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Histology of the Peripheral Nervous System

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Winter, 2009

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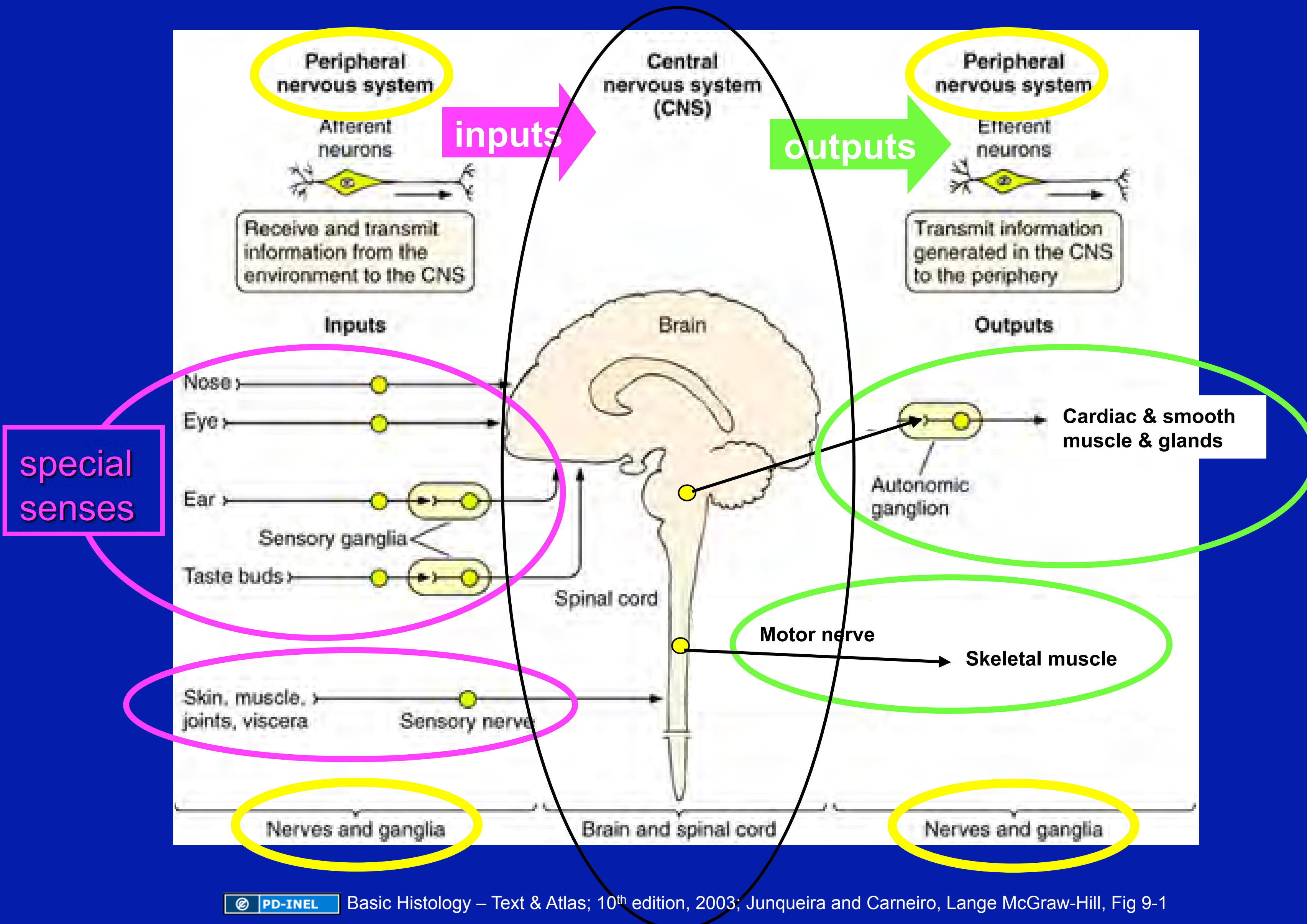
Objectives of PNS Histology:

- Discuss the general division/differences between CNS and PNS
- Appreciate the subdivision into somatic and autonomic nervous system
- Learn about the cellular components and the structural attributes of neuronal cells
- Discuss synaptic connections, using the motor end plate as an example
- Study the formation of the axonal myelin ensheathment
- Compare the histological features of myelinated and unmyelinated axons/nerves
- Recognize nerves in histological sections
- Identify the different connective tissue layers that are associated with nerves
- Understand the different organizational plans that are adopted by neuronal cells
- Identify and compare autonomic and sensory ganglia
- Learn about the basic histological features of the spinal cord
- Understand the organization and functions of mechanosensory receptors and neuromuscular spindles and be able to recognize them

Structural Organization of the Nervous System



 Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-1

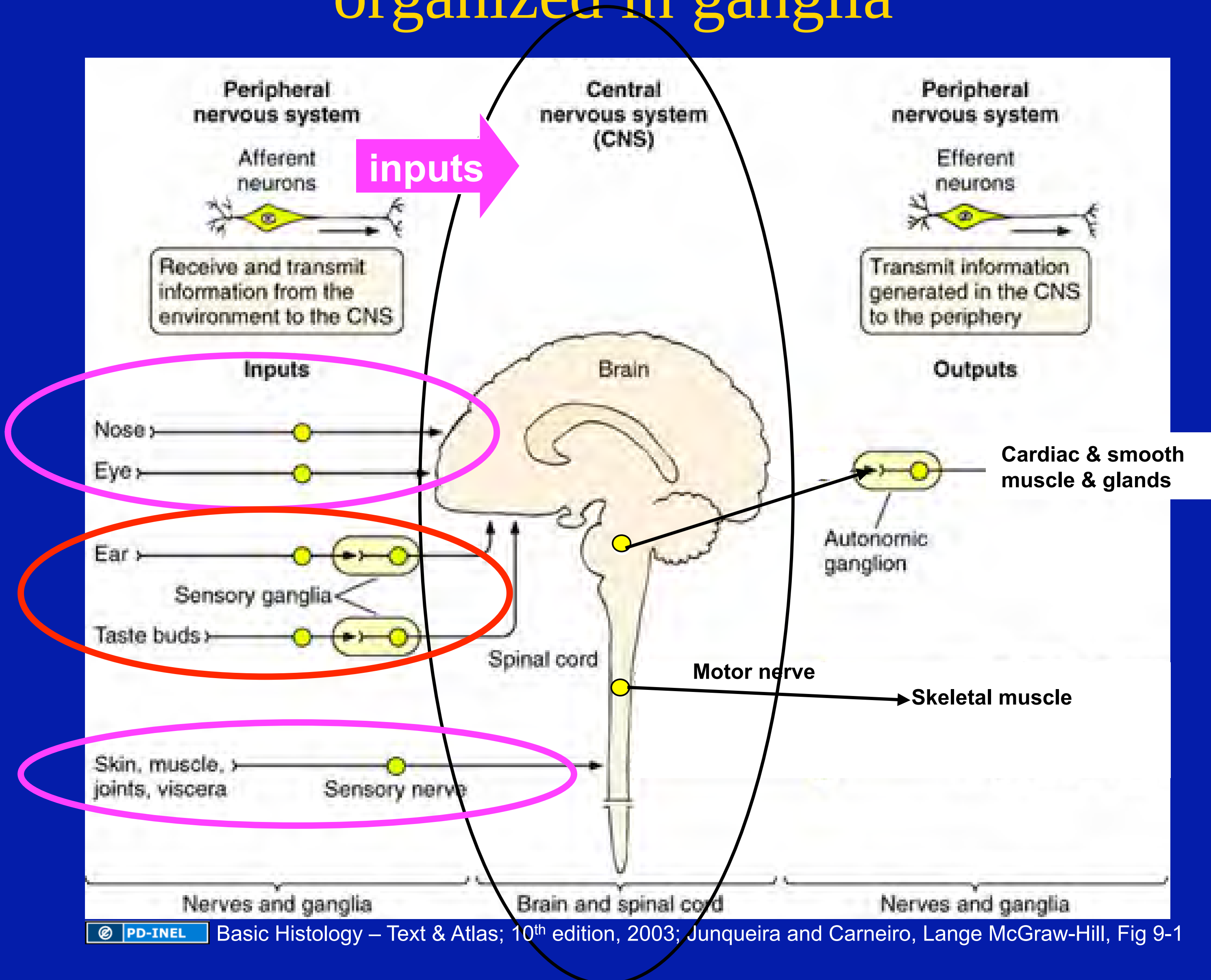
Functional Organization of the Nervous System

1. Somatic (conscious afferent* and efferent, voluntary motor control)
2. Autonomic (unconscious efferent, involuntary motor control of internal organs to maintain homeostasis)
   a. Sympathetic – thoracolumbar division
   b. Parasympathetic – craniosacral division

* Somatic afferents = sensory fibers from skin, muscle, joints, tendons.

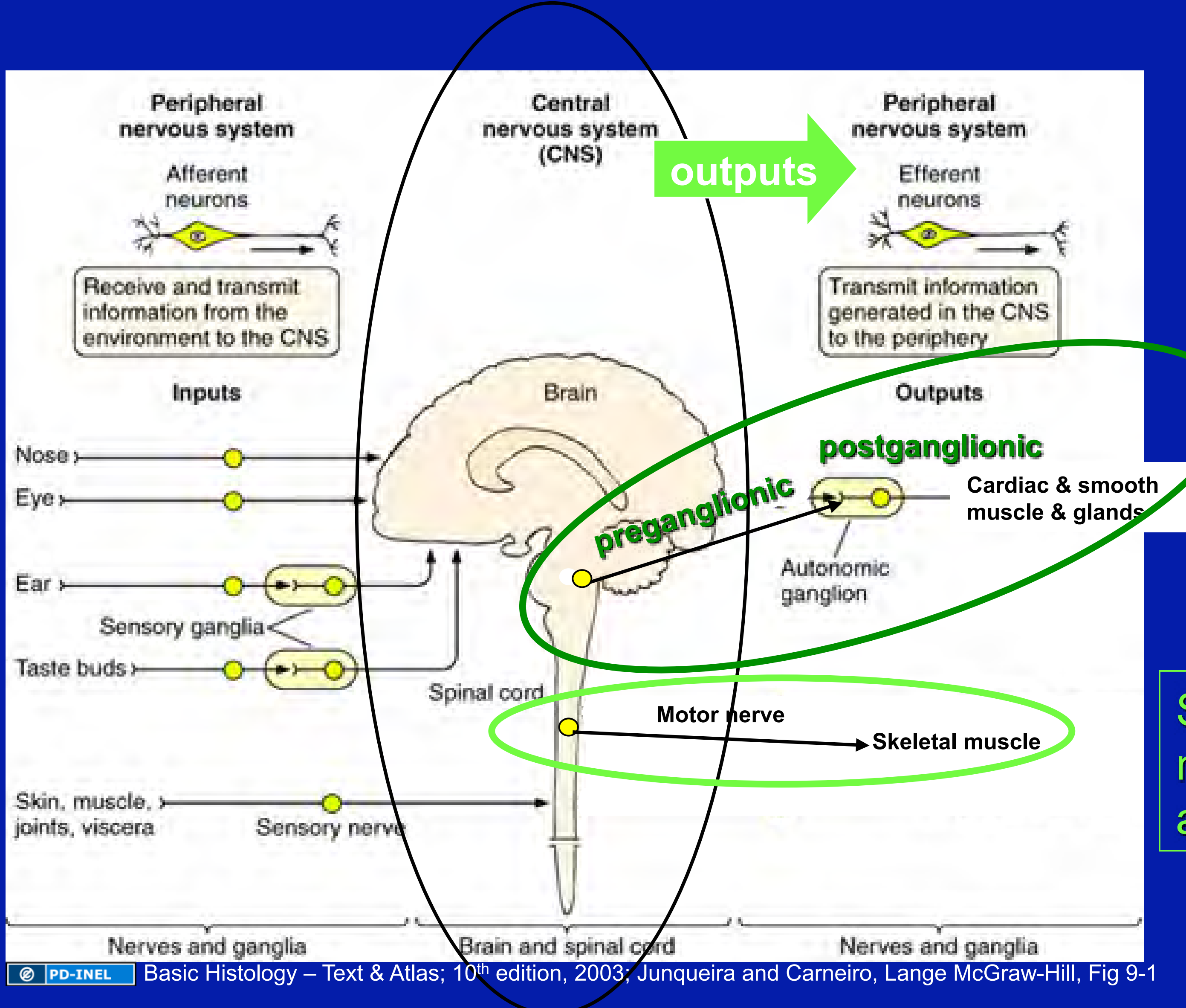
Visceral afferents = sensory fibers from visceral organs; some result in conscious sensations, but others do not. However, they are not considered part of the autonomic nervous system, which is entirely efferent.

Perikarya of sensory neurons are in the PNS, often organized in ganglia



PD-INEL Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-1

Motor neuron perikarya: somatic vs. autonomic



PD-INEL Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-1

Autonomic efferents = two neuron chain, with 1st neuron in the CNS and 2nd neuron in PNS ganglia

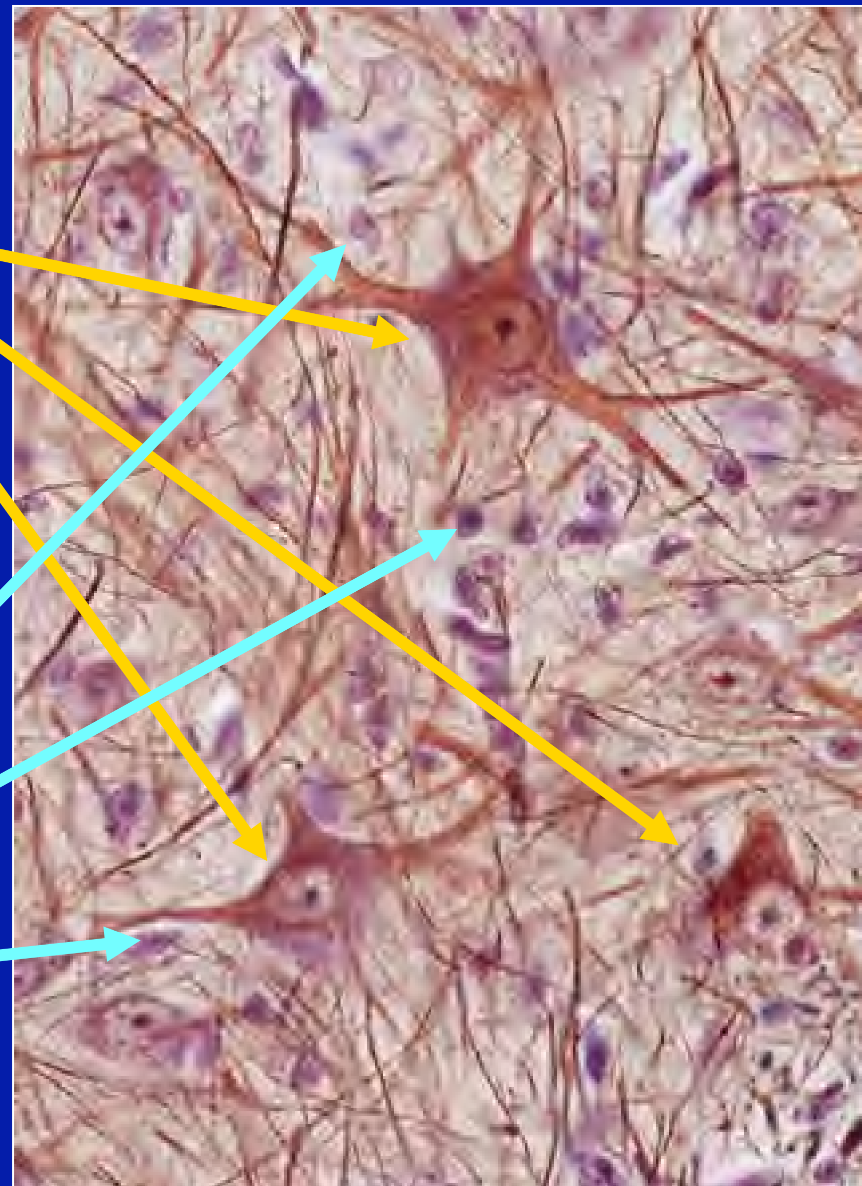
Somatic motor neuron perikarya are in the CNS

Cellular Components of the Nervous System

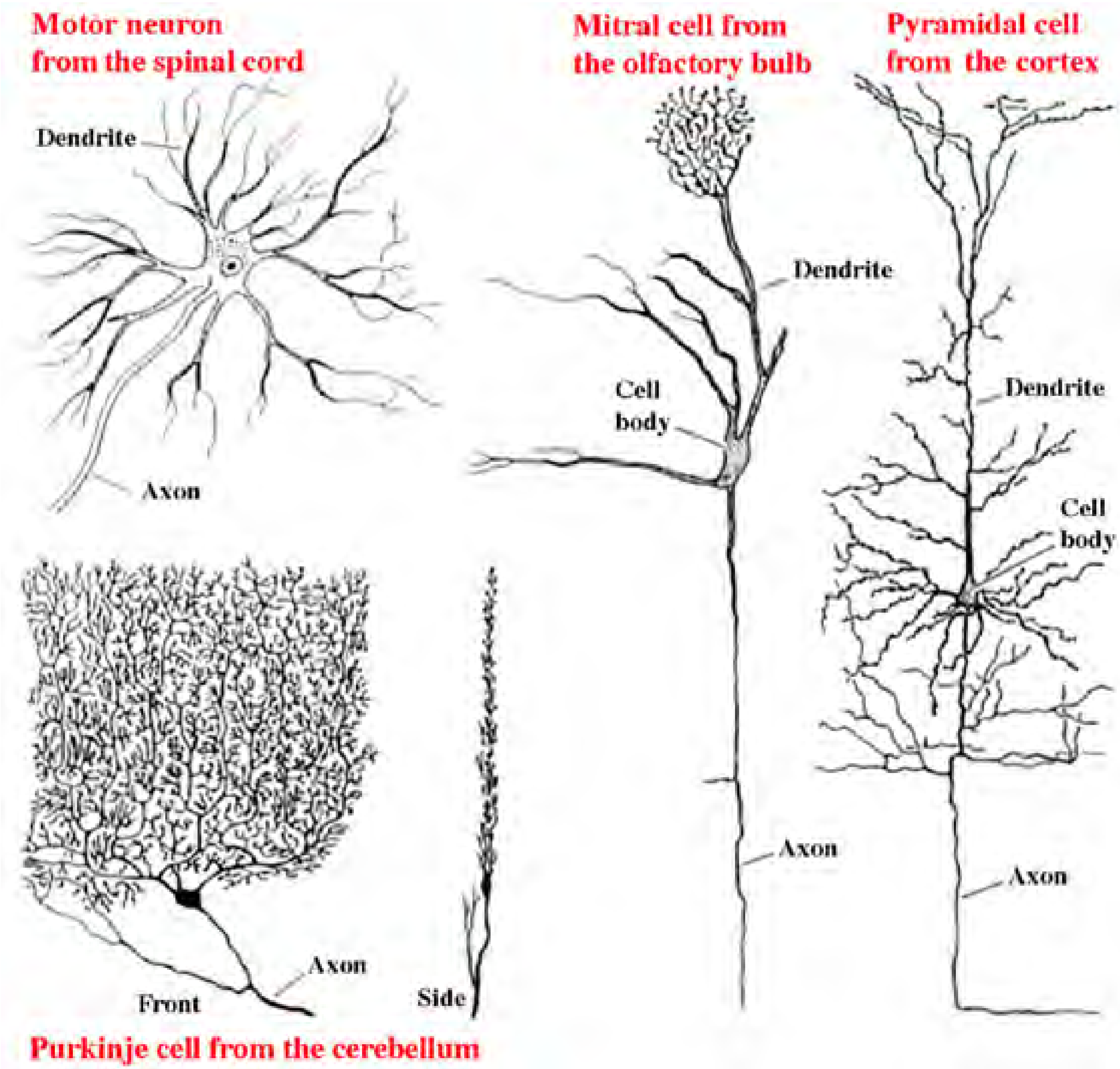
Heinrich Wilhelm Gottfried von Waldeyer-Hartz (1836-1921) Proposed the "neuron theory" of the nervous system.

Neurons

Glia
(support cells)



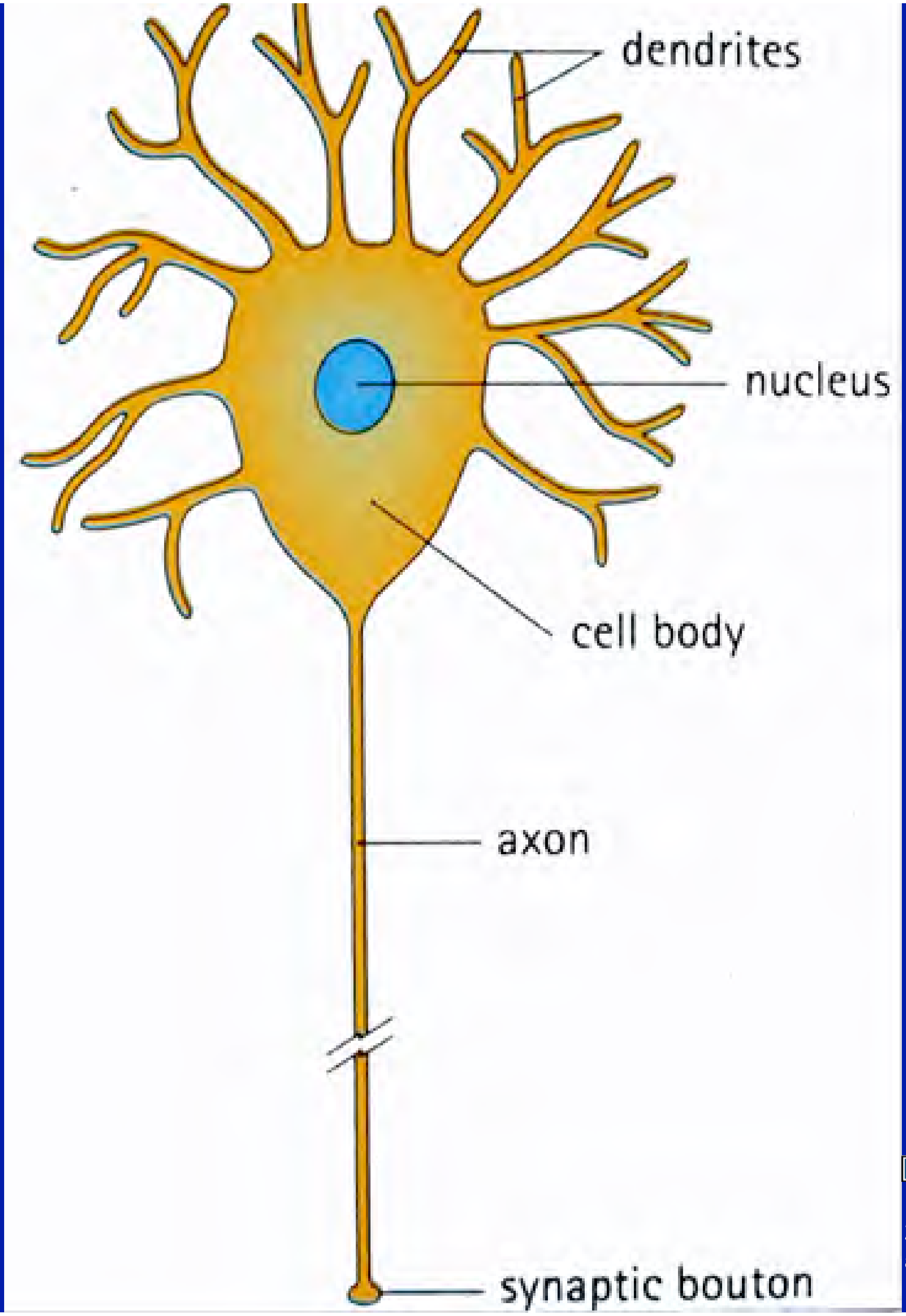
 Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.4d



Neurons come in many shapes and forms

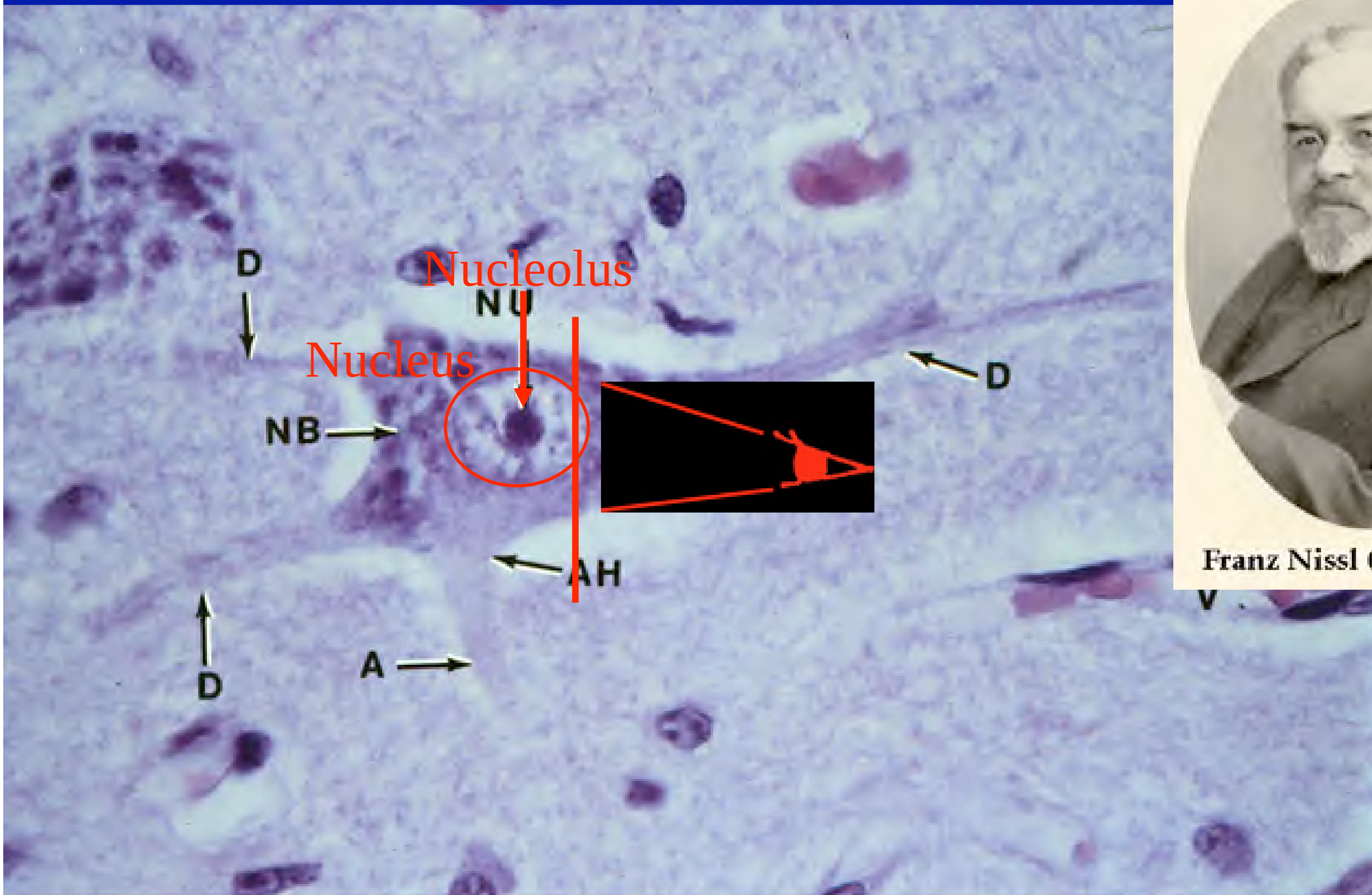
Neuron to Brain, 3rd edition, 1992; Nicholls, Martin and Wallace, Sinauer; Fig 6

Generic neuron



Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6-1

The cell body of a neuron is referred to as the soma or perikaryon

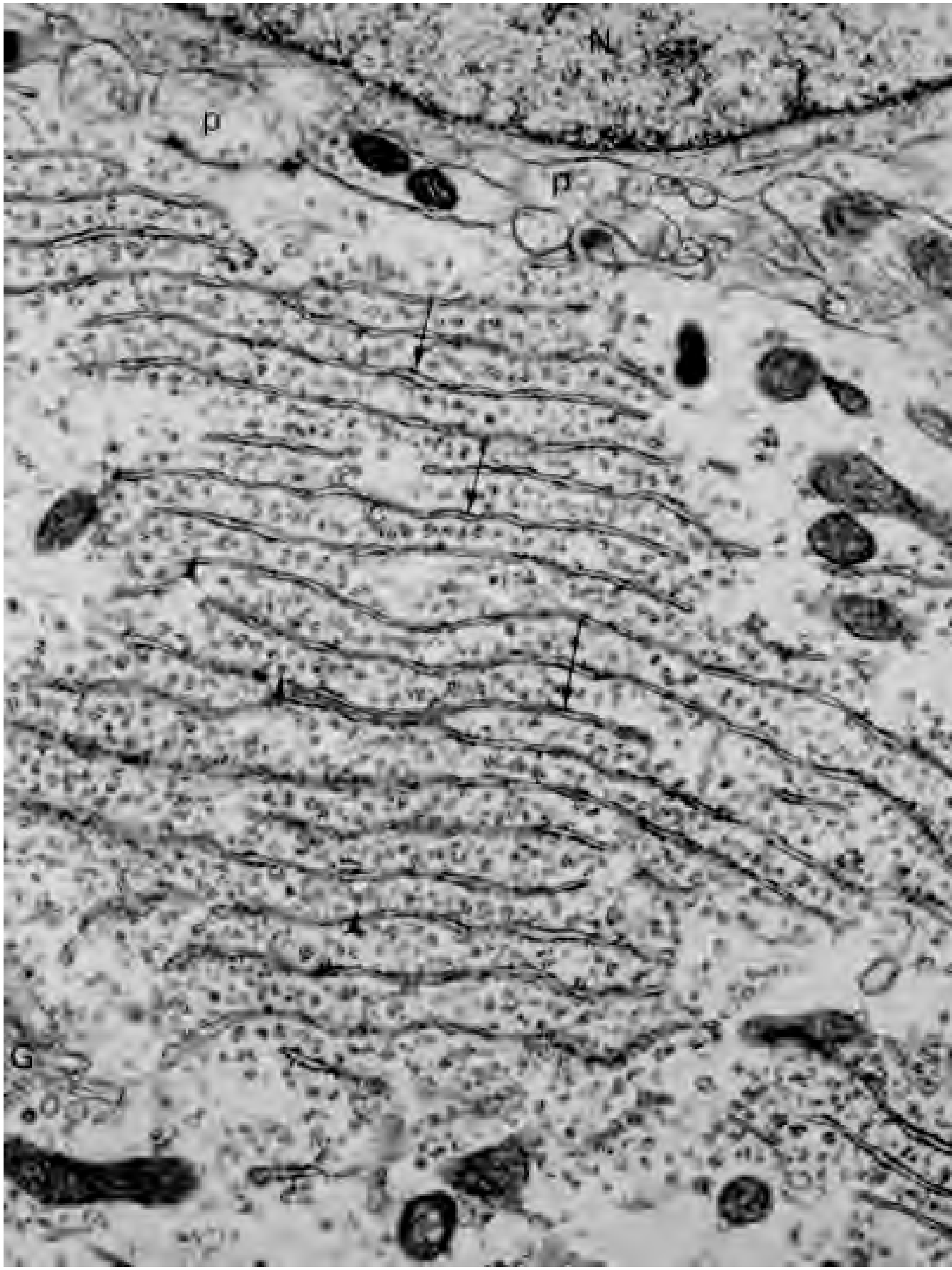


PD-INEL Color Atlas of Basic Histology; 1993; Berman; Appelton and Lange; Fig 6-4

Franz Nissl (1860-1919)

PD-EXP Wikipedia

Motor neuron with Nissl substance

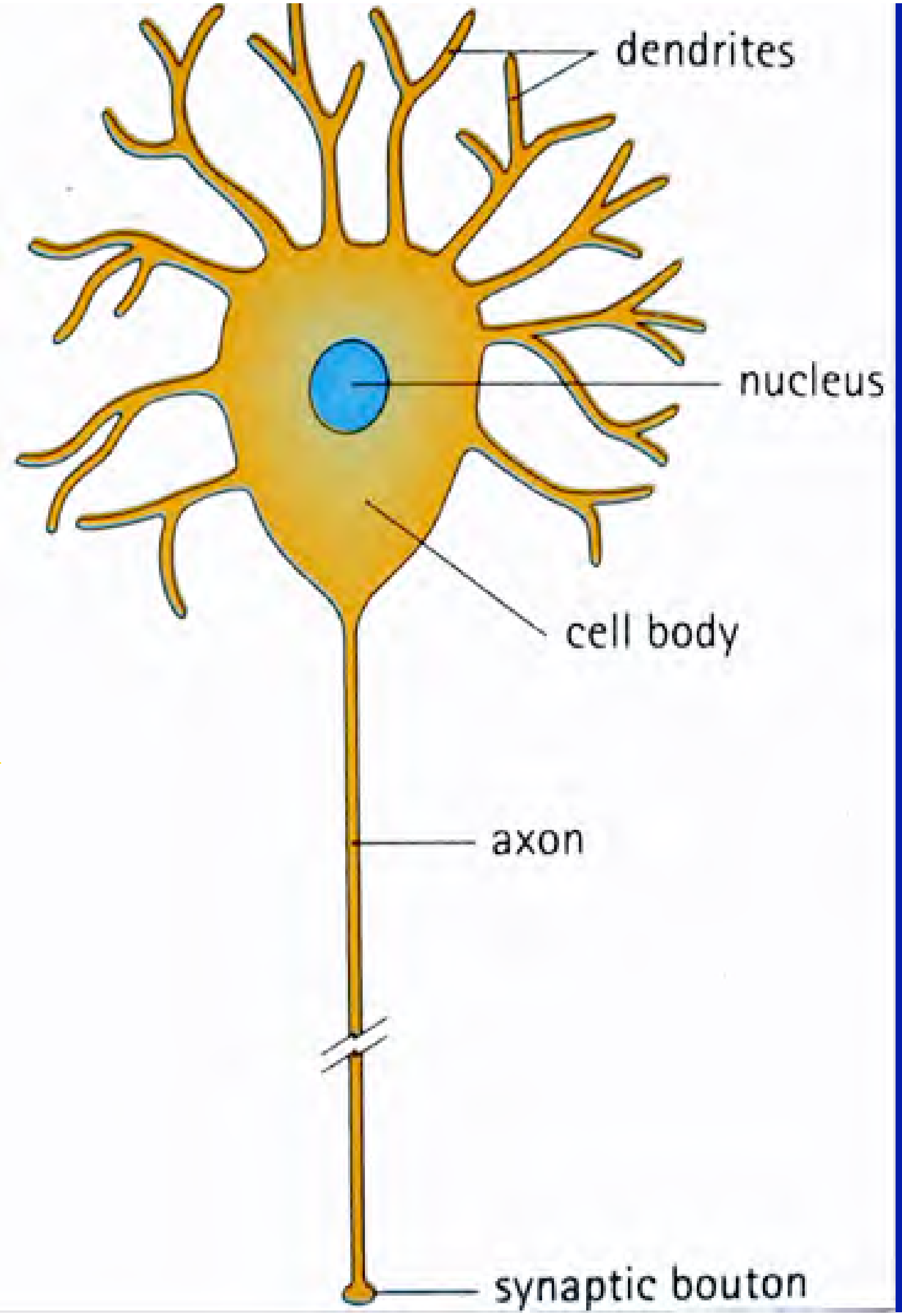


Nissl substance is rough endoplasmic reticulum

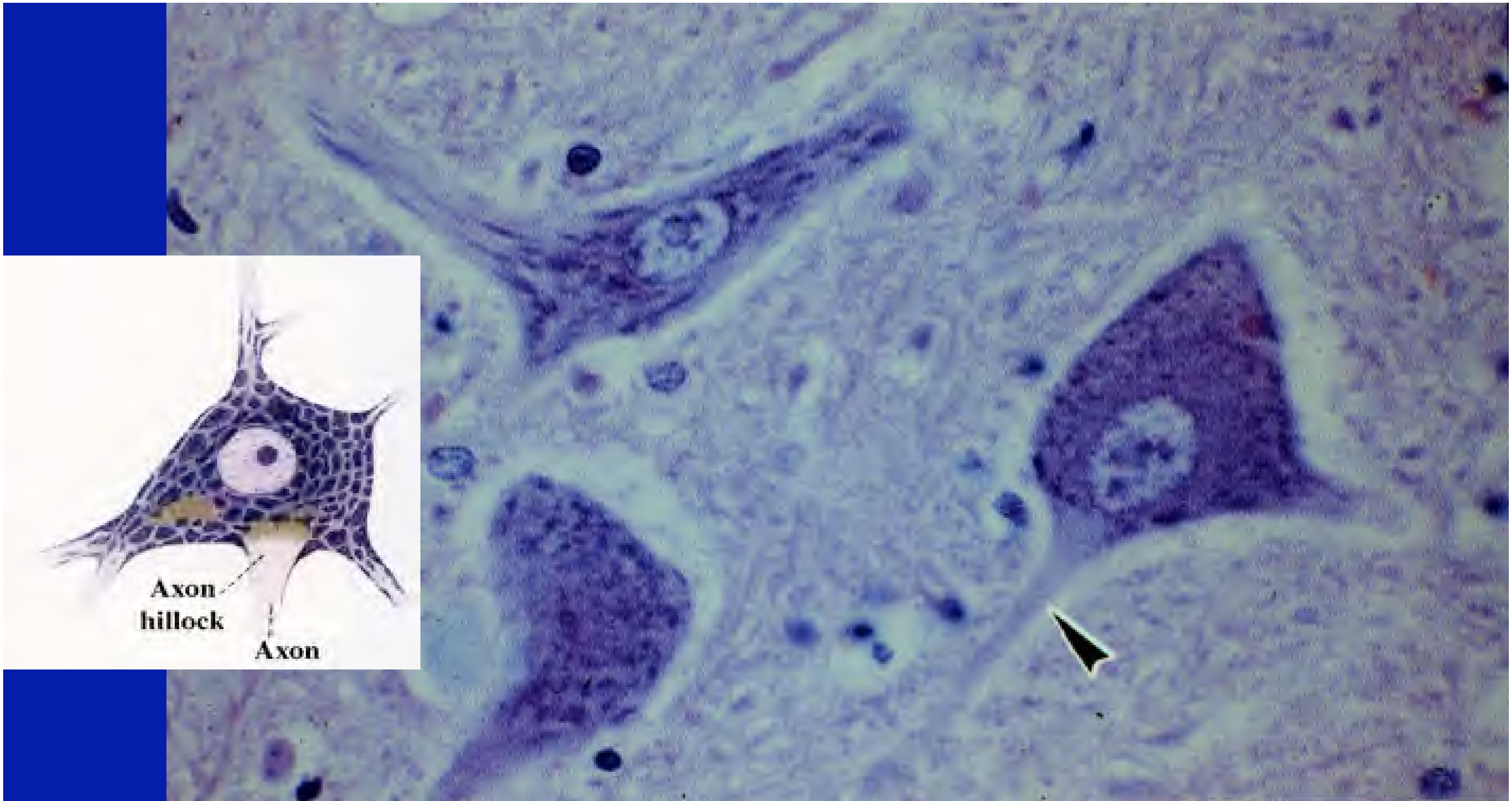
Cell and Tissue Ultrastructure – A Functional Perspective; 1993; Cross and Mercer, Freeman and Co.; Page 127

Neurons have <u>dendritic</u> and <u>axonal</u> extension

The <u>Law of Dynamic Polarization</u> states that neuronal signals only travel in one direction, from dendrites to the axon.
In humans axons can be up to 1.5 meters in length.
In a whale axonal length can reach up to 40 meters.



Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6-1

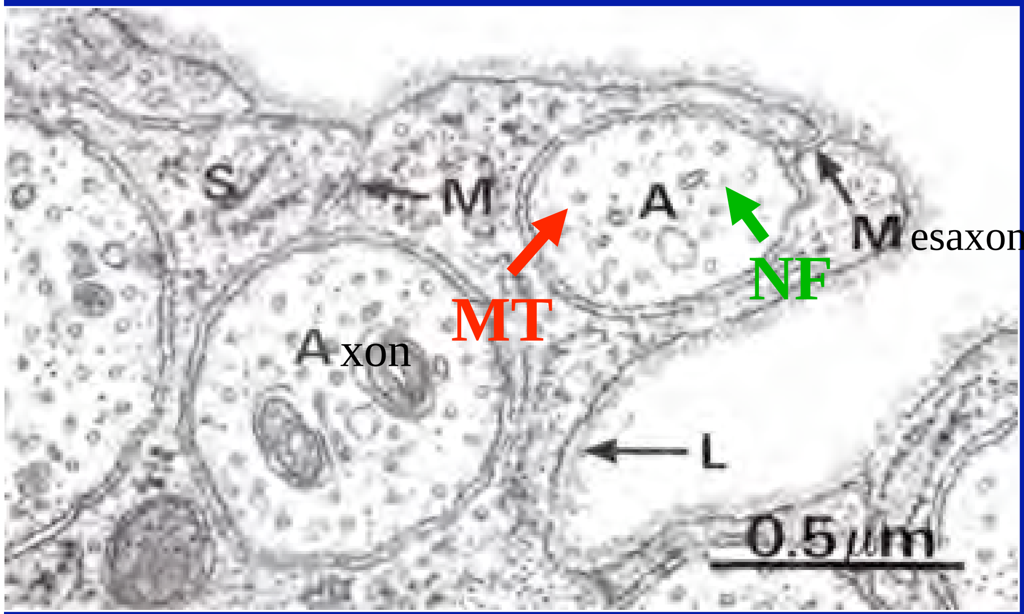


 Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9-3

Nissl substance is found in the neuronal cell body and dendrites, but not in the axon and the axon hillock or axon initial segment.

The ability of neurons to synthesize proteins at growth cones and at the presynaptic terminus is <u>very</u> limited.

How do axons grow to reach their targets and how is an adult axon maintained and supplied?

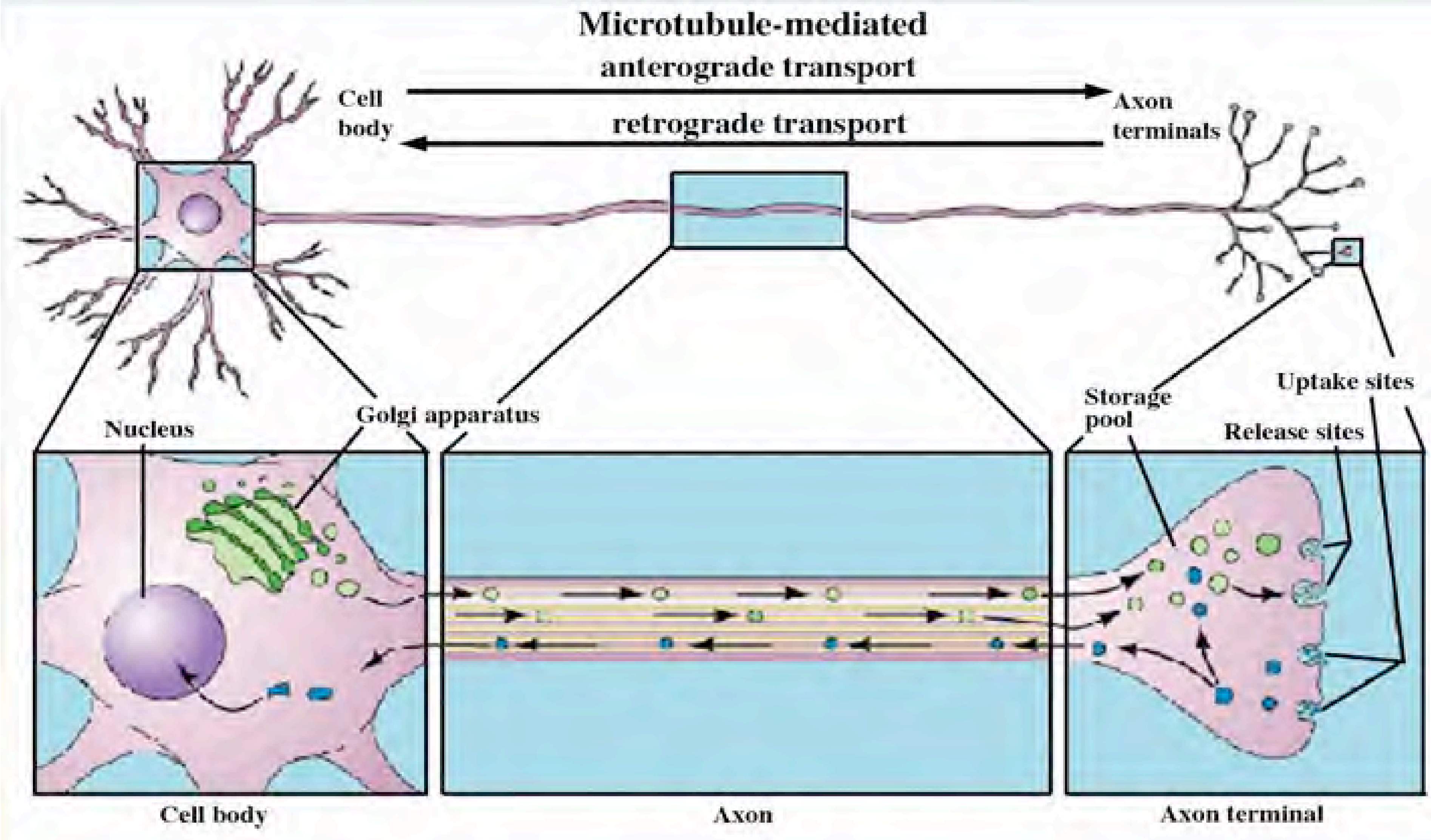


PD-INEL Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.5c

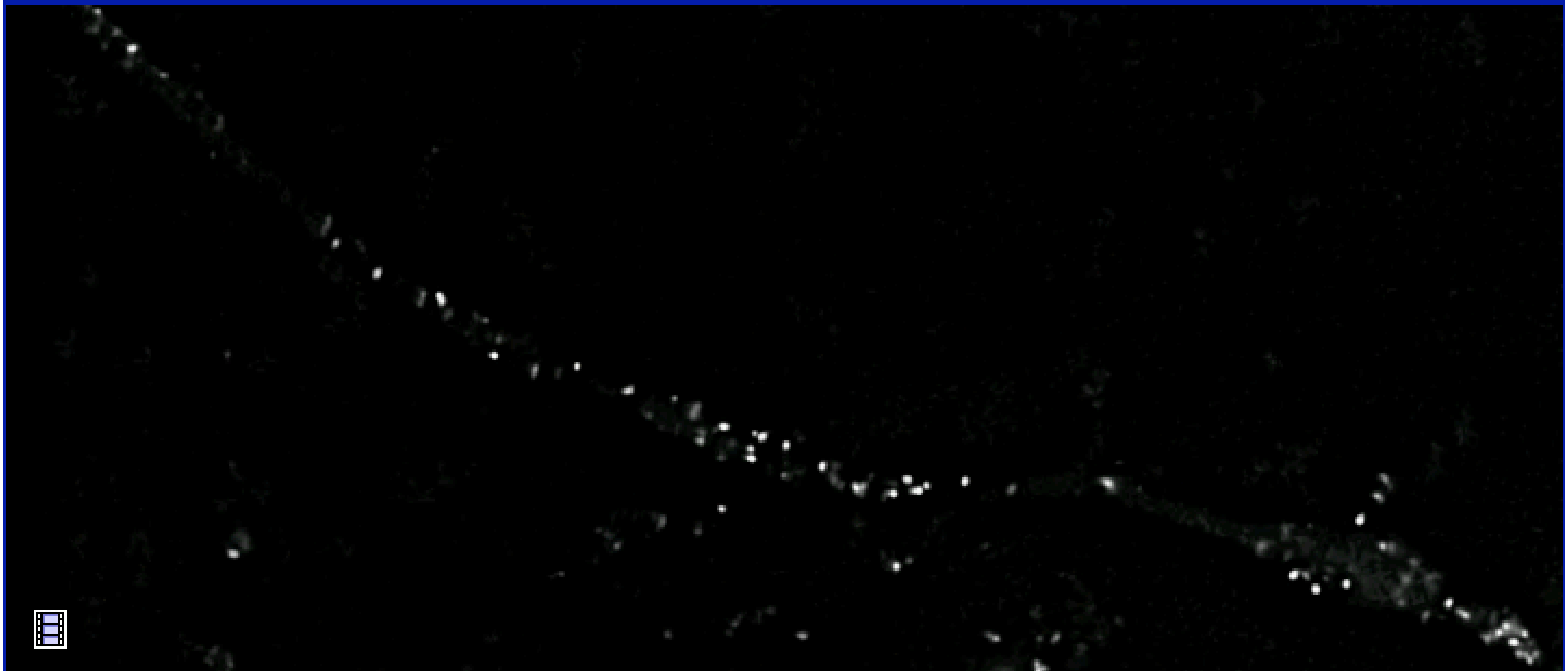
Axonal cytoskeletal elements play a central role in the two types of transport along axons. As shown in this electron micrograph, axons contain two classes of cytoskeletal elements, neurofilaments (NF), which are intermediate filaments, and microtubules (MT).

Slow axonal transport (0.2-8 mm/day) transports many proteins along the axons. The mechanism of slow axonal transport is still controversial (current Stop-Go model).

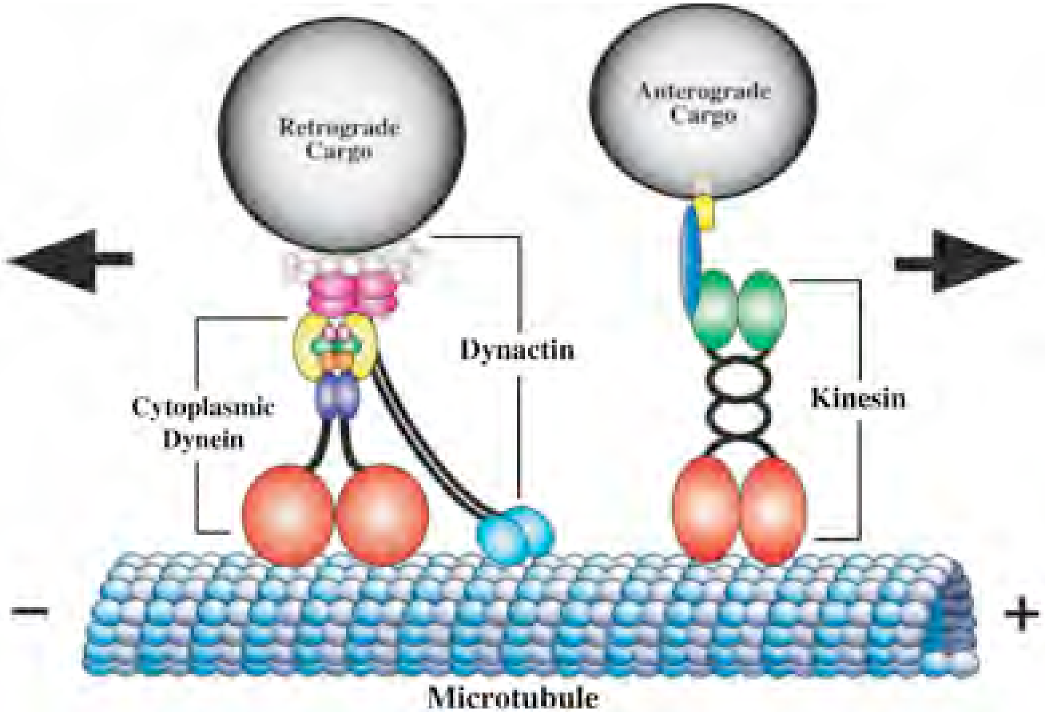
Fast axonal transport (up to 400 mm/day) is the main mechanism to move cell organelles and membrane vesicles along the axon.



Fast axonal transport goes in both directions (anterograde and retrograde) and relies on the axonal microtubule cytoskeleton.



Microtubule-mediated transport of secretory granules along the axon of a neuron. The majority of granules move toward the growth cone (anterograde transport), but some move away from the growth cone (retrograde transport). There are also some granules that reverse direction, move intermittently, or stall. In this neurite, there is a partial build up of granules in the growth cone; this build up would have become more extensive with time due to the net anterograde granule flux.



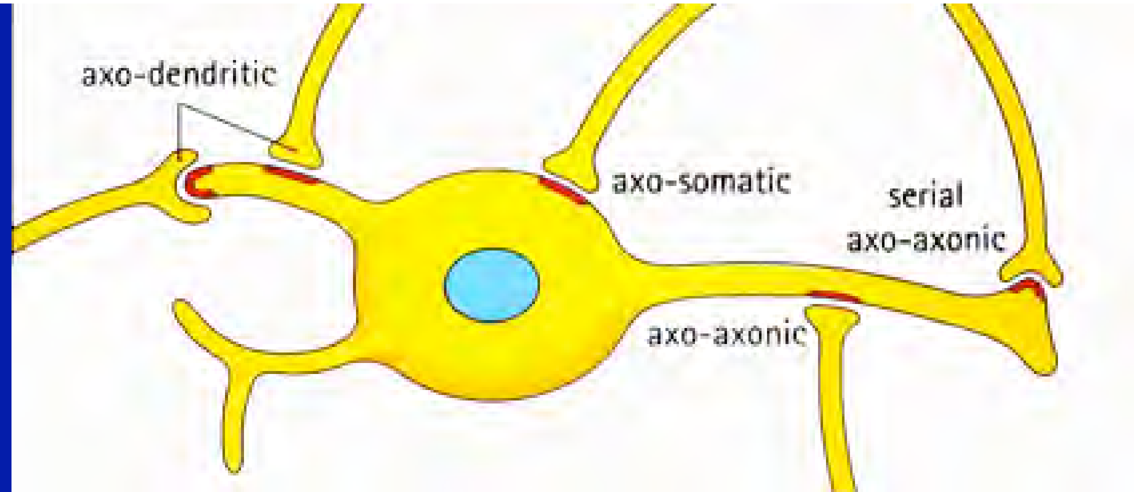
Anterograde microtubule-mediated transport is mediated by kinesins and retrograde transport by dyneins.
The microtubule-mediated transport enables the tip of an axon to grow during development and to regeneration. During this time is referred to as a growth cone.

Once a growth cone reaches its target, it might form synapses with its target cell. Synapses are predominantly supplied and maintained by fast, microtubule-mediated transport.

Snail growth cone stained for actin and microtubules.

Drosophila growth cone

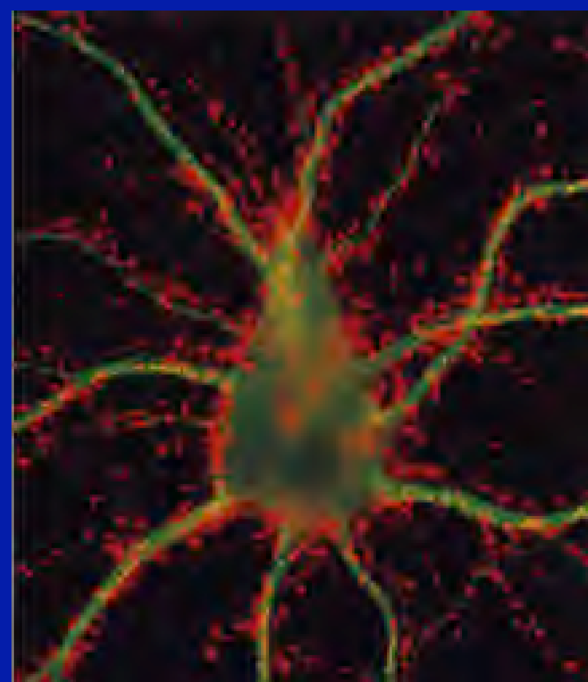
Synapses can form between many different parts of neurons and between a neuron and a non-neuronal cell, e.g., a muscle or a secretory cell.



 Human Histology, 2nd edition, Stevens and Lowe, Mosby ; Fig 6.7

Images of synapses and motor neuron cell body in spinal cord removed

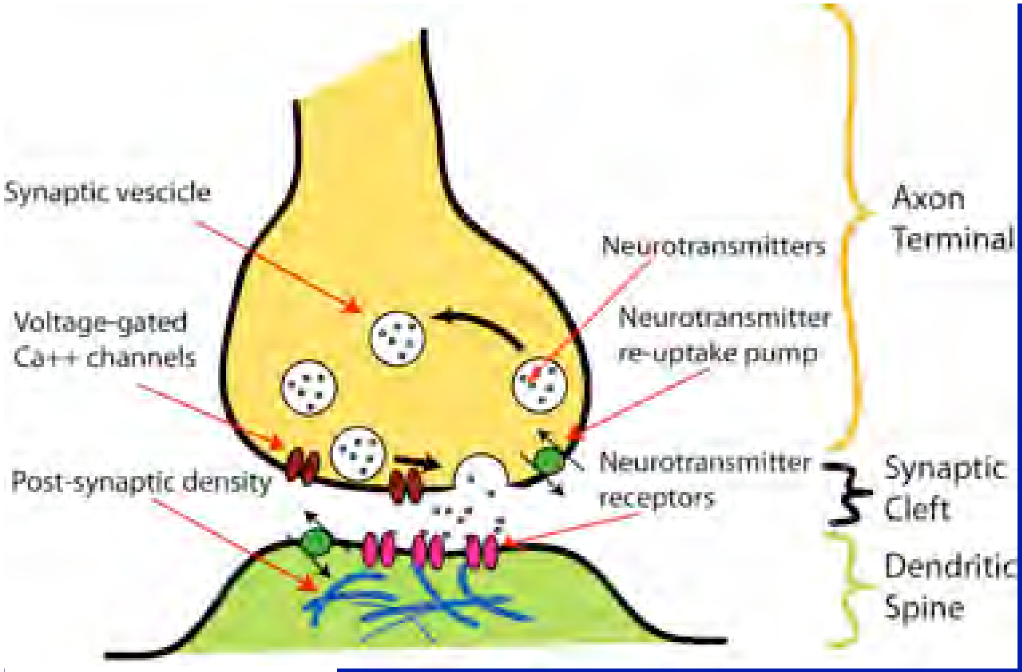
Source of Removed Image: The Molecular Biology of the Cell by B. Alberts et al., 4th edition, 2002, Garland Science
Fig. 11-38 A



A single neuron can receive activating or inhibiting inputs from thousands of synaptic connections.

Panel B courtesy of Olaf Mundigl and Pietro de Camilli in
The Molecular Biology of the Cell by B. Alberts et al., 4th edition, 2002, Garland Science

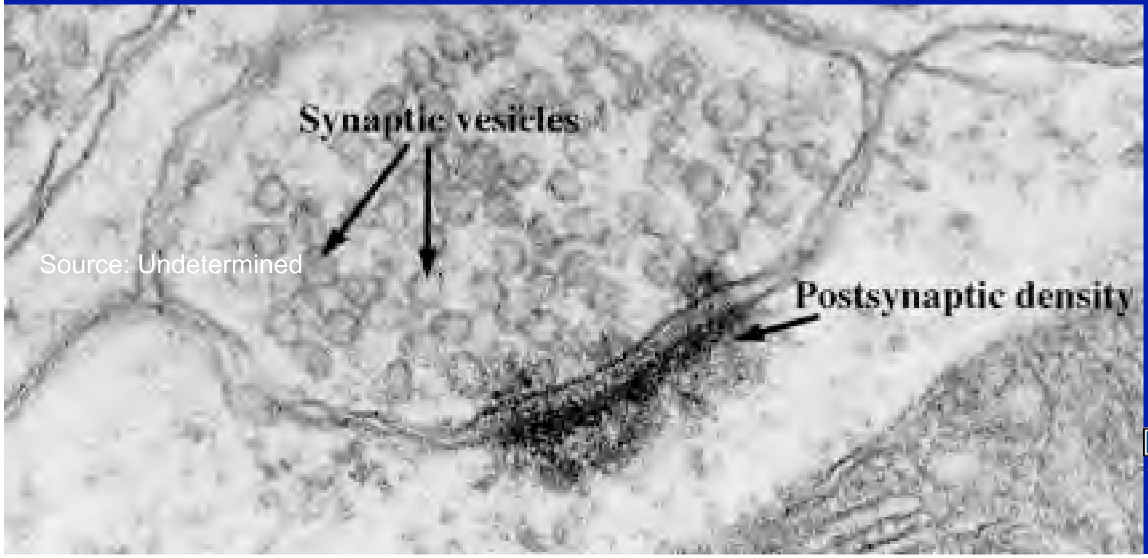
Motor neuron cell body in the spinal cord



Wikipedia

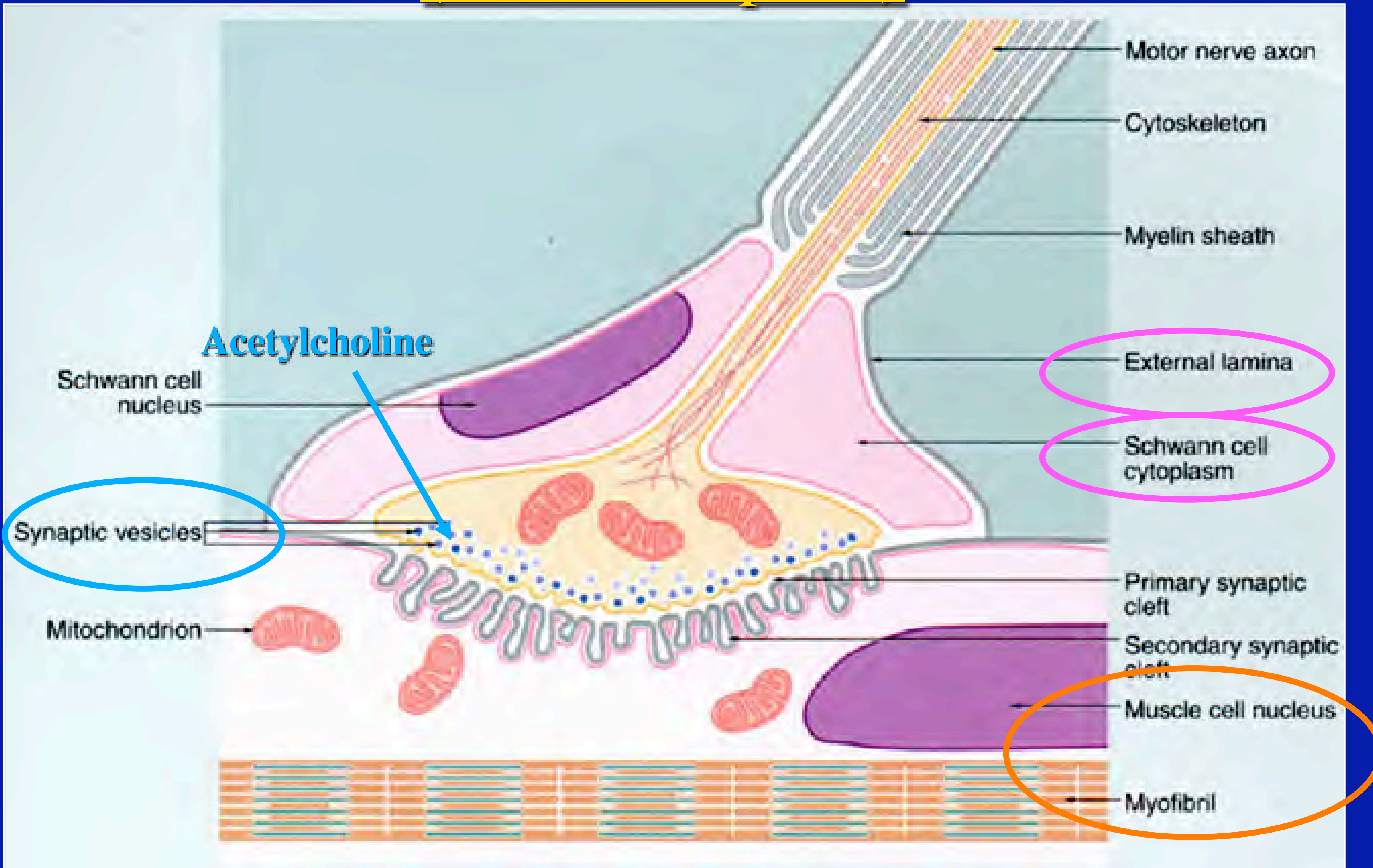
ORIGINAL TOP IMAGE Diagram of synapse downloaded from http://fantastrid.googlepages.com/anatomydrawings by Astrid Vincent Andersen
Web page http://fantastrid.googlepages.com/homedk

At a chemical synapse neurotransmitter release is triggered by the influx of Ca^{2+} and postsynaptic neurotransmitter receptors receive the signal.

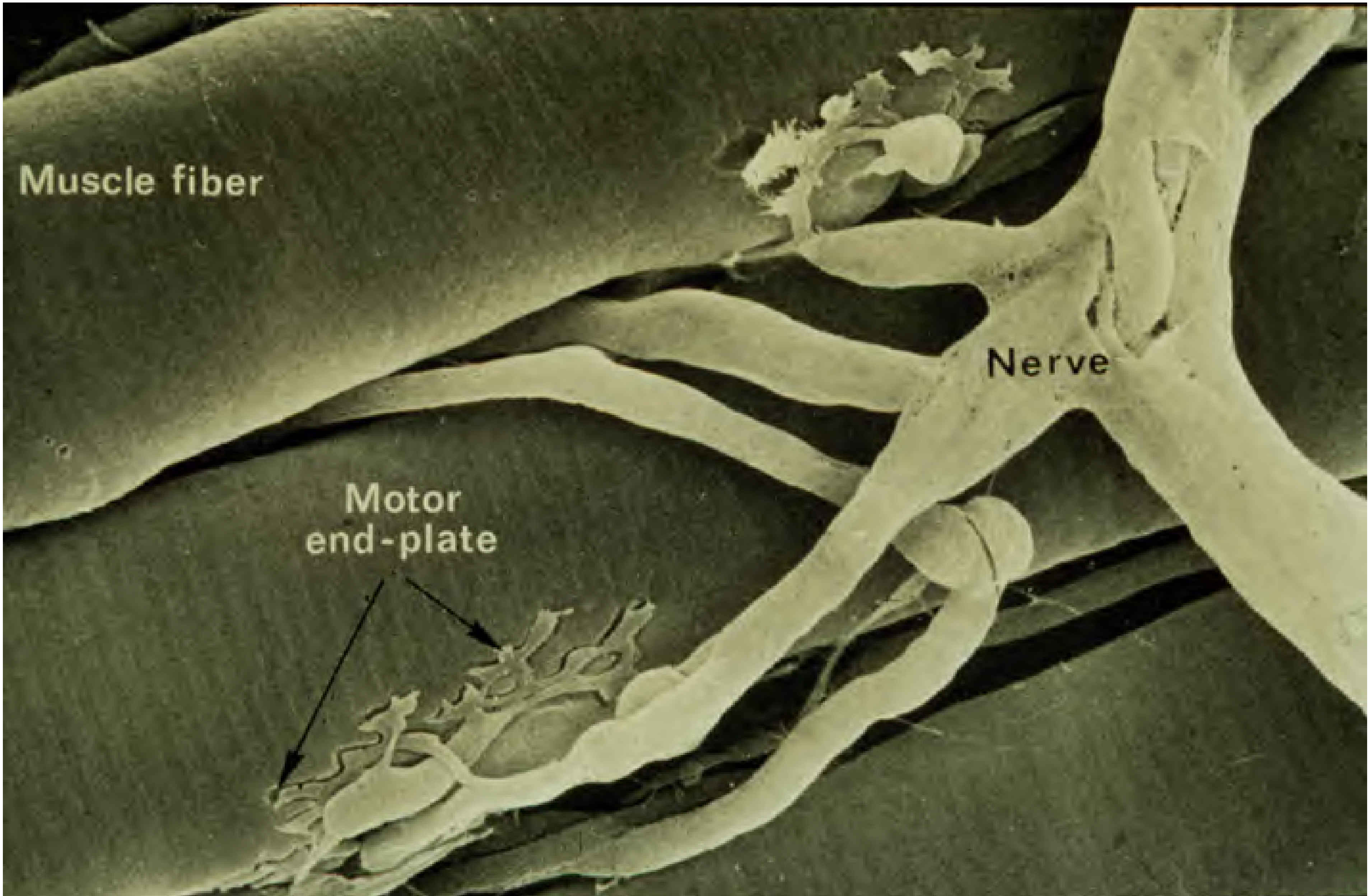


Cell and Tissue Ultrastructure – A Functional Perspective by Cross and Mercer; 1993; Freeman and Co. Page 135

Neuromuscular junction (motor endplate)



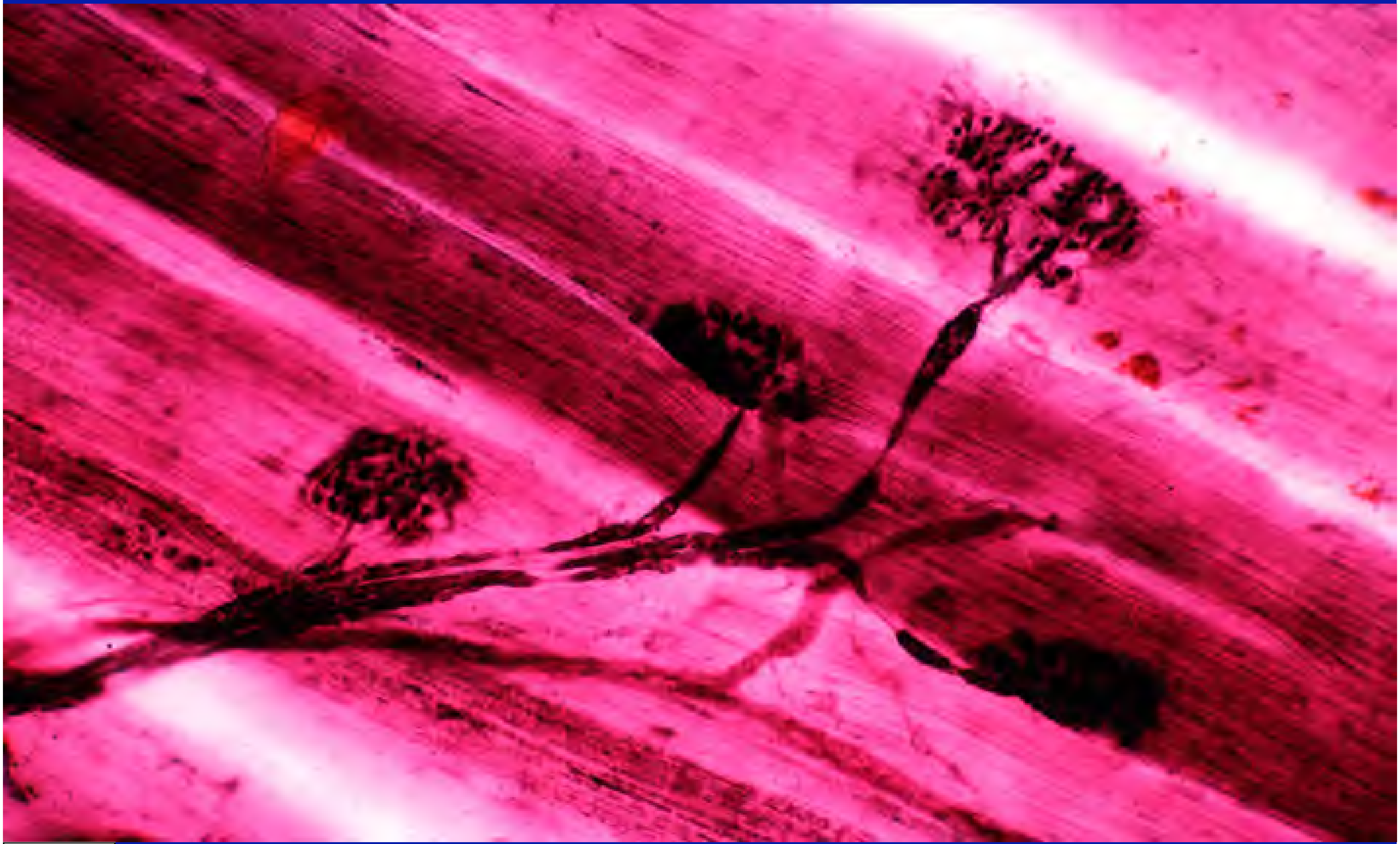
PD-INEL Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.12a



 Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 8-18

Scanning EM of motor endplate on a muscle fiber

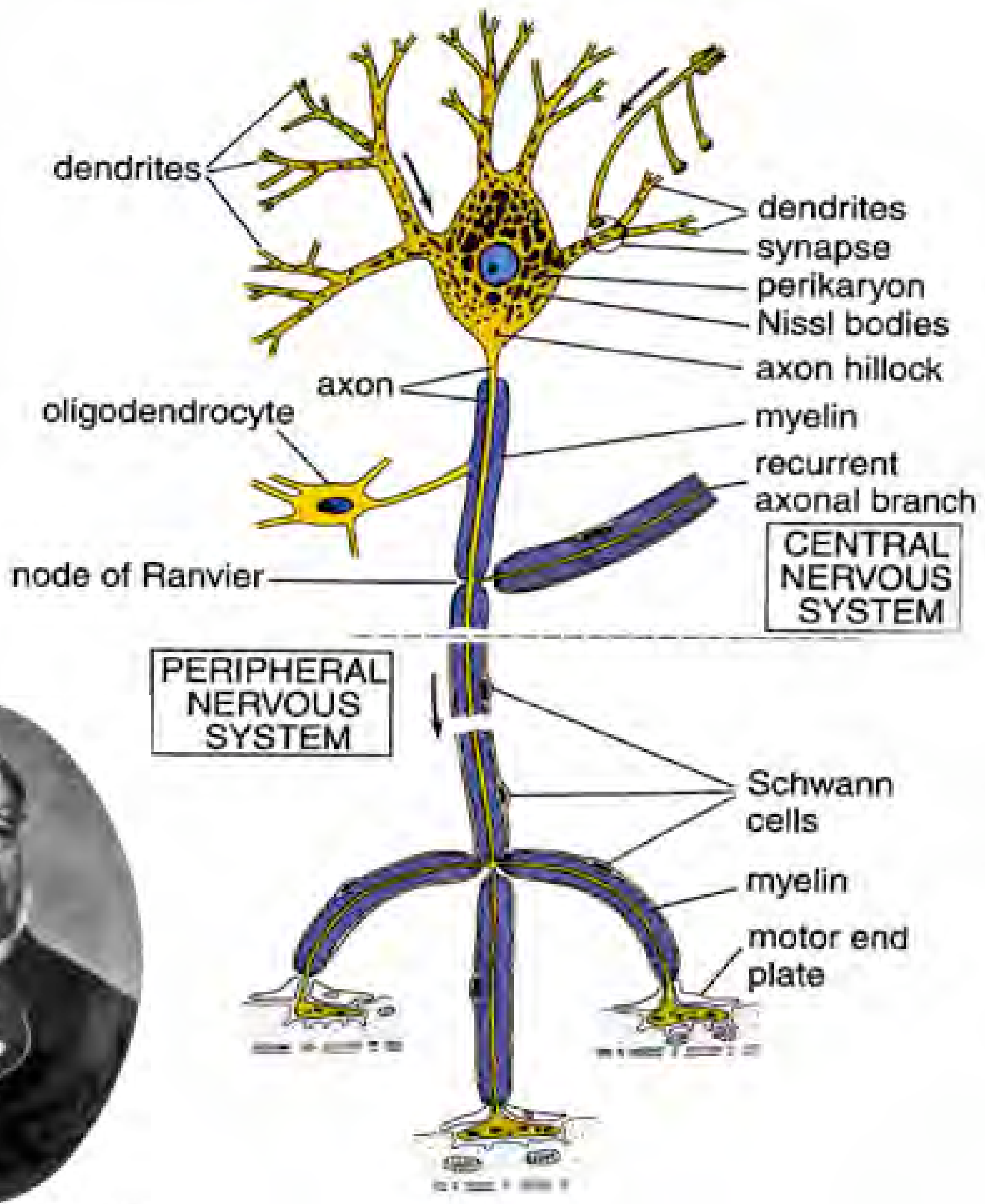
Motor endplates on skeletal muscle fibers

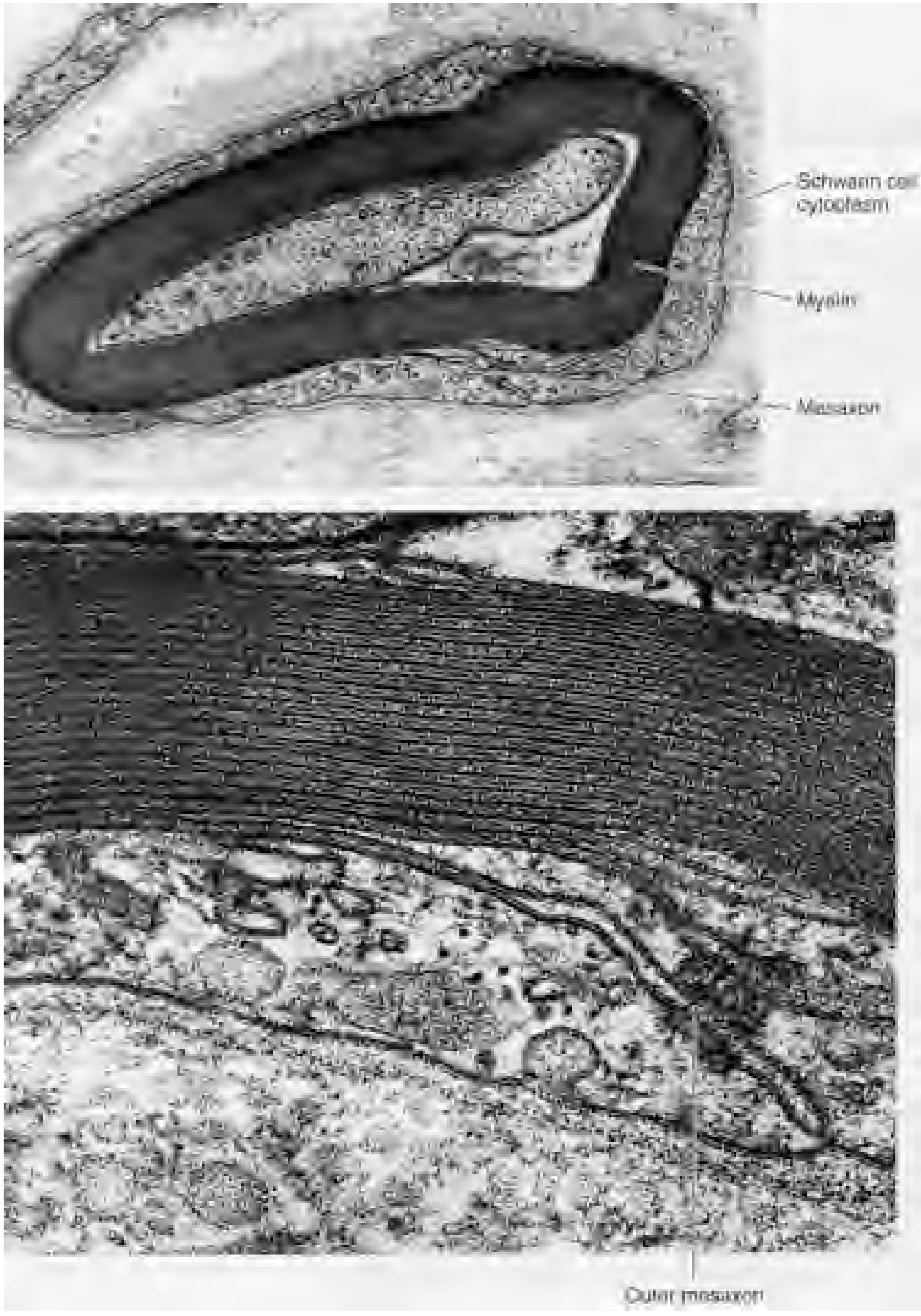


 Photograph by AK Christensen from slide by Ray Truex, Dept of Anatomy, Temple Univ. School of Medicine

Myelination in the CNS involves oligodendrocytes and Schwann cells in the PNS

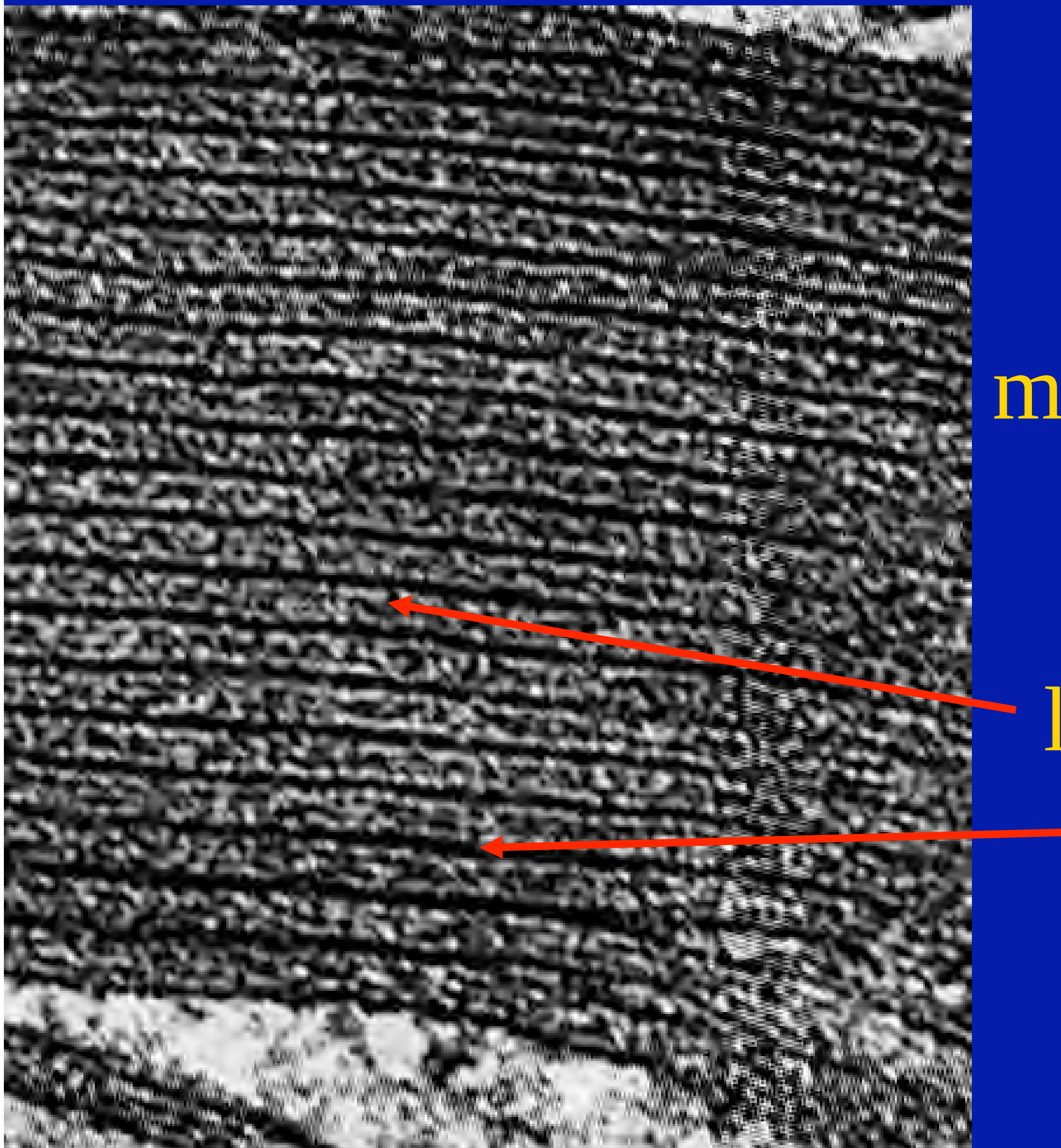
Theodor Schwann (1810-1882)





This electron micrograph of a single myelinated axon shows a series of lighter (intraperiod) and darker (major dense) lines

 Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-30



PD-INEL Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-30

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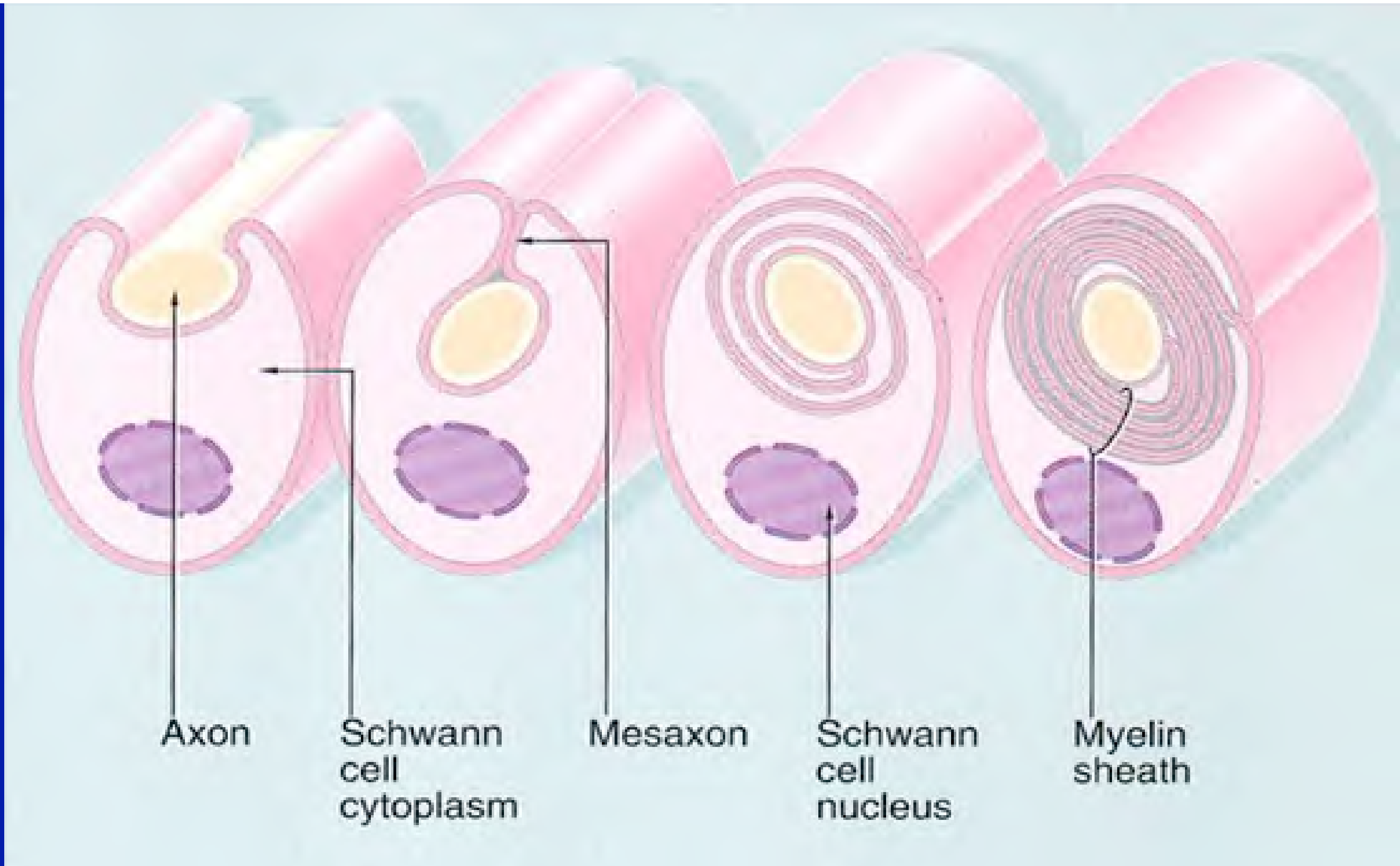
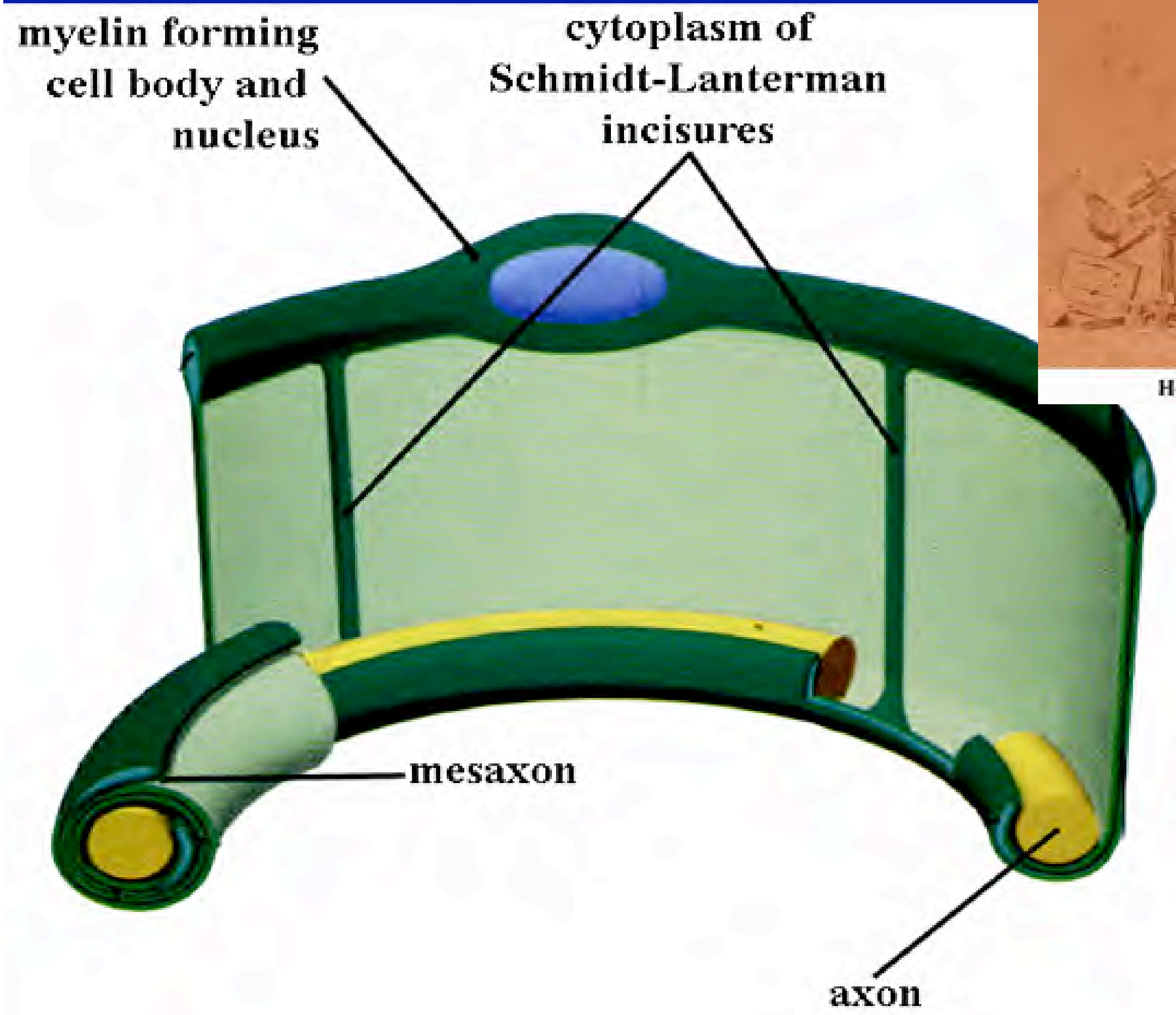


 Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.6a

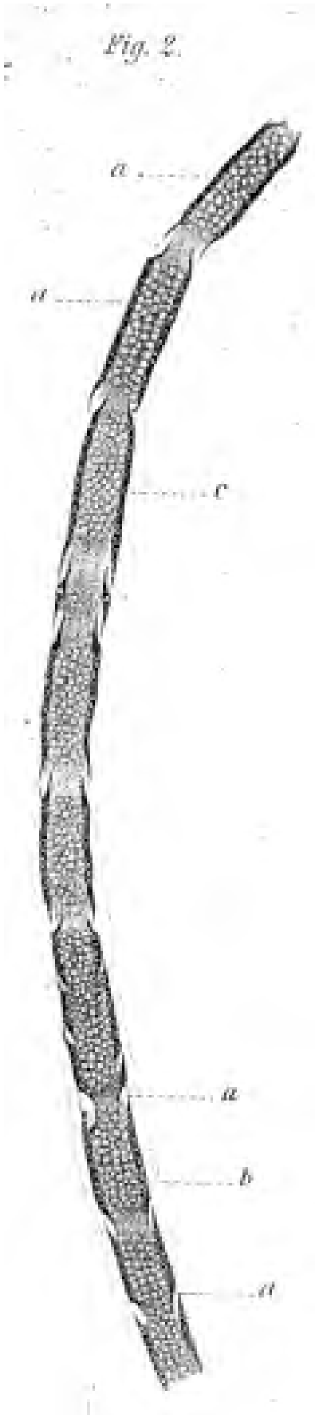
Myelination is a dynamic process, which involves the ensheathment of the the axon by the glial cell and subsequently the extrusion of cytoplasm from parts of the glial cell. Adhesive proteins on the cytoplasmic and the extracellular side of the plasma membrane contribute to a tight apposition of the lipid bilayers.

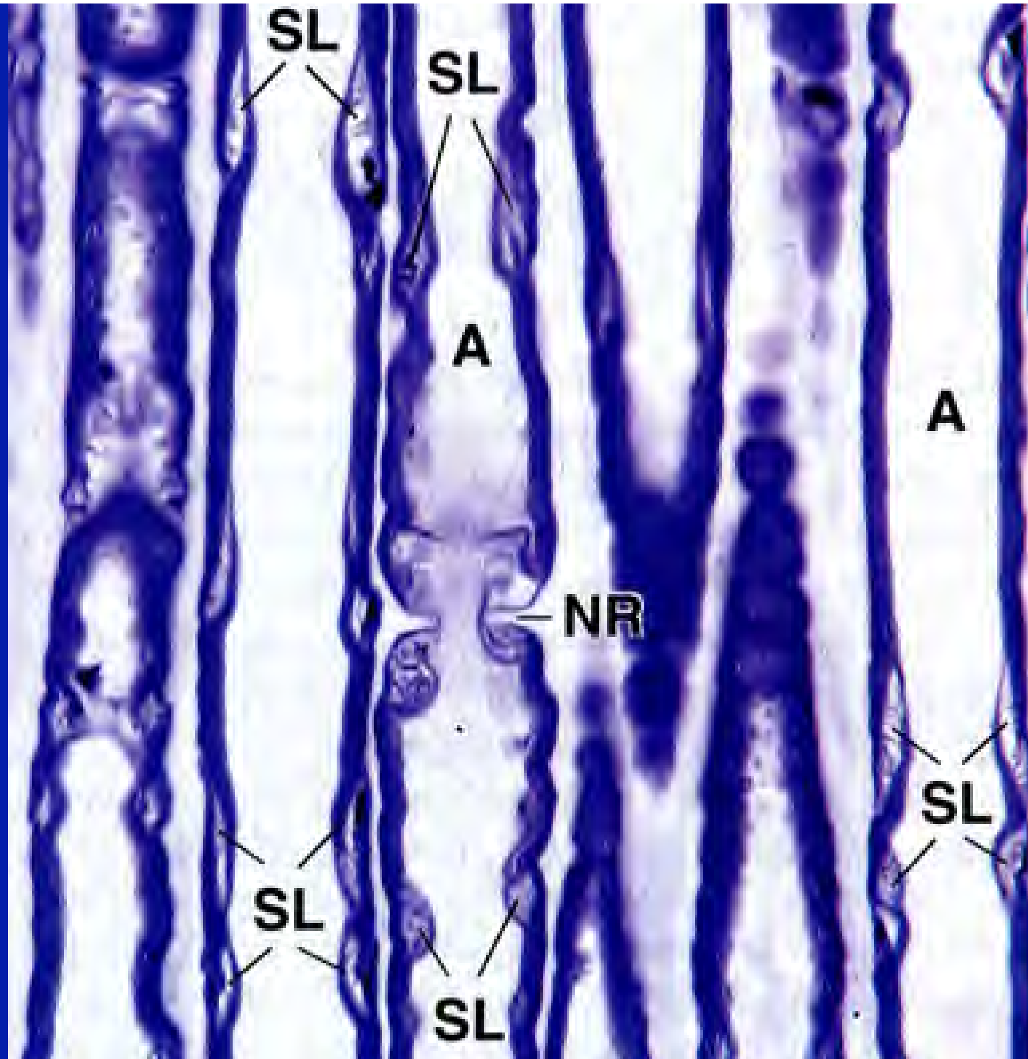
Original Image:
Histology-A Text and Atlas by M.H. Ross and W. Pawlina; 5th edition, 2006, Lippincott Williams and Wilkins, Fig 12.11



Henry D. Schmidt (1823-1888)

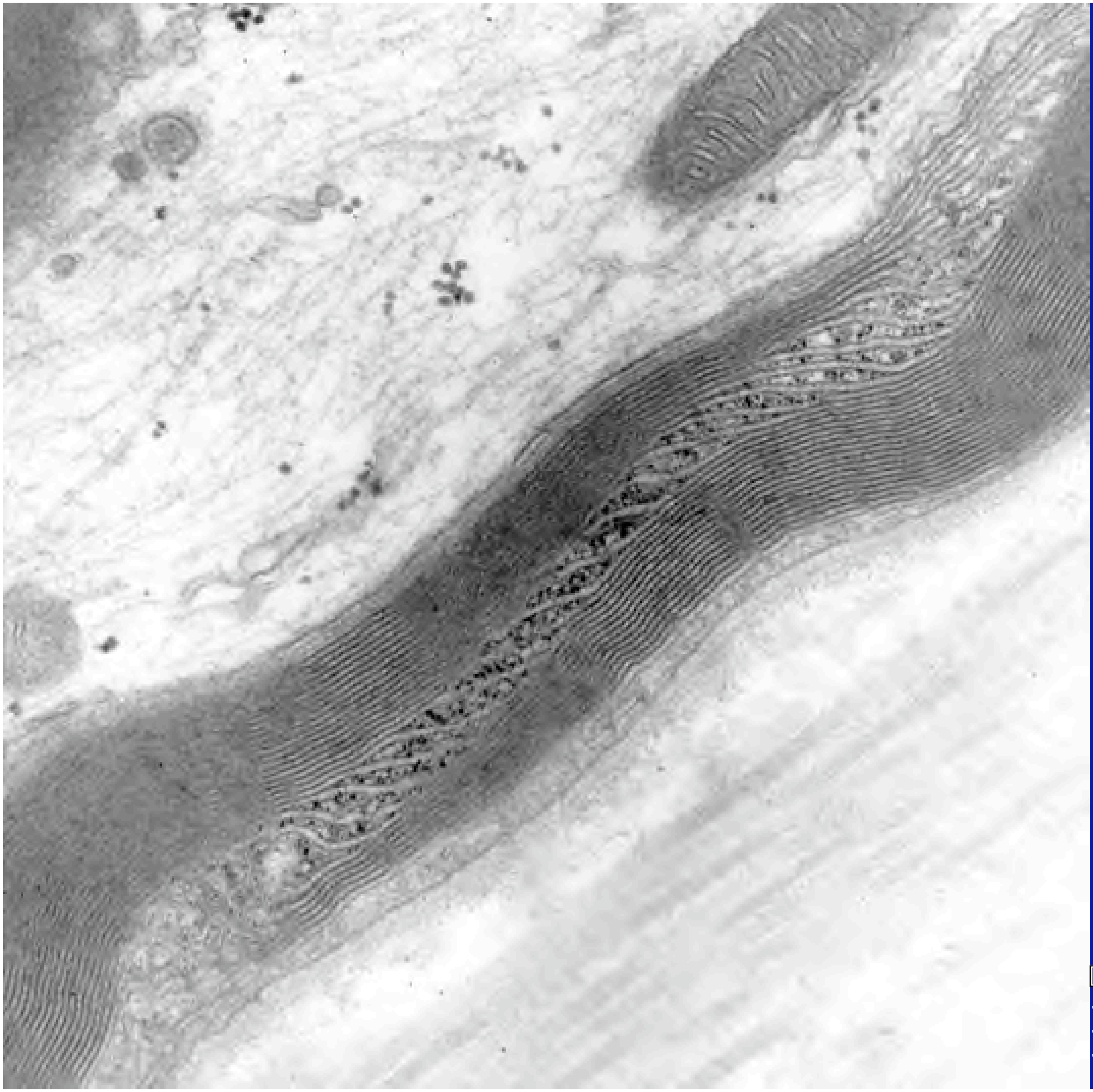
Some residual cytoplasm remains in special parts of the myelin sheath





Toluidine-stained peripheral nerve. A = axon; NR = node of Ranvier; SL = clefts of Schmidt-Lanterman

Schmidt-Lanterman incisures (or clefts) are one type of cytoplasmic remnant, which are believed to be important for the maintenance of the myelin sheet.

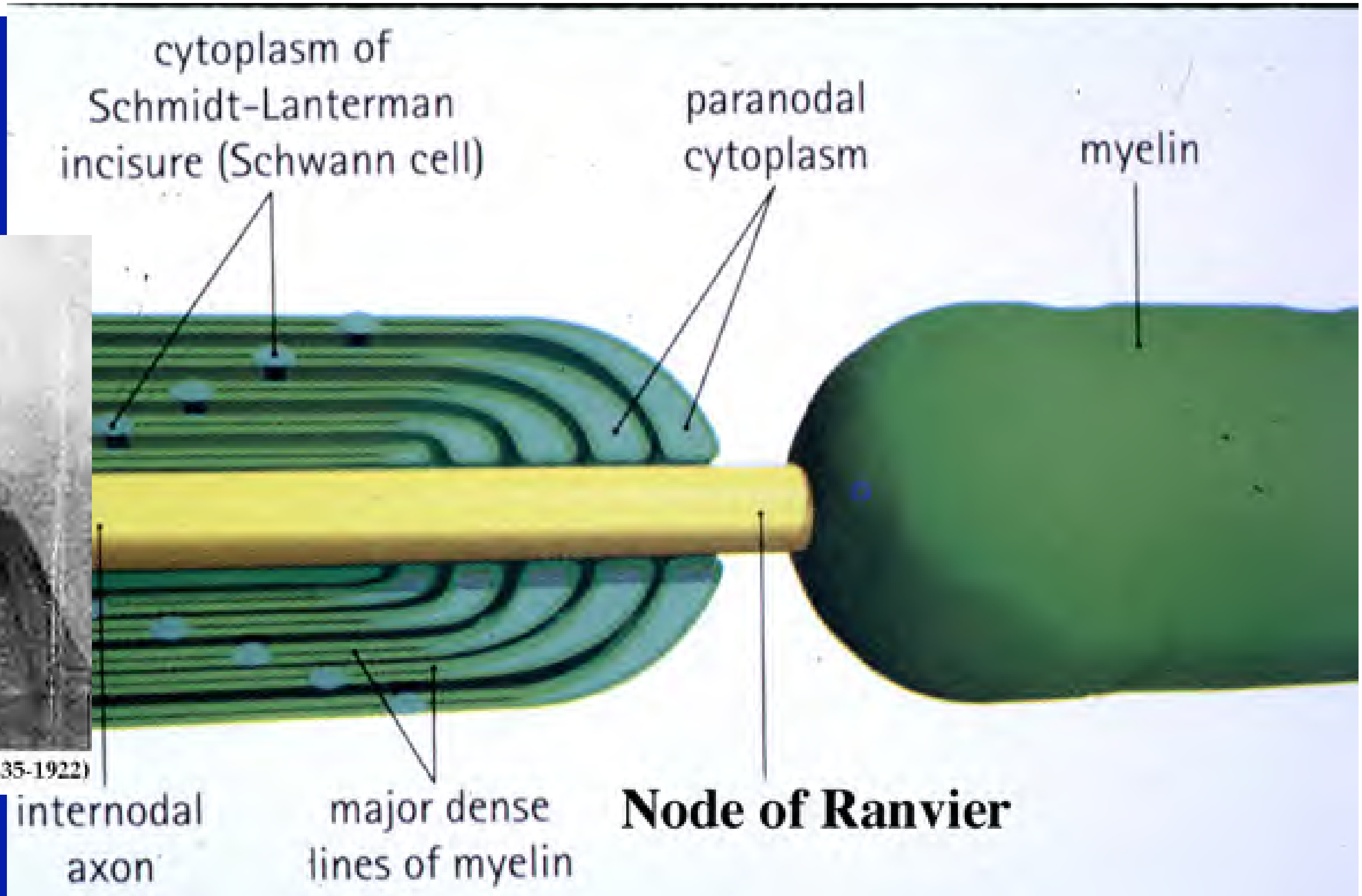


Schmidt-Lanterman incisures (or clefts) are one type of cytoplasmic remnant, which are believed to be important for the maintenance of the myelin sheet.

Electron micrograph of a Schmidt-Lanterman incisure

Service De Neurologie, Hôpital Universitaire Dupuytren, Limoges, France

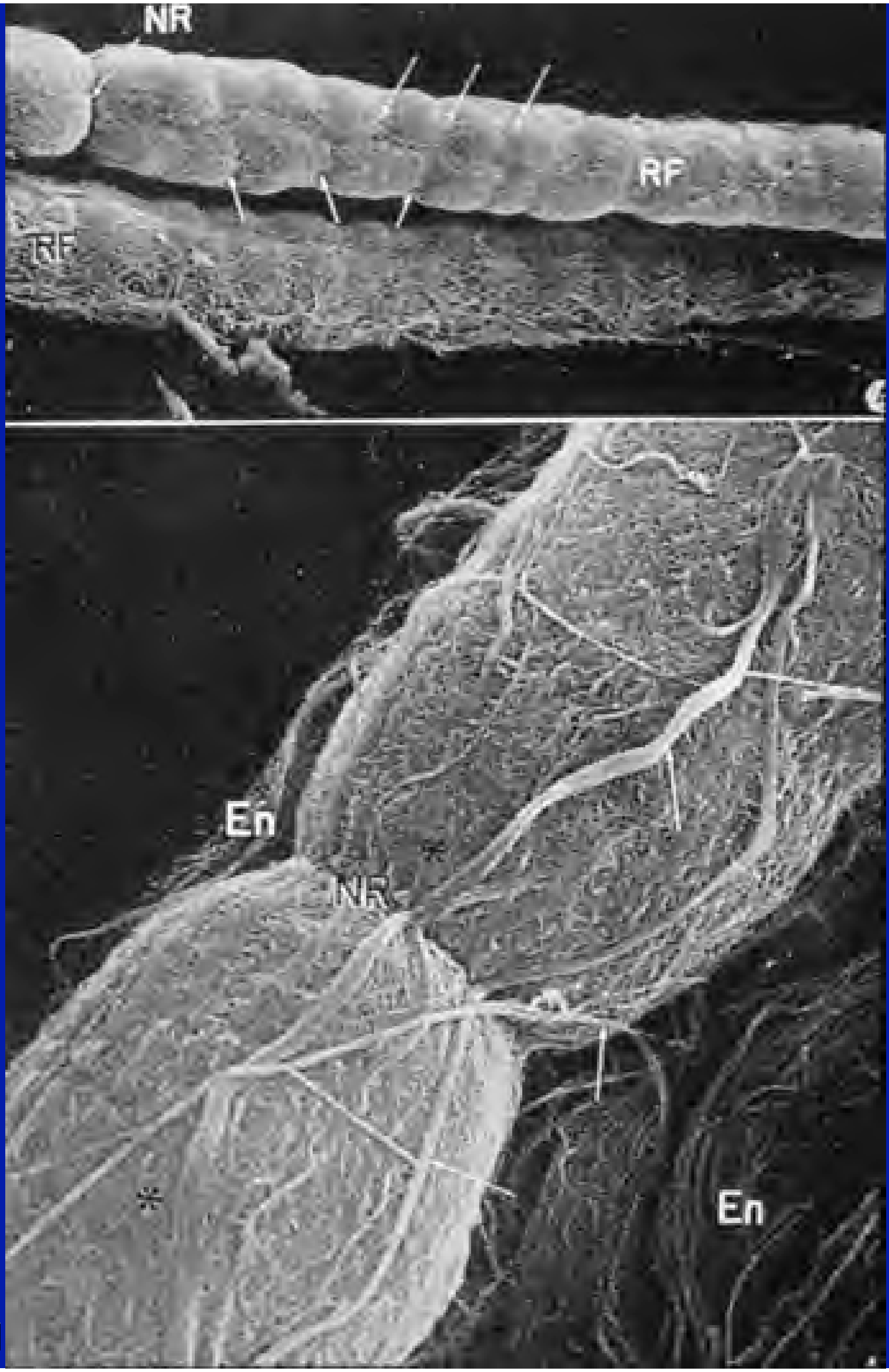
Louis-Antoine Ranvier (1835-1922)



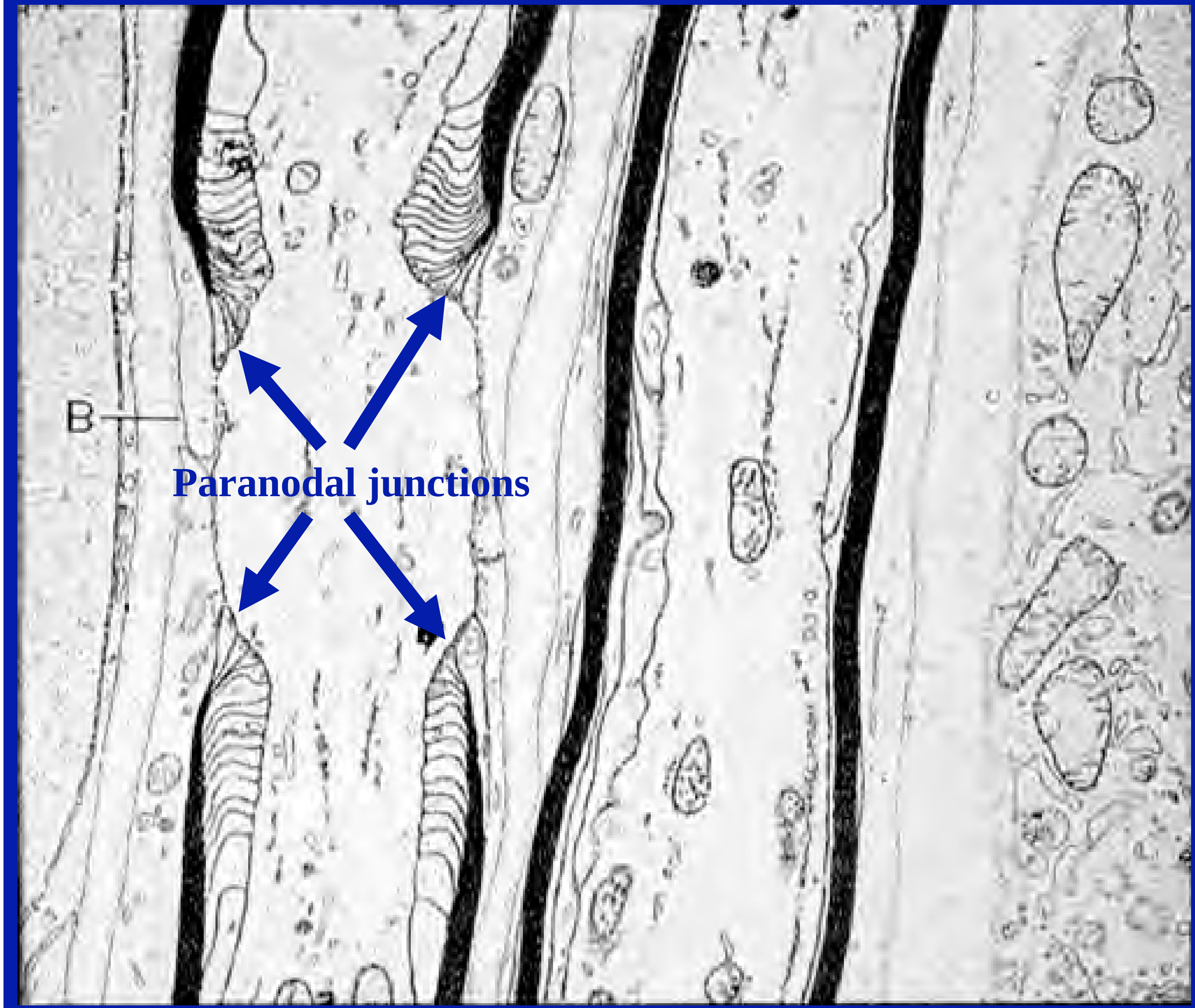
 Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6.10

Nodes of Ranvier are areas of the myelinated axon that are not covered by the myelin sheath. They are bordered by paranodal regions, which form paranodal junctions with the axonal plasma membrane and also retain some Schwann cell cytoplasm.

Scanning EMs depicting nodes of Ranvier



Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9-15

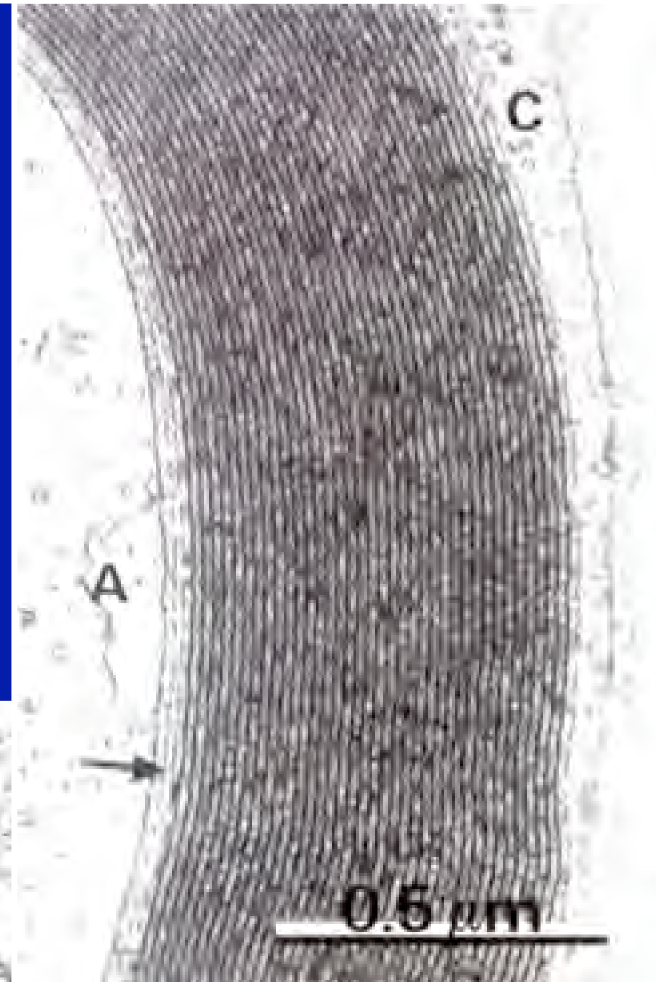


 Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9.14

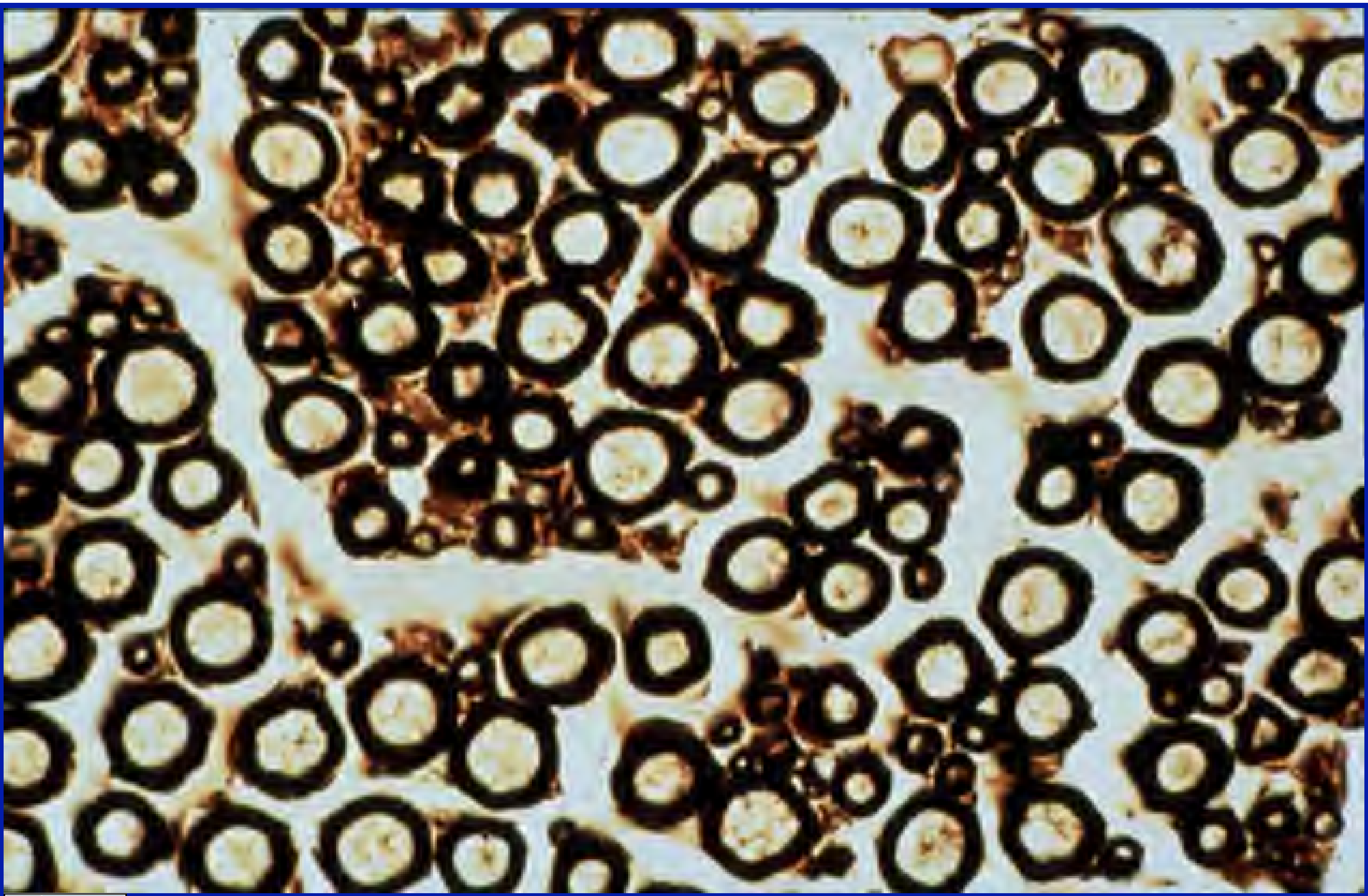
Transmission EM with node of Ranvier and paranodal region

Myelinated Nerve Fiber

The increased lipid content of the myelin sheath provides electrical insulation for the underlying axon.

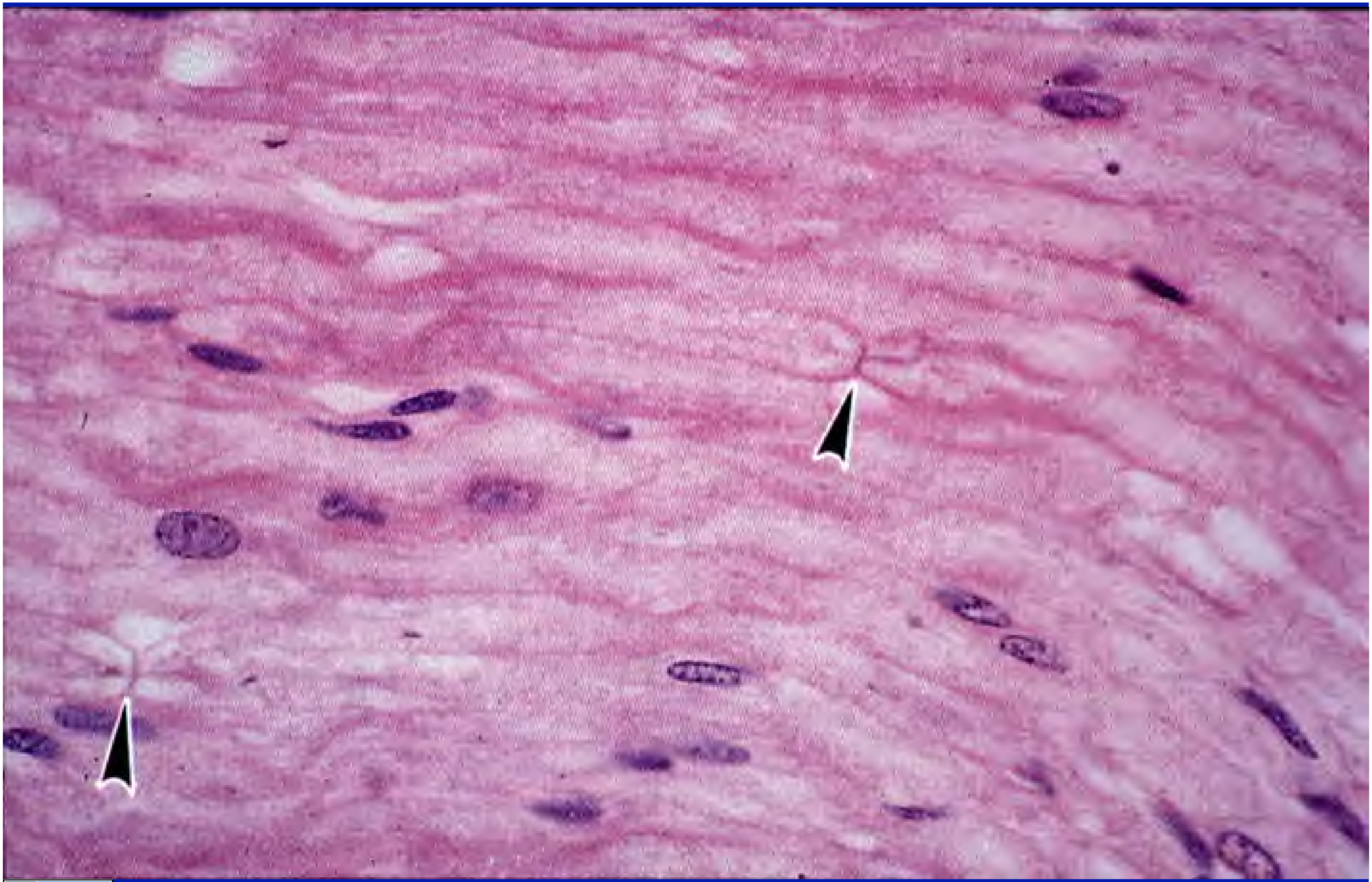


 Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig. 7.6
A, axon; S, Schwann cell nucleus.



PD-INEL Japanese Kodachrome slide set, Slide 1084

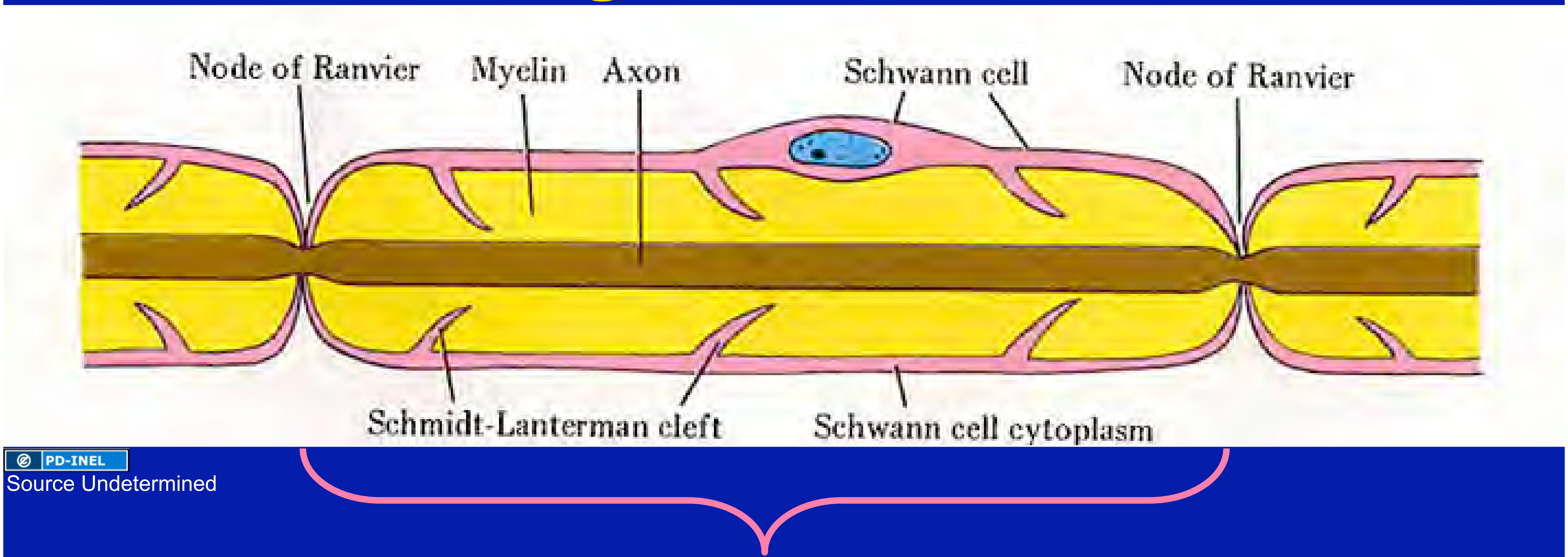
Silver-stained cross section of a myelinated nerve



PD-INEL Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9-13

Nodes of Ranvier in a longitudinal nerve section

Each Schwann cell myelinates a single internode



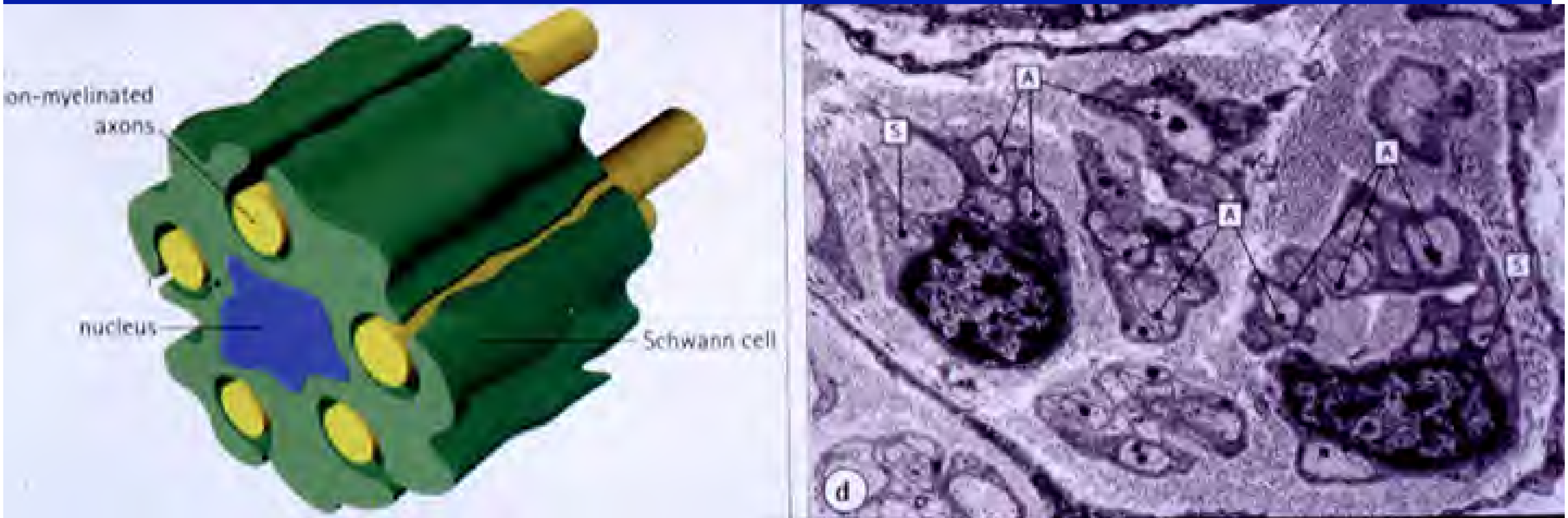
Internode length can be up to 1.5 mm in the largest nerve fibers

Diagram of myelinated axon and action potential propagation removed

Original Source Removed
Modified from
Neuroscience by D. Purves et al., 2001, 2nd ed., Sinauer
Fig. 3.13

Ion channels are concentrated at the nodes of Ranvier and the myelin sheath acts as an electrical insulator. This allows for saltatory conductance of the action potential and increases the transmission speed of the nerve impuls.

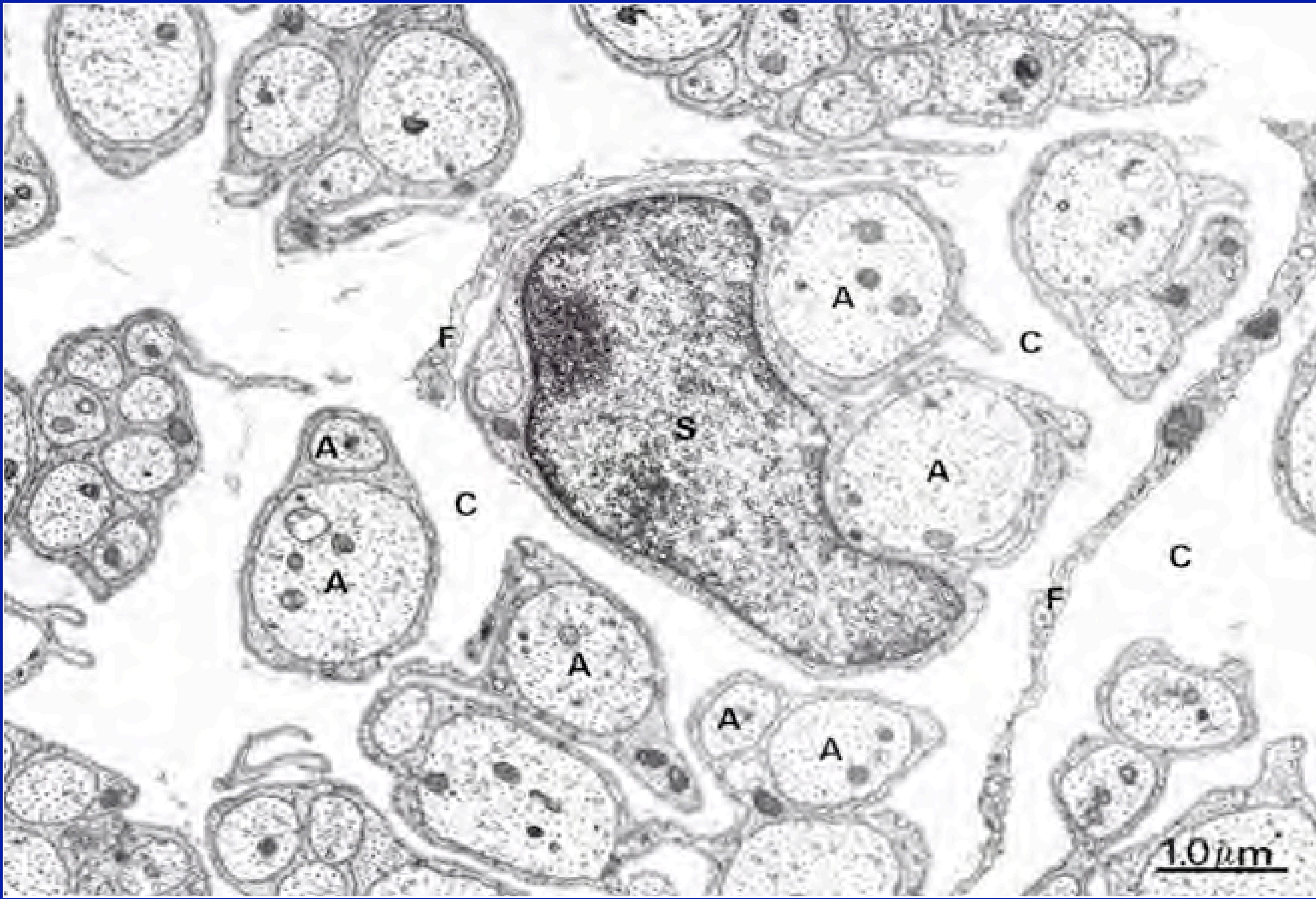
Depending on the diameter of the axon, myelination increases the action potential speed approximately 5 to 50fold (up to >110 m/sec).



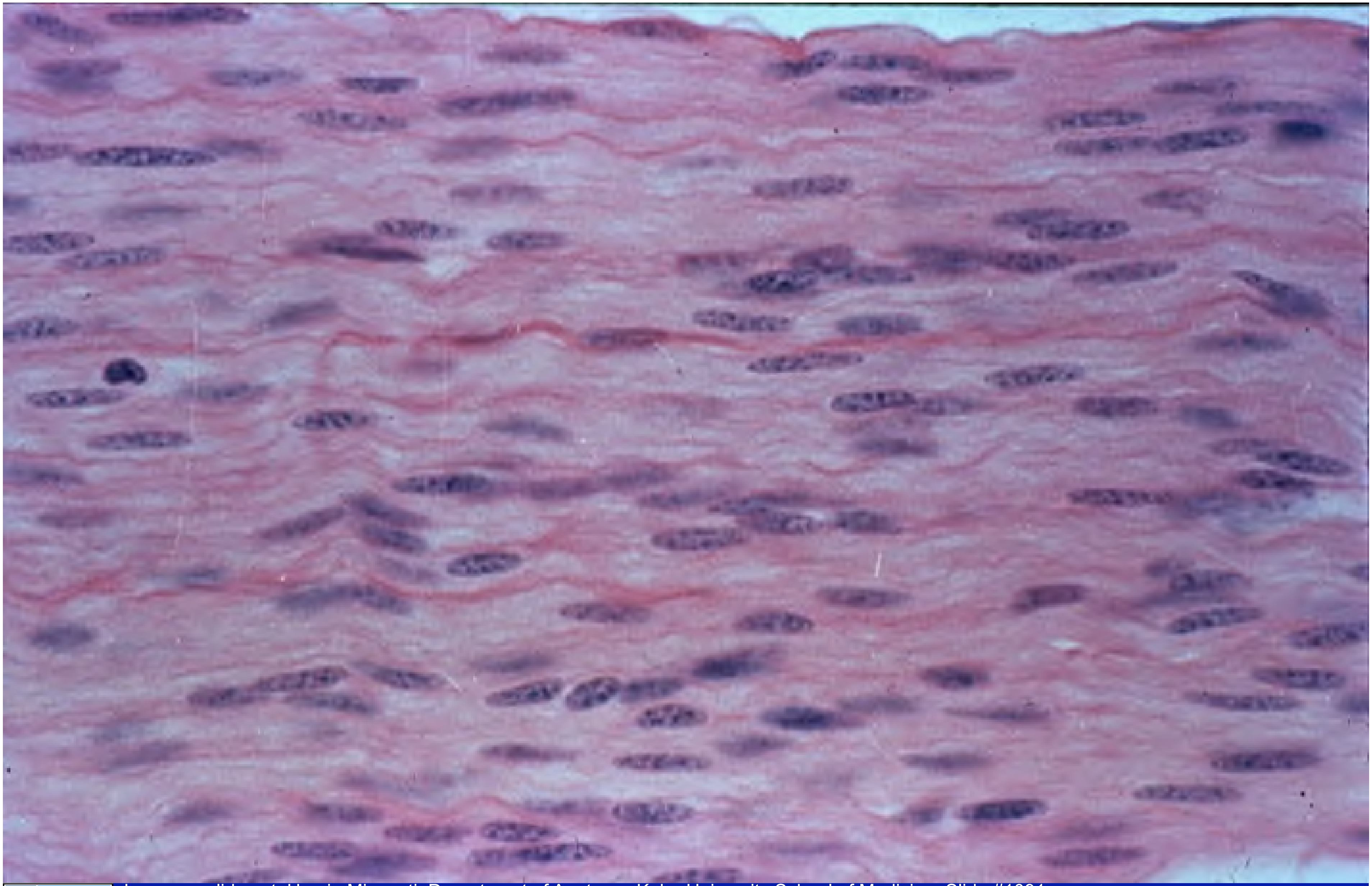
 Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6-21

One Schwann cell can ensheath multiple axons, but myelinates only one axon

Small diameter nerve fibers are non-myelinated

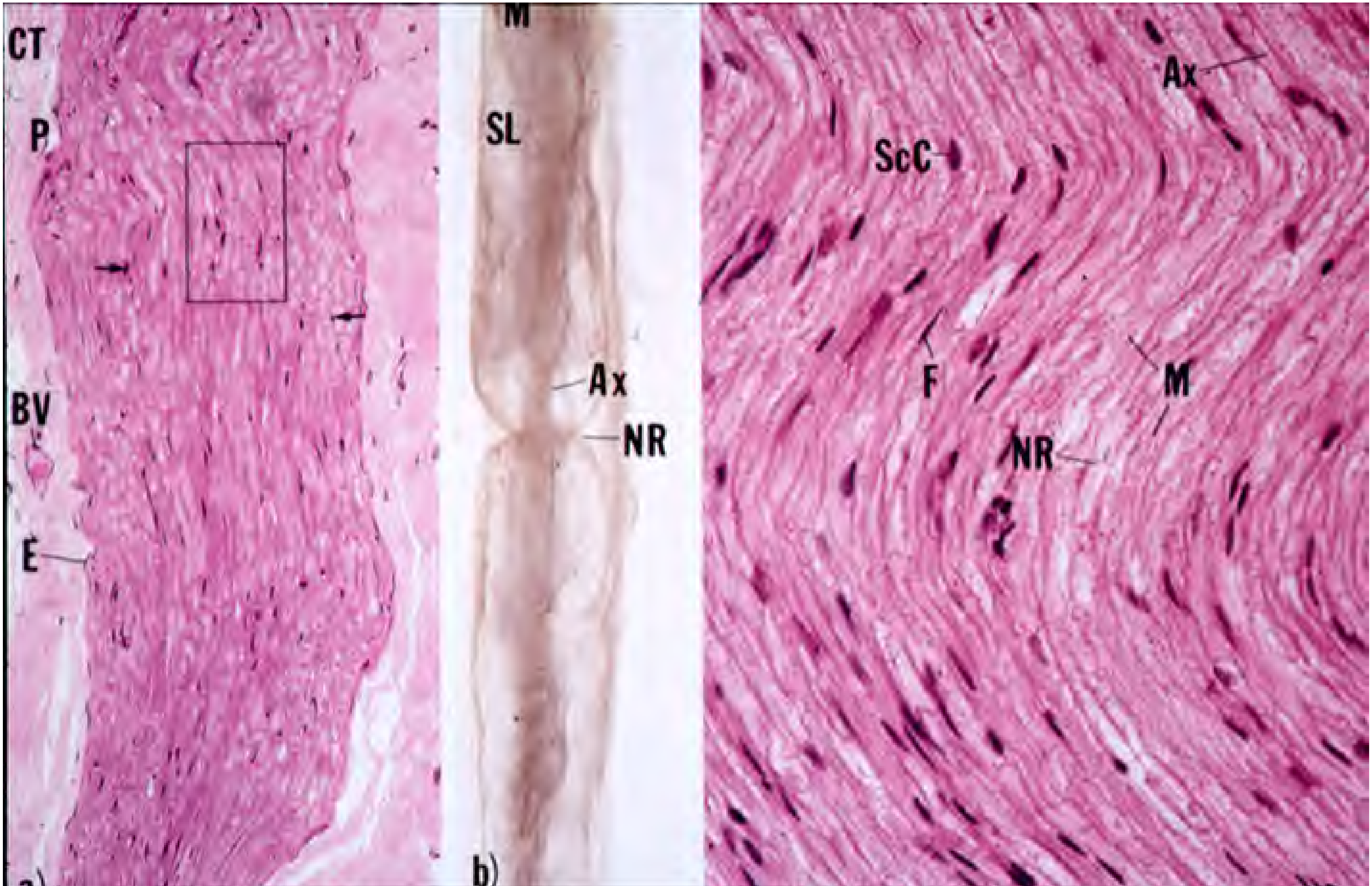


 Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.5b



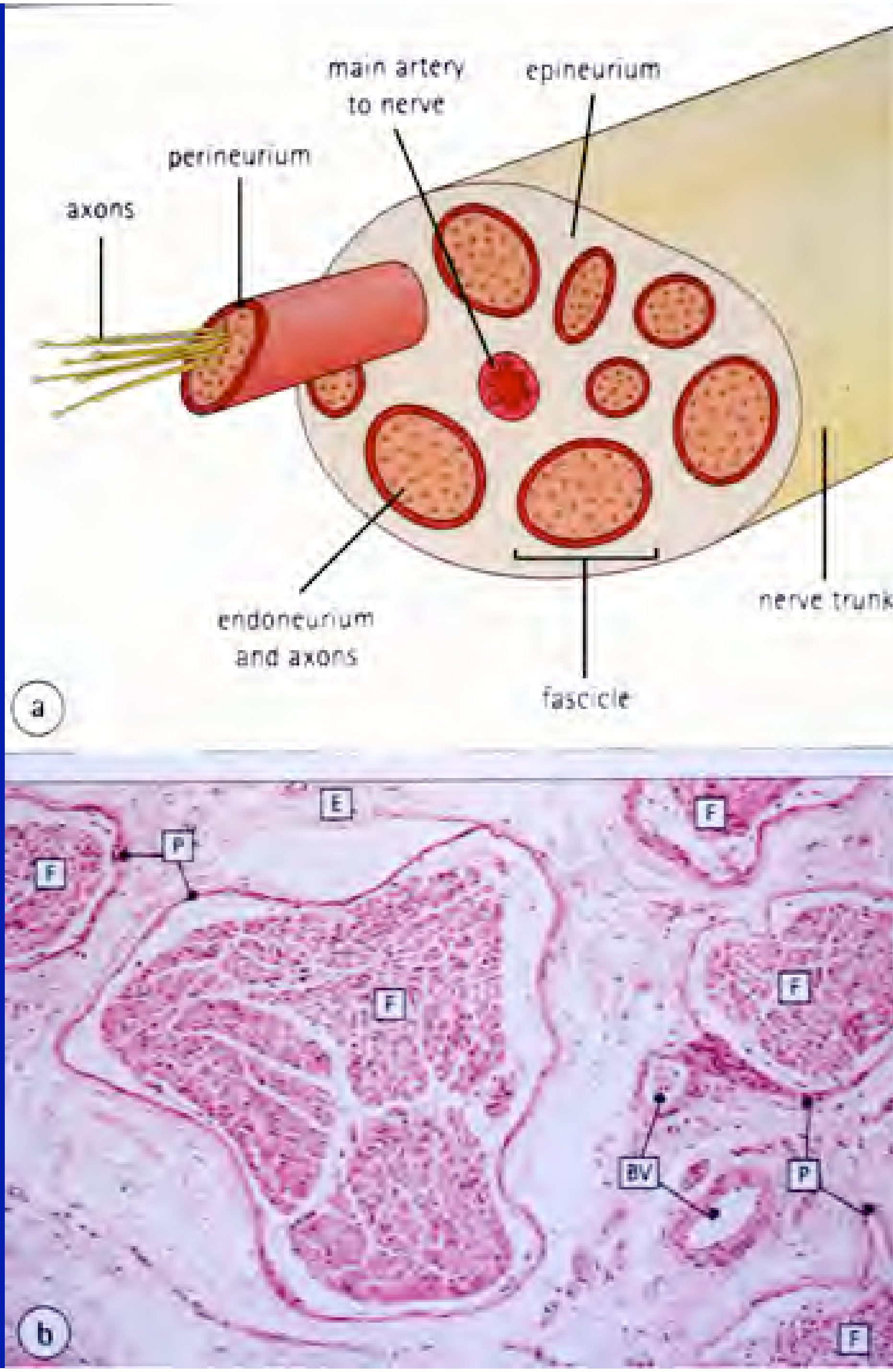
 Japanese slide set, Humio Mizoguti, Department of Anatomy, Kobe University School of Medicine, Slide #1091

Longitudinal section of an unmyelinated nerve



 Color Textbook of Histology; 2nd edition, 1994; Gartner and Hiatt; Williams and Wilkins; Fig 7.5

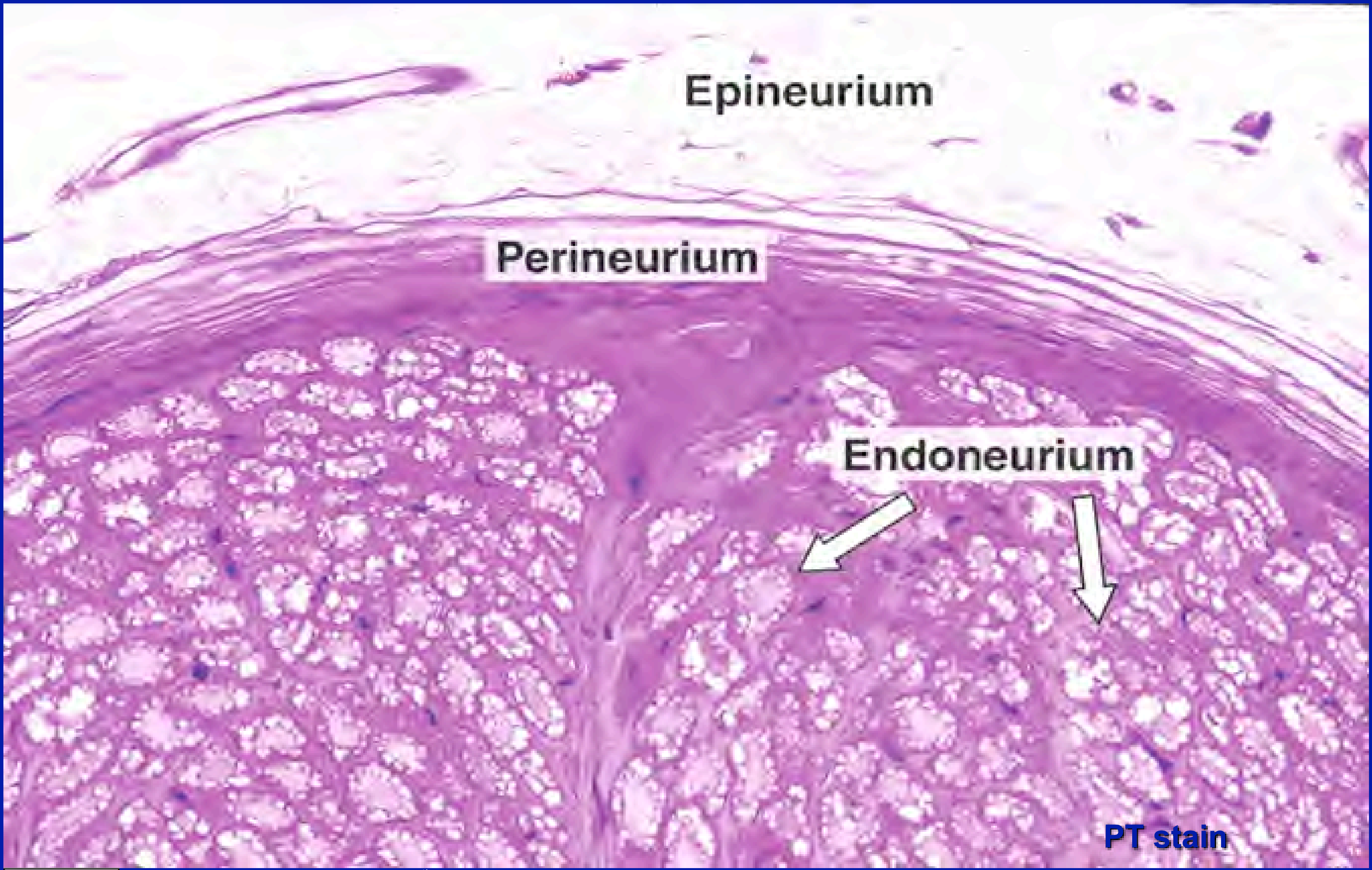
Wavy appearance of nerves



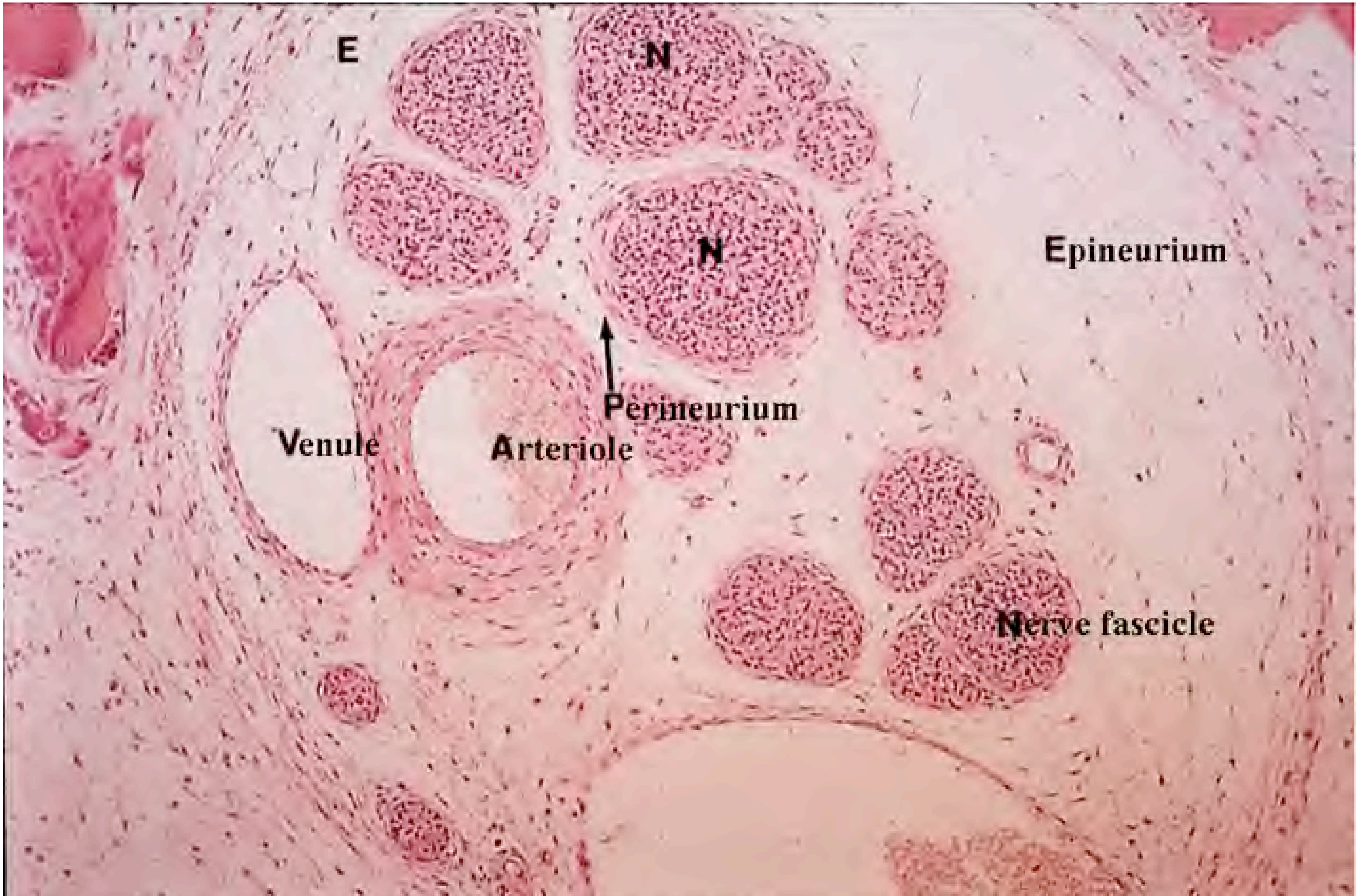
Connective tissue layers found in nerves: endoneurium surrounds axons, perineurium axon fascicles and epineurium the entire nerve

Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6.20

Connective tissue layers in a peripheral nerve. Tight junctions between perineurium cells form a important isolating barrier.

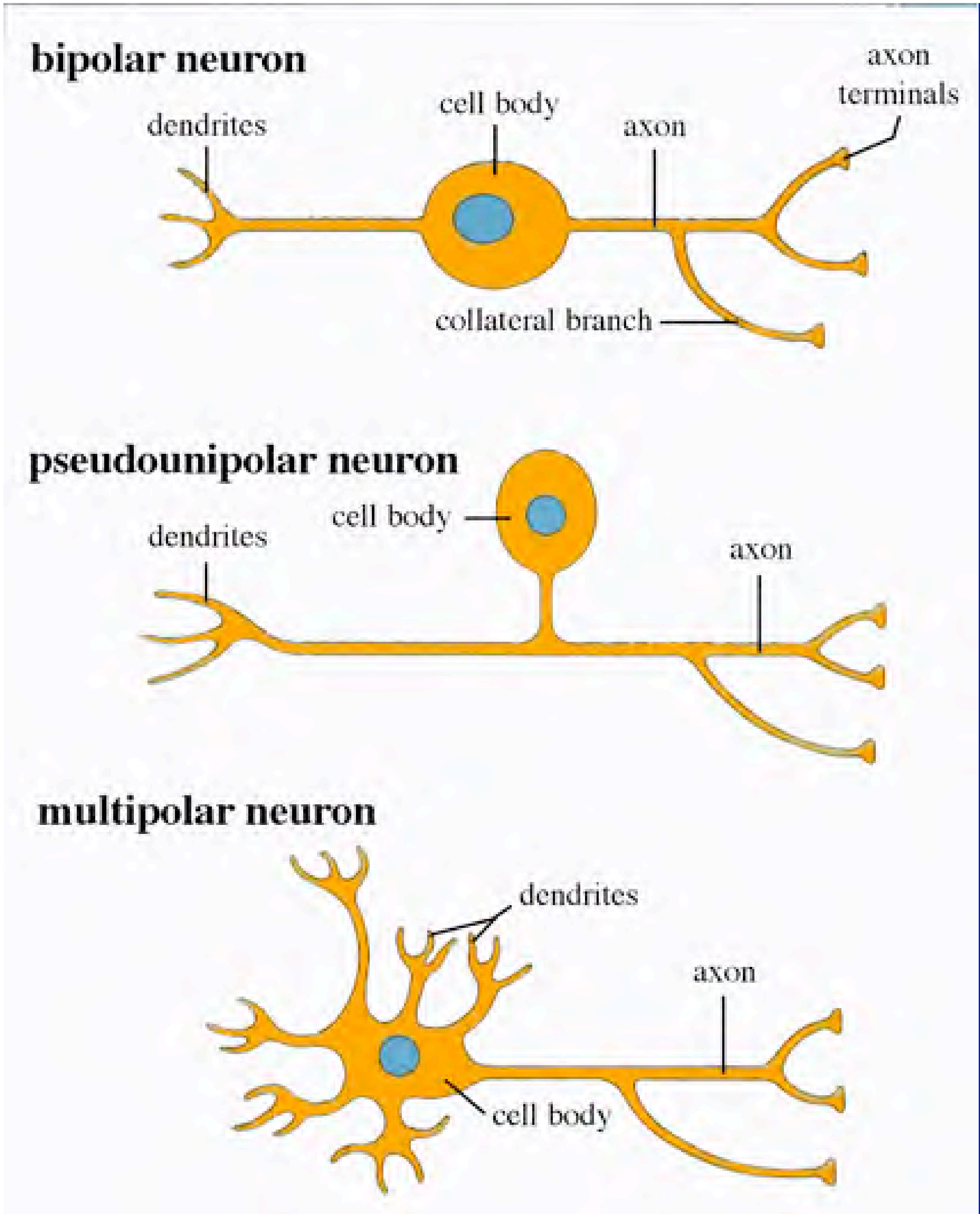


 Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9.34



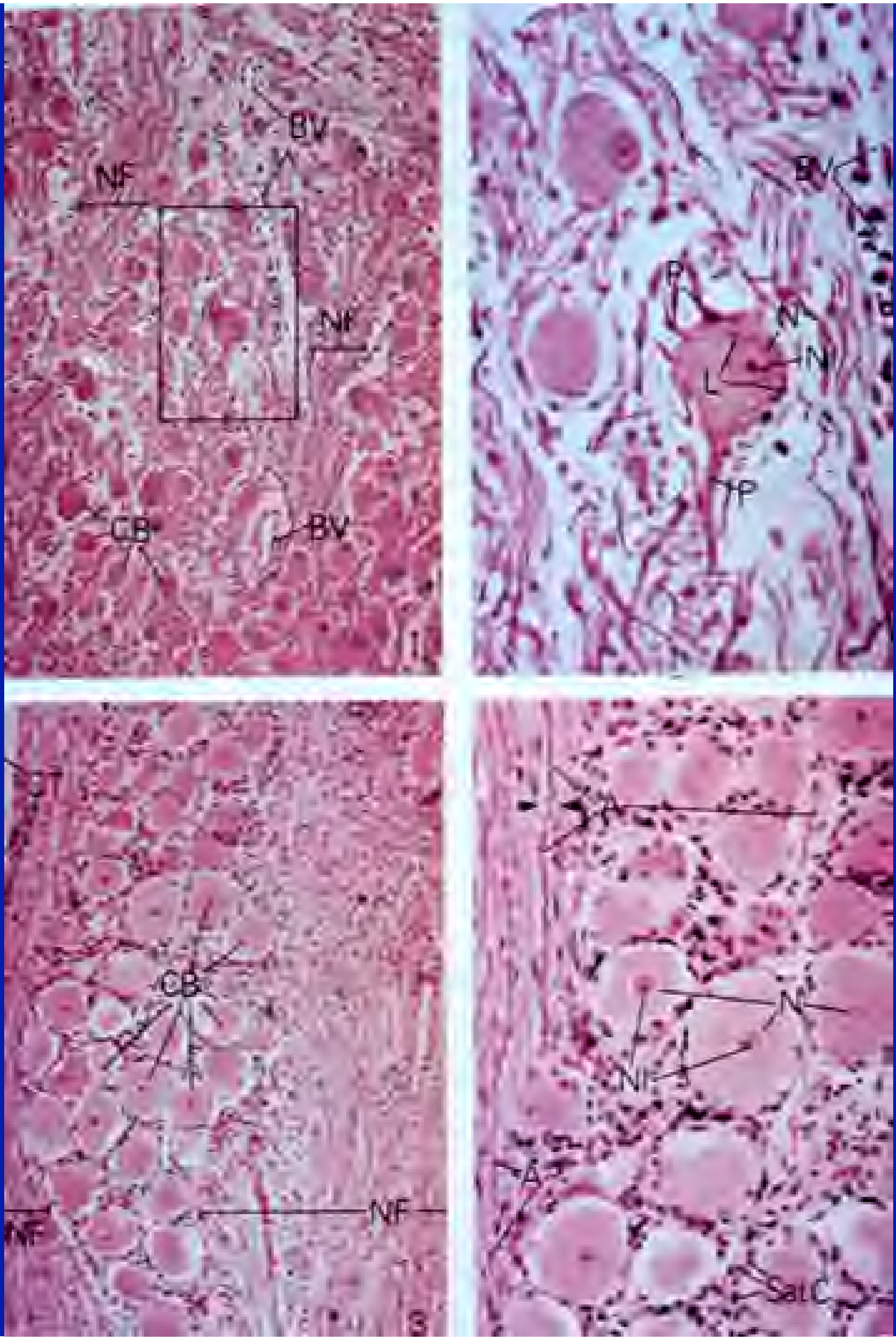
 Color Atlas of Basic Histology; 1993; Berman; Appelton and Lange; Fig 6.15

Connective tissue layers in a peripheral nerve cross section



Three different basic types of neuronal structure

Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6.3



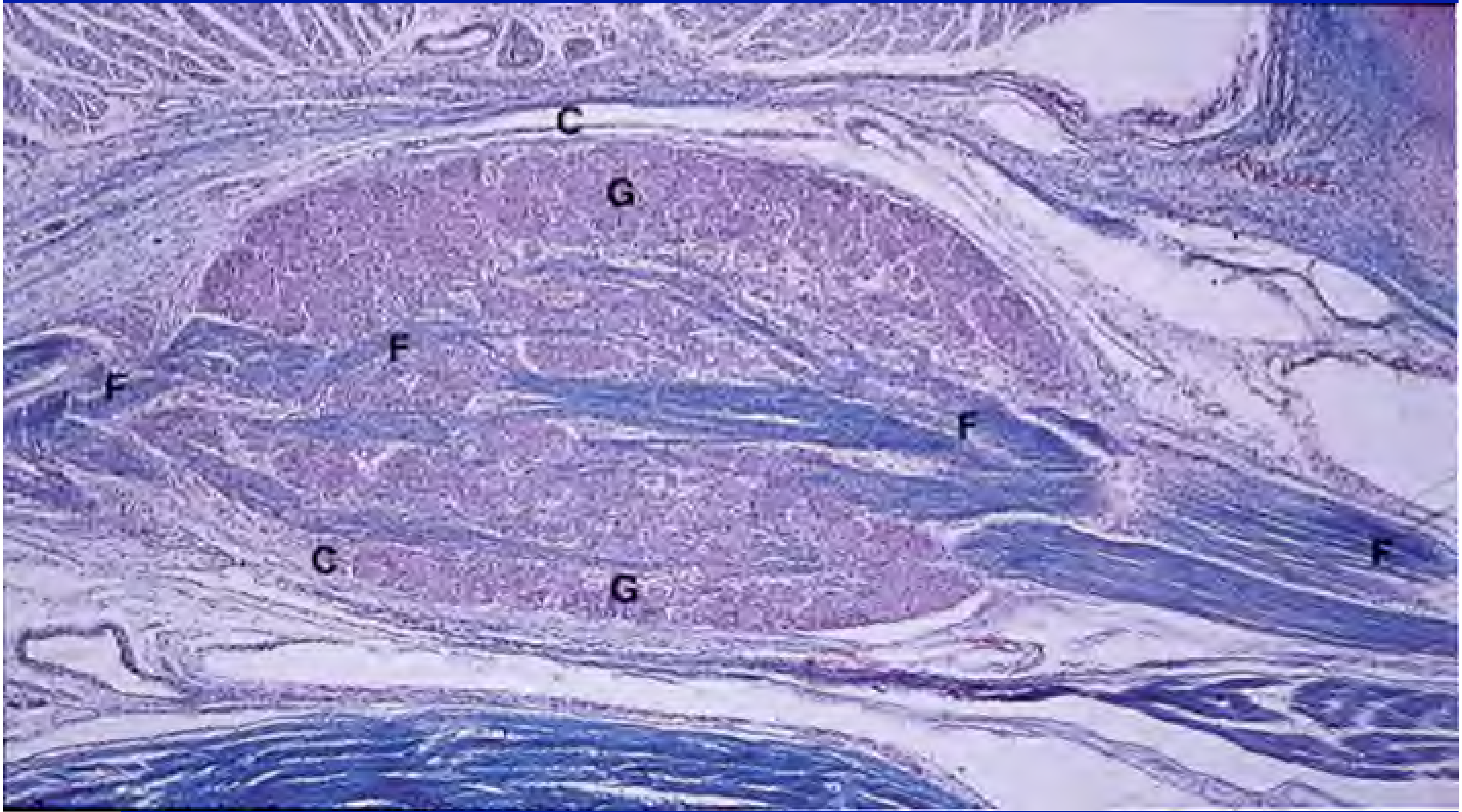
Autonomic ganglia with multipolar neurons are less organized than sensory ganglia (dorsal root ganglia) with pseudounipolar neurons.

Histology – A Text and Atlas; 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins ; Plate 23

Sensory Ganglia

- Two types: spinal (dorsal root) and cranial ganglia associated with spinal and cranial nerves, respectively
- Contain large sensory neurons and abundant small glial cells, called satellite cells
- Sensory neurons are pseudounipolar

Dorsal root ganglion with pseudounipolar neurons

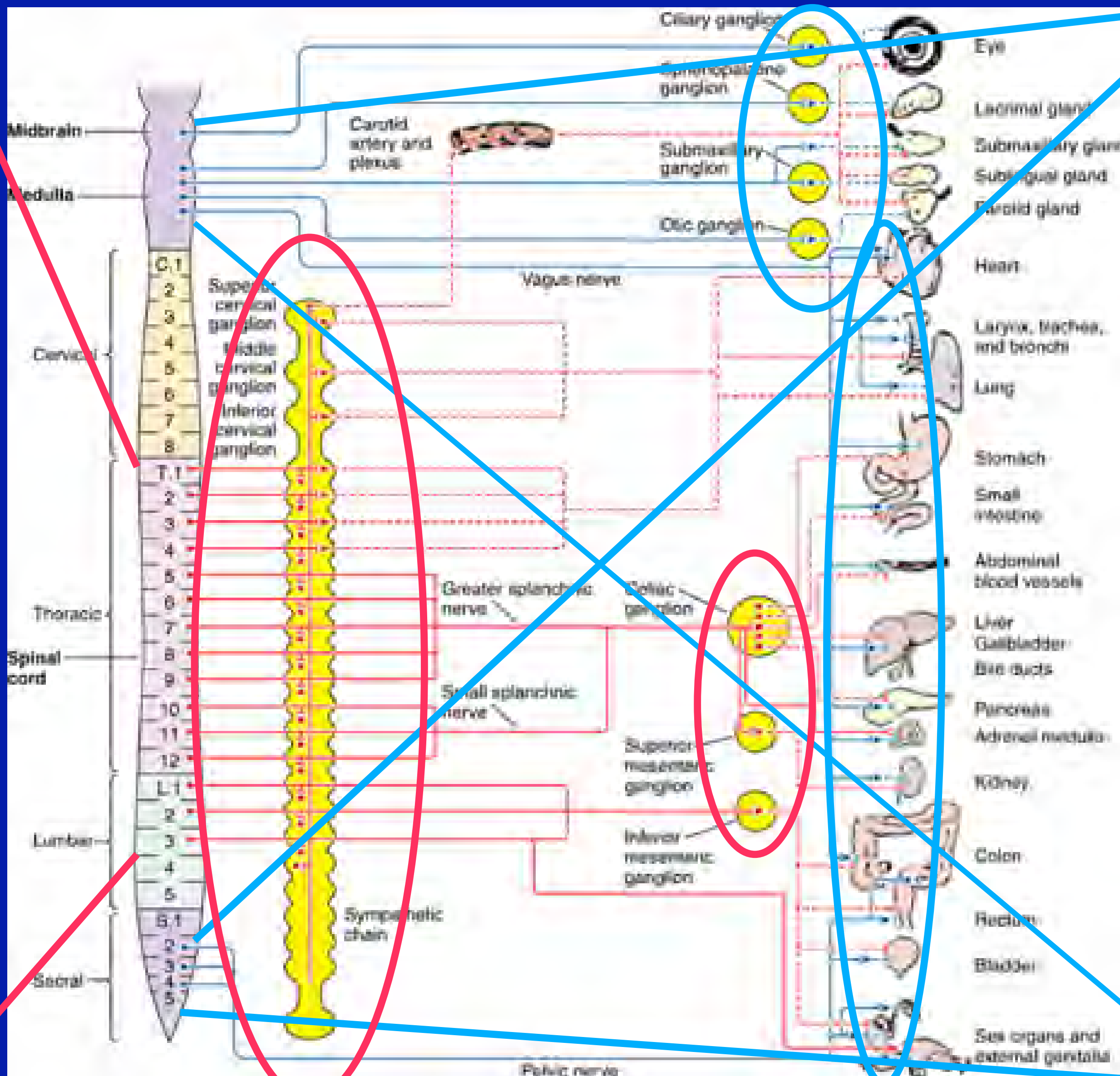


PD-INEL Source Color Atlas of Basic Histology; 1993; Berman; Appelton and Lange; Fig 6-10

Luxol blue staining of dorsal root ganglion

Efferent autonomic pathways

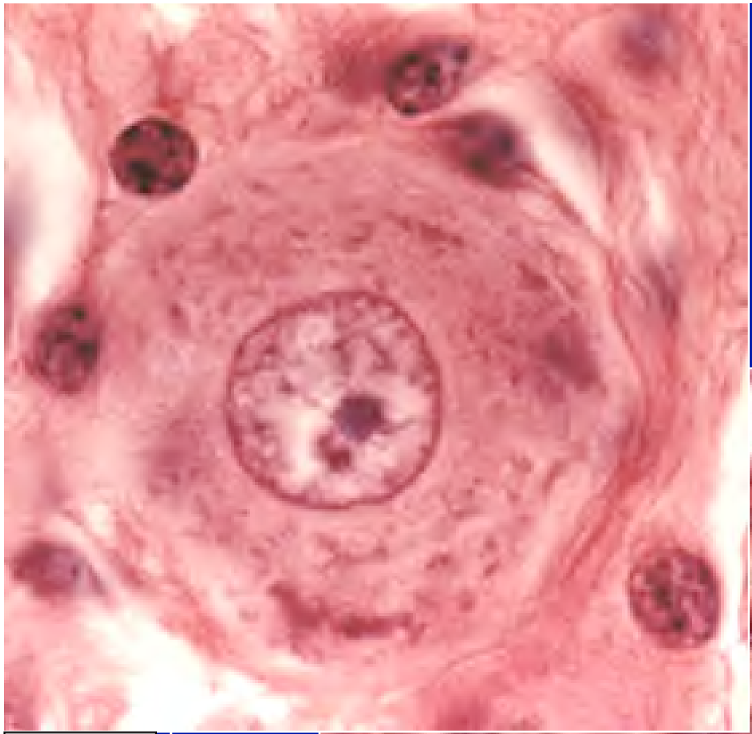
Sympathetic = thoracolumbar

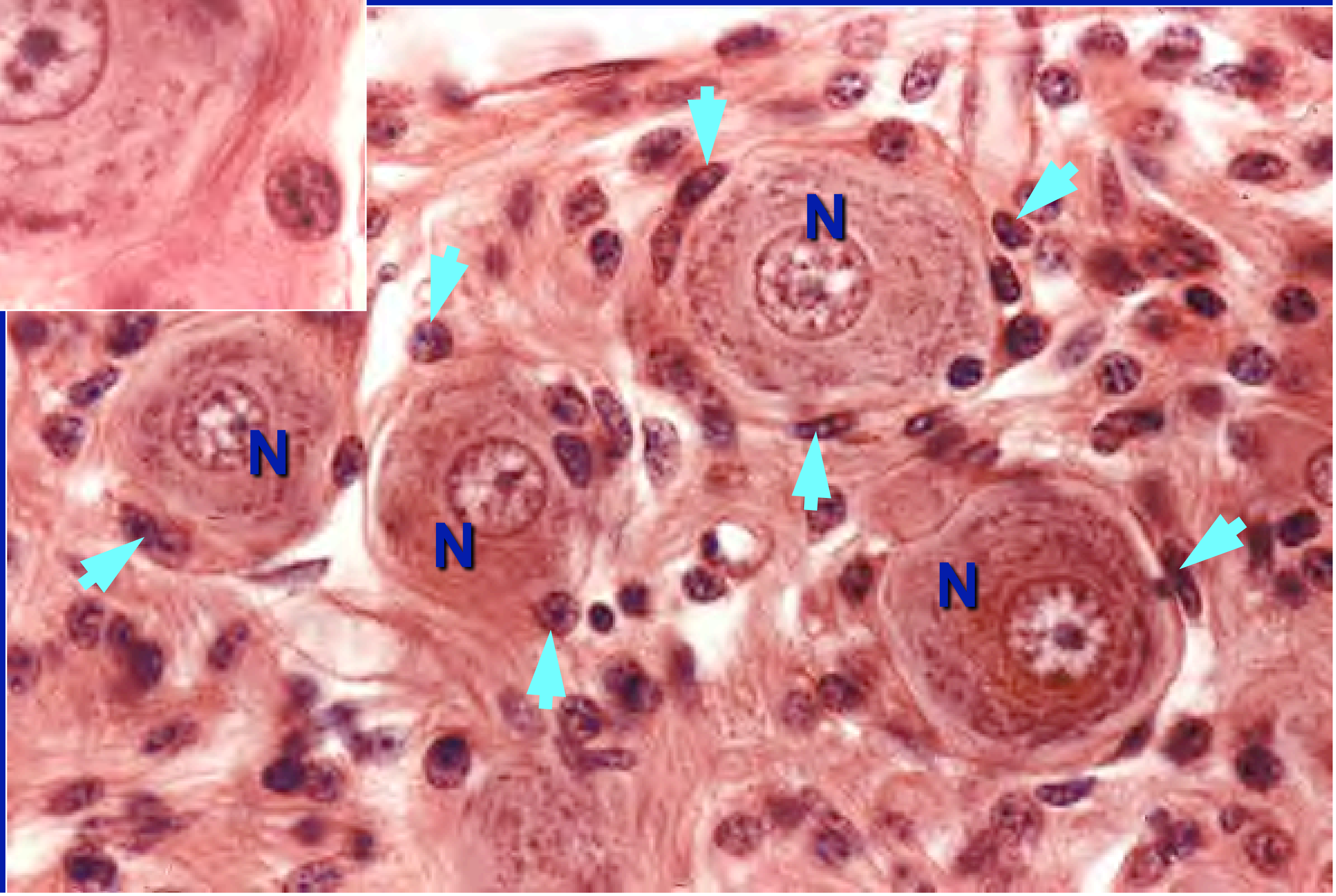


Parasympathetic = craniosacral

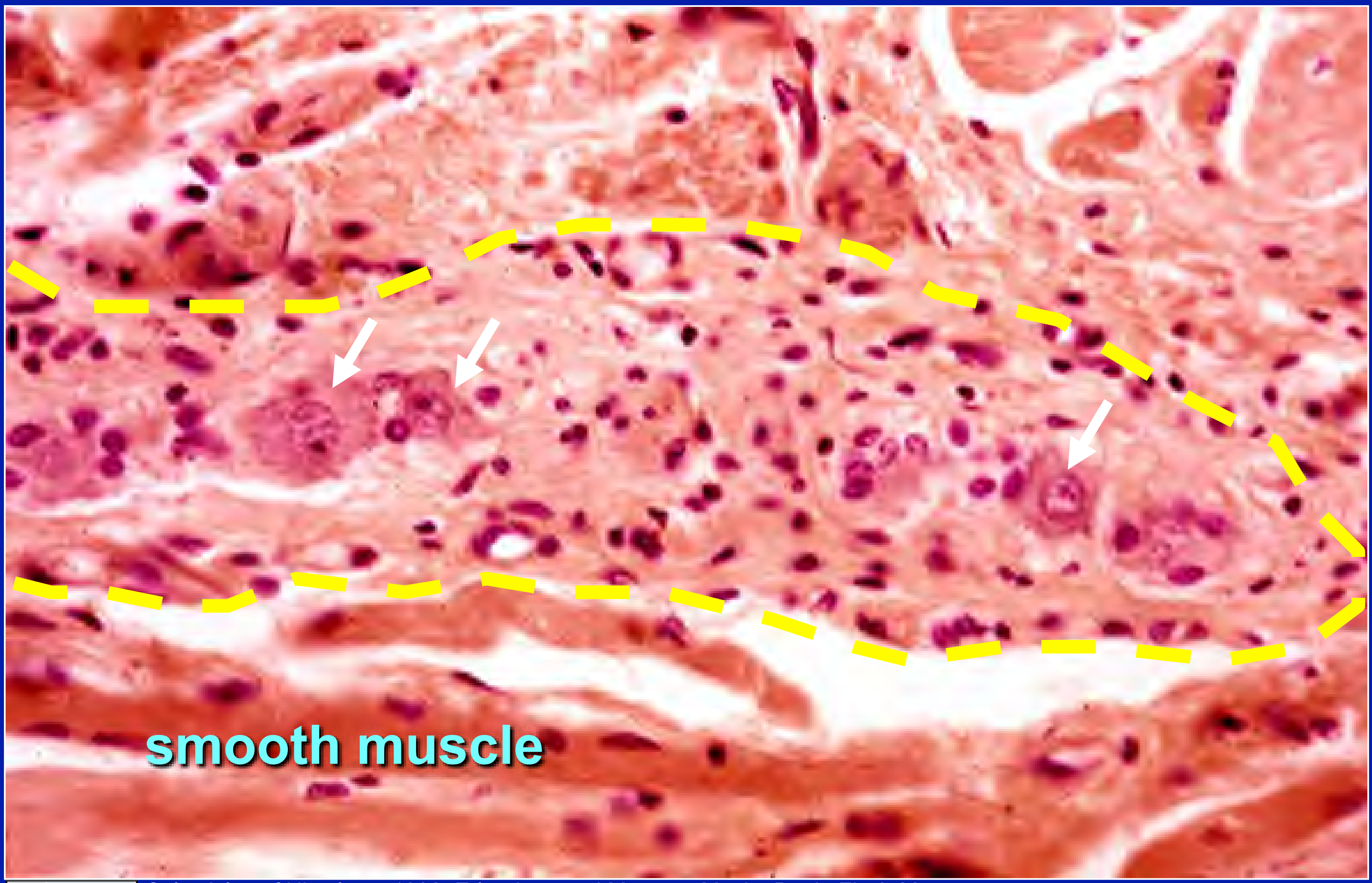
PD-INEL Modified from Basic Histology – Text & Atlas; 10th edition, 2003; Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-38

Autonomic Neurons in Sympathetic Ganglia are multipolar. These neurons are surrounded by satellite cells (glia cells marked by blue arrow heads).

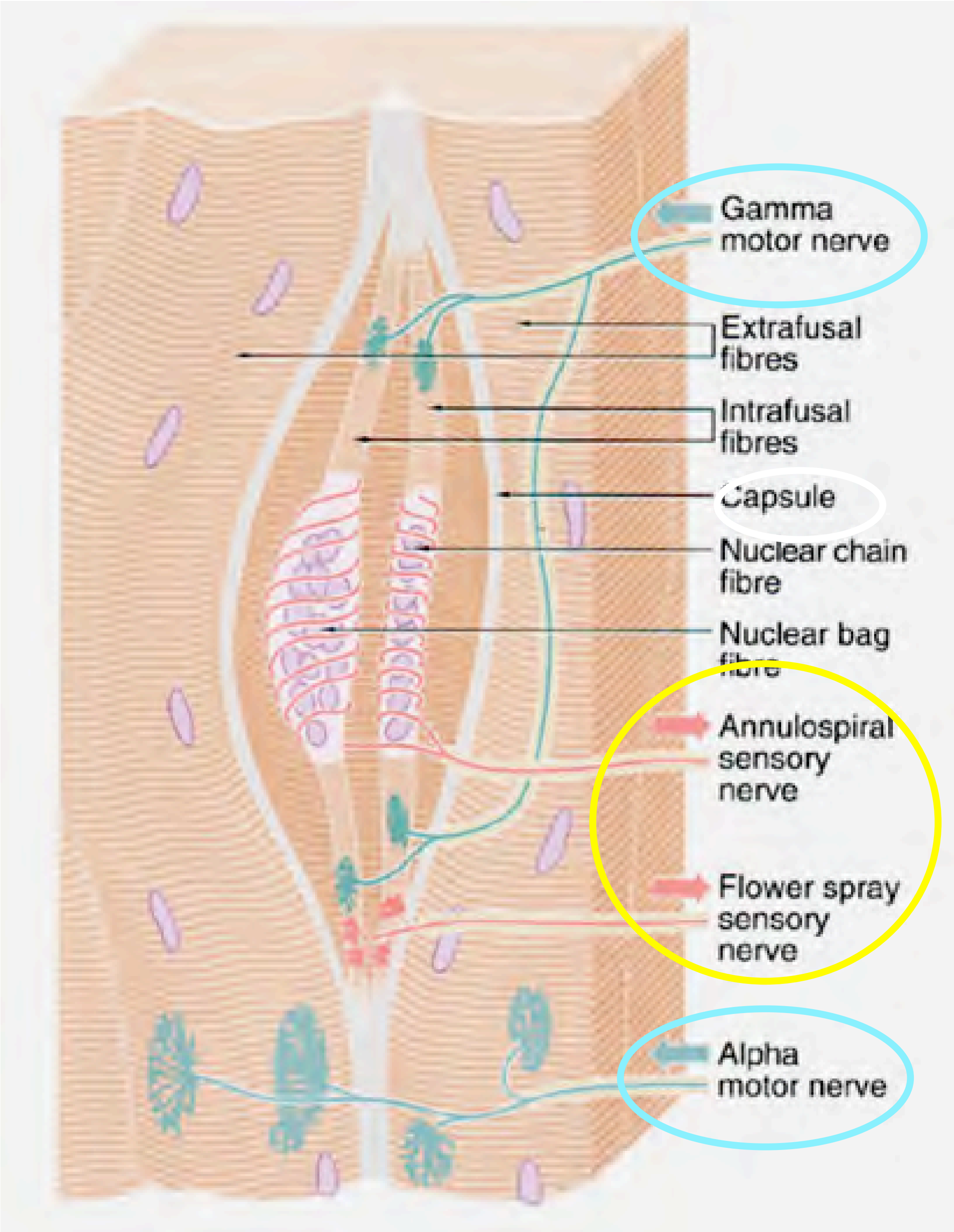




Parasympathetic ganglia are located within or near their effector organs



 Color Atlas of Histology; 1992; Erlandsen and Magney; Mosby Book; Fig 9-20



Neuromuscular spindle (of Kühne)

PD-EXP Wikipedia

Gamma motor nerve fibers innervate the intrafusal fibers

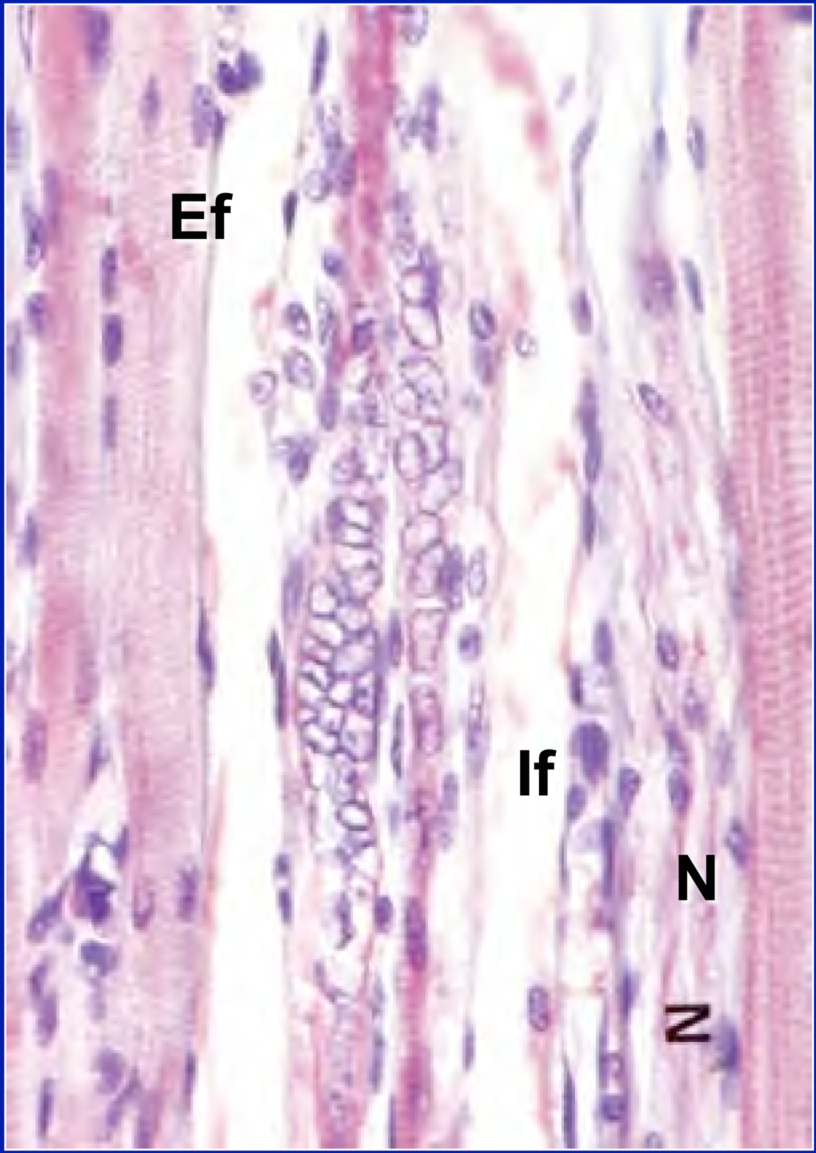
Sensory fiber endings are located on modified, small (intrafusal) muscle fibers

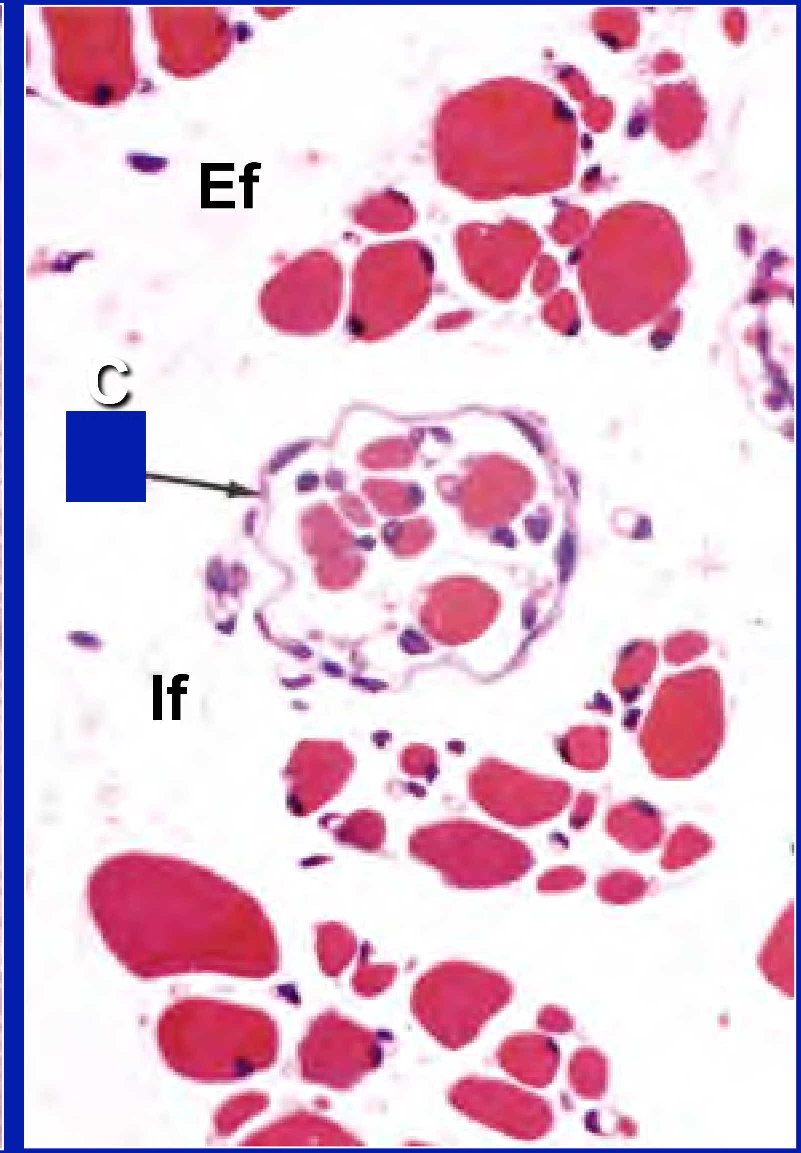
Alpha motor nerve fibers innervate the extrafusal fibers

Two-neuron stretch reflex

PD-INEL
Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 7.33a

Neuromuscular spindle





Longitudinal section

Transverse section

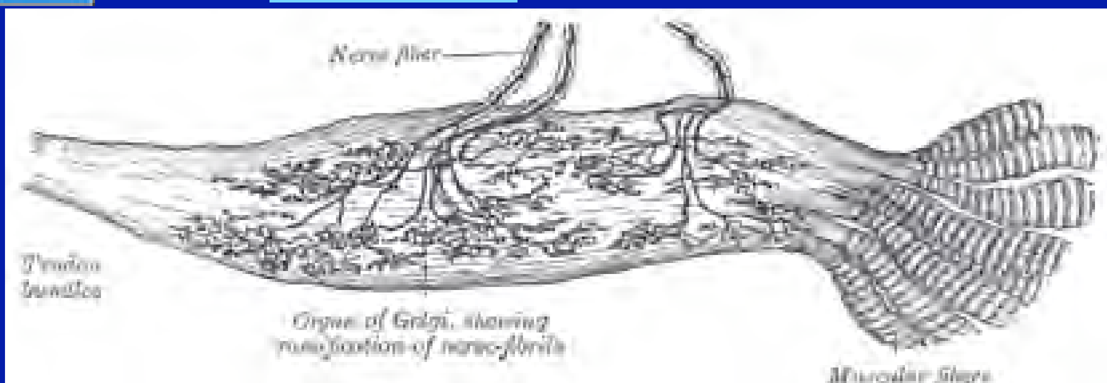
EM of a muscular spindle in the equatorial region

Netter's Essential Histology; 2008; Ovalle and Nahirney; Elsevier; Page 467

Sensory mechanoreceptor at the tendon-muscle junction:

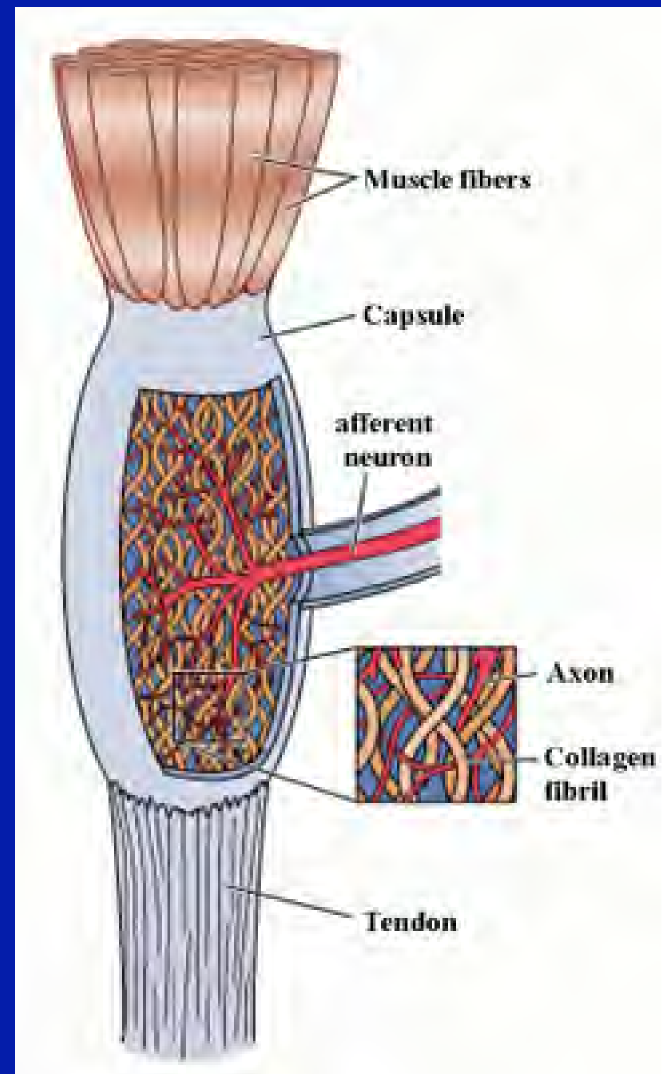
PD-EXP Modified from Wikimedia Commons

Organ of Golgi or neurotendinous spindle



PD-INEL Wikipedia

This organ of Golgi is an encapsulated stretch receptor. The capsule contains collagen fibers and endings of a single nerve fiber that is connected with interneurons in the spinal cord. Stretching forces will result in a depolarization of the axon and an inhibitory muscle reflex to protect muscles and tendons from excessive force.



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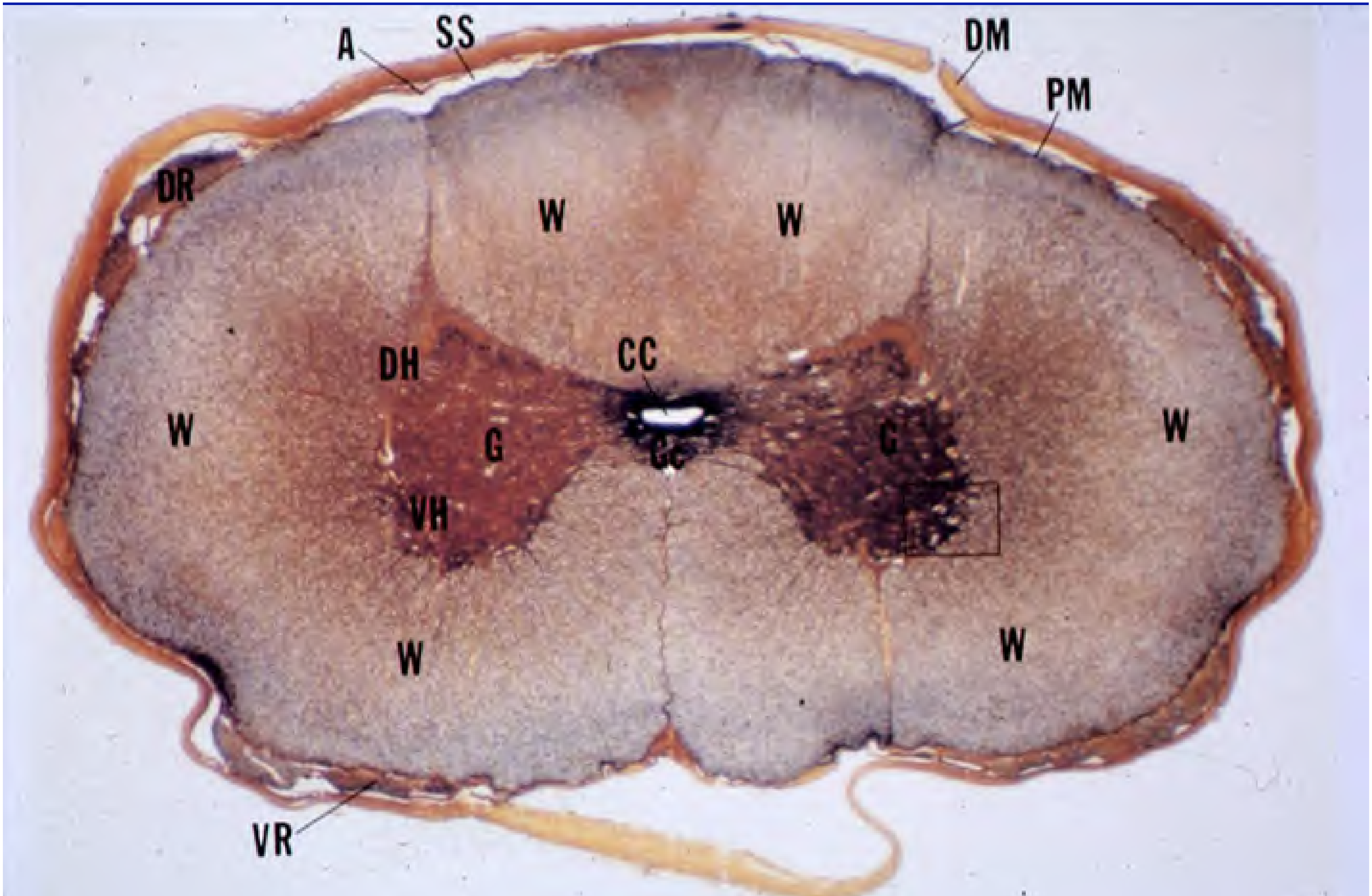
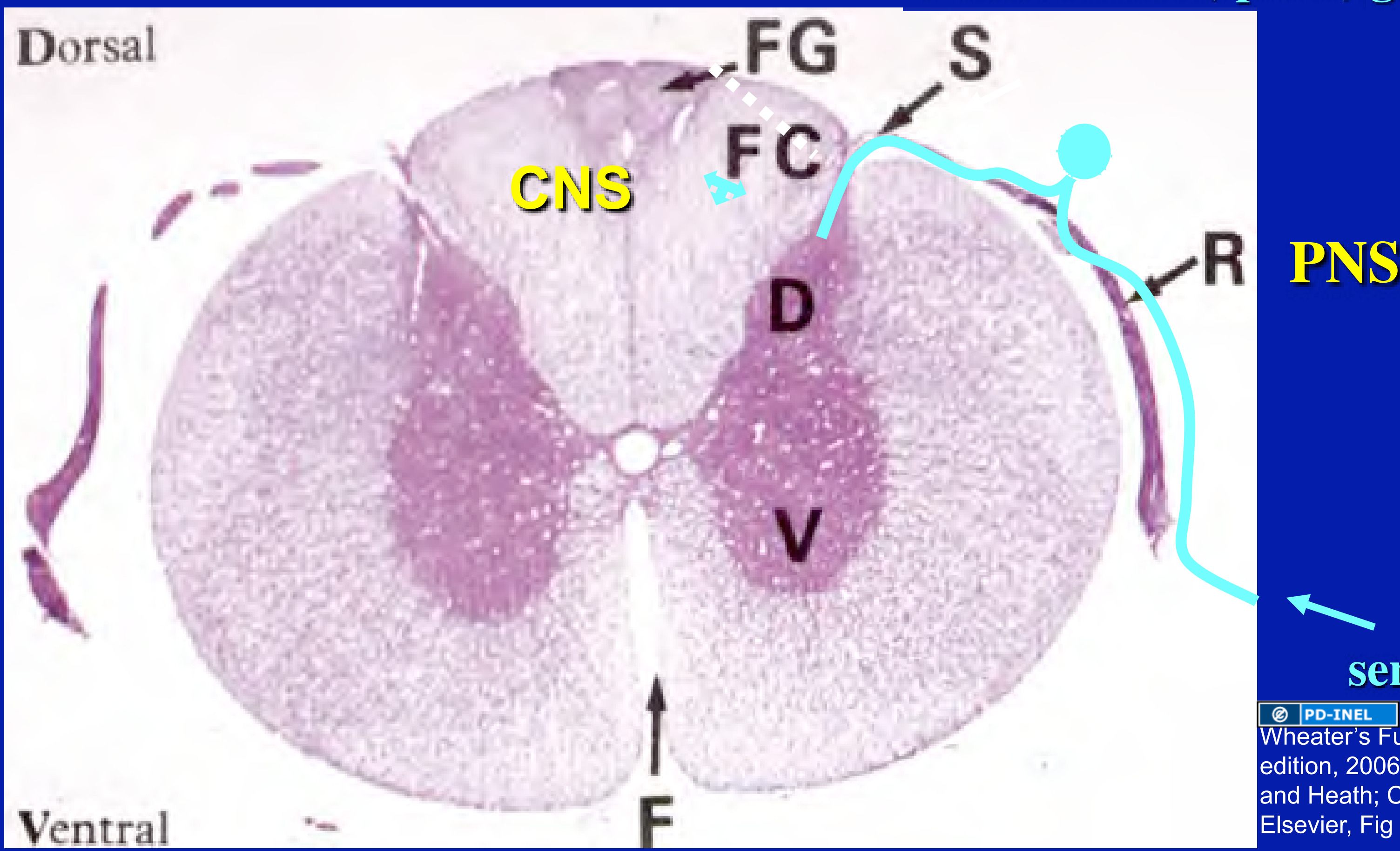


 Color Textbook of Histology; 2nd edition, 1994; Gartner and Hiatt; Williams and Wilkins; Fig 71.

Cross section of the spinal cord

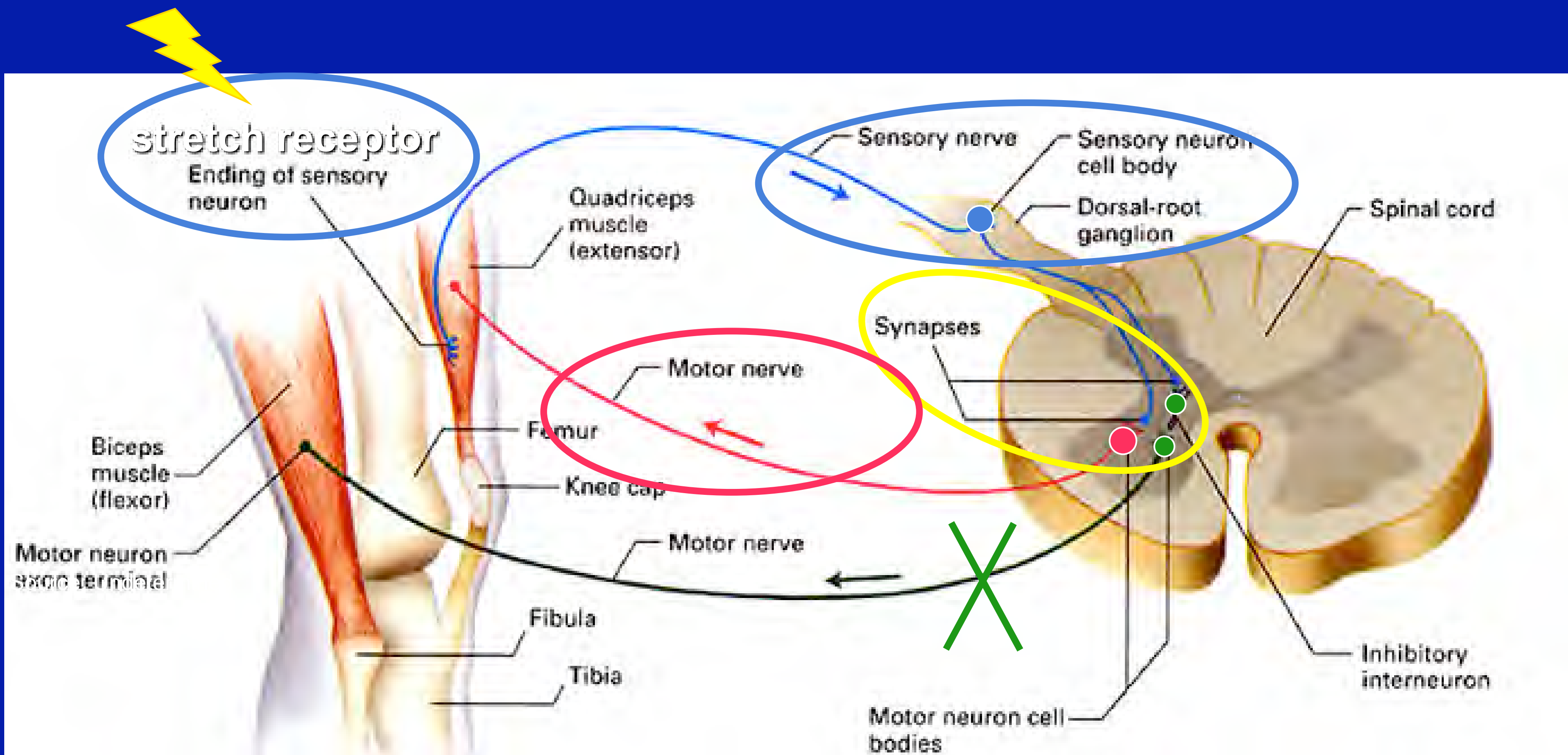
Somatic sensory neurons also have components in both CNS and PNS

pseudounipolar sensory neuron in a dorsal root (spinal) ganglion



Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 20.2a

Neuromuscular spindles are stretch receptors that regulate muscle tone via the spinal stretch reflex



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