Chapter 3 - Nervous system

The objectives of this chapter are:

1. Define the central and peripheral nervous system.
2. Describe the brain.
3. Name parts of the cerebrum, cerebellum, and brainstem.
4. Describe the spinal cord.
5. Describe the spinal nerves and spinal nerve plexuses.
6. Name the cranial nerves and their functions.
7. Describe the autonomic nervous system.

1 - Generalities

The nervous system is a set of structures that enable reception, integration and transmission of sensory information, and generation of adequate response to the information.

Basic cells of the nervous systems are neurons. A neuron has a body (soma), short, branched extensions called dendrites and long extension called axon, which can be enveloped in the myelin sheath.

The nervous system can be divided into categories in diverse ways:

- **Morphological division of the nervous system**
    - Central nervous system comprises the brain and the spinal cord.
    - Peripheral nervous system comprises 12 pairs of cranial nerves and 31 pairs of spinal nerves.
- **Functional division of the nervous system**
    - Nervous system of relational life: the somatic nervous system, conscious and voluntary.
    - Nervous system of vegetative life: the autonomic nervous

system, unconscious and involuntary. It consists of the sympathetic and parasympathetic nervous system.

2 - Morphological study of the nervous system

2.1 - Central nervous system

In the central nervous system, parts of neurons are arranged in such a way that they form the grey and the white matter:

- **The grey matter** contains mostly the bodies of neurons.
- **The white matter** contains mostly the nerve fibres – the axons with their myelin sheaths.

The central nervous system includes the brain and the spinal cord.

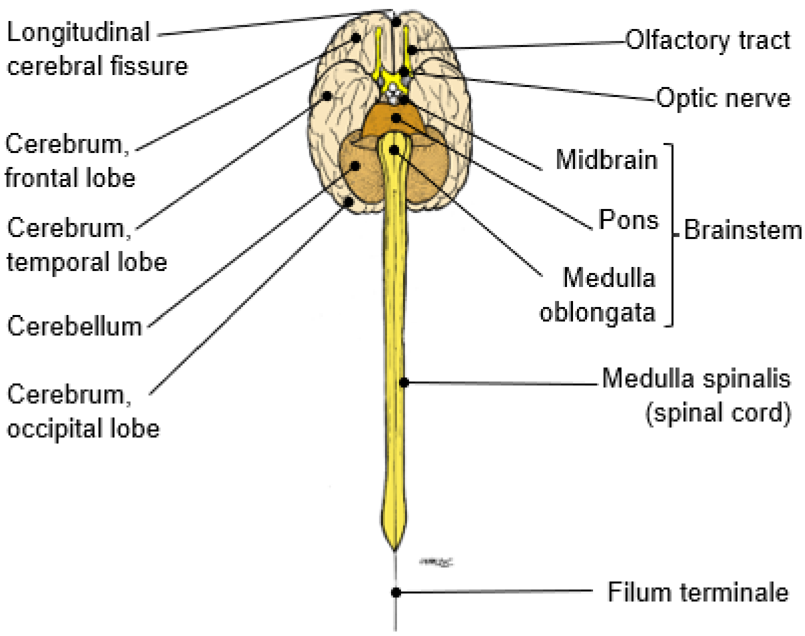

Figure 114: Anterior view of the central nervous system.

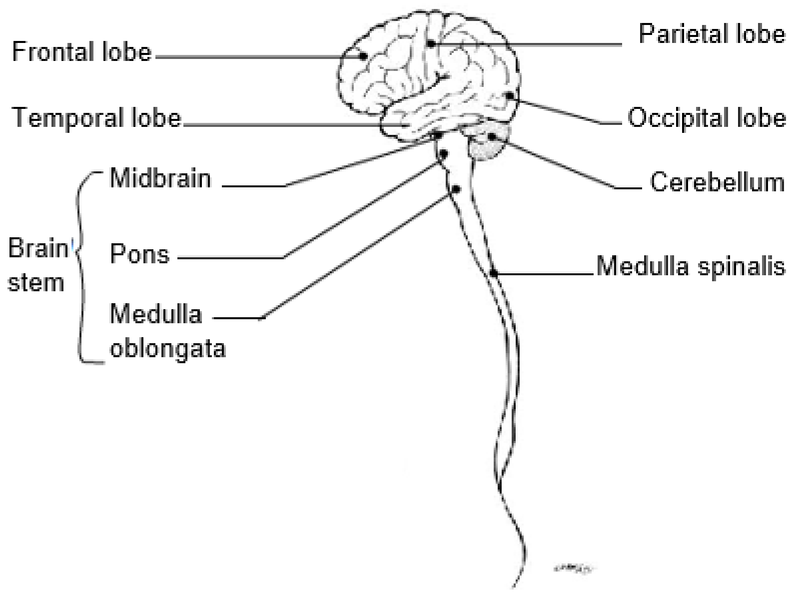

Figure 115: Left lateral view of the central nervous system.

Spinal cord

The spinal cord is about 45 cm long tubular structure with a diameter of about 1 cm. It lies within the vertebral canal and terminates at the level of vertebra L2, with the narrowing called the medullary cone. It has two enlargements, the cervical and lumbar one.

The grey matter of the spinal cord is located centrally, forming paired anterior (motor) column and paired posterior (sensory) column. The thoracic and sacral segments have an additional, lateral pair of columns.

On the cross-section, the grey matter has a shape of a letter H and is divided into paired anterior, posterior and lateral horns. The white matter is divided into paired anterior, posterior and lateral funiculi.

The central canal is a longitudinal hollow space in the centre of the spinal cord, spanning throughout its entire length. It is filled with the cerebrospinal fluid.

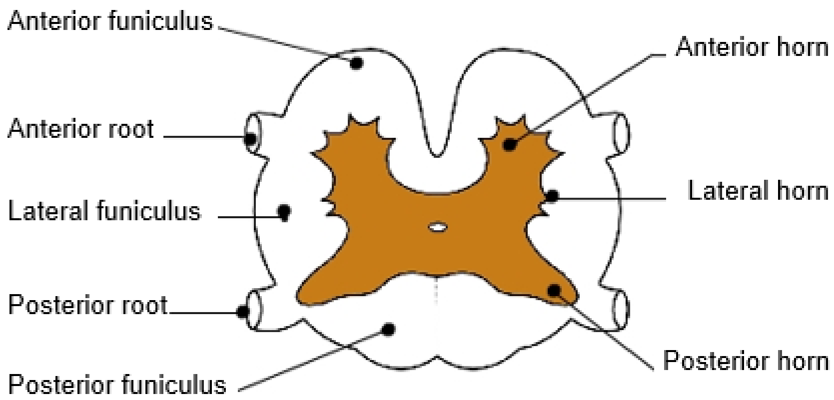

Figure 116: Cross-section through the spinal cord, morphological areas.

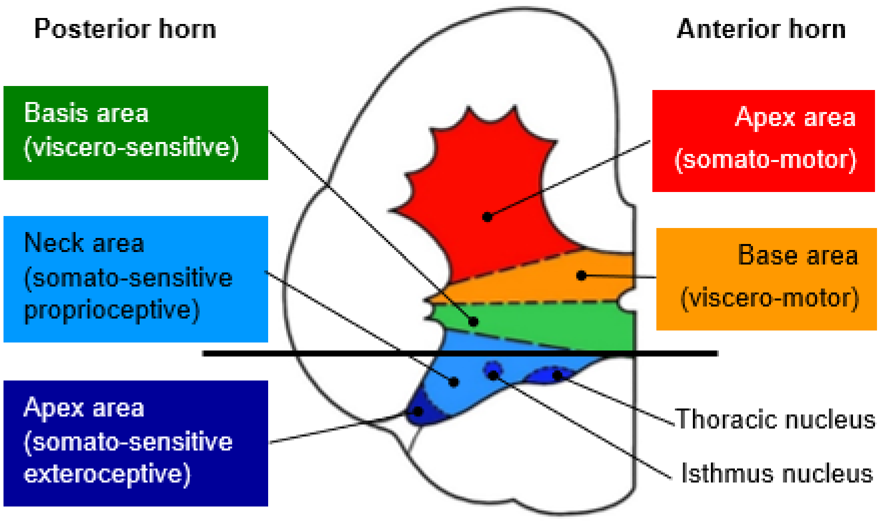

Figure 117: Cross-section through the spinal cord, functional areas.

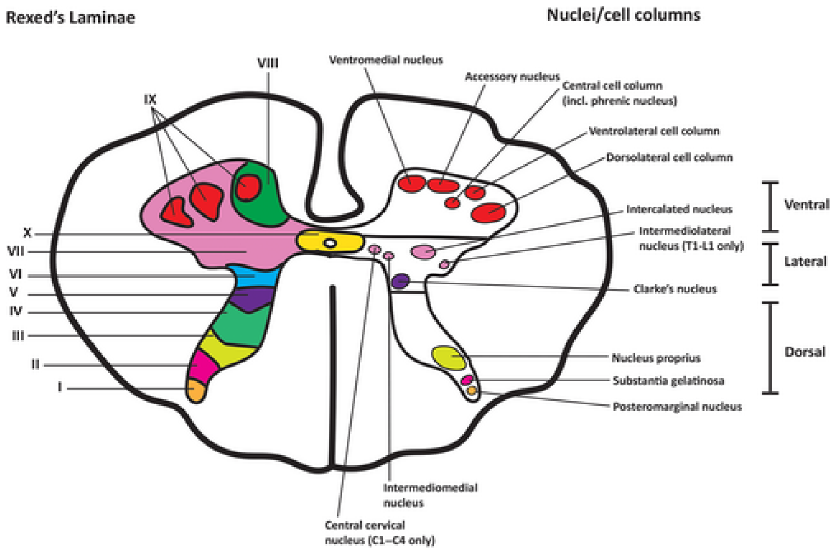

Figure 118: Cross-section through the spinal cord, lamination of grey matter.

Acute poliomyelitis is a viral disease that electively affects the anterior (motor) horn of the spinal cord and causes paralysis without affecting sensitivity. Contractures can develop.

Right leg: lateral view. ***Left foot: anterolateral view.***

Figure 119: Patient with poliomyelitis.

Brain

The brain is composed of three parts:

- The brainstem is the site of the vital centres.
- The cerebellum is the site of equilibrium maintenance and motor coordination.
- The cerebrum is the site of analysing and processing centres.

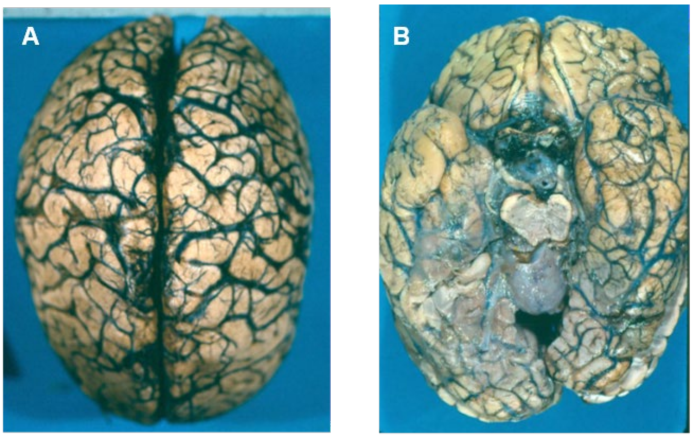

Figure 120: Superior (A) and inferior (B) view of the brain

Cerebrum

The cerebrum is the largest part of the brain and the highest level in functional hierarchy of the central nervous system. It is particularly well developed in humans. It is divided into two parts, the telencephalon and the diencephalon.

The telencephalon is formed by left and right cerebral hemispheres, connected by the corpus callosum. The hemispheres are separated in the midline by a deep sagittal fissure named the longitudinal cerebral fissure. Each hemisphere is divided into four lobes: the frontal, parietal, temporal and occipital lobes. Surface of the hemispheres is folded into ridges called cerebral gyri. The gyri are separated with furrows called cerebral sulci.

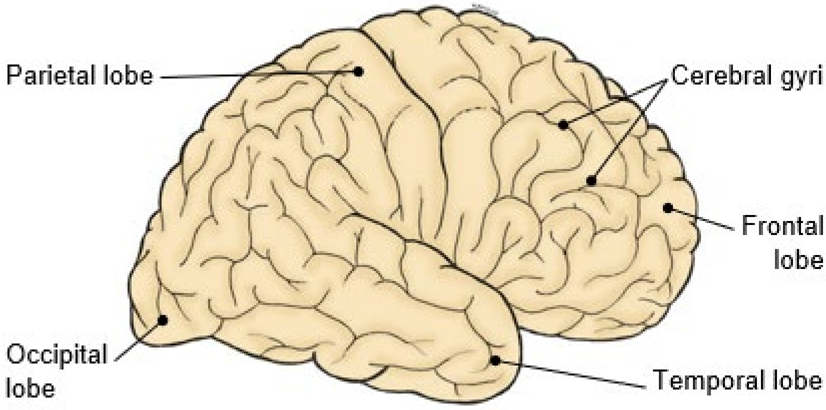

Figure 121: Right lateral view of the brain.

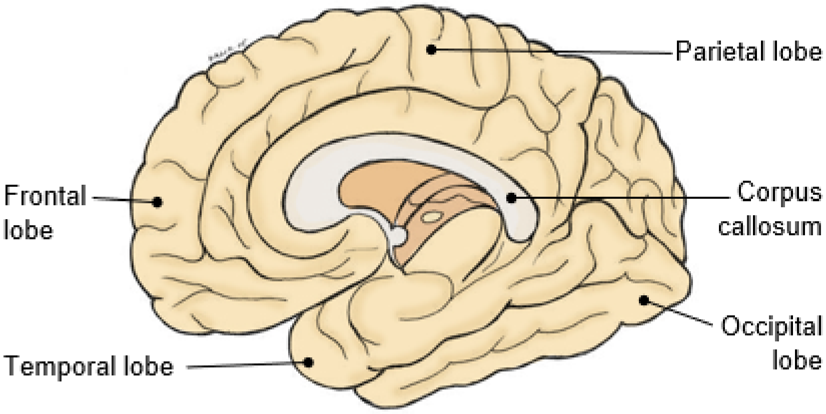

Figure 122: Median section of the cerebrum. View from the left.

The diencephalon is a much smaller part of the cerebrum, located in the middle of the brain. Its most important regions are the thalamus, the hypothalamus and the epithalamus.

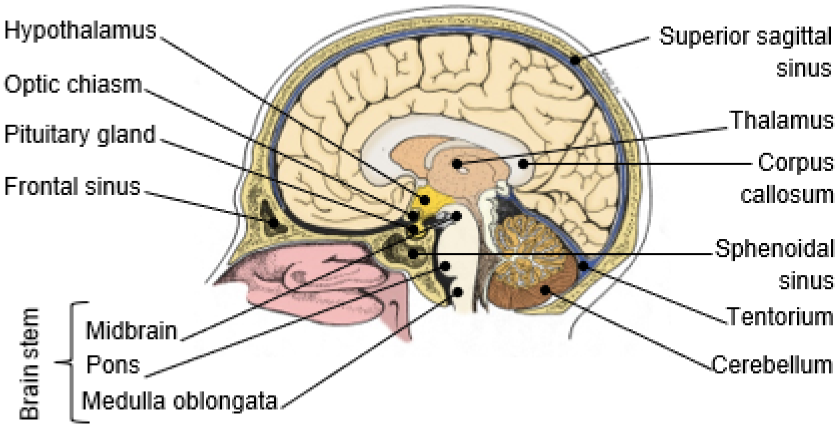

Figure 123: Median section of the brain. View from the left.

The grey matter of cerebrum is located on the surface of the hemispheres as the cerebral cortex, and also in the inner part as basal ganglia. In between are the bundles of white matter.

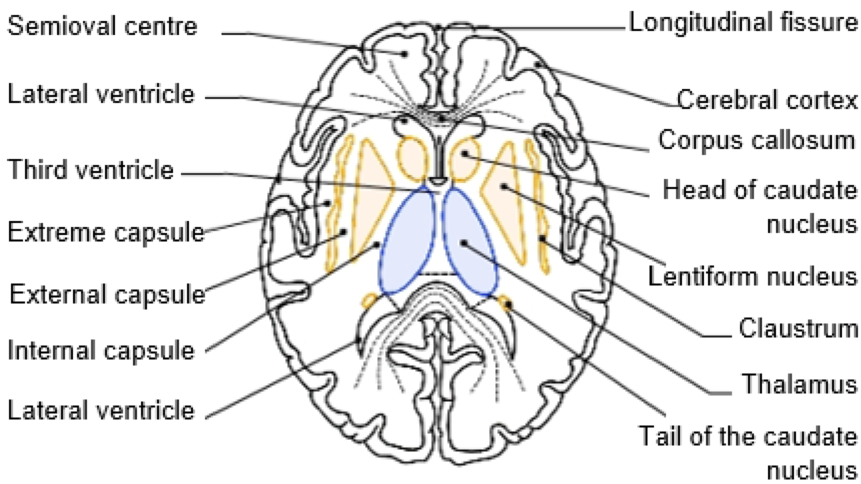

Figure 124: Scheme of the horizontal section of the cerebrum.

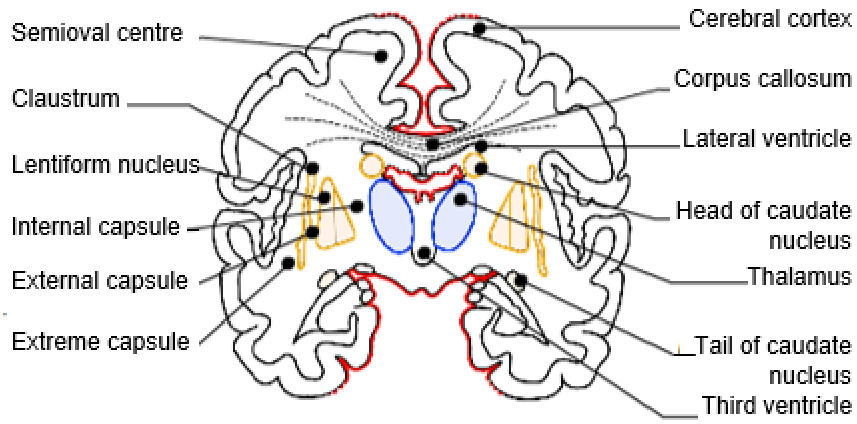

Figure 125: Scheme of the frontal section of the cerebrum.

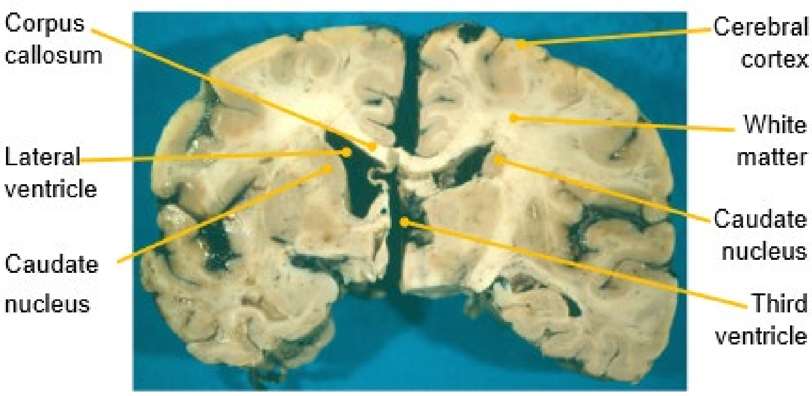

Figure 126: Photography of the frontal section of the cerebrum.

Cerebellum

The cerebellum is located in the posterior cranial fossa, posteriorly to the brainstem to which it is connected by the cerebellar peduncles.

It consists of the left and right cerebellar hemisphere and the vermis in-between them. The grey matter on the surface of cerebellum forms the cerebellar cortex. Some of the grey matter lies in deeper parts, forming the cerebellar nuclei.

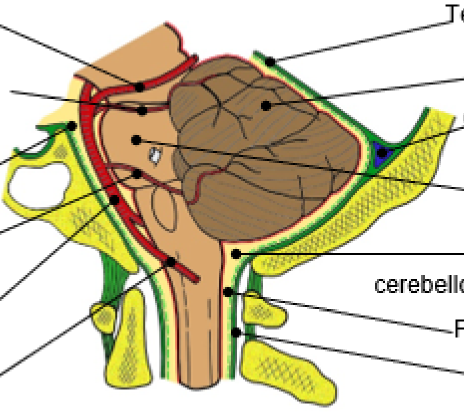

Figure 127: Sagittal section of the posterior cranial fossa with cerebellum and brainstem, view from the left.

Brainstem

The brainstem is located in the posterior cerebral fossa, in front of the cerebellum. It is an important passage between the spinal cord and the brain for the main motor, sensory and association pathways. It is the nerve structure from which most of the cranial nerves originate (cranial nerves III to XII). It is also a site where the so-called vital centres are located, enabling the body to maintain the vitally important functions, such as breathing, heart beating and blood pressure regulation.

The brainstem has a shape of truncated cone. It is 9-10 cm long and widens upwards. The grey matter is situated in the inner part of the brainstem and is intertwined by the white matter, thus forming reticular formation.

The brainstem is divided into three distinctive parts (from bottom to top):

- medulla oblongata (bulb) is continuation of the spinal cord;
- pons is connected posteriorly to the cerebellum;
- midbrain (mesencephalon) is connected superiorly to the cerebrum with paired cerebral peduncles.

Ventricles of brain

The ventricles of the brain are hollow spaces in the brain, filled with the cerebrospinal fluid (CSF).

There are four ventricles connected to each other. The lateral ventricles (1st and 2nd ventricle) are the largest and lie inside each cerebral hemisphere. They have a shape of a letter C and reach into all the lobes. Three horns of the ventricle wear the same name as the lobe they lie in while the central part lies inside the parietal lobe. The third ventricle is in the diencephalon. The fourth ventricle is located between the brainstem and the cerebellum.

Each lateral ventricle is connected to the 3rd ventricle through the interventricular foramen, while the 3rd and 4th ventricle communicate through the cerebral aqueduct which lies inside the midbrain. The 4th ventricle communicates with the subarachnoid space.

The ventricles contain choroid plexuses, which secrete about 500 ml of CSF per day. Excessive secretion of CSF can lead to hydrocephalus.

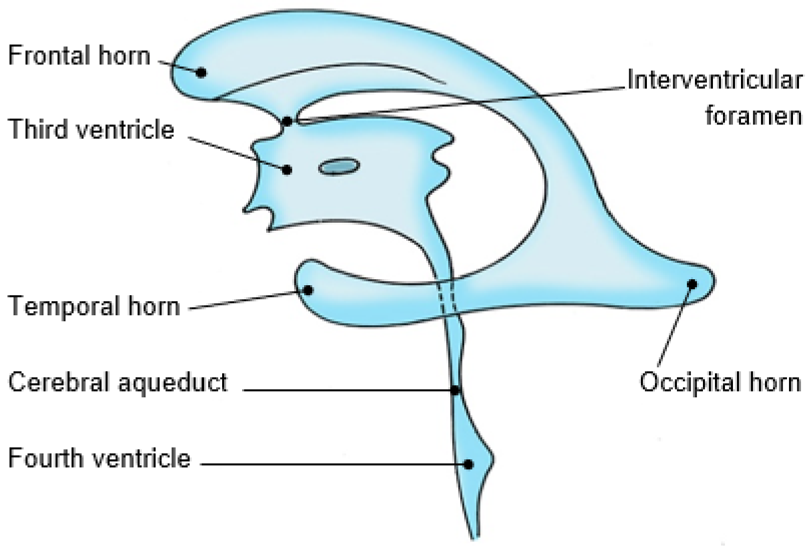

Figure 128: Ventricles of brain, left lateral view.

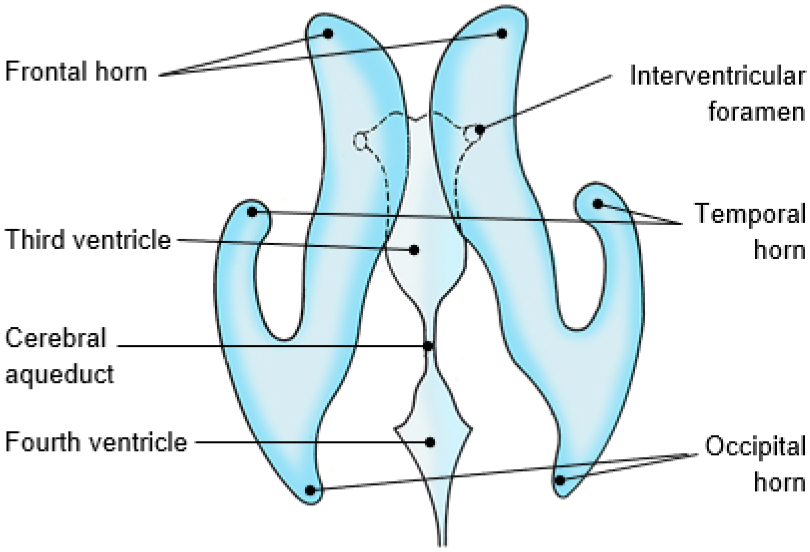

Figure 129: Ventricles of brain, superior view.

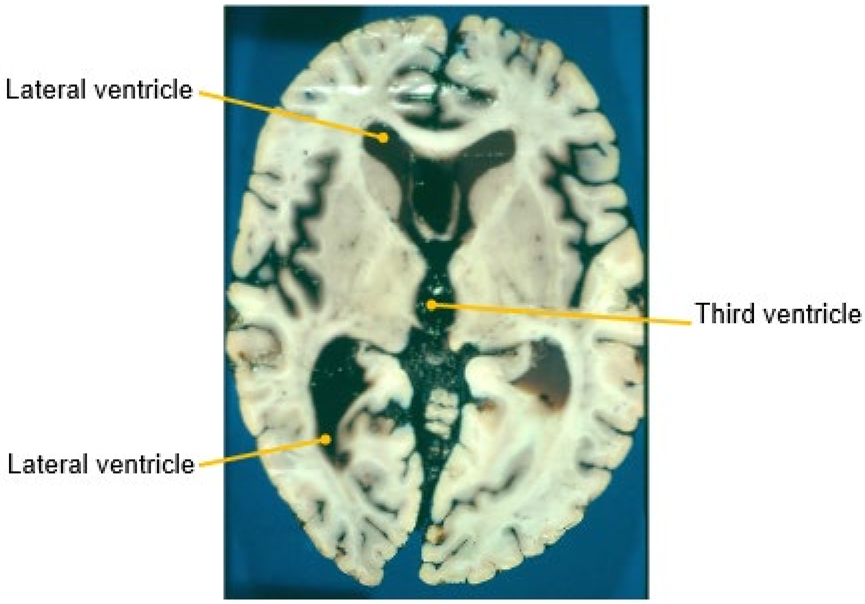

Figure 130: Horizontal section of the brain showing the ventricles.

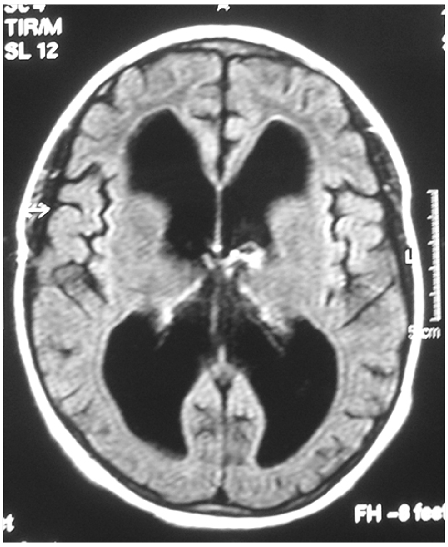

Figure 131: MRI, horizontal section of the brain showing hydrocephalus.

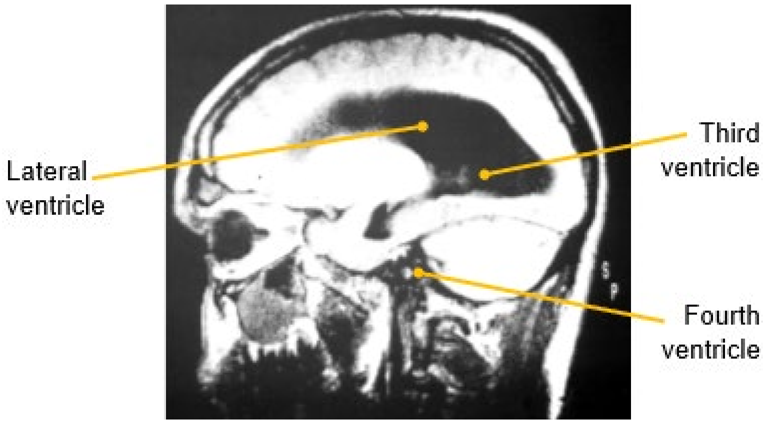

Figure 132: MRI, sagittal section of the brain showing the ventricles.

2.2 - Peripheral nervous system

The peripheral nervous system is formed by nerves exiting the central nervous system. According to the origin, the peripheral nervous system is divided into the spinal nerves originating from the spinal cord and the cranial nerves originating from the brain.

Spinal nerves

31 pairs of spinal nerves branch off from the spinal cord:

- 8 pairs of cervical nerves – spinal nerves C1 to C8.
- 12 pairs of thoracic nerves – spinal nerves T1 to T12.
- 5 pairs of lumbar nerves – spinal nerves L1 to L5.
- 5 pairs of sacral nerves – spinal nerves S1 to S5.
- 1 pair of coccygeal nerve – spinal nerve Co.

There are 8 pairs of cervical spinal nerves, although there are only seven cervical vertebrae. The numbering of the nerves starts at the top. The first pair (C1) runs between the occipital bone and vertebra C1. The second pair runs between the vertebrae C1 and C2, so the number of the nerve corresponds to the number of the vertebra below it. The pair of nerves C7 lies between the vertebrae C6 and C7, and the pair of nerves C8 lies between the vertebrae C7 and T1. The following pairs of nerves take the number of the vertebra above it.

The spinal nerve arises from the spinal cord as rootlets which converge to form two nerve roots, the anterior and posterior one.

The anterior root (motor root) of spinal nerve is formed by the axons of motor neurons, arising from the anterior horn of the spinal cord.

The posterior root (sensory root) of spinal nerve is formed by sensory neurons, which are pseudo-unipolar. The bodies of neurons form a knot on the posterior root, called the spinal ganglion. The peripheral axons join the motor fibres in the spinal nerve, and the central axons enter the posterior horn of the spinal cord.

The anterior and posterior root unite at the intervertebral foramen to form the spinal nerve. All spinal nerves are therefore mixed – they contain both motor and sensory fibres.

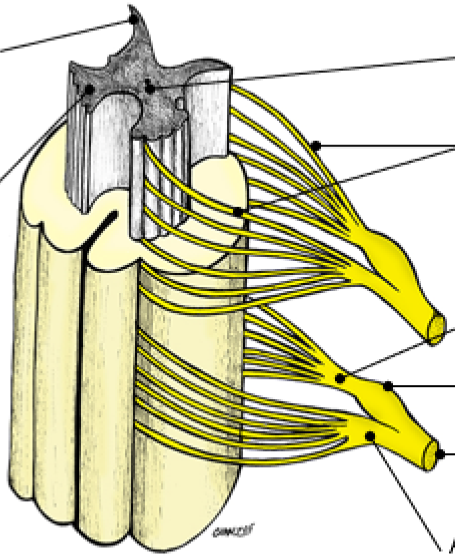

Figure 133: Spinal nerve, anterior and posterior root, spinal ganglion.

After exiting the intervertebral foramen, the spinal nerve divides into two branches – the anterior and posterior ramus of the spinal nerve.

The posterior rami remain separate from each other and innervate the deep muscles of the back and the skin above them in a segmental pattern.

The anterior rami innervate the anterior and lateral parts of the trunk and the upper and lower limbs. Only the rami of thoracic spinal nerves remain separate, innervating muscles and skin of the trunk in a segmental pattern. The anterior rami of cervical, lumbar and sacral spinal nerves form the nerve plexuses, from which the peripheral nerves emerge. In Latin, the term plexus means braid. This term efficiently describes the structure of the nerve plexuses.

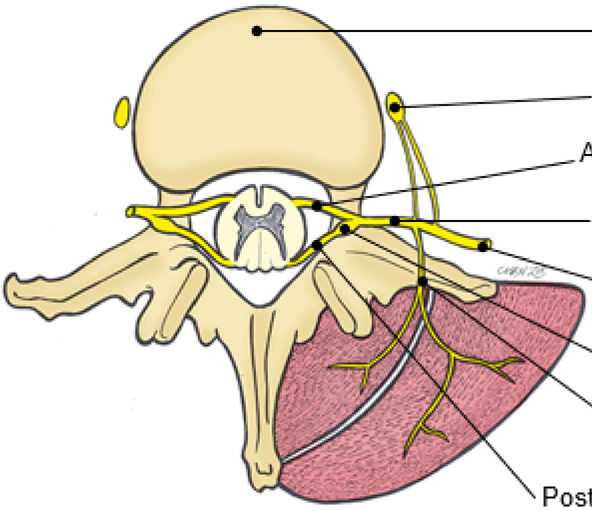

Figure 134: Spinal nerve: anterior and posterior ramus.

There are four distinctive nerve plexuses, namely, the cervical, the brachial, the lumbar and the sacral plexus.

Cervical plexus

The cervical plexus is formed by the anterior rami of spinal nerves C1, C2, C3, C4 and partly C5.

The main nerve of the cervical plexus is the phrenic nerve, which innervates the diaphragm. The plexus also provides motor supply to some neck muscles and cutaneous sensation to the skin of the neck and posterior side of head.

Brachial plexus

The brachial plexus is formed by the anterior rami of five spinal nerves: C5, C6, C7, C8 and T1. It innervates the upper limb.

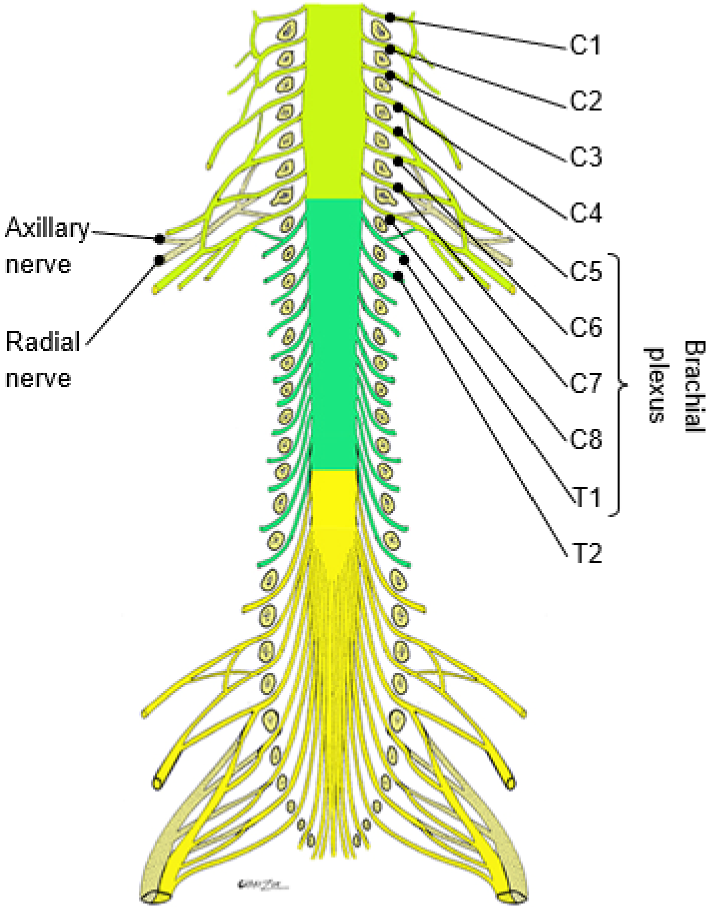

Figure 135: Brachial plexus.

The anterior rami of the five spinal nerves forming the brachial plexus unite into 3 trunks: the superior trunk is formed by the nerves C5 and C6, the middle trunk by a single nerve C7, and the inferior trunk is formed by the nerves C8 and T1.

These three trunks enter the axilla and recombine to form 3 cords, named according to their position to the axillary artery: the lateral, medial, and posterior cords. From the cords arise peripheral nerves.

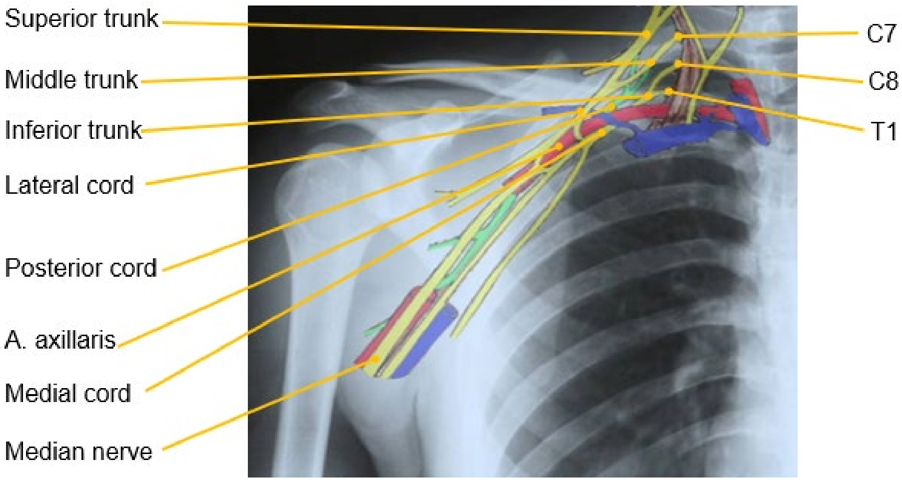

Figure 136: X-ray of the right shoulder with drawing of the axillary artery and the brachial plexus. Anterior view.

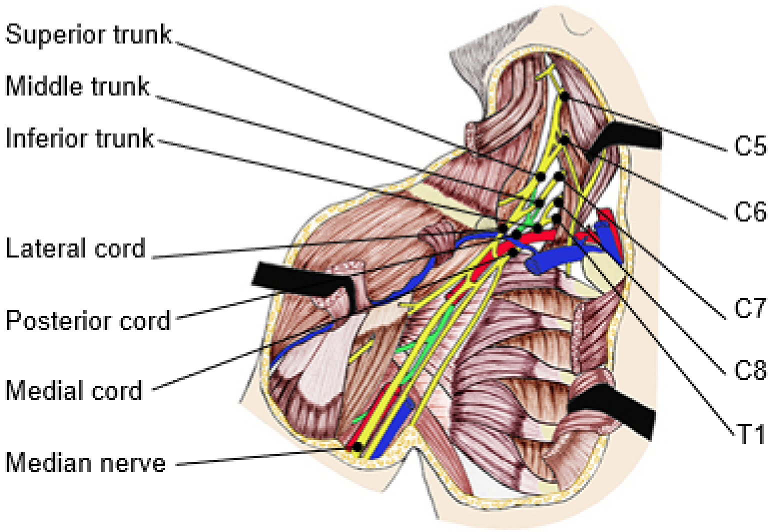

Figure 137: The right brachial plexus. Anterior view.

Lumbar and sacral plexuses

The lumbar plexus is formed by the anterior rami of the spinal nerves L1, L2, L3, and L4. The sacral plexus is formed by the anterior rami of the spinal nerves L4, L5, S1, S2, S3, and S4.

Both plexuses are interconnected, forming the lumbosacral plexus which innervates the lower limb.

The sacral plexus forms the largest peripheral nerve in the body, namely the sciatic nerve which contains the fibres of spinal nerves L4 to S3.

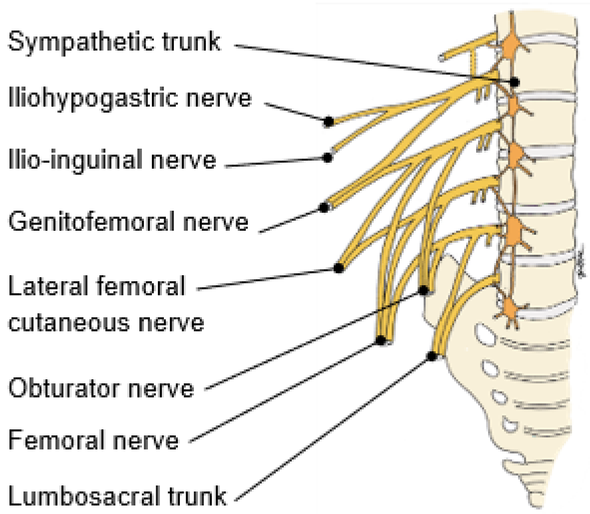

Figure 138: The lumbar plexus.

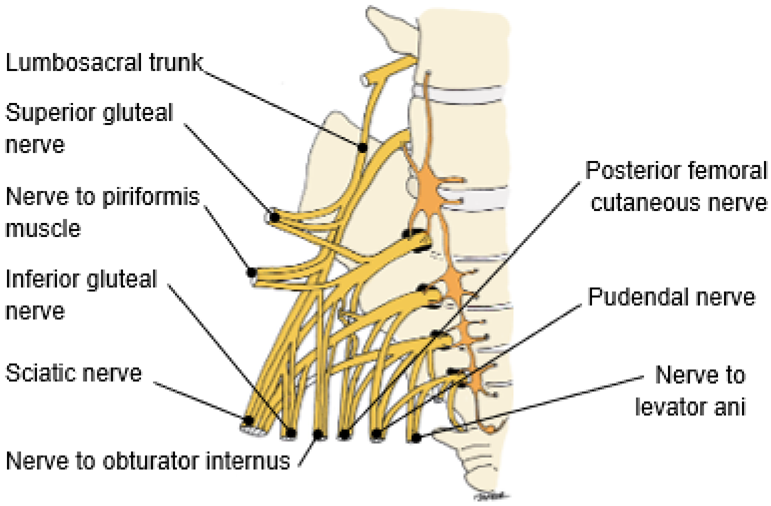

Figure 139: The sacral plexus.

Figure 140: Lumbar spine dissections.

Cranial nerves

There are 12 pairs of cranial nerves (CN), numbered from CN I to CN XII from the anterosuperior to the posteroinferior site. With the exception of the CN I and CN II, which originate from the cerebrum, all other cranial nerves originate from the brainstem.

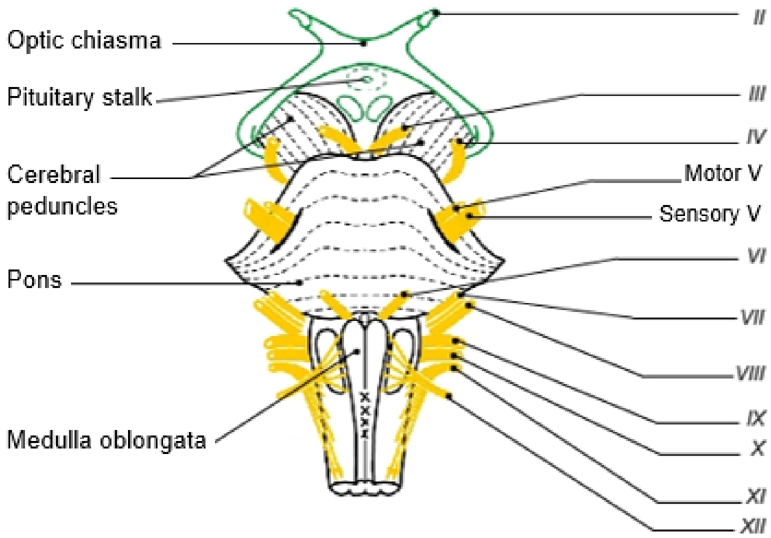

Figure 141: Origin of cranial nerves. Anterior view of the brainstem.

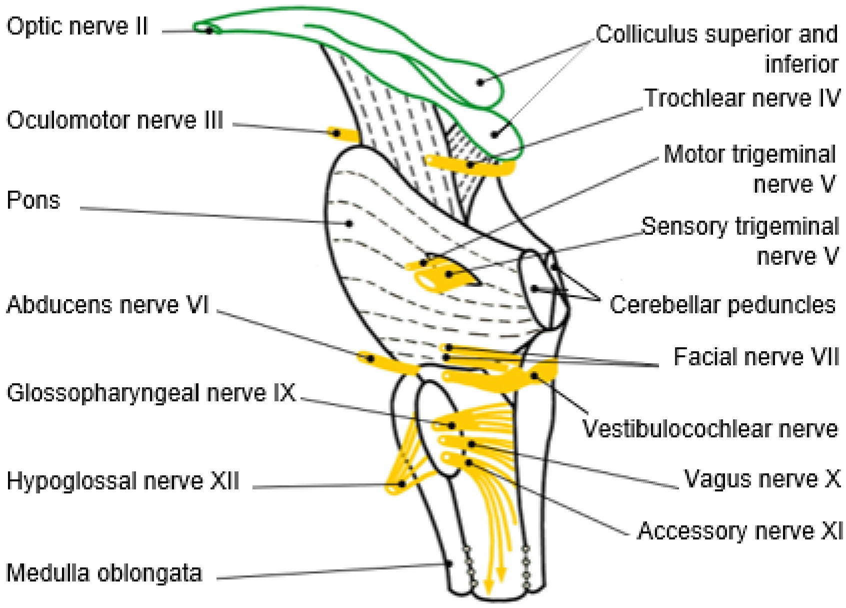

Figure 142: Origin of cranial nerves. Left lateral view of the brainstem.

Unlike the spinal nerves which are all mixed, the cranial nerves can contain only sensory fibres, only motor fibres, or both types of fibres. The sensory fibres end in the sensory nuclei inside the brainstem and the motor fibres arise from the motor nuclei inside the brainstem.

Similar to the spinal nerves, which leave the vertebral canal through the intervertebral foramina, cranial nerves leave the cranial cavity through the foramina in the base of the skull. Their course can therefore be divided into the intracranial and extracranial part.

Cranial nerves innervate structures of the head and the neck. The only cranial nerve that extends beyond the neck is the CN X, also called the vagus nerve, which innervates all the thoracic and most of the abdominal visceral organs.

Table 1: Cranial nerves

Numerical name	***Name***	***Type of fibres***
CN I	Olfactory nerve	sensory
CN II	Optic nerve	sensory
CN III	Oculomotor nerve	motor and parasympathetic
CN IV	Trochlear nerve	motor
CN V	Trigeminal nerve	sensory and motor
CN V1	Ophthalmic nerve	sensory
CN V2	Maxillary nerve	sensory
CN V3	Mandibular nerve	sensory and motor
CN VI	Abducent nerve	motor
CN VII	Facial nerve + intermediate nerve	sensory and motor + parasympathetic
CN VIII	Vestibulocochlear nerve	sensory nerve
CN IX	Glossopharyngeal nerve	sensory, motor, and parasympathetic
CN X	Vagus nerve	sensory, motor, and parasympathetic
CN XI	Accessory nerve	motor
CN XII	Hypoglossal nerve	motor

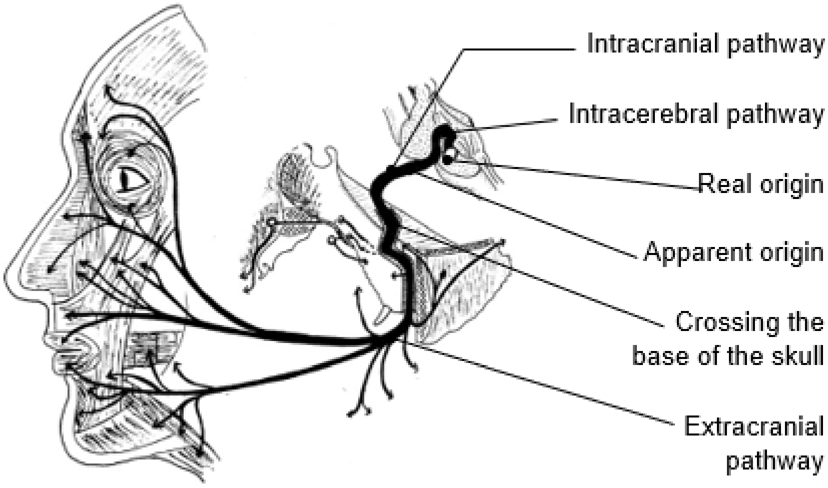

Figure 143: Cranial nerve pathways: the facialis nerve.

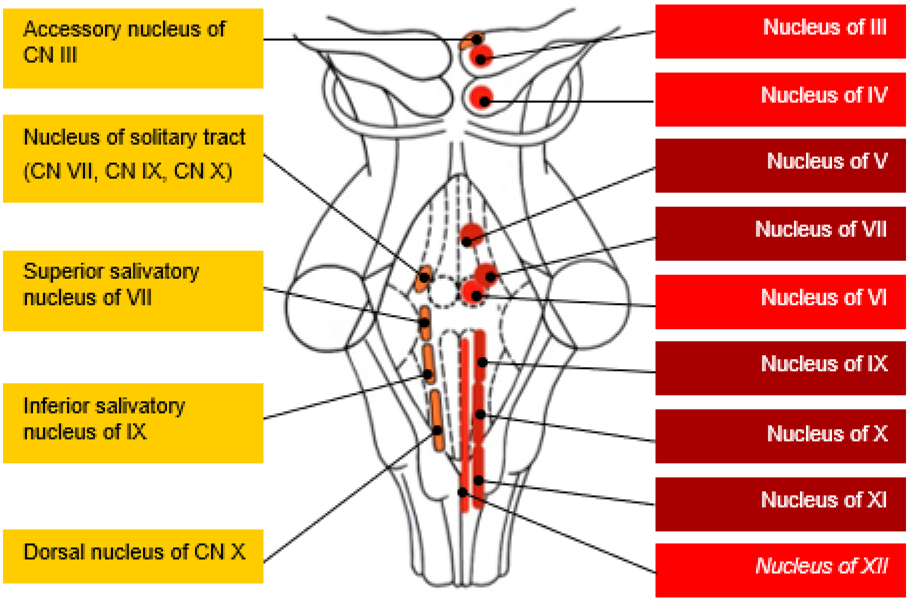

Figure 144: Diagram illustrating locations of the motor nuclei (nuclei of origin) of cranial nerves.

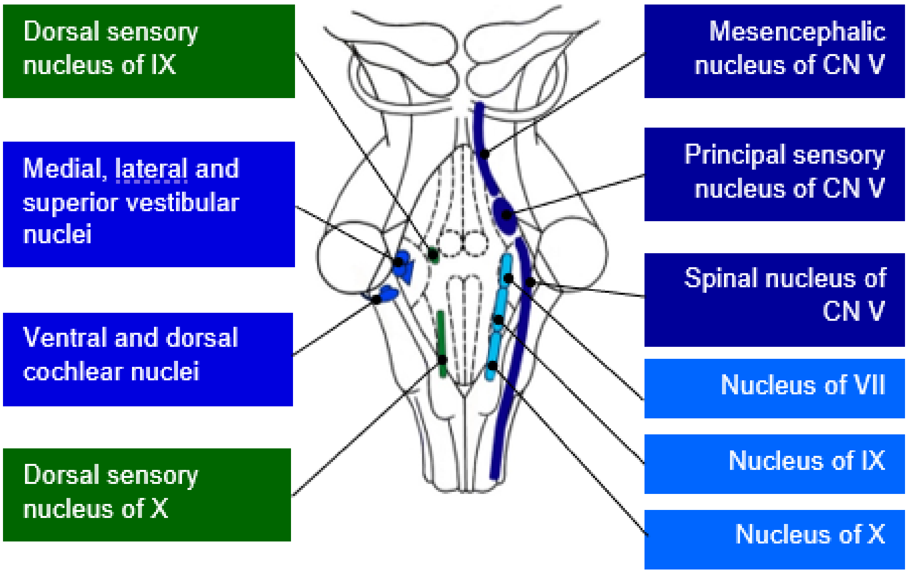

Figure 145: Diagram illustrating locations of the sensory nuclei (terminal nuclei) of cranial nerves.

3 - Histological study of the nervous system

Neuron

The neuron is a cell of the nervous tissue and consists of two basic elements: the body (soma; perikaryon) which contains the nucleus, and the extensions, which can be divided into two categories:

- dendrites – short, branched extensions which transmit impulse to the cell body,
- axon – usually a single myelinated extension that primarily conducts impulse away from the cell body; branched nerve ending forms the synapses.

Peripheral nerve

The peripheral nerves contain bundles of myelinated axons enveloped in the connective tissue.

Each axon is enveloped in a layer of connective tissue called the endoneurium. Several axons are grouped in a bundle called the fascicle. A layer of connective tissue enveloping the fascicle is called the perineurium. A layer of connective tissue enveloping whole nerve is called the epineurium.

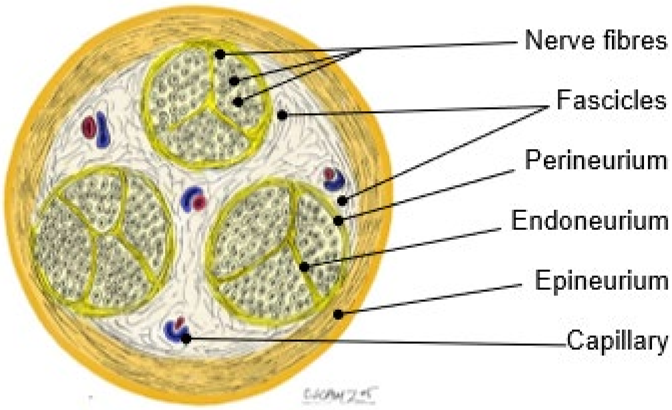

Figure 146: Cross-section of an axon of peripheral nerve.

The myelin sheath enveloping the individual axons of peripheral nerves is formed by the Schwann cells.

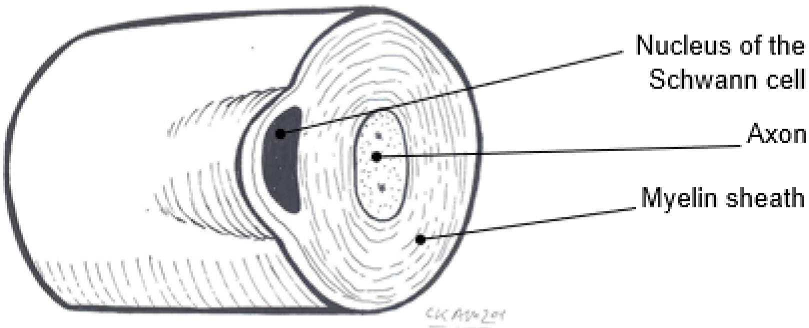

Figure 147: Myelinated nerve fibre.

Neurons are connected with each other with the synapses. At the synapse, the electrical signal that travels along the neuron is converted into the chemical signal. A synapse is a gap between two neurons. The neurotransmitters are released from the presynaptic neuron into the synaptic gap, and then binned to the receptors of the postsynaptic neuron. This way information is transmitted from one neuron to the next.

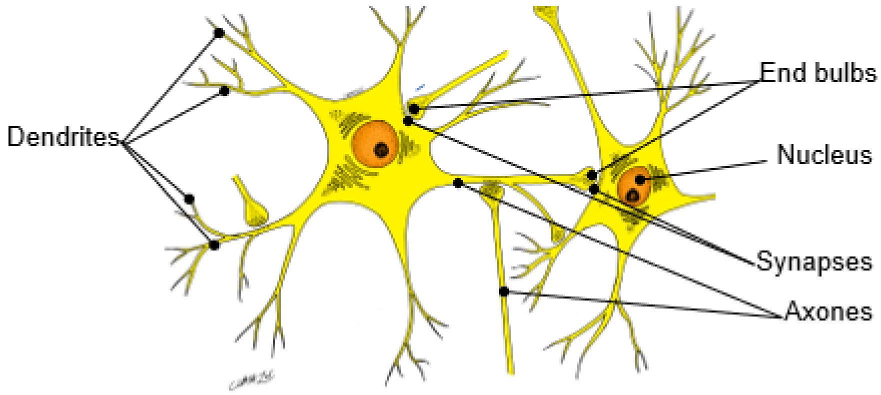

Figure 148: Synapses.

Neuroglia

The neuroglia, also called glia, glial cells, or gliocytes, are cells of the central nervous system that do not produce or conduct the electrical impulse. The function of the neuroglia is to provide support and protection for the neurons.
There are four types of gliocytes:

- Oligodendrocytes which provide myelin sheath for the axons.
- Astrocytes which form the blood-brain barrier, maintain homeostasis and provide support.
- Ependymal cells which participate in the secretion of cerebrospinal fluid.
- Microglia which are specialised macrophages, capable of phagocytosis.

4 - Functional study of the nervous system

4.1 - Somatic nervous system

Ascending and descending pathways of somatic nervous system are connected to the cerebral cortex.

Ascending (afferent) pathways

Ascending pathways are the sensory pathways. Nerve impulse is transmitted from the receptors on the periphery to the cerebral cortex of the parietal lobe. Primary somatosensory cortex is located at the postcentral gyrus (Brodmann areas 1, 2, and 3). The accuracy of sensory perception depends on the number of receptors on the periphery and the respective area of the cortex. For example, the skin of the face is more sensitive than that of the hand, which in turn is more sensitive than that of the foot.

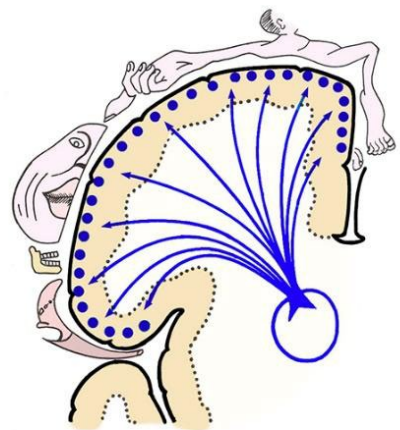

Figure 149: Sensory homunculus illustrating somatotopic organisation of the primary somatosensory cortex. Frontal section of the cerebral hemisphere.

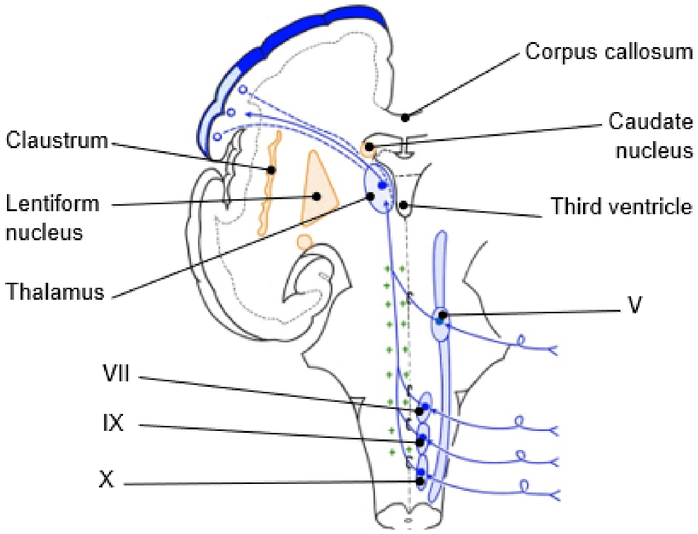

Figure 150: Ascending tracts of the cranial nerves. Frontal section of brain.

Descending (efferent) pathways

Descending pathways are the motor pathways. Nerve impulse is transmitted from the cerebral cortex of the frontal lobe to the skeletal muscles on the periphery. Primary motor cortex is located at the precentral gyrus (Brodmann area 4). The motor pathways are represented by the pyramidal and extrapyramidal tracts.
The paired pyramidal tract is divided into:

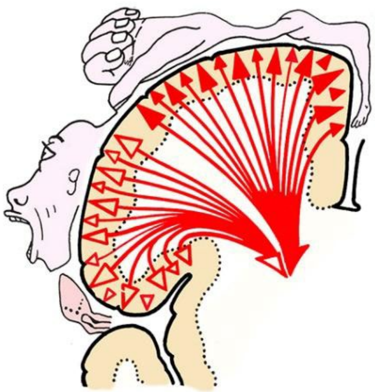

Figure 151: Motor homunculus illustrating somatotopic organisation of the primary motor cortex. Frontal section of the cerebral hemisphere.

- Corticonuclear (corticobulbar) pathway: nerve fibres of the central motor neuron run from the primary motor cortex to the motor nuclei of the cranial nerves. At the motor nucleus, impulse is transmitted through the synapse from the central motor neuron to the peripheral motor neuron which runs to the muscles as part of the cranial nerve. Movements of the head and neck, facial mimics, and movements of the eyes are enabled via this pathway.

- Corticospinal pathway: nerve fibres run from the primary motor cortex to the anterior horn of the spinal cord. At the anterior horn, impulse is transmitted through the synapse from the central motor neuron to the peripheral motor neuron which runs to the muscles as part of the spinal nerve.

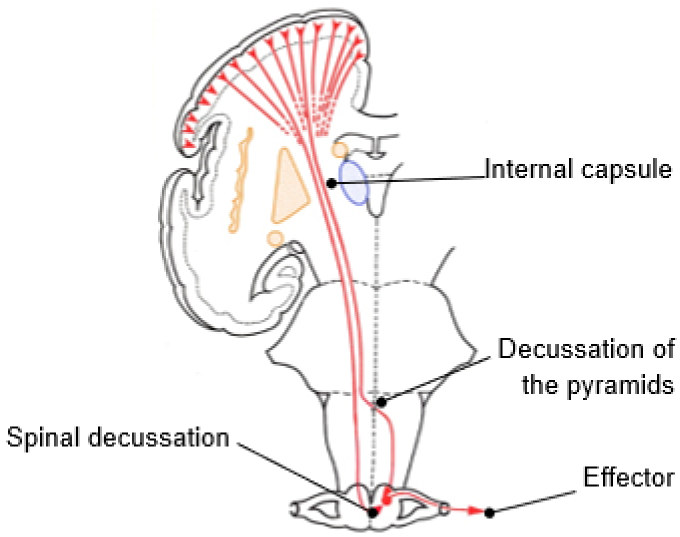

Figure 152: Scheme of the corticospinal (pyramidal) tract. Frontal section of brain.

Decussation

The majority of sensory and motor nerve fibres cross from one side to the contralateral side of the body. The crossing of the left and right pathways is called decussation.

Clinically, a lesion in one cerebral hemisphere results in malfunction on the opposite side of the body.

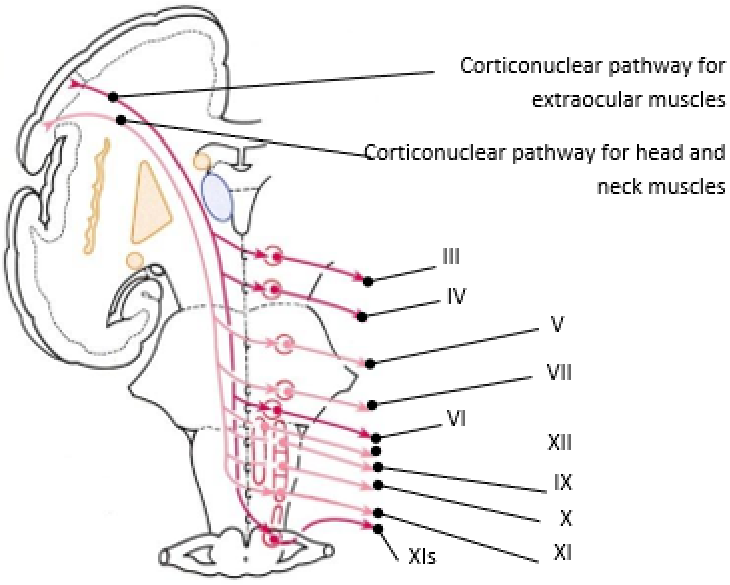

Figure 153: The corticonuclear pathway. Frontal section of brain.

4.2 - The autonomic nervous system

The autonomic (vegetative) nervous system regulates basic bodily functions, such as respiration, circulation, digestion, urination, sexual arousal and pupillary reflex.

The autonomic nervous system is regulated by reflex actions at the level of spinal cord and brainstem. Parts of the cerebrum involved in the regulation and integration of the autonomic functions are hypothalamus and the limbic system.

The autonomic nervous system consists of two antagonistic systems:

- The sympathetic nervous system, known as the “fight or flight” system.
- The parasympathetic nervous system, known as the “rest and digest” system.

Together with the endocrine glands, the autonomic nervous system forms the neuro-endocrine system.

Organisation of the autonomic nervous system

The afferent neurons of autonomic nervous system conduct visceral pain and subconscious visceral sensations important for the reflex response. Their bodies are located in the spinal ganglia or in the cranial sensory ganglia, along with the bodies of somatic afferent neurons.

The efferent neurons of autonomic nervous system conduct impulses to the effectors – smooth muscles, cardiac muscle and glands. Two neurons form the conduction pathway:

- Preganglionic neurons have bodies located in the grey matter of the spinal cord or in the nuclei of the brainstem. Their axons end in the autonomic (visceral) ganglia where they form synapses with the postganglionic neurons.
- Postganglionic neurons have bodies located inside the autonomic ganglia. Their axons end in the organ they innervate, forming synapses with the effectors.

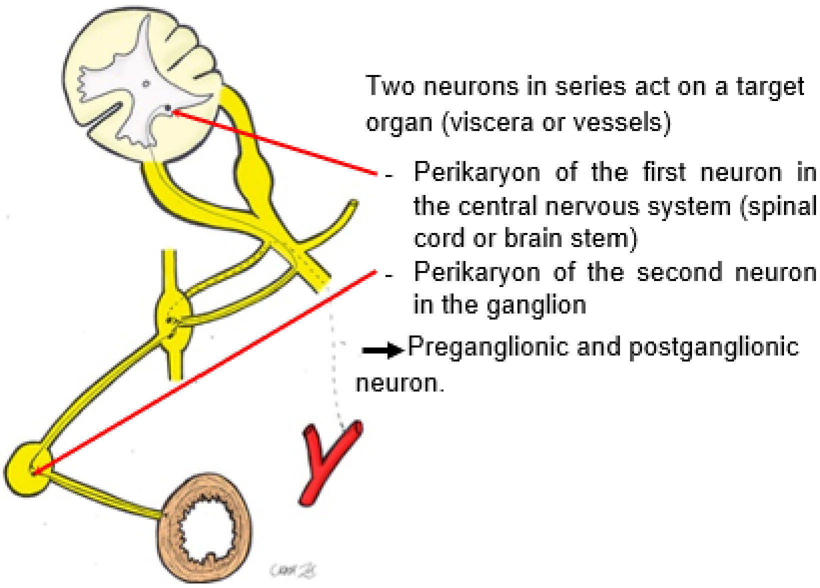

Figure 154: Arrangement of efferent neurons of the autonomic nervous system.

Sympathetic nervous system

The efferent part of sympathetic nervous system is composed of:

- Preganglionic neurons: their bodies are located in the lateral horns of the thoracolumbar segments of the spinal cord (T1 to L2) and their axons travel to the sympathetic ganglia.
- Sympathetic ganglia: paravertebral ganglia are located on each side of the vertebrae forming the paired sympathetic trunk and prevertebral ganglia are located in front of the vertebrae.
- Postganglionic neurons: their bodies are located in the sympathetic ganglia and their axons most often form the periarterial plexuses, which follow the arteries supplying the organ that the neurons innervate.

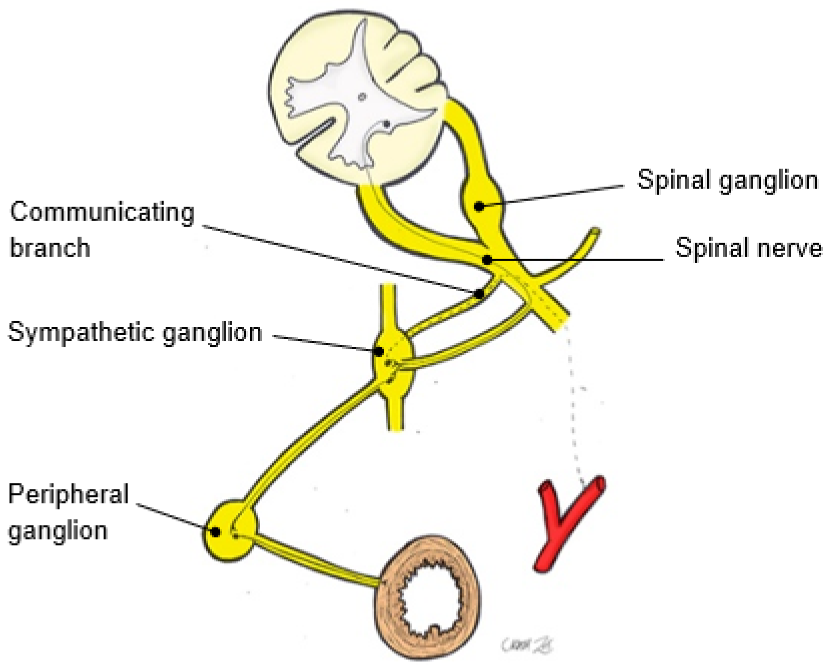

Figure 155: Sympathetic innervation.

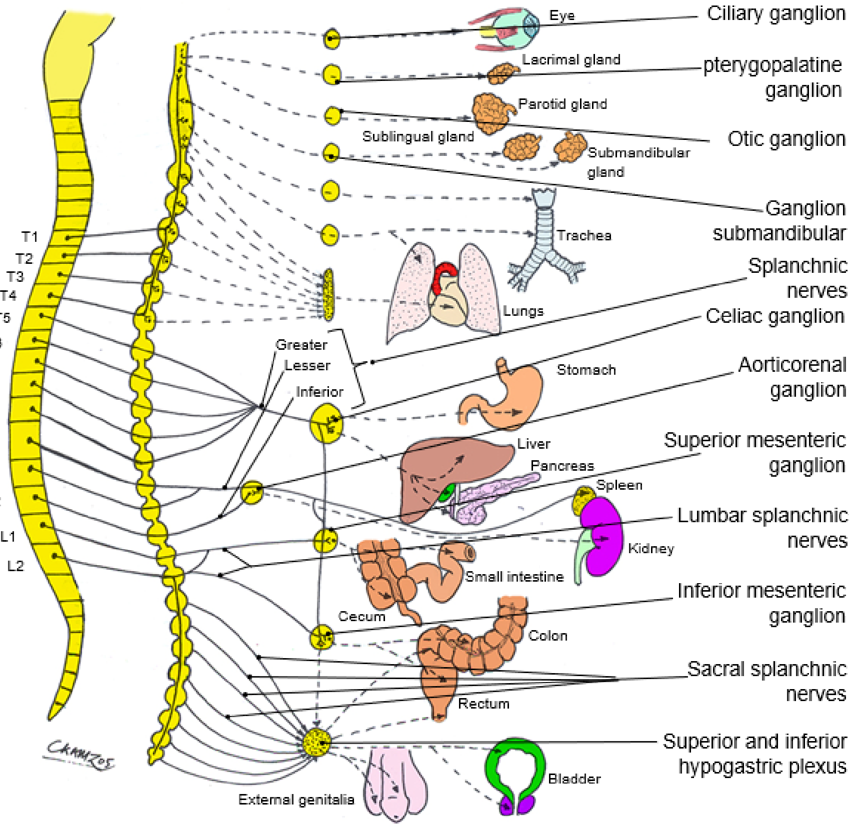

Figure 156: Sympathetic visceral innervation.

Parasympathetic nervous system

The efferent part of parasympathetic nervous system is composed of the cranial and sacral part:

- Cranial parasympathetic outflow: bodies of the preganglionic neurons are located in the grey matter of the brainstem and their axons exit the central nervous system as part of the cranial nerves III, VII, IX, and X.
- Sacral parasympathetic outflow: bodies of the preganglionic neurons are located in the grey matter of the sacral segments (S2 to S4).

- Parasympathetic ganglia are usually located in the wall or close to the wall of the target organ.
- Postganglionic neurons are very short.

Cranial part provides mostly parasympathetic innervation of the head (eye, salivary glands). The only exception is the CN X, which provides parasympathetic innervation of the thoracic and abdominal organs.

Sacral part provides parasympathetic innervation of the pelvic visceral organs and the external genitalia.

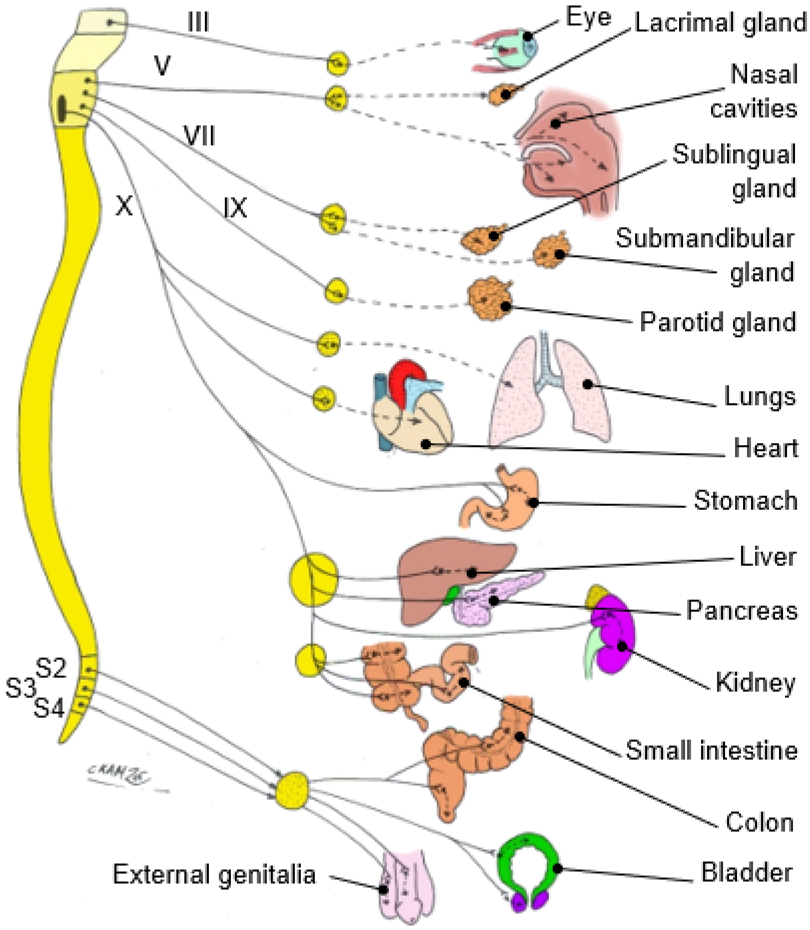

Figure 157: Parasympathetic visceral innervation.

4.3 - The reflex response

At the level of the spinal cord, connection between the sensory and motor neuron allows rapid, stereotyped involuntary movement named the reflex.

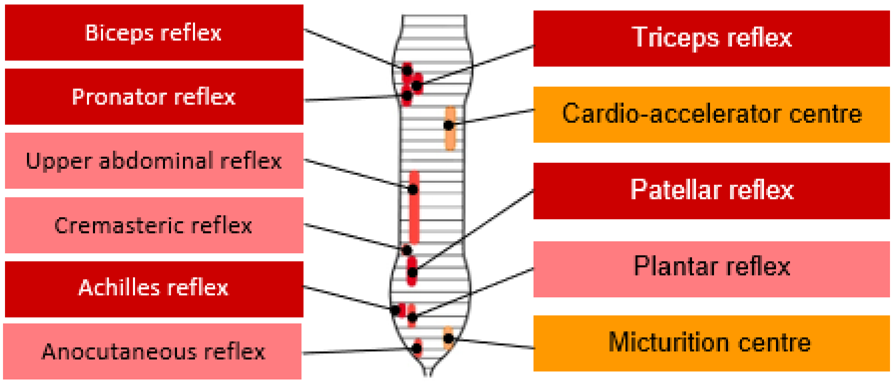

Figure 158: Spinal cord centers.

Sensory and motor neuron can be connected directly or through a spinal interneuron. Spinal interneurons do not leave the spinal cord. They receive the afferent input and send the impulse to the motor neurons of either the same segment of the spinal cord or can ascend or descend to reach the motor neurons in higher or lower segments of the spinal cord.

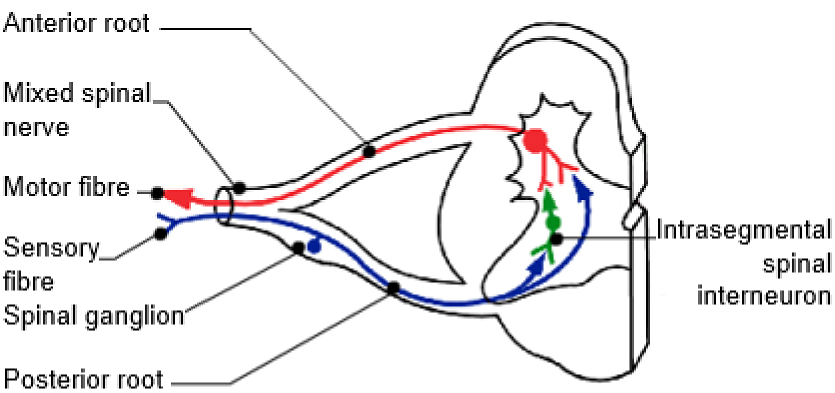

Figure 159: A reflex arc. Intrasegmental spinal interneuron.

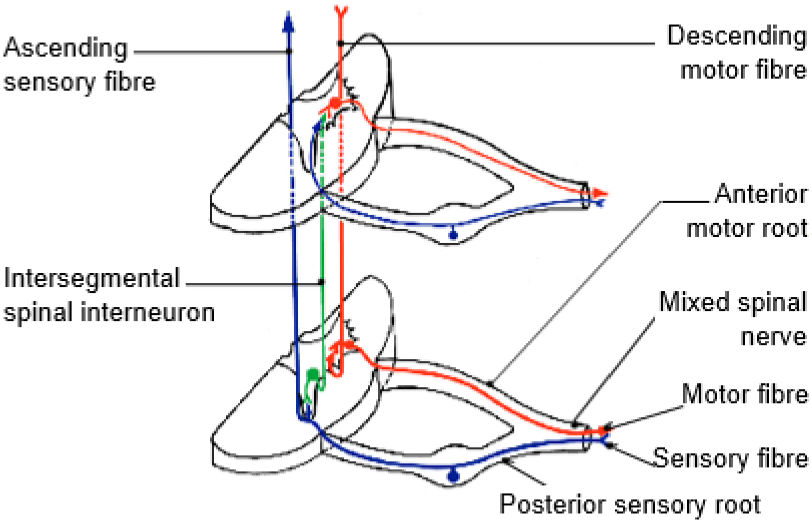

Figure 160: A reflex arc. Intersegmental spinal interneuron.

4.4 - Projection, association and commissural fibres of the brain

The projection, association and commissural fibres of the brain form the white matter of the brain.

The projection fibres are the ascending (afferent) and descending (efferent) fibres that connect cerebral cortex with other areas of the central nervous system – the deep cerebral nuclei, cerebellum, brainstem and spine.

The association fibres connect different cortical areas of the same hemisphere.

The commissural fibres connect the same cortical area in the opposite hemispheres. The most important bundle of commissural fibres is corpus callosum – a C-shaped thick layer of white matter that curves from front to back superior to the thalamus. It forms a link between the analytic left hemisphere and the creative right hemisphere.

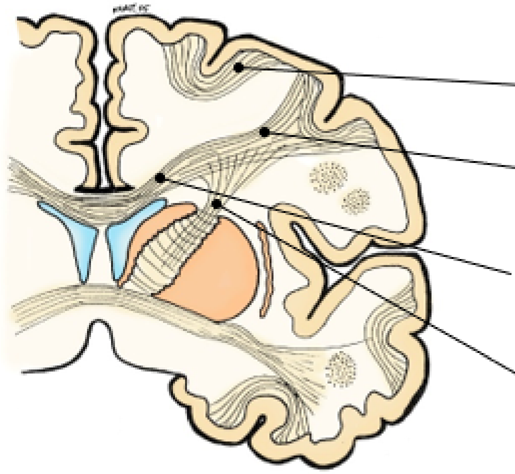

Figure 161: The white matter of the cerebrum. Frontal section of brain.

5 - Protective elements of the central nervous system

5.1 - The bony protection

The bony protection of brain consists of the cranial bones forming the bony case, neurocranium, which encloses the cranial cavity.

The bony protection of spinal cord consists of the vertebrae enclosing the vertebral canal.

5.2 - The meninges

The central nervous system is completely enveloped by three membranes, named the meninges: dura, arachnoid and pia.

Dura

The dura is a strong, thick, fibrous outermost membrane.

The cranial dura consists of two layers – the outer, periosteal cranial dura, which forms the periosteum of the bones enclosing the cranial cavity, and the inner, meningeal cranial dura. Both layers are firmly attached to each other and are only separated at the sites of the venous sinuses.

The cranial dura matter has four double folds:

- the cerebral falx separates the two hemispheres of the cerebrum,
- the cerebellar tentorium separates the cerebrum and the cerebellum,
- the cerebellar falx separates the two hemispheres of the cerebellum,
- the sellar diaphragm forms the roof over the sella turcica.

The spinal dura has only one layer. Together with the periosteum of the vertebral canal it delimits a space called the epidural space, in which the internal venous plexuses are located. This explains the possibility of epidural anaesthesia.

Arachnoid

The arachnoid is the middle of the 3 meninges. It loosely surrounds the entire brain and spinal cord. Arachnoid is in direct contact with the dura but can be easily separated from it. Arachnoid and pia are separated by the subarachnoid space which is filled with the cerebrospinal fluid. Note that the subarachnoid space communicates with the fourth ventricle.

The spinal arachnoid extends to the end of the vertebral canal, while the spinal cord ends at the level of L1. A wide part of the subarachnoid space below the L1 level is called the lumbar cistern and allows a safe lumbar puncture, which is usually performed between the vertebral arches of vertebrae L3 and L4.

Pia

The pia is a highly vascular innermost membrane, closely related to the surface of the brain and spinal cord, extending into the sulci.
In the ventricles of the brain, a double layer of cranial pia together with ependymal cells forms the tela choroidea, which produces the cerebrospinal fluid.

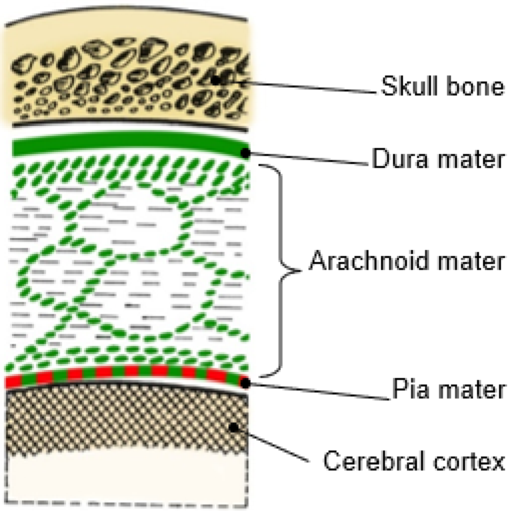

Figure 162: Cranial meninges.

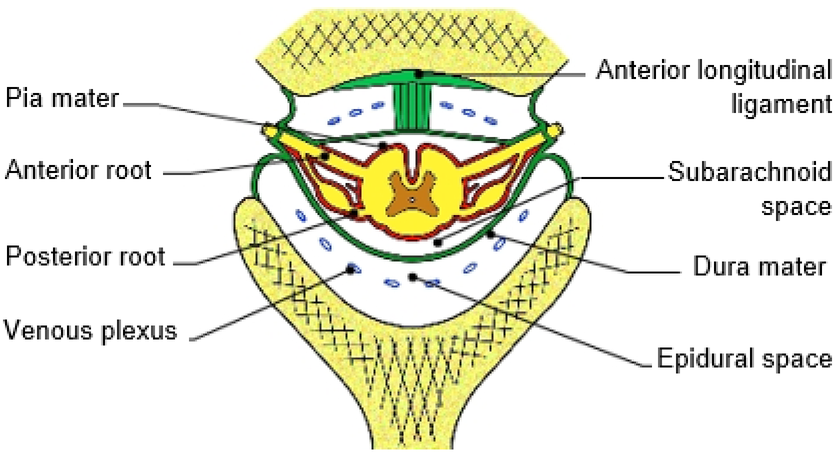

Figure 163: Spinal meninges.

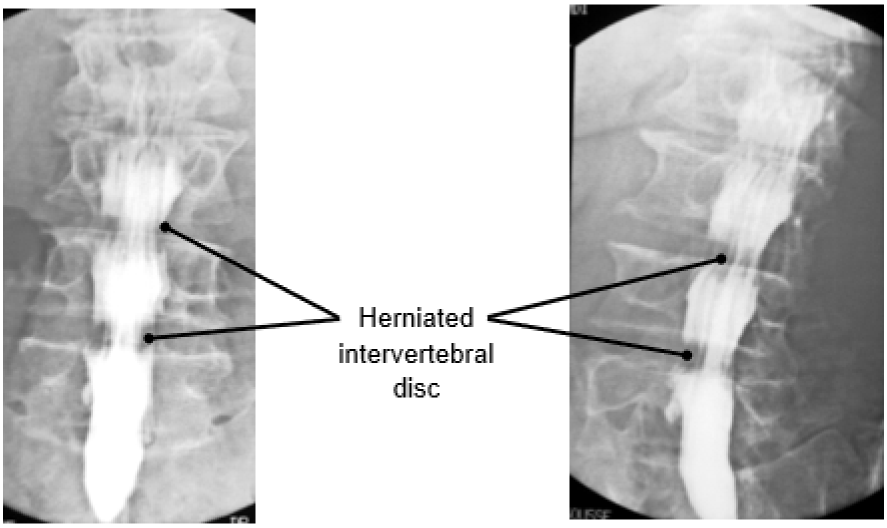

Figure 164: Radiculography showing compression of the dural sac by the herniated intervertebral discs.

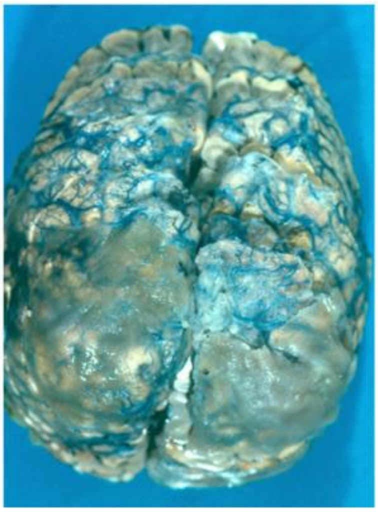

Figure 165: Photography of meninges in meningitis (a coating is formed in the subarachnoid space).