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Muscle Tissue

Matthew Velkey, Ph.D.

Fall 2008

Muscle Tissue

I. Striated Muscle - regularly arranged contractile units

A. Skeletal Muscle - long, cylindrical multinucleated cells with peripherally placed nuclei. Contraction is typically quick and vigorous and under voluntary control. Used for locomotion, mastication, and phonation.

B. Cardiac Muscle - elongated, branched cells with a single centrally placed nucleus and intercalated discs at the ends. Contraction is involuntary, vigorous, and rhythmic.

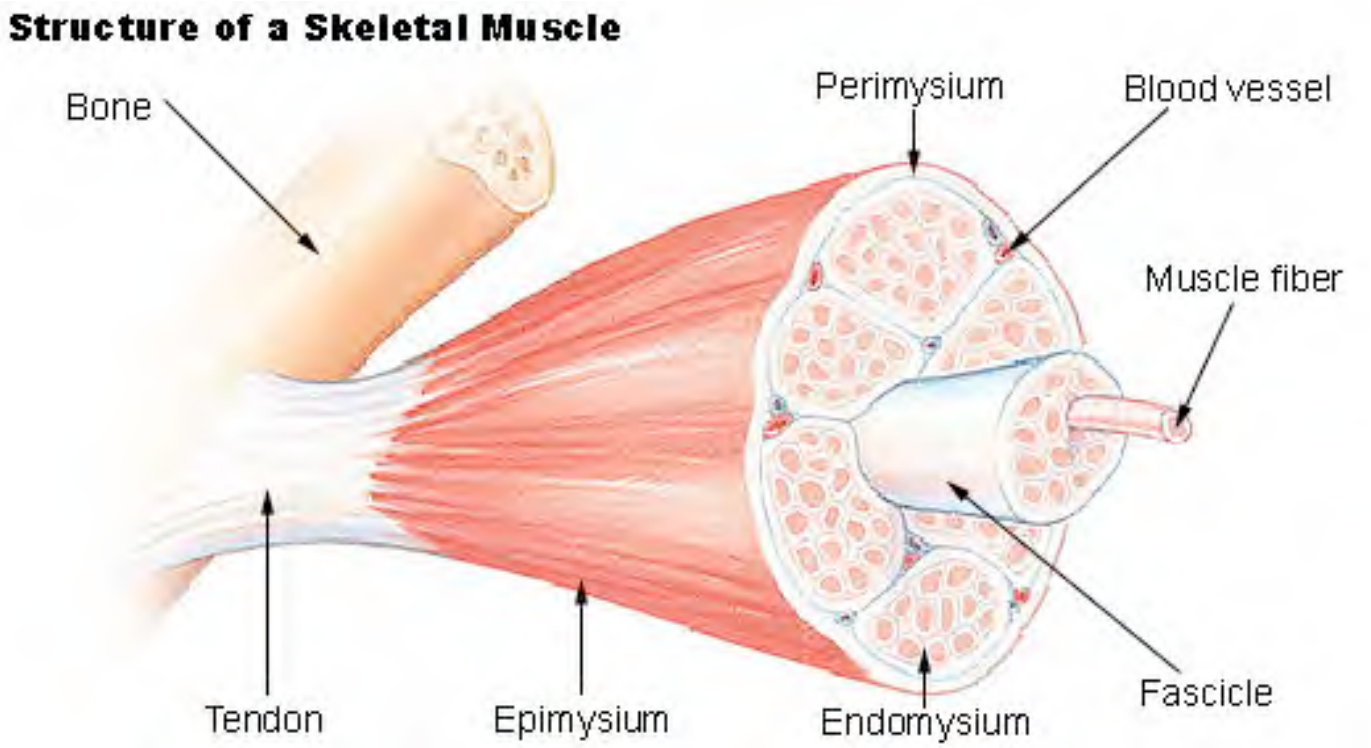
II. Smooth Muscle - possesses contractile machinery, but it is irregularly arranged (thus, non-striated). Cells are fusiform with a central nucleus. Contraction is involuntary, slow, and long lasting.

Skeletal Muscle Investments

Epimysium - dense irr. c.t.

Perimysium - less dense irr. c.t.

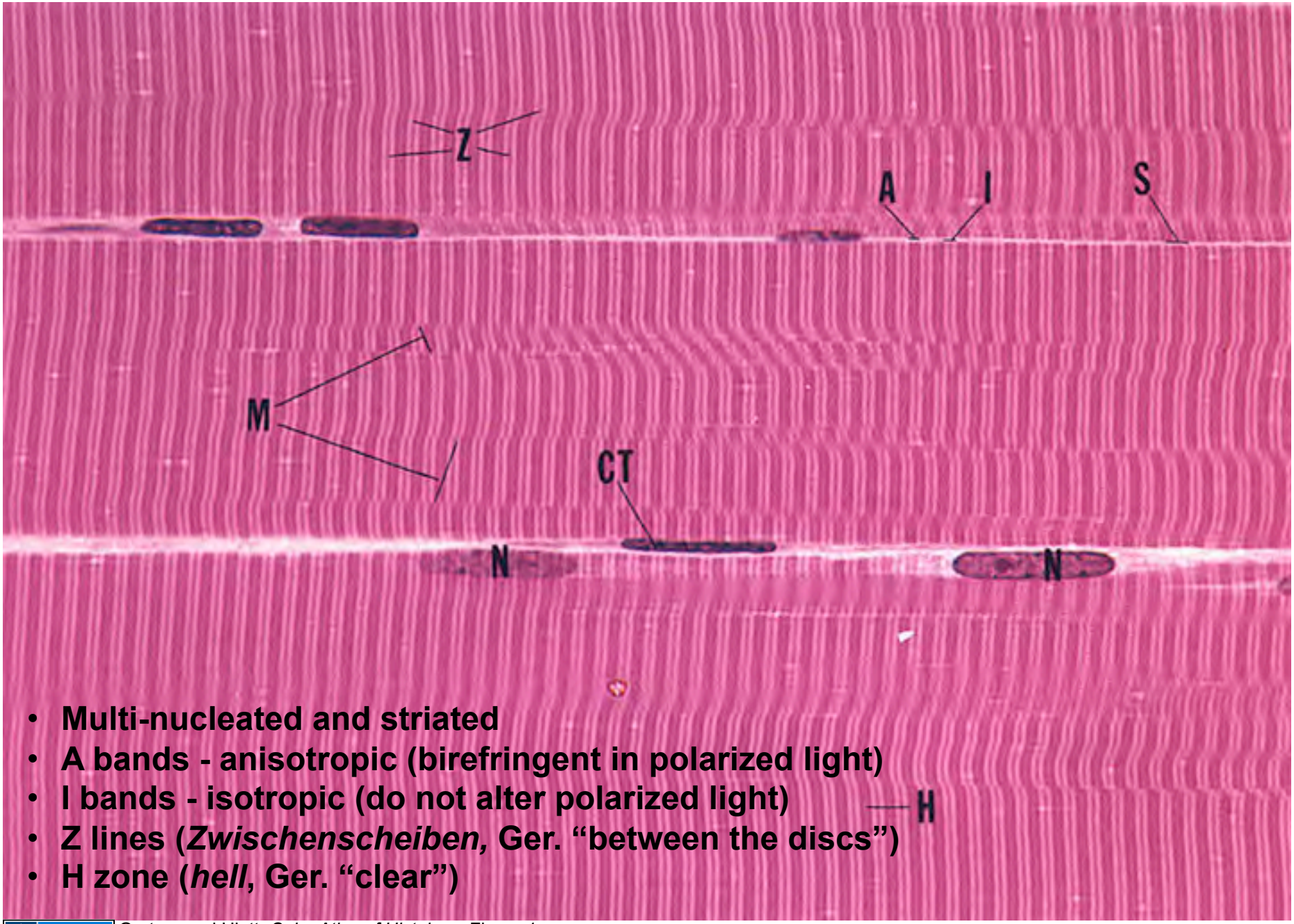
Endomysium - basal lamina and reticular fibers



PD-GOV National Cancer Institute, Wikipedia

ALL MUSCLE CELLS HAVE BASAL LAMINAE!

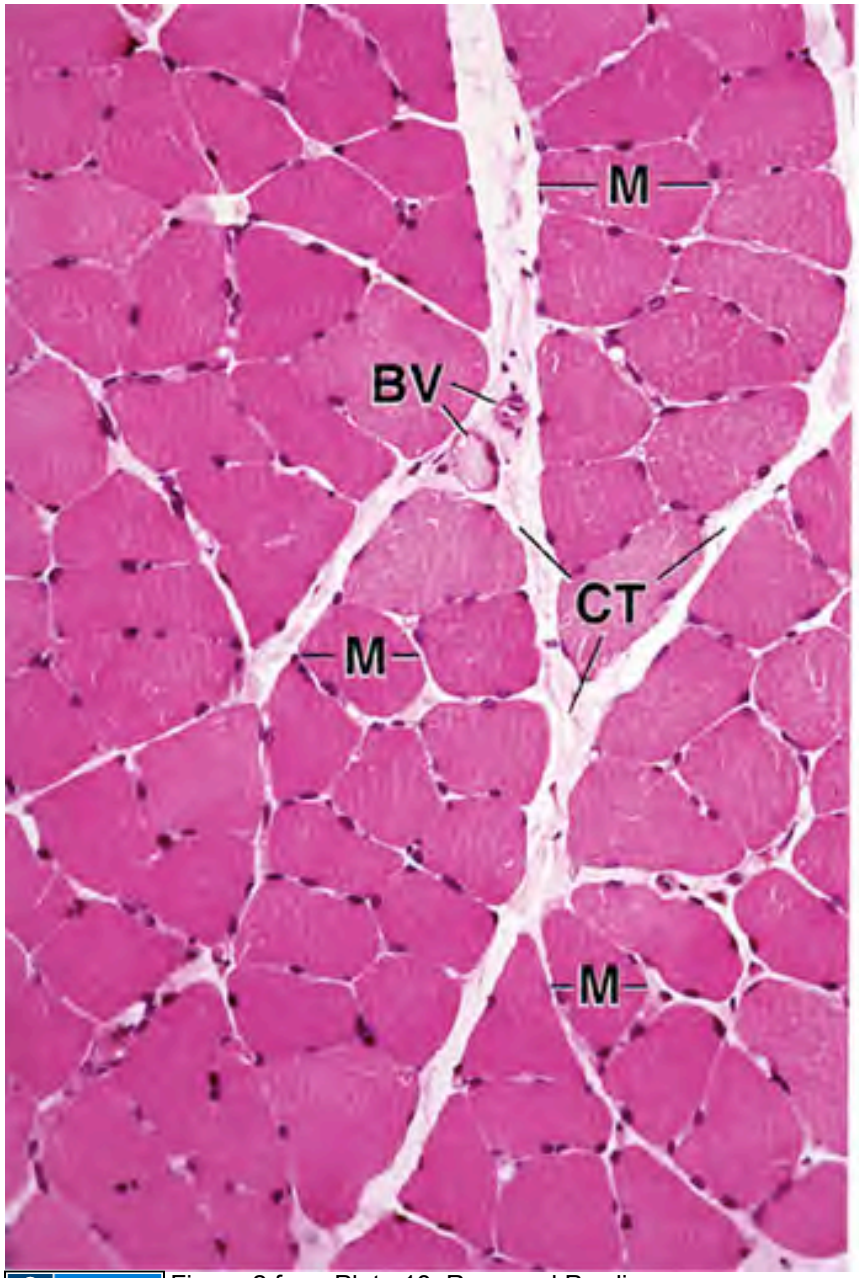
Skeletal Muscle as seen in longitudinal section in the light microscope...



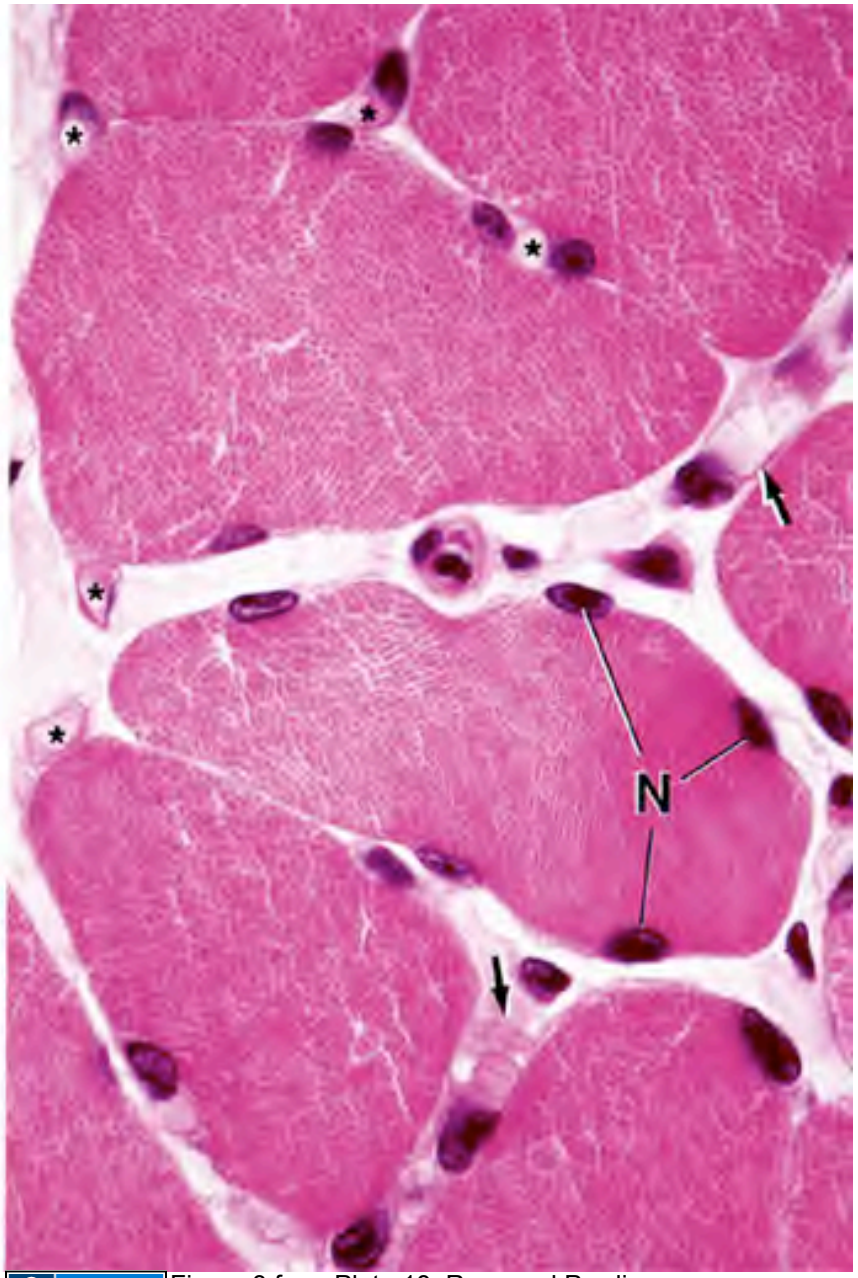
- Multi-nucleated and striated
- A bands - anisotropic (birefringent in polarized light)
- I bands - isotropic (do not alter polarized light)
- Z lines (*Zwischenscheiben,* Ger. “between the discs”)
- H zone (*hell*, Ger. “clear”)

 Gartner and Hiatt. *Color Atlas of Histology*. Figure 1.

Skeletal Muscle as seen in transverse section in the light microscope...

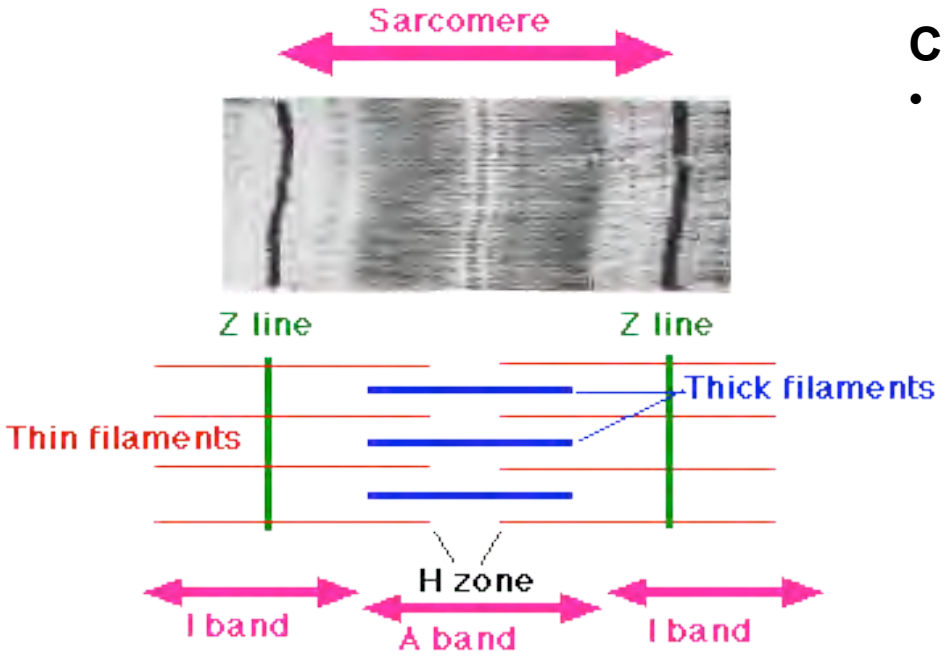


PD-INEL Figure 2 from Plate 18. Ross and Pawlina



PD-INEL Figure 3 from Plate 18. Ross and Pawlina

Organization of Skeletal Muscle Fibers THE SARCOMERE…



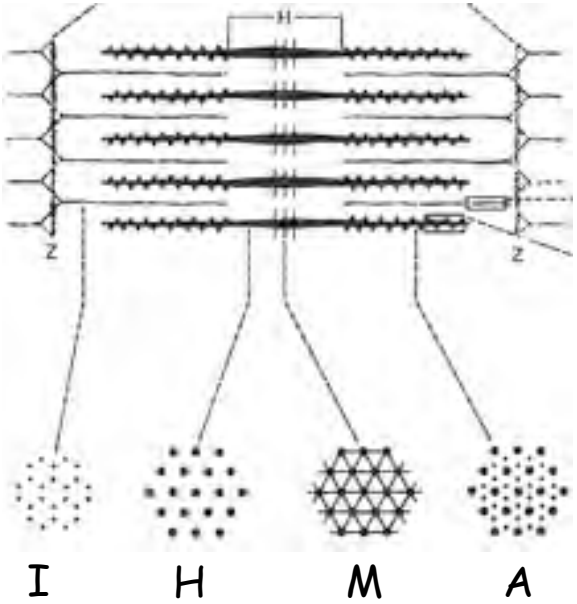
PD-SELF Sameerb, Wikipedia

Contractile unit of striated muscle

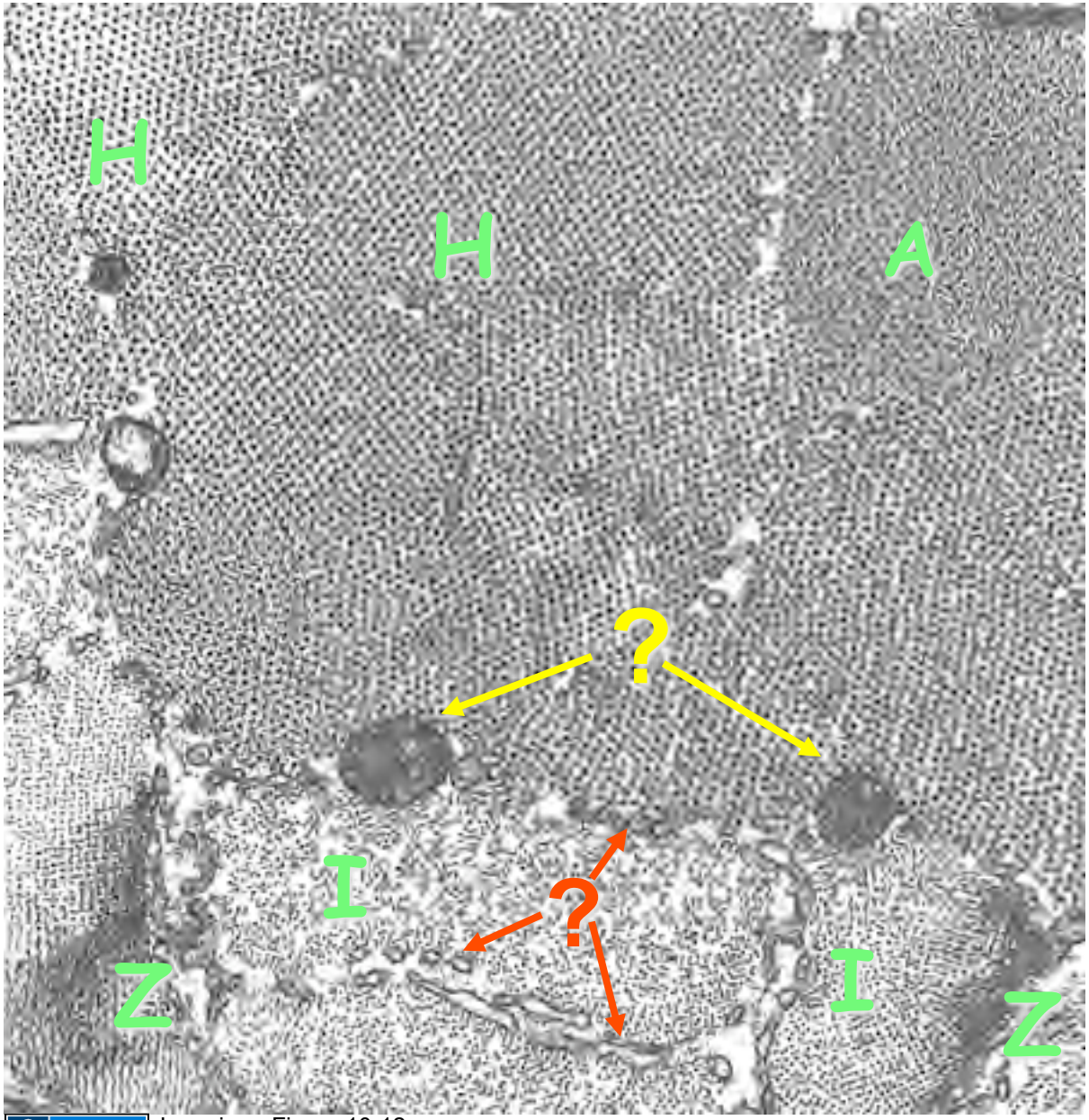
- Structures between Z lines
  - 2 halves of I bands
  - A band
  - H zone
  - M line (*Mittelscheibe,* Ger. "middle of the disc")
  - Myofilaments
    - Actin
    - Myosin
  - Other structural proteins
    - Titin (myosin-associated)
    - Nebulin (actin-associated)
    - Myomesin (at M line)
    - α actinin (at Z line)
    - Desmin (Z line)
    - Vimentin (Z line)
    - Dystrophin (cell membrane)

Transverse Section of Skeletal Muscle: TEM view

- H zone: thick filaments only
  - –At M-line: thick filaments and myomesin lattice
- A band: thick & thin filaments
- I Band: thin filaments only



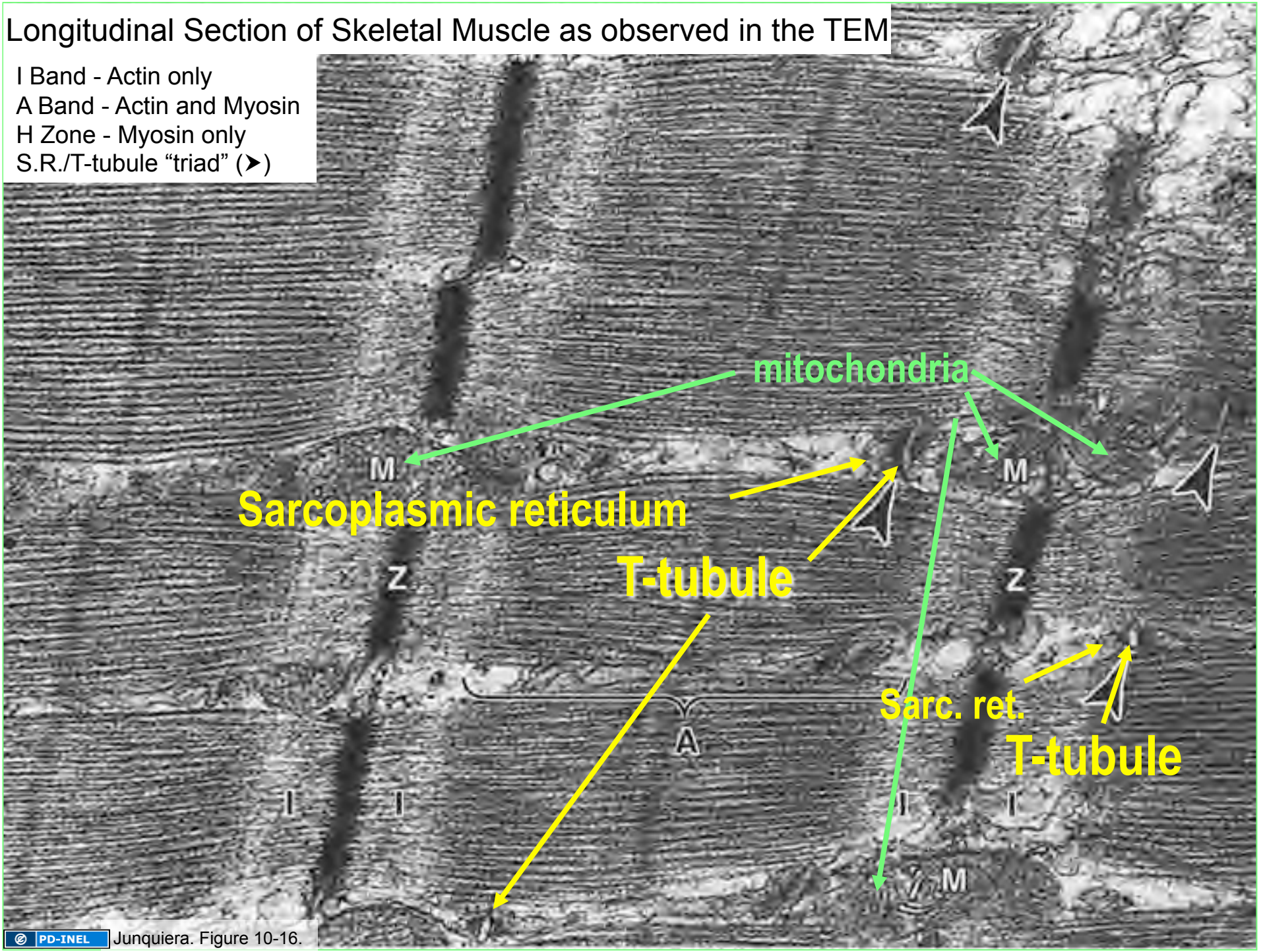
PD-INEL Figure 10-11 from Junquiera.



PD-INEL Junquiera. Figure 10-12.

Longitudinal Section of Skeletal Muscle as observed in the TEM

I Band - Actin only
A Band - Actin and Myosin
H Zone - Myosin only
S.R./T-tubule "triad" (➤)



 Junquiera. Figure 10-16.

T-tubule System:
Propagation of the Signal and Release of Ca^{2+}

T (transverse) Tubules

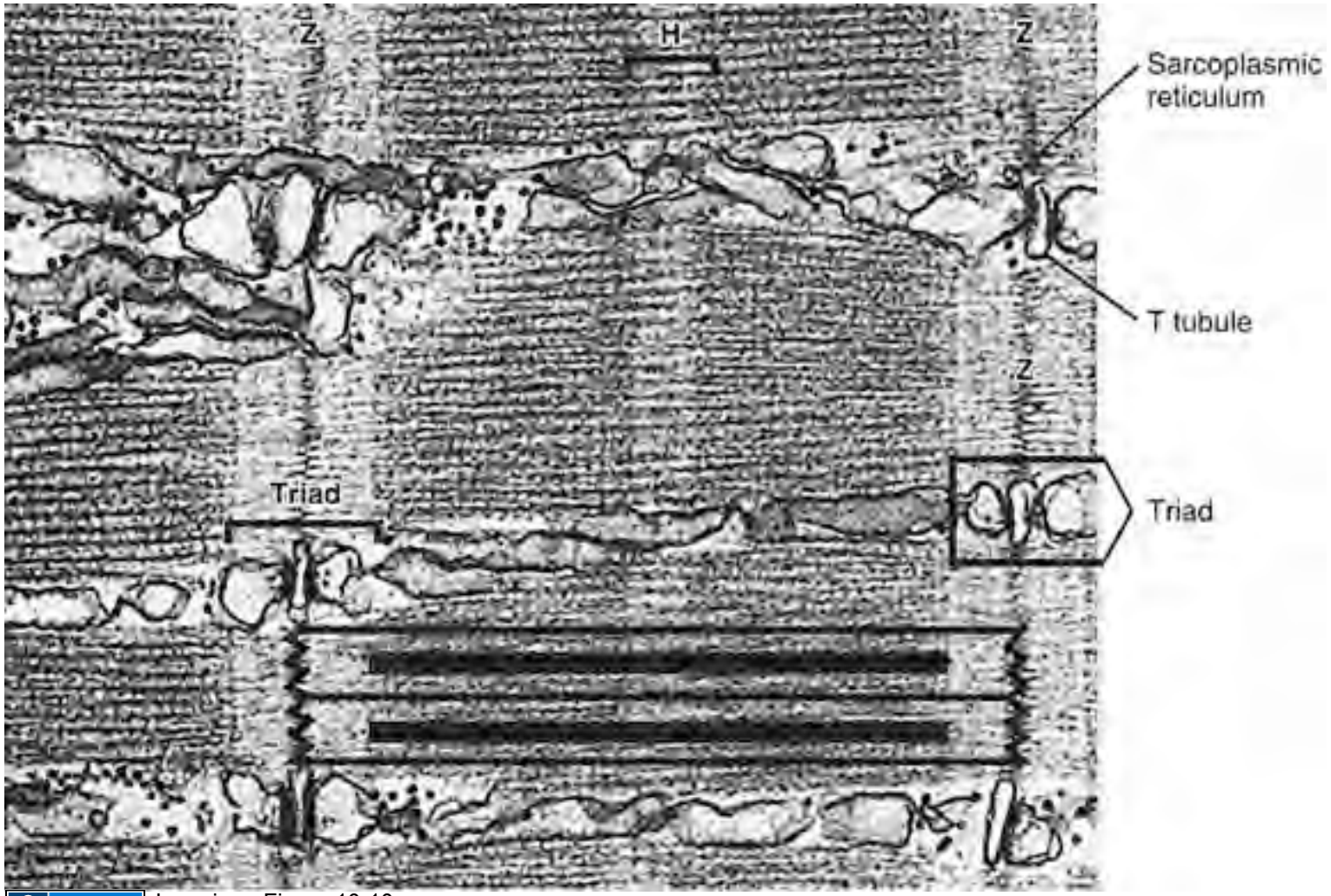
- run perpendicular (transversely) to myofibrils
- conduct membrane depolarization deep into fibers

Sarcoplasmic Reticulum

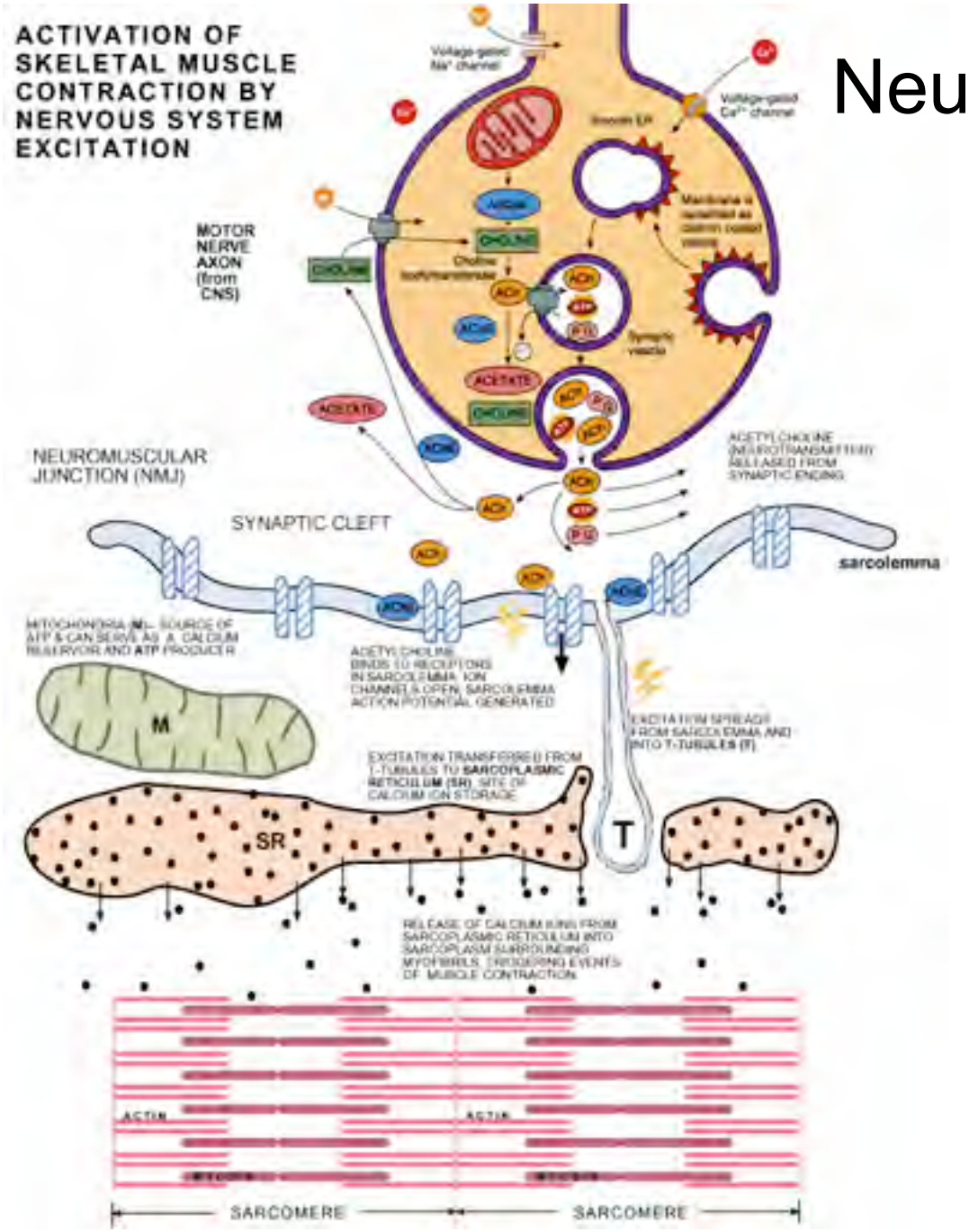
- smooth ER
- site of Ca^{2+} storage & release
- terminal cisternae abut T-tubules forming triads when myofibrils are viewed in longitudinal section

Longitudinal section of muscle showing triads

- 1 T tubule
- 2 terminal cisternae of sarcoplasmic reticulum
- Normally at A/I junctions in mammals (this sample is from an amphibian)



 Junquiera. Figure 10-10.



Neuromuscular Junction

Synapse:

- Action potential (AP) stimulates release of acetylcholine from axon terminal into synaptic cleft
- Acetylcholine in synaptic cleft binds Na^+ channel receptors –initiates sarcolemma AP

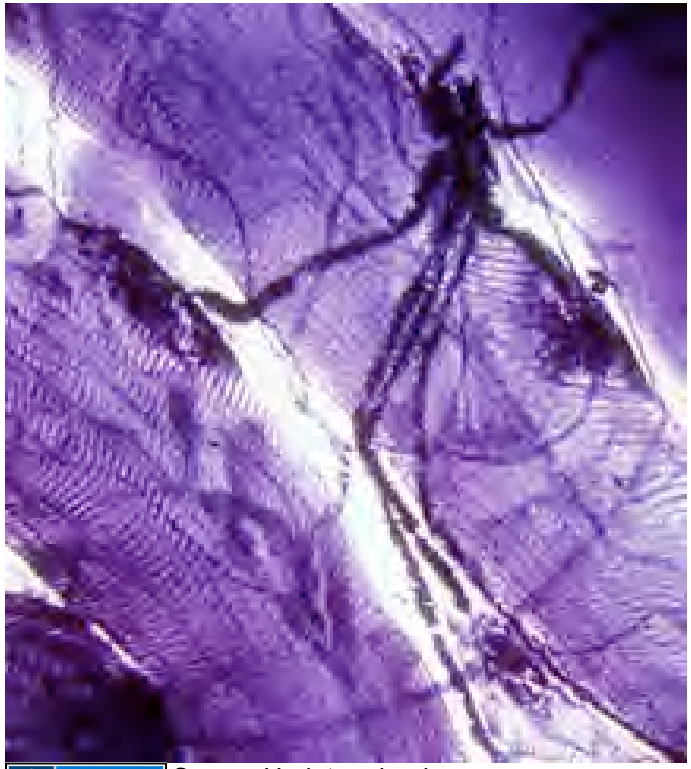
Signal Propagation: T (transverse) Tubules

- Run perpendicular (transversely) to myofibrils
- Conduct membrane depolarization deep into fibers

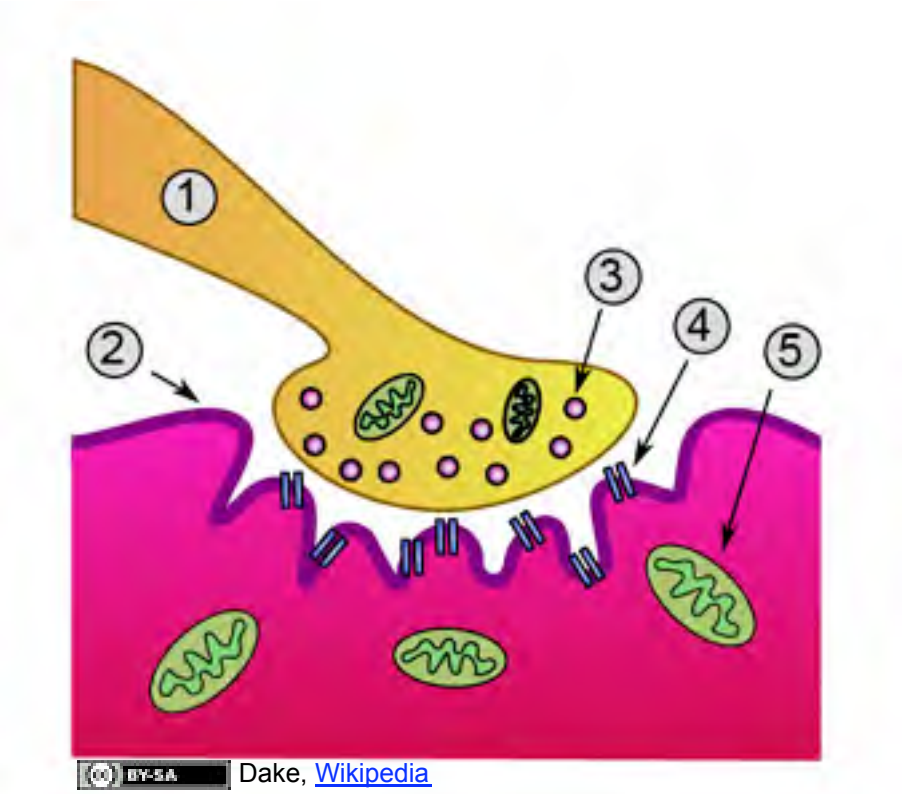
Intracellular Ca^{2+} release: Sarcoplasmic Reticulum

- Smooth ER, site of Ca^{2+} storage
- Voltage-gated channels in SR detect membrane depolarization in T-tubule and release Ca^{2+}

Muscle Innervation: Motor End Plate



PD-INEL Source Undetermined

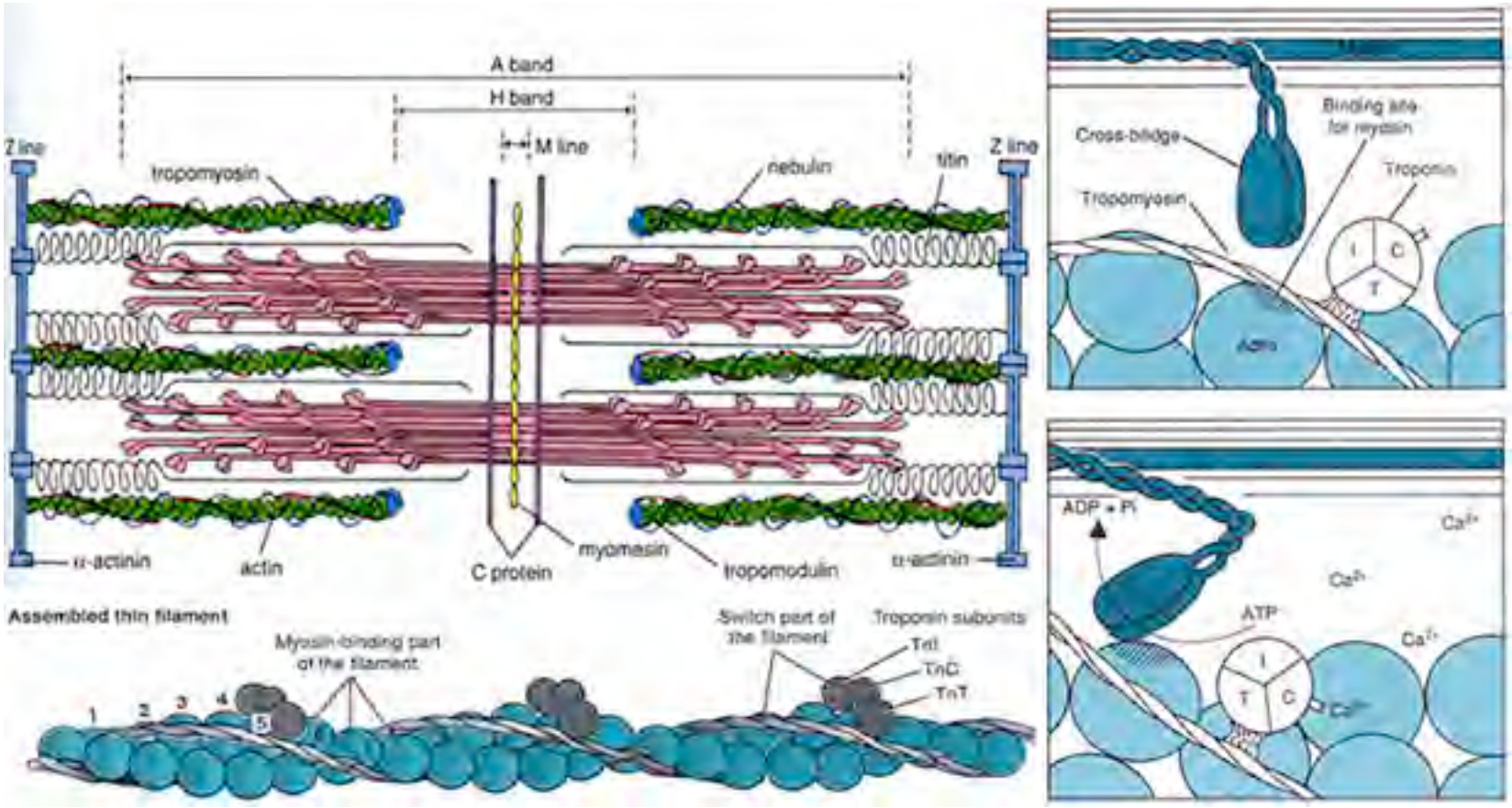


BY-SA Dake, Wikipedia

1. presynaptic terminal
2. sarcolemma
3. synaptic vesicles
4. Acetylcholine receptors
5. mitchondrion

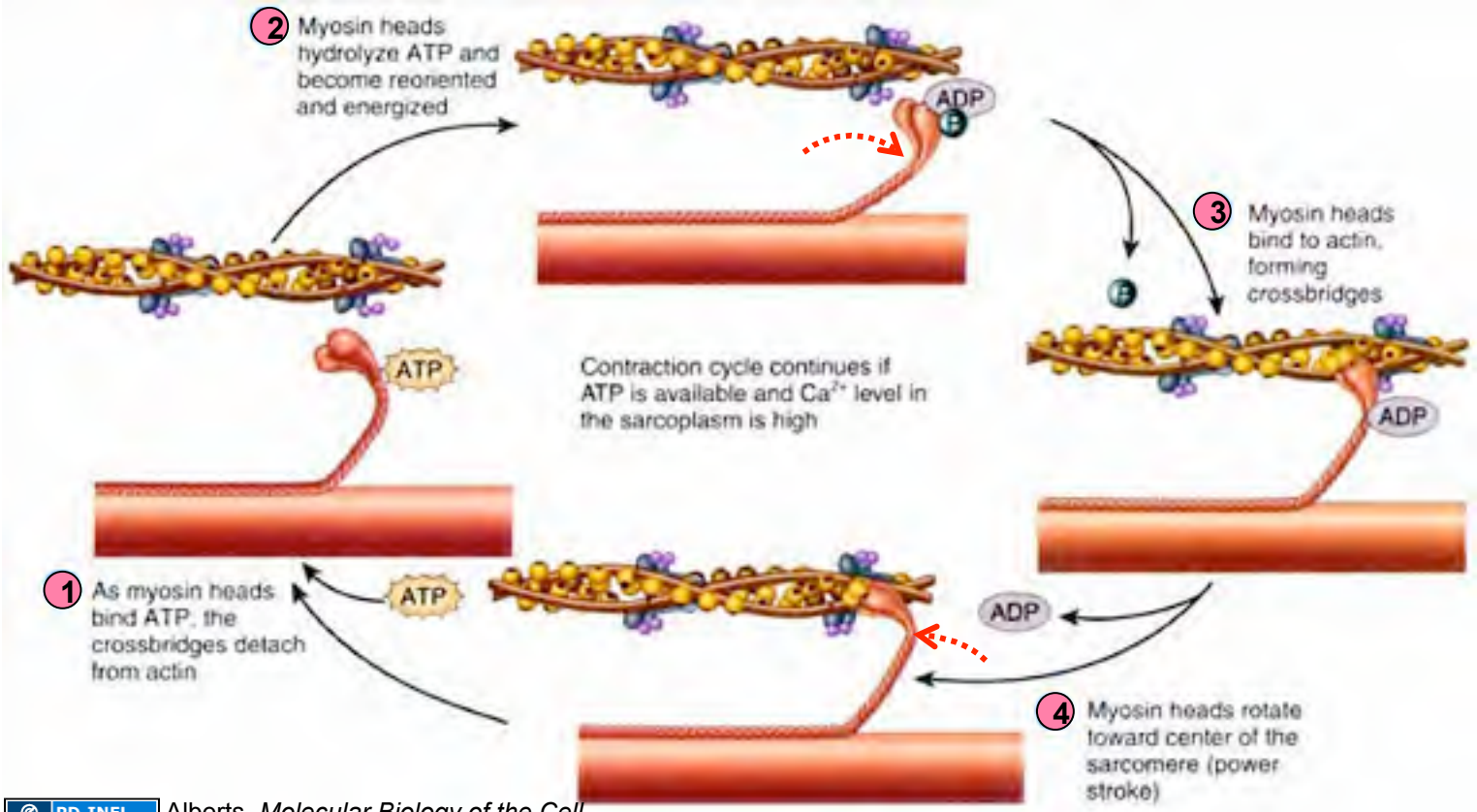
Ca^{2+} Stimulates Myosin-Actin Binding and Initiates Contraction

- Myosin-actin binding inhibited by TnI
- TnC binds Ca^{2+} (if present) and induces release of TnI from actin
- Myosin binds actin; hydrolysis of ATP induces **power stroke**
- Actin filaments move relative to myosin



PD-INEL Top left from Ross and Pawlina. Figure 11.7.
Bottom left and right. Figures 10-13 and 10-14 (right). Junquiera.

Contraction Cycle

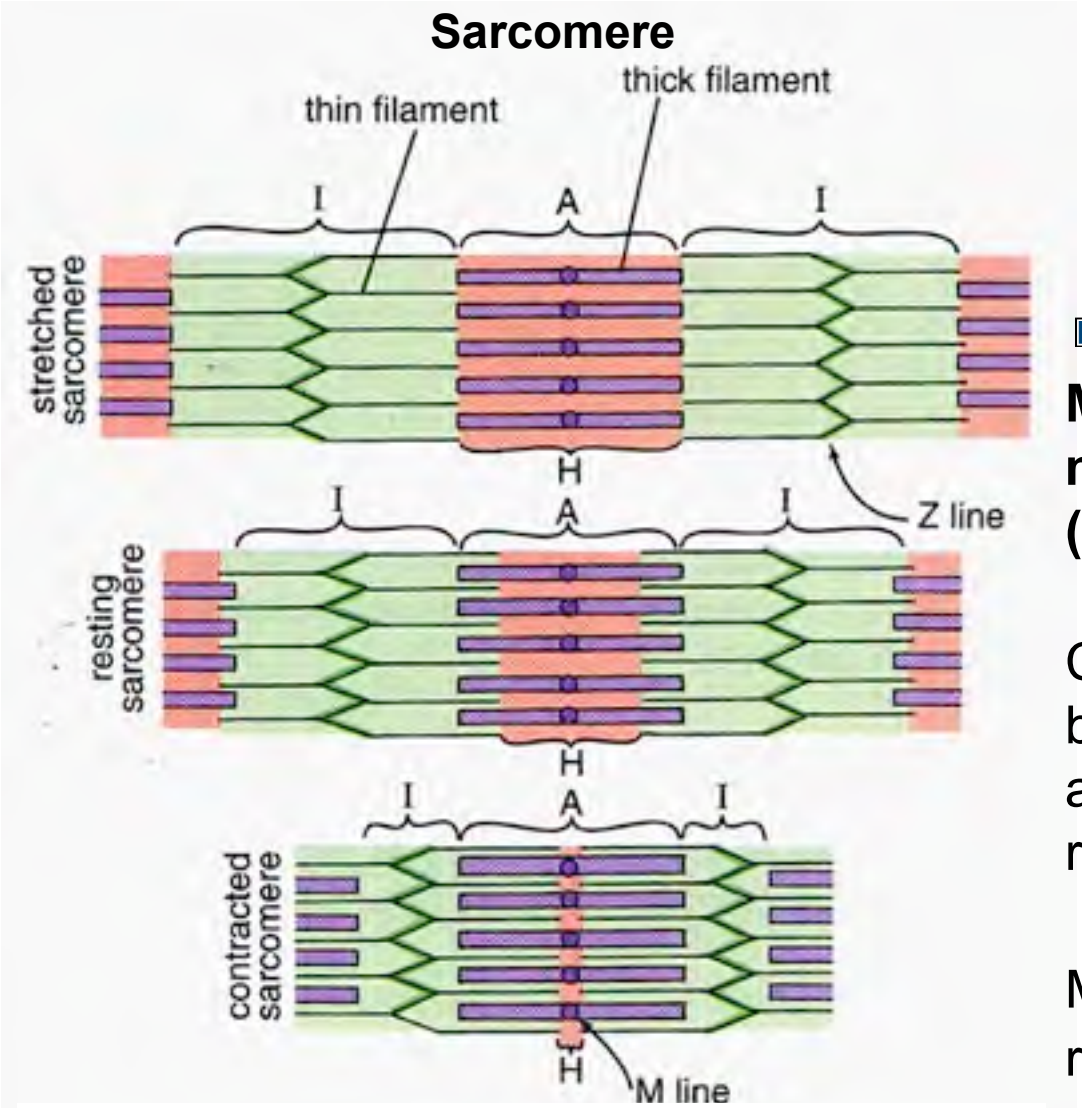


PD-INEL Alberts. *Molecular Biology of the Cell*.

1. ATP binds myosin – myosin releases actin
2. ATP hydrolysis induces conformational change – myosin head cocks forward 5nm ($ADP+P_i$ remain bound to myosin).
3. Myosin binds weakly to actin, causing release of P_i
4. Release of P_i induces strong binding, power stroke, and release of ADP

Myosin remains bound to actin if no more ATP is available (rigor conformation)

Sliding Filament Theory



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

PD-INEL Source Undetermined

PD-INEL Source Undetermined

Muscle fibers are composed of many contractile units (sarcomeres)

Changes in the amount of overlap between thick and thin filaments allows for contraction and relaxation of muscle fibers

Many fibers contracting together result in gross movement

Cardiac Muscle

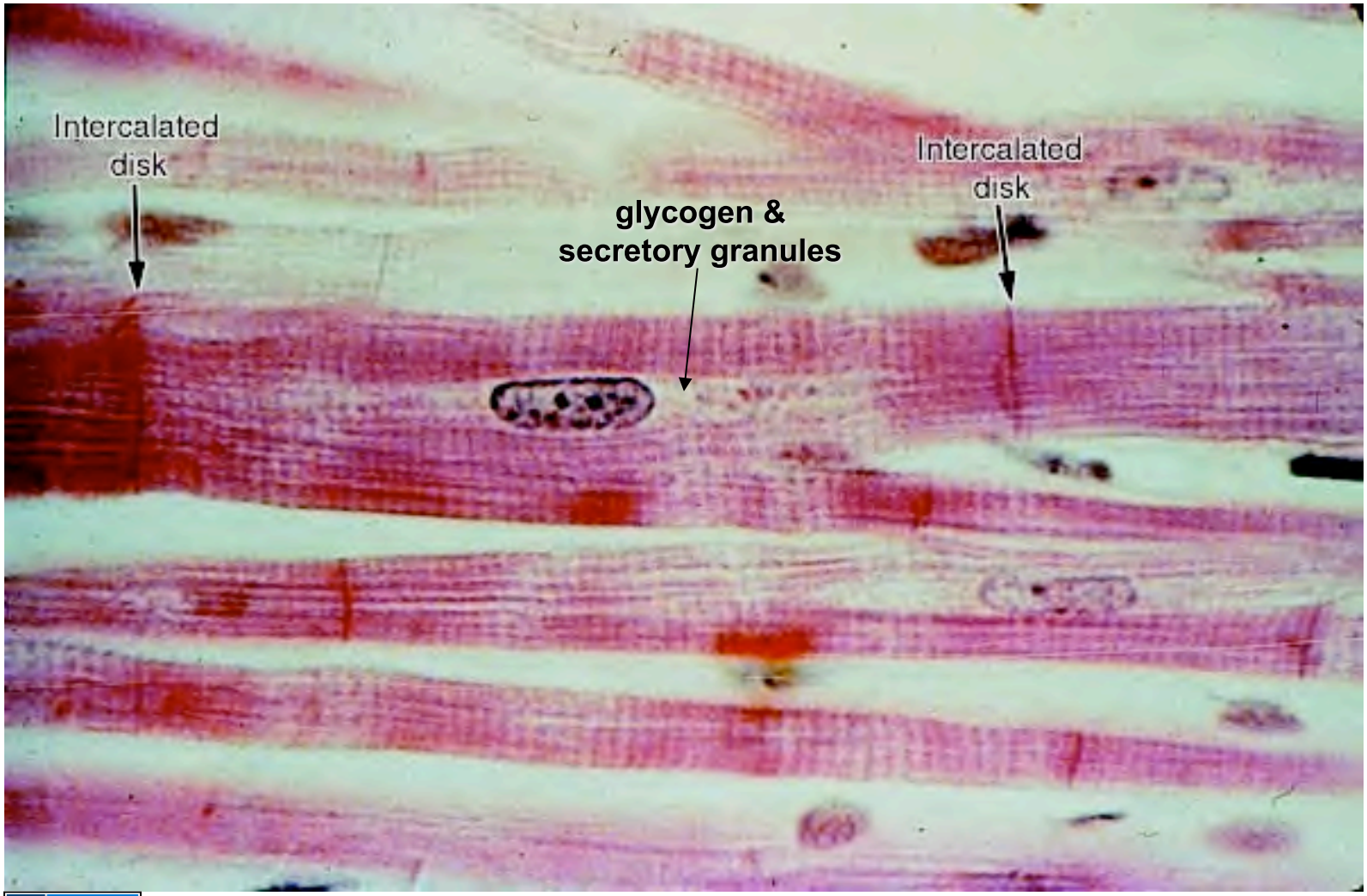
Tissue Features:

- Striated (same contractile machinery)
- Self-excitatory and electrically coupled
- Rate of contractions modulated by autonomic nervous system
  - innervation is neuroendocrine in nature (i.e. no “motor end plates”)

Cell Features:

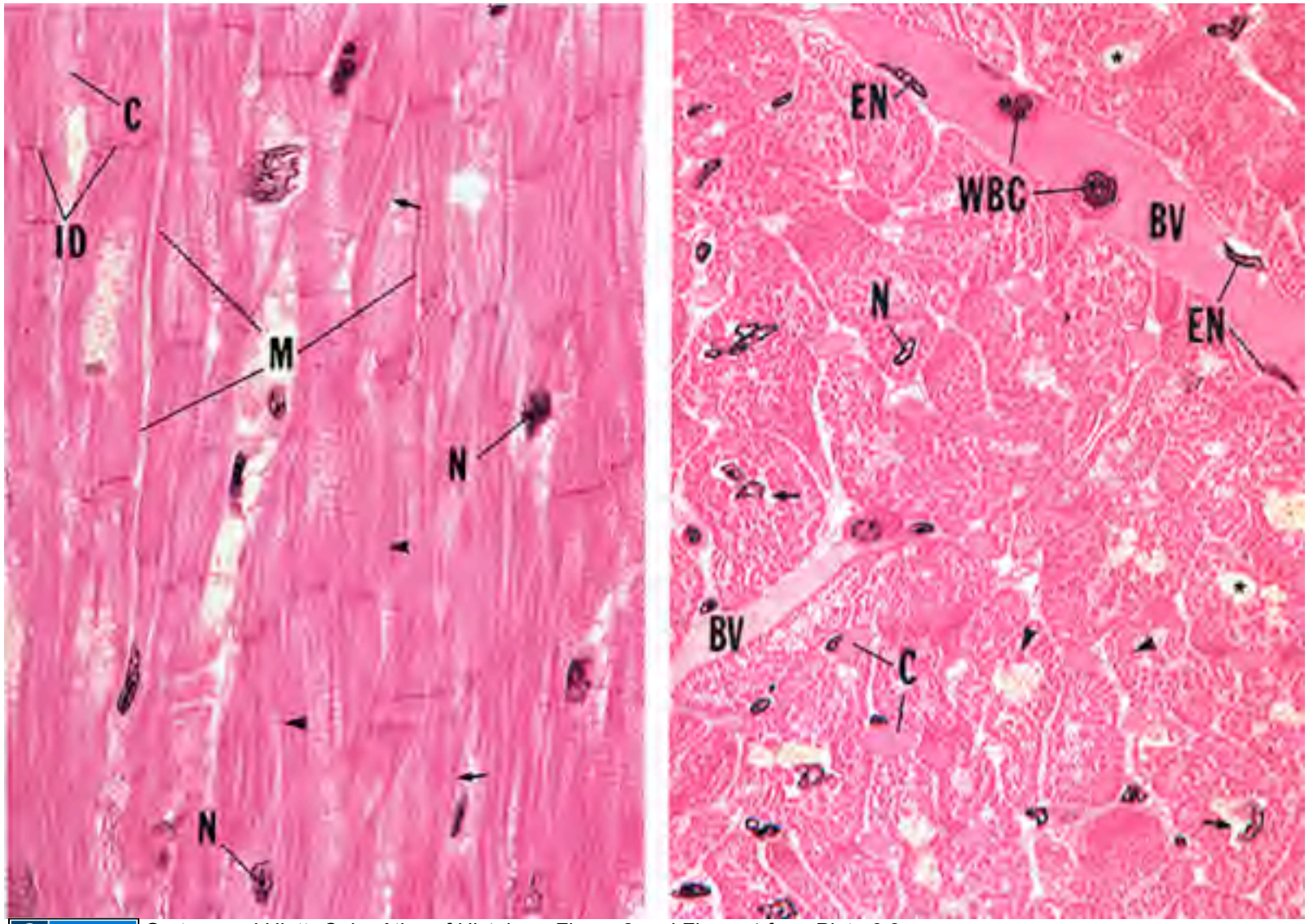
- 1 or 2 centrally placed nuclei
- Branched fibers with intercalated discs
- Numerous mitochondria (up to 40% of cell volume)
- Sarcoplasmic reticulum & T-tubules appear as diads at Z lines
  - Sarcoplasmic reticulum does not form terminal cisternae
  - T tubules are about 2x larger in diameter than in skeletal muscle
    - transport Ca^{2+} into fibers

Cardiac Muscle (longitudinal section)



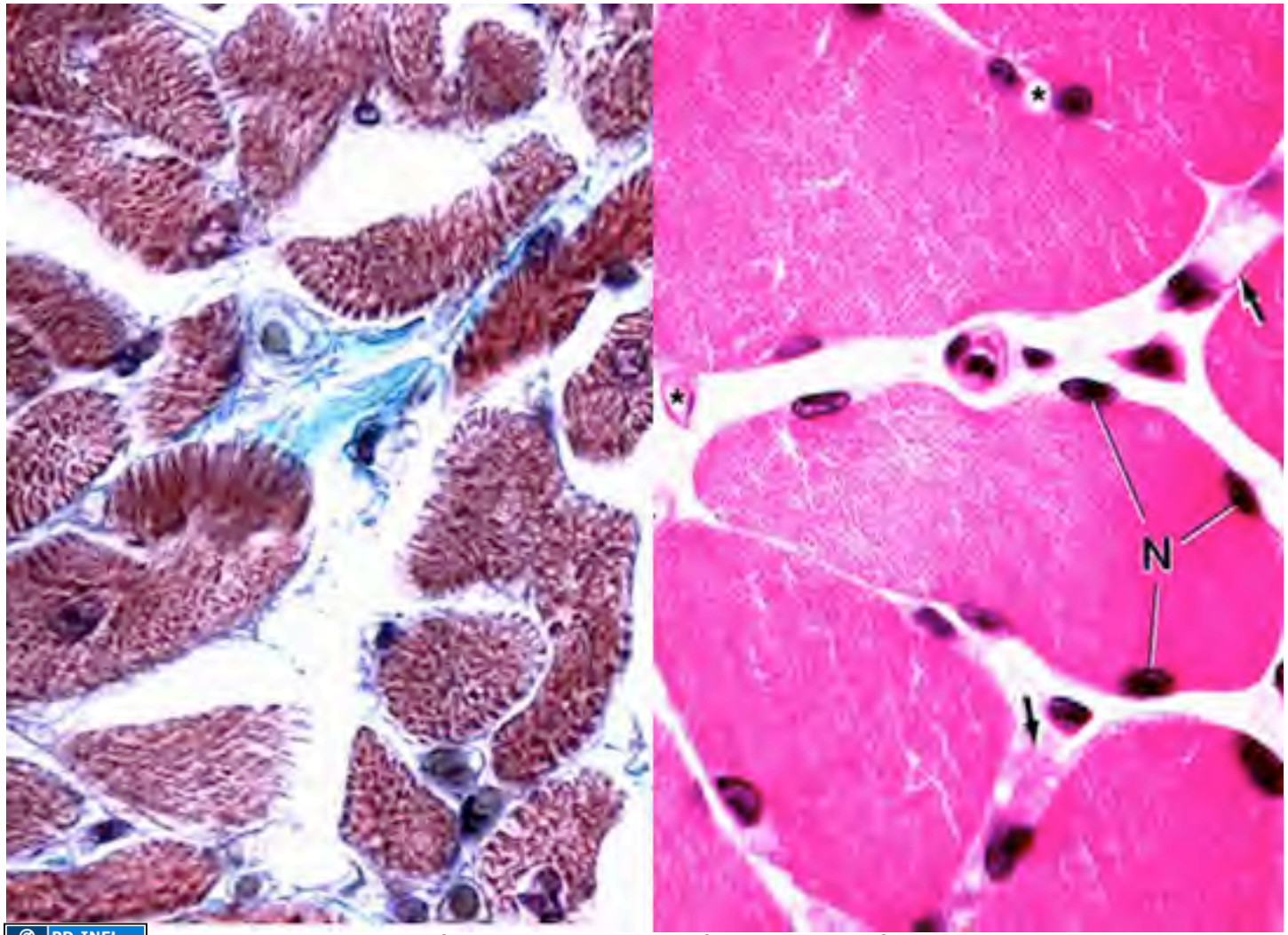
Cardiac Muscle (longitudinal section)

Cardiac Muscle (transverse section)



 Gartner and Hiatt. *Color Atlas of Histology*. Figure 2 and Figure 4 from Plate 6.8

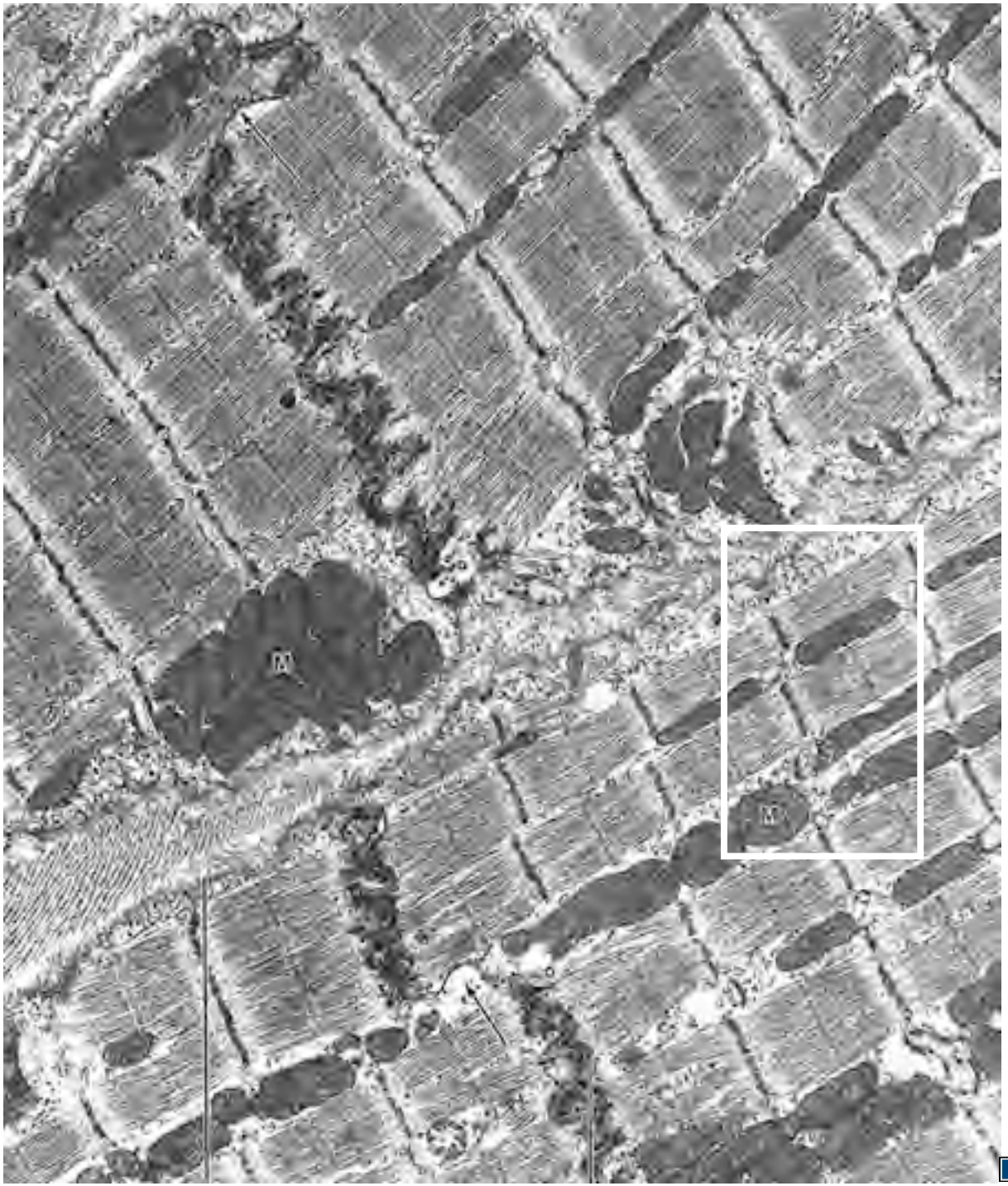
Transverse Section of Cardiac Muscle versus Skeletal Muscle

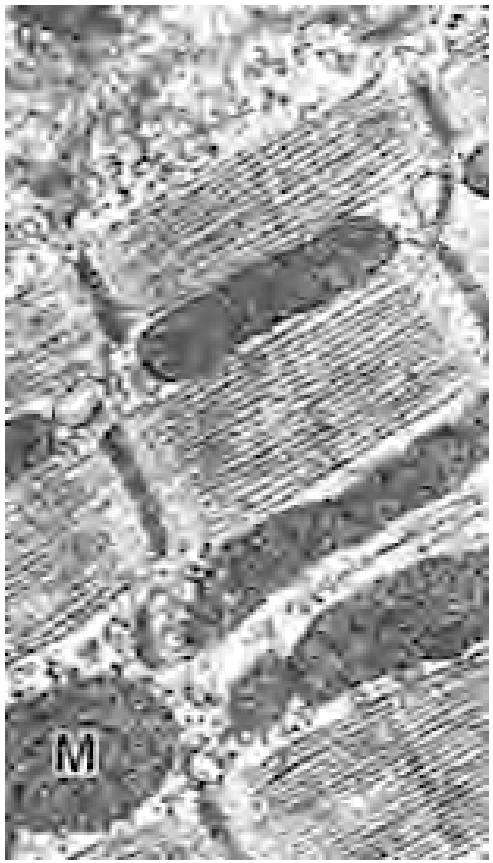


 Ross and Pawlina Figure 3 from Plate 18 on right. Left U-M Histology Collection

Cardiac Muscle (TEM)

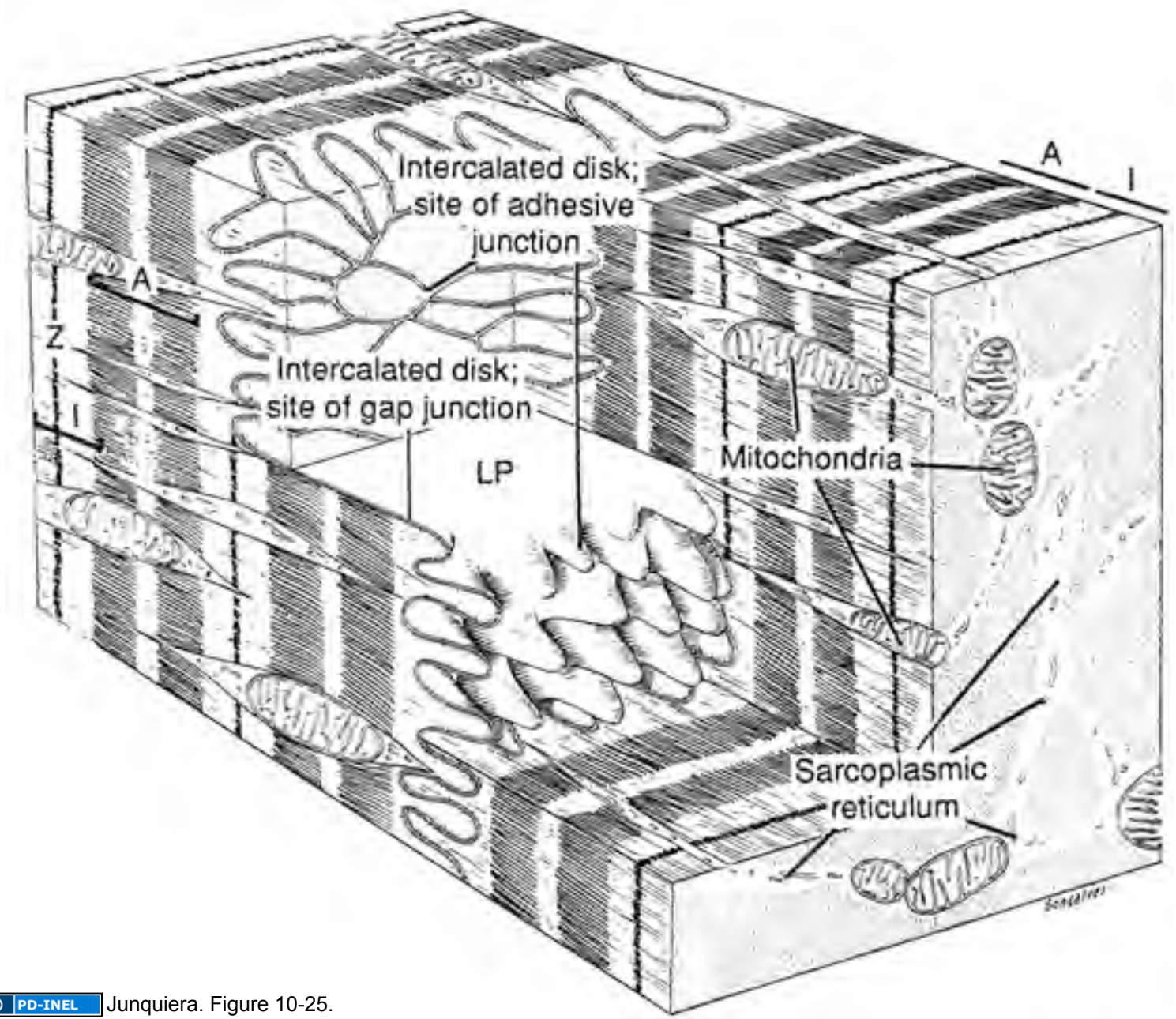
T Tubule/SR Diads





Left from Junquiera. Figure 10-24.
Right: Source Undetermined

Intercalated Discs Couple Heart Muscle Mechanically and Electrically

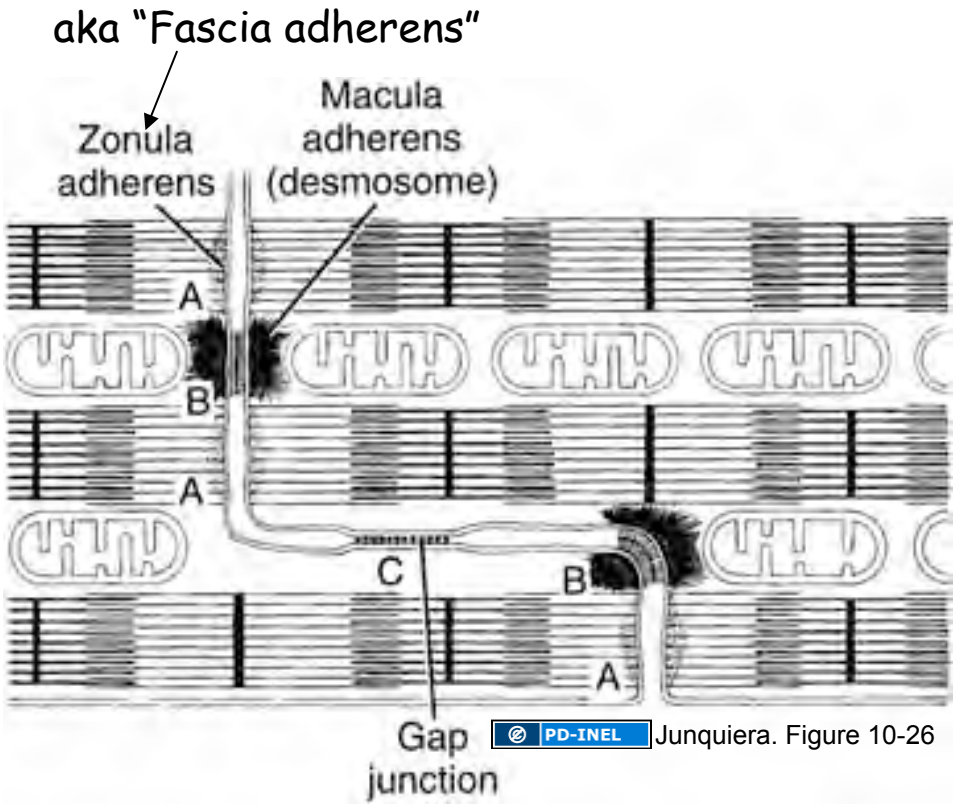


 Junquiera. Figure 10-25.

Transverse portion:
forms mechanical coupling

PD-INEL Source Undetermined

Lateral Portion:
forms electrical coupling

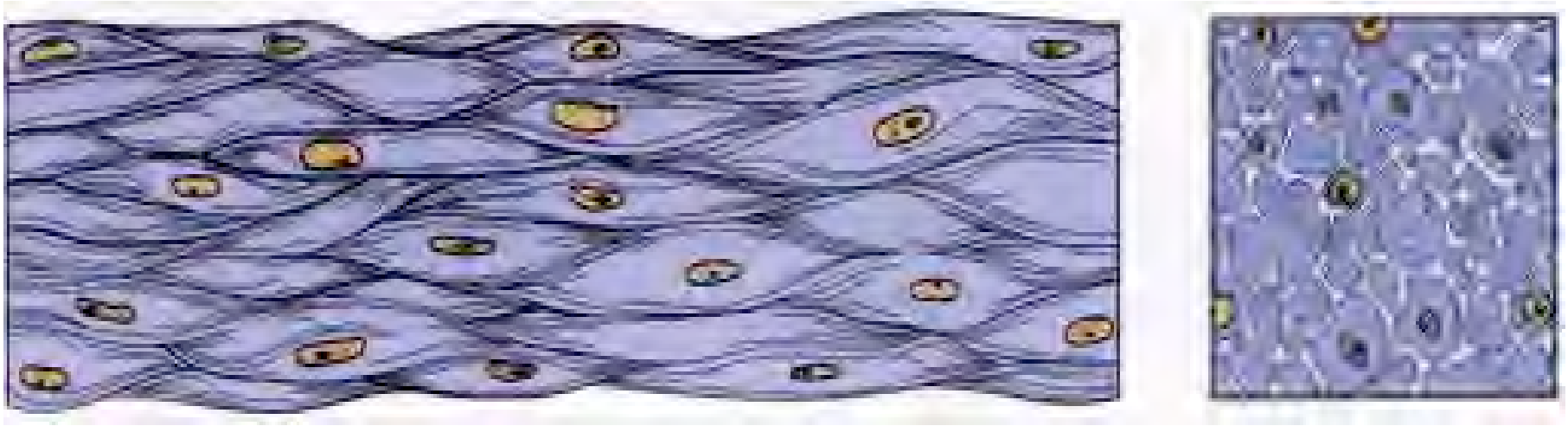


PD-INEL Junquiera. Figure 10-26

PD-INEL Cross and Mercer. *Cells and Tissue Ultrastructure.* 1993. Plate 120

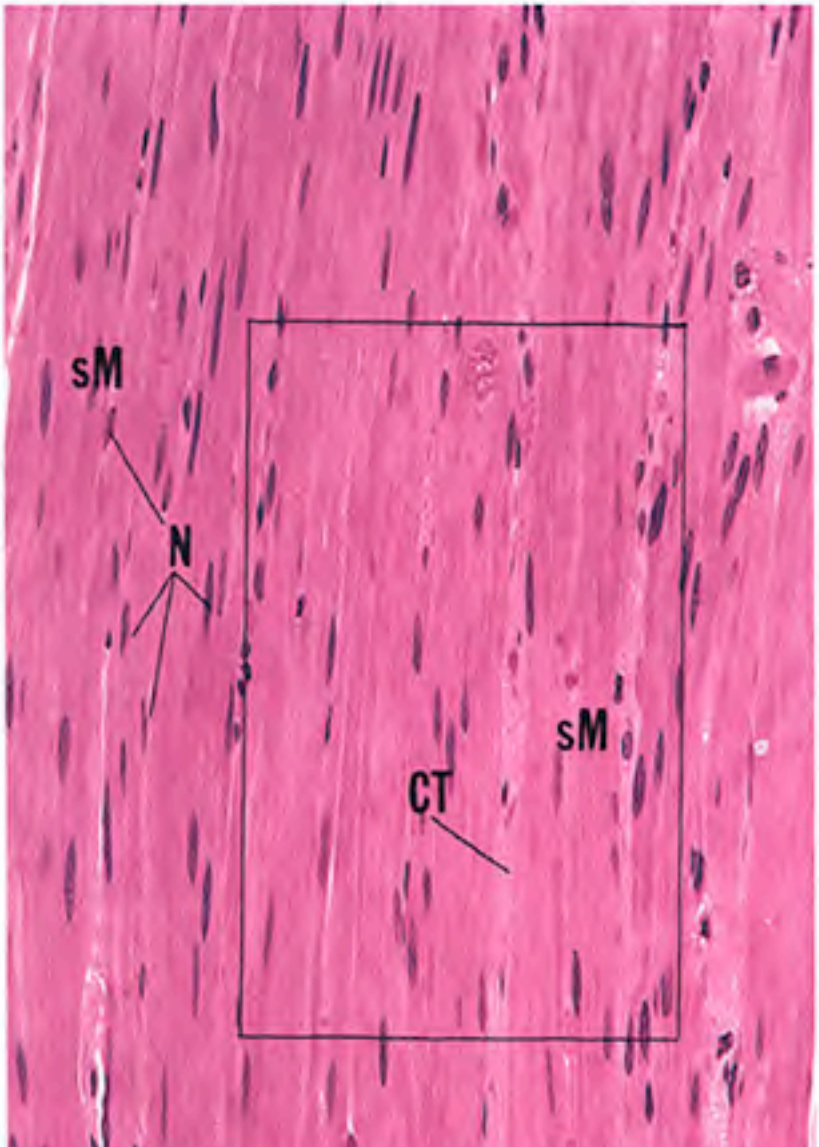
Smooth Muscle

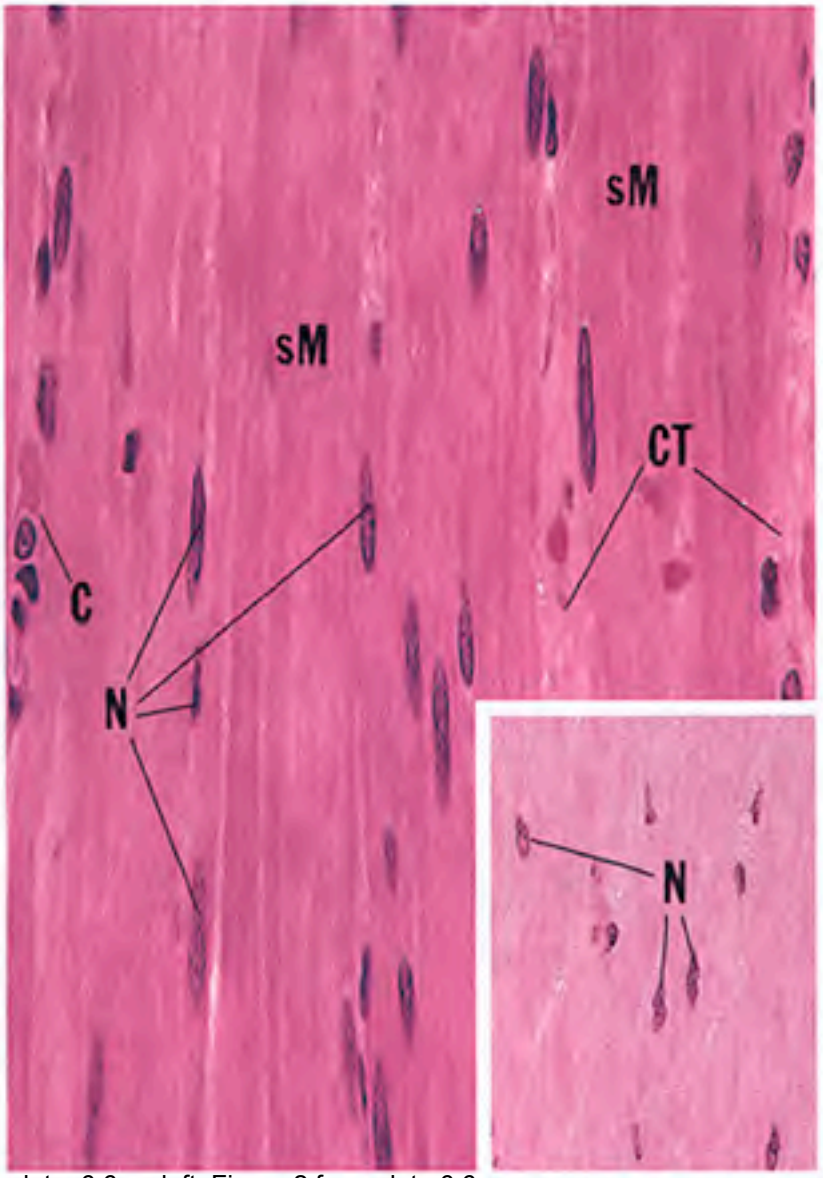
- Fusiform, non-striated cells
- Single, centrally-placed nucleus
- Contraction is non-voluntary
- Contraction is modulated in a neuroendocrine manner
- Found in blood vessels, GI and urogenital organ walls, dermis of skin



 Junquiera. Figure 10-1.

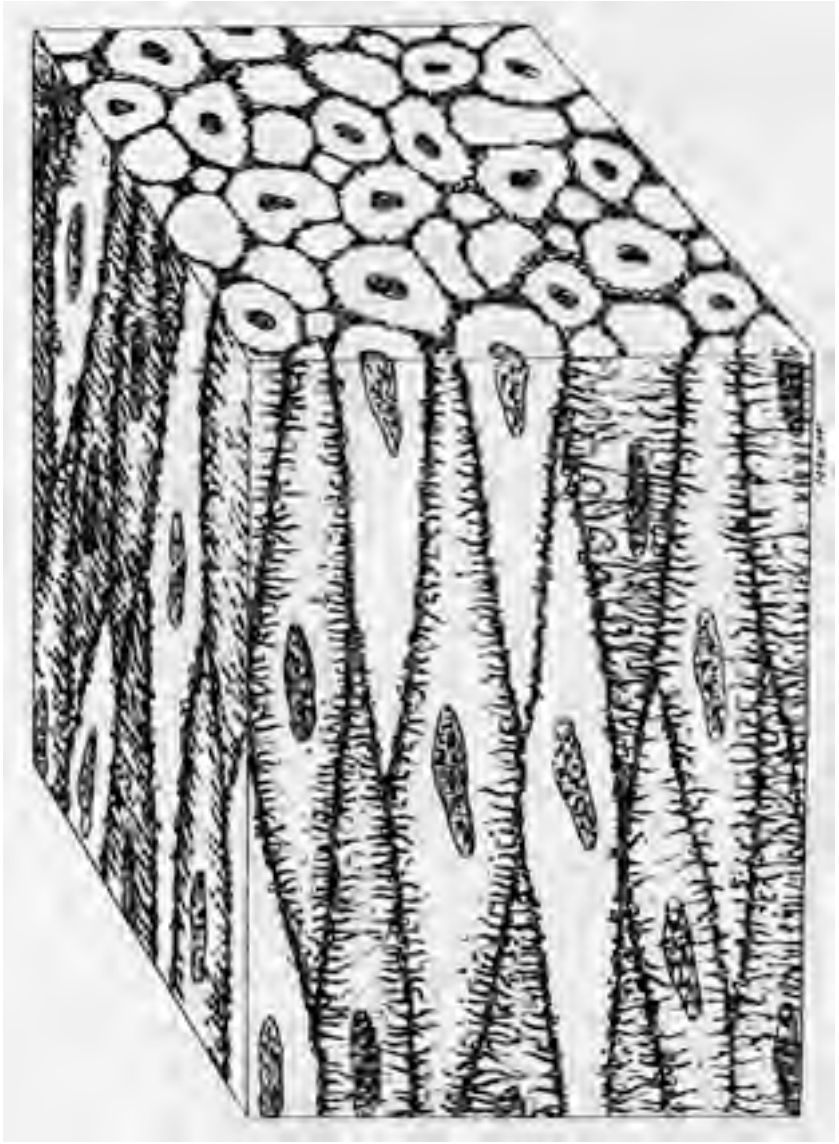
Smooth Muscle (longitudinal section)



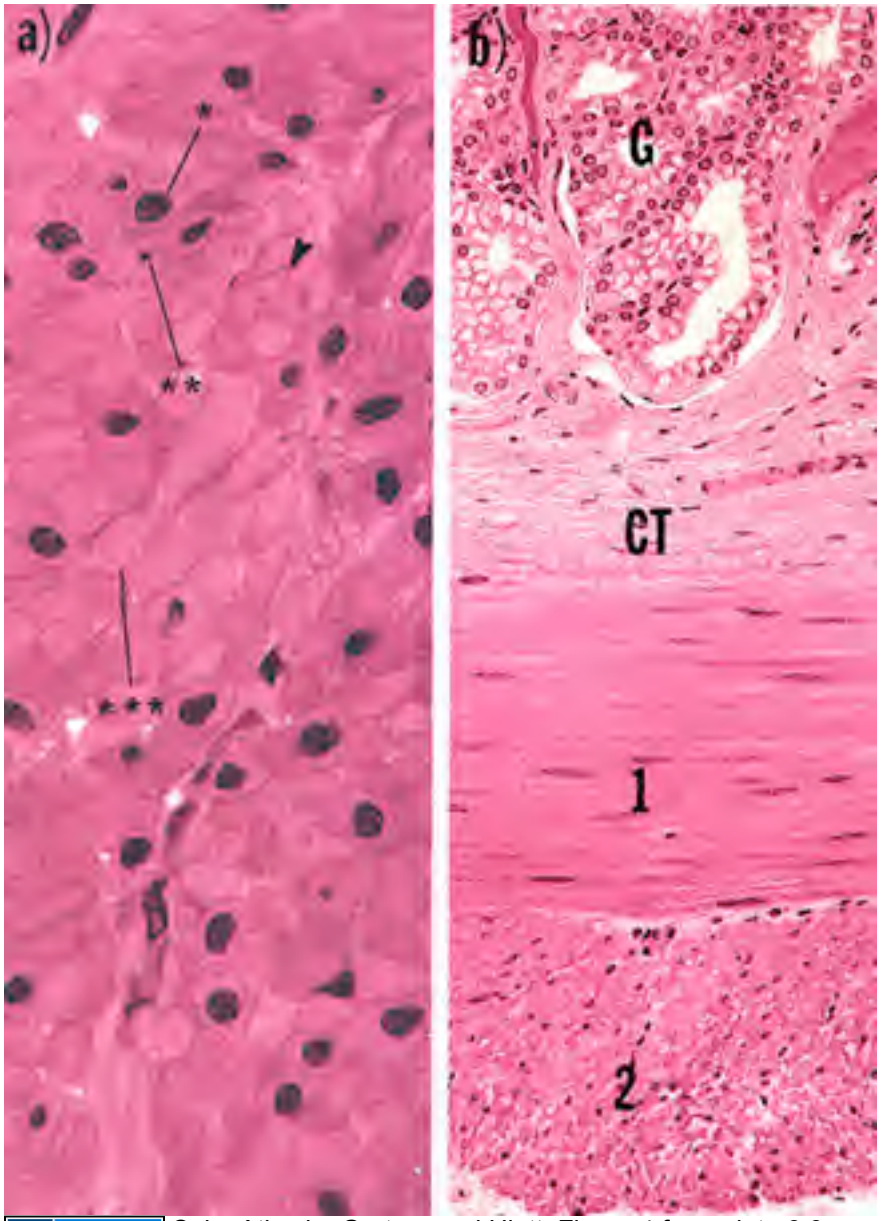


 Gartner and Hiatt. *Color Atlas of Histology*. Figure 1 from plate 6.6 on left. Figure 2 from plate 6.6.

Smooth Muscle Viewed in Transverse and Longitudinal Section



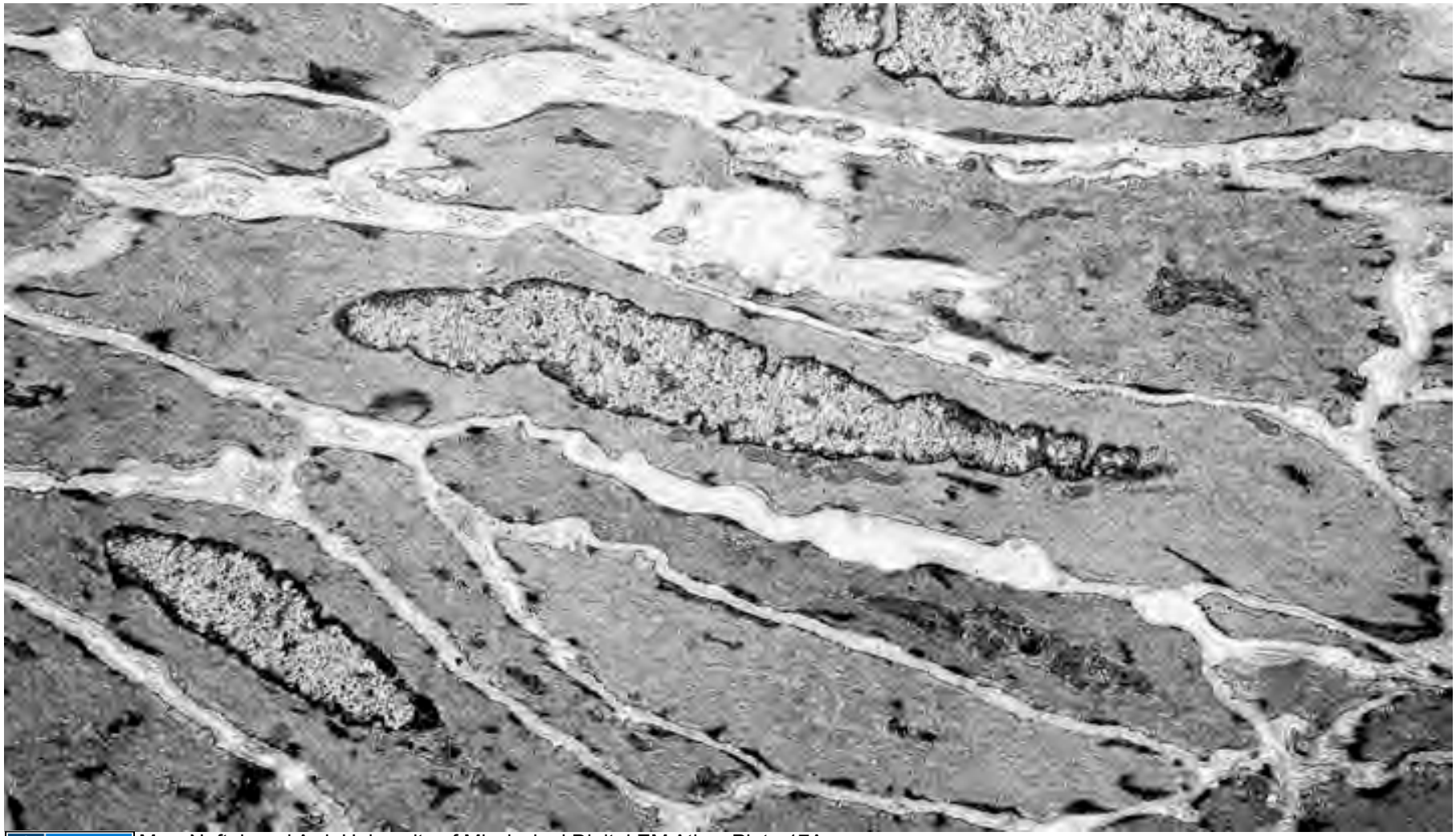
PD-INEL Junquiera. Figure 10-30.



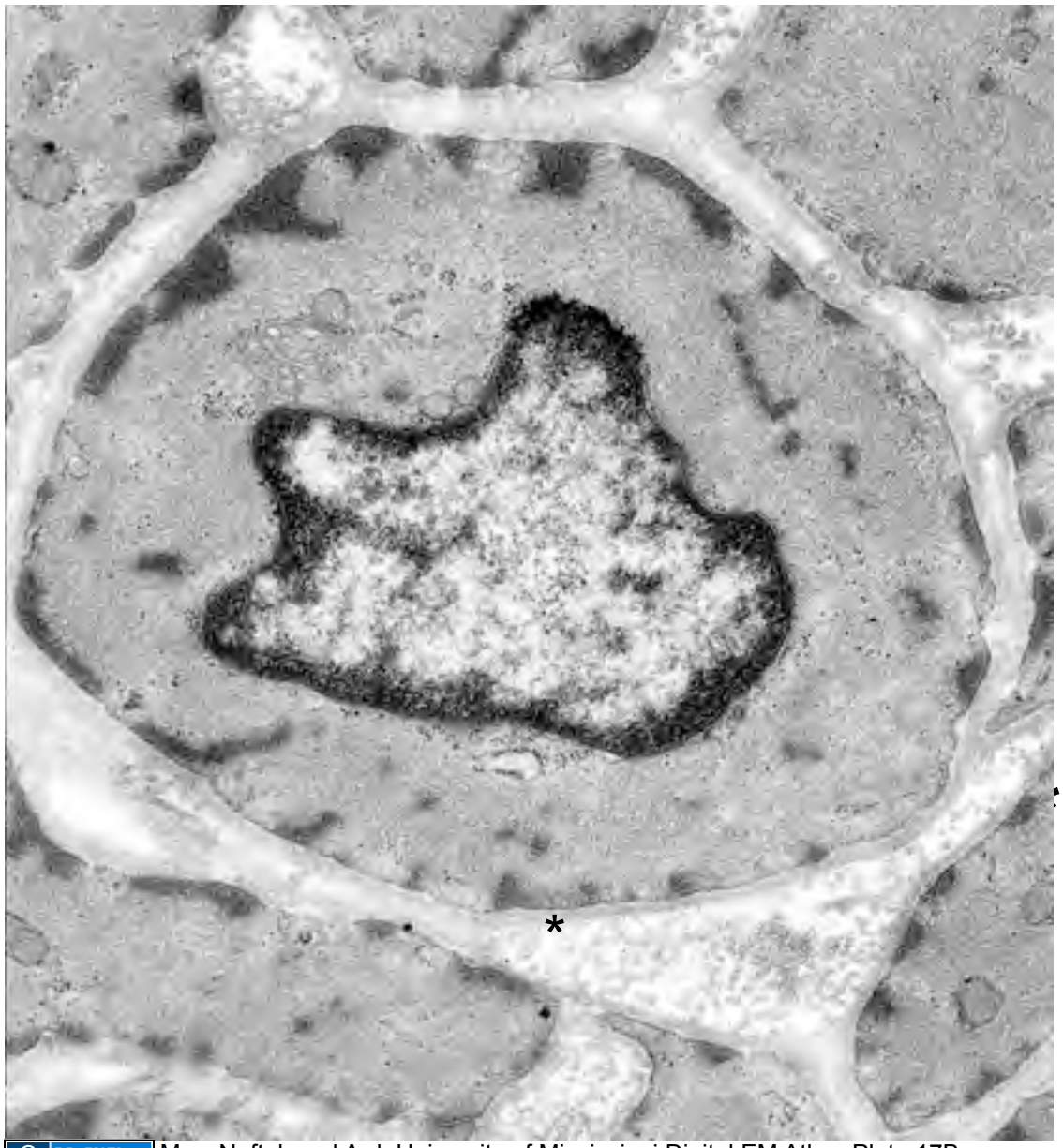
PD-INEL Color Atlas by Gartner and Hiatt. Figure 4 from plate 6.6.

Ultrastructure of Smooth Muscle:

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



 May, Naftel, and Ard. University of Mississippi Digital EM Atlas. Plate 17A.



 May, Naftel, and Ard. University of Mississippi Digital EM Atlas. Plate 17B

Smooth Muscle Viewed in Cross Section (TEM)

What is the structure marked by * ?

Also, note collagen – SMC secrete ECM: collagen (I,III, IV), elastin, and proteoglycans

More Ultrastructure of Smooth Muscle Cells:

- microtubules (curved arrows)
- actin filament (arrowheads)
- intermediate filaments
- dense bodies (desmin/vimentin plaques)
- caveoli (membrane invaginations & vesicular system contiguous with SER **–functionally analogous to sarcoplasmic reticulum**)

 Cross and Mercer. Inset of plate 114.

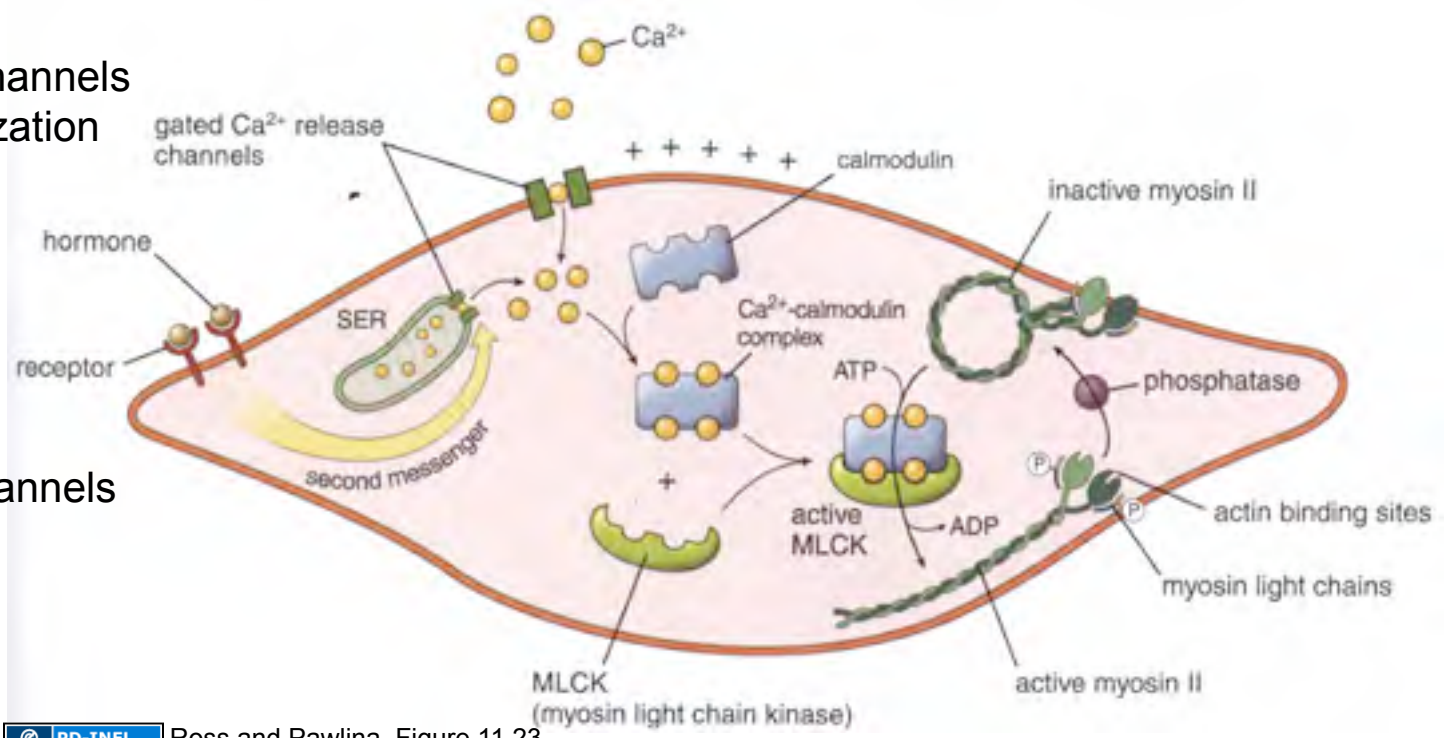
Smooth Muscle Contraction:

also Ca+ dependent, but mechanism is different than striated muscle

1. Ca2+ ions released from caveloae/SER and complex with calmodulin
2. Ca2+-calmodulin activates myosin light chain kinase
3. MLCK phosphorylates myosin light chain
4. Myosin unfolds & binds actin; ATP-dependent contraction cycle ensues.
5. Contraction continues as long as myosin is phosphorylated.
6. “Latch” state: myosin head attached to actin dephosphorylated causing decrease in ATPase activity –myosin head unable to detach from actin (similar to “rigor mortis” in skeletal muscle).

Triggered by:

- Voltage-gated Ca+ channels activated by depolarization
  - Mechanical stimuli
  - Neural stimulation
- Ligand-gated Ca+ channels



PD-INEL Ross and Pawlina. Figure 11.23.

Image of smooth muscle cell contraction removed

Mechanics of Smooth Muscle Contraction

- Dense bodies are analogous to Z lines (plaques into which actin filaments insert)
- Myosin heads oriented in “side polar” arrangement
- Contraction pulls dense bodies together

Additional notes:

- Contraction cycle generally about ~10% as fast as skeletal muscle
- Visceral (unitary) smooth muscle cells may be **electrically coupled** via gap junctions and exhibit either **rhythmic** or **tonic** contraction –innervation generally MODIFIES smooth muscle activity rather than initiating it.
- Multiunit smooth muscle cells are innervated individually and can contract rapidly for more precise control.
- **Innervation is always at a distance (no motor end plates)**

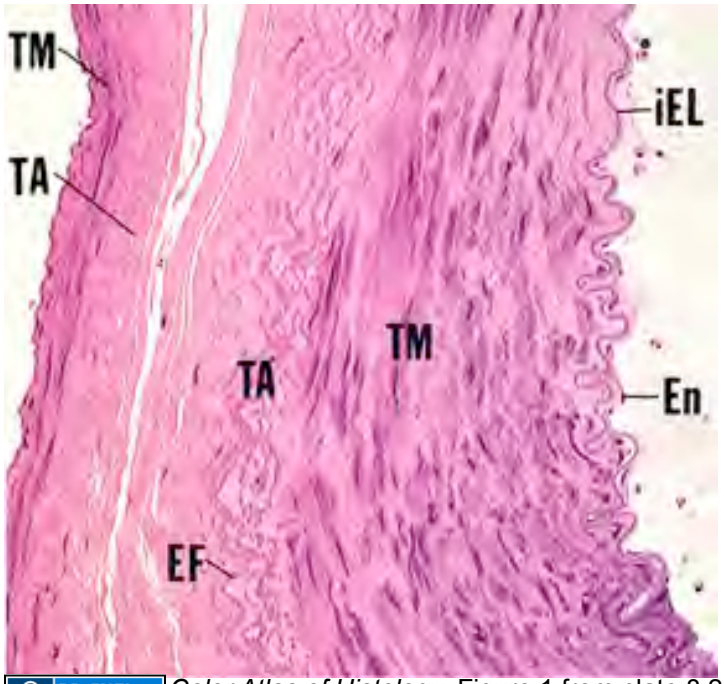
Smooth Muscle (vascular)

PD-INEL Source Undetermined

Relaxed

PD-INEL Source Undetermined

Contracted

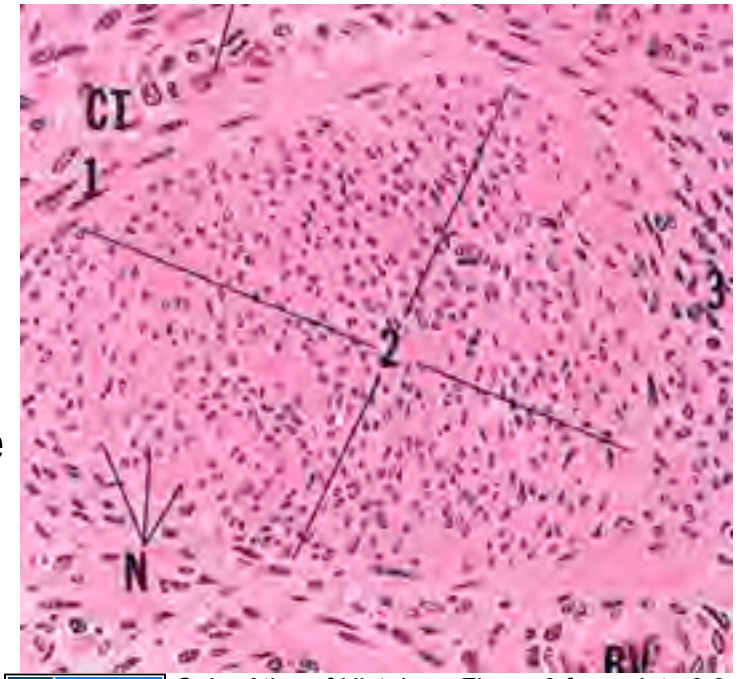


PD-INEL *Color Atlas of Histology*. Figure 1 from plate 8.2.

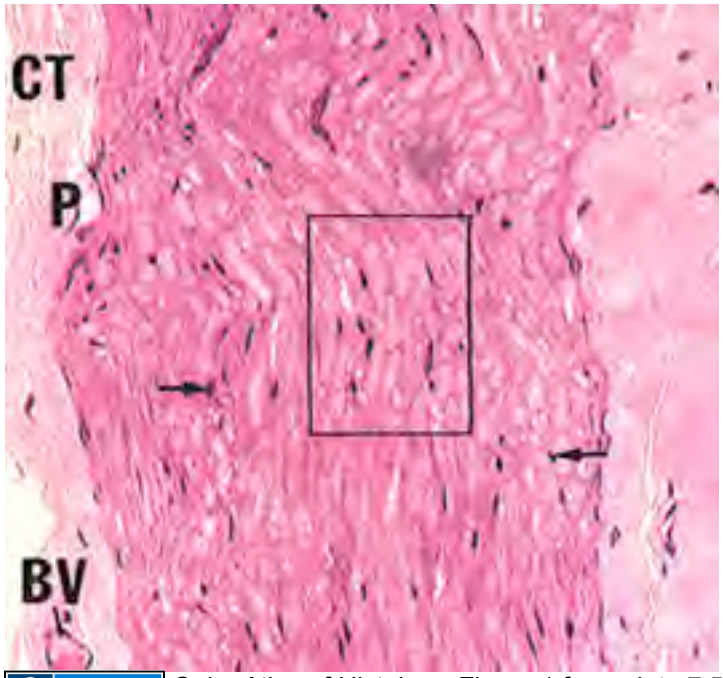
Smooth Muscle

VERSUS

Nerve



PD-INEL *Color Atlas of Histology*. Figure 3 from plate 6.6

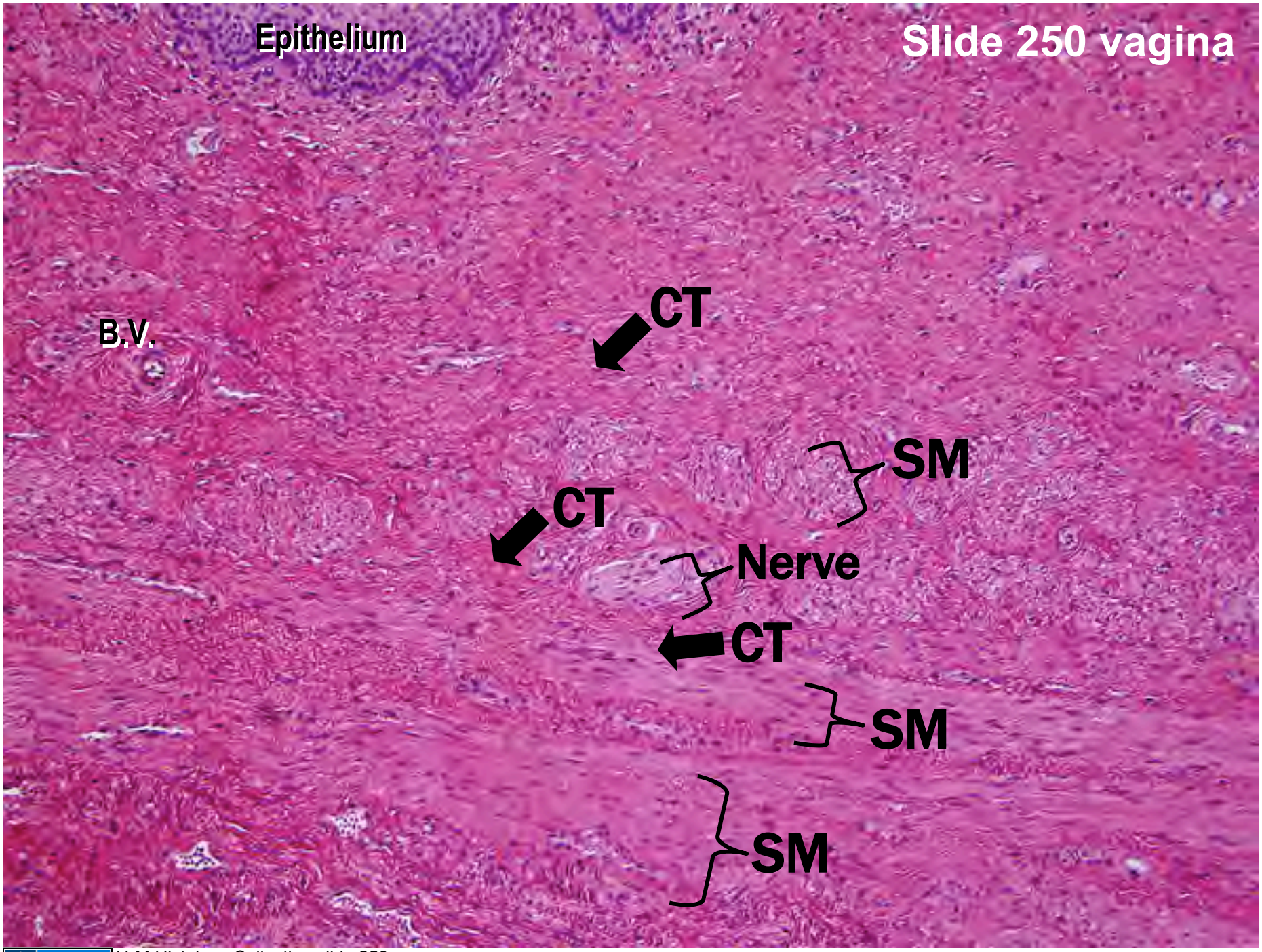


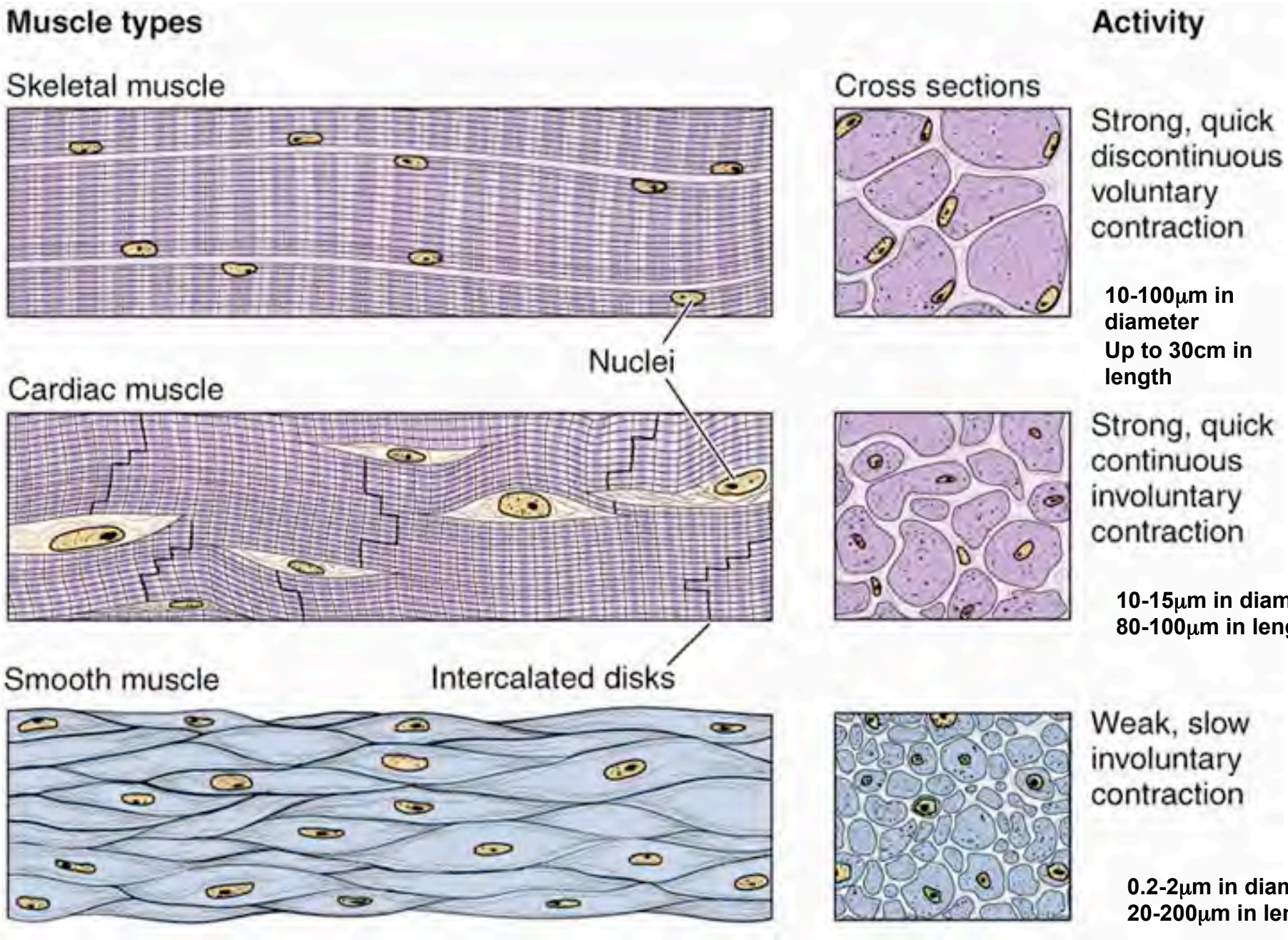
PD-INEL *Color Atlas of Histology*. Figure 1 from plate 7.5

VERSUS

Connective Tissue

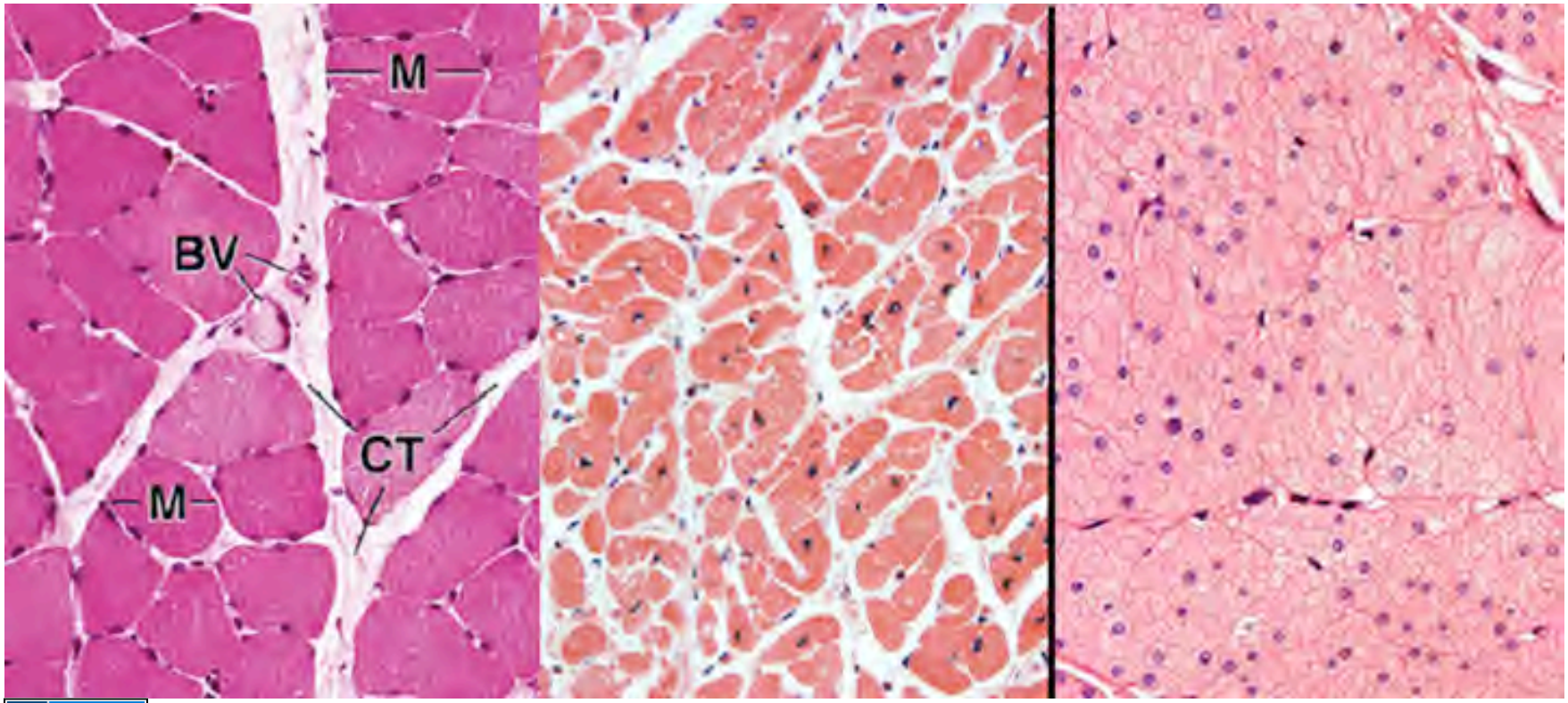
PD-INEL *Color Atlas of Histology*. Figure 3 from plate 7.5





 Junquiera. Figure 10-1.

Skeletal Muscle Cardiac Muscle Smooth Muscle



Left: Ross and Pawlina. Figure 2 from plate 18.
Middle: Unknown
Right: Unknown

Muscle Regeneration and Growth

Skeletal Muscle

- Increase in size (hypertrophy)
- Increase in number (regeneration/proliferation)
    - Satellite cells are proposed source of regenerative cells

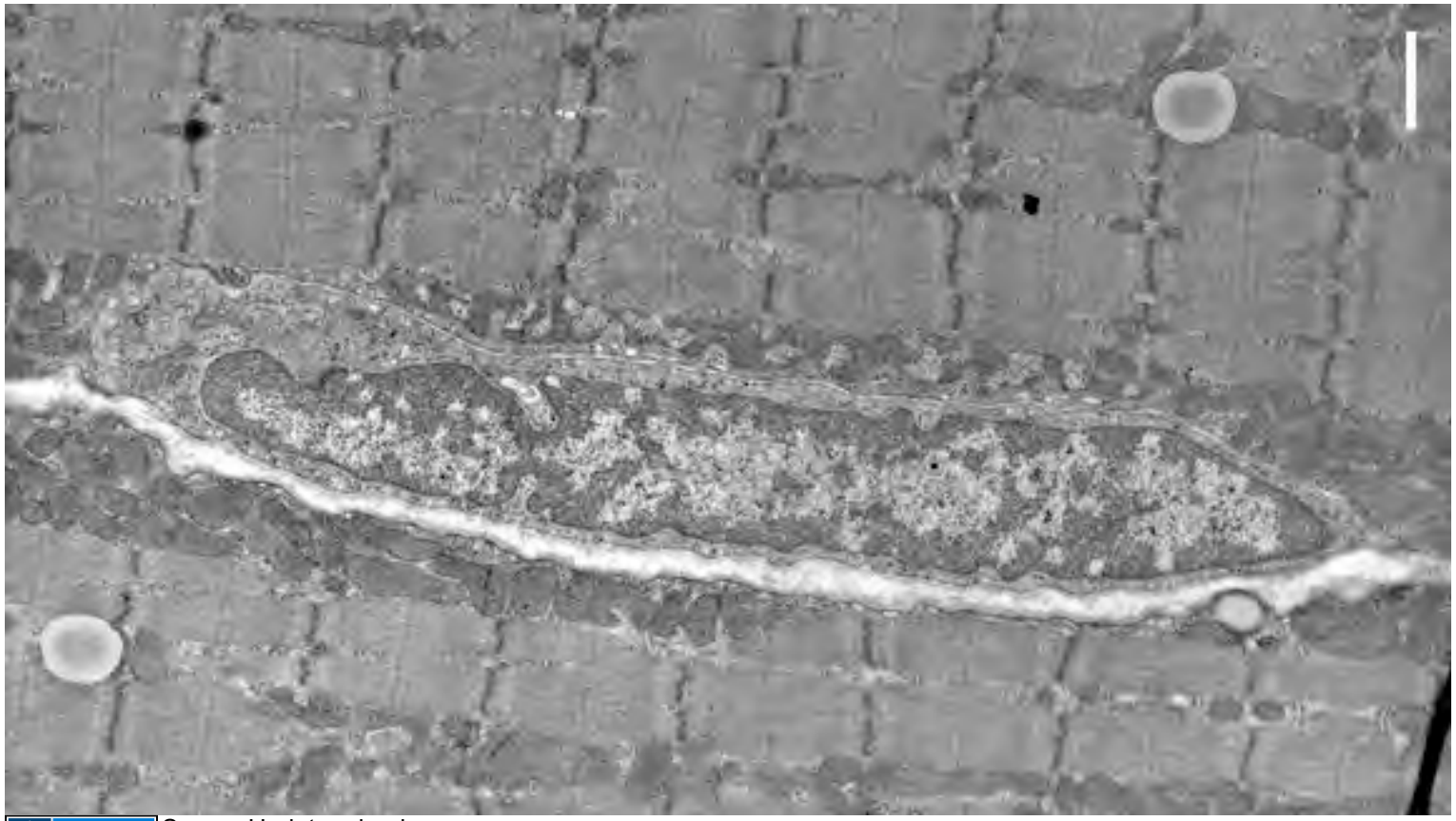
Smooth Muscle

- Increase in size (hypertrophy)
- Increase in number (regeneration/proliferation)
    - Smooth muscle cells are proliferative
    (e.g. uterine myometrium and vascular smooth muscle)
    - Vascular pericytes can also provide source of smooth muscle

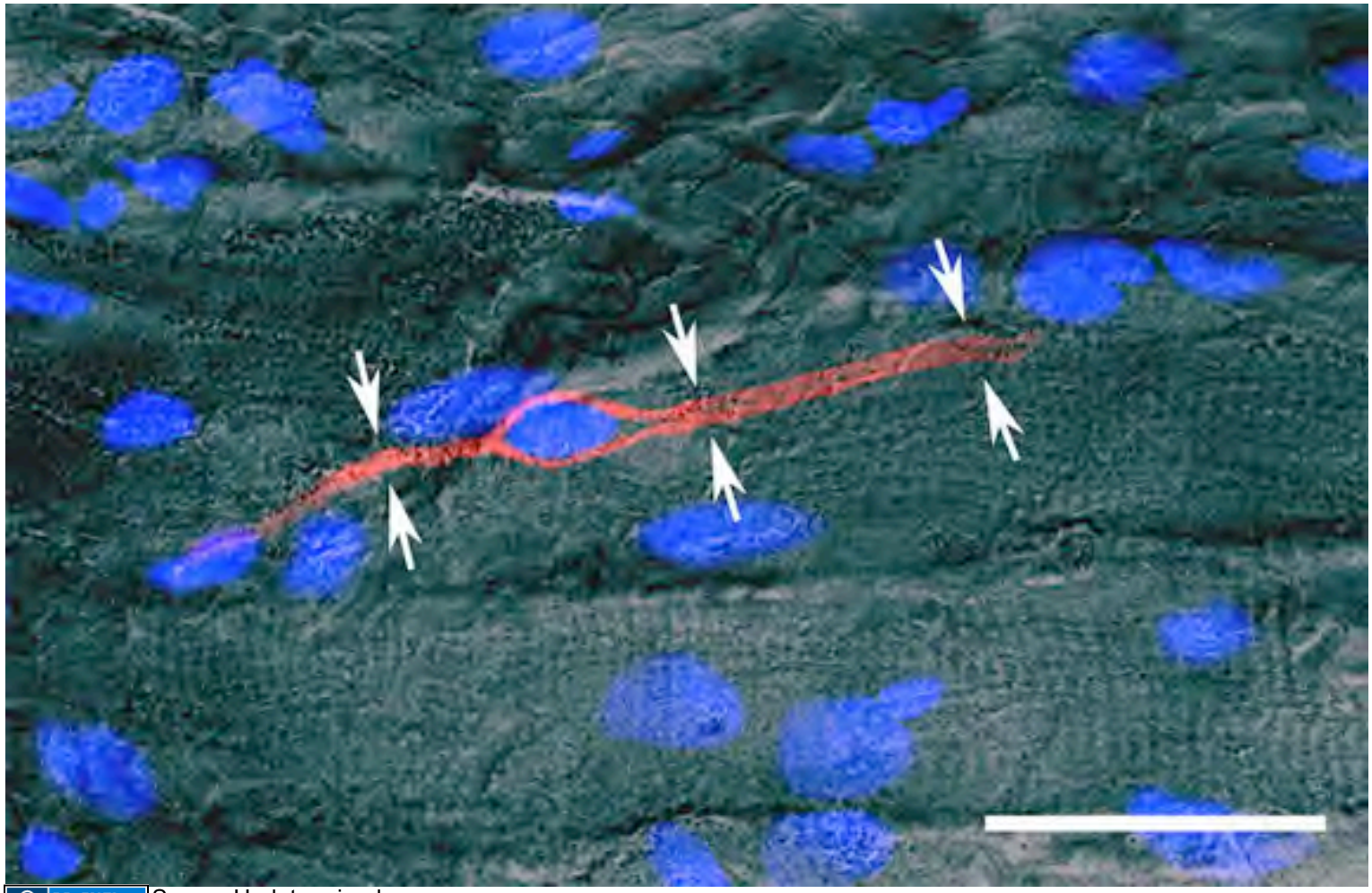
Heart Muscle

- Increase in size (hypertrophy)
- Formerly thought to be non-proliferative
    - Post-infarction tissue remodeling by fibroblasts (fibrosis/scarring)
    - New evidence suggests mitotic cardiomyocytes and regeneration by blood or vascular-derived stem cells

Skeletal Muscle Satellite Cell



Activated satellite cell in skeletal muscle



Learning Objectives

1. Be able to identify the three types of muscle at the light and electron microscope levels, including distinctive features of each, such as the intercalated disk of cardiac muscle.

2. Be able to describe the structural basis of muscle striation.

3. Know the structural elements that harness muscle contraction (i.e., the shortening of myofibrils) to the movement of a body part (i.e., via connection to bone) as well as the mechanism by which muscle cells contract.

4. Understand the function and organization of the connective tissue in muscle (endo-, peri-, and epiysium).

5. Be familiar with the regenerative potential of each muscle type.

Additional Source Information

for more information see: http://open.umich.edu/wiki/CitationPolicy

Slide 5: National Cancer Institute, Wikimedia, http://en.wikipedia.org/wiki/File:Illu_muscle_structure.jpg
Slide 6: Source Undetermined
Slide 7: Source Undetermined
Slide 8: Sameerb, Wikipedia, http://en.wikipedia.org/wiki/File:Sarcomere.gif
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