Citation Key

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

Use + Share + Adapt

{ Content the copyright holder, author, or law permits you to use, share and adapt. }

PD-GOV **Public Domain – Government**: Works that are produced by the U.S. Government. (17 USC §105)

PD-EXP **Public Domain – Expired**: Works that are no longer protected due to an expired copyright term.

PD-SELF **Public Domain – Self Dedicated**: Works that a copyright holder has dedicated to the public domain.

ZERO **Creative Commons – Zero Waiver**

BY **Creative Commons – Attribution License**

BY-SA **Creative Commons – Attribution Share Alike License**

BY-NC **Creative Commons – Attribution Noncommercial License**

BY-NC-SA **Creative Commons – Attribution Noncommercial Share Alike License**

GNU-FDL **GNU – Free Documentation License**

Make Your Own Assessment

{ Content Open.Michigan believes can be used, shared, and adapted because it is ineligible for copyright. }

PD-INEL **Public Domain – Ineligible**: Works that are ineligible for copyright protection in the U.S. (17 USC § 102(b)) *laws in your jurisdiction may differ

{ Content Open.Michigan has used under a Fair Use determination. }

FAIR USE **Fair Use**: Use of works that is determined to be Fair consistent with the U.S. Copyright Act. (17 USC § 107) *laws in your jurisdiction may differ

Our determination **DOES NOT** mean that all uses of this 3rd-party content are Fair Uses and we **DO NOT** guarantee that your use of the content is Fair.

To use this content you should **do your own independent analysis** to determine whether or not your use will be Fair.

Histology of the Central Nervous System

Michael Hortsch, Ph.D.
Department of Cell and Developmental Biology

M1 - CNS

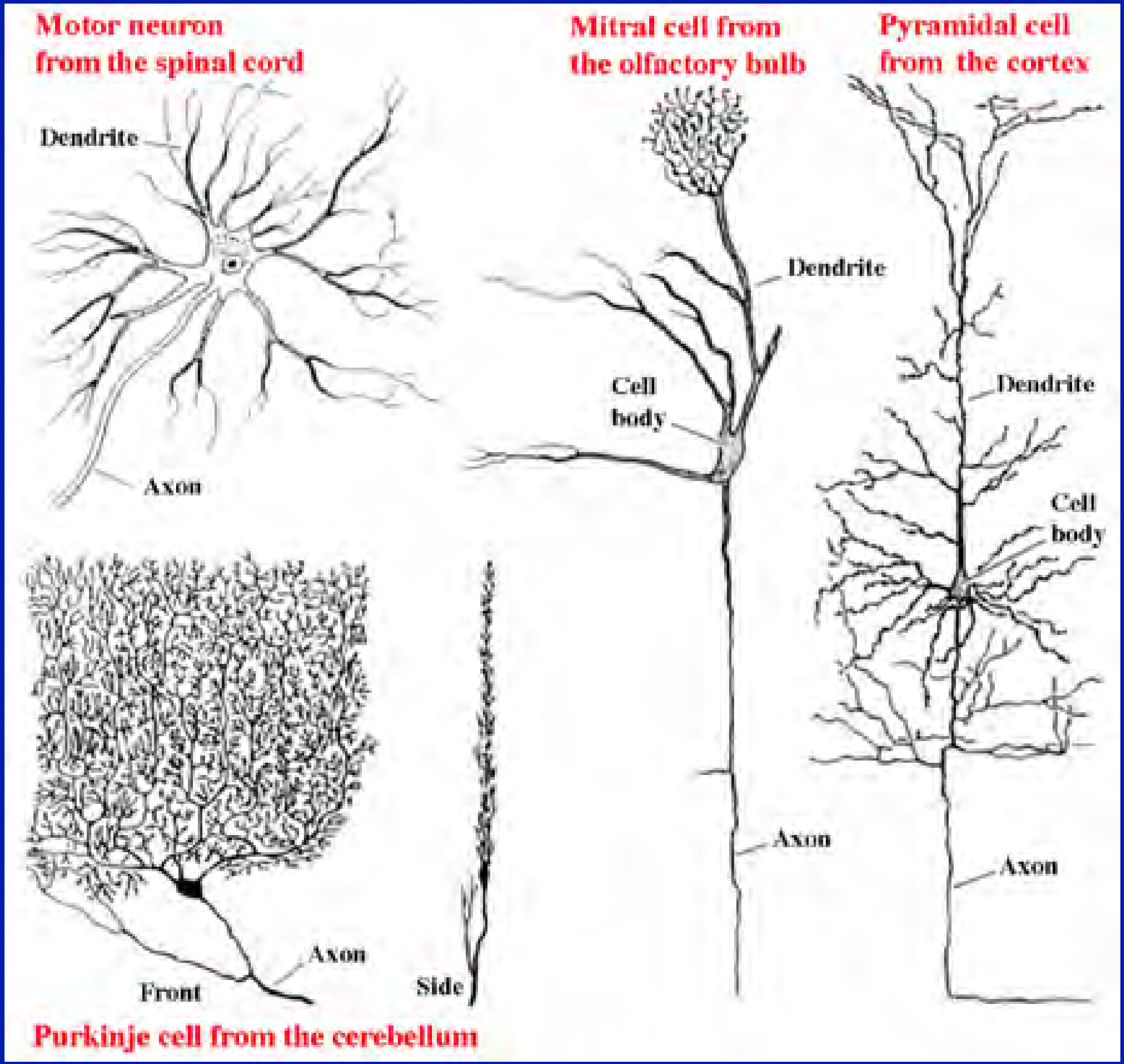
University of Michigan

Winter, 2009

University of Michigan Medical School

Objectives CNS Histology:

- Review neuronal cell structure and neuronal cellular components
- Learn about the major types of glial cells and their functions
- Review myelination and the differences between PNS and CNS
- Discuss the cellular differences between gray and white matter
- Study the layered organization in different parts of the CNS and its major cell types
- Look at the regional differences in the hippocampus and the cerebral cortex.

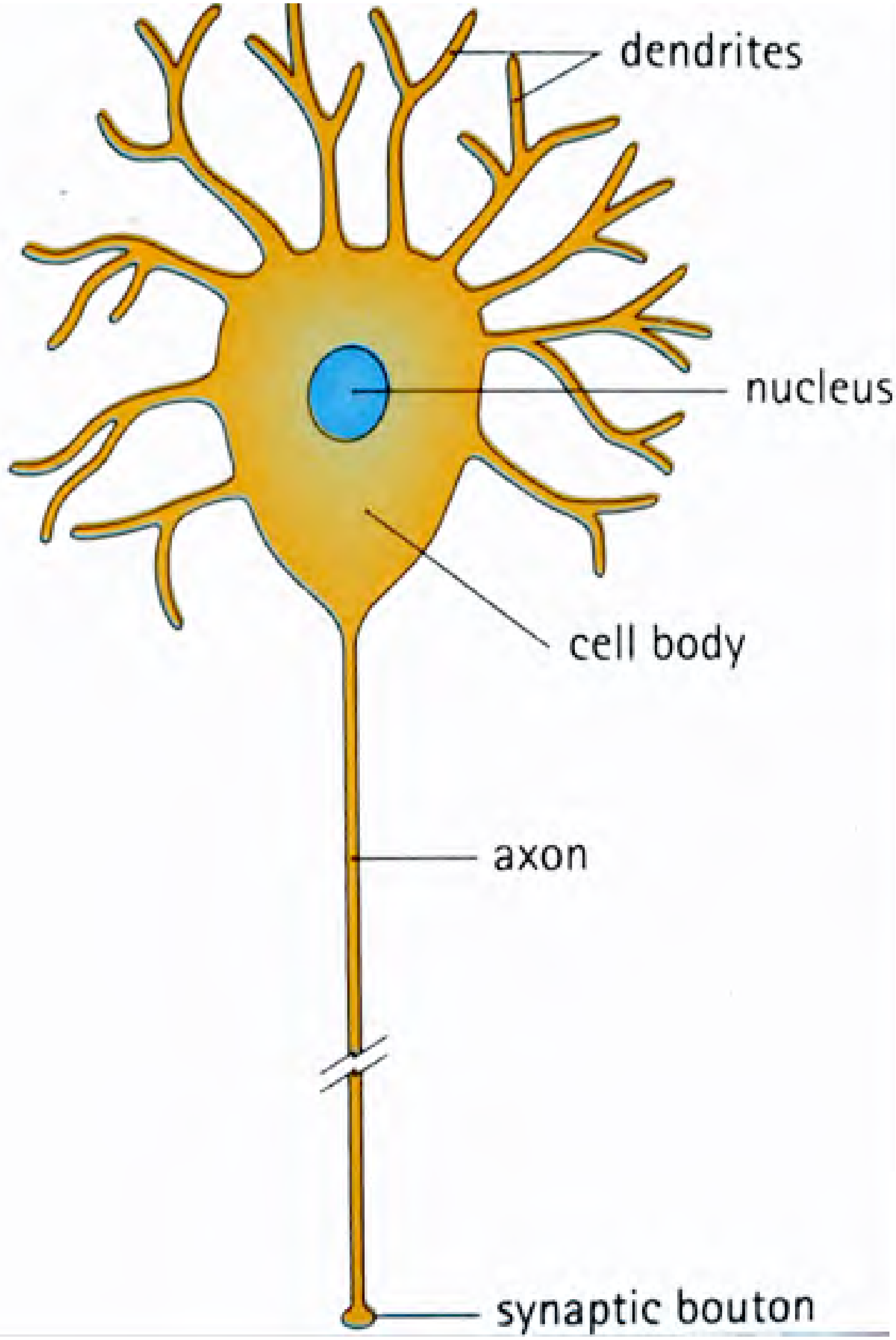


 Neuron to Brain, 3rd edition, 1992; Nicholls, Martin and Wallace, Sinauer; Fig 6

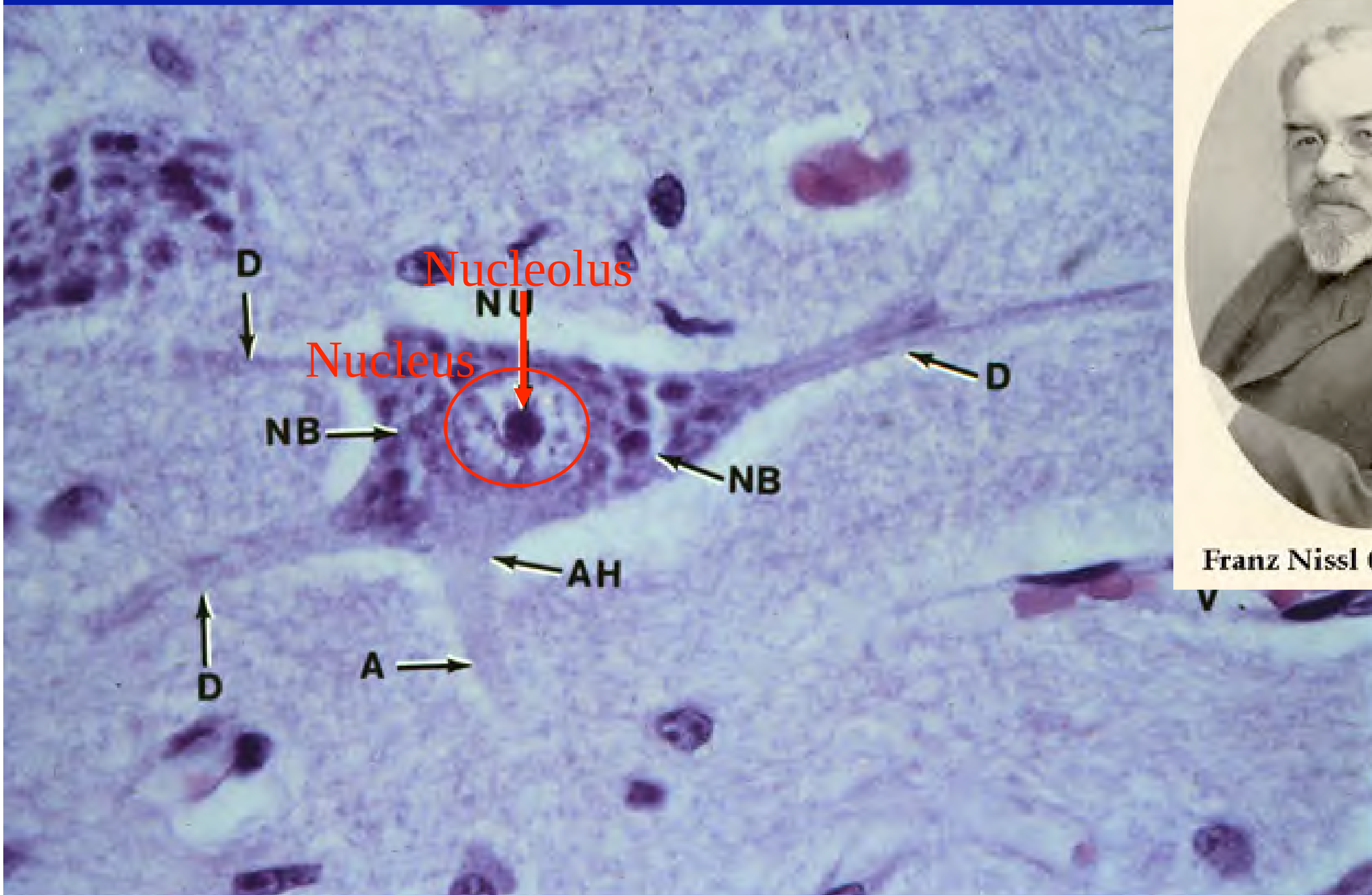
Neurons come in many shapes and forms

Generic neuron

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



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



PD-EXP Clendening Library Portrait Collection

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

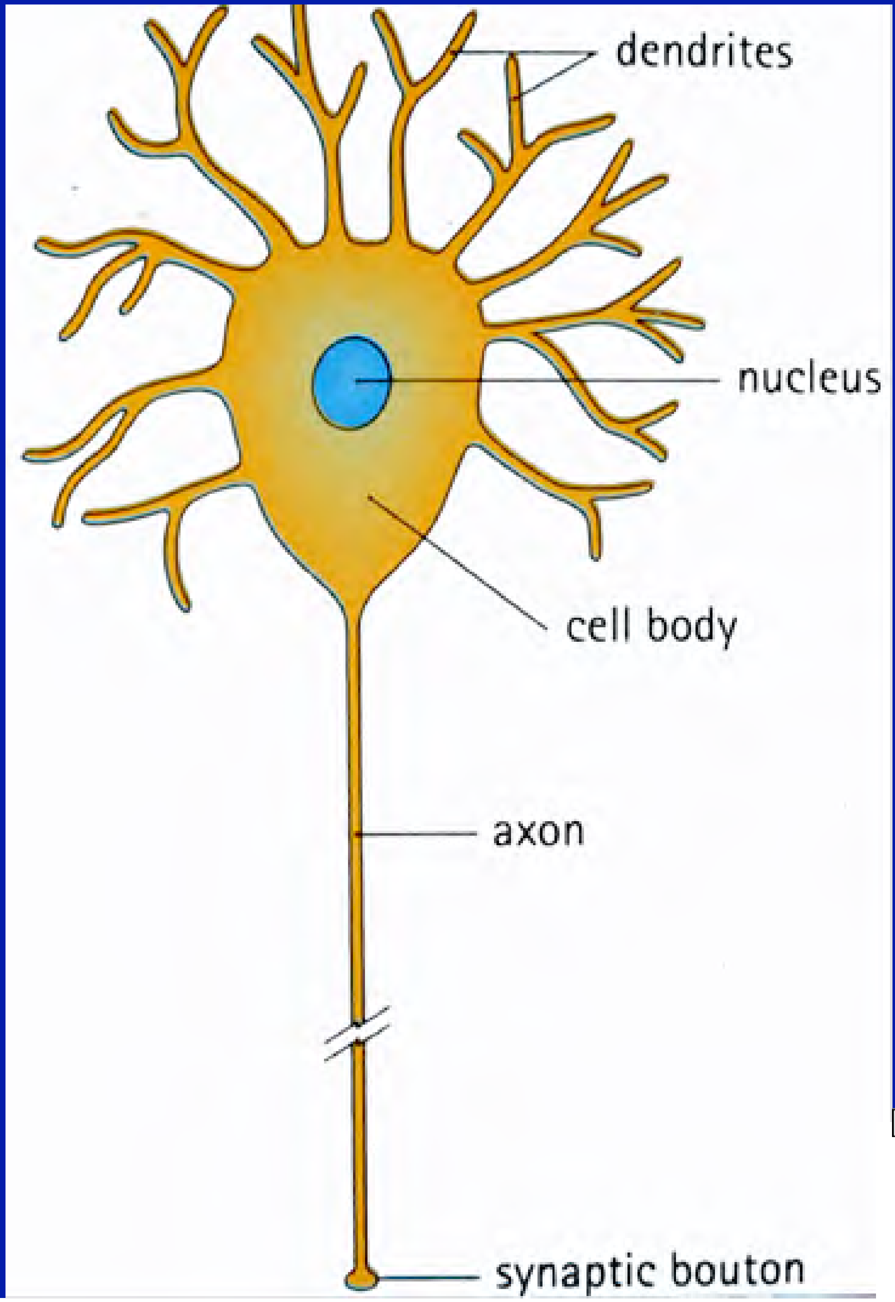
Motor neuron with Nissl substance

Nissl substance is rough endoplasmic reticulum

PD-INEL Cell and Tissue Ultrastructure – A Functional Perspective; 1993; Cross and Mercer, Freeman and Co.; Pg. 127

Neurons have dendritic and axonal extension

The Law of Dynamic Polarization 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.

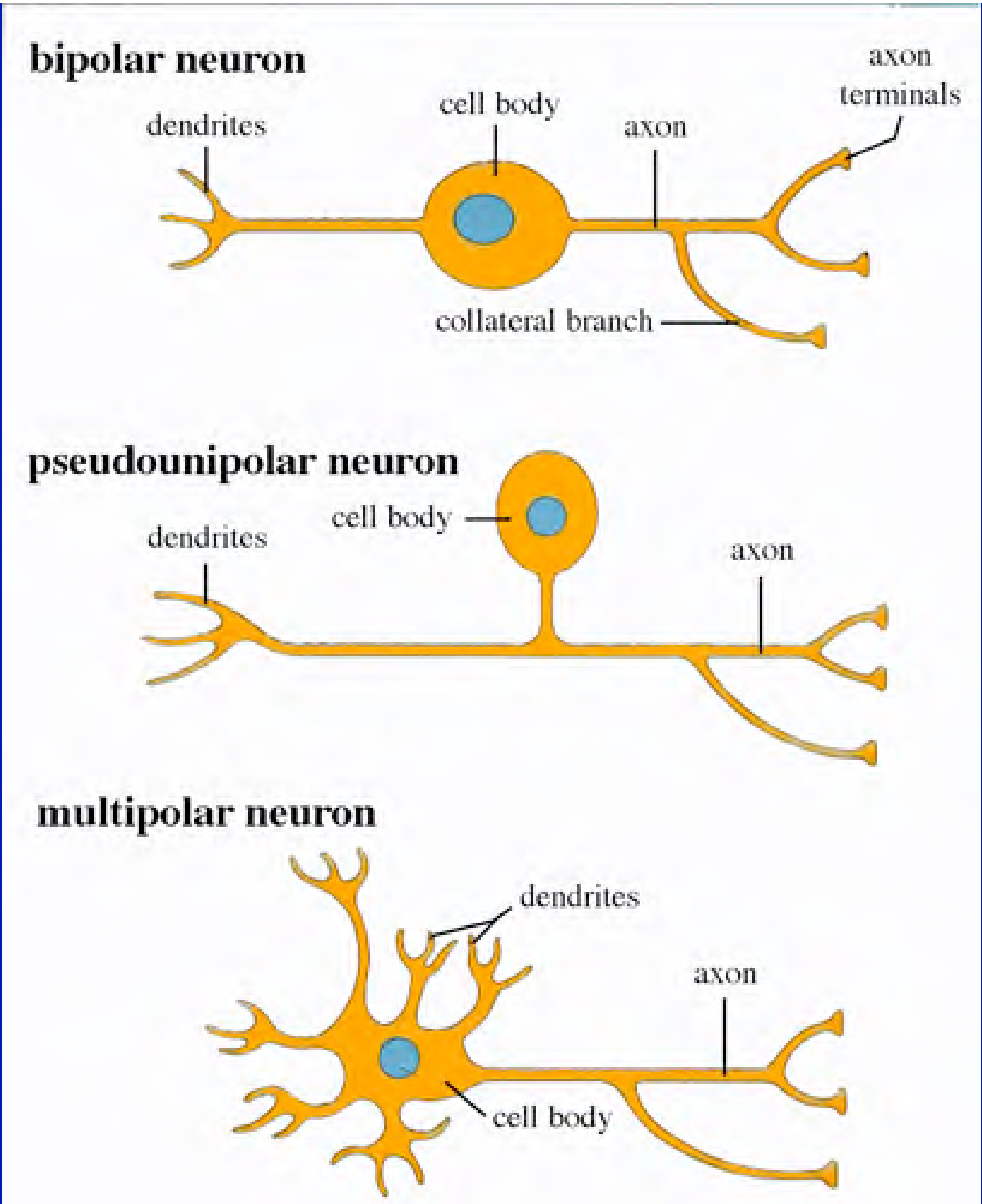


Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig. 6-1

PD-INEL 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.

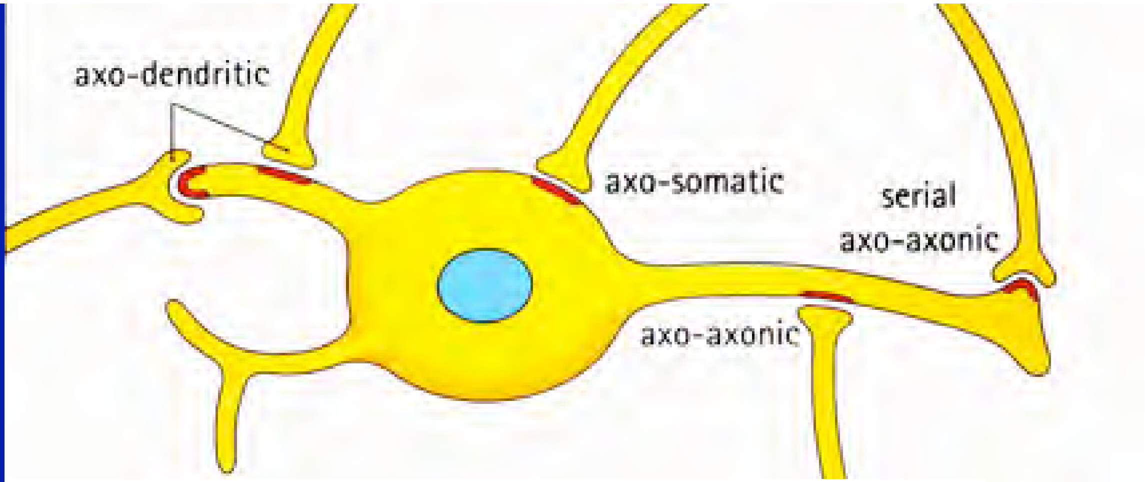
The ability of neurons to synthesize proteins at growth cones and at the presynaptic terminus is very limited.



Three different basic types of neuronal structure

Modified by Dr. Hortsch Human Histology, 2nd edition, Stevens and Lowe, Mosby; Fig 6.3

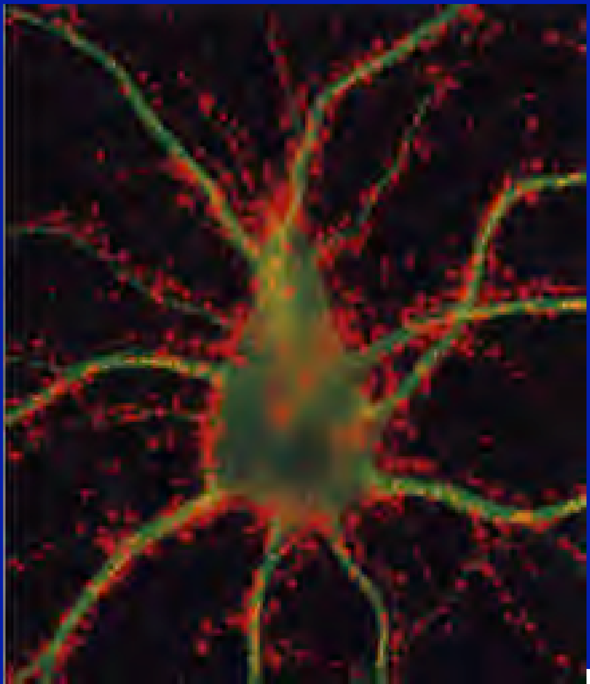
Synapses can form between many different parts of neurons and between a neuron and a non-neuronal cell, e.g., a muscle or a secretory cell.



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

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

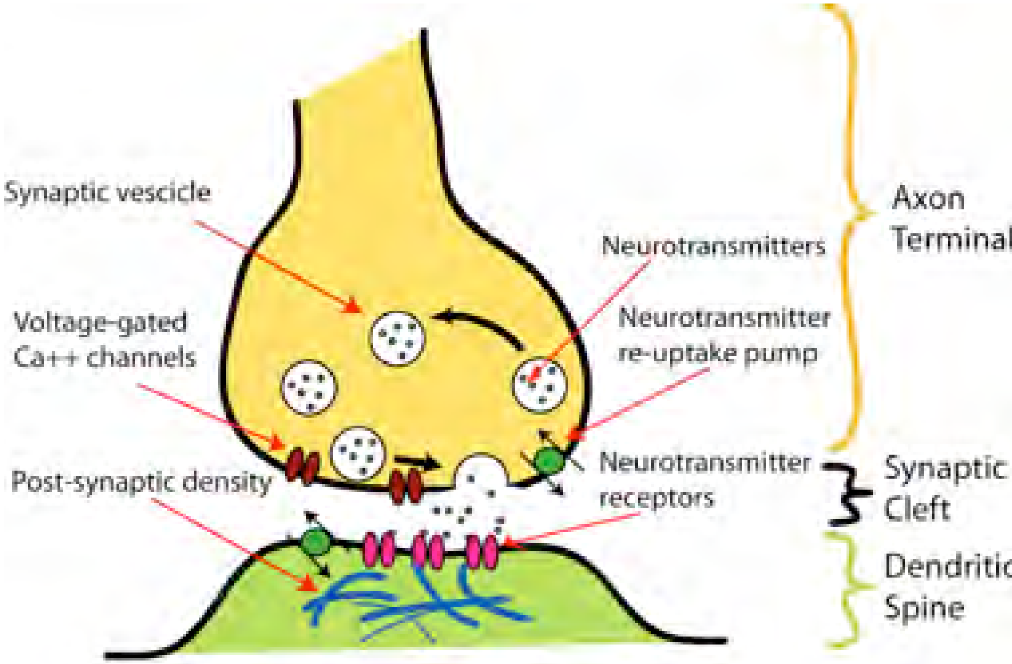
Source of Removed Image: The Molecular Biology of the Cell by B. Alberts et al., 4th edition, 2002, Garland Science
Fig. 11-38 A

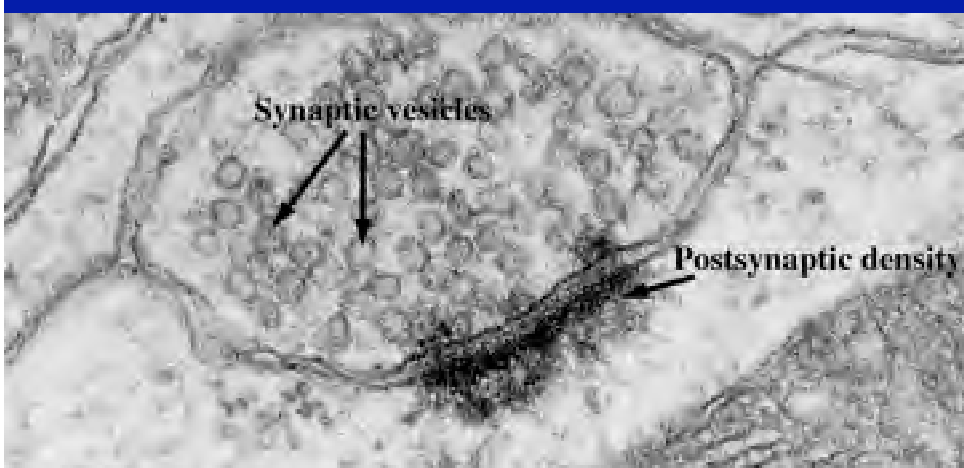


Panel B courtesy of Olaf Mundigl and Pietro de Camilli PD-INEL
The Molecular Biology of the Cell by B. Alberts et al., 4th edition, 2002, Garland Science

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

Motor neuron cell body in the spinal cord





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

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

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

Glial cells are about ten times more abundant than neuronal cells and have many different functions.

The four major types of glial cells in the CNS:

Image of glial cells removed

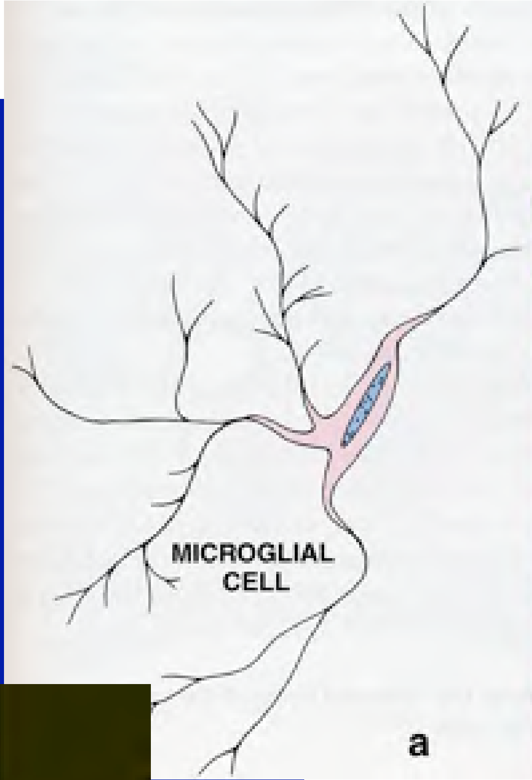
a) Microglia

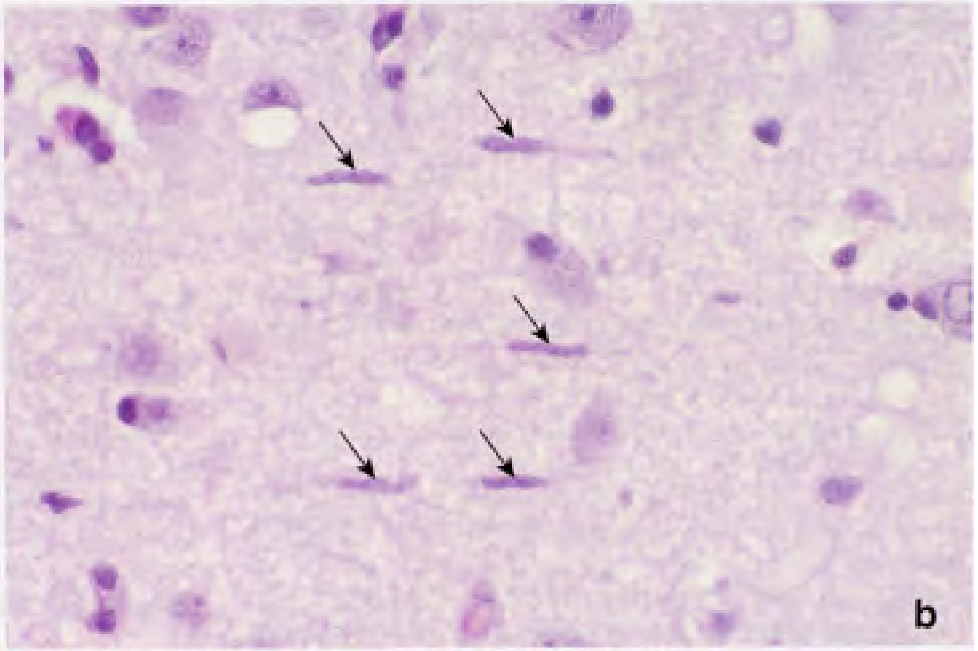
b) Ependymal cells

c) Astrocytes

d) Oligodendrocytes

Source of Removed Images: http://academic.kellogg.cc.mi.us/herbrandsonc/bio201_McKinley/Nervous%20System.htm



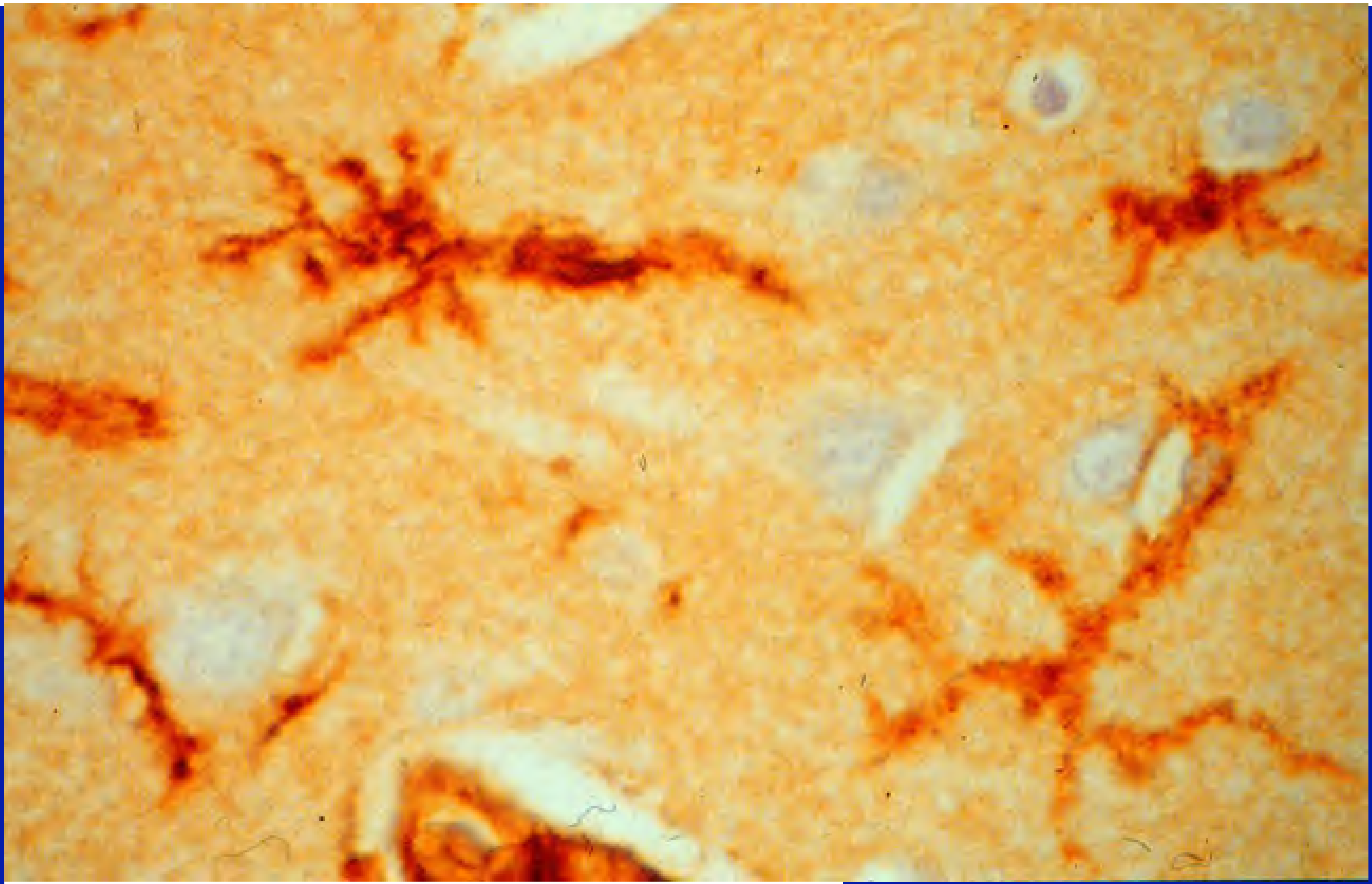


PD-INEL Histology Image Source: Histology - A Text and Atlas; 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins; Fig 11.18

Pio del Rio Hortega (1882-1945)

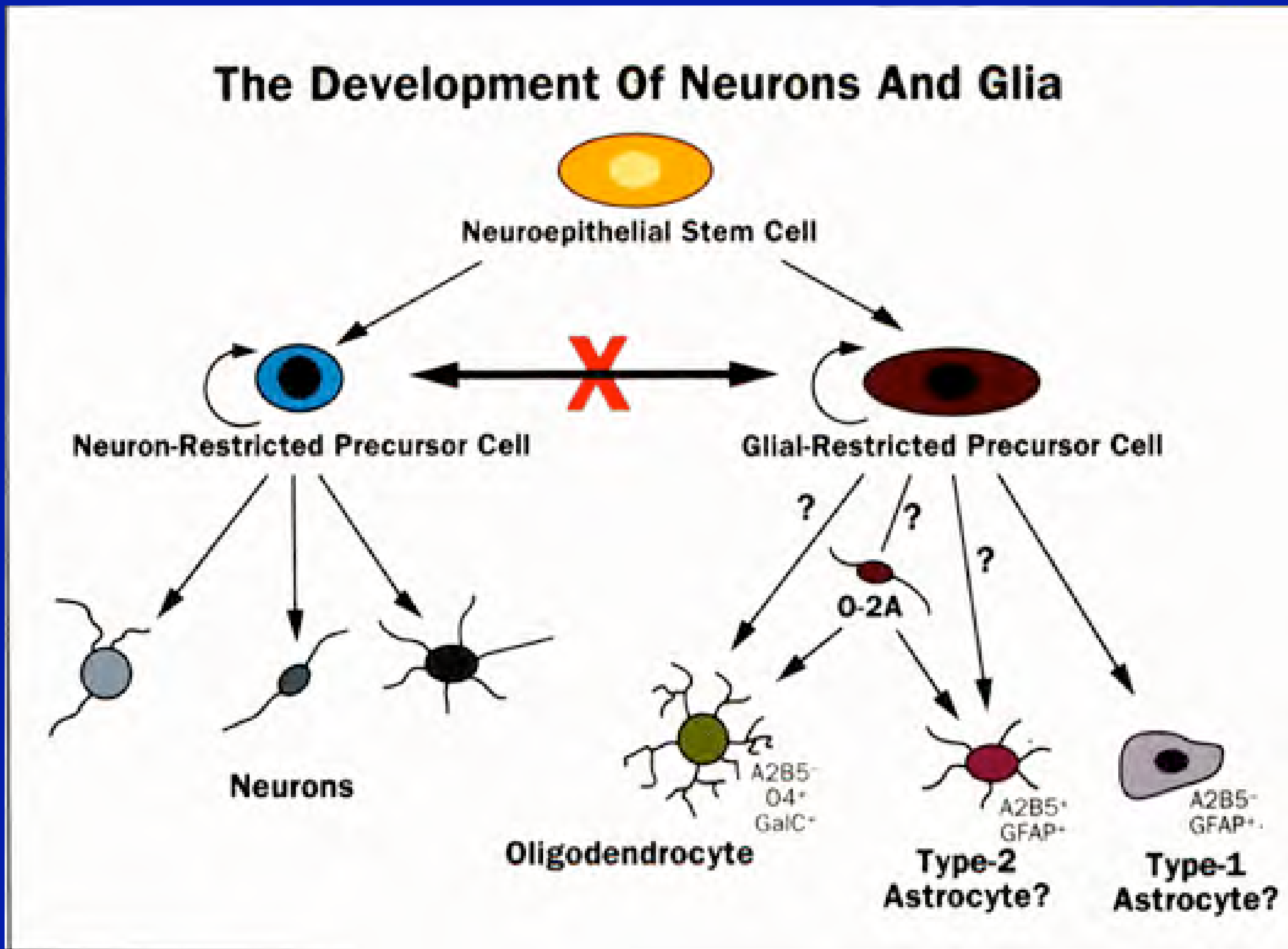
PD-GOV Wilder Penfield

Microglia or Hortega cells are difficult to identify in a routine H&E preparation. They are bone marrow-derived and belong to the mononuclear phagocytic system.

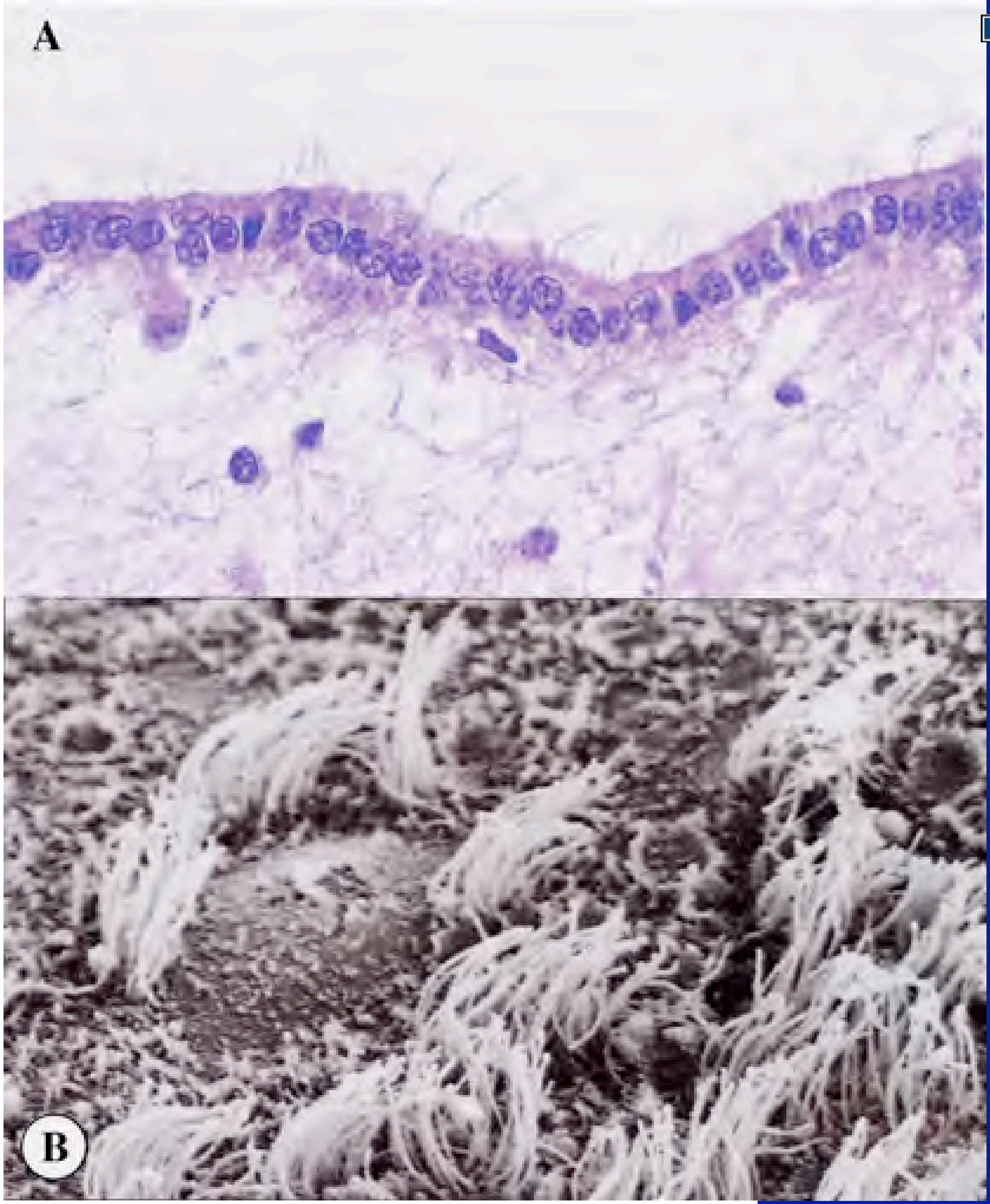


Human Histology, 2nd edition, Stevens and Lowe, Mosby ; Fig 6.12

Microglia cells, which were stained with a specific lectin marker



Neurons and glial cells develop from common stem cells

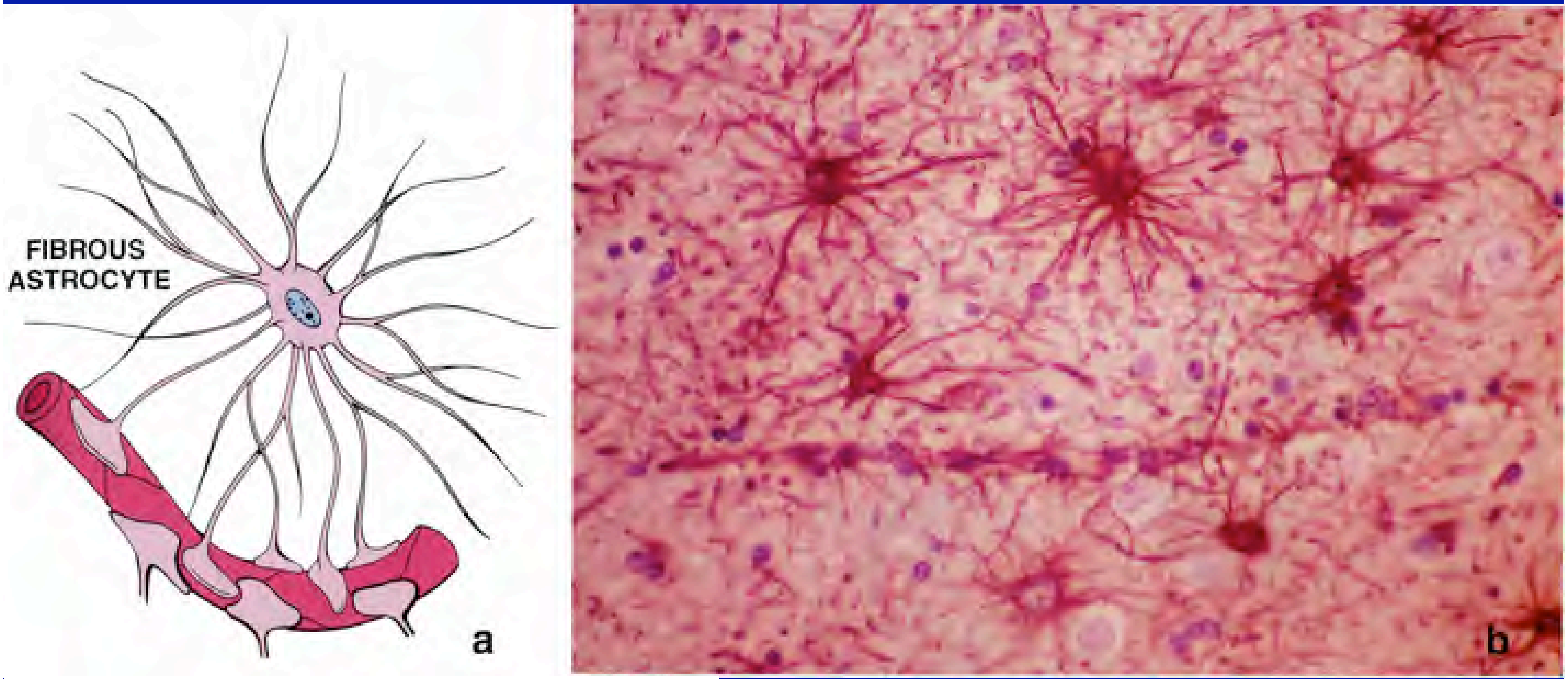


 Stevens and Lowe, Human Histology, 2nd ed Fig 7.24

 Wheater's Human Histology, 2nd ed, Fig 6.15b

Ependymal cells are ciliated and form an epithelial-like lining along the ventrical and the spinal canal surface.

Their cilia help to move the cerebrospinal fluid.



PD-INEL Histology-A Text and Atlas 4th ed, Ross et al ; Fig 11.20

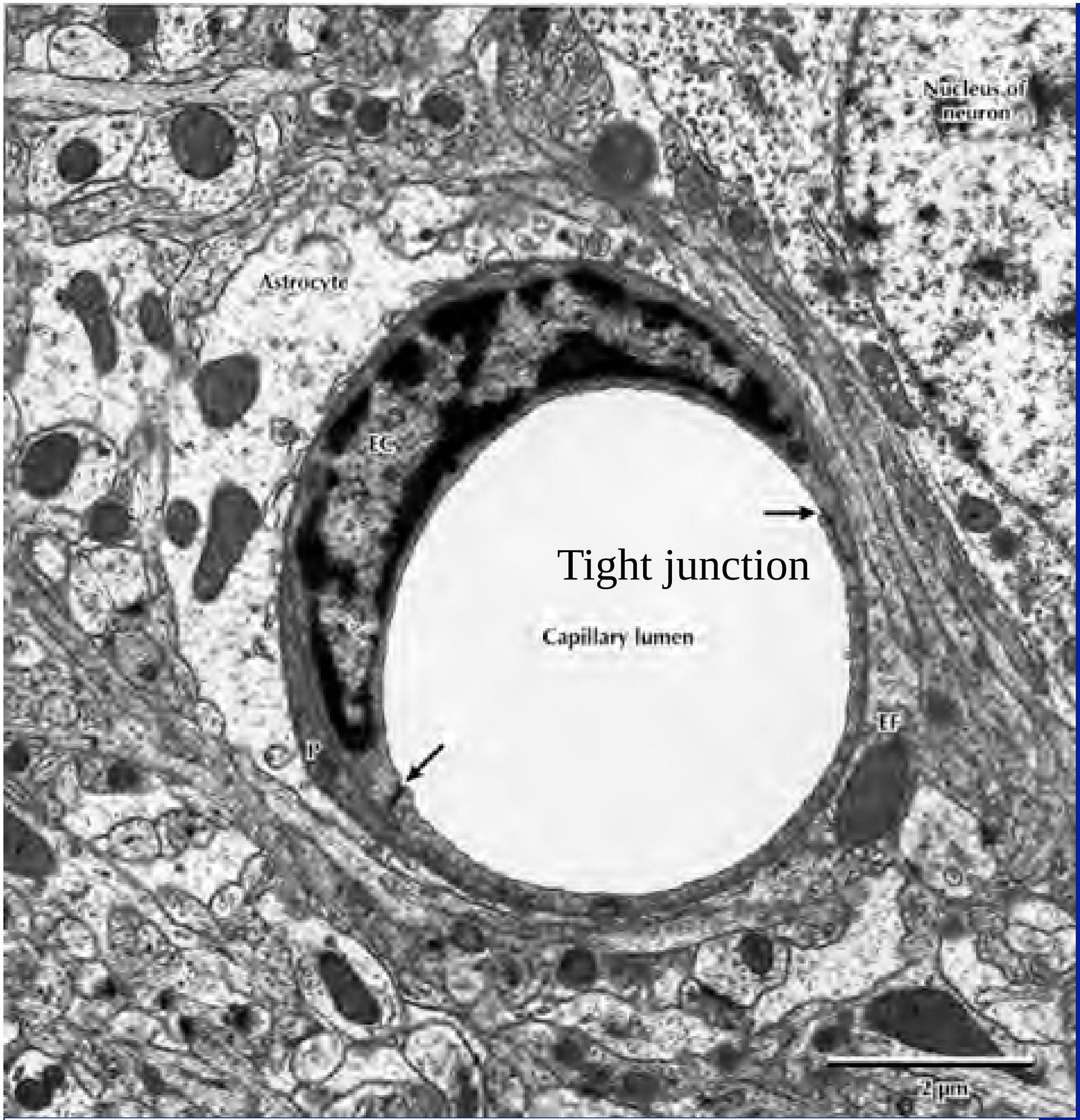
GFAP immunostaining for astrocytes
(Glial Fibrillary Acidic Protein)

The word astrocyte is derived from the Greek word άστϱον = astron for star or star-shaped)

We will not deal with differences between fibrous (white matter) and protoplasmic (gray matter) astrocytes.

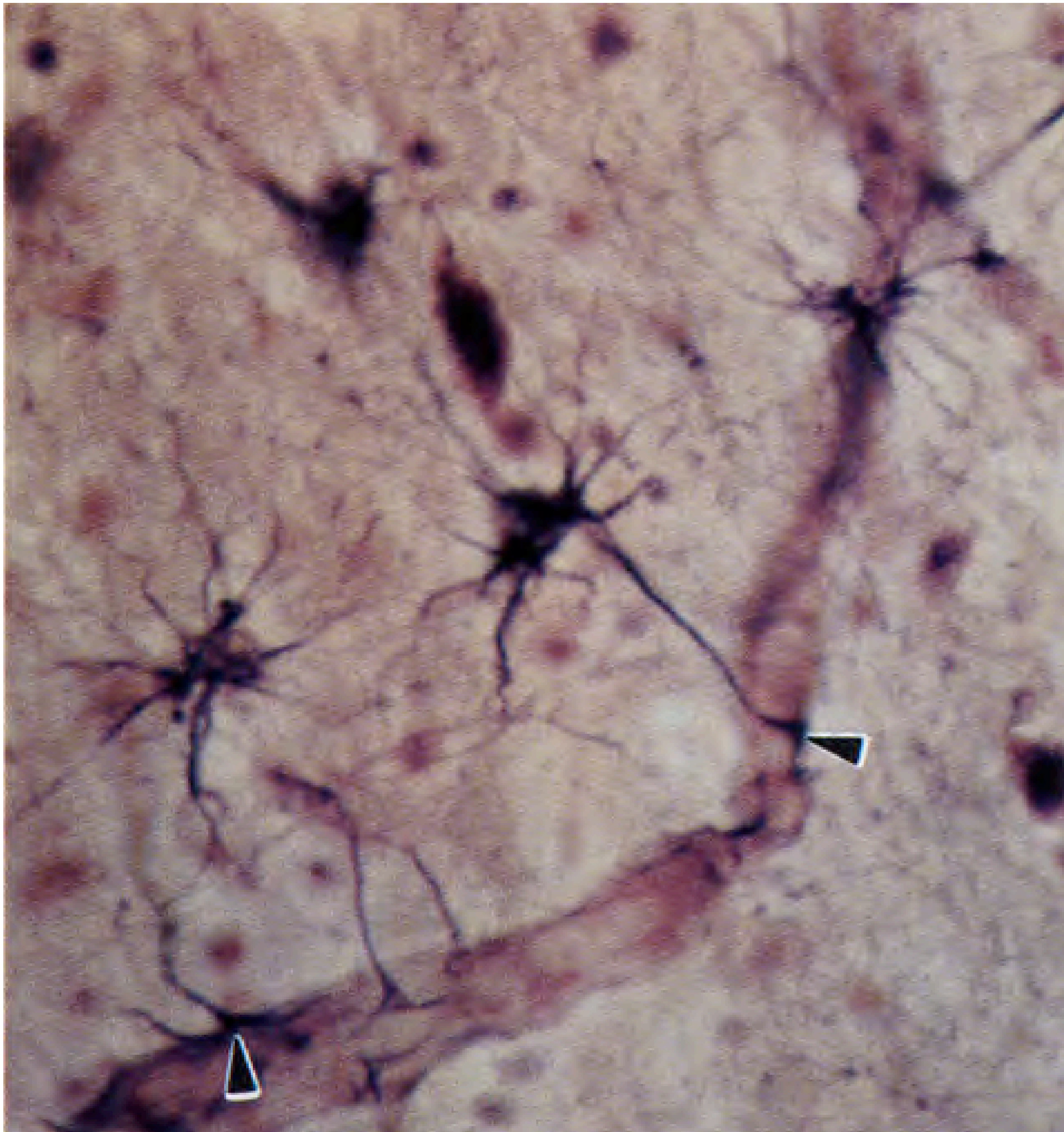
Cellular Functions of Astrocytes:

- general structural support of the brain tissue
- supply neuronal cells with nutrients, e.g. glucose
- supports synaptic activity
- reuptake and processing of neurotransmitter molecules
- stimulation of oligodendrocytes to initiate myelination
- component of glial scars



 Netter's Essential Histology; 2008; Ovalle and Nahirney; Elsevier; Pages 114 and 115

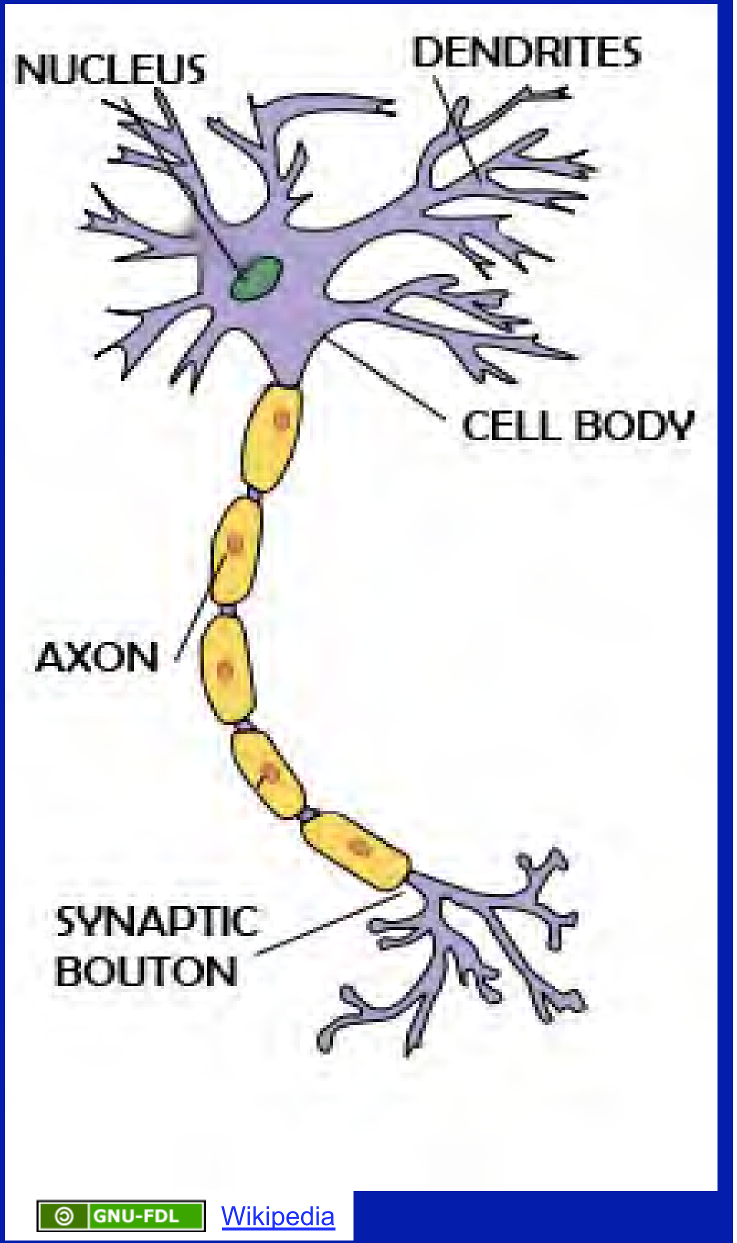
Astrocyte foot processes together with endothelial cells, which are connected by tight junctions, and the basement membrane form the <u>blood-brain barrier</u>.



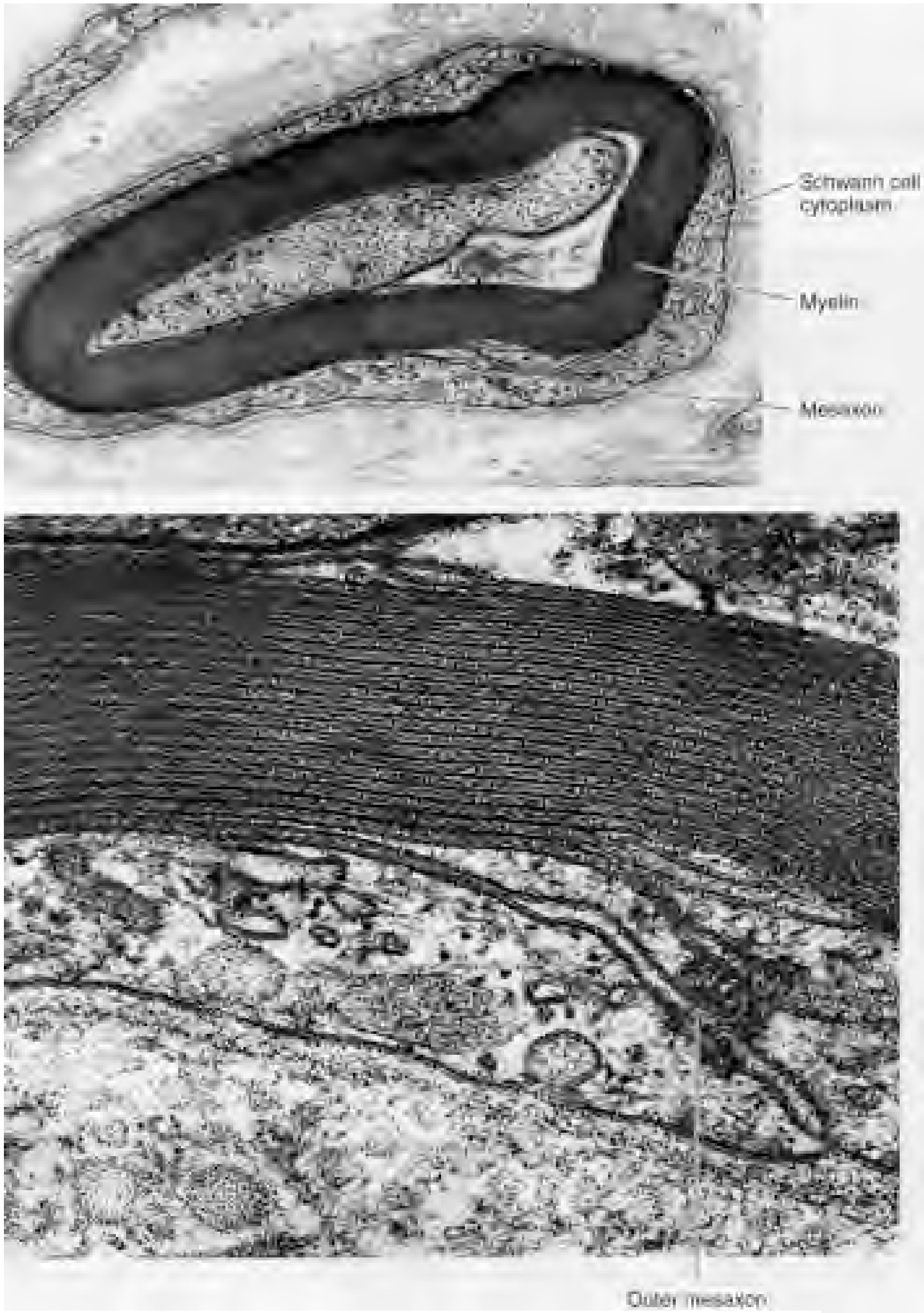
Fibrous astrocytes with foot processes wrapping around a blood capillary

 Basic Medical Histology, 1998, Kessel, Oxford University Press; Plate 27E

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

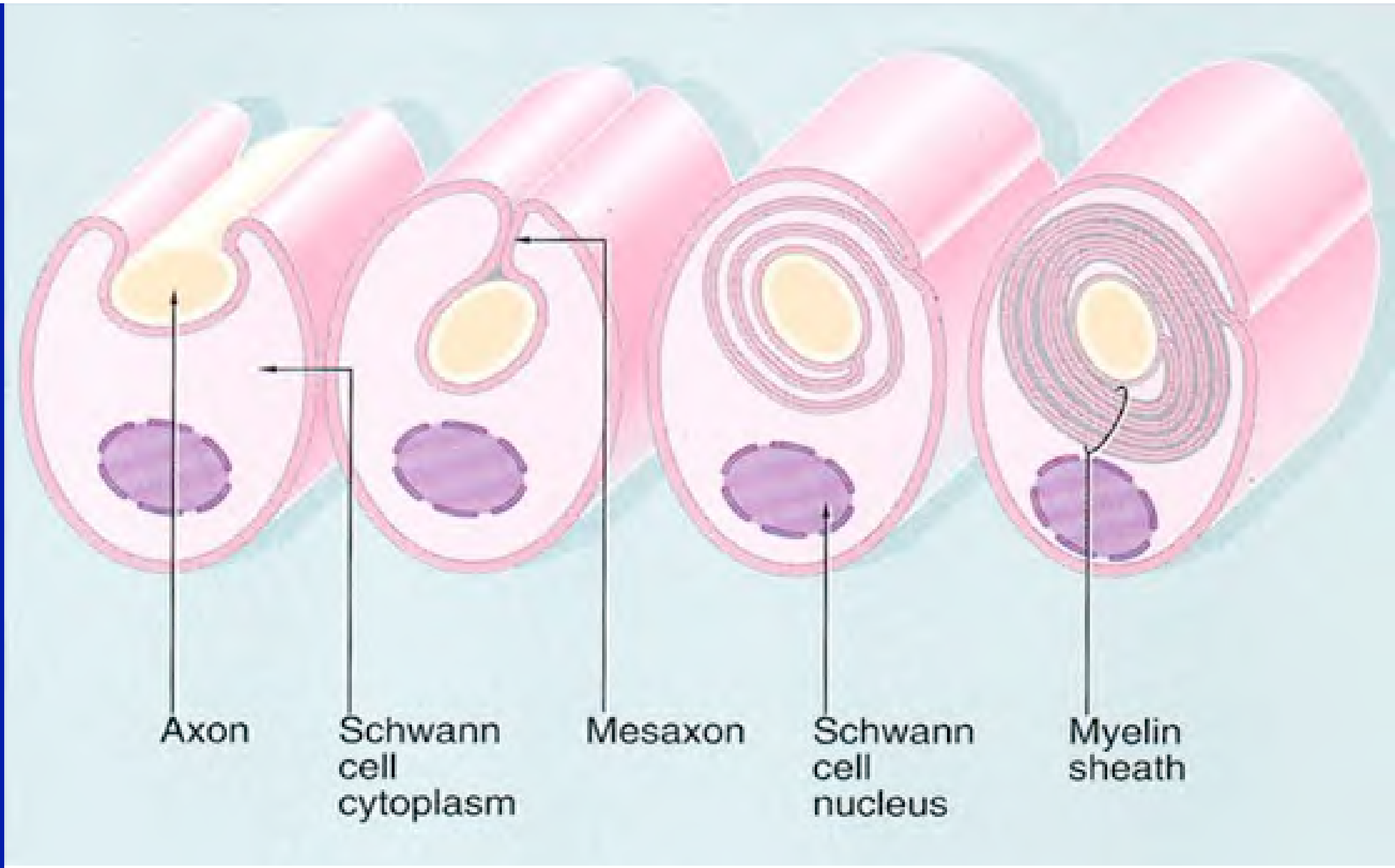


Original Image: Kelley, Kaye and Pawlina, "Histology, a Text and Atlas," 4th ed., page 284. Neuron-Ross4-284.tif.



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

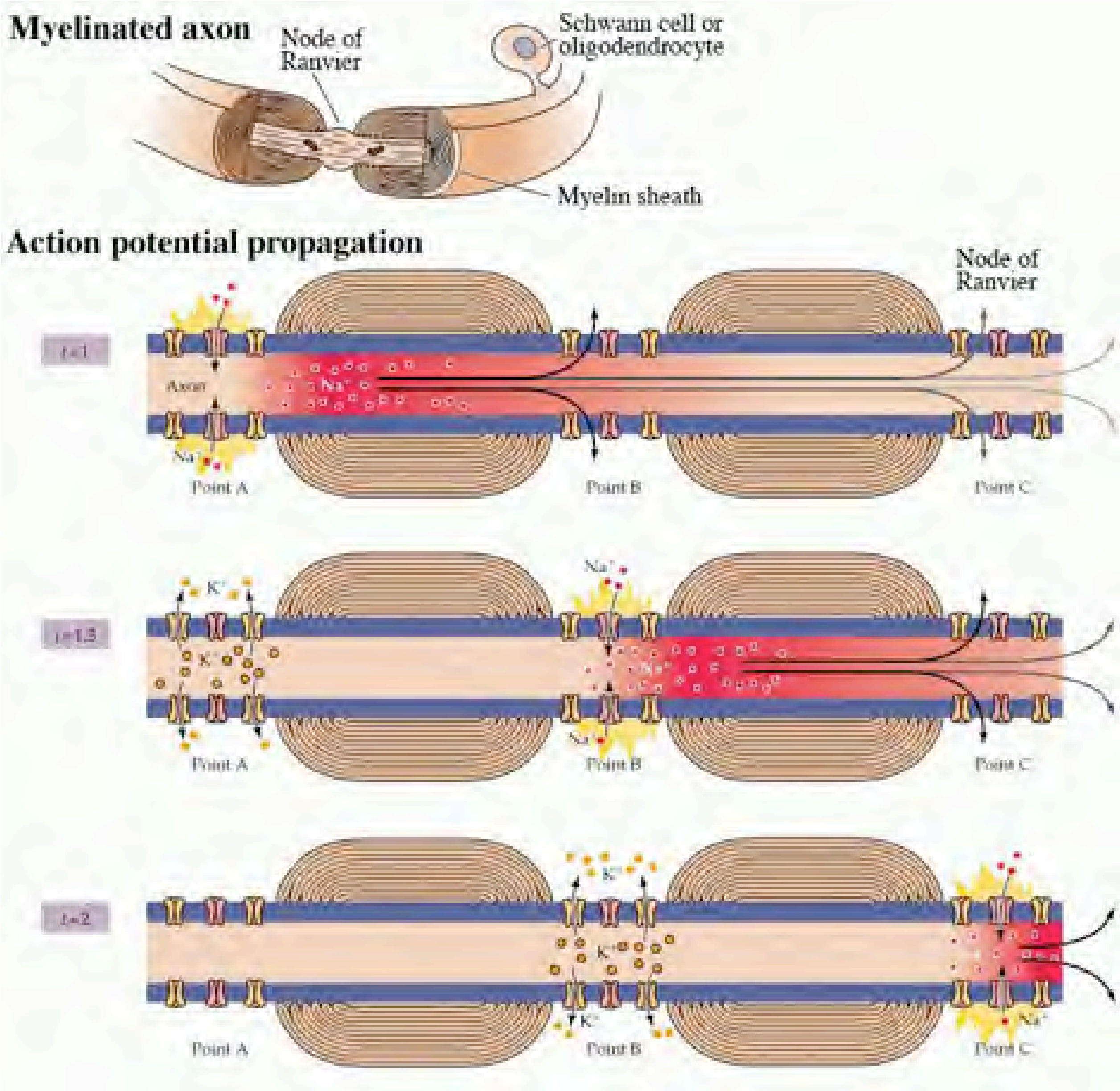
This electron micrograph of a single myelinated axon shows a series of lighter (intraperiod) and darker (major dense) lines



PD-INEL 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



PD-INEL Neuroscience by D. Purves et al., 2001, 2nd ed., Sinauer

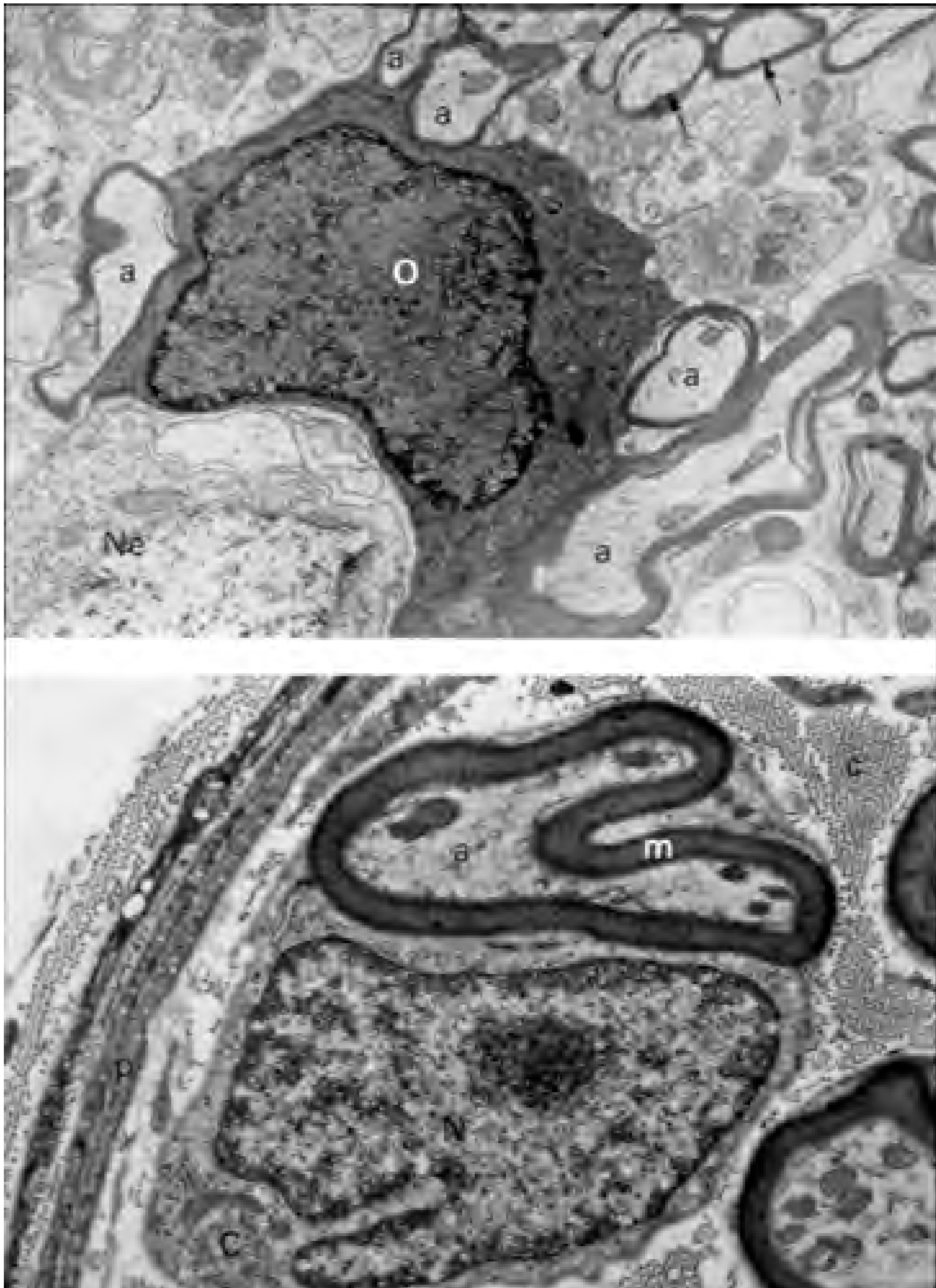
Ion channels are concentrated at the nodes of Ranvier and the myelin sheath acts as an electrical insulator. This allows for saltatory conductance of the action potential and increases the transmission speed of the nerve impuls.

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

Image of oligodendrocyte removed

Source of Removed Image:
Human Histology by Stevens and Lowe, 2nd edition, 1997, Mosby Fig 6.13a

In the PNS Schwann cells myelinate axons and in the CNS oligodendrocytes fulfill the same function. Whereas one Schwann cell myelinates only one axon, a single oligodendrocyte can myelinate multiple axons.

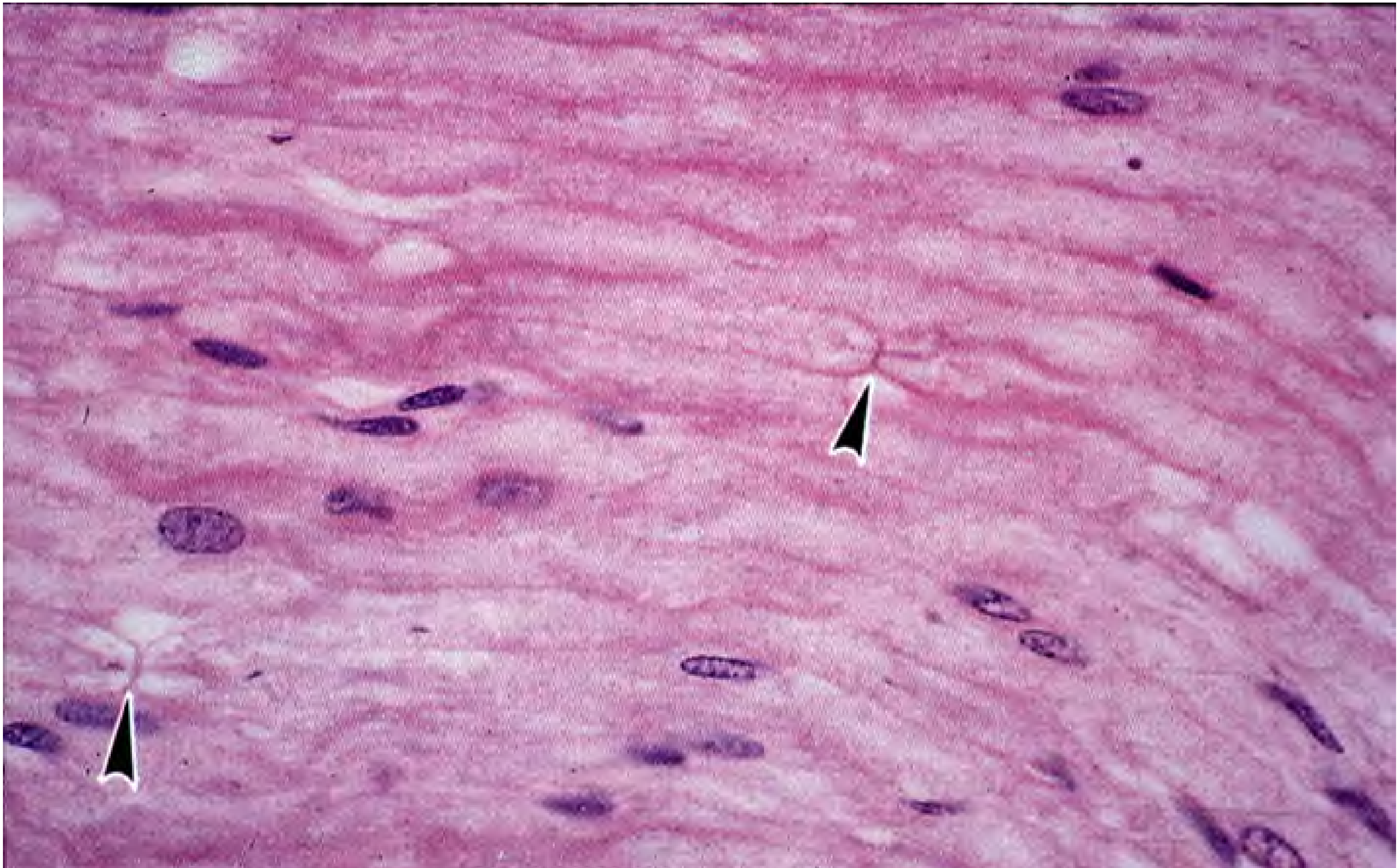


 Cell and Tissue Ultrastructure – A Functional Perspective; 1993; Cross and Mercer, Freeman and Co.; p. 139

Oligodendrocyte in the CNS

and

Schwann cell in the PNS

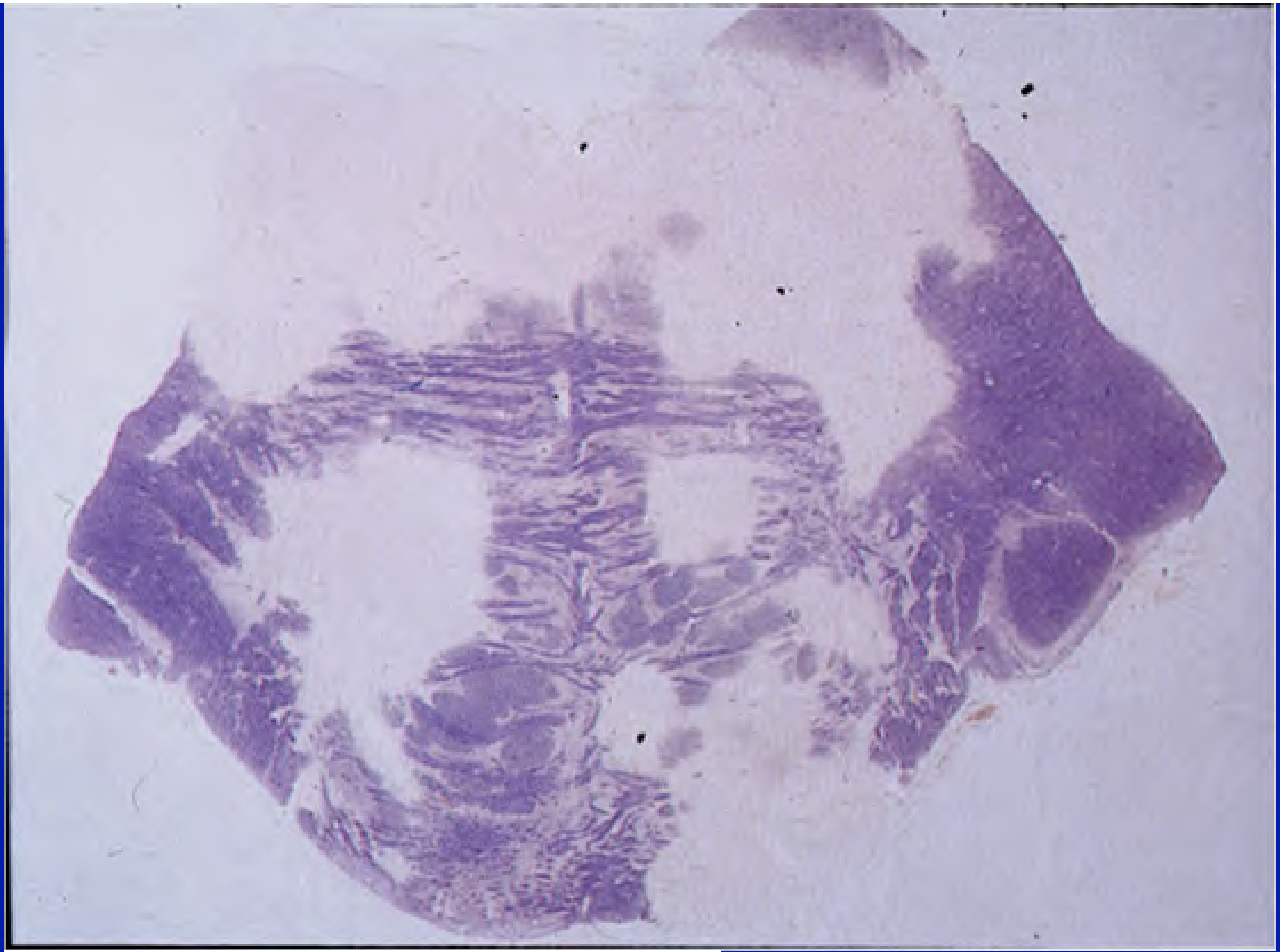


Nodes of Ranvier in a longitudinal nerve section

Diagram of the process of multiple sclerosis removed

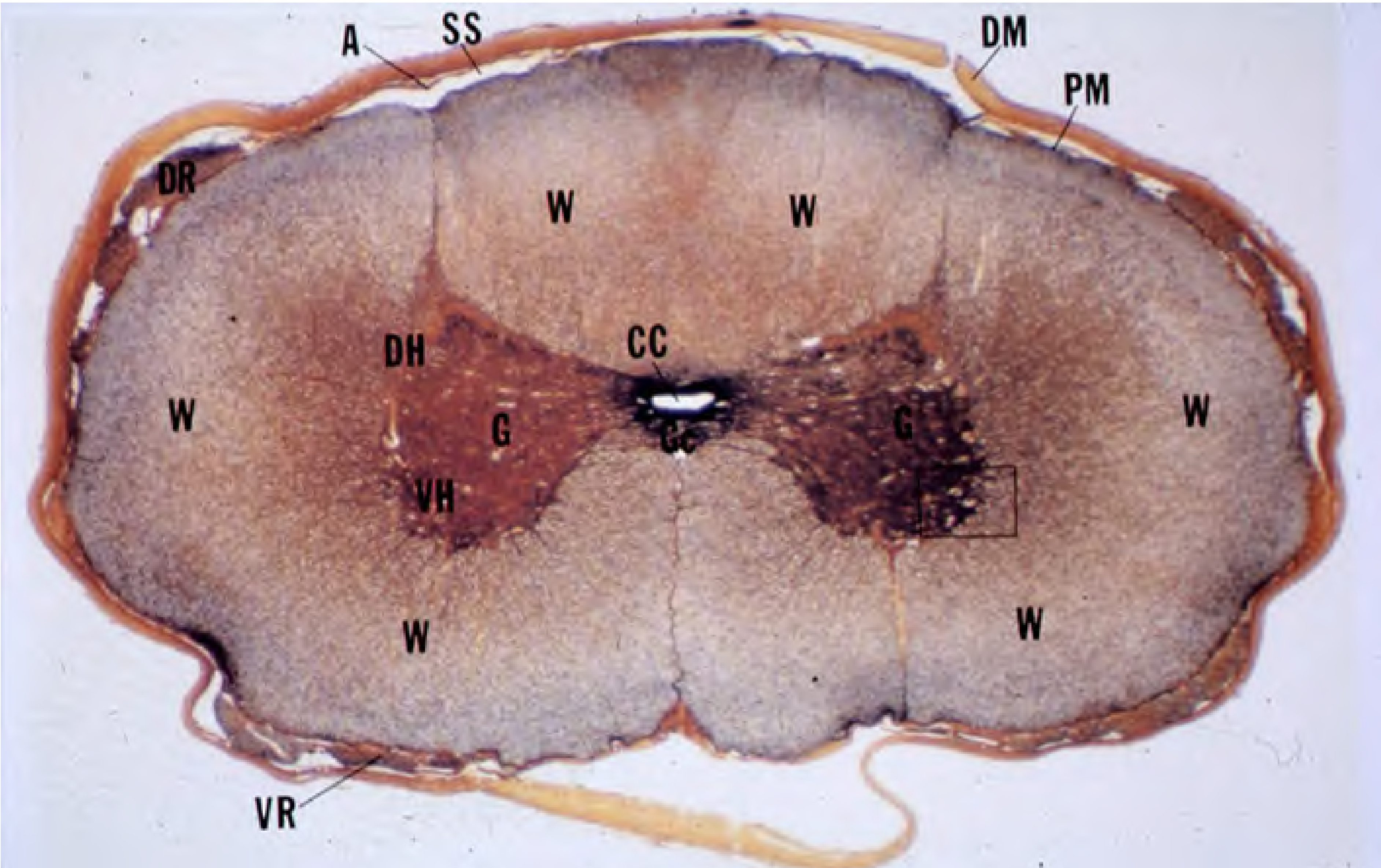
Source of Removed Image: R&D Systems Autoimmunity Poster 2006 R&D Systems, Inc.

In Multiple Sclerosis (MS) patients the myelin is destroyed by an autoimmune response



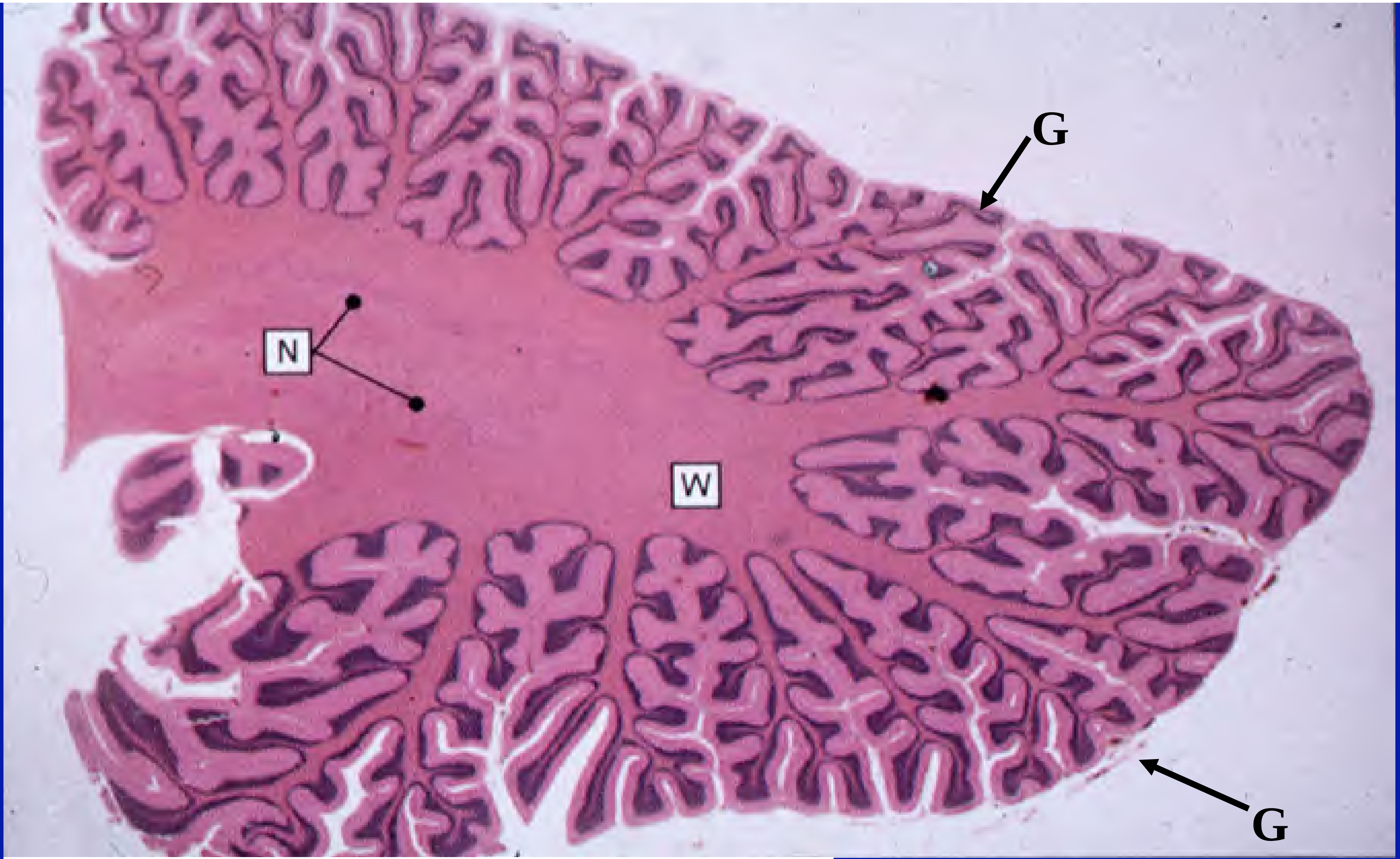
PD-INEL Stevens and Lowe Human Histology 2nd ed; Fig 6.14

Pons region of an MS patient (blue stain represents myelin)



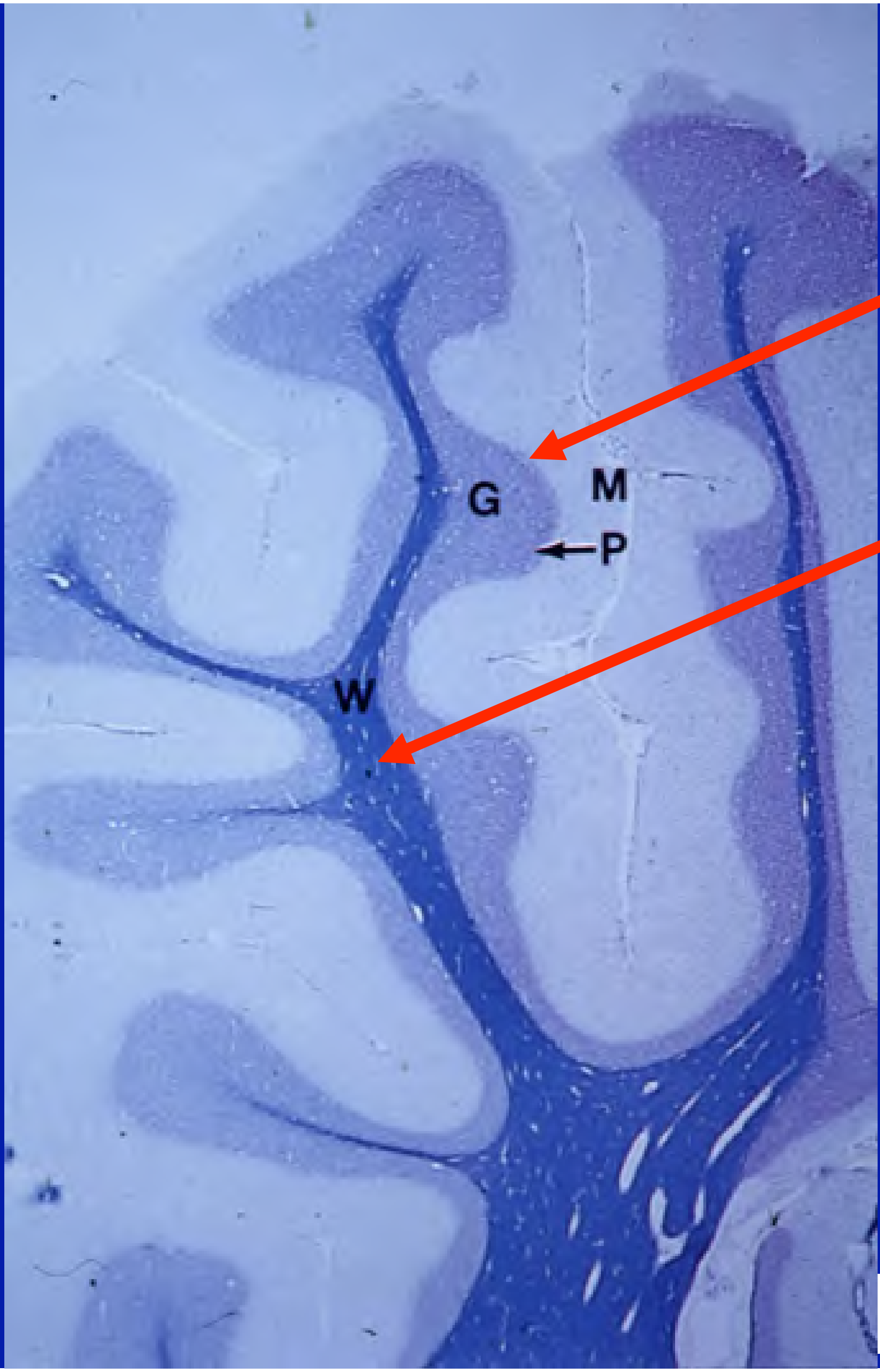
Color Textbook of Histology; 2nd edition, 1994; Gartner and Hiatt; Williams and Wilkins; Fig 71

Cross section of the spinal cord. Gray matter (G) contains the neuronal cell bodies and the white matter (W) mostly axons and glial cells.



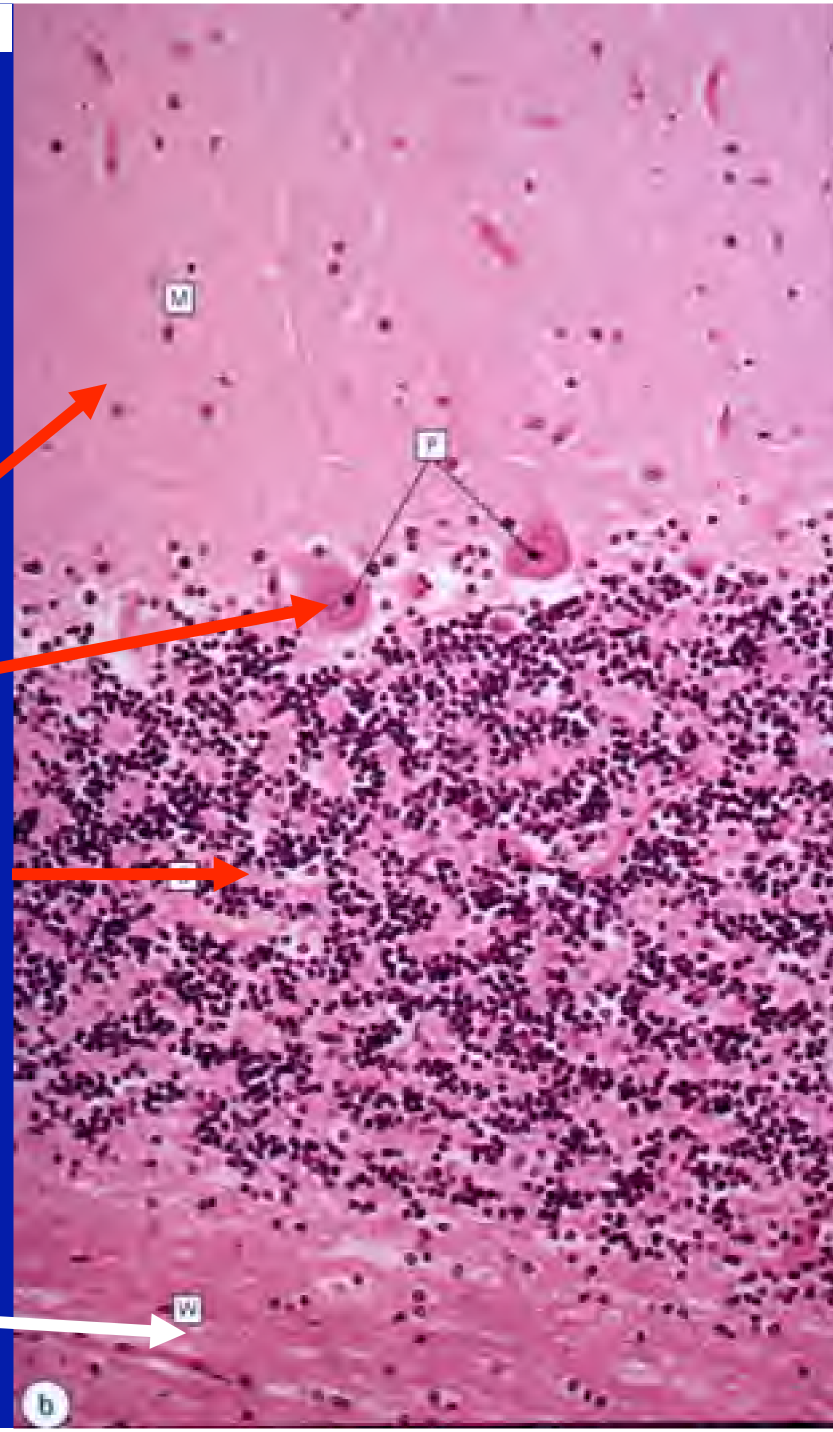
 Human Histology, 2nd edition, Stevens and Lowe, Mosby ; Fig. 6.27a

Similarly, in the cerebellum white matter (W) contains mostly axonal tracts, whereas the external gray matter (G) neuronal cell bodies, dendrites and axons. Note the folded structure of the cerebellar cortex.



Gray (G, P and M) and white matter (W) in a cerebellum section, which was stained with Luxol blue.

The three layer structure of the gray matter in the cerebellum is very obvious.



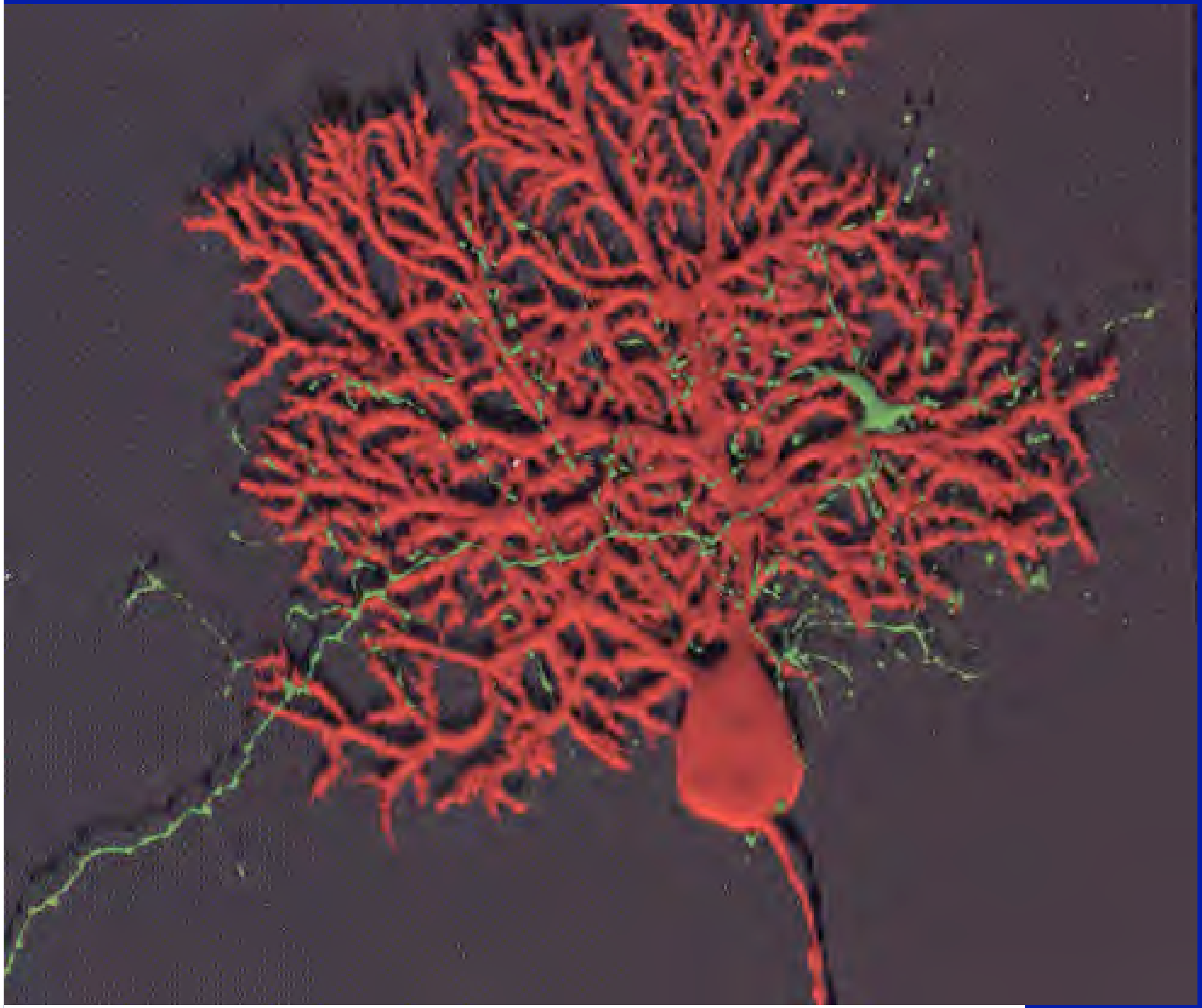
Molecular layer

Purkinje cell layer

Granular layer

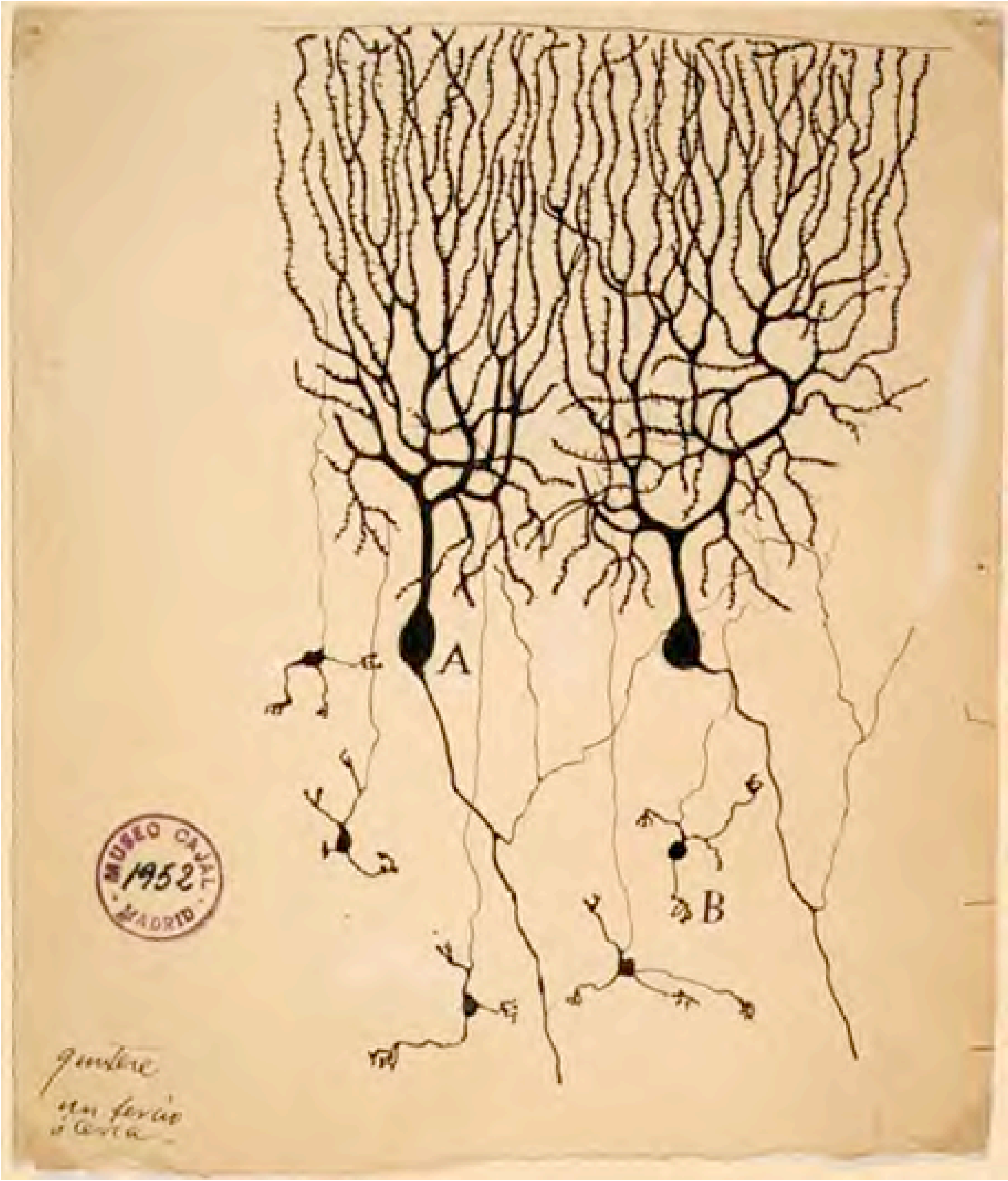
White matter

Jan Evangelista Purkinje (1787-1869)

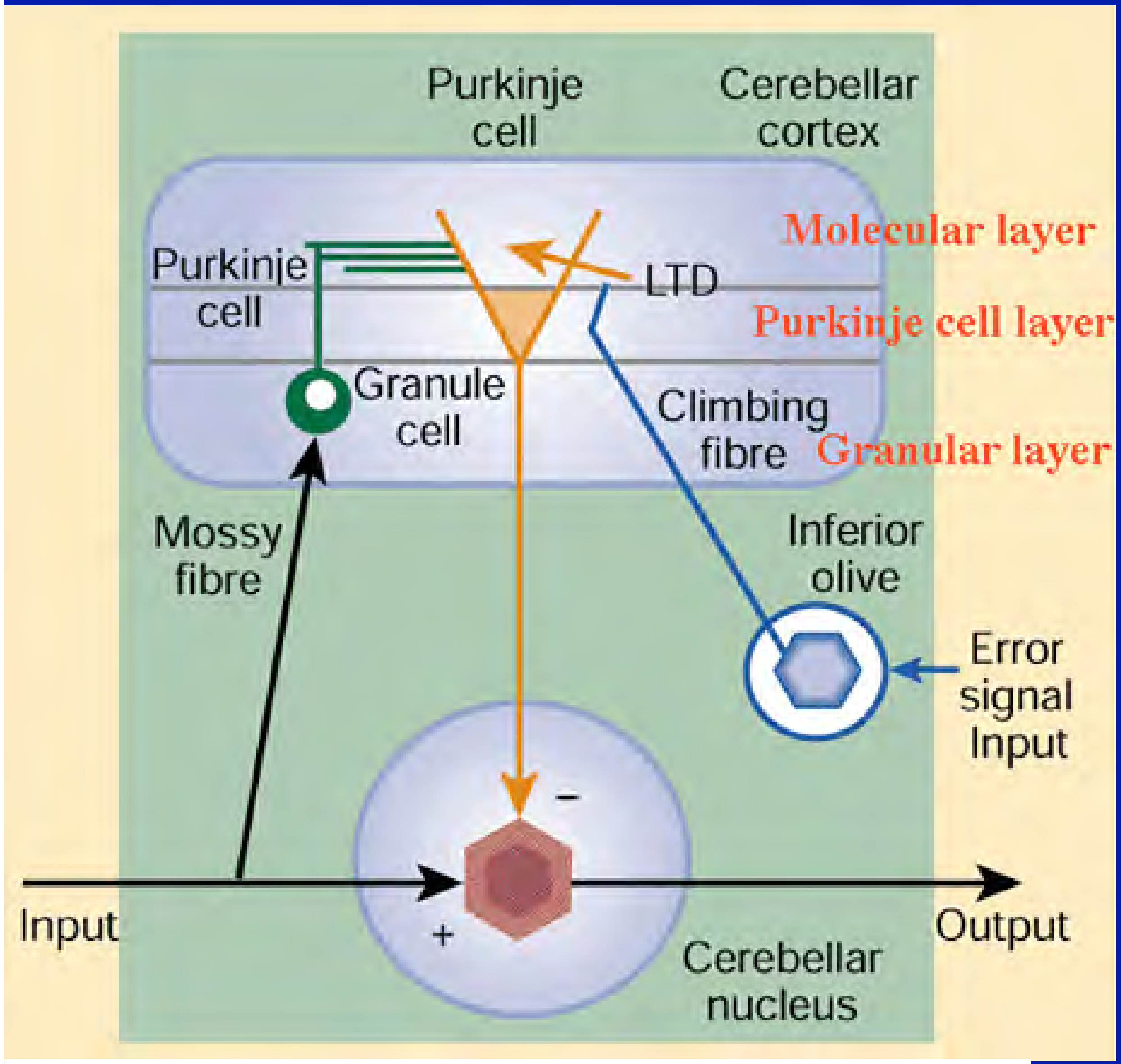


PD-INEL Dr. Michael Häuser, Dr. B. Clark, Univers ity College London, United Kingdom

Purkinje cells have an extensive dendritic tree that extends throughout the molecular layer. Shown is a Purkinje cell (Texas Red) in culture, which has developed multiple synaptic connections with an interneuron (Lucifer Yellow).



- Drawing of Purkinje cells (A) and granule cells (B) from a pigeon cerebellum.
- Purkinje cells are GABAergic neurons, which receive excitatory inputs from deeper layer glutamatergic granule cells and inhibitory inputs from molecular layer neurons.
- Purkinje cells themselves send inhibitory projections to deeper cerebellar nuclei.

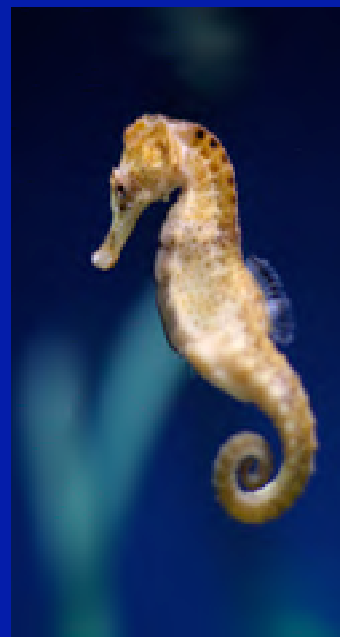


 Neurobiology: Internal model visualized; Masao Ito; Nature 403, 153-154 (2000)

Neuronal cells in each cerebellar layer have specific stereotypic excitatory or inhibitory connections with other neurons in the same layer, in other layers of the cerebellum and/or other parts of the nervous system.

Animation of hippocampal formation and septal region removed

Source of Removed Animation: http://video.google.com/videoplay?docid=-9215765857714551521

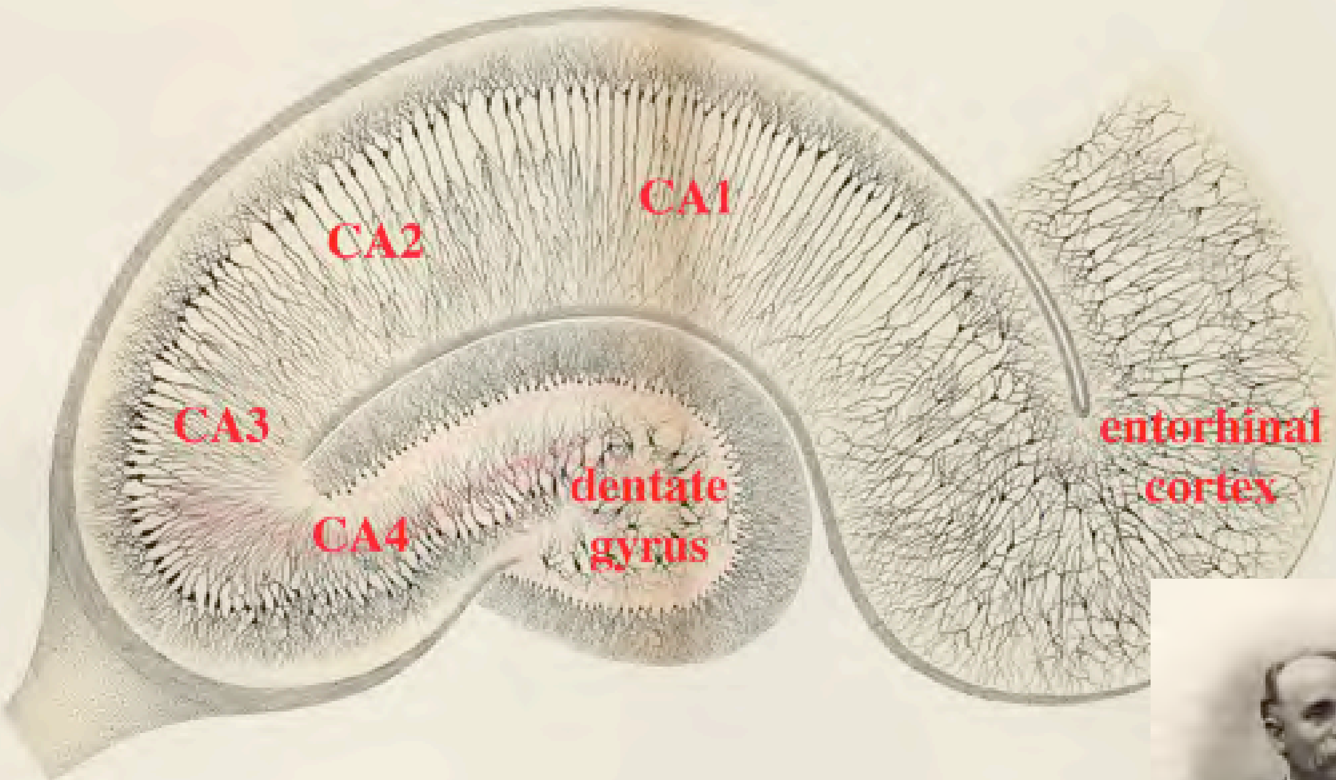


Also other parts of the CNS follow the same organizational principles as the cerebellum. Another example is the hippocampus (also Cornu Ammonis) that is part of the forebrain, an "old" brain structure.

The hippocampus is important for long term memory and is especially sensitive to hypoxia. It is also the first part of the brain that is affected by Alzheimer's disease.

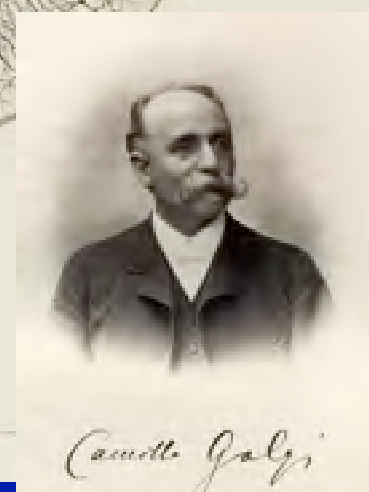
It derives its name "hippocampus" from the Greek word for seahorse (ἵπποκαμπος for horse monster) as its resembles the shape of a seahorse.

Drawing of the hippocampus by Camillo Golgi
Subregions of the hippocampus exhibit histological differences



C. Golgi del.

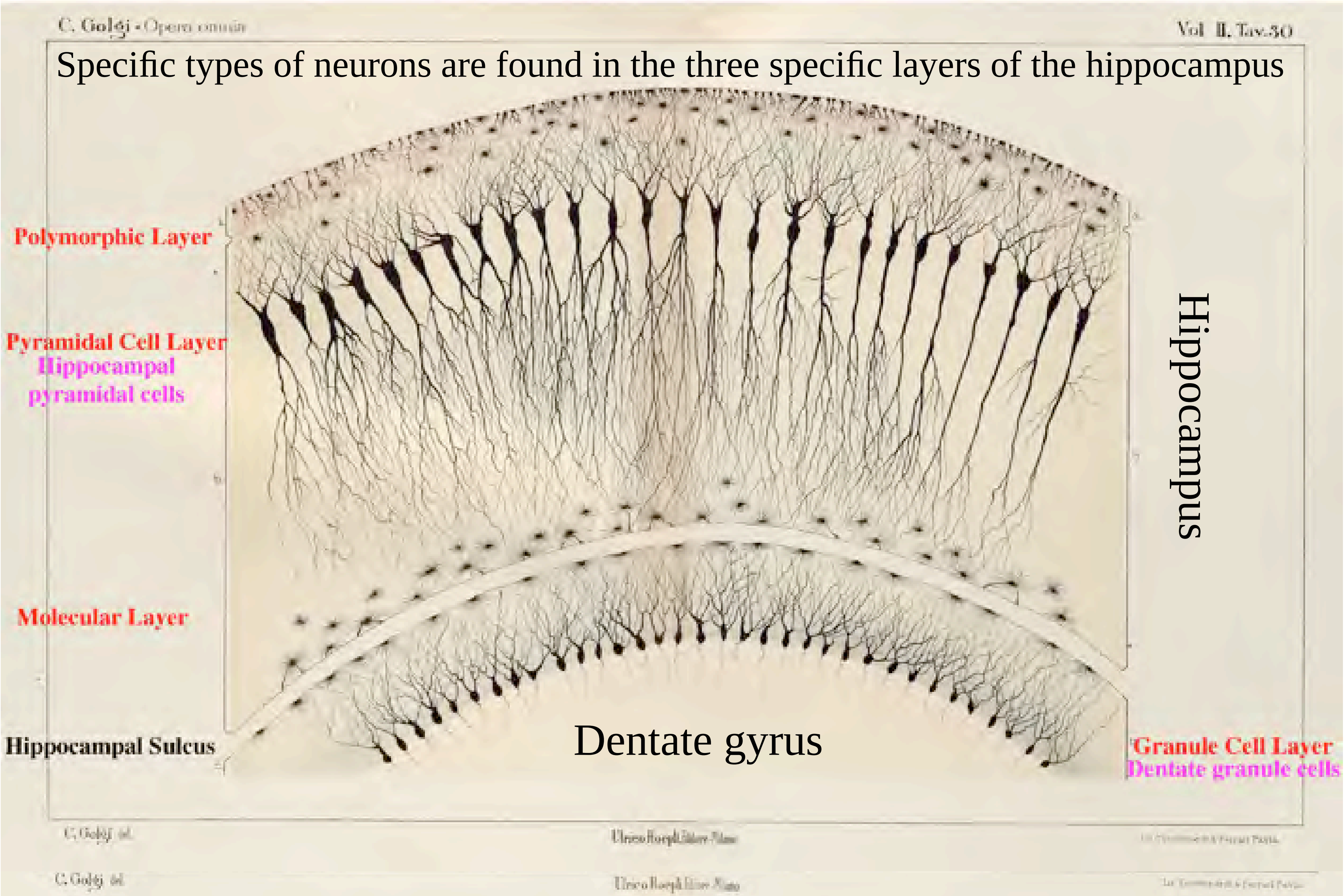
Ulrico Hoepli Editore Milano



Camillo Golgi (1843-1926)

Camillo Golgi "Opera Omnia" Vol. II Sulla fina anatomia degli organi centrali del sistema nervoso. Ulrico Hoepli, Milano (1903)

Specific types of neurons are found in the three specific layers of the hippocampus



Camillo Golgi “Opera Omnia” Vol. II Sulla fina anatomia degli organi centrali del sistema nervoso. Ulrico Hoepli, Milano (1903)

Hippocampus polymorphic layer

Pyramidal cell layer (Hippocampal Pyramidal cells)

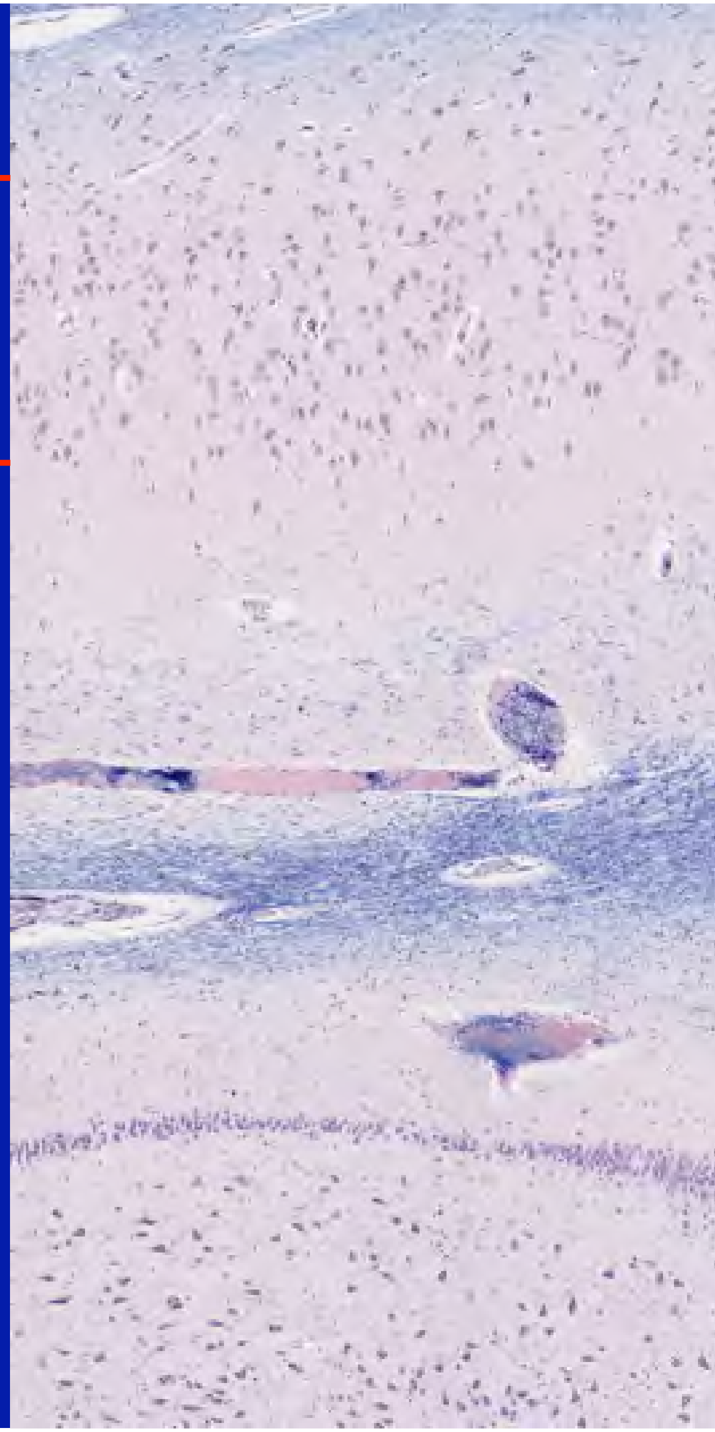
Hippocampus molecular layer

Dentate molecular layer

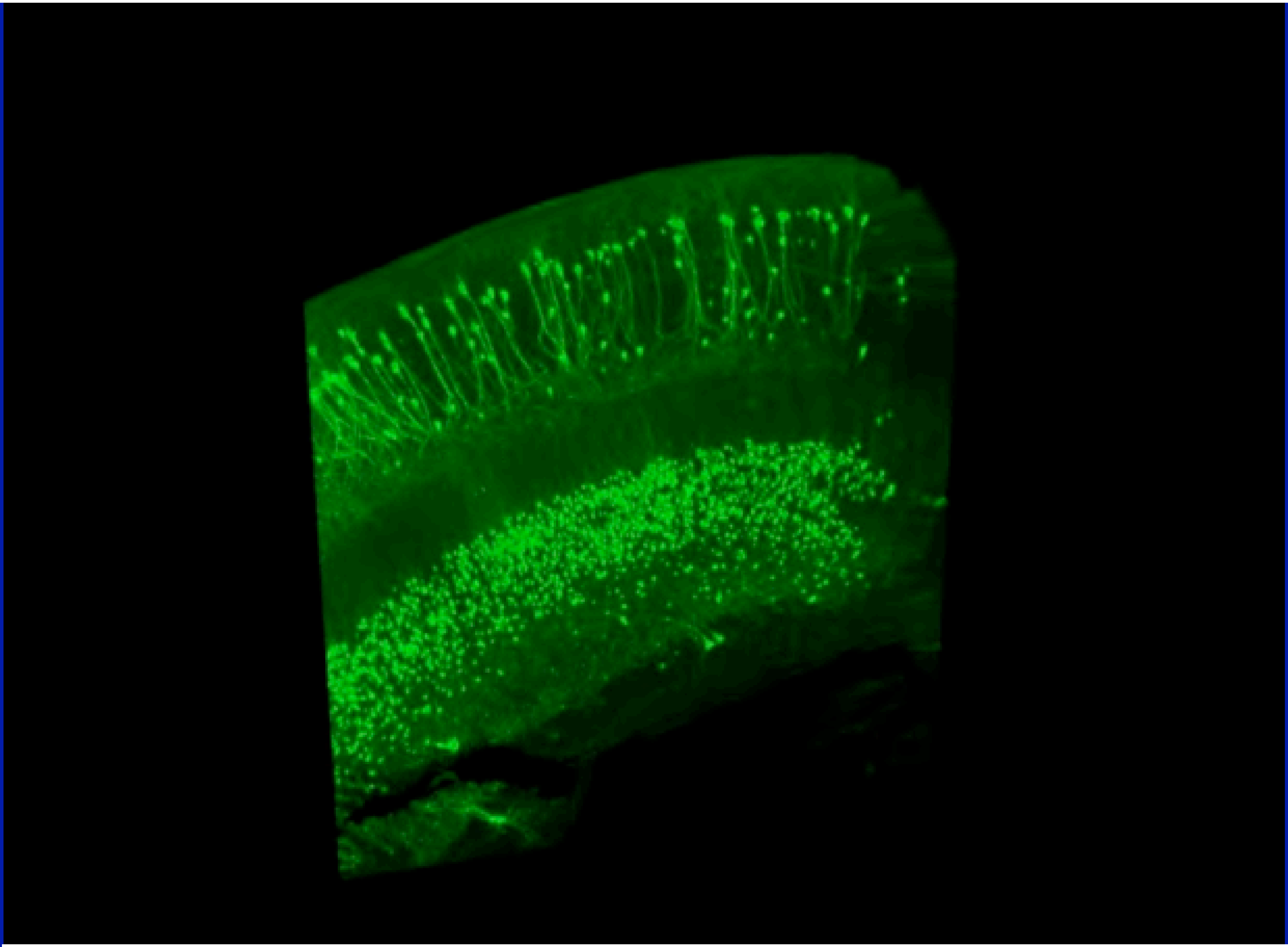
Granule Cell Layer (Dentate granule cells)

*

Dentate polymorphic layer

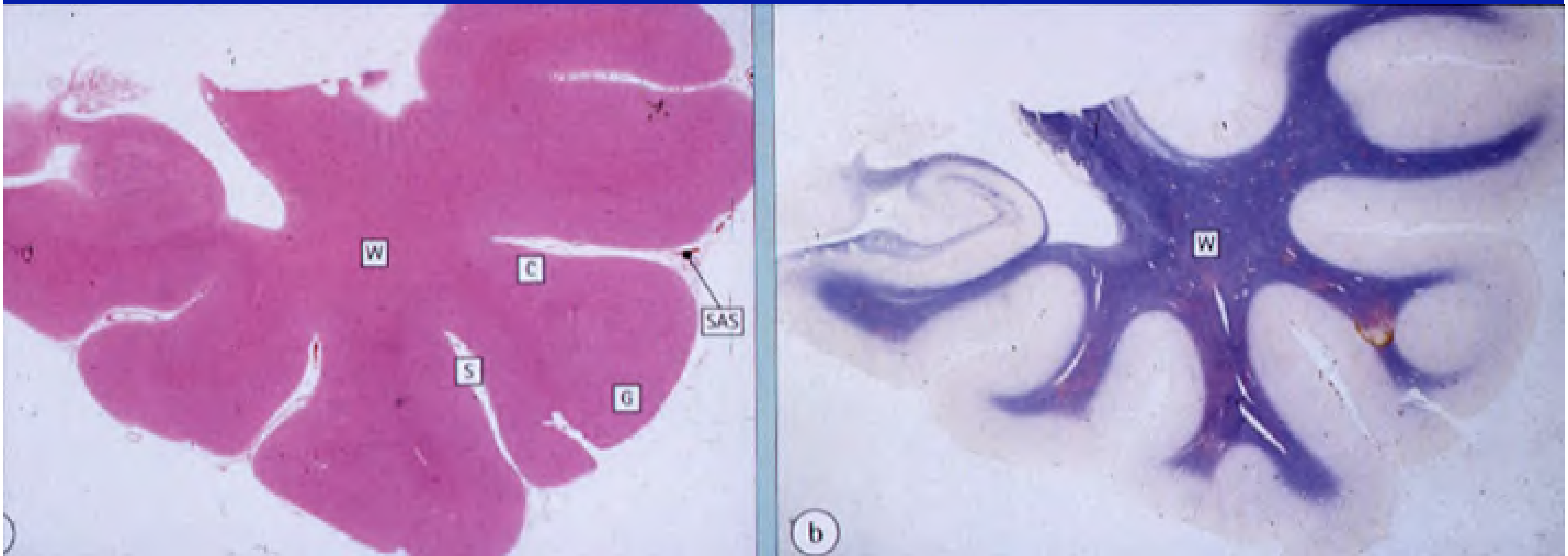


Luxol blue staining of the CA1 region of the hippocampus and part of the dentate gyrus.



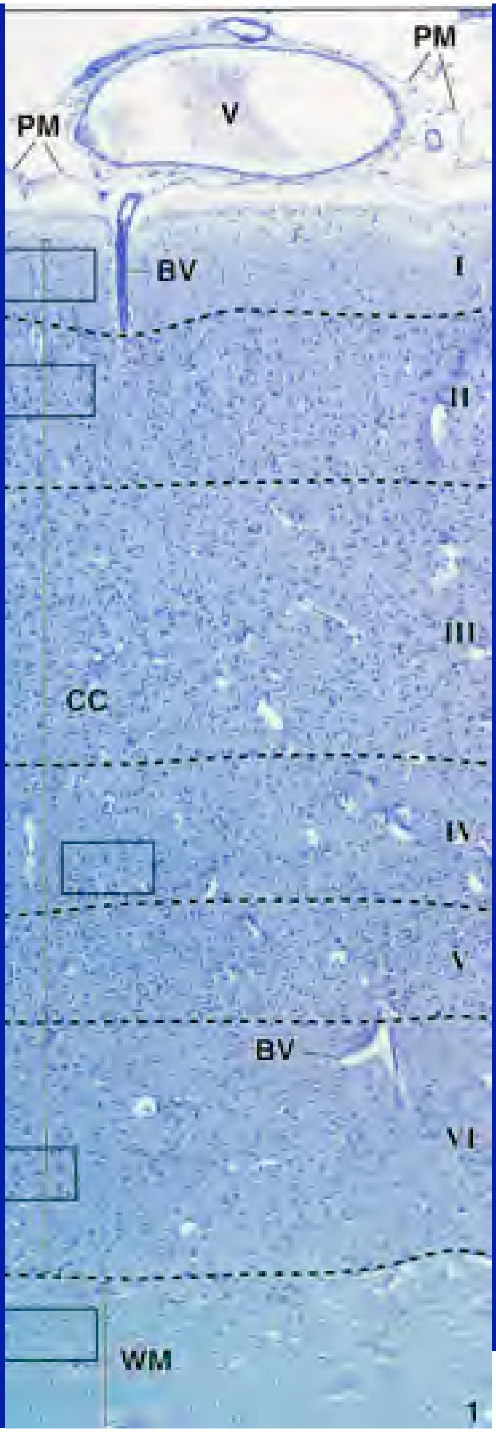
PD-INEL Nature Methods - 4, 331-336 (2007) “Ultramicroscopy: three-dimensional visualization of neuronal networks in the whole mouse brain” by Dodt et al.

3D-reconstruction and animation of a part of a whole mouse hippocampus. Neuronal cells are labeled green by the expression of GFP.



PD-INEL Human Histology, 2nd edition, Stevens and Lowe, Mosby ; Fig. 6.24

Similar to the cerebellum the folded structure (gyri and sulci) of the cerebral cortex increases its size.
The cerebral cortex is also subdivided into gray (G) and white (W) matter.

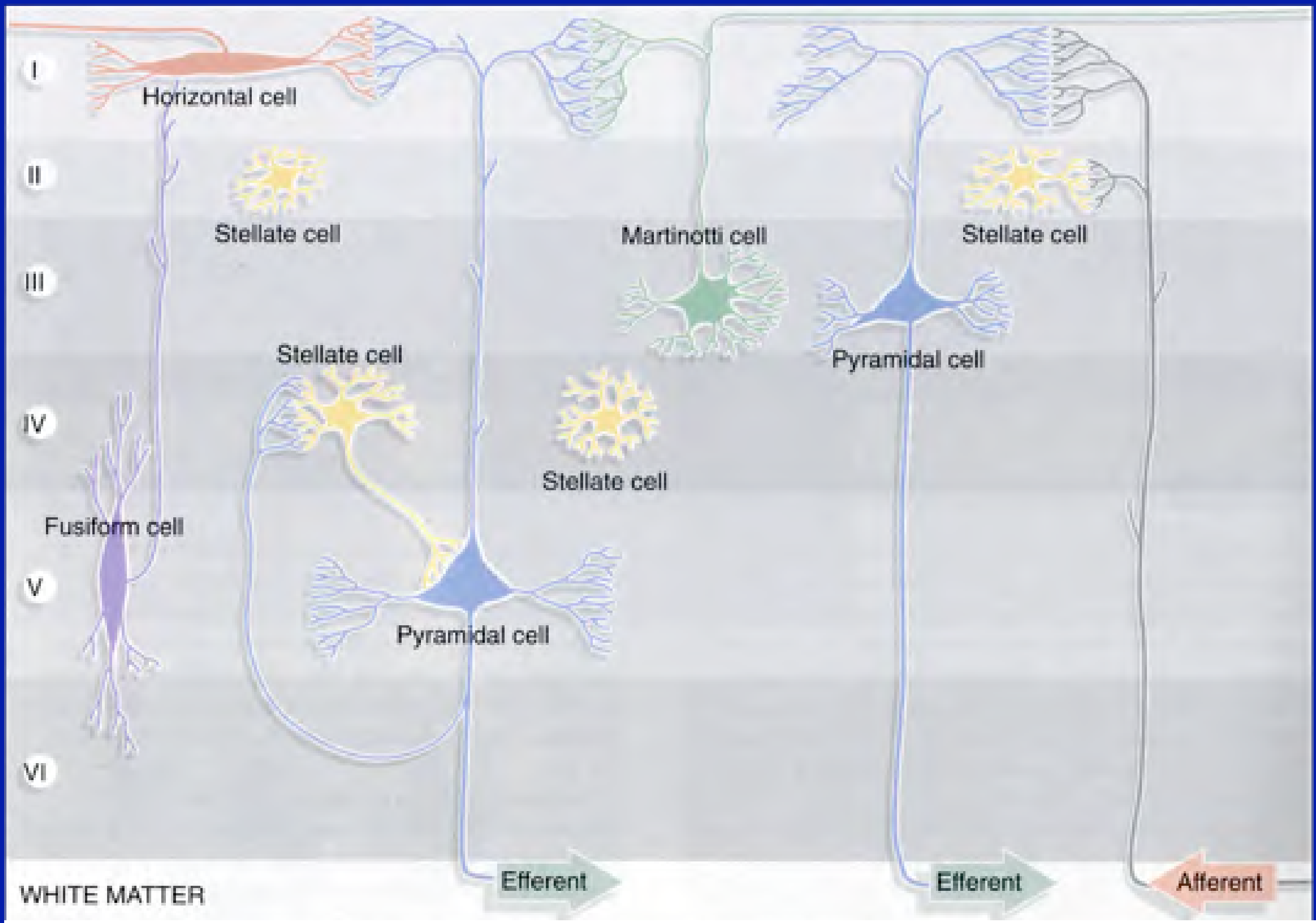


The layered structure of the cerebral cortex is more complex than that of the hippocampus and the cerebellum.

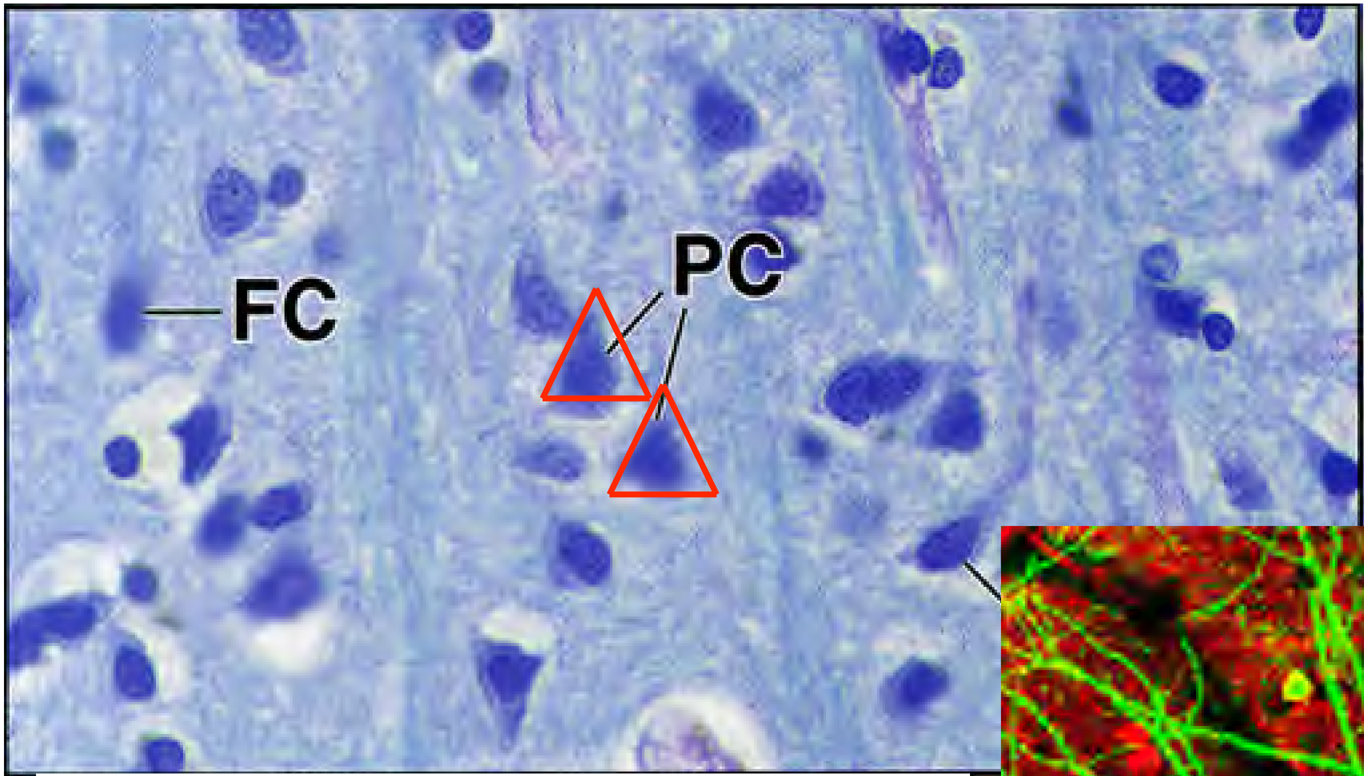
It is subdivided into 6 cellular layers, which have unique neuronal cell types and connections.

 Histology-A Text and Atlas; 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins; Part of Plate 25

Each cerebral layer has its characteristic neuronal cell types, which are stereotypically connect to other neurons in its own layer or with neurons in other cerebral layers or other parts of the nervous system.



 Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 20.8a



 Histology – A Text and Atlas; 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins; Part of Plate 25

Fig 6f from "Dynamic Remodeling of Dendritic arbors in GABAergic Interneurons of Adult Visual Cortex" by Lee et al in PLoS Biology Vol. 4 No. 2 e29

E.g., pyramidal cells (P), which are named for the shape of their somata, are found in layers 3 and 5 of the cerebral cortex.

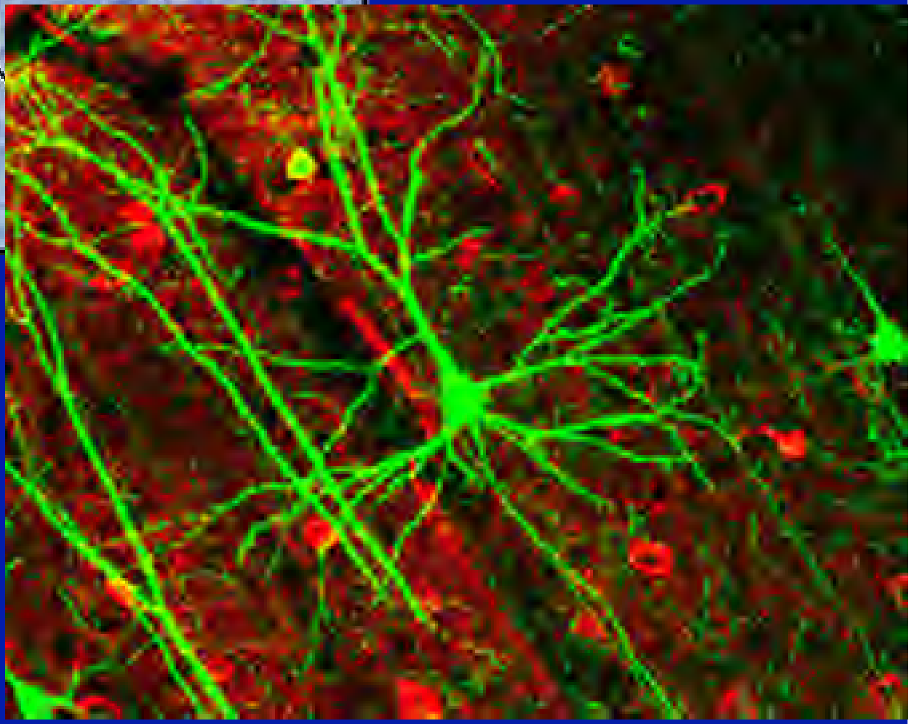
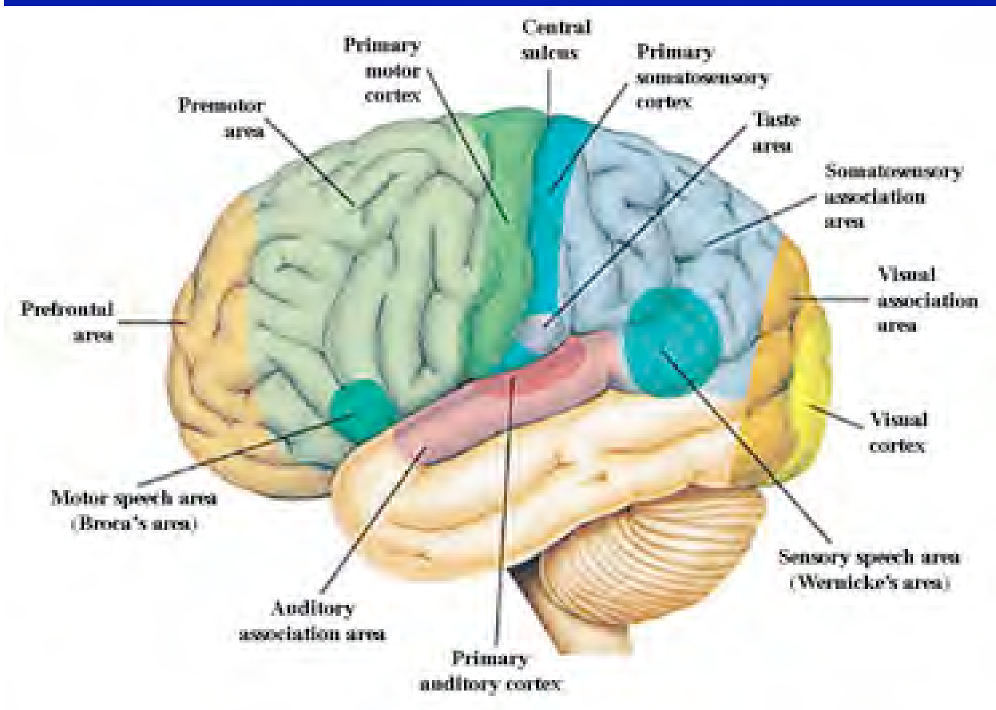


Image of pyramidal neurons in mouse cerebral cortex expressing GFP. The red staining indicates GABAergic interneurons.

The stratification of the cerebral cortex is like a Black Forest Cake.

It always has the same types of layers with the same composition (chocolate cake, cherries and cream). However, the thickness of the layers and the size of the cherries (neurons) exhibits regional differences.



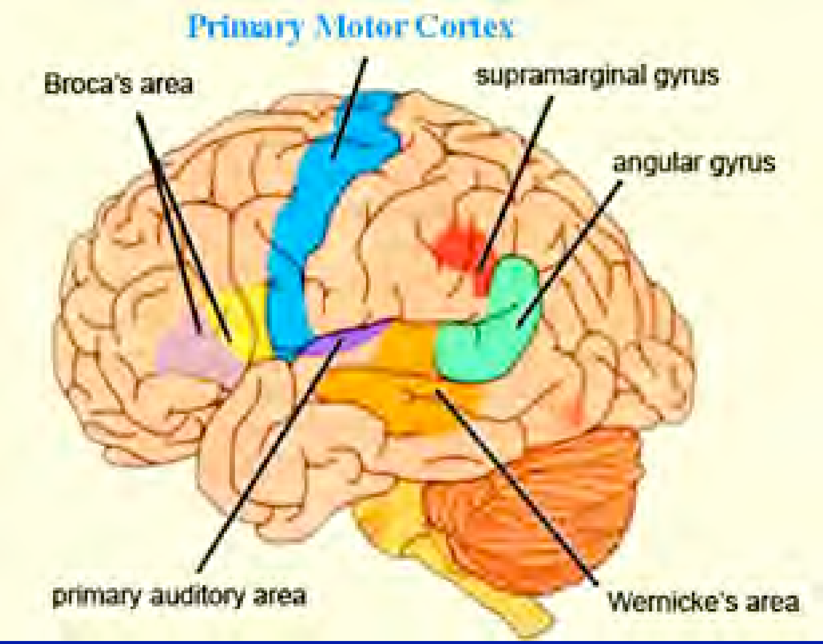
 Essentials of Anatomy & Physiology, Seeley and others, p. 210

Image of neocortex layer variation removed

Source of Removed Image:
http://www.learningdiscoveries.com.au/StagesofBrainDevelopment.htm

This typical six layer structure is conserved throughout the cerebral cortex.

However, there are regional differences in the thickness of individual layers and the appearance of specific neuronal cell types.

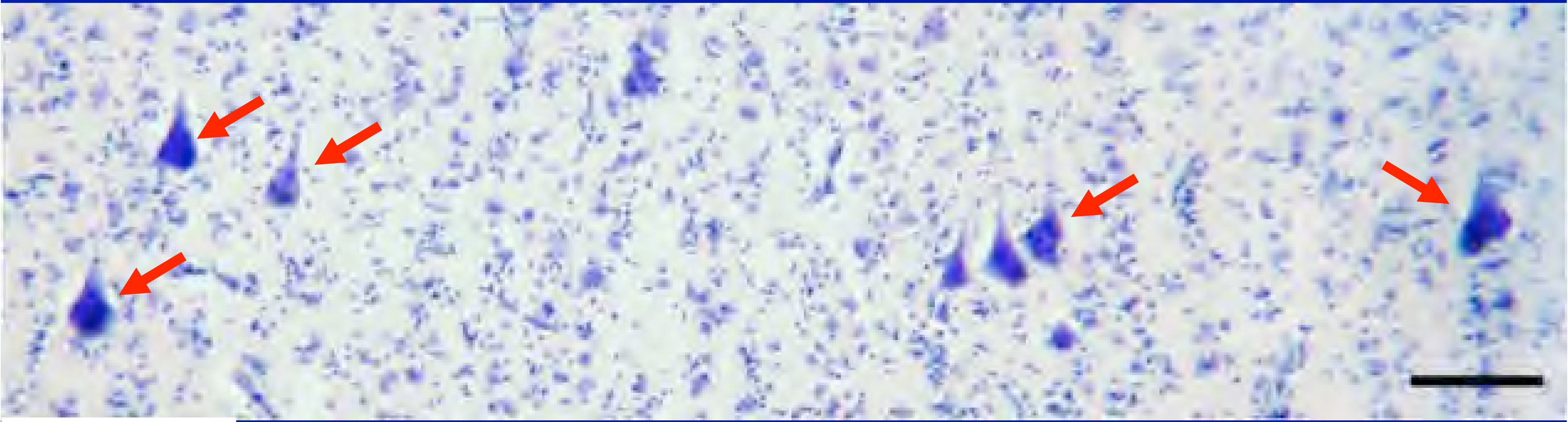


PD-INEL Canadian Institute of Neurosciences

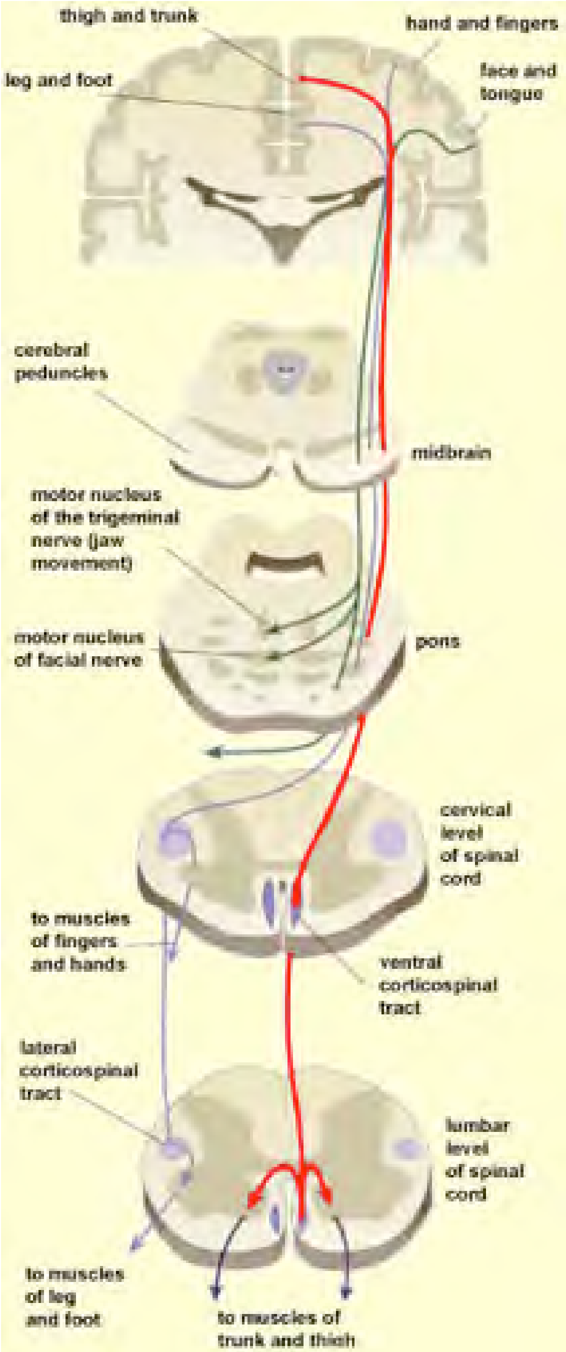
Layer 5 of the primary cerebral motor cortex has especially large pyramidal cells (up to 100 μm in size), which are named Betz cells after their discoverer.

Vladimir Alekseyevich Betz (1834-1894)

GNU-FDL Wikipedia

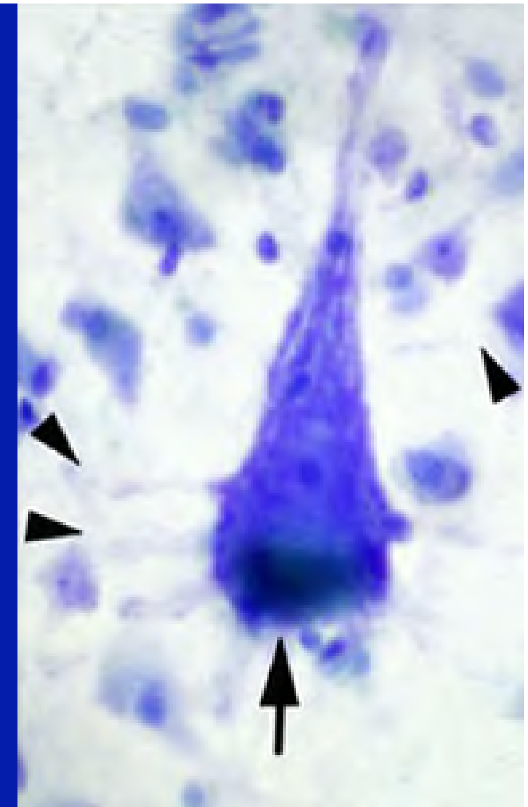


PD-INEL Picasa



PD-INEL [Canadian Institute of Neurosciences]

PD-INEL Source Undetermined



PD-INEL Claire-Bénédicte Rivara, [Les cellules de Betz du cortex moteur primaire analyse stéréologique et fonctionnelle]

Betz cells are multipolar, glutamatergic neurons and provide the major output of the primary cerebral motor cortex. Via the corticospinal tract their axons connect with alpha motor neurons in the ventral horn of the spinal cord.

Principles of CNS organization:

- All parts of the CNS are subdivided into gray and white matter.
- Gray matter contains neuronal cell bodies, axons and dendrites, as well as glial cells. White matter contains mainly axons and glial cells.
- Gray matter regions of the CNS are usually arranged in multiple unique layers.
- Each gray matter layer has its characteristic composition of neuronal subtypes, which connect to other neurons or cells in a reproducible, stereotypic pattern.
- Several parts of the CNS exhibit a folded structure to increase the overall size (examples cerebellum and cerebral cortex).

Additional Source Information

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

Slide 5: Neuron to Brain, 3rd edition, 1992, Nicholls, Martin and Wallace, Sinauer, Fig 6

Slide 6: Wikipedia, http://en.wikipedia.org/wiki/File:Neuron_Hand-tuned.svg; Original Image: Human Histology, 2nd edition, Stevens and Lowe, Mosby, Fig. 6-1

Slide 7: Color Atlas of Basic Histology, 1993, Berman, Appelton and Lange, Fig 6-4, Clendening Library Portrait Collection

Slide 8: Cell and Tissue Ultrastructure – A Functional Perspective, 1993, Cross and Mercer, Freeman and Co., Pg. 127

Slide 9: Wikipedia, http://en.wikipedia.org/wiki/File:Neuron_Hand-tuned.svg; Original Image Human Histology, 2nd edition, Stevens and Lowe, Mosby , Fig. 6-1

Slide 10: Color Atlas of Histology, 1992, Erlandsen and Magney, Mosby Book, Fig 9-3

Slide 11: Modified by Dr. Hortsch Human Histology, 2nd edition, Stevens and Lowe, Mosby, Fig 6.3

Slide 12: Human Histology, 2nd edition, Stevens and Lowe, Mosby, Fig 6.7, 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

Slide 13: Wikipedia, http://en.wikipedia.org/wiki/GNU_Free_Documentation_License; Modified from Cell and Tissue Ultrastructure – A Functional Perspective by Cross and Mercer, 1993, Freeman and Co. pg. 135; Original Top Image From Diagram of synapse downloaded from http://fantastrid.googlepages.com/anatomydrawings by Astrid Vincent Andersen

Slide 14: Source of Removed Images: http://academic.kellogg.cc.mi.us/herbrandsonc/bio201_McKinley/Nervous%20System.htm

Slide 15: Wilder Penfield, http://commons.wikimedia.org/wiki/File:P%C3%ADo_del_R%C3%ADo_Hortega_en_1924.jpg; Histology Image Source: Histology - A Text and Atlas, 5th edition, 2006, Ross and Pawlina,
Lippincott Williams and Wilkins, Fig 11.18

Slide 16: Human Histology, 2nd edition, Stevens and Lowe, Mosby , Fig 6.12

Slide 17: NIH Journal 1997 9:32

Slide 18: Stevens and Lowe, Human Histology, 2nd ed Fig 7.24

Slide 19: Source of Removed Image: Histology-A Text and Atlas 4th ed, Ross et al; Histology-A Text and Atlas 4th ed, Ross et al , Fig 11.20

Slide 21: Netter's Essential Histology, 2008, Ovalle and Nahirney, Elsevier, Pages 114 and 115

Slide 22: Basic Medical Histology, 1998, Kessel, Oxford University Press, Plate 27E

Slide 23: Wikipedia, http://en.wikipedia.org/wiki/File:Neuron_Hand-tuned.svg; Original Image: Kelley, Kaye and Pawlina, "Histology, a Text and Atlas," 4th ed., page 284. Neuron-Ross4-284.tif.

Slide 24: Basic Histology – Text & Atlas, 10th edition, 2003,
Junqueira and Carneiro, Lange McGraw-Hill, Fig 9-30

Slide 25: Wheater's Functional Histology; 5th edition, 2006, Young, Lowe, Stevens and Heath; Churchill Livingstone Elsevier, Fig 17.6a; Source of Removed Image: Histology-A Text and Atlas by M.H. Ross and W. Pawlina, 5th edition, 2006, Lippincott Williams and Wilkins, Fig 12.11

Slide 26: Neuroscience by D. Purves et al., 2001, 2nd ed., Sinauer, http://www.ncbi.nlm.nih.gov/books/bookres.fcgi/neurosci/ch3f13.gif

Slide 27: Source of Removed Image: Human Histology by Stevens and Lowe, 2nd edition, 1997, Mosby Fig 6.13a

Slide 28: Cell and Tissue Ultrastructure – A Functional Perspective, 1993, Cross and Mercer, Freeman and Co., p. 139

Slide 29: Color Atlas of Histology, 1992, Erlandsen and Magney, Mosby Book, Fig 9-13

Slide 30: Source of Removed Image: R&D Systems Autoimmunity Poster 2006 R&D Systems, Inc.

Slide 31: Stevens and Lowe Human Histology 2nd ed, Fig 6.14

Slide 32: Color Textbook of Histology, 2nd edition, 1994, Gartner and Hiatt, Williams and Wilkins, Fig 71

Slide 33: Human Histology, 2nd edition, Stevens and Lowe, Mosby , Fig. 6.27a

Slide 34: Color Atlas of Basic Histology, 1993, Berman, Appelton and Lange, Fig 6-2

Slide 35: Human Histology, 2nd edition, Stevens and Lowe, Mosby , Fig 6.27b, Library of Congress

Slide 36: Dr. Michael Häuser, Dr. B. Clark, University College London, United Kingdom

Slide 37: Wikipedia, http://en.wikipedia.org/wiki/Image:PurkinjeCell.jpg

Slide 38: Neurobiology: Internal model visualized, Masao Ito, Nature 403, 153-154 (2000)

Slide 39: Source of Removed Animation: http://video.google.com/videoplay?docid=-9215765857714551521,Oscar Alexander (flickr)

Slide 40: Camillo Golgi “Opera Omnia” Vol. II Sulla fina anatomia degli organi centrali del sistema nervoso. Ulrico Hoepli, Milano (1903); Source Undetermined

Slide 41: Camillo Golgi “Opera Omnia” Vol. II Sulla fina anatomia degli organi centrali del sistema nervoso. Ulrico Hoepli, Milano (1903)

Slide 42: Michigan Medical Histology Slide Collection

Slide 43: Nature Methods, http://www.fke.tuwien.ac.at/BIOELECTRONICS/Hauptseite.html, - 4, 331-336 (2007) “Ultramicroscopy: three-dimensional visualization of neuronal networks in the whole mouse brain” by Dodt et al.

Slide 44: Human Histology, 2nd edition, Stevens and Lowe, Mosby, Fig. 6.24

Slide 45: Histology-A Text and Atlas, 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins, Part of Plate 25

Slide 46: Wheater’s Functional Histology, 5th edition, 2006, Young, Lowe, Stevens and Heath, Churchill Livingstone Elsevier, Fig 20.8a

Slide 47: Histology – A Text and Atlas, 5th edition, 2006, Ross and Pawlina, Lippincott Williams and Wilkins, Part of Plate 25, Fig 6f from “Dynamic Remodeling of Dendritic arbors in GABAergic Interneurons of Adult Visual Cortex” by Lee et al in PLoS Biology Vol. 4 No. 2 e29

Slide 48: Modified from ShadowWolf13, flickr, http://www.flickr.com/photos/15442697@N06/3151783047/

Slide 49: Essentials of Anatomy & Physiology, Seeley and others, p. 210; Source of Removed Image: http://www.learningdiscoveries.com.au/StagesofBrainDevelopment.htm

Slide 50: Stephen Walter Ranson; Wikipedia; Picasa, http://picasaweb.google.com/inchlife/NervousSystemI#5121554293641981490; Canadian Institute of Neurosiences, http://thebrain.mcgill.ca/flash/index_d.html

Slide 51:Canadian Institute of Neurosiences, http://thebrain.mcgill.ca/flash/i/i_06/i_06_cl/i_06_cl_mou/i_06_cl_mou.html ; Source Undetermined; Claire-Bénédicte Rivara , Les cellules de Betz du cortex moteur primaire analyse stéréologique et fonctionnelle