

# A Primer on the basic Anatomy and Function of Neurons and Glia

Neurons are cells that conduct electric potentials and transform these electric impulses into signals that coordinate our bodily functions, thoughts, sensations, and perceptions of the world. The fine, branching extensions of the neuron used to pick up electric impulses from other cells are called dendrites (Figure 1A). Some neurons develop only a few dendrites, whereas others (such as the Purkinje neurons; Figure 2A) develop extensive, branching dendritic arbors. Few dendrites are found on cortical neurons (neurons of the cerebral cortex) at birth, and one of the amazing events of the first year of human life is the increase in the number of these receptive cellular processes. During this year, each cortical neuron develops enough dendritic surface area to accommodate as many as 100,000 connections, or synapses, with other neurons. The average neuron in the highly developed cortex of the human cerebrum connects with 10,000 other neural cells, enabling the human cortex to function as the center for learning and reasoning.

Another important feature of a developing neuron is its axon. Whereas dendrites are often numerous and do not extend far from the neuronal cell body, or soma, axons may extend 2–3 feet (see Figure 1A). The pain receptors on your big toe, for example, must transmit messages all the way to your spinal cord. One of the features of a neuron that is fundamental to how a nervous system functions is that the axon is a continuous extension of the nerve cell body. The process by which neuronal connections between cell bodies are established from soma to soma through axons has been one of the most investigated events in neural development. As we will describe in Chapter 15, to “wire up” the embryonic brain, axons extend from the cell body, led by a motile growth cone at their tip that uses the cue-laden environment to navigate to its target for synaptic connection.

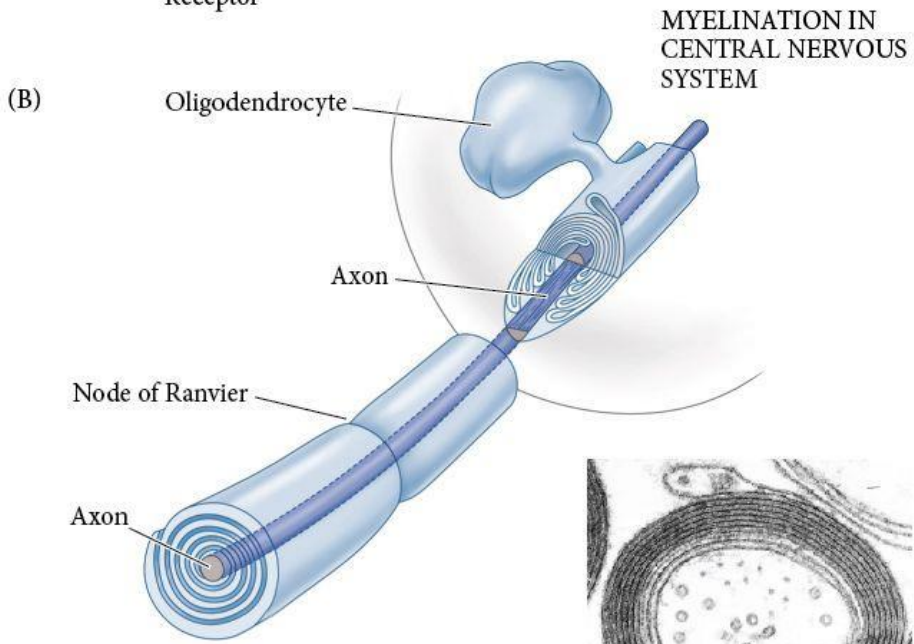
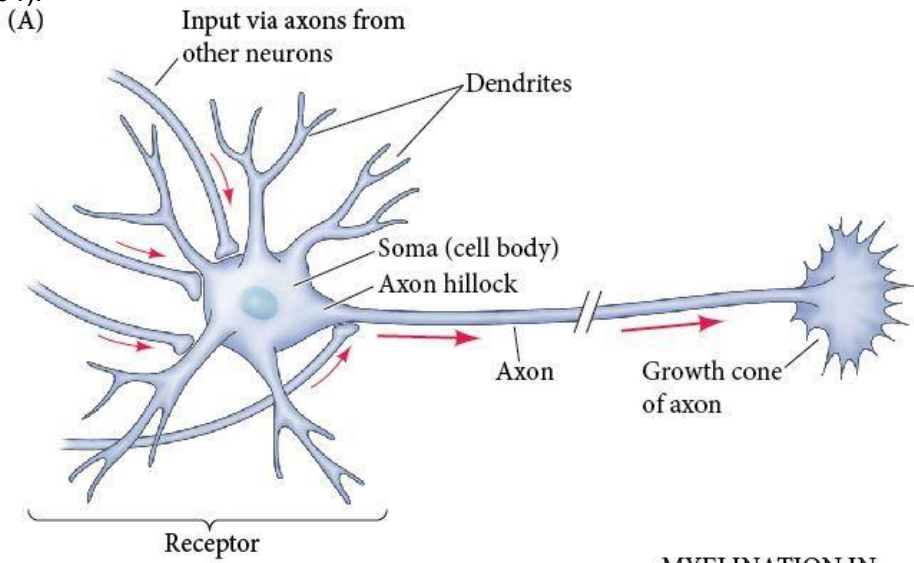
## Neuronal signaling

A variety of different molecules known as neurotransmitters are critical in generating many action potentials. Axons are specialized for secreting specific neurotransmitters across a small gap—the synaptic cleft—that separates the axon of a signaling neuron from the dendrite or soma of its target cell. Some neurons develop the ability to synthesize and secrete acetylcholine (the first known neurotransmitter), whereas others develop the enzymatic pathways for making and secreting epinephrine, norepinephrine, octopamine, glutamate, serotonin,  $\gamma$ -aminobutyric acid (GABA), or dopamine, among other neurotransmitters. Each neuron must activate those genes responsible for making the enzymes that can synthesize its neurotransmitter. Thus, neuronal development involves both structural and molecular differentiation.

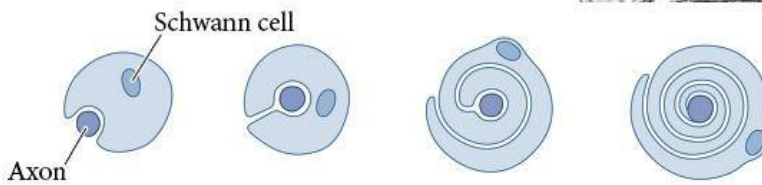
## Glial cells

There are three categories of glial cells in the CNS: oligodendrocytes, astroglia, and microglia. Neurons transmit information via electric impulses that travel from one region of the body to another along the axons. To prevent dispersal of the electric signal and to facilitate conduction to its target cell, axons in the CNS are insulated by oligodendrocytes (Figure 2B). The oligodendrocyte wraps itself around the developing axon and then produces a specialized cell membrane called the myelin sheath (Figure 1B). In the peripheral nervous system (i.e., all the nerves and neurons outside of the central nervous system), myelination is accomplished by a similar type of glial cell, the Schwann cell (Figure 1C). Transplantation experiments have shown that the axon, and not the glial cell, controls

the thickness of the myelin sheath by the amount of neuregulin-1 the axon secretes (Michailov et al. 2004).



(C) MYELINATION IN PERIPHERAL NERVOUS SYSTEM



1 C After K. L. Moore and T. V. M. Persaud, 1977. *The Developing Human: Clinically Oriented Embryology*, 2nd edition, p. 336. W. B. Saunders Co.: Philadelphia. Micrograph courtesy of C. S. Raine.

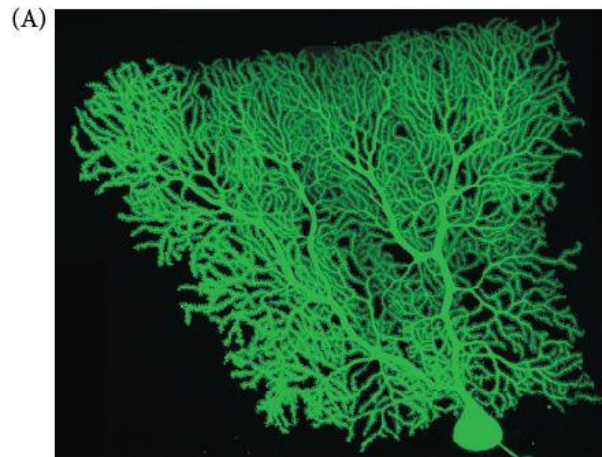
**Figure 1** Neural transmission and myelination. (A) A motor neuron. Electric impulses (red arrows) are received by the dendrites, and the stimulated neuron transmits impulses through its axon to its target tissue. The axon (which may be 2–3 feet long) is a cellular extension, or process, through which the neuron sends its signals. The axon's growth cone is both a locomotor and a sensory apparatus that actively explores the environment, picking up directional cues that tell it where to go. Eventually, the growth cone will form a connection, or synapse, with the axon's target tissue. (B,C) In the peripheral nervous system, Schwann cells wrap themselves around the axon; in the central nervous system, myelination is accomplished by the processes of oligodendrocytes. The micrograph shows an axon enveloped by the myelin membrane of a Schwann cell.

The myelin sheath is essential for proper nerve function and also helps keep axons alive for decades. Loss of this sheath (demyelination) is associated with convulsions, paralysis, and certain debilitating afflictions such as multiple sclerosis (Emery 2010; Nave 2010). There are mouse mutants in which subsets of neurons are poorly myelinated. In the *trembler* mutant, the Schwann cells are unable to produce a particular protein component such that myelination is deficient in the peripheral nervous system but normal in the CNS. Conversely, in the mouse mutant *jimpy*, the CNS is deficient in myelin but the peripheral nerves are unaffected (Sidman et al. 1964; Henry and Sidman 1988).

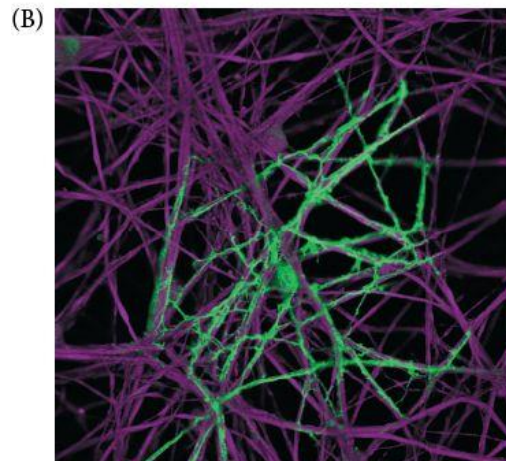
Astroglial cells represent a diverse class of glial cells that include radial glia and a variety of differentiated subtypes of astrocytes (Figure 2C). Astrocytes were originally named after their star (astral) shape appearance in a culture dish, and, historically astrocytes were presumed to function as the connective tissue of the nervous system, that is, its “glue.” However, modern studies have revealed that astrocytes carry out an array of functions critical to the adult nervous system. These functions include establishing the blood-brain barrier, responding to inflammation in the CNS, and (perhaps most importantly) supporting synapse homeostasis and neural transmission.

A major marker for astroglia is an intermediate filament protein called glial fibrillary acidic protein (GFAP). Protein-misfolding mutations in the human *GFAP* gene can lead to Alexander disease, a neurodegenerative disease caused by fibrous protein aggregates that impair multiple functions of the nervous system (Brenner et al. 2001; Hagemann et al. 2006).

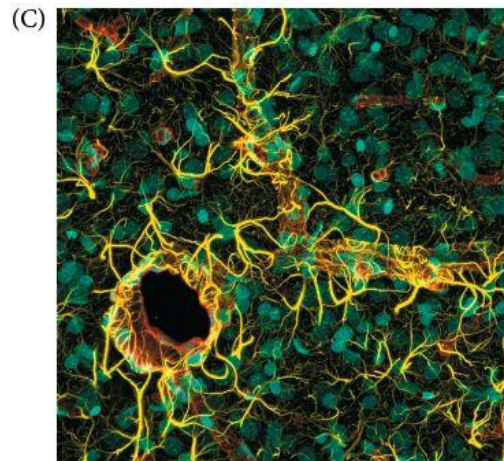
Microglia are often considered the “immune cells” of the central nervous system, since they function to engulf dying and dysfunctional neurons and glia. As their name implies, microglia are small relative to the other cell types of the nervous system. They are also very motile, with behaviors reminiscent of macrophages. In fact, microglia are not born in the nervous system, but are first generated by myeloid progenitor cells (which give rise to various types of blood cells; see Figure 20.24) derived from the yolk sac (Wieghofer et al. 2015). These circulating microglial progenitors take root in the CNS prior to formation of the blood-brain barrier. Functionally, microglia play major roles in synaptic pruning and the removal of neurotoxic factors present in the brain. Of clinical importance, microglial dysfunction has been implicated in a number of neurodegenerative diseases such as Alzheimer's disease.



A courtesy of Boris Barbour.



B from R. D. Fields. 2013. *Nature* 501: 25-27, courtesy of Doug Fields.



C, micrograph by Madelyn May, Honorable Mention, 2011 Olympus BioScapes Digital Imaging Competition.

**Figure 2** Cell types of the CNS(A) A Purkinje neuron with its elaborate dendritic processes. If you look carefully, you will see that those dendrites are not blurry; rather, postsynaptic membrane protrusions called spines are faintly visible. (B) Derived from a mouse hippocampus, a single oligodendrocyte (green) wrapping around multiple axons (purple) in co-culture. (C) Rat cerebral cortex with astroglial (yellow) endfeet wrapping around blood vessels (red). Cell nuclei are cyan.

## Literature Cited

Brenner, M., A. B. Johnson, O. Boespflug-Tanguy, D. Rodriguez, J. E. Goldman, and A. Messing. 2001. Mutations in GFAP, encoding glial fibrillary acidic protein, are associated with Alexander disease. *Nat. Genet.* 27: 117–120.

[PubMed Link](#)

Emery, B. 2010. Regulation of oligodendrocyte differentiation and myelination. *Science* 330: 779–782.

[PubMed Link](#)

Hagemann, T. L., J. X. Connor, and A. Messing. 2006. Alexander disease-associated glial fibrillary acidic protein mutations in mice induce Rosenthal fiber formation and a white matter stress

response. *J. Neurosci.* 26: 11162–11173.

[PubMed Link](#)

Henry, E. W. and R. L. Sidman. 1988. Long lives for homozygous *trembler* mutant mice despite virtual absence of peripheral nerve myelin. *Science* 241: 344–346.

[PubMed Link](#)

Michailov, G. V. and 9 others. 2004. Axonal neuregulin-1 regulates myelin sheath thickness. *Science* 304: 700–703.

[PubMed Link](#)

Nave, A. K. 2010. Myelination and support of axonal integrity by glia. *Nature* 468: 244–252.

[PubMed Link](#)

Sidman, R. L., M. M. Dickie and S. H. Appel. 1964. Mutant mice (*quaking* and *jimpy*) with deficient myelination in the central nervous system. *Science* 144: 309–312.

[PubMed Link](#)

Wieghofer, P., K. P. Knobloch, and M. Prinz. 2015. Genetic targeting of microglia. *Glia* 63:1–22.

[PubMed Link](#)

All the material on this website is protected by copyright. It may not be reproduced in any form without permission from the copyright holder.

© 2023 Oxford University Press |