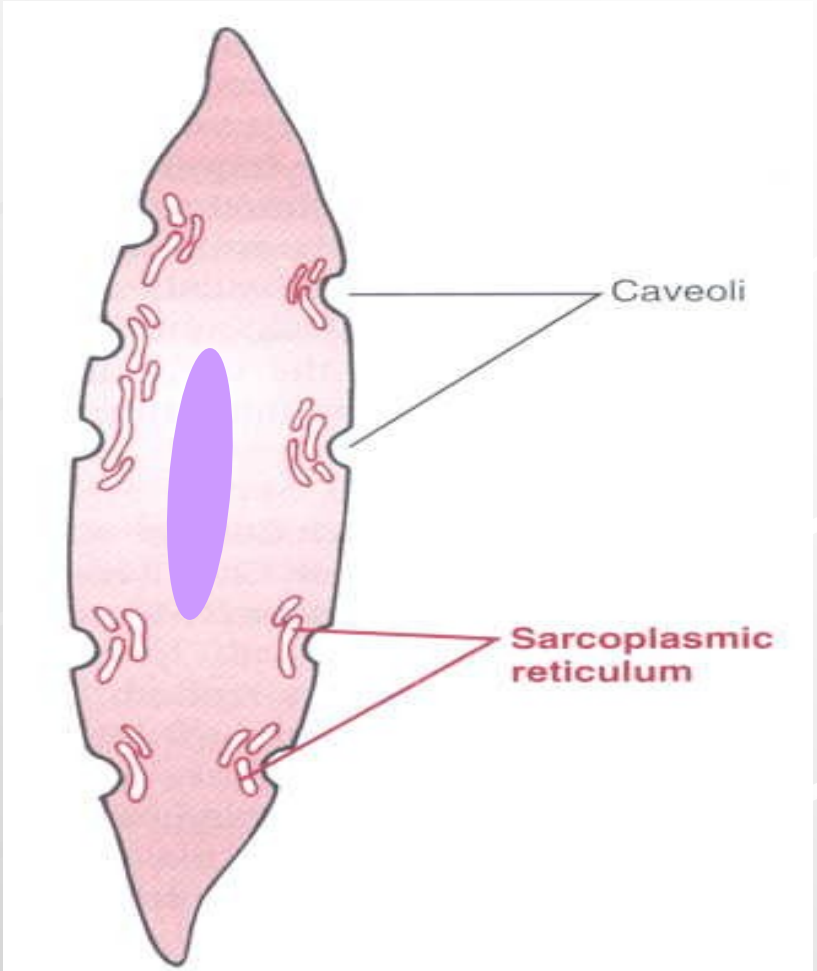
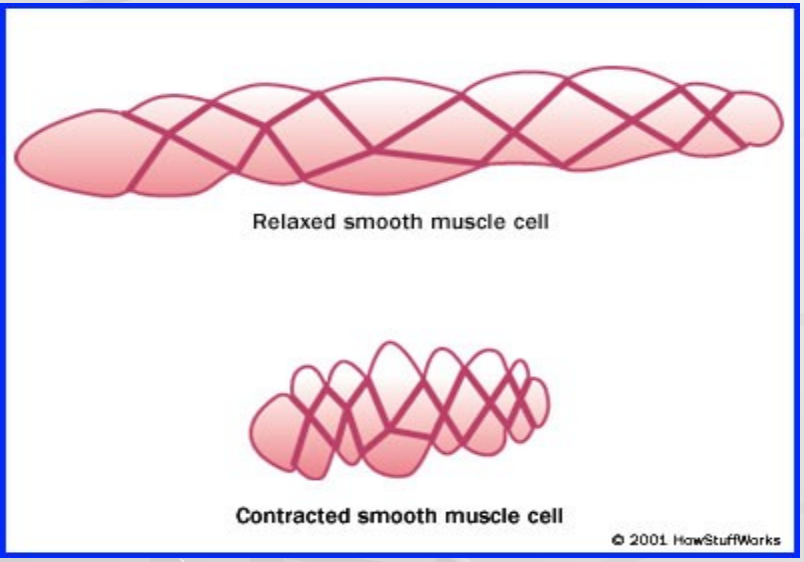


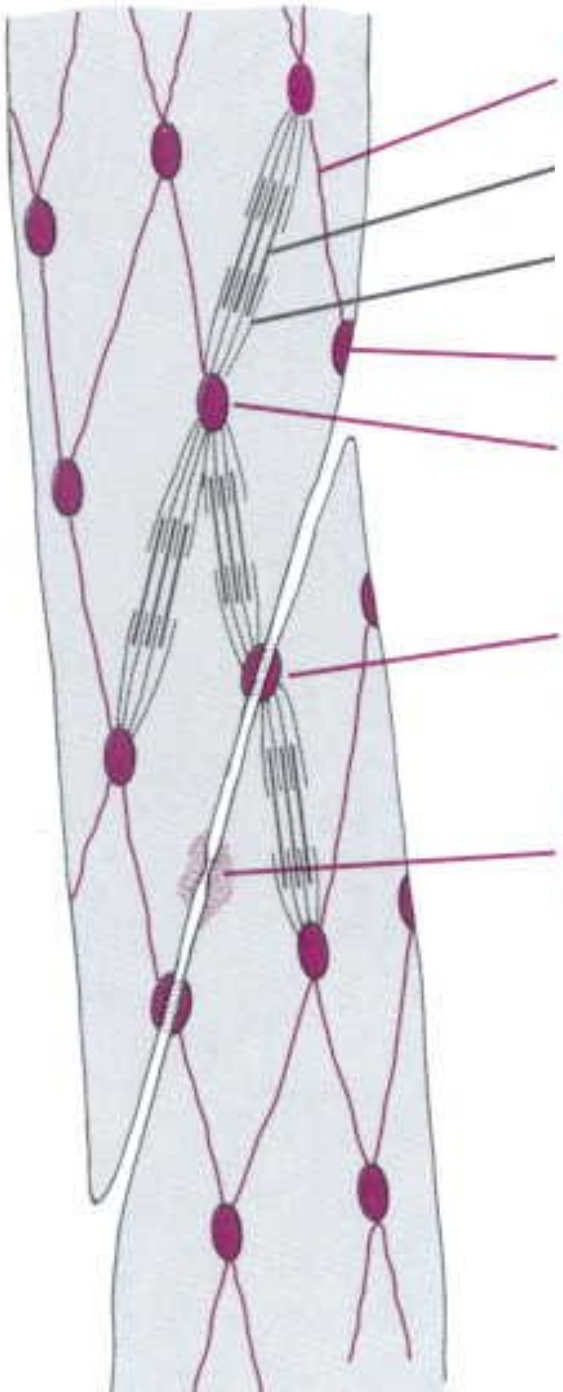
FIG. 10-2 E/M OF SMOOTH MUSCLE

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



Leiomyocyte:
contractile filaments





Intermediate filament

Myosin flaments

Actin filaments

Membrane dense area

Dense body

Mechanical junction coupling cells

Gap junction for electrical and chemical communication

\+

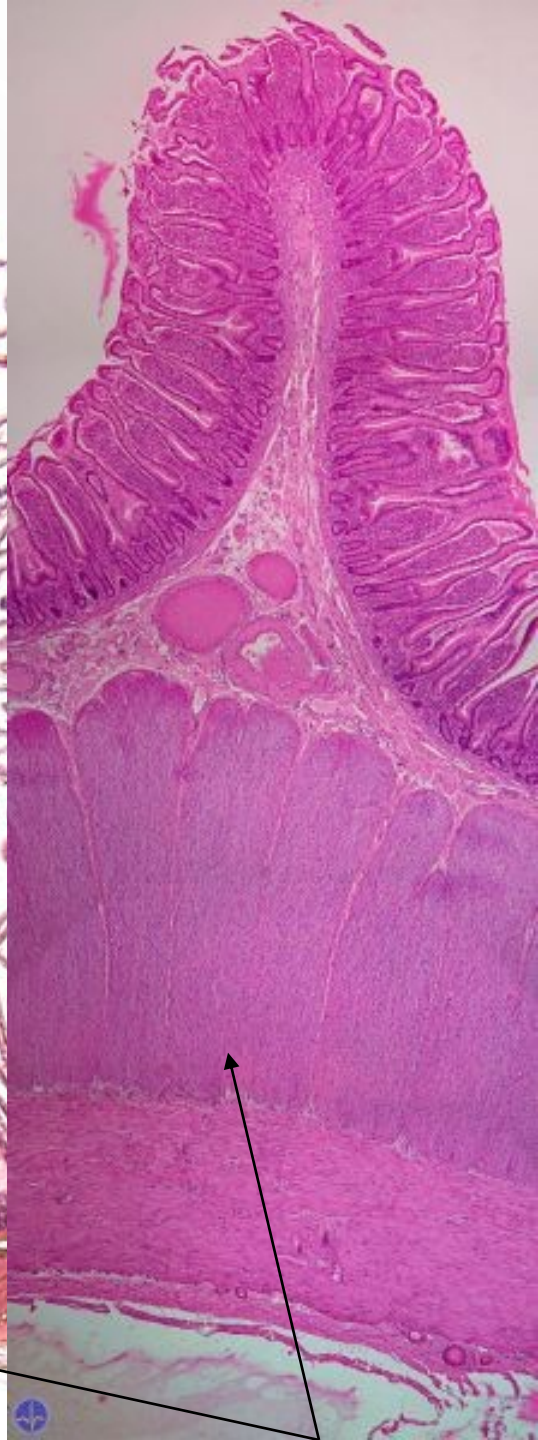
nexuses

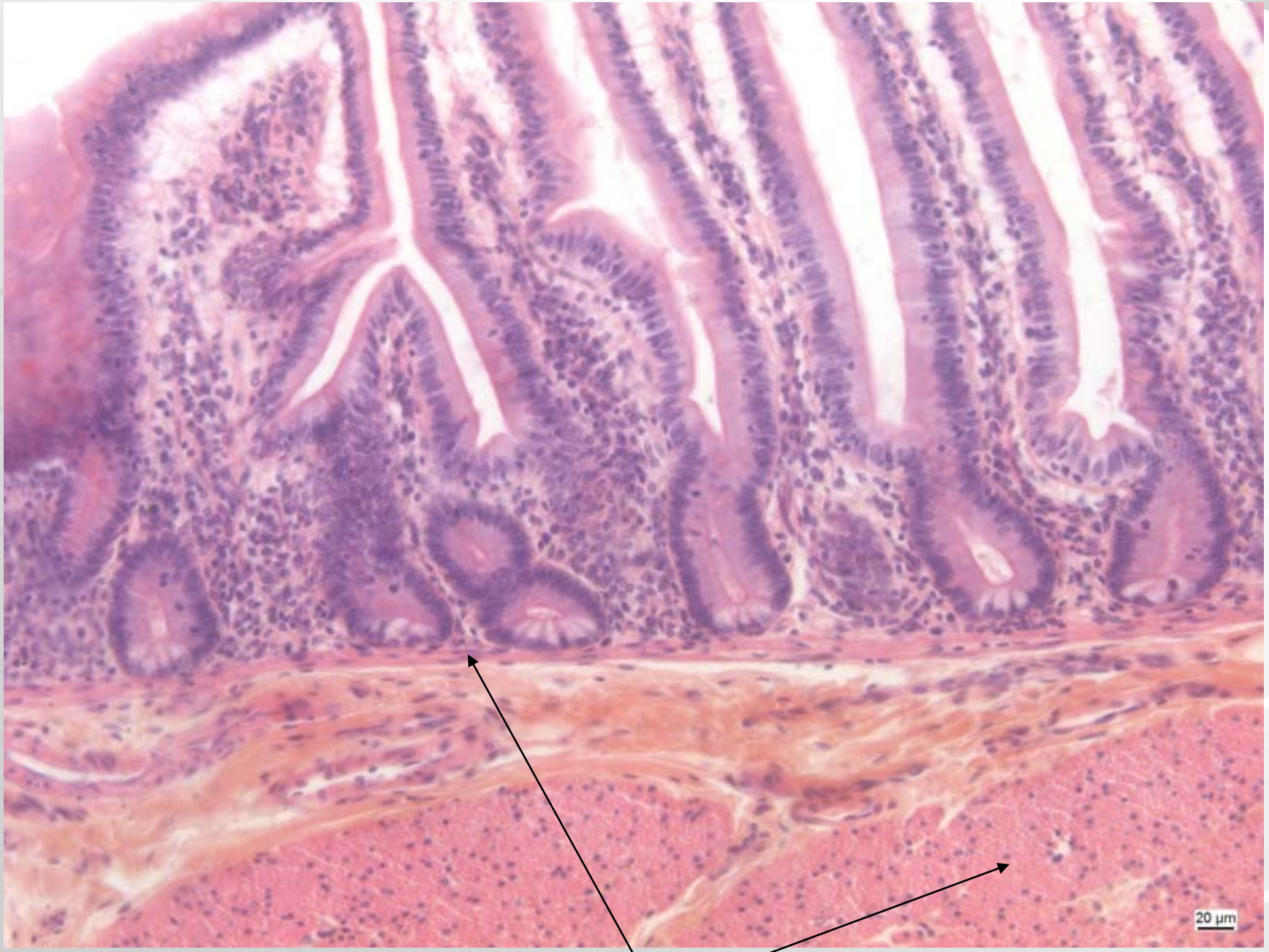
Muscle tissue

Slides:

- Skeletal muscle (2 – Apex linguae)
- Heart muscle (64, 65 – Myocardium)
- Smooth muscle (16 – Intestinum tenue)

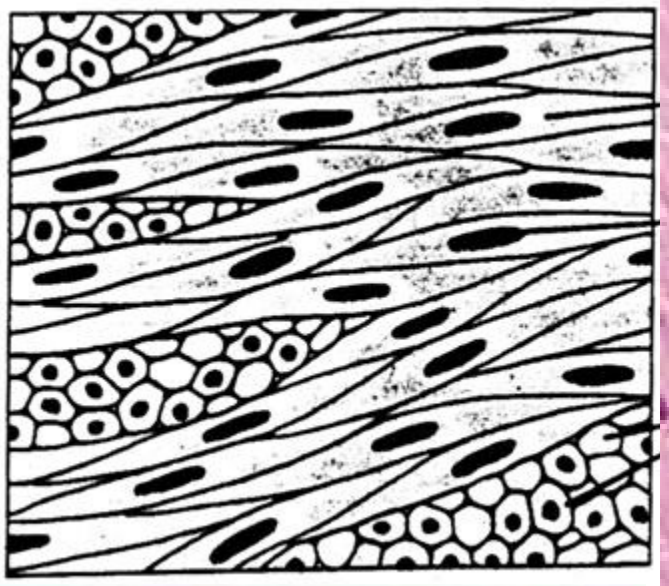
Smooth muscle

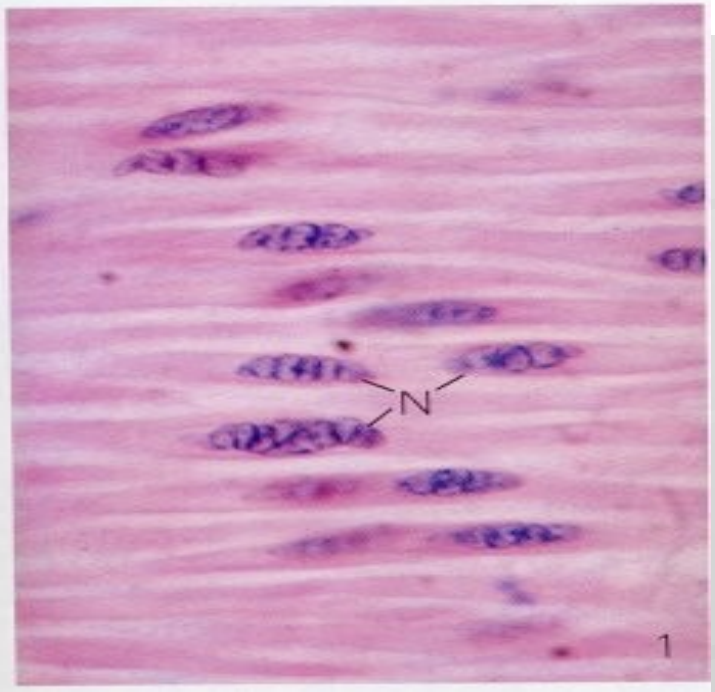


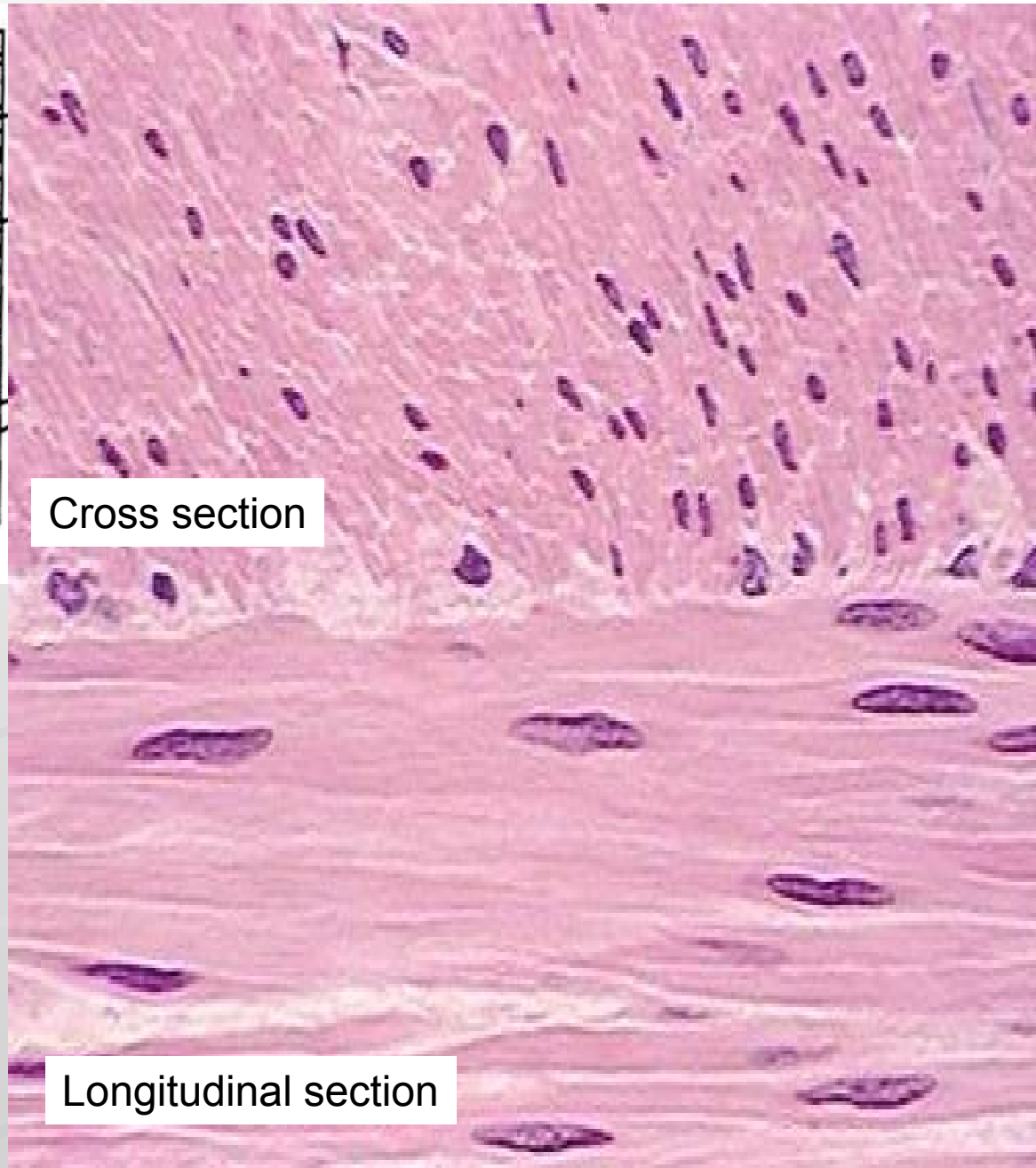


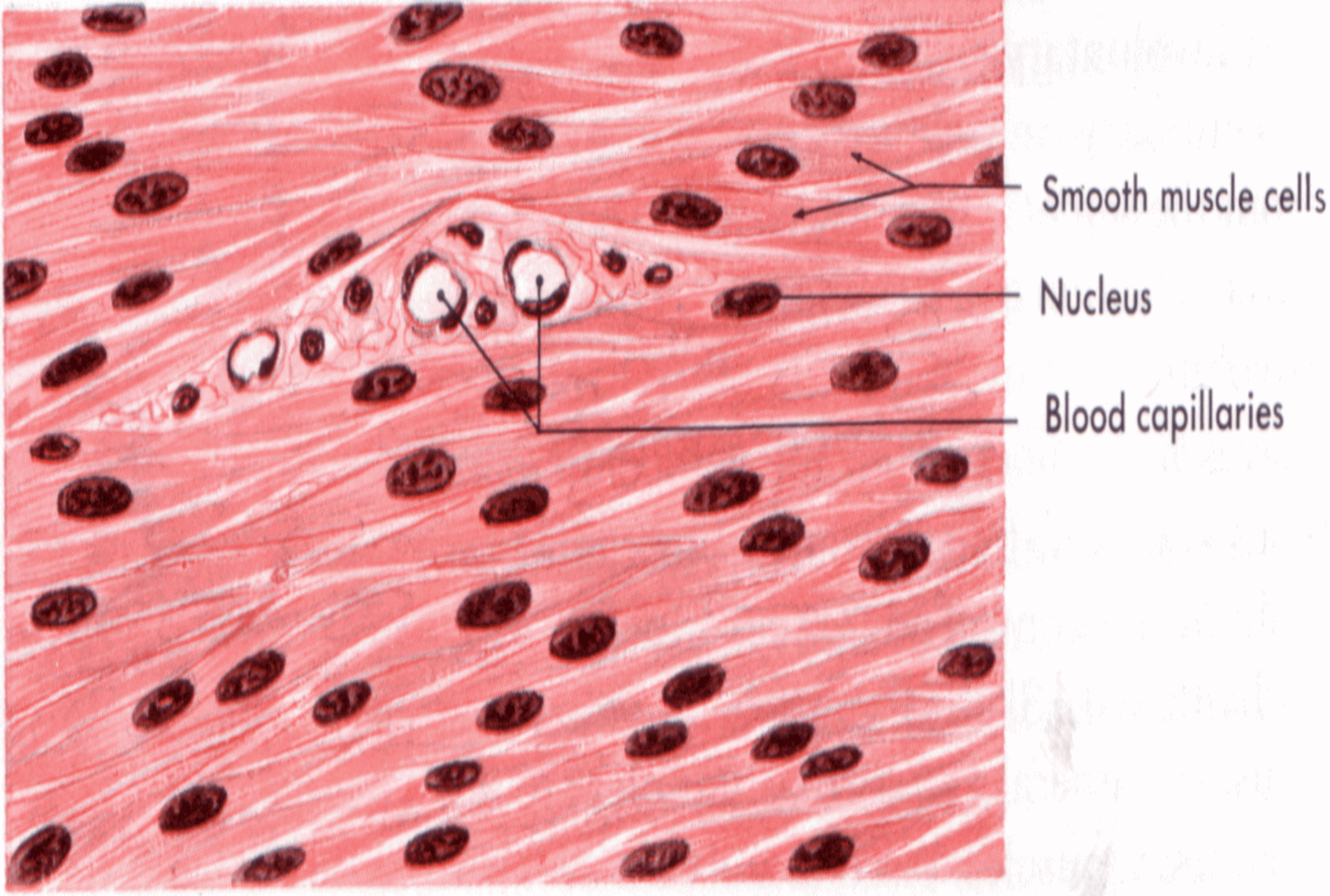
intestinum tenue – smooth muscle

Leiomyocytes are arranged into laeyers of wall of hollow (usually tubular) organs

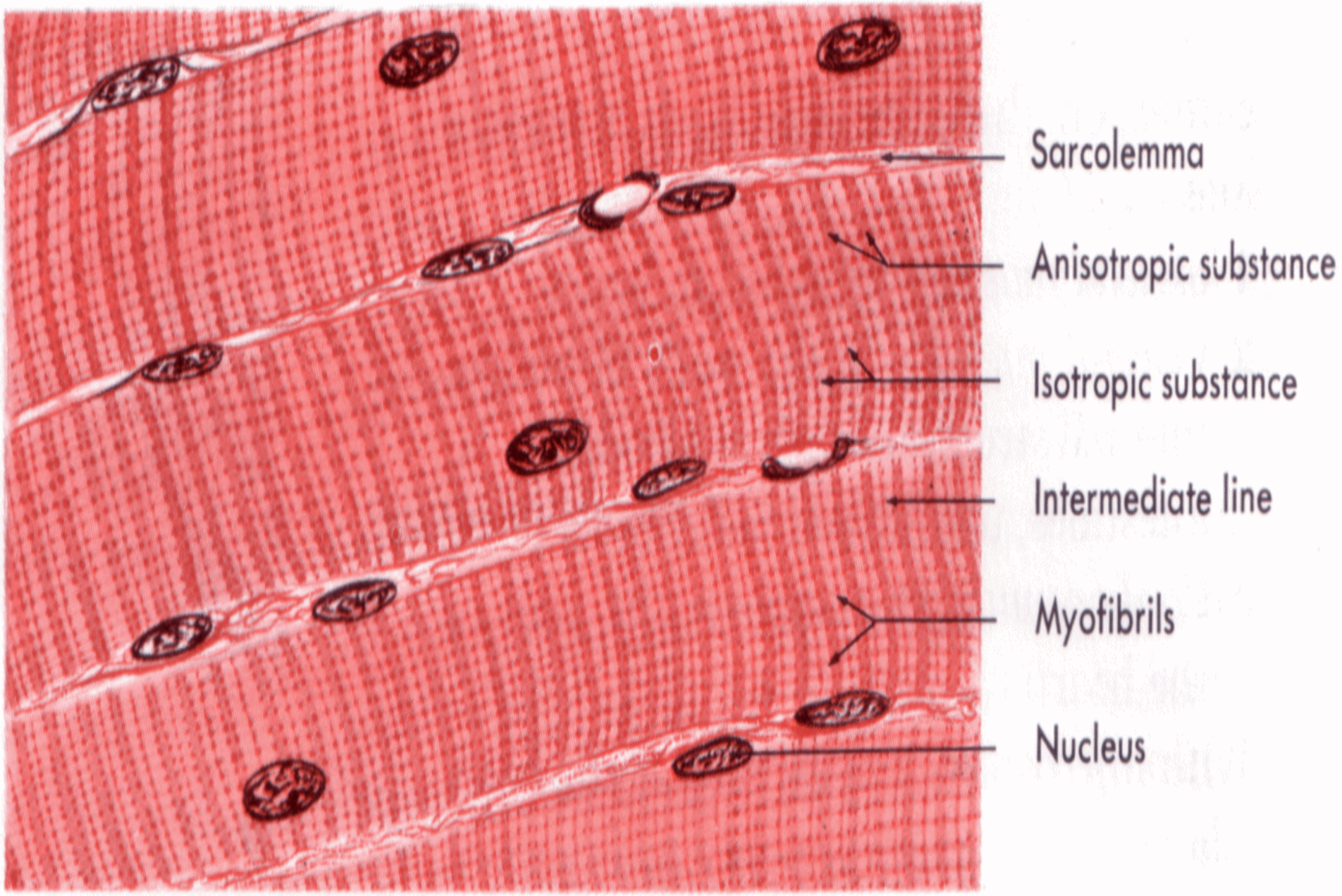




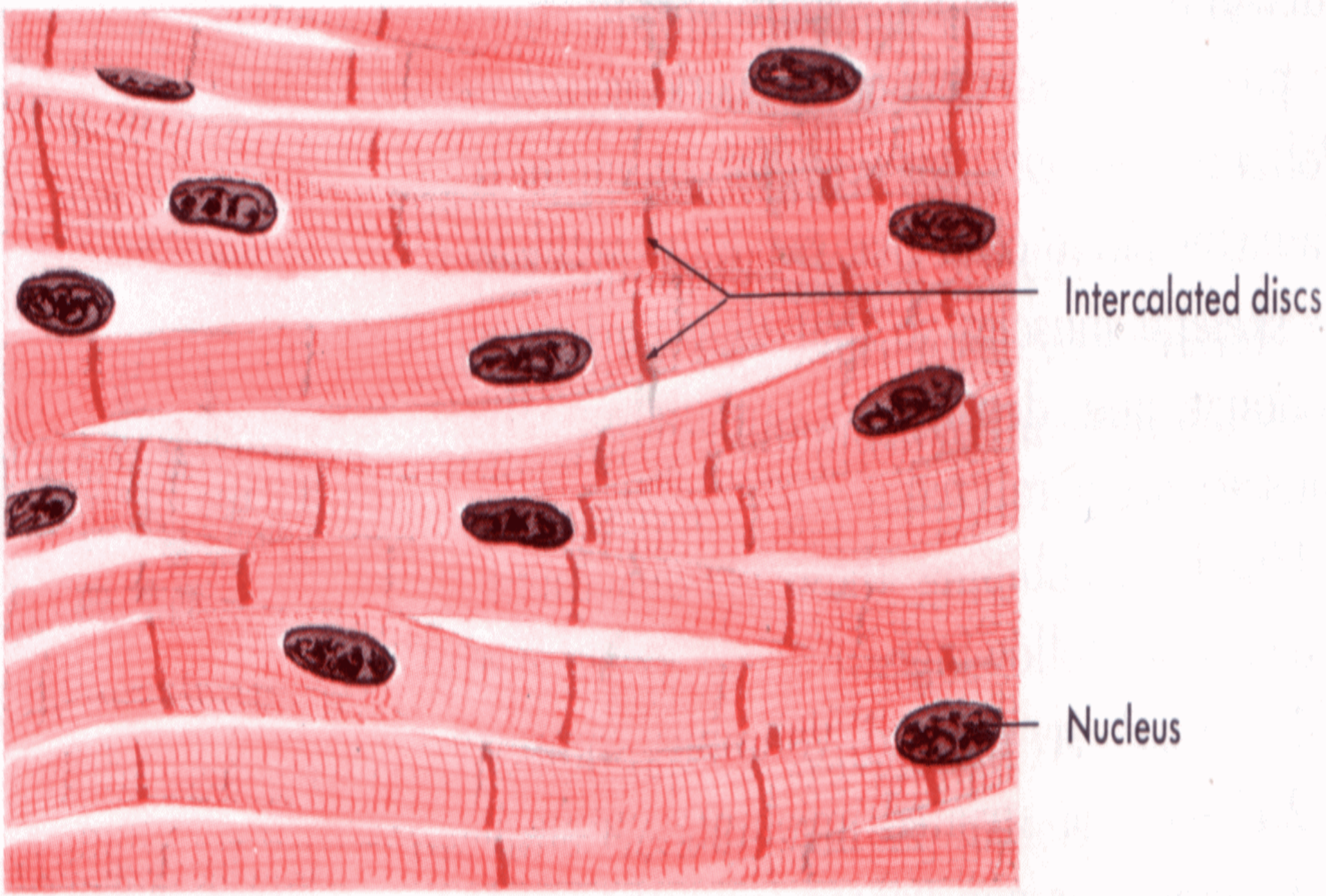




Visceral or nonstriated (smooth) involuntary muscle tissue.



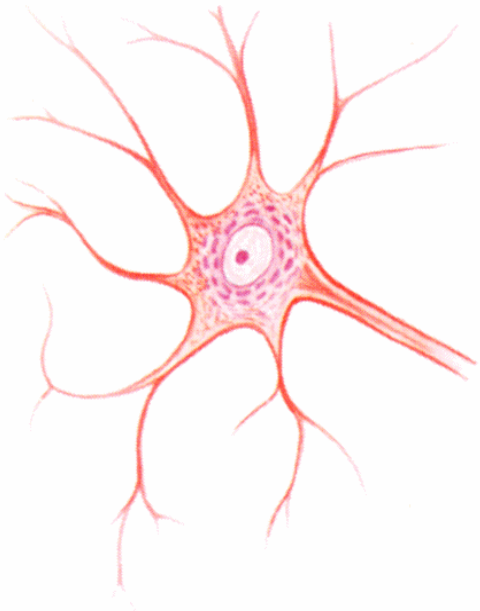
Skeletal or striated voluntary muscle tissue.



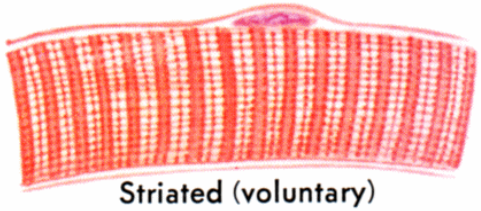
Cardiac or striated involuntary muscle tissue.

TYPES OF CELLS

NERVE CELL

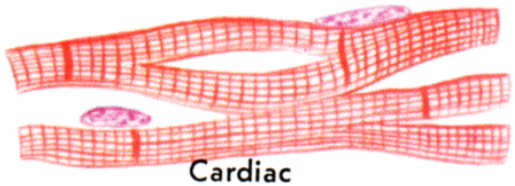


MUSCLE CELLS



Striated (voluntary)

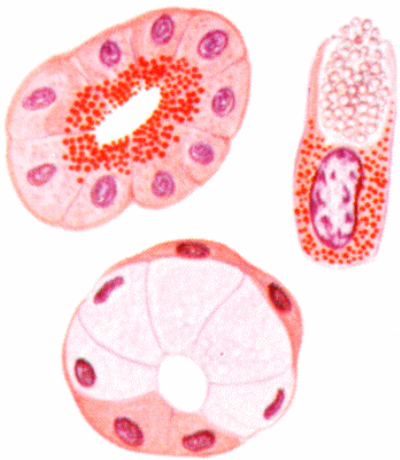
Smooth (involuntary)



Cardiac

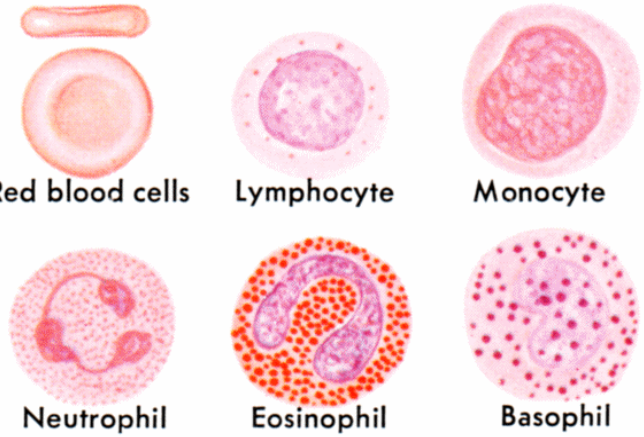
BONE CELL

GLAND CELLS



BLOOD CELLS

White blood cells



Red blood cells

Lymphocyte

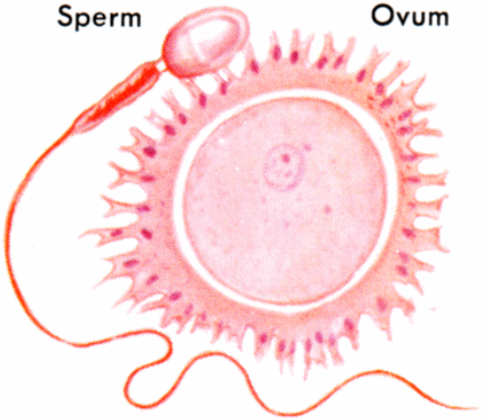
Monocyte

Neutrophil

Eosinophil

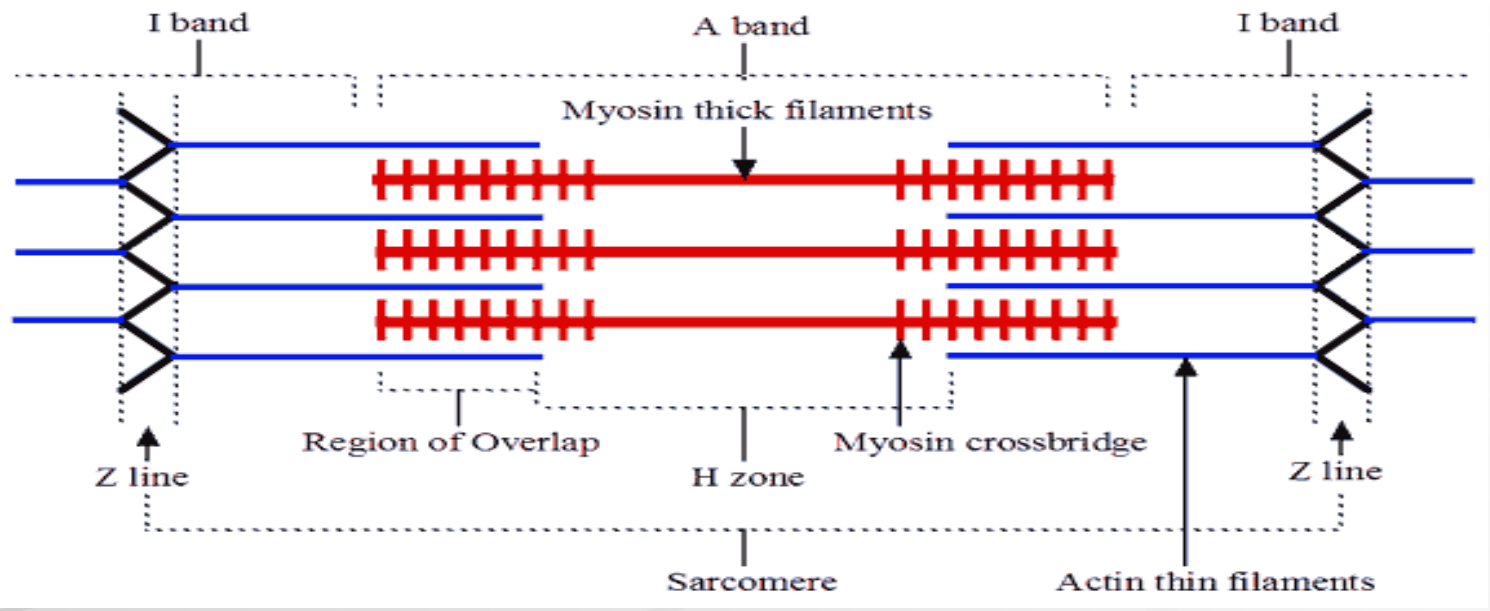
Basophil

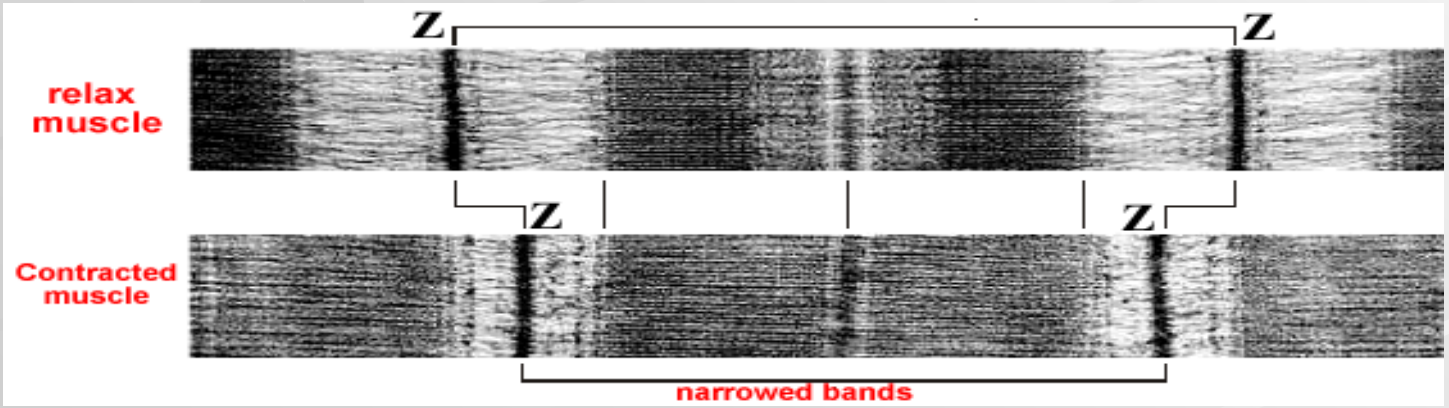
REPRODUCTIVE CELLS

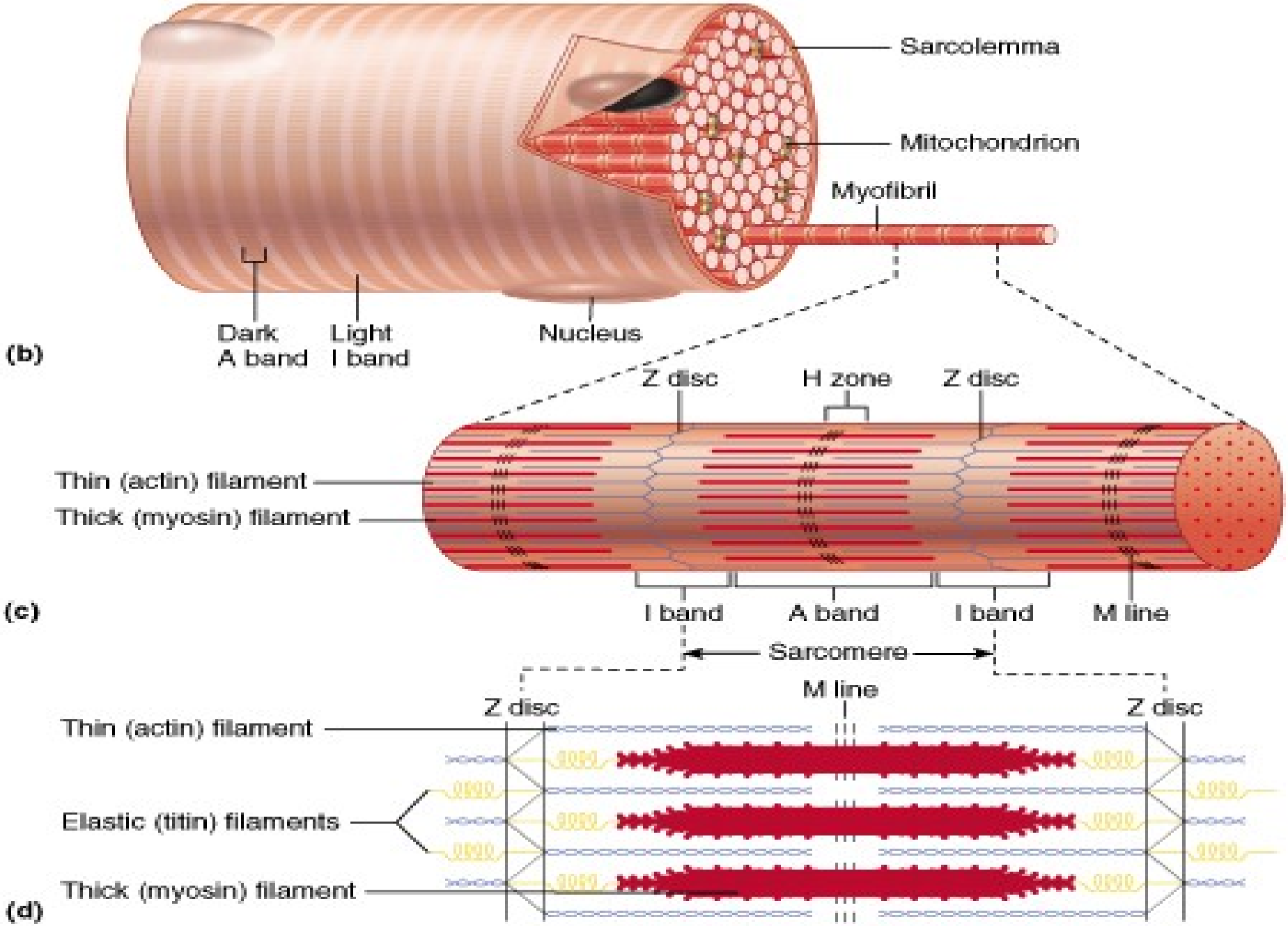


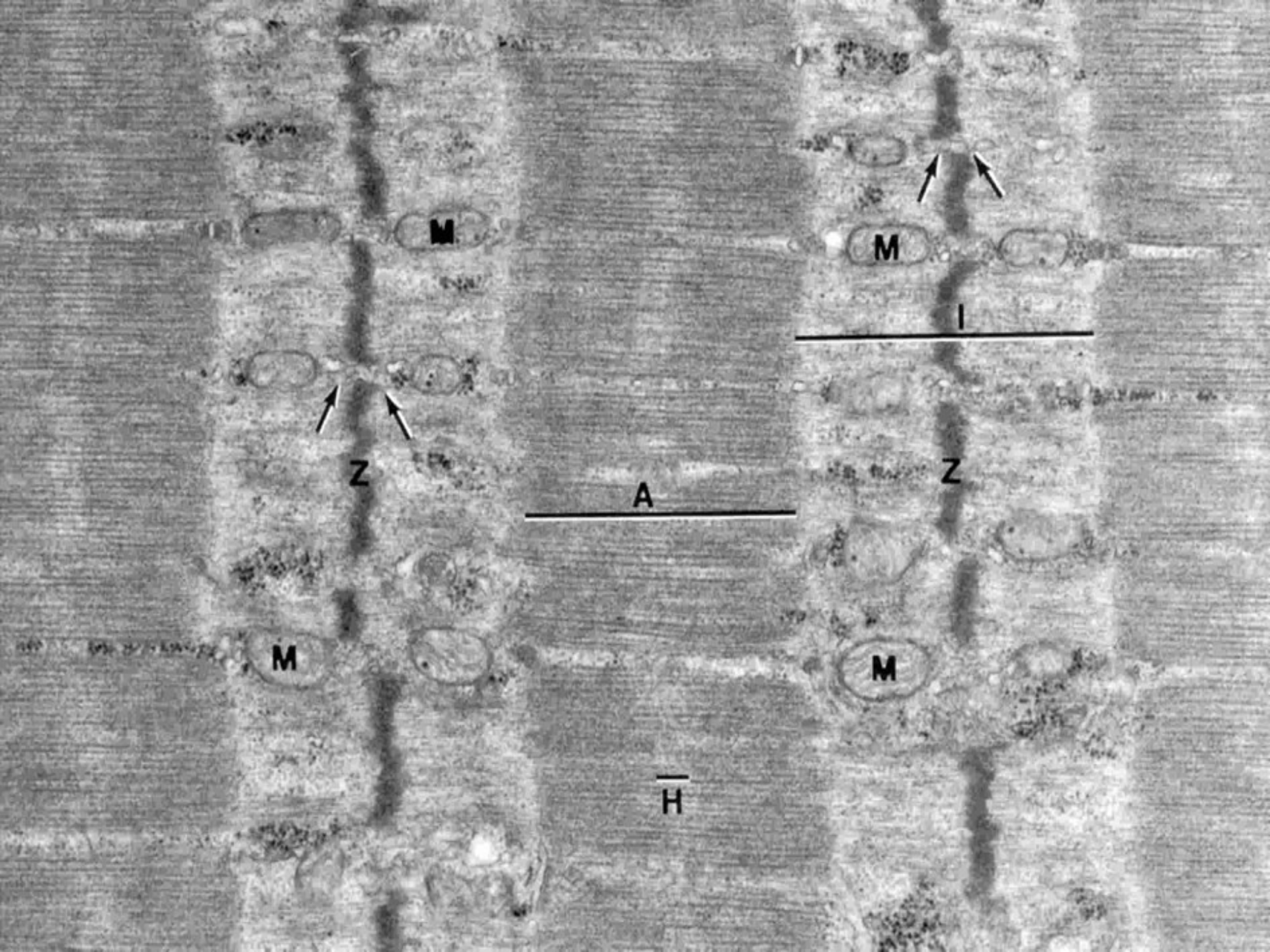
Sperm

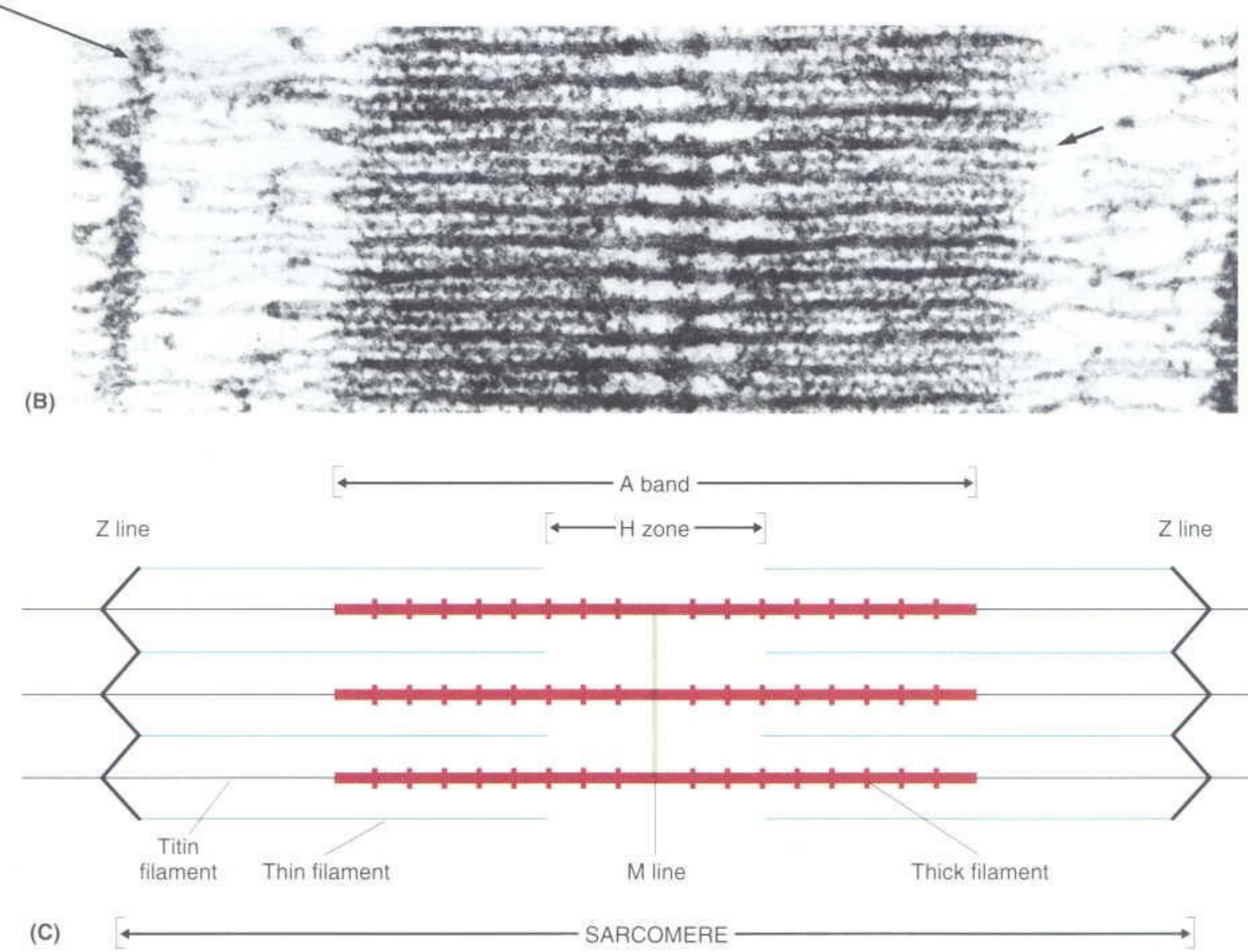
Ovum

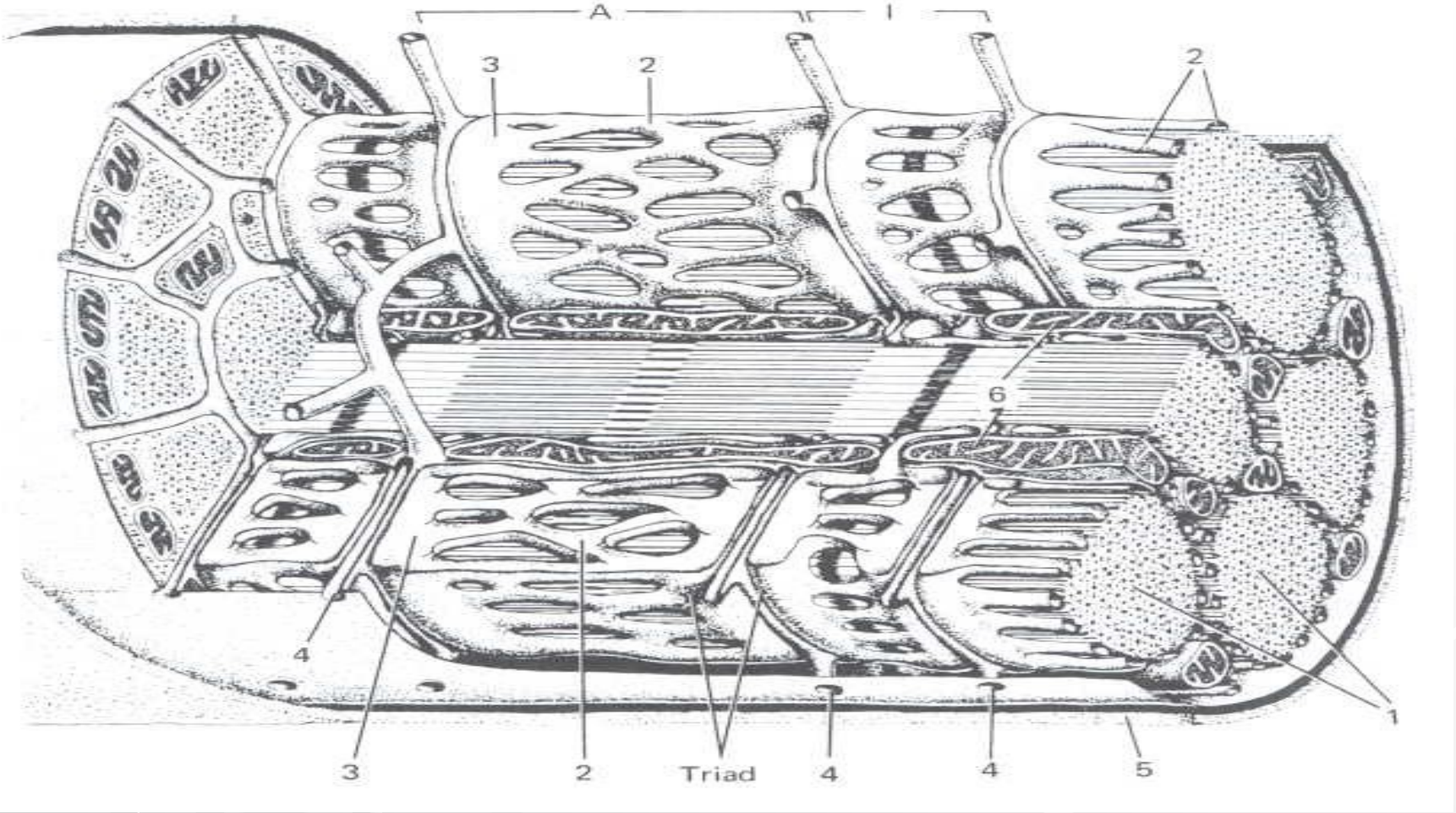

I band
A band
I band
Myosin thick filaments
Region of Overlap
H zone
Myosin crossbridge
Z line
Z line
Sarcomere
Actin thin filaments

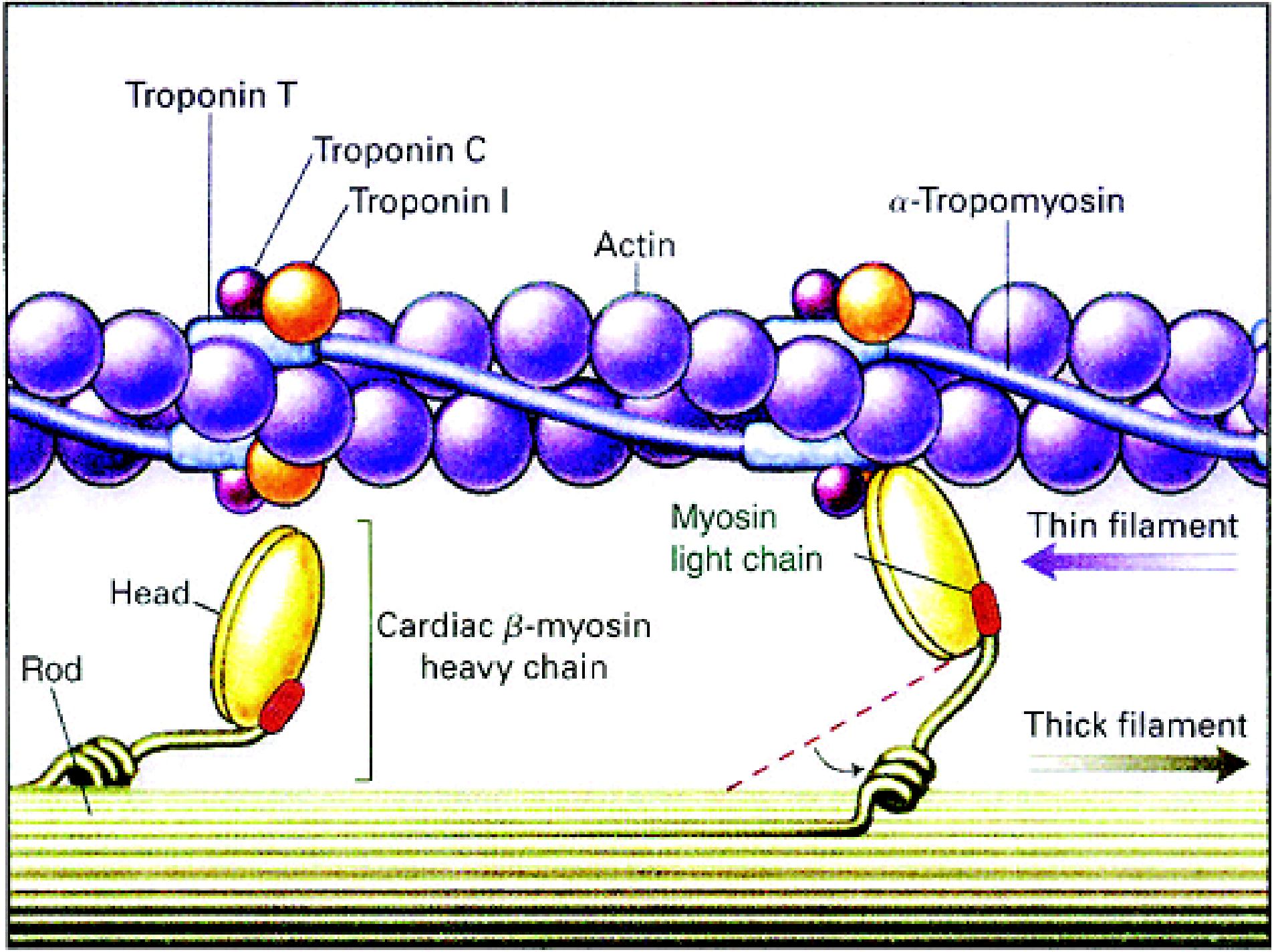

Z
Z
relax muscle
Z
Z
Contracted muscle
narrowed bands



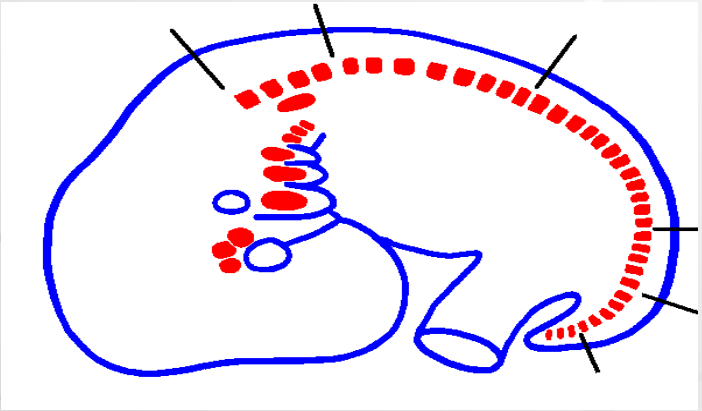

M
M
I
Z
Z
A
M
M
H


(B)
A band
H zone
Z line
Z line
Titin filament
Thin filament
M line
Thick filament
(C)
SARCOMERE


A
I
3
2
2
6
4
1
3
2
Triad
4
4
5

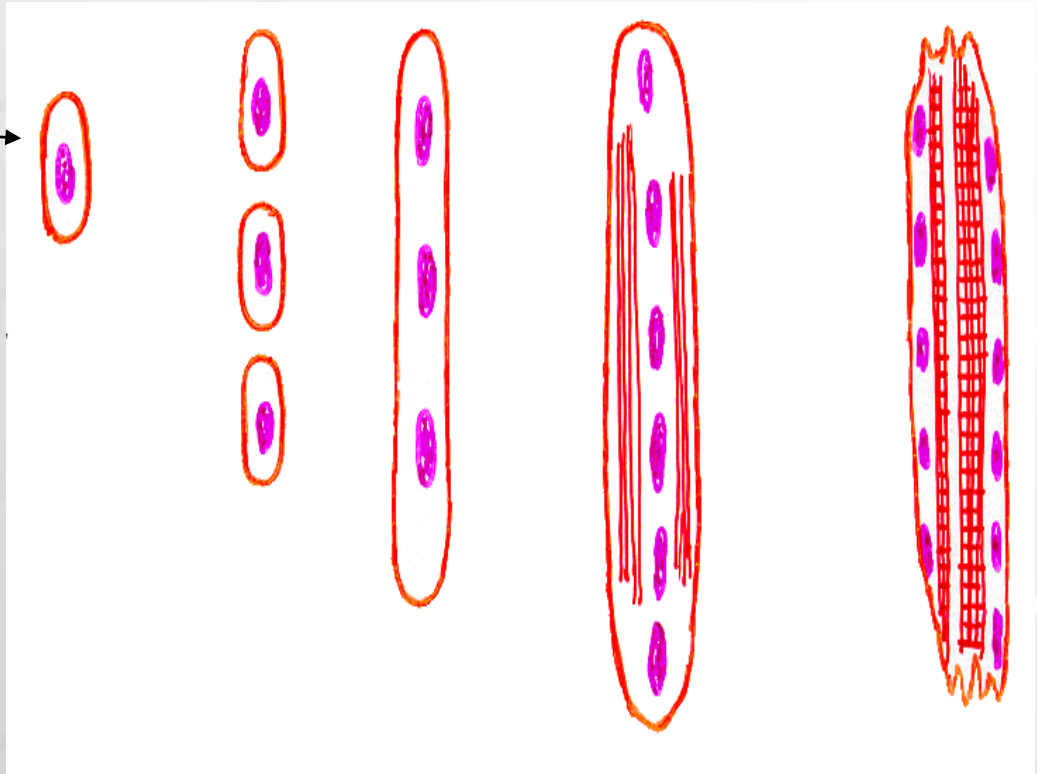

Troponin T
Troponin C
Troponin I
Actin
α-Tropomyosin
Myosin
light chain
Thin filament
Head
Rod
Cardiac β-myosin
heavy chain
Thick filament

Development of rhabdomyocyte



Origin of skeletal muscle:
paraaxial mesoderm – somites – myotomes

Fusion of myoblasts (primitive muscle cells in myotomes) into multinucleated muscle fiber

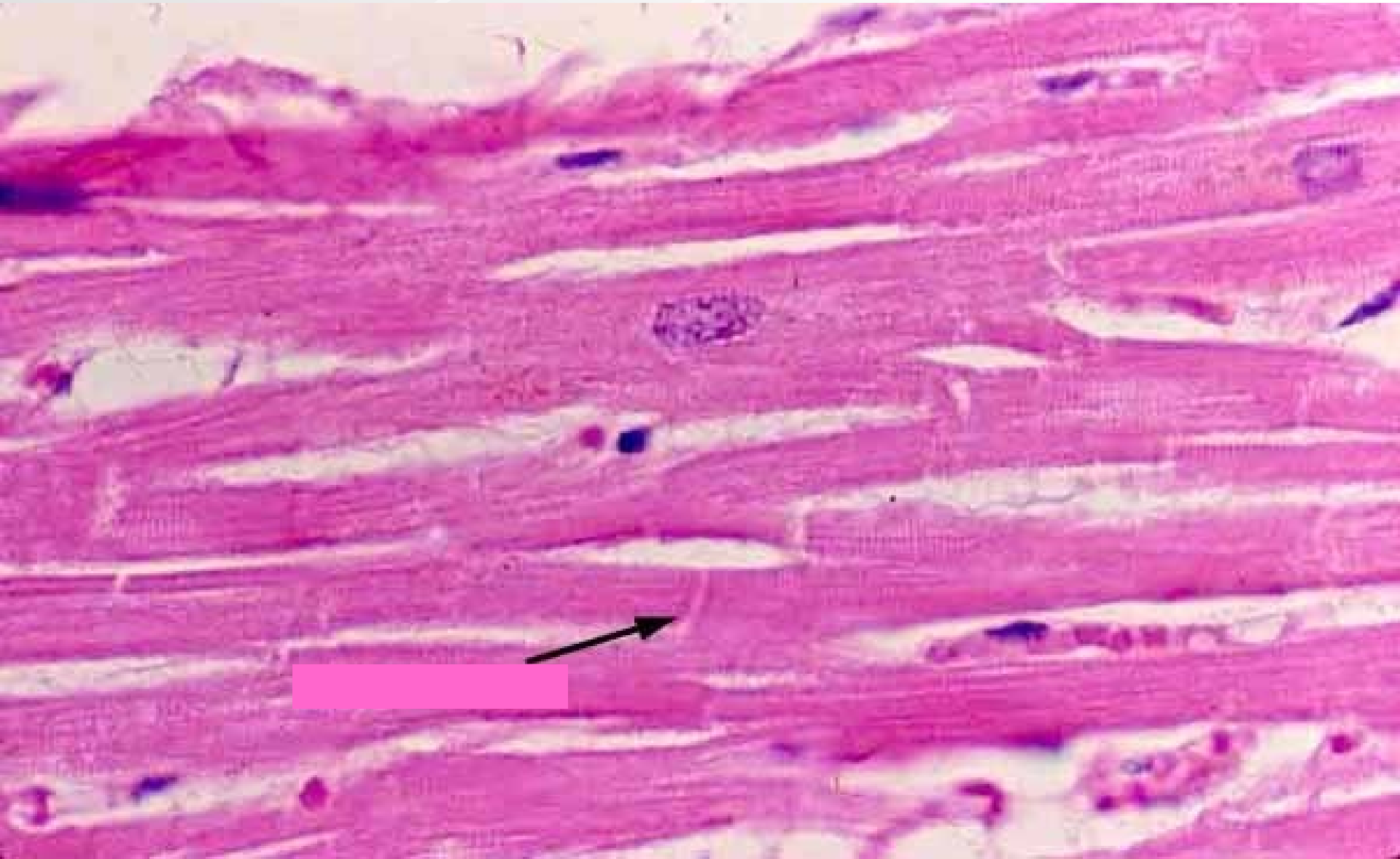


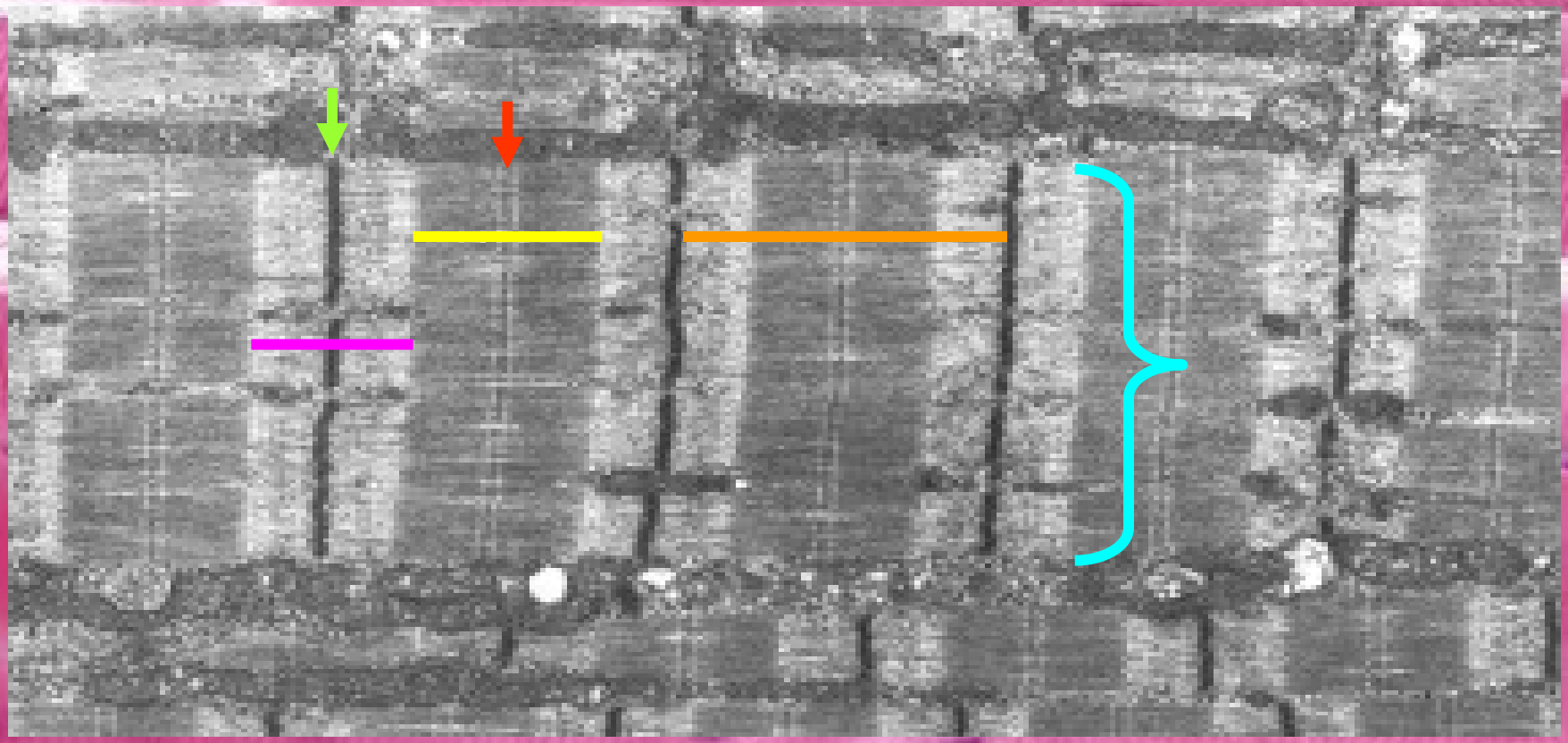
Development of cardiomyocytes and leiomyocytes

Practice and Quiz

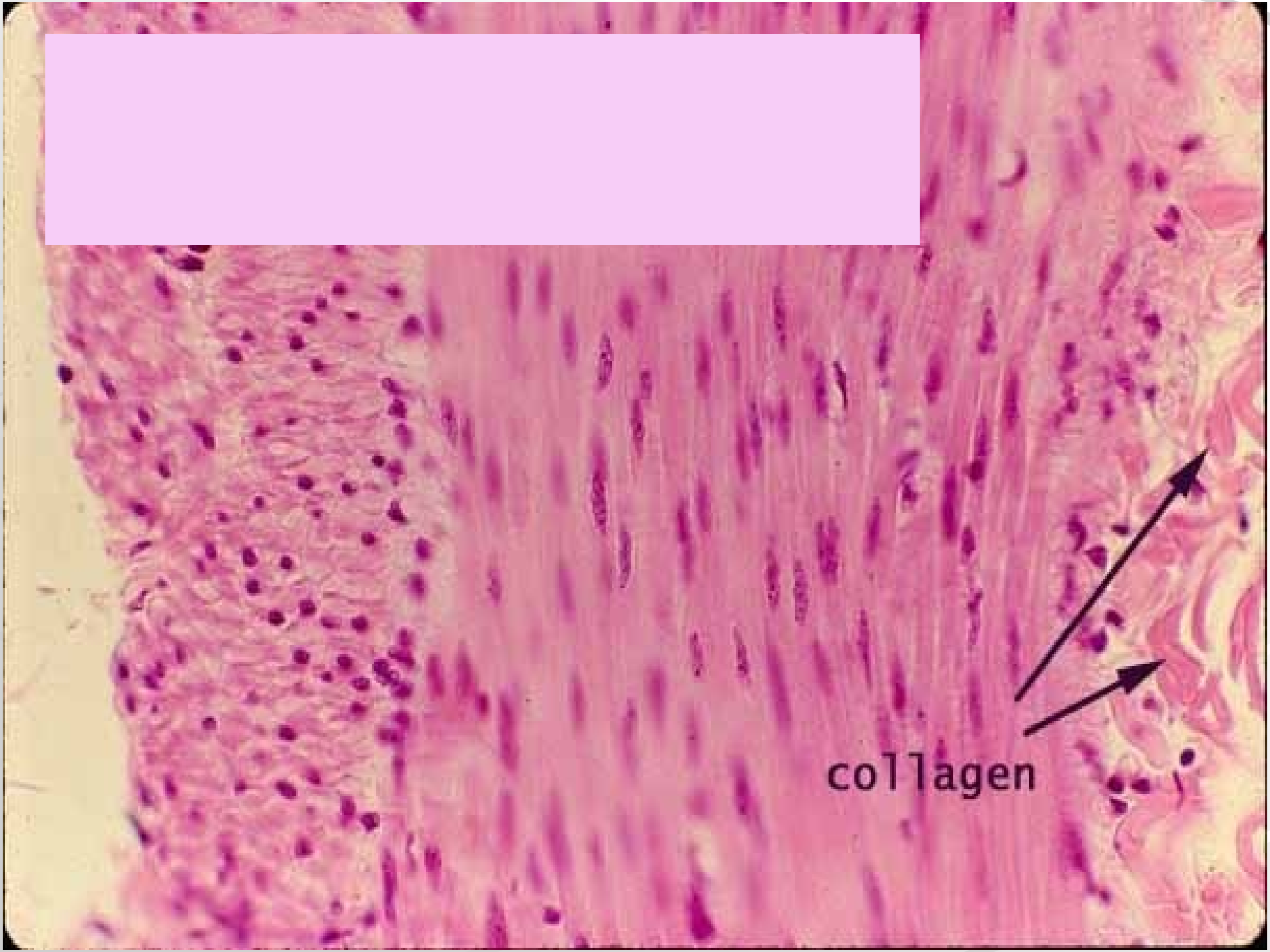
- Rhabdomyocyte
- Endomysium
- Sarcomere
- T-tubule
- Troponin
- Myofilament
- Myofibril
- Sarcoplasmic reticulum
- Actin
- Sarcolemme
- Perimysium

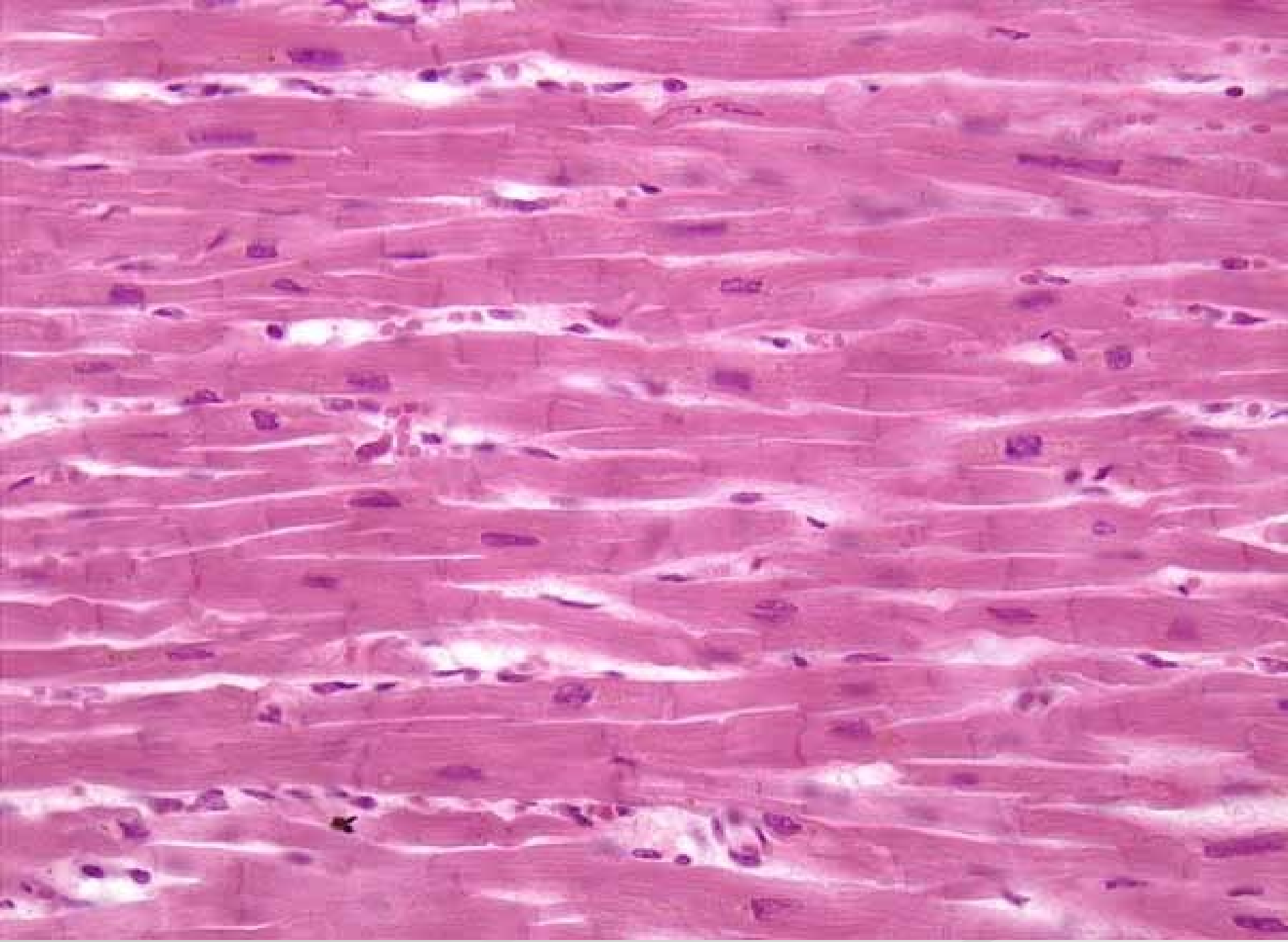
- Leiomyocyte
- Myosin
- Epimysium
- Triad
- Intercalated disc
- A-band
- Cardiomyocyte
- M-line
- Myosin
- Fascia adherens
- Motor-end-plate

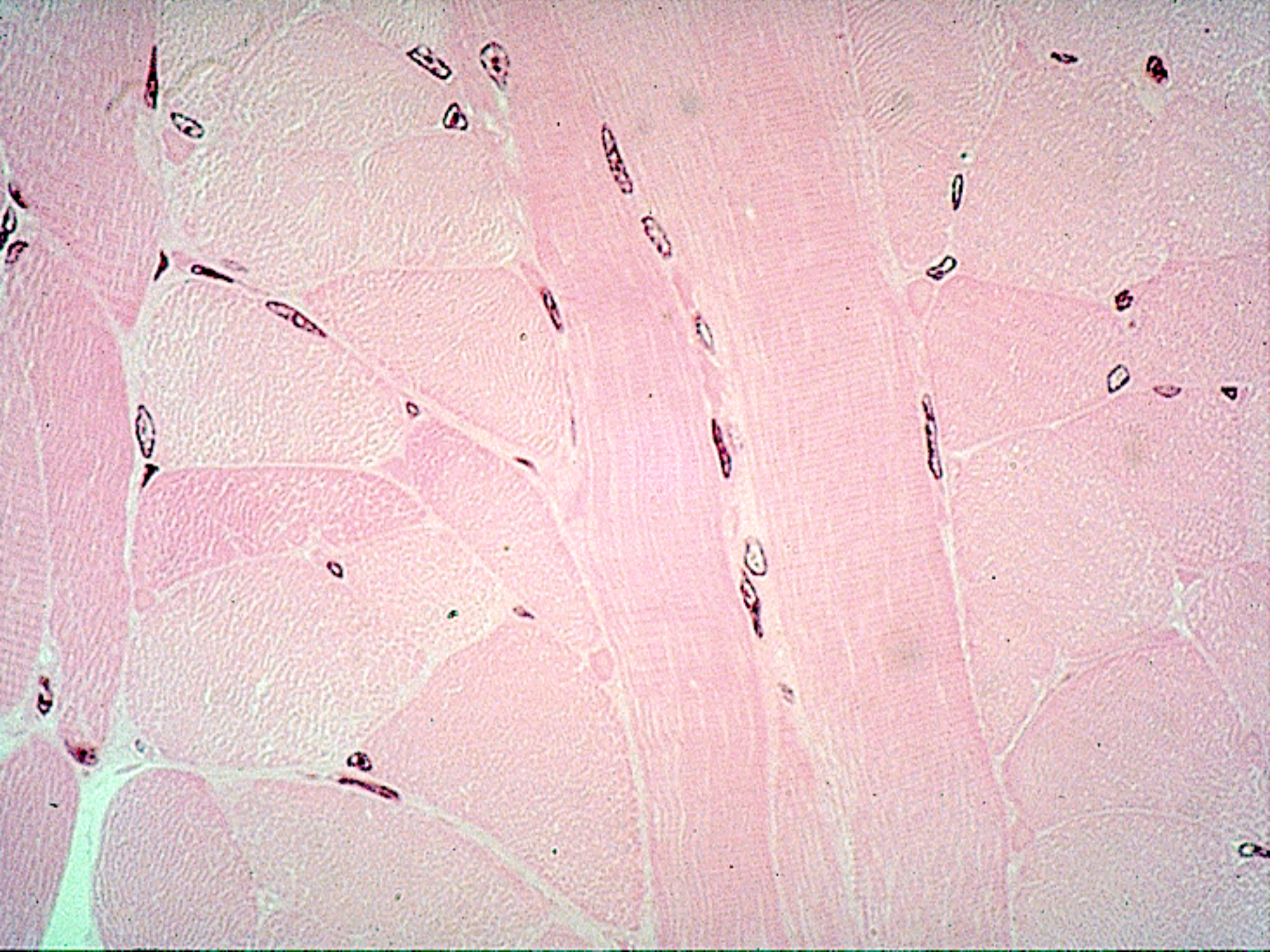


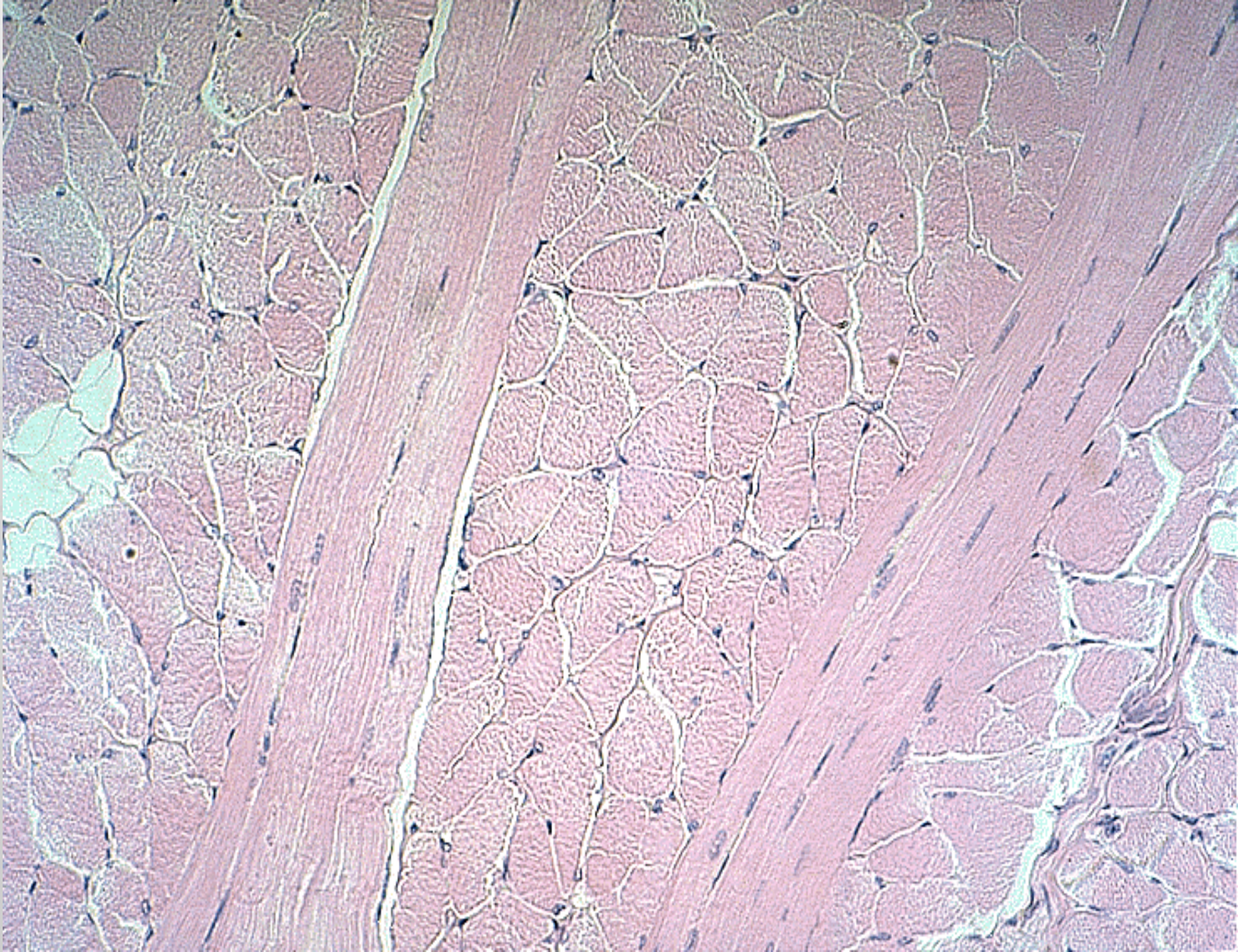


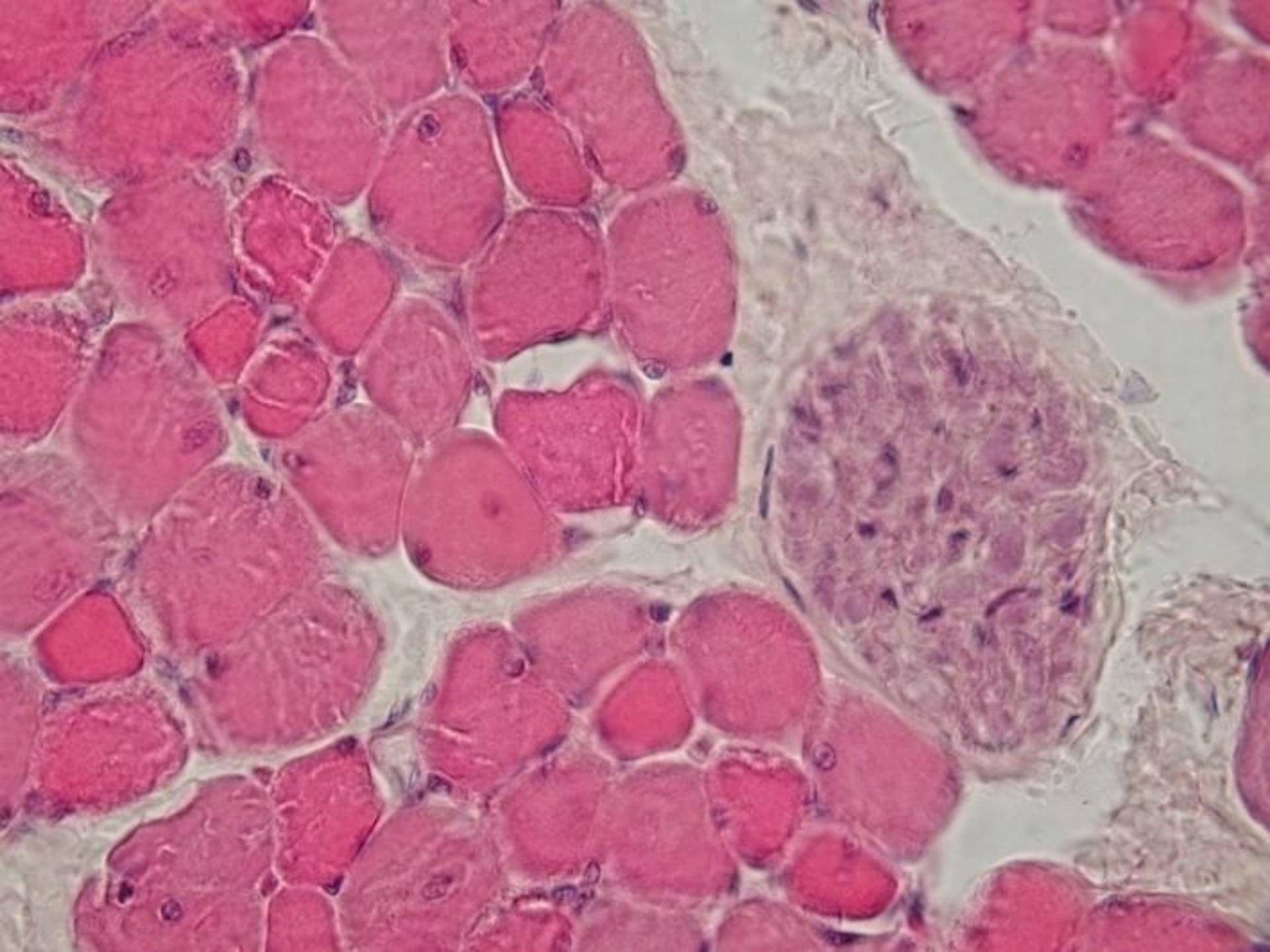

Auerbach's
plexus
serosa
mesothelium

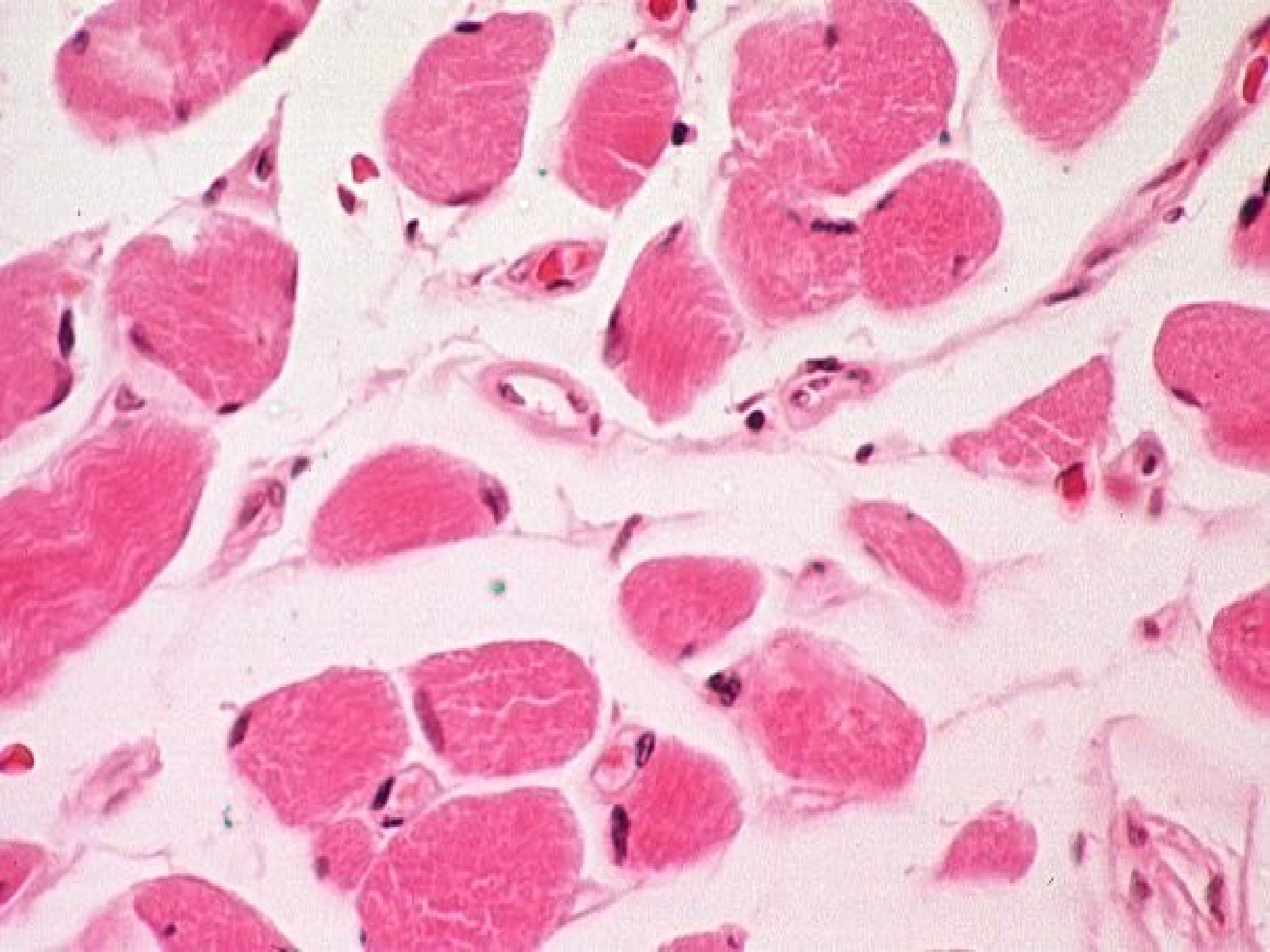

collagen

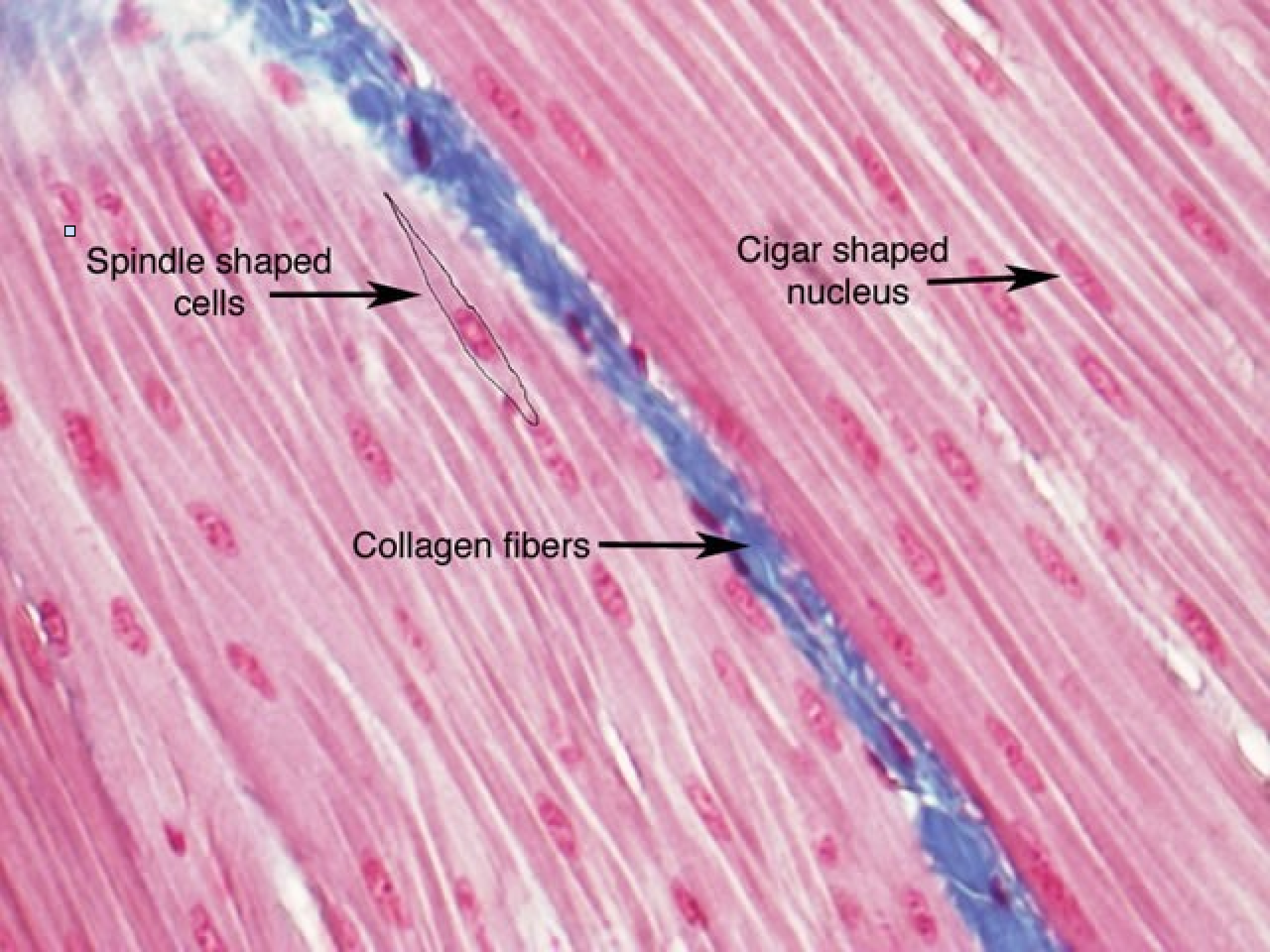


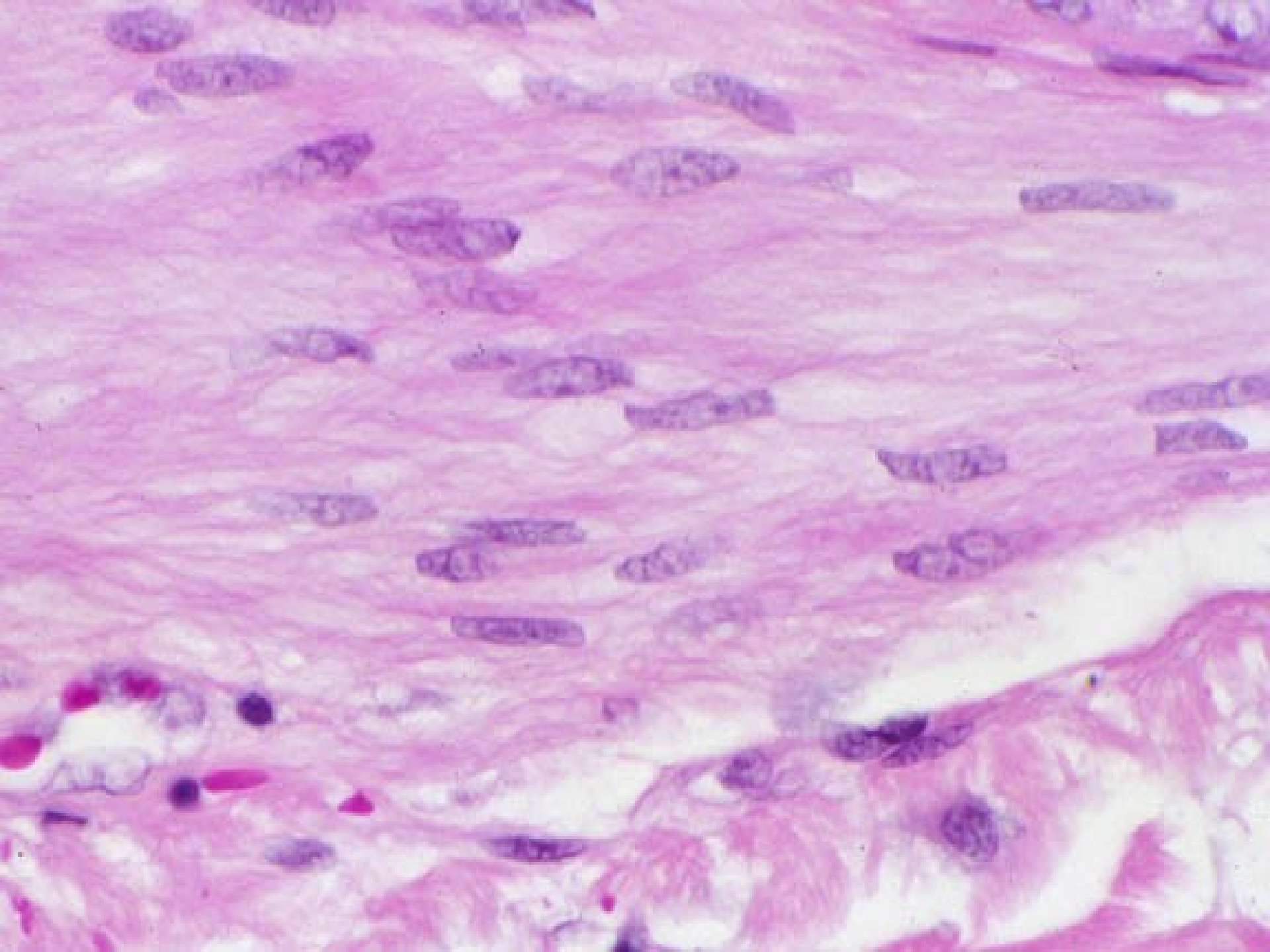


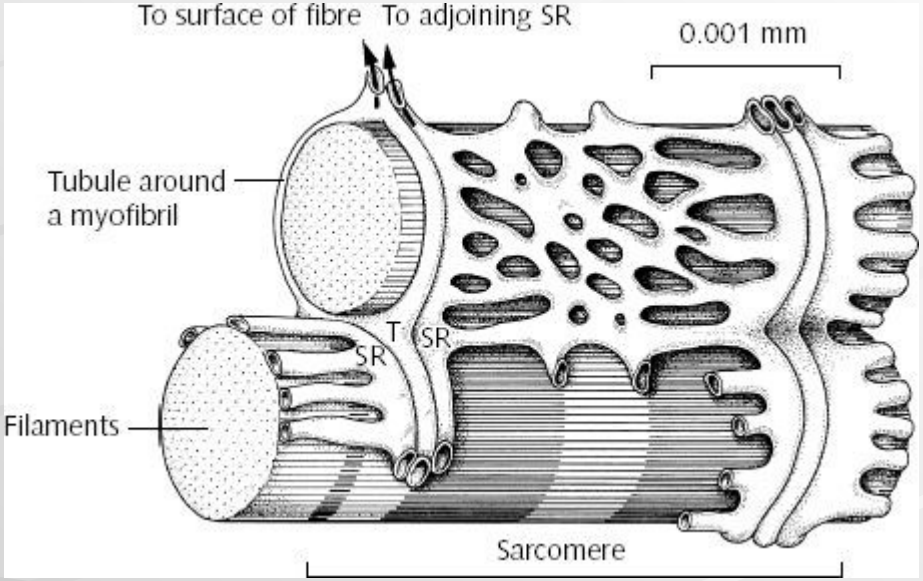


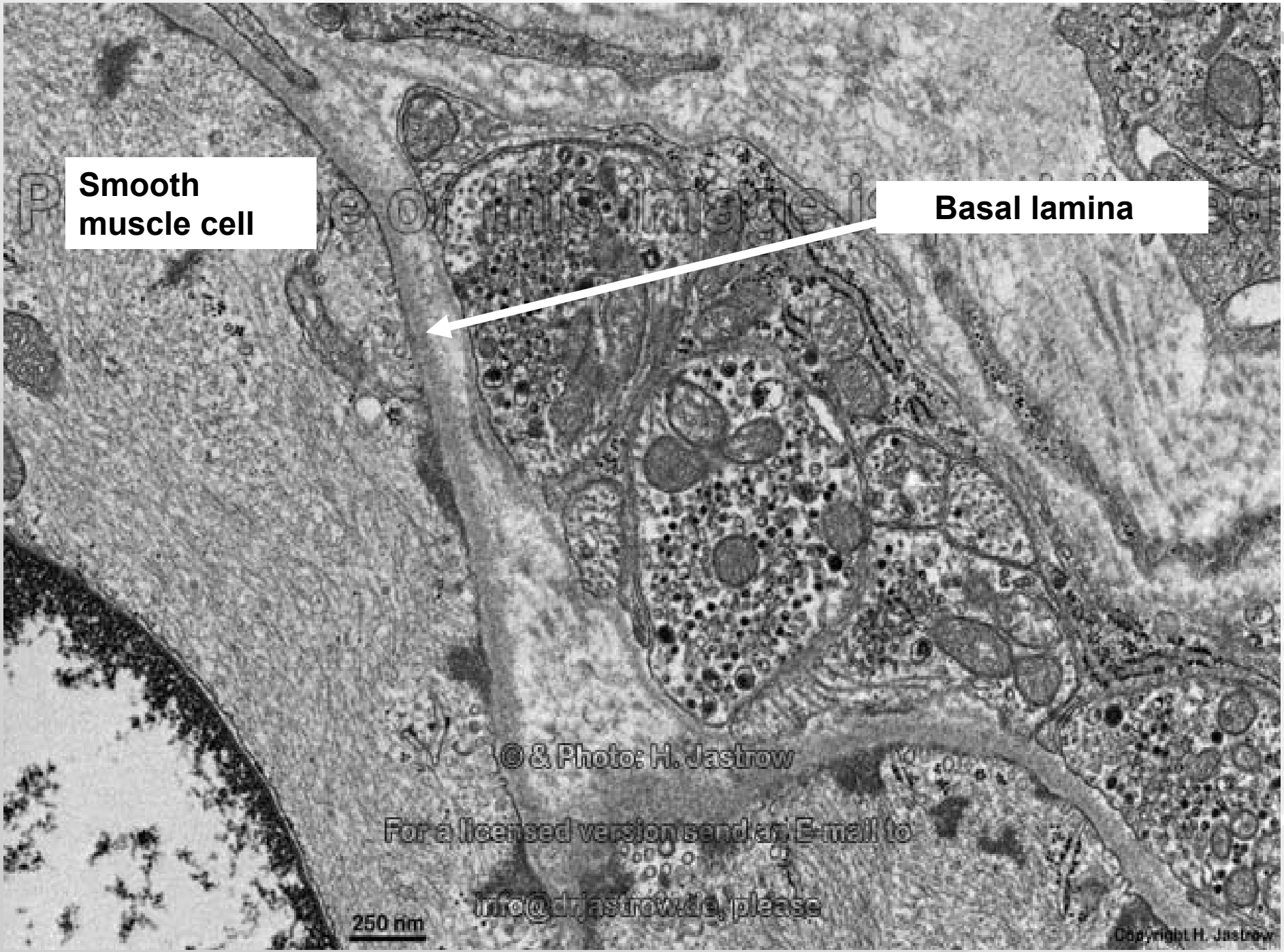




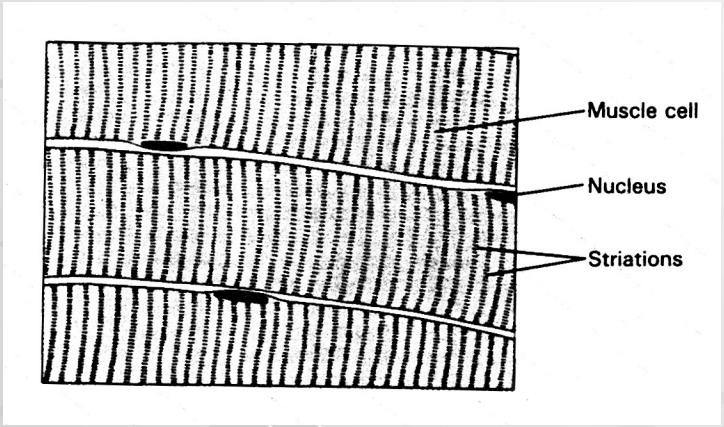

Spindle shaped cells
Cigar shaped nucleus
Collagen fibers

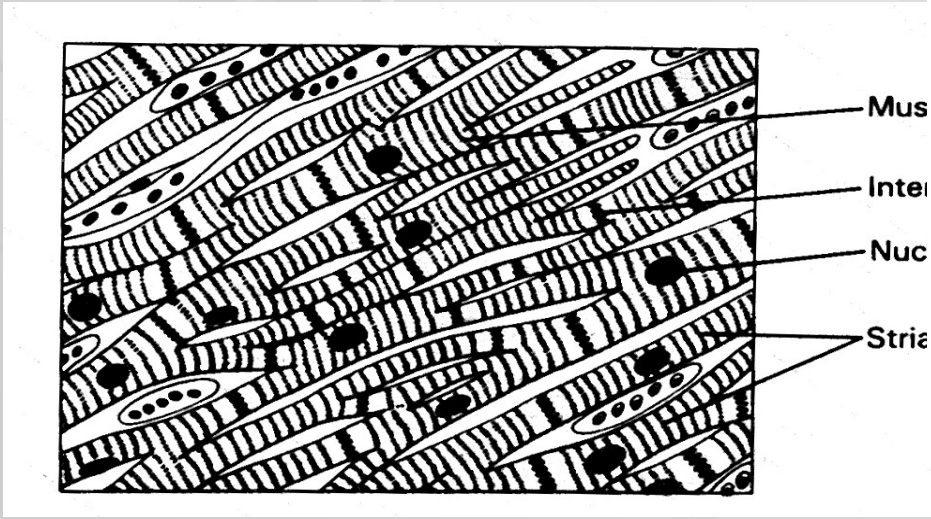


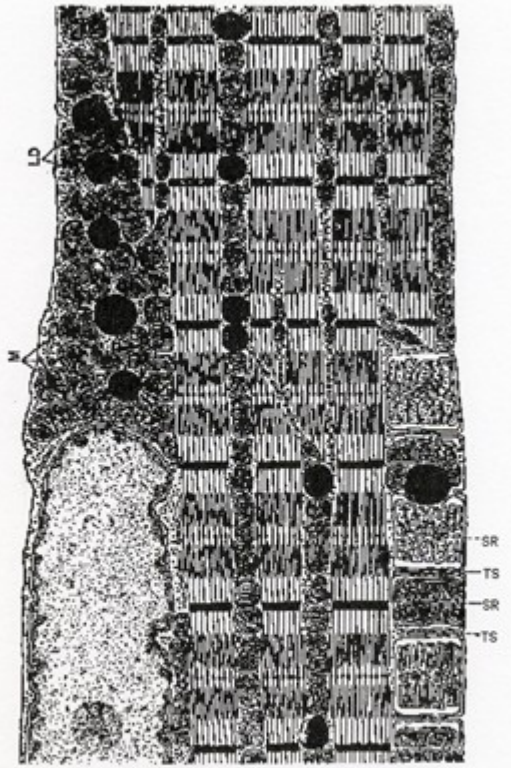

To surface of fibre
To adjoining SR
0.001 mm
Tubule around
a myofibril
T
SR
SR
Filaments
Sarcomere

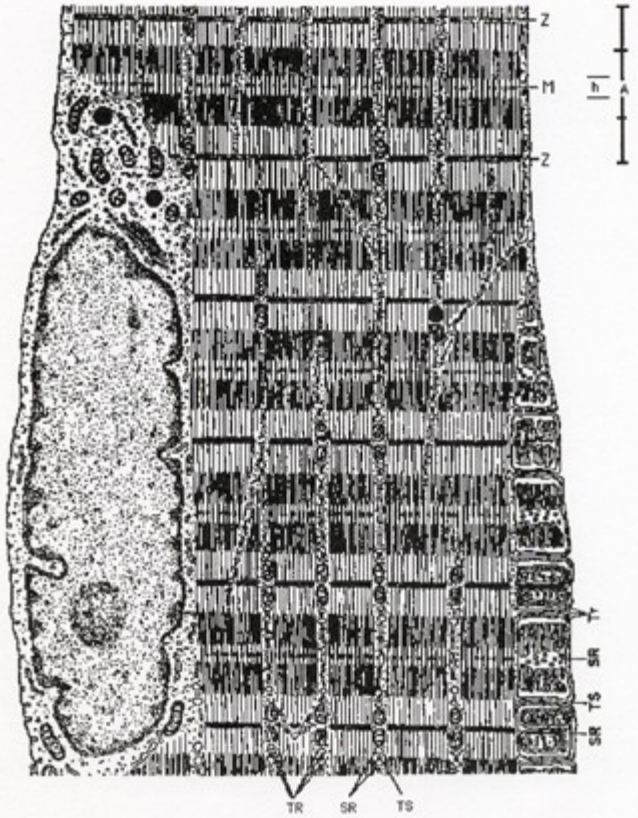

Smooth muscle cell
Basal lamina
© & Photo: H. Jastrow
For a licensed version send an E-mail to
info@drjastrow.de, please
250 nm
Copyright H. Jastrow

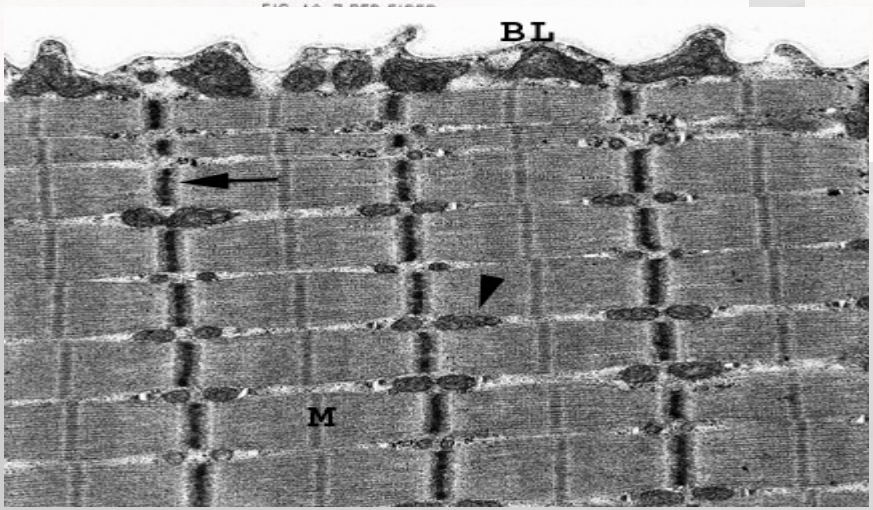
???


Muscle cell
Nucleus
Striations


Mus
Inter
Nuc
Stria


SR
TS
SR
TS


Z
M
Z
I
A
SR
TS
SR
TR
SR
TS


BL
M

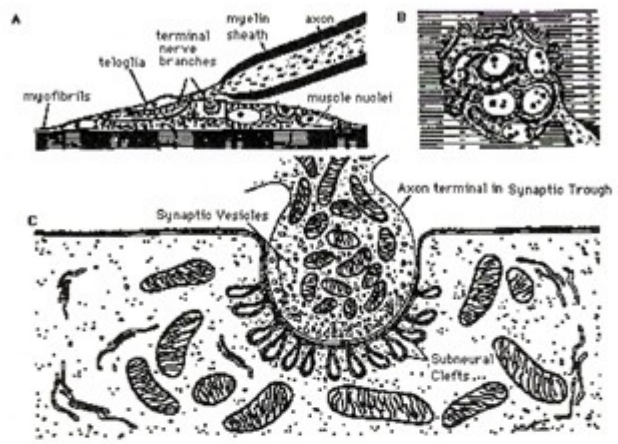
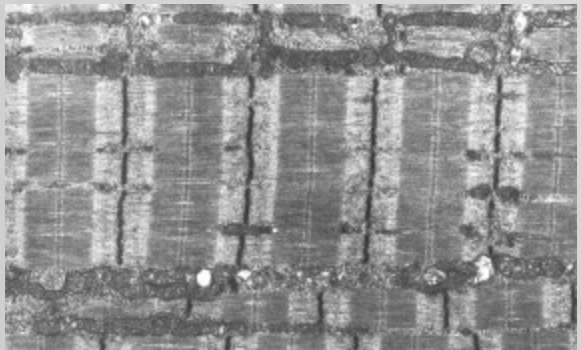


FIG. 10-9 SCHEMATIC REPRESENTATIONS OF MOTOR END PLATE AS SEEN BY LIGHT AND ELECTRON MICROSCOPY.

A. End plate as seen in histological sections in the long axis of the muscle fiber

B. As seen in surface view with the light microscope

C. As seen in electron micrograph of an area of such as that in the rectangle on "A".



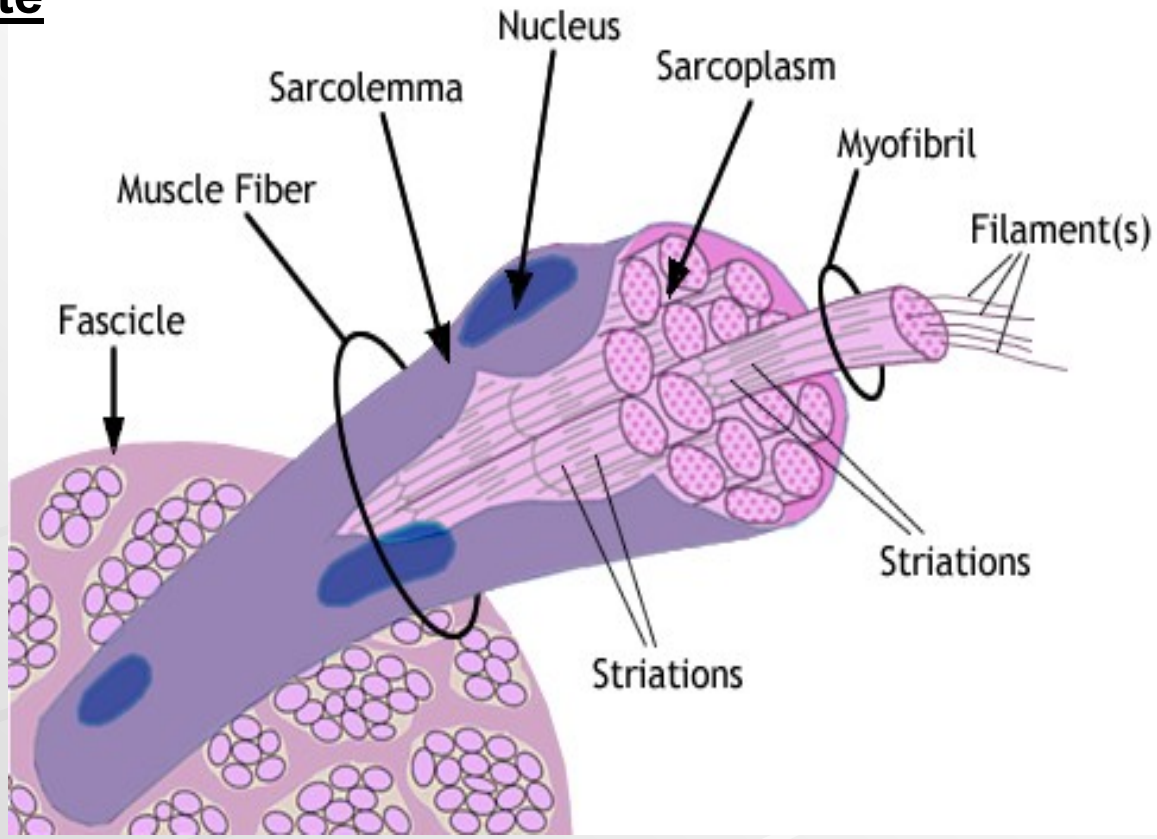
Structure or rhabdomyocyte

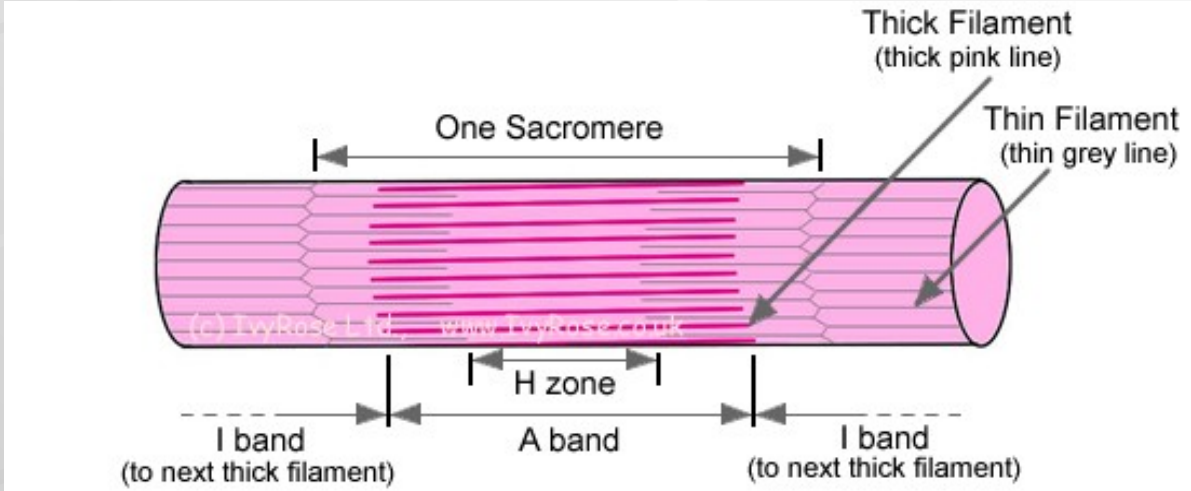
Sarcolemme + **t-tubules**,

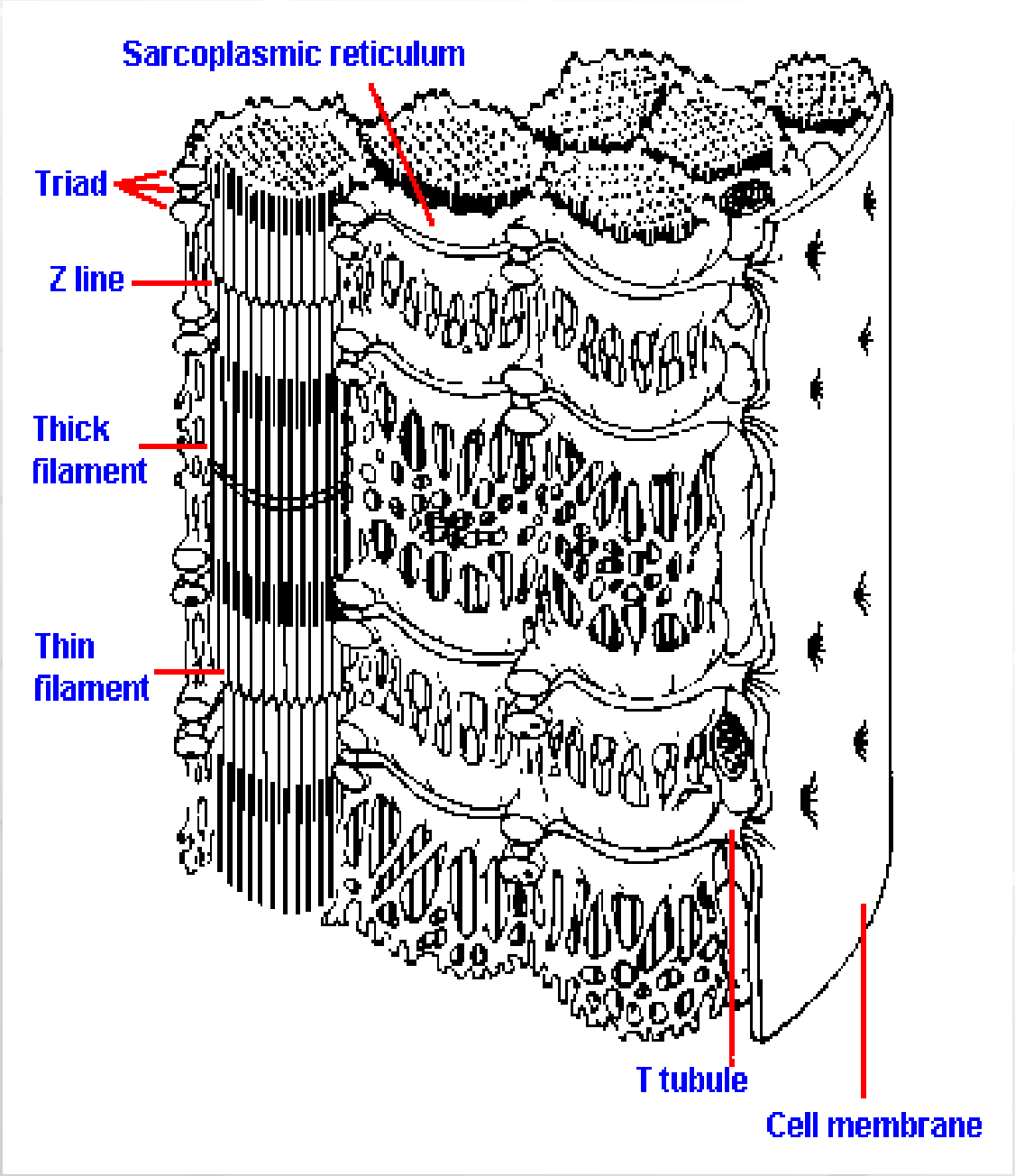
In **sarcoplasm**:
Nuclei,
Mitochondria,
Golgi apparatus,
Glycogen (beta granules)
(*sarcoplasm with organelles forms columns among myofibrils*)

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

Myofibrils (parallel to the length of the muscle fiber)






Sarcoplasmic reticulum
Triad
Z line
Thick filament
Thin filament
T tubule
Cell membrane

Mechanism of contraction:

The chemical players in muscle contraction are:

1. myosin (protein)
2. actin (protein)
3. tropomyosin (protein)
4. troponin (protein)
5. ATP (nucleotide)
6. calcium ions

- There are two binding sites on each myosin head, one for ATP and one for actin. ATP is hydrolyzed into ADP + phosphate and energy is transferd into the head of myosin.
- Thin filaments are made of these three protein molecules: 1. actin, 2. tropomyosin,
- 3. troponin.
- The major component of the thin filament, actin is composed of a double strand of
- actin subunits each of which contain myosin binding sites.
- The regulatory protein tropomyosin twists around the actin. When the sarcomere
- is not shortening, the position of the tropomyosin covers the binding sites on the
- actin subunits and prevents myosin cross bridge binding.
- Troponin, which is found periodically along the tropomyosin strand, functions to
- move the tropomyosin aside, exposing the myosin binding sites. - Role of calcium in muscle contraction: action potential occurs - calcium ions are
- released from the terminal cisternae - calcium ions then bind to troponin –
- tropomyosin moves away from the myosin binding sites on actin.

Review of participants in the Cross Bridge Cycle:

Participant	Will bind to:
1. Myosin	ATP, Actin
2. Actin	Myosin, Troponin
3. Tropomyosin	Troponin
4. Troponin	Calcium, Actin, Tropomyosin
5. ATP	Myosin
6. Calcium ions	Troponin

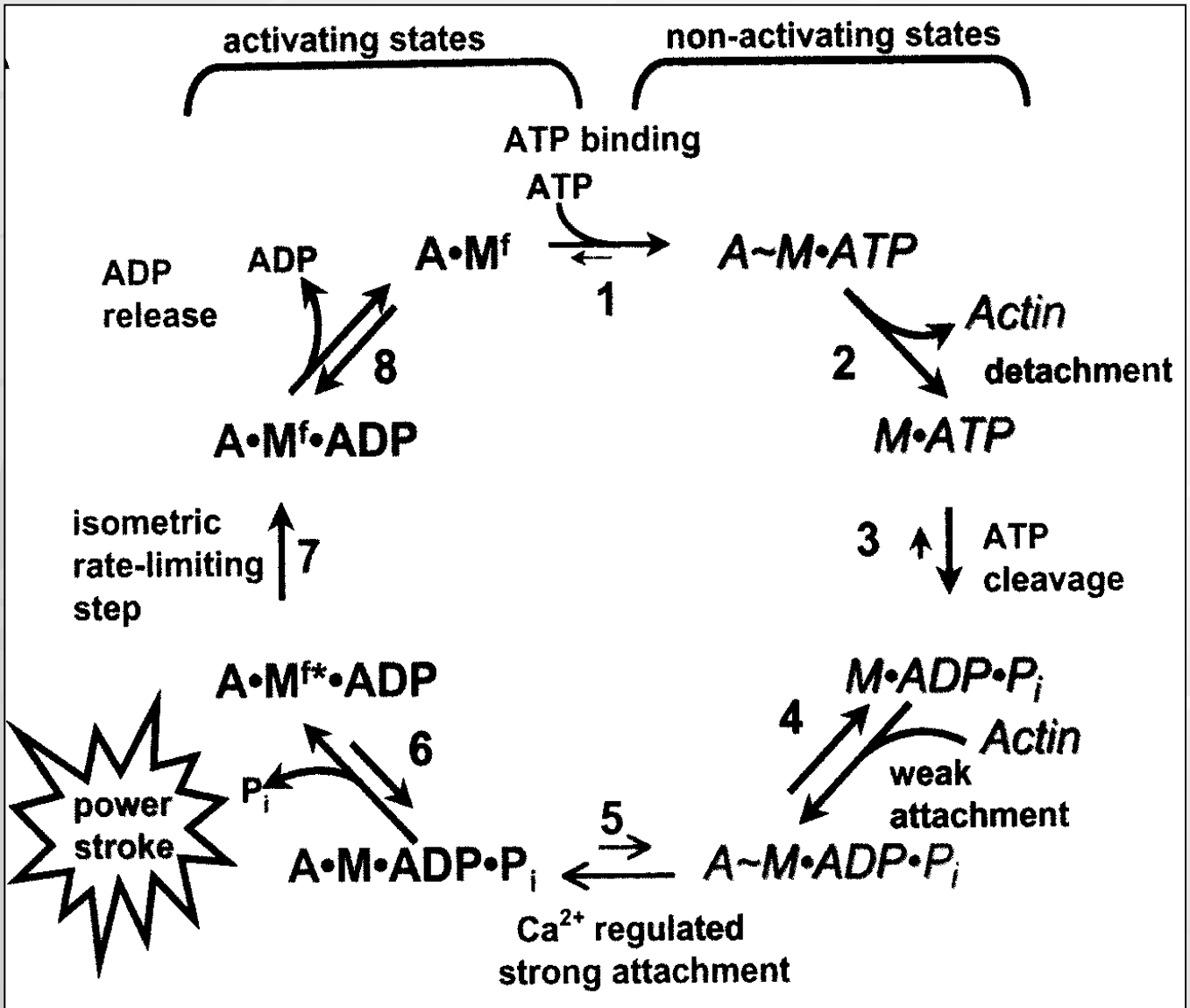
Detail of steps required to expose the binding sites on actin:

- Presence of an action potential in the muscle cell membrane.
- Release of calcium ions from the terminal cisternae.
- Calcium ions rush into the cytosol and bind to the troponin.
- There is a change in the conformation of the troponin-tropomyosin complex.
- This tropomyosin slides over, exposing the binding sites on actin.

Summary of the role that ATP plays in the contraction of muscle:

- 1. ATP transfers its energy to the myosin cross bridge, which in turn energizes the power stroke.
- 2. ATP disconnects the myosin cross bridge from the binding site on actin.
- 3. ATP fuels the pump that actively transports calcium ions back into the sarcoplasmic reticulum.

ATP is required to cleave the avidly formed bond between actin and myosin. In the absence of ATP the cross linking becomes fixed, and the muscle becomes rigid and inextensible. This condition is seen shortly after death when the muscles' energy supply is used up, and is known as **rigor mortis.**



The thin actin filament is a dimeric polymer of G-actin sub-units arranged like two strings of beads twisted together.
Attached to the actin chain of the thin filament, are the proteins **troponin** (Tn) and **tropomyosin**.
A **tropomyosin** molecule runs along each actin chain, bound to the actin. Each tropomyosin sub-unit covers about 7 G-actin sub-units.

The **troponin** molecule has three sub-units: **TnT** that binds to tropomyosin near the ends of the tropomyosin sub-units; **TnI** that binds to the actin; and **TnC** that binds to the TnI and TnT sub-units, and which also has a strong affinity for Ca2+ at four binding sites.

The thick filaments, at either end, have sticking off at regular intervals, the fibrillar necks and globular, **ATPase** heads of the myosin subunits - the polymerized tails of which make the backbone of the filament.

The heads at the opposite ends of the thick filament stick off in opposite directions leaving a bare middle region (pseudo H-zone) on the filament.

Each successive myosin head is staggered so that six rows of heads stick off in six directions (60o intervals) around the filament.

Each myosin filament is surrounded by six actin filaments and each actin filament by three myosins.

Each myosin filament is surrounded by six actin filaments and each actin filament by three myosins.