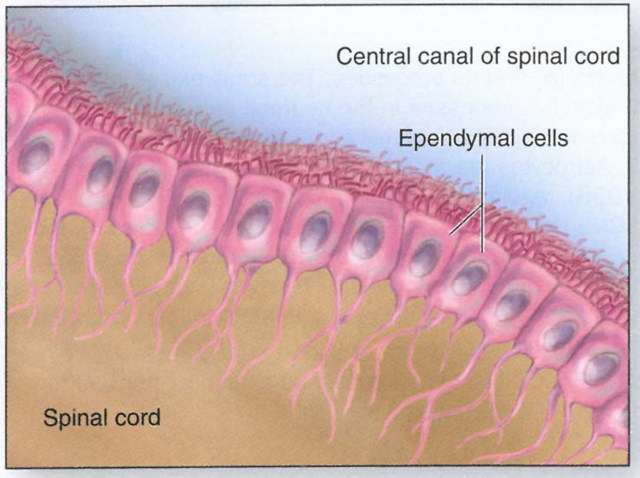
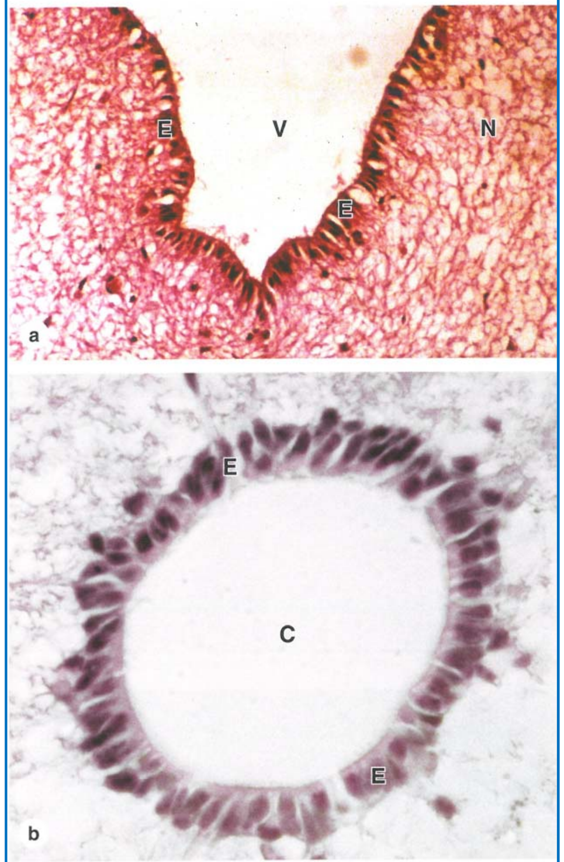
Ependymal cell

- Cuboid or columnar
- Lin the brain ventricle & central canal of spinal cord
- Cilia & long microvillus on apical surface
- Cell j. like epithelial cells
- No basement membrane
- Base end extend process to adjucent neuropil



c Ependymal cells

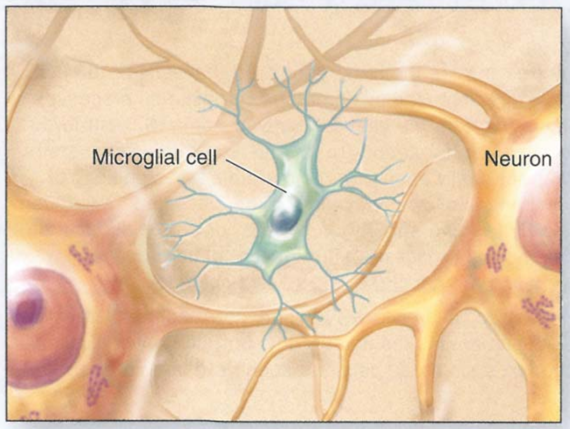
FIGURE 9–11 Ependymal cells.



Ependymal cells are epithelial-like cells that form a single layer lining the fluid-filled ventricles and central canal of the CNS. **(a)** Lining the ventricles of the cerebrum, columnar ependymal cells (**E**) extend cilia and microvilli from the apical surfaces into the ventricle (**V**). These modifications help circulate the CSF and monitor its contents. Ependymal cells have junctional complexes at their apical ends like those of epithelial cells but lack a basal lamina. The cells' basal ends are tapered, extending processes that branch and penetrate some distance into the adjacent neuropil (**N**). Other areas of ependyma are responsible for production of CSF. X100. H&E. **(b)** Ependymal cells (**E**) lining the central canal (**C**) of the spinal cord help move CSF in that CNS region. X200. H&E.

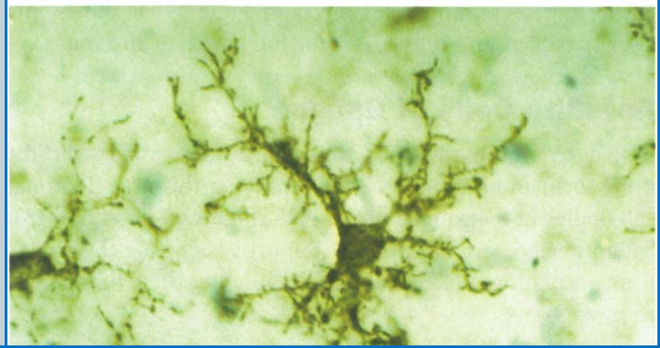
Microglia

- Small cells
- Less in number
- Short & irregular processes
- Homogen distribution in white & gray matter
- Migration through neuropils
- scanning tissue fore dameged cell & microorganisms
- Secreting immunoregulatory cytokins
- Originate from monocytes
- APCs
- Small, condensed & elongated nucleus



d Microglial cell

FIGURE **9–12** **Microglial cells.**



HLA-DR and peroxidase.

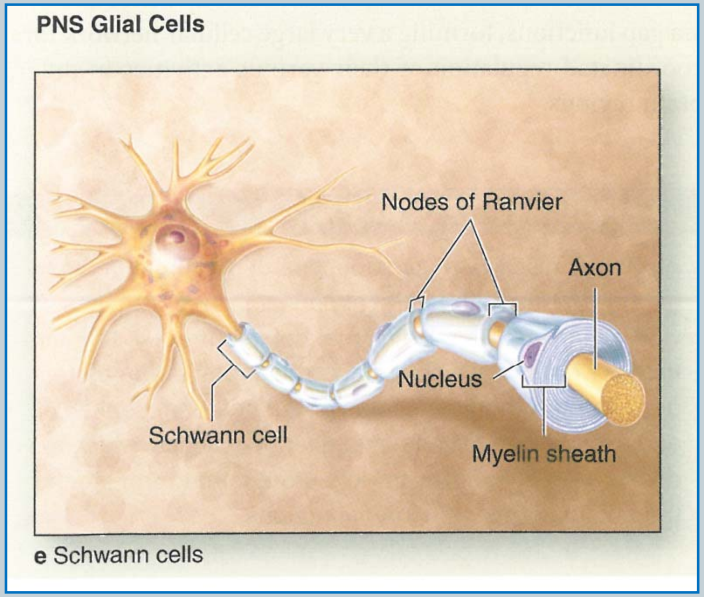
(Used, with permission, from Wolfgang Streit, Department of Neuroscience, University of Florida College of Medicine, Gainesville.)

» MEDICAL APPLICATION

In **multiple sclerosis** (MS) the myelin sheaths surrounding axons are damaged by an autoimmune mechanism that interferes with the activity of the affected neurons and produces various neurologic problems. T lymphocytes and microglia, which phagocytose and degrade myelin debris, play major roles in progression of this disease. In MS destructive actions of these cells exceeds the capacity of oligodendrocytes to produce myelin and repair the myelin sheaths.

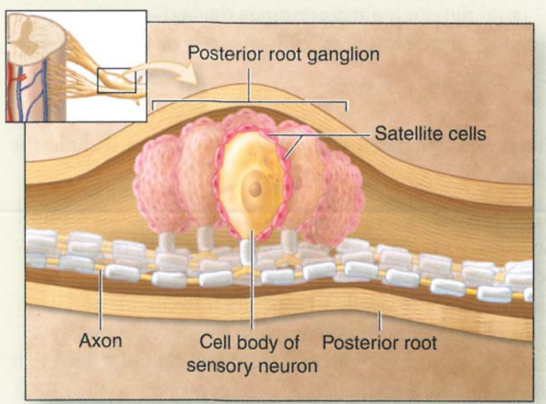
Schwan cell

- Neurolemmocyte
- Only in **PNS**
- Neural crest origin
- Nurishment
- Myelinating
- Only one neuron



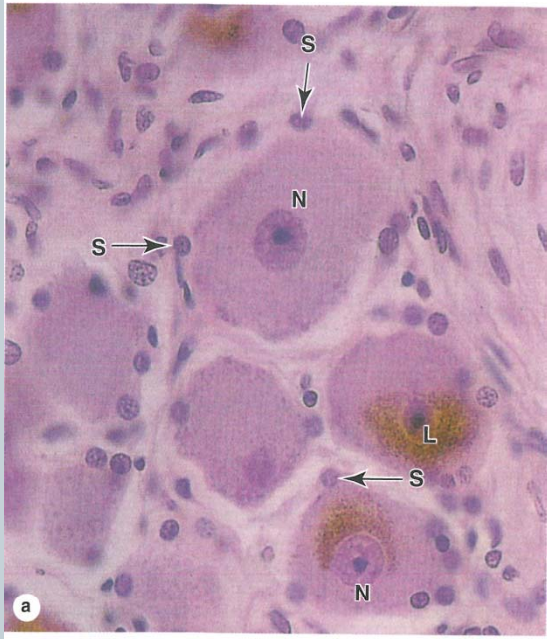
Satellite cell

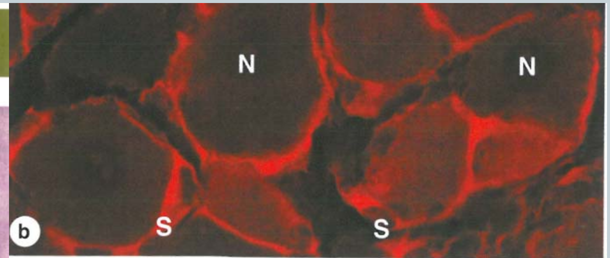
- Neural crest origin
- Covering layer for ganglionic large neuronal body
- Trophic & supportive
- Insulation
- Nurishment
- Microenvironment regulation



f Satellite cells

FIGURE **9–13** **Satellite cells around neurons of ganglia in the PNS.**





Satellite cells are very closely associated with cell bodies of sensory nerves and support these cells in various ways. **(a)** Nuclei of the many satellite cells (**S**) surrounding the perikarya of neurons (**N**) in a dorsal root ganglion can be seen by light microscopy, but the cytoplasmic extensions from the cells are not visible. These long-lived neurons commonly accumulate brown lipofuscin (**L**). X560. H&E.

(b) Immunofluorescent staining of satellite cells (**S**) reveals cytoplasmic sheets extending from these cells and surrounding neuronal cell bodies (**N**). Like the effect of Schwann cells on axons, satellite glial cells insulate, nourish, and regulate the microenvironment of the neuronal cell bodies. X600. Rhodamine red-labeled antibody against glutamine synthetase.

(*With permission, from Menachem Hanani, laboratory of Experimental Surgery, Hadassah University Hospital, Jerusalem, Israel.*)

Central nervous system

1. Cerebrum
2. Cerebellum
3. Spinal cord

- Covered by 3 layers meninges
- Very low collagen or fibrous tissue

CNS:

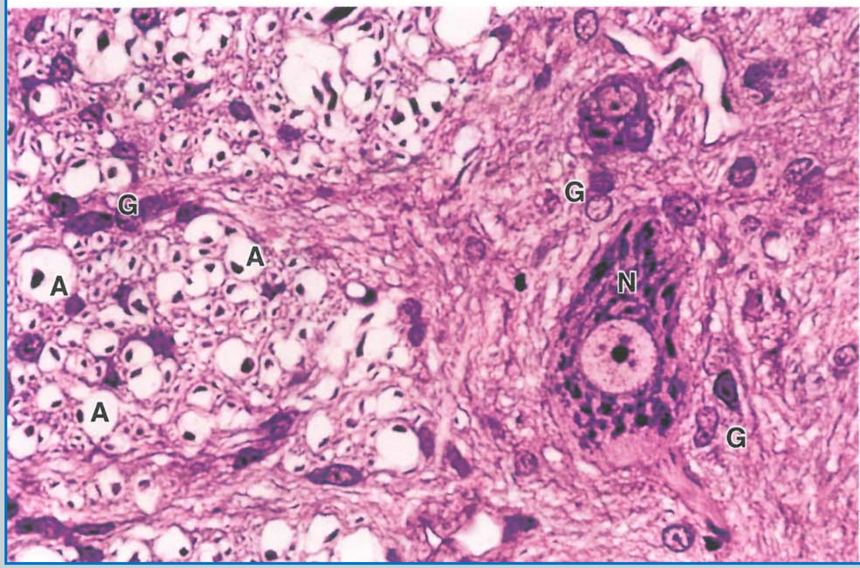
- **White matter**

Neuron axon
Oligodendrocytes
Microglia
Astrocytes

- **Gray matter**

Perikaryon
Axon primary segment
Astrocytes
microglia
nuclei

FIGURE **9–14** **White versus gray matter.**



A cross section of H&E-stained spinal cord shows the transition between white matter (left region) and gray matter (right). The gray matter has many glial cells (**G**), neuronal cell bodies (**N**), and neuropil; white matter also contains glia (**G**) but consists mainly of axons (**A**) whose myelin sheaths were lost during preparation, leaving the round empty spaces shown. Each such space surrounds a dark-stained spot that is a small section of the axon. X400.

Cerebral cortex

- Integration of sensory information
- Initiation of voluntary motor responses
- 6 layers
- The pyramidal neurons

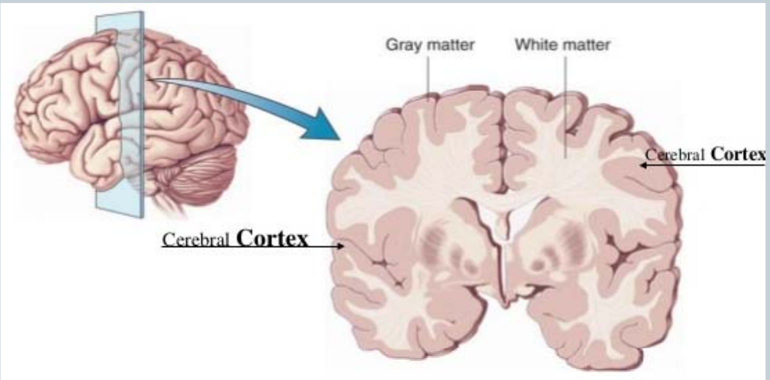
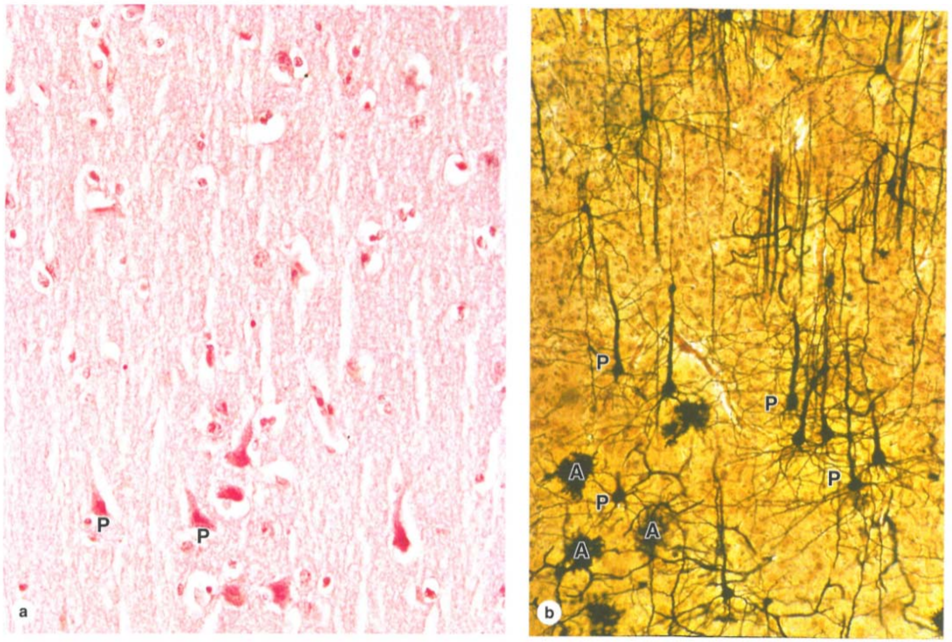
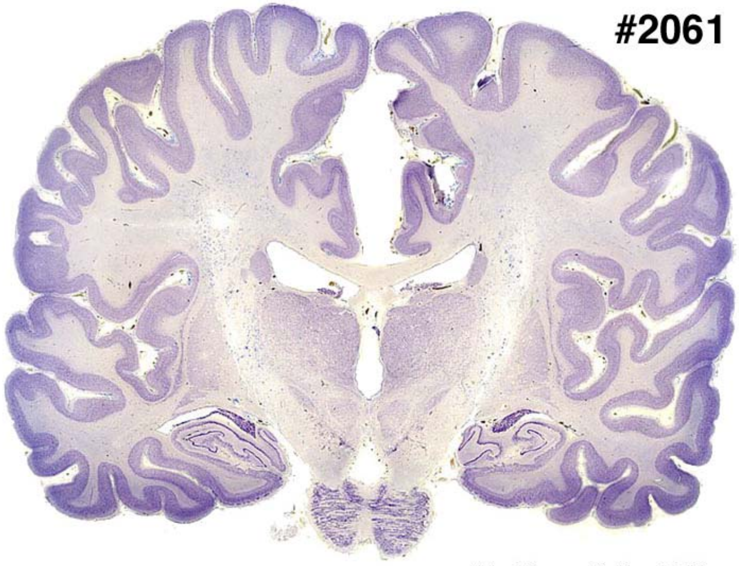


FIGURE **9–15** **Cerebral cortex.**



(a) Important neurons of the cerebrum are the pyramidal neurons (**P**), which are arranged vertically and interspersed with numerous smaller glial cells, mostly astrocytes, in the eosinophilic neuropil. X200. H&E.

(b) From the apical ends of pyramidal neurons (**P**), long dendrites extend in the direction of the cortical surface, which can be best seen in thick silver-stained sections in which only a few other protoplasmic astrocytes (**A**) cells are seen. X200. Silver.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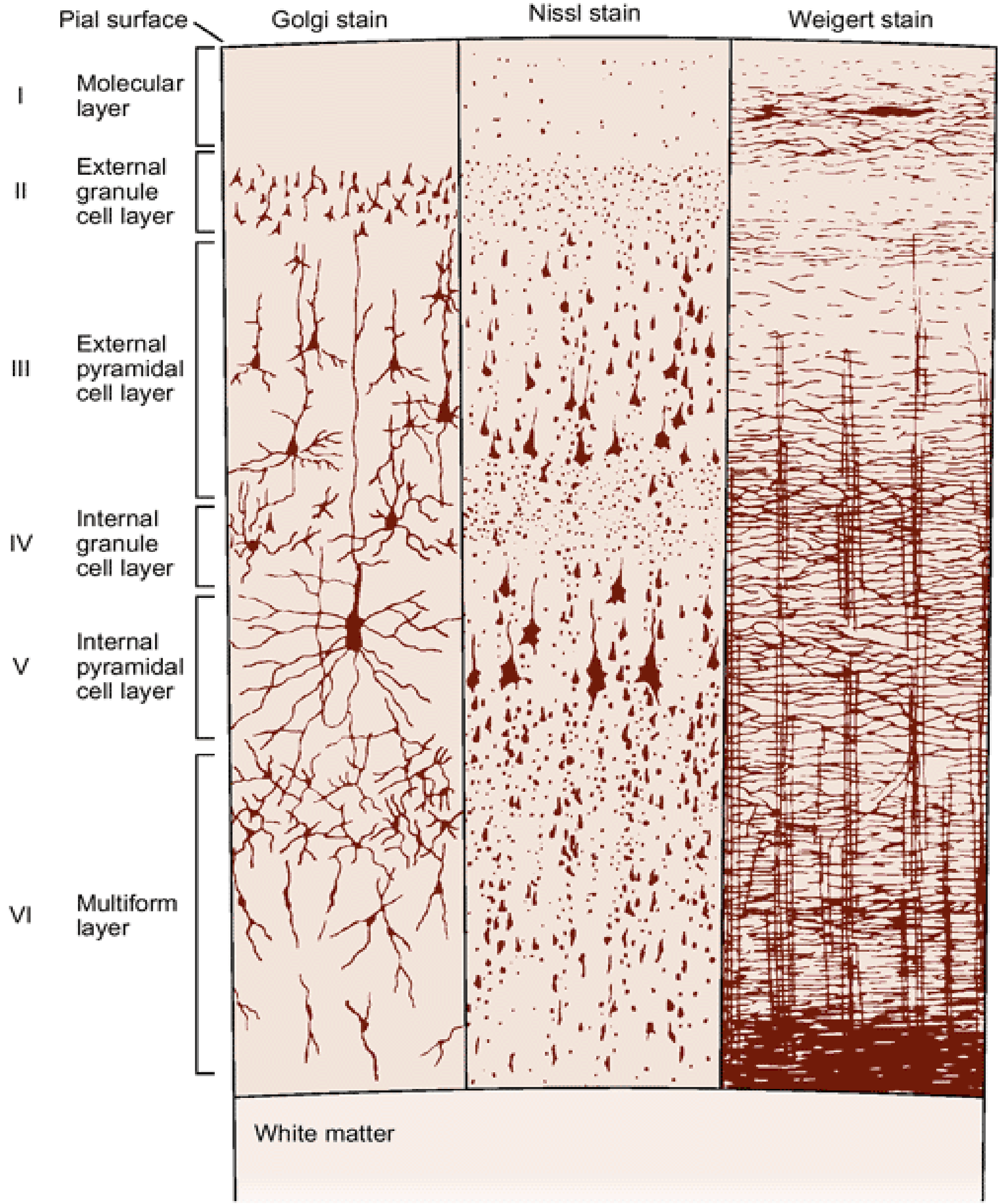

Pial surface
Golgi stain
Nissl stain
Weigert stain
I
Molecular layer
II
External granule cell layer
III
External pyramidal cell layer
IV
Internal granule cell layer
V
Internal pyramidal cell layer
VI
Multiform layer
White matter

Cerebellar cortex

- Coordinate muscular activity

1. Outer molecular layer
2. Central layer of purkinje cells
3. Inner granule layer

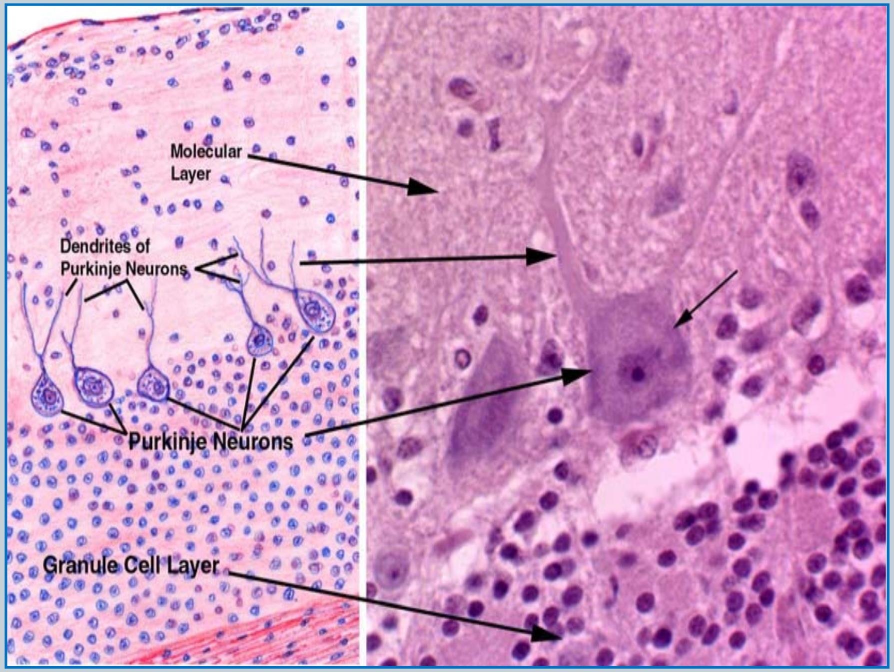
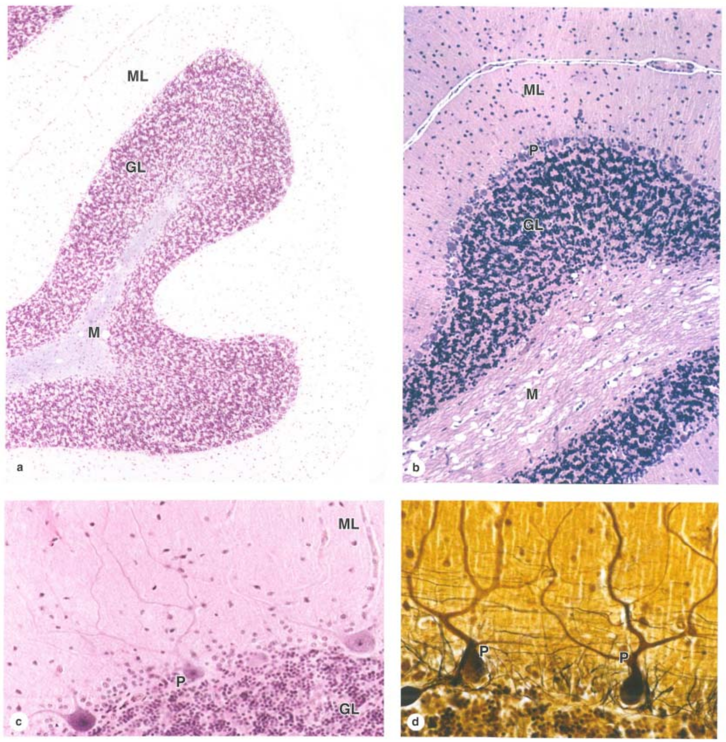


FIGURE **9–16** **Cerebellum.**



(a) The cerebellar cortex is convoluted with many distinctive small folds, each supported at its center by tracts of white matter in the cerebellar medulla (**M**). Each fold has distinct molecular layers (**ML**) and granular layers (**GL**). X6. Cresyl violet.

(b) Higher magnification shows that the granular layer (**GL**) immediately surrounding the medulla (**M**) is densely packed with several different types of very small rounded neuronal cell bodies. The outer molecular layer (**ML**) consists of neuropil with fewer, much more scattered small neurons. At the interface of these two regions a layer of large Purkinje neuron (**P**) perikarya can be seen. X20. H&E.

(c) A single intervening layer contains the very large cell bodies of unique Purkinje neurons (**P**), whose axons pass through the granular layer (**GL**) to join tracts in the medulla and whose multiple branching dendrites ramify throughout the molecular layer (**ML**). Dendrites are not seen well with H&E staining. X40. H&E.

(d) With appropriate silver staining dendrites from each large Purkinje cell (**P**) are shown to have hundreds of small branches, each covered with hundreds of dendritic spines. Axons from the small neurons of the granular layer are unmyelinated and run together into the molecular layer where they form synapses with the dendritic spines of Purkinje cells. X40. Silver.

Spinal cord

- Central canal

CSF

- Anterior horns
- Posterior horns

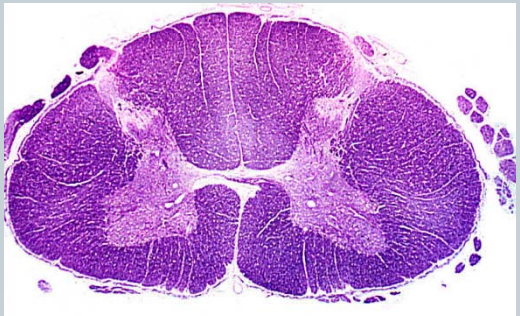
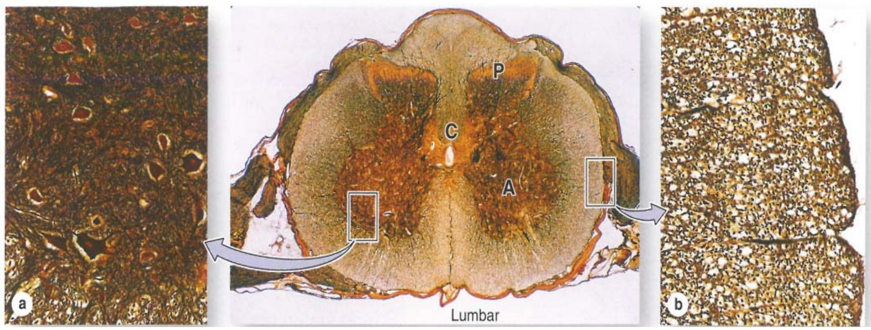


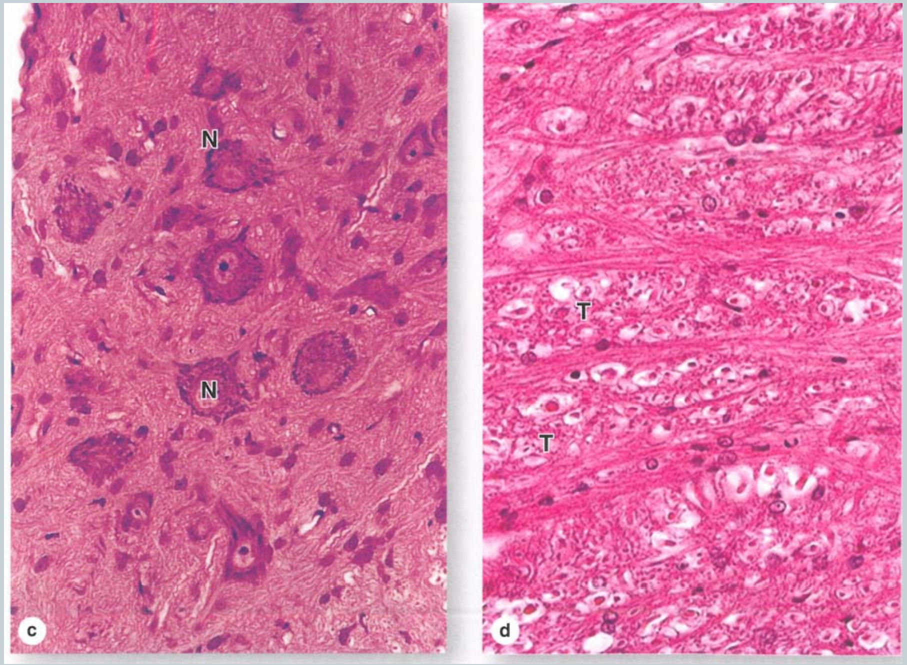
FIGURE 9–17 Spinal cord.



The spinal cord varies slightly in diameter along its length but in cross section always shows bilateral symmetry around the small, CSF-filled central canal (**C**). Unlike the cerebrum and cerebellum, in the spinal cord the gray matter is internal, forming a roughly H-shaped structure that consists of two posterior (**P**) horns (sensory) and two anterior (**A**) (motor) horns, all joined by the gray commissure around the central canal.

(a) The gray matter contains abundant astrocytes and large neuronal cell bodies, especially those of motor neurons in the ventral horns. **(b)** The white matter surrounds the gray matter and contains primarily oligodendrocytes and tracts of myelinated axons running along the length of the cord. Center X5, a, b X100. All silver-stained.

(c) With H&E staining the large motor neurons (**N**) of the ventral horns show large nuclei, prominent nucleoli, and cytoplasm rich in Nissl substance, all of which indicate extensive protein synthesis to maintain the axons of these cells that extend great distances. **(d)** In the white commissure ventral to the central canal, tracts (**T**) run lengthwise along the cord, seen here in cross section with empty myelin sheaths surrounding axons, as well as small tracts running from one side of the cord to the other. Both X200. H&E.



Meninges

- **Dura mater**

Dense con. Tissue & fibroblast

In spinal cord epidural space (VEINS &alveolar con. Tissue)

Subdural space

Simple squamous epithelium

- **Arachnoid**

1. Sheet of con. Tissue
2. Loosely arranged trabecula (collagen & fibroblast)

Subarachnoid space (CSF)

- **Pia mater**

Flattened mesenchymal cell

Glial limitans

Perivascular spaces

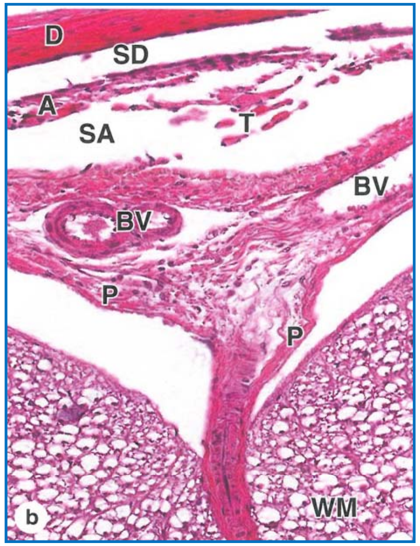
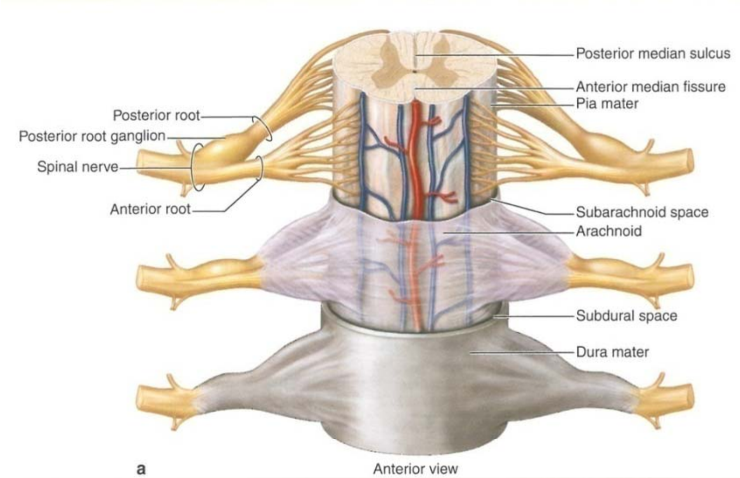


FIGURE 9–18 Spinal cord and meninges.

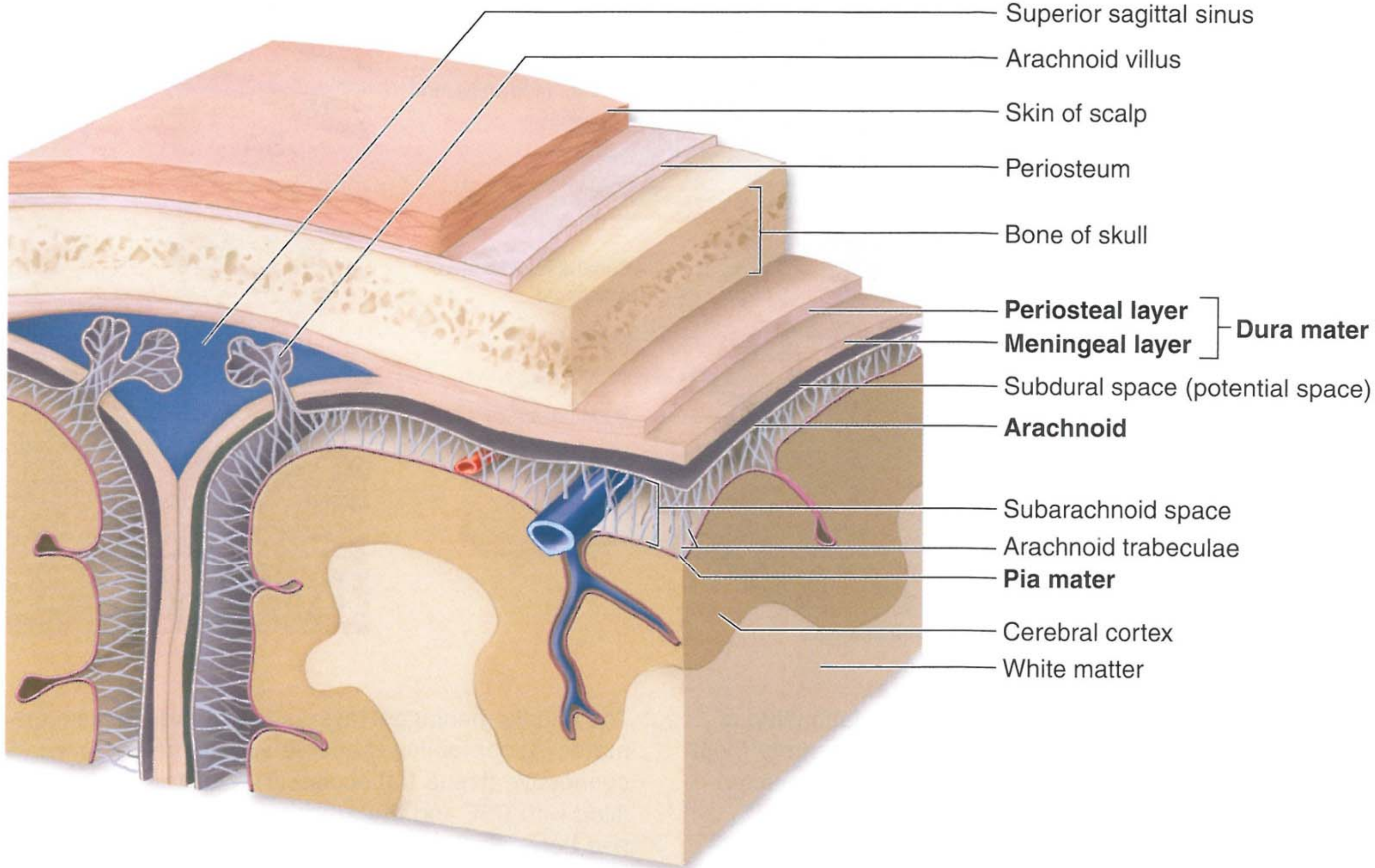


(a) A diagram of the spinal cord indicates the relationship of the three meningeal layers of connective tissue: the innermost **pia mater**, the **arachnoid**, and the **dura mater**. Also depicted are the blood vessels coursing through the subarachnoid space and the nerve rootlets that fuse to form the posterior and anterior roots of the spinal nerves. The posterior root ganglia contain the cell bodies of sensory nerve fibers and are located in intervertebral foramina.

(b) Section of an area near the anterior median fissure showing the tough dura mater (**D**). Surrounding the dura, the epidural space (not shown) contains cushioning adipose tissue and vascular plexuses. The subdural space (**SD**) is an artifact created by separation of the dura from underlying tissue.

The middle meningeal layer is the thicker weblike arachnoid mater (**A**) containing the large subarachnoid space (**SA**) and connective tissue trabeculae (**T**). The subarachnoid space is filled with CSF and the arachnoid acts as a shock-absorbing pad between the CNS and bone. Fairly large blood vessels (**BV**) course through the arachnoid. The innermost pia mater (**P**) is thin and is not clearly separate from the arachnoid; together, they are sometimes referred to as the pia-arachnoid or the leptomeninges. The space between the pia and the white matter (**WM**) of the spinal cord here is an artifact created during dissection; normally the pia is very closely applied to a layer of astrocytic processes at the surface of the CNS tissue. X100. H&E.

FIGURE **9–19** **Meninges around the brain.**



The **dura, arachnoid, and pia maters** also surround the brain and as shown here the relationships among the cranial meninges are similar to those of the spinal cord. The diagram includes **arachnoid villi**, which are outpocketings of arachnoid away from the brain, which penetrate the dura mater and enter blood-filled **venous sinuses** located within that layer.

The arachnoid villi function in releasing excess CSF into the blood. Blood vessels from the arachnoid branch into smaller arteries and veins that enter brain tissue carrying oxygen and nutrients. These small vessels are initially covered with pia mater, but as capillaries they are covered only by the perivascular feet of astrocytes.

Blood-brain barrier (BBB)

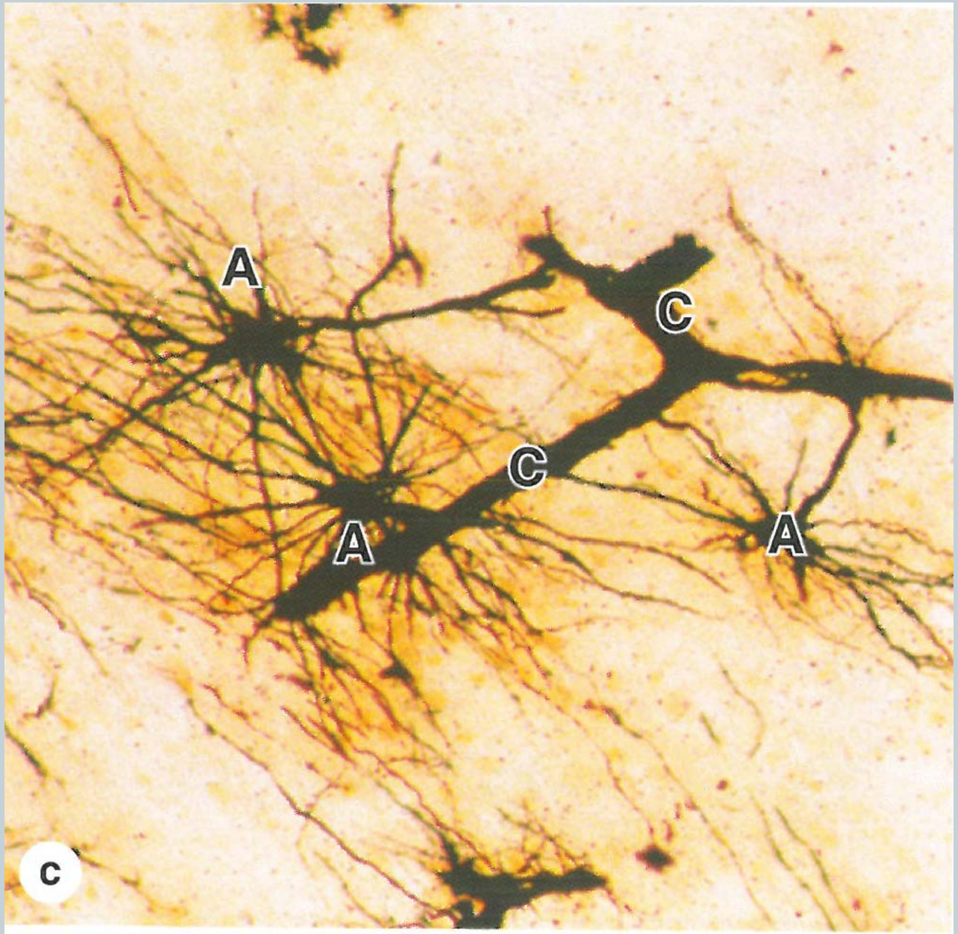
- **Functional barrier**

- Structural components:
  - Capillary Endothelium

Developed occluding j.

No transcytosis activity

  - limiting layer of perivascular astrocytic feet



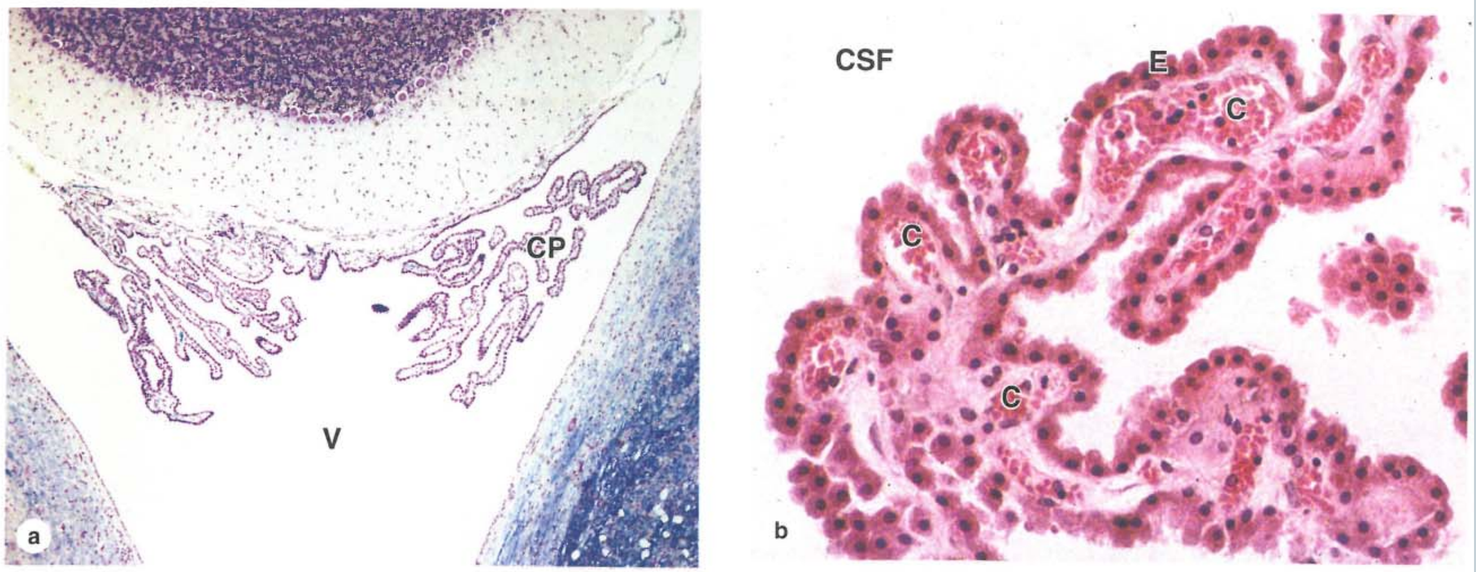
No BBB in:

1. choroid plexus (CSF production)
2. Posterior pituitary (hormone secretion)
3. Hypothalamus (plasma monitoring)

Choroid plexus

- Elaborate folds
- Many villi projects
- Brain 4th ventricle
- Direct contact of Ependymal layer & pia mater

FIGURE 9–20 Choroid plexus.



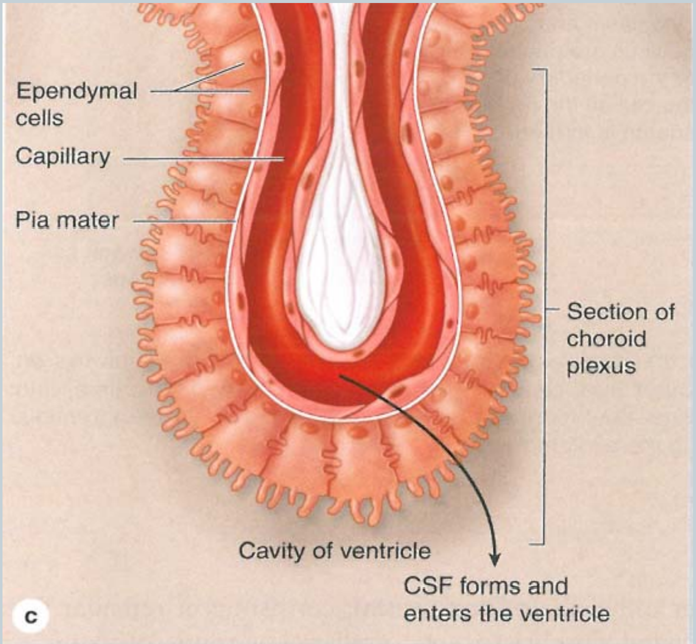
Choroid plexus

Each villus:

- Thin layer of well-vascularized pia mater
- Cuboid ependymal cell
- Na+, K+ & Cl-
- Low pr.
- lymphocytes

» MEDICAL APPLICATION

A decrease in the absorption of CSF or a blockage of outflow from the ventricles during fetal or postnatal development results in the condition known as **hydrocephalus** (Gr. *hydro*, water + *kephale*, head), which promotes a progressive enlargement of the head followed by mental impairment.



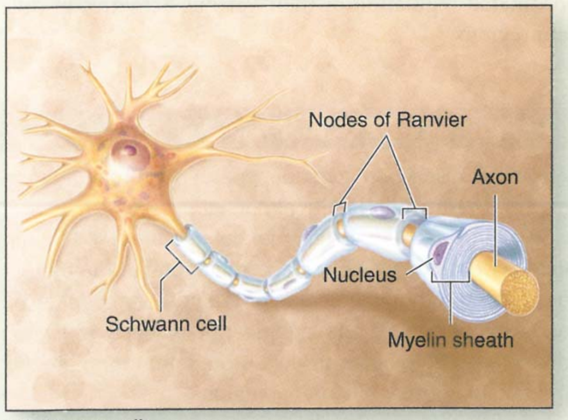
The choroid plexus consists of ependyma and vascularized pia mater and projects many thin folds from certain walls of the ventricles. **(a)** Section of the bilateral choroid plexus (**CP**) projecting into the fourth ventricle (**V**) near the cerebrum and cerebellum. X12. Kluver-Barrera stain.

(b) At higher magnification each fold of choroid plexus is seen to be well-vasculorized with large capillaries (**C**) and covered by a continuous layer of cuboidal ependymal cells (**E**). X150. **(c)** The choroid plexus is specialized for transport of water and ions across the capillary endothelium and ependymal layer and the elaboration of these as CSF.

Peripheral nervous system

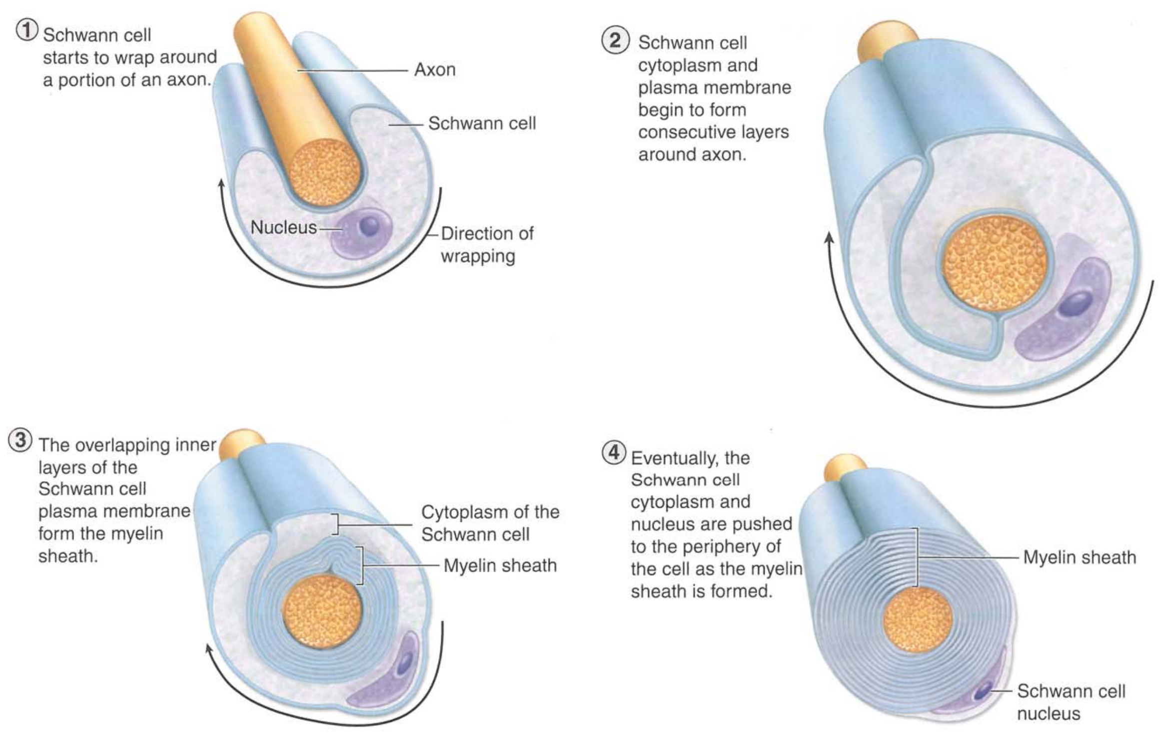
- Nerves
- Ganglia
- Nerve endings

PNS Glial Cells



e Schwann cells

FIGURE 9–21 Myelination of large-diameter PNS axons.

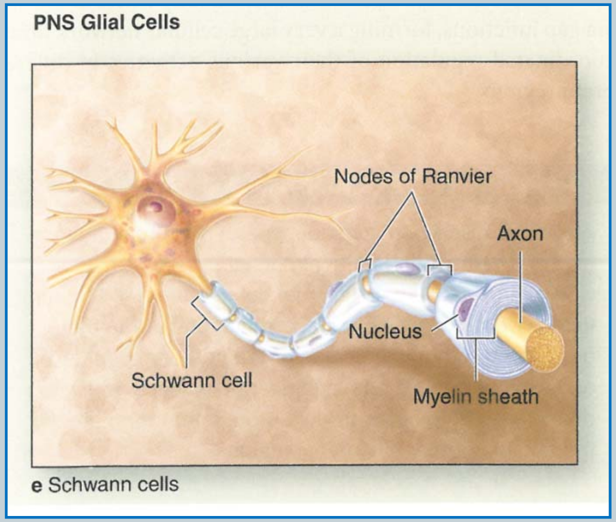


A Schwann cell (neurolemmocyte) engulfs one portion along the length of a large-diameter axon. The Schwann cell membrane fuses around the axon and elongates as it becomes wrapped around the axon while the cell body moves around the axon many times. The Schwann cell membrane wrappings constitute the myelin sheath, with the Schwann cell body always on its outer surface. The myelin layers are very rich in lipid, and provide insulation and facilitate formation of action potentials along the axolemma.

Nerves

- Schwann cell

1. Myelinated
2. Unmyelinated



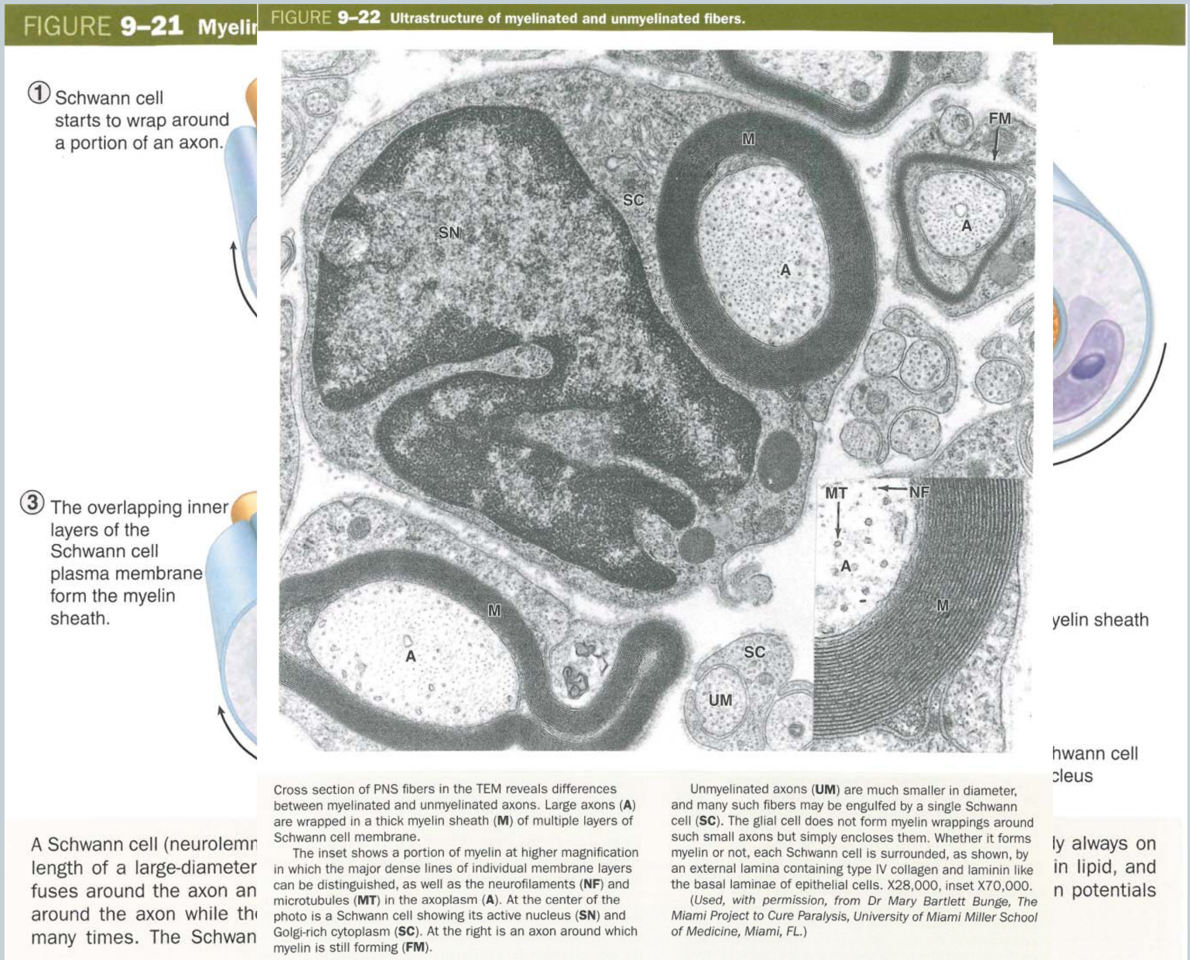
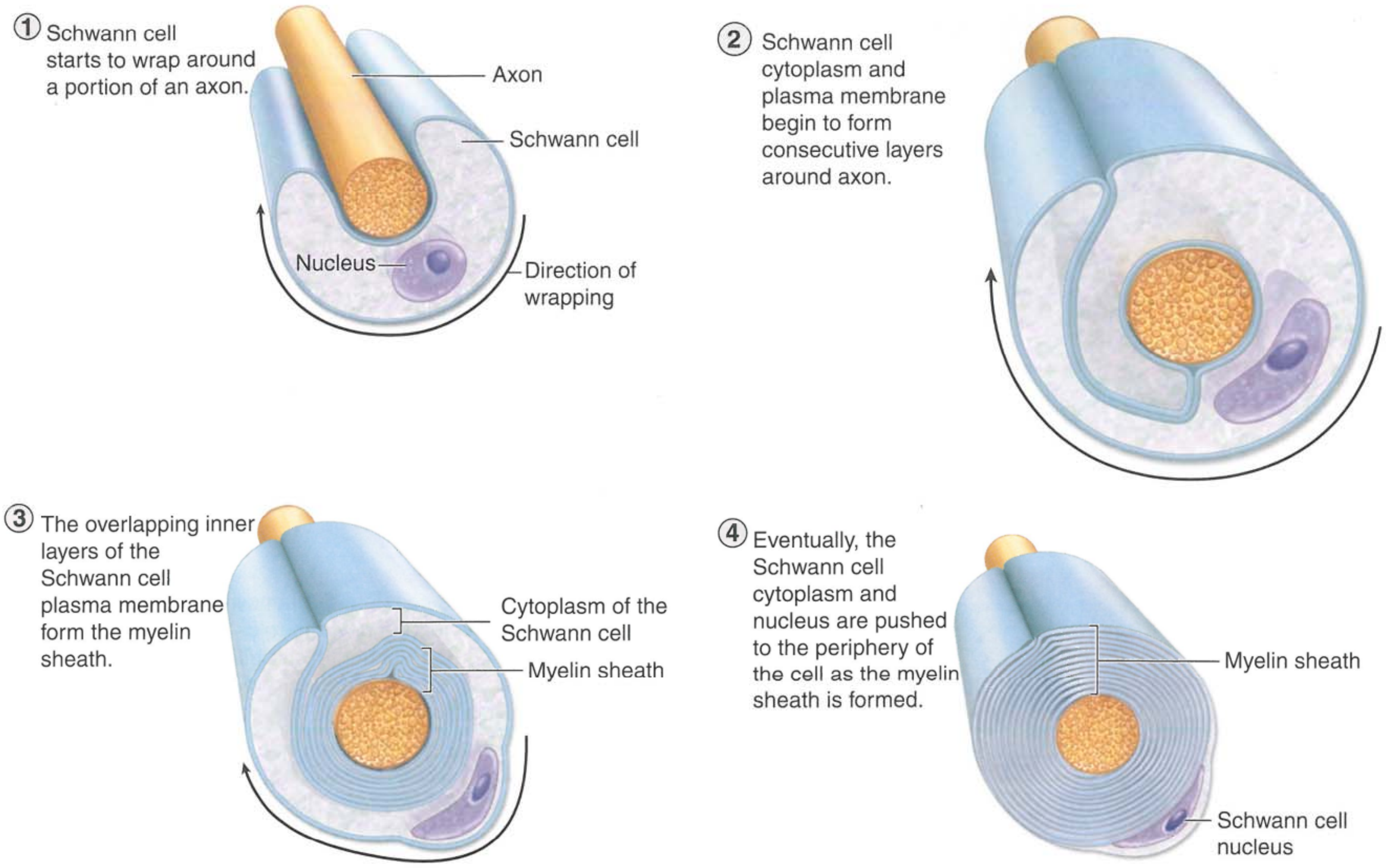


FIGURE 9–21 Myelination of large-diameter PNS axons.



A Schwann cell (neurolemmocyte) engulfs one portion along the length of a large-diameter axon. The Schwann cell membrane fuses around the axon and elongates as it becomes wrapped around the axon while the cell body moves around the axon many times. The Schwann cell membrane wrappings constitute the myelin sheath, with the Schwann cell body always on its outer surface. The myelin layers are very rich in lipid, and provide insulation and facilitate formation of action potentials along the axolemma.

FIGURE 9–23 Myelin maintenance and nodes of Ranvier.

The middle diagram shows schematically a myelinated peripheral nerve fiber as seen under the light microscope. The axon is enveloped by the myelin sheath, which, in addition to membrane, contains some Schwann cell cytoplasm in spaces called **Schmidt-Lanterman or myelin clefts** between the major dense lines of membranes.

The upper diagram shows one set of such clefts ultrastructurally. The clefts contain Schwann cell cytoplasm that was not displaced to the cell body during myelin formation. This cytoplasm moves slowly along the myelin sheath, opening temporary spaces (the clefts) that allow renewal of some membrane components as needed for maintenance of the sheath.

The lower diagram depicts the ultrastructure of a single **node of Ranvier** or nodal gap. Interdigitating processes extending from the outer layers of the **Schwann cells (SC)** partly cover and contact the axolemma at the nodal gap. This contact acts as a partial barrier to the movement of materials in and out of the periaxonal space between the axolemma and the Schwann sheath. The basal or external lamina around Schwann cells is continuous over the nodal gap. The axolemma at nodal gaps has abundant voltage-gated Na^+ channels important for impulse conductance in these axons.

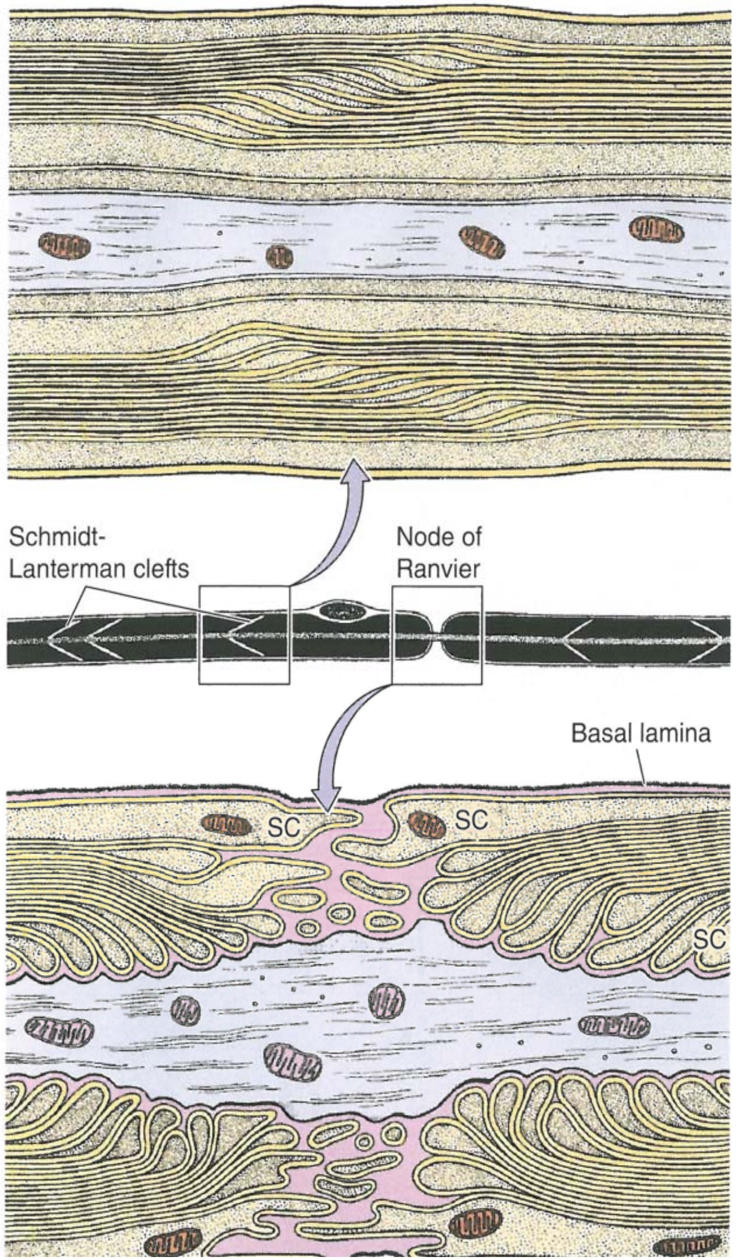
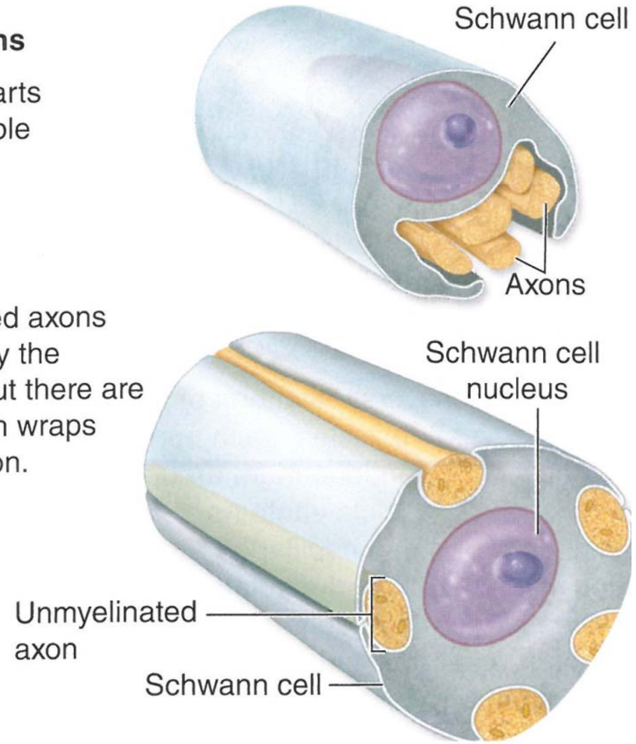


FIGURE 9–25 Unmyelinated nerves.

Unmyelinated axons

① Schwann cell starts to envelop multiple axons.

② The unmyelinated axons are enveloped by the Schwann cell, but there are *no* myelin sheath wraps around each axon.



During development, portions of several small-diameter axons are engulfed by one Schwann cell. Subsequently the axons are separated and each typically becomes enclosed within its own fold of Schwann cell surface. No myelin is formed by wrapping. Small-diameter axons utilize action potentials whose formation and maintenance do not depend on the insulation provided by the myelin sheath required by large-diameter axons.

Nerve organization

- Schwann cell

- 3layers

☐ Endoneurium

Reticular fibers, fibroblasts & capillaries

☐ Perineurium

Fascicles

Fibrocytes & tight junction

2-6 layers of this structure

Blood-nerve barrier

☐ Epineuria

- Sensory nerve
- Motor nerve
- Mixed nerve

FIGURE 9–24 Node of Ranvier

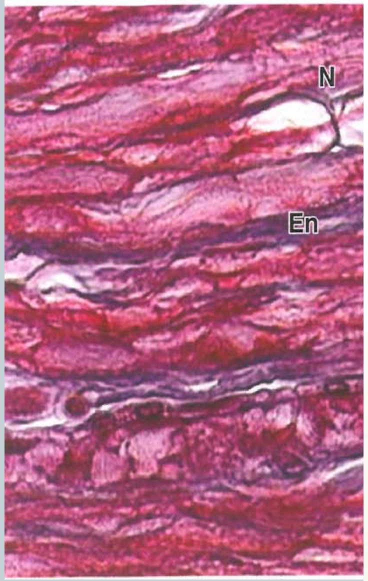
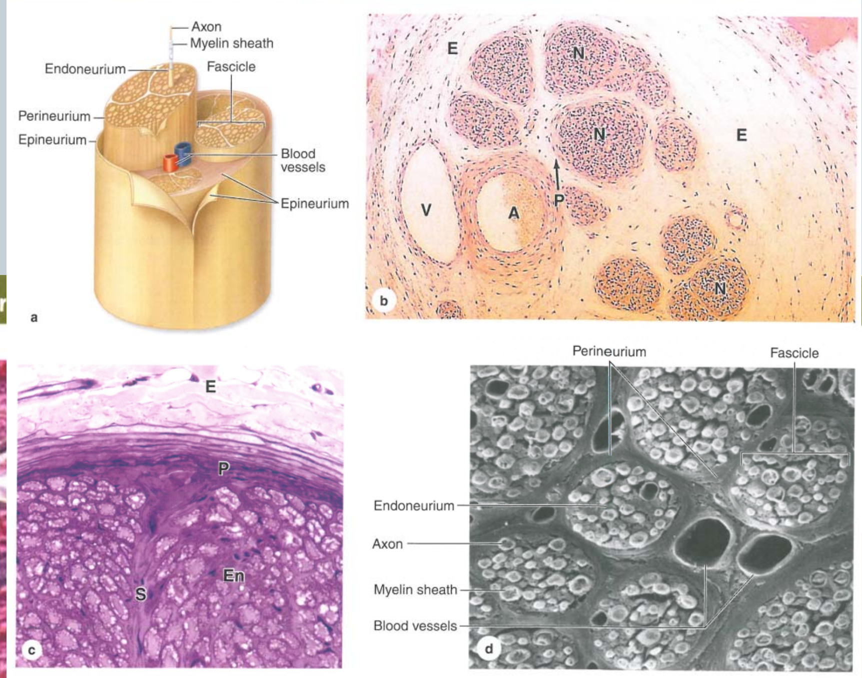


FIGURE 9–26 Peripheral nerve connective tissue: Epi-, peri-, and endoneurium.

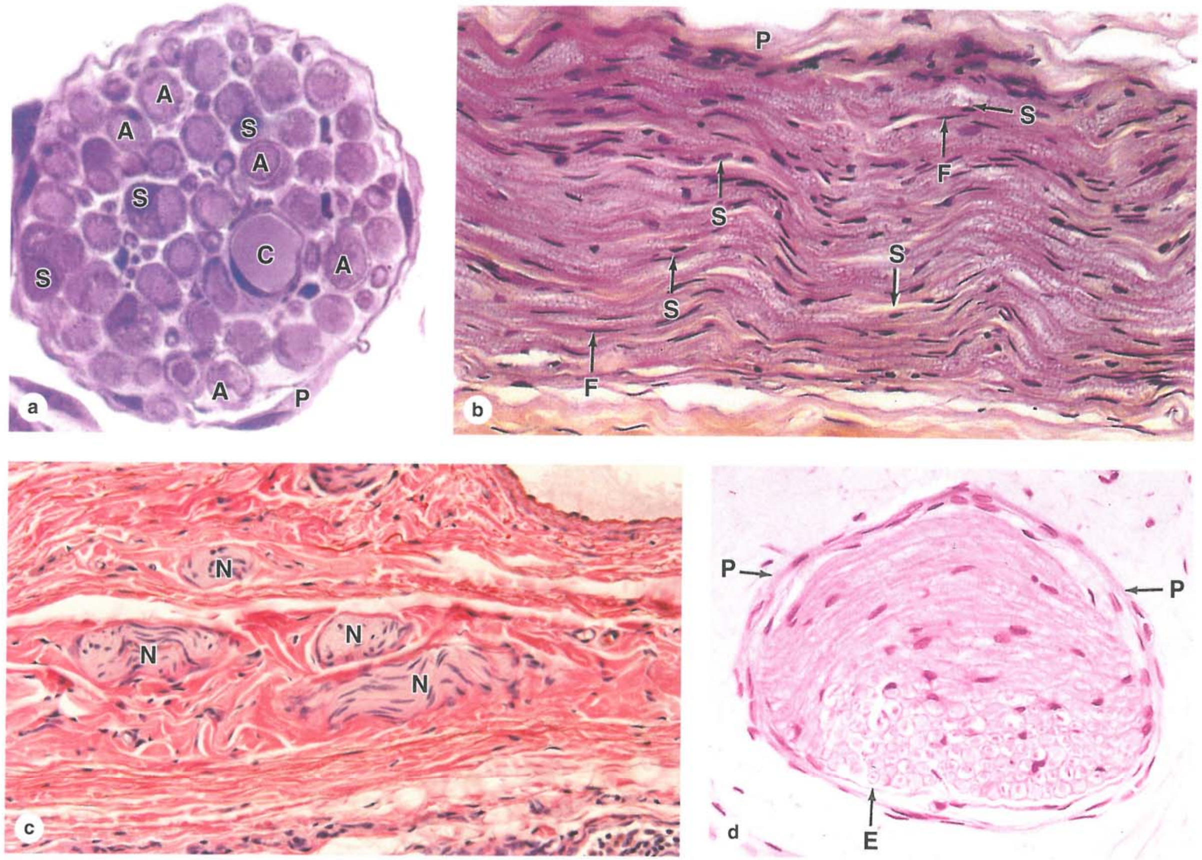


(a) The diagram shows the relationship among these three connective tissue layers in large peripheral nerves. The epineurium (**E**) consists of a dense superficial region and a looser deep region that contains the larger blood vessels. **(b)** The micrograph shows a small vein (**V**) and artery (**A**) in the deep epineurium (**E**). Nerve fibers (**N**) are bundled in fascicles. Each fascicle is surrounded by the perineurium (**P**), consisting of a few layers of unusual squamous fibroblastic cells that are all joined at the peripheries by tight junctions. The resulting blood-nerve barrier helps regulate the microenvironment inside the fascicle. Axons and Schwann cells are in turn surrounded by a thin layer of endoneurium. X140. H&E.

(c) As shown here and in the diagram, septa (**S**) of connective tissue often extend from the perineurium into larger fascicles. The endoneurium (**En**) and lamellar nature of the perineurium (**P**) are also shown at this magnification, along with some adjacent epineurium (**E**). X200. PT.

(d) SEM of transverse sections of a large peripheral nerve showing several fascicles, each surrounded by perineurium and packed with endoneurium around the individual myelin sheaths. Each fascicle contains at least one capillary. Endothelial cells of these capillaries are tightly joined as part of the blood-nerve barrier and regulate the kinds of plasma substances released to the endoneurium. Larger blood vessels course through the deep epineurium that fills the space around the perineurium and fascicles. X450.

FIGURE 9–28 Small nerves.



Small nerves can be seen in sections from most organs. **(a)** In cross section an isolated, resin-embedded nerve is seen to have a thin perineurium (**P**), one capillary (**C**), and many large axons (**A**) associated with Schwann cells (**S**). A few nuclei of fibroblasts can be seen in the endoneurium between the myelinated fibers. X400. PT.

(b) In longitudinal sections the flattened nuclei of endoneurial fibroblasts (**F**) and more oval nuclei of Schwann cells (**S**) can be distinguished. Nerve fibers are held rather loosely in the endoneurium and in low-magnification longitudinal section are seen to be wavy rather than straight. This indicates a slackness of fibers within the nerve, which allows nerves to stretch slightly during body movements with no potentially damaging tension on the fibers. X200. H&E.

(c) In sections of mesentery and other tissues, a highly wavy or tortuous disposition of a single small nerve (**N**) will be seen as multiple oblique or transverse pieces as the nerve enters and leaves the area in the section. X200. H&E. **(d)** Often, a section of small nerve will have some fibers cut transversely and others cut obliquely within the same fascicle, again suggesting the relatively unrestrained nature of the fibers within the endoneurium (**E**) and perineurium (**P**). X300. H&E.

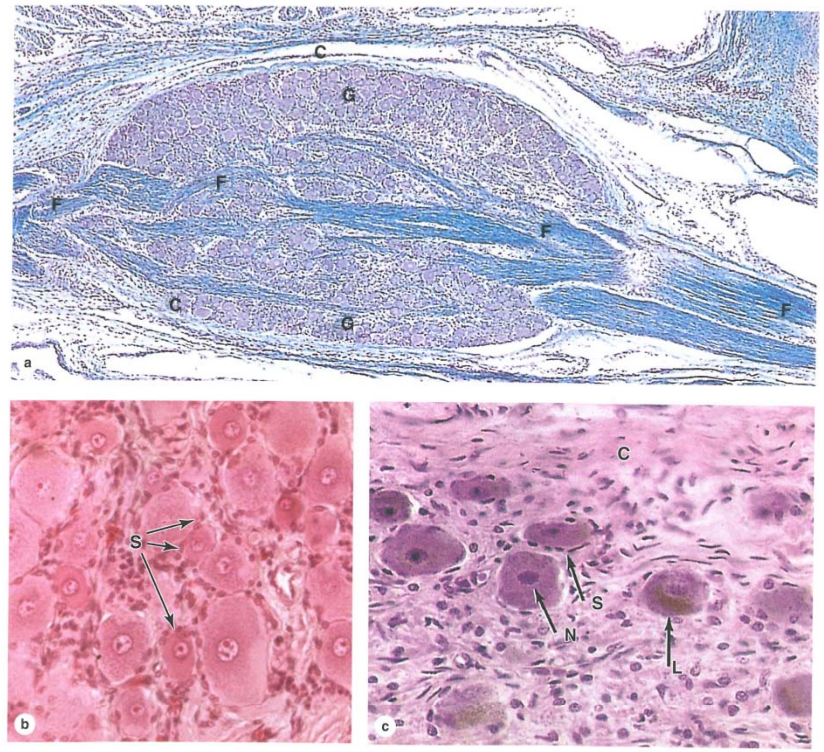
Ganglia

- Oval structures
- Perikaryon & glial satellite cells
- Capsulated

Types:

1. Sensory ganglia
2. Autonome ganglia

FIGURE **9–29** **Ganglia.**



(a) A sensory ganglion (**G**) has a distinct connective tissue capsule (**C**) and internal framework continuous with the epineurium and other components of peripheral nerves, except that no perineurium is present and that there is no blood-nerve barrier function. Fascicles of nerve fibers (**F**) enter and leave these ganglia. X56. Kluver-Barrera stain.

(b) Higher magnification shows the small, rounded nuclei of glia cells called satellite cells (**S**) that produce thin, sheetlike cytoplasmic extensions that completely envelop each large neuronal perikaryon. X400. H&E.

(c) Sympathetic ganglia are smaller than most sensory ganglia but similar in having large neuronal cell bodies (**N**), some containing lipofuscin (**L**). Sheets from satellite cells (**S**) enclose each neuronal cell body with morphology slightly different from that of sensory ganglia. Autonomic ganglia generally have less well-developed connective tissue capsules (**C**) than sensory ganglia. X400. H&E.

Ganglia

- Oval structures
- Perikaryon & glial satellite cells
- Capsulated

Types:

1. Sensory ganglia
2. Autonome ganglia

Neural plasticity & nerve repair

Neurotrophines by:

- Neurons
- Glial cells

Neural embryonic cells

- between ependymal cells

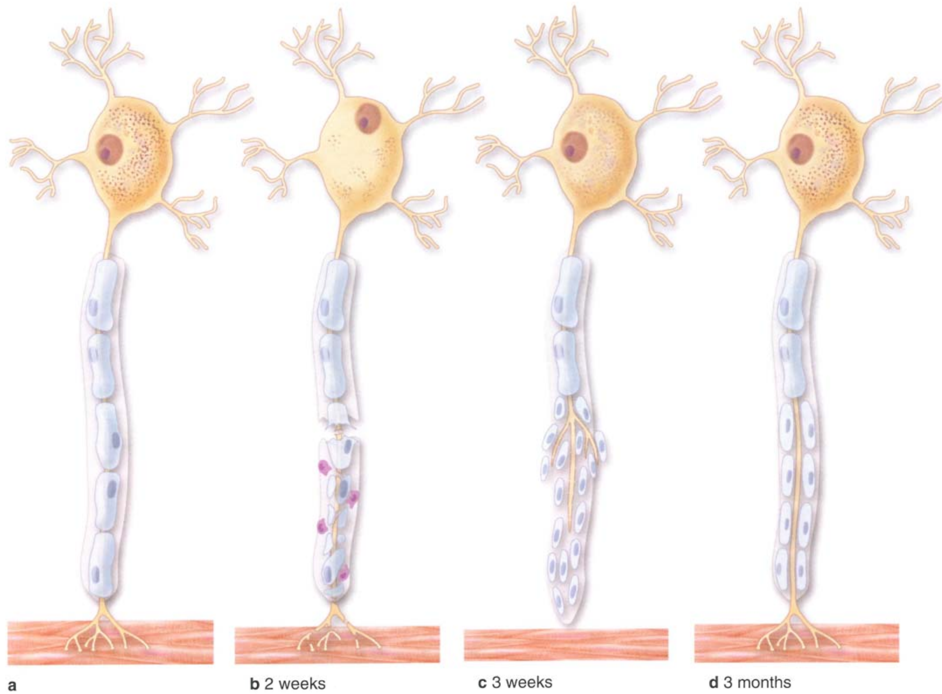
Nerve repair

- chromatolysis

» MEDICAL APPLICATION

Regeneration of peripheral nerves is functionally efficient only when the fibers and the columns of Schwann cells are directed properly. In a mixed nerve, if regenerating sensory fibers grow into columns formerly occupied by motor fibers connected to motor end plates, the function of the muscle will not be reestablished. When there is an extensive gap between the distal and proximal segments of cut or injured peripheral nerves or when the distal segment disappears altogether (as in the case of amputation of a limb), the newly growing axons may form a swelling, or **neuroma**, that can be the source of spontaneous pain.

FIGURE **9–30** **Regeneration in peripheral nerves.**



In an injured or cut peripheral nerve, proximal axon segments can regenerate from their cut ends after a delay. The main changes that take place in an injured nerve fiber are shown here. **(a)** Normal nerve fiber, with its perikaryon, extensive RER (Nissl substance), and effector cell (muscle).

(b) When the axon is injured, the RER is greatly reduced initially and the nerve fiber distal to the injury degenerates along with its myelin sheath. Debris is phagocytosed by macrophages (shown in purple).

(c) In the following weeks after injury, muscle fiber shows denervation atrophy, but Schwann cells proliferate to form a compact cord penetrated by the regrowing axon. The axon grows at the rate of 0.5-3 mm/d.

(d) After some months, the nerve fiber regeneration is successful and functional connections with the muscle fiber are restored.