The Nervous System

Central nervous system (CNS)

The major structures comprising the CNS are the **brain** (**cerebrum, cerebellum, and brainstem) and spinal cord** (Figure 1). The CNS is completely covered by connective tissue layers, the **meninges**, but CNS tissue contains very little collagen or similar material, making it relatively soft and easily damaged by injuries affecting the protective skull or vertebral bones.

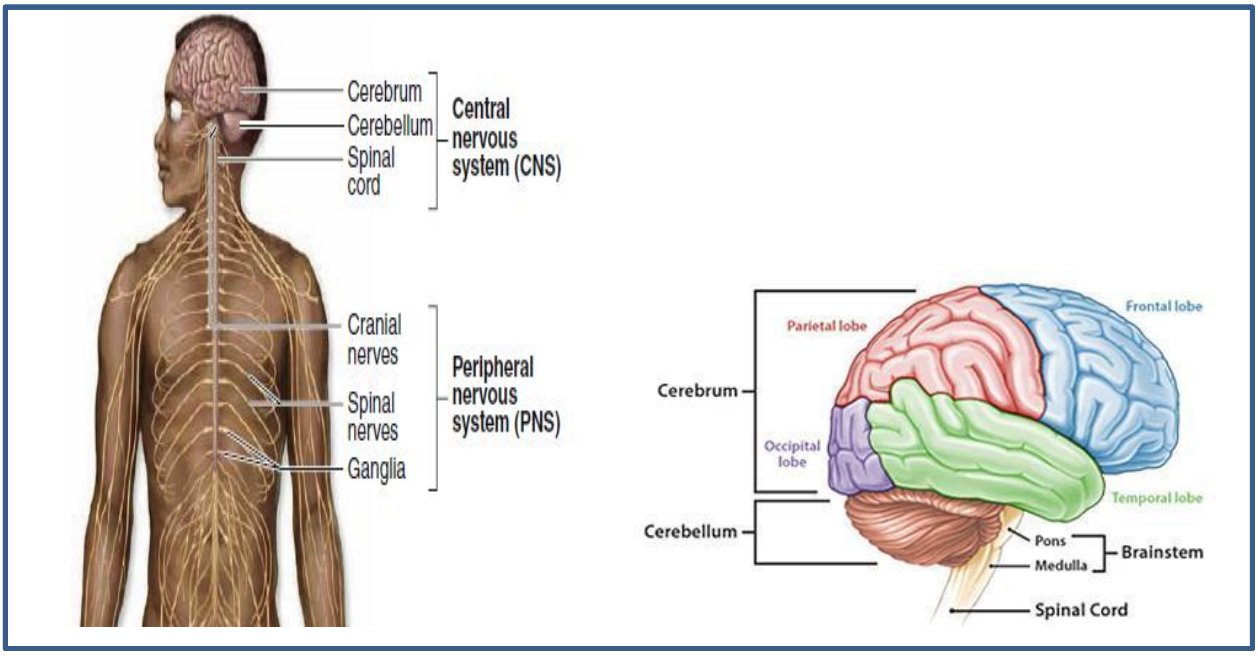
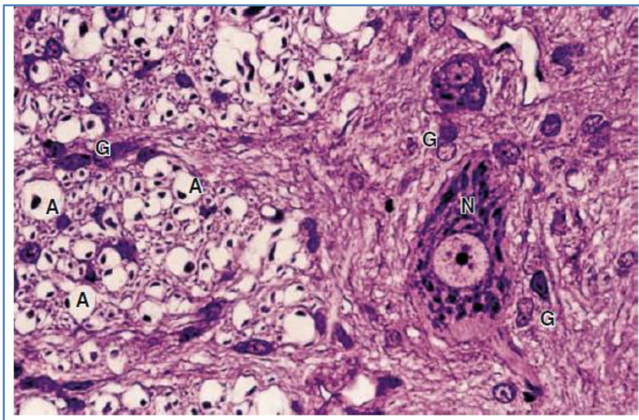


Figure 1 The general organization of the nervous system

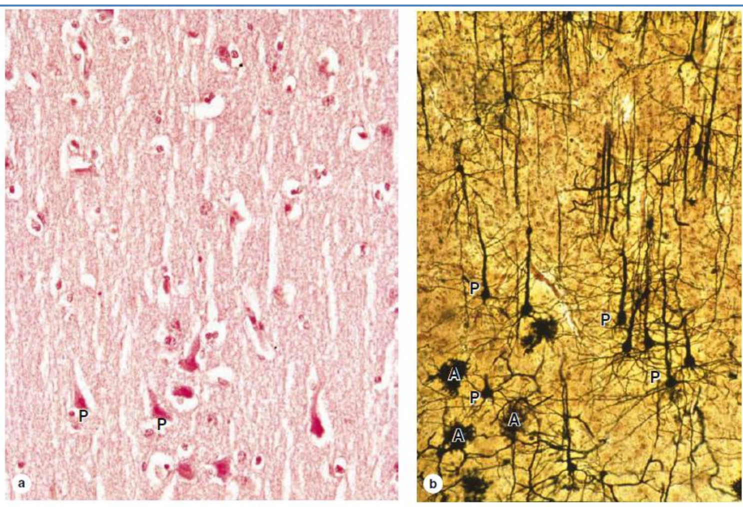
Many structural features of CNS tissues can be seen in unstained, freshly dissected specimens. Many regions show organized areas of **white matter** and **gray matter**, differences caused by the differential distribution of lipid-rich myelin. The main components of white matter are **myelinated axons** (Figure 2), often grouped together as tracts, and the myelin-producing oligodendrocytes. Astrocytes and microglia are also present, but very few neuronal cell bodies. Gray matter contains abundant **neuronal cell bodies**, **dendrites, astrocytes, and microglial cells,** and is where most synapses occur. Gray matter makes up the thick cortex or surface layer of both the cerebrum and the cerebellum; most white matter is found in deeper regions. Deep within the brain are localized, variously shaped darker areas called the **cerebral nuclei**, each containing large numbers of aggregated neuronal cell bodies.



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)

Figure 2 the transition between white matter (left region) and gray matter (right)

In the folded **cerebral cortex** neuroscientists recognize **six layers of neurons** with different sizes and shapes. The most conspicuous of these cells are the **efferent pyramidal neurons** (Figure 3). Neurons of the cerebral cortex function in the integration of sensory information and the initiation of voluntary motor responses.



(**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)

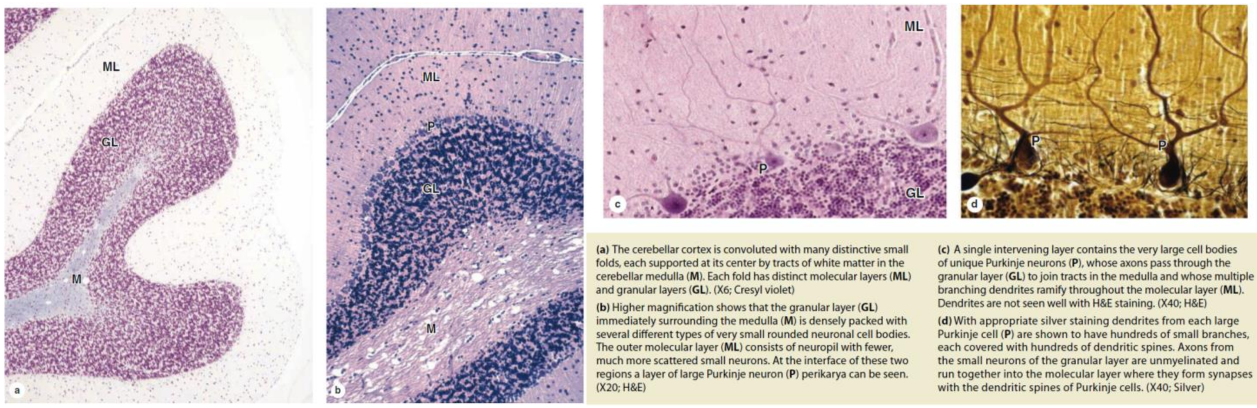
Figure 3 The pyramidal neurons

The sharply folded **cerebellar cortex** coordinates muscular activity throughout the body and is organized with three layers (Figure 4):

1- Molecular layer: A thick outer layer has much neuropil and scattered neuronal cell bodies.

2- Purkinje cells: A thin middle layer consists only of very large neurons. These are conspicuous even in H&E-stained sections, and their dendrites extend throughout the molecular layer as a branching basket of nerve fibres (Figure 4c).

3- Granular layer: A thick inner contains various very small, densely packed neurons (including granule cells, with diameters of only 4-5 μm) and little neuropil.



(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)

Figure 4 The Cerebellum

In cross sections of the **spinal cord** the white matter is peripheral and the gray matter forms a deeper, H-shaped mass (Figure 5). The two anterior projections of this gray matter, the anterior horns, contain cell bodies of very large **motor neurons** whose axons make up the ventral roots of spinal nerves. The two posterior horns contain **interneurons** which receive sensory fibres from neurons in the spinal (dorsal root) ganglia. Near the middle of the cord the gray matter surrounds a small central canal, which develops from the lumen of the neural tube, is continuous with the ventricles of the brain, is lined by ependymal cells, and contains cerebrospinal fluid (CSF).

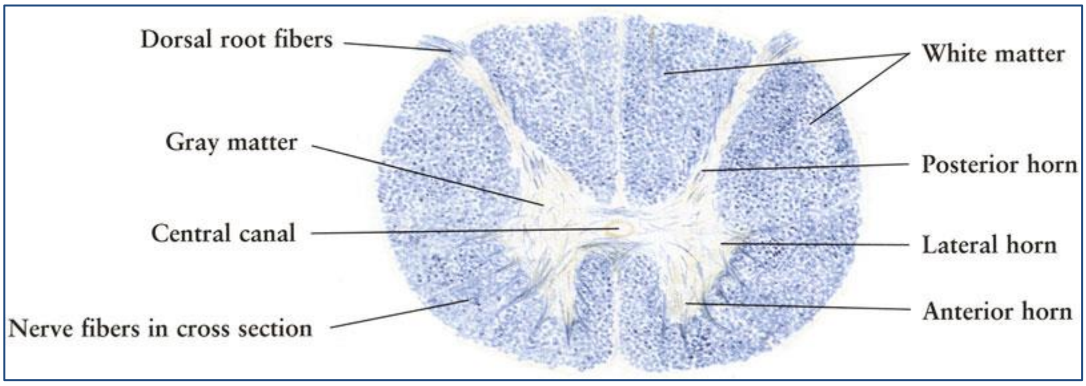
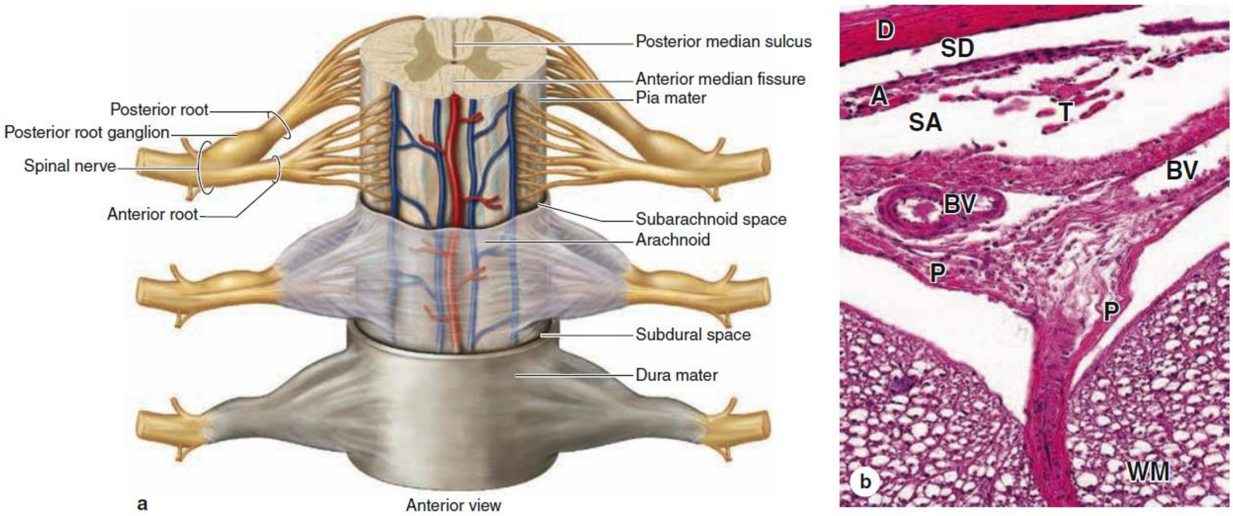


Figure 5 cross section of the spinal cord

Meninges

The skull and the vertebral column protect the CNS, but between the bone and nervous tissue are membranes of connective tissue called the meninges. Three meningeal layers are distinguished: **the dura**, **arachnoid**, and **pia maters** (Figures 6).



(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 6 Spinal cord and meninges

Blood-Brain Barrier

The blood-brain barrier (BBB) is a functional barrier that allows much tighter control than that in most tissues over the passage of substances moving from blood into the CNS tissue. The main structural component of the BBB is the capillary endothelium, in which the cells are tightly sealed together with well-developed occluding junctions, with little or no transcytosis activity, and surrounded by the basement membrane. The BBB protects neurons and glia from bacterial toxins, infectious agents, and other exogenous substances, and helps maintain the stable composition and constant balance of ions in the interstitial fluid required for normal neuronal function. The BBB is not present in regions of the hypothalamus where plasma components are monitored, in the posterior pituitary which releases hormones, or in the choroid plexus where CSF is produced.

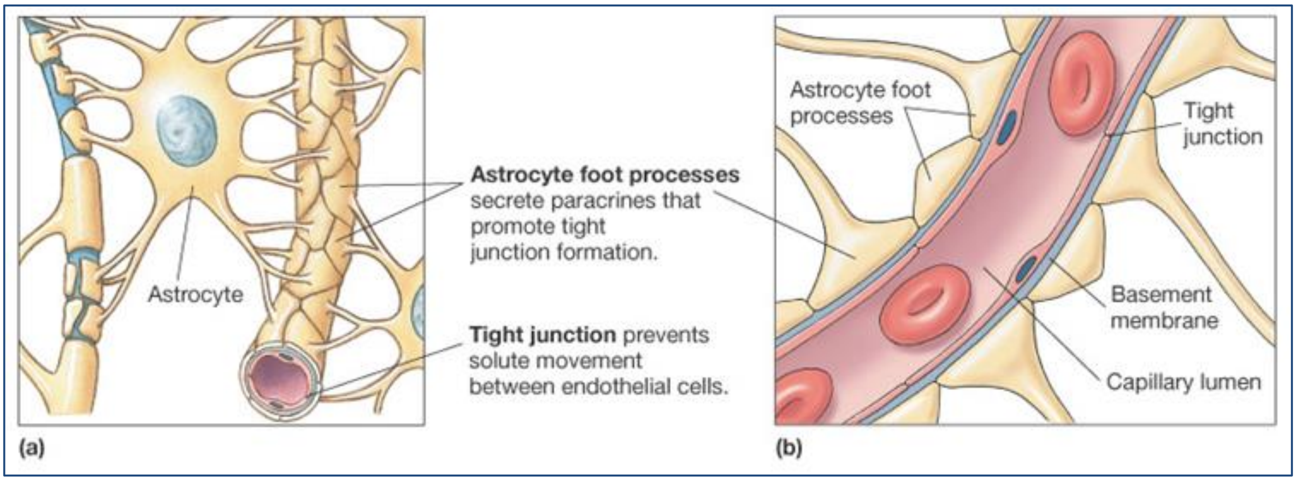


Figure 7 Blood Brain Barrier

Choroid plexus

The choroid plexus is a vascular structure, it is found in the roofs of the third and fourth ventricles and in parts of the two lateral ventricular walls, all regions in which the ependymal lining directly contacts the pia mater. Its main function is to remove water from blood and release it as the CSF. CSF is clear, contains Na+, K+, and Cl^- ions but very little protein, and its only cells are normally very sparse lymphocytes.

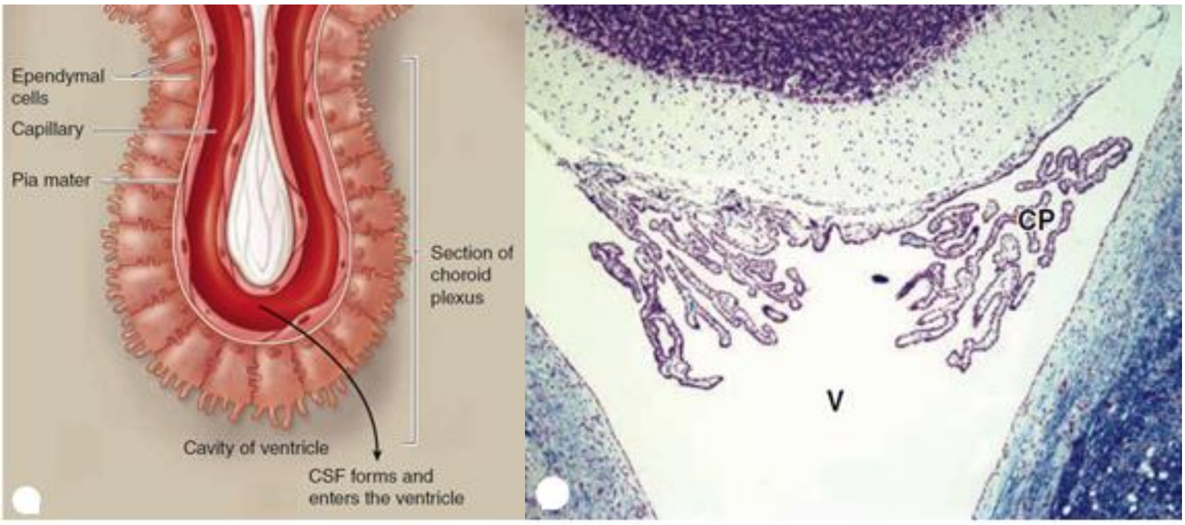


Figure 8 The choroid plexus

Choroid plexus (**CP**) projecting into the fourth ventricle (**V**) near the cerebellum

Peripheral Nervous System (PNS)

The main components of the peripheral nervous system (PNS) are the **nerves**, **ganglia**, and **nerve endings**.

Nerve Fibres

Nerves are **bundles of nerve fibres (axons) surrounded by Schwann cells and layers of connective tissue**. Nerve fibres are containing axons enclosed within sheaths of glial cells specialized to facilitate axonal function. In peripheral nerve fibres, axons are sheathed by **Schwann cells**. The sheath may or may not form myelin around the axons, depending on their diameter.

Myelinated fibres

In myelinated fibres of the PNS, the plasmlemma of the covering Schwann cell winds and wraps around the axon. The layers of membranes of the sheath cell unite and form **myelin**. Myelin consists of many layers of modified cell membranes. These membranes have a higher proportion of **lipids** than do other cell membranes. CNS myelin contains two major **proteins**: **myelin basic protein** and **proteolipid protein**. The myelin sheath shows gaps along its path called the **nodes of Ranvier** (or nodal gaps, Figures 9): these represent the spaces between adjacent Schwann cells along the length of the axon. The distance between two nodes is called an **internode** and consists of one Schwann cell. There are no Schwann cells in CNS; here; the myelin sheath is formed by the processes of the **oligodendrocytes**.

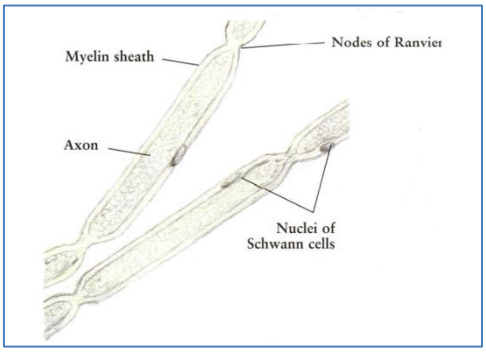


Figure 9 nodes of Ranvier

Unmyelinated fibres

Unmyelinated nerve fibres in the CNS are completely naked axons, but in the PNS they are surrounded by Schwann cell cytoplasm. In these unmyelinated fibres the glial cell does not form the multiple wrapping of a myelin sheath (Figure 10). In unmyelinated fibres, each Schwann cell can enclose portions of many axons with small diameters. Without the thick myelin sheath, nodes of Ranvier are not seen along unmyelinated nerve fibres.

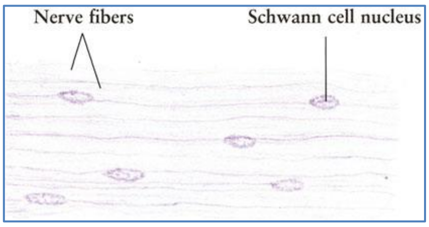


Figure 10 Unmyelinated fibres

Nerve Organization

In peripheral nerves (**spinal nerves** and **cranial nerves)**, each individual axon is seen either enveloped by the myelin sheath (myelinated fibres) formed by Schwann cells, or surrounded by the cytoplasm of Schwann cells (unmyelinated fibres), which can be observed under the electron microscope. Between these nerve fibres is a delicate loose connective tissue, the **endoneurium** (see Figure 11), in close contact with the individual nerve fibers. The nerve fibres are grouped into bundles or fascicles, and covered by the **perineurium**, a layer of dense connective tissue composed of fibroblasts and collagen fibres. Each peripheral nerve is composed of one or more fascicles of nerve fibres and is surrounded by a layer of loose connective tissue, the **epineurium**, which extends from the outside and binds the fascicles together. The nerves establish communication between brain and spinal cord centres and sense organs and effectors (muscles, gland, etc.). They possess afferent and efferent fibres to and from the CNS. Afferent fibres carry the information obtained from the interior of the body and the environment to the CNS. Efferent fibres carry impulses from the CNS to the effector organs commanded by these centres. Nerves possessing only sensory fibres are called **sensory nerves**; those composed only of fibres carrying impulses to the effecters are called **motor nerves**. Most nerves have both sensory and motor fibres and are called **mixed nerves**.

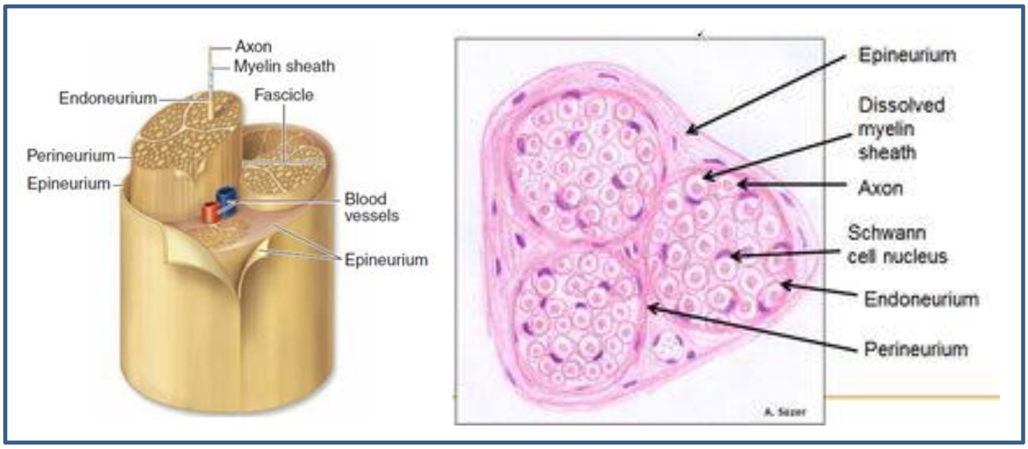


Figure 11 Structure of nerves

Ganglia

Ganglia are typically ovoid structures containing neuronal cell bodies. Each ganglion cell body is surrounded by a layer of flat satellite cells, which provide structural and metabolic support to the neurons. The ganglion is enclosed by loss and a dense connective tissue capsule, which divides into trabeculae to provide a framework for the neuronal cells (Figure 12). Because they serve as relay stations to transmit nerve impulses, at least one nerve enters and another exits from each ganglion. The direction of the nerve impulse determines whether the ganglion will be a **sensory or an autonomic ganglion**.

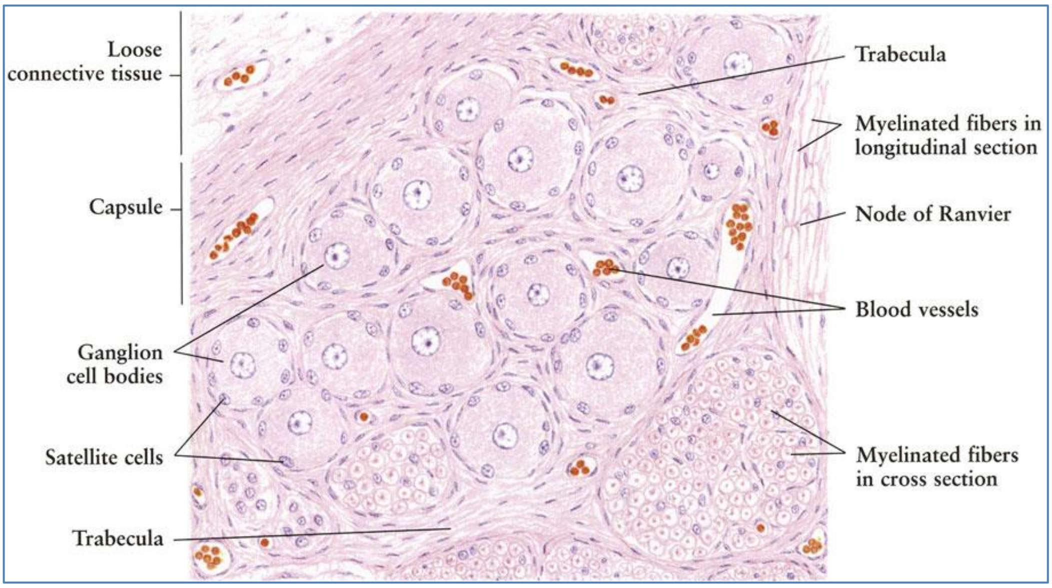


Figure 12 Spinal ganglion

Autonomic nervous system (ANS)

The ANS is a two-neuron network, each neuron is linked by way of a ganglion **(a ganglion is an accumulation of nerve cell bodies outside the brain or spinal cord)**. The first neuron starts with the CNS and runs out to the ganglion, the second neuron has its cell body within the ganglion and its axon runs to the organ. The first neuron is called preganglionic; the second neuron is called postpreganglionic. The ANS is composed of two parts that differ both anatomically and functionally, sympathetic and parasympathetic systems. Both systems transmit across their ganglia employing neurotransmitter acetylcholine.

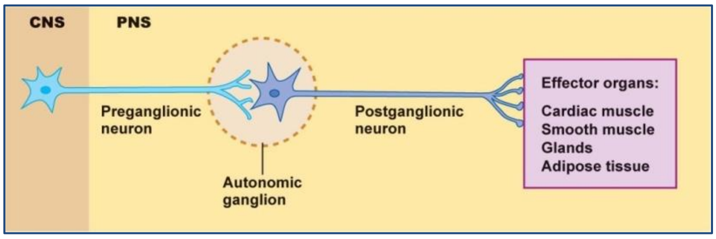


Figure 13 The autonomic nervous system

The sympathetic system

These nerves originate from the middle region (thoracic and lumbar) of the spinal cord, therefore this system is called the thoracolumbar system. These nerves leave the spinal cord and unite at a ganglion lying just alongside. The preganglionic nerve axon of the sympathetic system is very short; the postganglionic nerve axon is much longer. At the nerve endings of the postganglionic fibres a neurotransmitter called noradrenalin (norepinephrine) is secreted, for this reason these sympathetic nerve fibres are described as adrenergic. The preganglionic fibres employ acetylcholine as a neurotransmitter. The function of the sympathetic nervous system is to prepare the body for emergencies.

The parasympathetic system

The nerves of this system arise from the base of the brain and from the bottom region of the spinal cord (sacral portion). The preganglionic fibre is long and travels to a ganglion that is on or near the organ being supplied, the postganglionic fibre is very short. The chemical transmitter used by the parasympathetic system is acetylcholine and therefore these fibres are described as cholinergic. The function of parasympathetic nervous system is to maintain the body in a resting "normal" state.

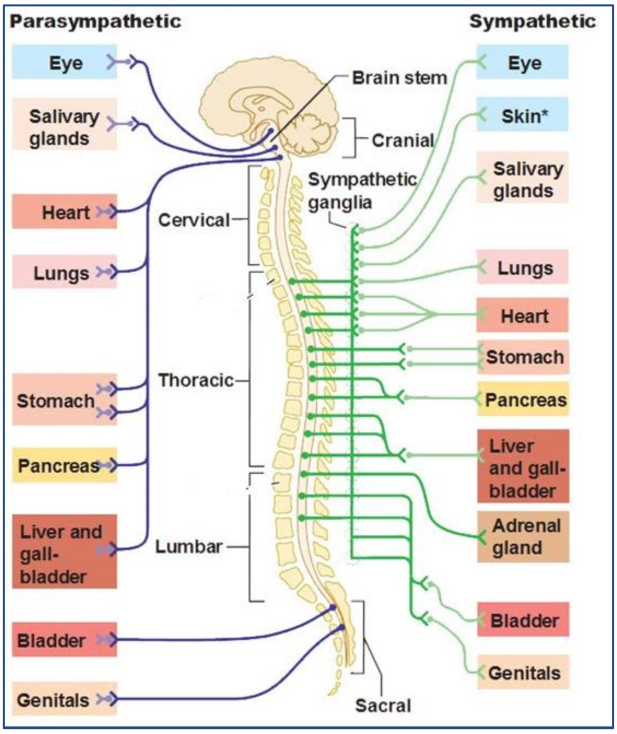


Figure 14 Sympathetic and parasympathetic nervous system