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## Human Anatomy: Central Nervous System

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# 1. The cerebrum

The nervous system has two main anatomical divisions:

- A. The central nervous system (CNS) represented by the brain and spinal cord
- B. The peripheral nervous system (PNS) represented by the spinal nerves, cranial nerves and autonomic nervous system (ANS)

N.B. In the CNS the collections of nerve cells bodies forms nuclei while in the PNS are forming ganglia.

The adult brain is proportional to body size and has an average weight of 1600 gr in men and 1450 gr in women.

The anatomical divisions of the brain are: the cerebrum, the cerebellum and the brainstem. The cerebrum is the main part of the brain and consists of two cerebral hemispheres, while the cerebellum lies inferior to the cerebrum and is the second-largest part of the brain. About the parts of the brainstem there are different opinions. Some considered that the brainstem consists of medulla oblongata, pons, midbrain and diencephalon and others include in the brainstem only the first three of these parts and considered the diencephalon a separate structure.

The internal configuration of the cerebrum is represented by gray and white matter and cavities. The gray matter consists of cortex and nuclei. The white matter is composed of tracts and bundles of axons connecting one part of the hemispheres to the other. Each hemisphere has a cavity within it called lateral ventricle.

The cerebrum bony landmarks:

- superiorly and lateral – the calvaria
- inferiorly the floors of anterior and middle cranial fossae and above the tentorium cerebelli of posterior cranial fossa.

If the calvaria is removed, the meningeal coverings of the brain can be seen. The thick opaque external layer is the dura mater and after it is dissected the external features of the cerebral cortex can be seen through the two transparent layers arachnoid and pia mater. Gyri (folds), sulci (grooves) and fissures (clefts) represent the gross structures that can be analyzed.

The cerebral hemispheres are incompletely separated by a deep median cleft called the longitudinal cerebral fissure. Each hemisphere is divided further in four lobes-frontal, parietal, occipital and temporal lobes. The central sulcus separates the frontal lobes from the parietal lobes. The lateral sulcus separates the frontal and parietal lobes from the temporal lobes. The occipital lobes are separated from the parietal and temporal lobes by the parieto-occipital sulcus.

Each cerebral hemisphere presents the following common features:

1. three poles
2. three surfaces
3. six borders

1. Each hemisphere has a rounded **frontal pole**, a pointy **occipital pole** and a **temporal pole**.
2. Each cerebral hemisphere has the following three surfaces:
  - ⊙ the **superolateral surface**-convex, extensive and facing upwards and laterally
  - ⊙ the **medial surface** – flat, vertical and with a C-shaped cut surface: *the corpus callosum*.
  - ⊙ the **inferior surface** divided by **stem of lateral sulcus** into two parts one anterior part, the *orbital surface* and a large posterior part, the *tentorial surface*

The six borders of the cerebral hemisphere are:

1. The **superomedial border** separates the superolateral surface from the medial surface.
2. The **supraciliary border** is at the junction of superolateral and orbital surfaces.
3. The **inferolateral border** separates the superolateral surface from the tentorial surface.
4. The **medial orbital border** separates the medial surface from the orbital surface.
5. The **inferomedial/hippocampal border** surrounds the cerebral peduncle.
6. The **medial occipital border** separates the medial surface from the tentorial surface.

Gross aspect of the cortex

The cerebral cortex is folded into **gyri or convolutions**. Each gyrus consists of a central core of white matter covered by an outer layer of grey matter. The grooves between the gyri are termed as sulci. Main cerebral sulci are considered to be the following: lateral, central, calcarine and parieto-occipital sulci.

Features of the main cerebral sulci

1. **Lateral sulcus/Sylvius sulcus** has a **stem** and **three rami**. The stem of the sulcus on the inferior surface of the cerebral hemisphere at the level of the anterior perforated substance and extends laterally to reach the superolateral surface. On reaching the superolateral surface it divides into three rami:
  - (a) *anterior horizontal*
  - (b) *anterior ascending*
  - (c) *posterior*.
2. **Central sulcus/ Rolando sulcus** begins at the superomedial border of the hemisphere about 1 cm behind the midpoint between the frontal and occipital poles, runs sinuously downwards and forwards, and ends just above the posterior ramus of the lateral sulcus. Its upper end usually extends into the medial surface.
3. **Calcarine sulcus** is seen on the medial surface of the cerebral hemisphere. It begins as a deep fissure, below the posterior end of the corpus callosum and follows a course with a convexity upwards to the occipital pole. This sulcus may extend slightly onto the superolateral surface.
4. **Parieto-occipital sulcus** is present on the medial surface of the hemisphere. It begins at the midpoint of the calcarine sulcus and courses upwards and slightly backwards to cut the superomedial border of the hemisphere. This sulcus may extend slightly onto the superolateral surface.

Main features of the superolateral surface:

⊙ ***In the area belonging to the frontal lobe can be seen:***

1. The **precentral sulcus**-running downwards and forwards parallel and little anterior to the central sulcus. The area between the central and precentral sulci is called **precentral gyrus**.

2. Anterior to the precentral sulcus there are two sulci called **superior** and **inferior frontal sulci** which run horizontally. These sulci divide the region of frontal lobe in front of precentral sulcus into **superior, middle, and inferior frontal gyri**. The **inferior frontal gyri are divided by the anterior and ascending rami of lateral sulcus** into three parts:

- a) *pars orbitalis*
- (b) *pars triangularis*
- (c) *pars opercularis*.

⊙ ***In the area belonging to the parietal lobe can be seen:***

1. The **postcentral sulcus**- running downwards and forwards, behind and parallel to the central sulcus. The area between these two sulci is called **postcentral gyrus**.

2. The remaining of the parietal lobe is divided by the **intraparietal sulcus** into **superior and inferior parietal lobules**.

⊙ ***In the area belonging to the temporal lobe can be seen:***

1. Two sulci running parallel to the posterior ramus of the lateral sulcus: the **superior and inferior temporal sulci**. These sulci divide the temporal lobe into **superior, middle, and inferior temporal gyri**.

- ⊙ The superior surface of superior temporal gyrus presents *two transverse temporal gyri*. The anterior transverse temporal gyrus also called **Heschl's gyrus** forms the primary auditory area of the cortex.

The occipital lobe possesses rather three short sulci, **lateral**, and **transverse occipital** sulci, and **lunate** sulcus.

***In the area belonging to the occipital lobe can be seen:*** three short sulci, **lateral** and **transverse occipital** sulci and the **lunate** sulcus.

Main features of the medial surface:

- ⊙ 1. The most prominent sulcus is the **cingulate sulcus**: which runs about 1 cm above and parallel to the upper convex margin of corpus callosum. Anteriorly it ends below the genu of corpus callosum, posteriorly it turns upwards to reach the superomedial border of the hemisphere, a little posteriorly to the upper end of the central sulcus.

- The area between the cingulate sulcus and corpus callosum is called the **cingulate gyrus**.

- ⊙ 2. **Callosal sulcus**-separates the cingulate gyrus from corpus callosum.

(a) The anterior part of medial surface between the cingulate sulcus and the superomedial border of the hemisphere is divided by a short offshoot sulcus ascending from the cingulate sulcus above the middle of the trunk of corpus callosum into two parts:

- a small part around the upper part of the central sulcus, the *paracentral lobule*, and
- a large medial part the *medial frontal gyrus*.

(b) The posterior part of medial surface behind the paracentral lobule has two main sulci: the calcarine sulcus, and the parieto-occipital.

- *Calcarine sulcus* (already described). A small region between the splenium and calcarine sulcus is termed **isthmus**.
- *Parieto-occipital sulcus* (already described).
- The triangular area between the posterior part of the calcarine sulcus (also called **postcalcarine sulcus**) and the parieto-occipital sulcus is called *cuneus*.
- The quadrangular area between the parietooccipital sulcus and paracentral lobule is termed *precuneus*.

Main sulci and gyri on the inferior surface:

☉ ***On the orbital part of inferior surface (orbital surface)***

1. **Olfactory sulcus**: It is a straight sulcus which runs anteroposteriorly close to the medial border of the orbital surface. It is called olfactory sulcus because it lodges the olfactory bulb and tract. The area medial to this sulcus is called **gyrus rectus**.
2. **Orbital sulcus**: It is an irregular H-shaped sulcus and divides the rest of the orbital surface into **anterior, posterior, medial, and lateral orbital gyri**.

☉ ***On the tentorial part of inferior surface (tentorial surface)***

1. The tentorial surface is marked by two major sulci that run anteroposteriorly.
  - ☉ The medial one is called **collateral sulcus** and the lateral one, the **occipitotemporal sulcus**. The latter is continuous around the inferolateral margin with the inferior temporal gyrus.

2. Posteriorly the collateral sulcus is parallel to the calcarine sulcus and here the area between these two sulci is termed *lingual gyrus*.

Anteriorly the lingual gyrus is continuous with the **parahippocampal gyrus**. Anterior end of parahippocampal gyrus hooks sharply backwards and is limited laterally by a short *rhinal sulcus*. This hook-like anterior end of parahippocampal gyrus is called **uncus**.

Posteriorly the parahippocampal gyrus is continuous with the cingulate gyrus through the isthmus.

The area between the *occipitotemporal sulcus* laterally and the *collateral* and *rhinal* sulci medially is known as **medial occipitotemporal gyrus**.

The area lateral to the occipitotemporal sulcus is termed **lateral occipitotemporal gyrus**. This gyrus is continued around the inferolateral margin of the hemisphere with the inferior temporal gyrus.

***Lobes of the cerebral hemisphere***

- ☉ The superolateral surface of each cerebral hemisphere is arbitrarily divided into four lobes, *viz.* frontal, parietal, temporal, and occipital with the help of: (a) three main sulci: central, lateral and parieto-occipital, and (b) two imaginary lines:
  - ☉ The *first imaginary line* is a vertical line joining the parieto-occipital sulcus to the preoccipital notch, and the second *imaginary line* is a backward continuation of the horizontal part of the posterior ramus of the lateral sulcus till it joins the first line.
- ☉ The **frontal lobe** lies anterior to the central sulcus and above the posterior ramus of the lateral sulcus.
- ☉ The **parietal lobe** lies behind the central sulcus and in front of the upper part of the first imaginary line. Below it is bounded by the posterior ramus of the lateral sulcus and the second imaginary line.

- ⊙ The **temporal lobe** lies below the posterior ramus of lateral sulcus and second imaginary line. It is separated from the **occipital lobe** by the lower part of the first imaginary line.
- ⊙ The **occipital lobe** lies behind the **vertical** line joining the parieto-occipital sulcus and preoccipital notch.

#### The insula/central lobe

- ⊙ It is customary to consider the insula separately from the four main lobes (vide supra) of the cerebral hemisphere.
- ⊙ The insula is the submerged (hidden) portion of the cerebral cortex in the floor of the lateral sulcus. It has been submerged from the surface during development of brain due to the overgrowth of the surrounding cortical areas and can be seen only when the lips of the lateral sulcus are widely pulled apart. It is triangular in shape and surrounded all around by a sulcus, the **circular sulcus**, except anteroinferiorly at its apex called **limen insulae** which is continued with the anterior perforated substance.
- ⊙ The insula is divided into two regions, anterior and posterior by a **central sulcus**. The anterior region presents 3 or 4 short gyri called **gyri brevia** and the posterior region presents 1 or 2 long gyri called **gyri longa**.
- ⊙ The insula is hidden from the surface view by the overgrown cortical areas of frontal, parietal, and temporal lobes. These areas are termed **frontal, frontoparietal, and temporal opercula** (operculum = lid).
- ⊙ The superior surface of the temporal operculum presents the **anterior and posterior transverse temporal gyri**.

#### The cerebral cortex

- ⊙ The cerebral cortex is the surface layer of grey matter covering the cerebral hemisphere.
- ⊙ The main functions of the cerebral cortex include:
  - ⊙ 1. **Mental activities** involved in memory, learning, speech, language, intelligence, and creative thinking.
  - ⊙ 2. **Sensory perception**, such as perception of pain, touch, temperature, sight, hearing, taste, smell, etc.
  - ⊙ 3. **Initiation of motor commands** to control activities of skeletal muscles.

#### **Functional areas**

- ⊙ The surface of cerebral cortex was demarcated by Brodmann (1909) into 47 areas according to their function.
- ⊙ **Types of cortical areas:**

According to classical teaching, the cerebral cortex possesses three types of functional areas:

- ⊙ 1. **Motor areas:** primarily concerned with the motor functions.
- ⊙ 2. **Sensory areas:** primarily concerned with the sensory functions.
- ⊙ 3. **Association areas:** not concerned with primary motor or sensory functions but have more important associative, integrative, and cognitive functions.
- ⊙ **N.B.** Association areas occupy over 75% of the total surface area of the cerebral cortex in human beings.

## **Functional areas-frontal lobe**

### Primary motor area (area 4 of Brodmann)

- ⊙ Primary motor area is located in the precentral gyrus on the superolateral surface and extends to the anterior part of paracentral lobule on the medial surface of the cerebral hemisphere.
  - *About 40% pyramidal (corticospinal and corticonuclear) fibres arise from this area.*
- ⊙ Specific regions within the area are responsible for movements in the specific parts of the body. Only movements are represented in this area and not the muscles.
- ⊙ In the motor area of the cerebrum, the human body is represented upside down, i.e. uppermost part controls the feet and the lowermost part controls the head, neck, face, and fingers.
- ⊙ **Lesions of primary motor area** in one hemisphere produce spastic paralysis of the extremities of the opposite half of the body (*hemiplegia*). The masticatory, laryngeal, pharyngeal, upper facial, and extraocular muscles are spared for being represented bilaterally.

### Premotor area (area 6 of Brodmann)

- ⊙ Premotor area is located anterior to the primary motor area in the posterior parts of superior, middle, and inferior frontal gyri and extends on to the medial surface of the hemisphere.
- ⊙ The premotor area is responsible for successful performance of the voluntary motor activities initiated in the primary motor area.

### The frontal eye field (area 8 of Brodmann)

- ⊙ The frontal eye field is located in the posterior part of the middle frontal gyrus just anterior to the facial area of the precentral gyrus. It is responsible for **conjugate movements of the eyes** to the opposite side.

### The motor speech area (area 44 and 45 of Brodmann)

- ⊙ The motor speech area is usually located in the pars triangularis (area 45) and pars opercularis (area 44) of inferior frontal gyrus of frontal lobe of left hemisphere (the *dominant hemisphere* in right-handed and most of the left-handed individuals).
- ⊙ **Lesions of motor speech area of Broca** result in loss of ability to produce proper speech, called *expressive aphasia* (also called *motor aphasia*). The patients face difficulty in finding the right words to express what they wish to say, but they can understand what others say.

### Primary sensory area (areas 3,2 and 1 of Brodmann)

- ⊙ Primary sensory area is located in the postcentral gyrus and extends into the posterior part of the paracentral lobule on the medial surface of the hemisphere. The opposite half of the body is represented upside down exactly in same fashion as in the primary motor area. *The primary sensory area is concerned with the perception of exteroceptive (pain, touch, and temperature) and proprioceptive (vibration, muscle, and joint sense) sensations from the opposite half of the body.*

**Lesions of primary sensory area** lead to loss of appreciation of exteroceptive and proprioceptive sensations from the opposite half of the body.



### **Sensory association area**

Sensory association area occupies the superior parietal lobule corresponding to the Areas 5 and 7 of Brodmann. *It is concerned with the perception of shape, size, roughness, and texture of the objects.* Thus, it enables the individual to recognize the objects placed in his/her hand without seeing. Such ability is referred to as **stereognosis**.

### **Sensory speech area of Wernicke**

- ⊙ Sensory speech area is located in the left dominant hemisphere occupying the posterior part of the superior temporal gyrus of temporal lobe and angular (Area 39) and supramarginal (Area 40) gyri of the inferior parietal lobule.
- ⊙ *The Wernicke's area is concerned with the understanding of speech, i.e. interpretation of language through visual and auditory input.*

**Lesions of Wernicke's area in the dominant hemisphere** produce loss of ability to understand the spoken and written speech. This condition is called *receptive aphasia*.

- ⊙ **N.B.** Recently, it has been found that traditional motor and sensory areas are not exclusively motor or sensory but sensorimotor in nature. The motor areas are predominantly motor while the sensory areas are predominantly sensory, and they are abbreviated as **Ms** and **Sm** respectively according to *relative* significance of their functional attributes. Thus primary somatomotor area is abbreviated as M<sub>1</sub>, supplementary motor area as M<sub>2</sub>, first somatosensory area as S<sub>1</sub> and second somatosensory area as S<sub>2</sub>.

### **Functional areas in the temporal lobe**

#### Primary auditory area (Brodmann areas 41 and 42)

- ⊙ Primary auditory area is located on the superior surface of the superior temporal gyrus occupying the anterior transverse temporal gyrus (**Heschl's gyrus**) and extends slightly to the adjacent part of the superior temporal gyrus

#### Secondary auditory area/auditory association area (Brodmann area 22)

Secondary auditory area is situated on the lateral surface of the superior temporal gyrus, slightly posterior to the primary auditory area which it surrounds

- ⊙ The primary and secondary auditory areas receive fibres from the medial geniculate body via the auditory radiation.
- ⊙ The cochleae are bilaterally represented. Therefore, a lesion in one cortex does not cause unilateral deafness.

### **Functional areas in the occipital lobe**

#### Primary visual area (area 17)

- ⊙ Primary visual area is situated mainly on the medial surface of the occipital lobe in the walls and floor of the posterior part of the calcarine sulcus (**postcalcarine sulcus**) and extends around the occipital pole onto the lateral surface of the occipital lobe as far as the **lunate sulcus**
- ⊙ The most marked structural feature of the visual cortex is the presence of **white line/visual stria (of Gennari)**, hence the name—striate area.

- ⊙ The cortex adjacent to the primary visual area on the medial and lateral surfaces of the occipital lobe is occupied by secondary visual area (visual association area).

### Secondary visual area (area 18 and 19)

- ⊙ The visual cortex receives afferent fibers from lateral geniculate body via optic radiations. The visual cortex receives fibers from temporal half of the ipsilateral retina and the nasal half of the contralateral retina, i.e. it registers impulses from opposite field of vision. Thus, right half of the field of vision is represented in the visual cortex of the left cerebral hemisphere and vice versa. It is also important to note that impulses from the superior retinal quadrants (inferior field of vision) pass to the superior wall of the calcarine sulcus, while the inferior retinal quadrants (superior field of vision) pass to the inferior wall of the calcarine sulcus.
- ⊙ The **macular area** which is the central area of retina and responsible for maximum visual acuity (*keenest vision*) has extensive cortical representation, occupying approximately posterior one-third of the visual cortex.
- ⊙ The white matter of the cerebrum is a compact mass of a vast number of myelinated nerve fibers.

### **The white matter of the cerebrum**

#### **TYPES OF FIBRES IN WHITE MATTER**

- ⊙ They are classified into the following three types, on the basis of the types of connections they provide:
  - 1. Association fibers.
  - 2. Commissural fibers.
  - 3. Projection fibers.

#### **1. Association fibers**

- ⊙ The association fibers interconnect the different regions of the cerebral cortex in the same hemisphere (*intrahemispheric fibers*). These are of the following two types:
  - 1. **Short association fibers**, which interconnect the adjacent gyri by hooking around the sulcus, hence they are also called *arcuate fibers*.
  - 2. **Long association fibers**, which travel for long distances and interconnect the widely separated gyri, *viz.* gyri of different lobes.

#### **2. Commissural fibers**

- ⊙ The commissural fibers interconnect the identical cortical areas of the two cerebral hemispheres (*interhemispheric fibers*). The bundles of such fibers are termed commissures.
- ⊙ The important commissures of the brain are as follows:
  - 1. Corpus callosum.
  - 2. Anterior commissure.
  - 3. Posterior commissure.
  - 4. Hippocampal commissure.
  - 5. Habenular commissure

## 1. The corpus callosum

- ⊙ The corpus callosum is the **largest commissure of the brain**. It consists of about 100 million fibers.
- ⊙ **External features of corpus callosum:** Corpus callosum forms a massive arched interhemispheric bridge in the floor of the *median longitudinal cerebral fissure* connecting the medial surfaces of the two cerebral hemispheres.
- ⊙ In sagittal section of cerebrum, it is seen as C-shaped mass of white fibers on the medial surface of the hemisphere forming the roof of the lateral ventricle
- ⊙ The concave inferior aspect of corpus callosum is attached with the convex superior aspect of the fornix by *septum pellucidum*.
- ⊙ The corpus callosum is divided from before backwards into the following four parts:
  - ⊙ 1. **Genu**
  - ⊙ 2. **Rostrum**
  - ⊙ 3. **Trunk**
  - ⊙ 4. **Splenium**
- ⊙ 1. **Genu:** It is thick curved anterior extremity of corpus callosum which lies 4 cm behind the frontal pole. The fibers of genu sweep (curve) forwards on either side into the anterior parts of the frontal lobes, forming a forklike structure, the **forceps minor**
- ⊙ 2. **Rostrum:** The genu extends downwards and backwards as a thin prolongation to join the lamina terminalis forming, rostrum of corpus callosum.
- ⊙ 3. **Trunk:** The trunk is the main (middle) part of the corpus callosum between its thick anterior (genu) and massive posterior (splenium) extremities.
- ⊙ 4. **Splenium:** The splenium is the massive posterior extremity of the corpus callosum, lying 6 cm in front of the occipital pole. The fibers of the splenium connect the parietal (posterior parts), temporal, and occipital lobes of the two hemispheres. The fibers connecting the occipital lobes sweep backwards on either side above the calcarine sulcus forming a large fork-like structure, the **forceps major**.

**Functions of the corpus callosum:** The corpus callosum is largely responsible for **interhemispheric transfer of information** which is essential for bilateral responses and learning processes.

## 2. The anterior commissure

The anterior commissure is a small round bundle of white fibers which crosses the midline in the upper part of the lamina terminalis, immediately in front of the anterior column of the fornix and interventricular foramen.

The anterior commissure consists of two components:

1. A large **posterior neocortical component**, which interconnects the lower and anterior parts of the temporal lobes.
2. A smaller **anterior paleocortical component**, which interconnects the olfactory regions of the two hemispheres.

## 3. The posterior commissure

The posterior commissure is a slender bundle of white fibers which crosses the midline through the inferior lamina of the stalk of pineal gland.

**4. Hippocampal commissure** interconnects the crura of fornix of the two sides and thus forms the **hippocampal formation**.

**5. The habenular commissure** is a slender bundle of white fibers which crosses the midline through the superior lamina of the stalk of pineal gland.

### **3. Projection fibers**

The projection fibers connect the cerebral cortex to the subcortical centers (such as the corpus striatum, thalamus, brainstem) and spinal cord. These fibers are of the following two types:

- ⊙ 1. **Corticofugal fibers**, which *go away* from the cortex (cortical efferents) to centers in the other parts of the CNS.
- ⊙ 2. **Corticopetal fibers**, which *come* to the cerebral cortex from the other centers in the CNS.

The projection fibers of neocortex constitute the *corona radiata* and *internal capsule* while those of allocortex (i.e., archicortex and paleocortex) constitute the *fimbria* and *fornix*.

- ⊙ **The most important bundles of projection fibers are: internal capsule and fornix.**

**The internal capsule** is a compact bundle of projection fibers between the thalamus and caudate nucleus medially and the lentiform nucleus laterally. It consists of ascending and descending nerve fibers which connect the cerebral cortex to the brainstem and spinal cord.

- ⊙ The afferent (sensory) fibers pass up from thalamus to the cerebral cortex and efferent (motor) fibers pass down from the cerebral cortex to the cerebral peduncle of the midbrain.
- ⊙ These sensory and motor fibers of internal capsule are mainly responsible for the sensory and motor innervation of the opposite half of the body.
- ⊙ **N.B.** The sensory fibers radiate from thalamus in different directions to reach the widespread areas of the cerebral cortex and constitute the *thalamic radiation*.
- ⊙ In a horizontal section of the cerebral hemisphere, the internal capsule appears as a V-shaped compact bundle of white fibers with its concavity directed laterally
- ⊙ The internal capsule is divided into the following five parts:
  1. **Anterior limb**—between the head of caudate nucleus and the anterior part of the lentiform nucleus.
  2. **Posterior limb**—between the thalamus and the posterior part of the lentiform nucleus.
  3. **Genu**—the bend between the anterior and posterior limbs with concavity of the bend facing laterally.
  4. **Retrolentiform part**—behind the lentiform nucleus.
  5. **Sublentiform part**—below the lentiform nucleus.
- ⊙ **Lesions of internal capsule:** The internal capsule is frequently involved in the cerebrovascular disorders. The most common cause of arterial hemorrhage is atheromatous degeneration of an artery in individuals suffering from high blood pressure. The hemorrhage commonly occurs due to rupture of the Charcot's artery, the larger lateral striate branch of the middle cerebral artery (also called *Charcot's artery of cerebral hemorrhage*), which supplies the posterior limb of the internal capsule.

Damage to the internal capsule caused by hemorrhage or infarction, leads to loss of sensations and spastic paralysis of the opposite half of the body (contralateral hemiplegia).

## Basal nuclei

- ⊙ The basal nuclei (or ganglia) are large subcortical masses of grey matter located inside the white matter in the basal part of the cerebral hemisphere.
- ⊙ Anatomically, the term *basal ganglia* include:
  - (a) corpus striatum,
  - (b) claustrum, and
  - (c) amygdaloid body.
- ⊙ Functionally, basal ganglia also include substantia nigra, red nucleus, and subthalamus.
- ⊙ The basal nuclei are important in organizing and coordinating motor movements. The major function of the basal nuclei is to decrease muscle tone and inhibit unwanted muscular activity.
- ⊙ The corpus striatum is situated lateral to the thalamus.
- ⊙ Topographically, it is almost completely divided into the **caudate nucleus** and the **lentiform nucleus** by a band of nerve fibers, the *internal capsule*. However, anteroinferior ends of these nuclei remain connected by a few bands of grey matter across the anterior limb of the internal capsule. These bands give it a striated appearance, hence the name corpus striatum
- ⊙ The lentiform nucleus consists of two parts: a darker lateral part *putamen* and a medial paler part *globus pallidus*.
- ⊙ Phylogenetically, corpus striatum forms two distinct functional units, the **paleostriatum** and the **neostriatum**.
- ⊙ The globus pallidus is relatively ancient and termed *paleostriatum/pallidum*. The caudate nucleus and putamen being recent in development, together form the *neostriatum/ striatum*.
- ⊙ Caudate nucleus is a large comma-shaped mass of grey matter, which surrounds the thalamus and is itself surrounded by the lateral ventricle. The whole length of its convexity projects into the cavity of lateral ventricle. Its rounded anterior part in front of interventricular foramen is called its **head**. The head gradually and imperceptibly tapers caudally into the **body** and then into a **tail**, which merges at its anterior extremity with an almond shaped mass of grey matter called *amygdaloid body*
- ⊙ Lentiform nucleus is a large lens-shaped (biconvex) mass of grey matter beneath the insula forming the lateral boundary of the internal capsule. In horizontal section of cerebrum, it appears wedge shaped with broad convex base directed laterally.
- ⊙ It is divided into two parts by a vertical plate of white matter (*external medullary lamina*): an outer darker part, the *putamen* and an inner lighter part the *globus pallidus*.
- ⊙ The larger lateral part, the **putamen** consists of densely packed small cells, and is structurally similar to the caudate nucleus.
- ⊙ The **globus pallidus** is smaller medial part and consists of large (motor) cells. It is also known as *pallidum* as it appears pale in section (pallid = pale). The globus pallidus is further subdivided by an *internal medullary lamina of white matter* into outer and inner segments

- ⊙ The striatum (caudate nucleus and putamen) is the receptive part while globus pallidus is the efferent part (outflow center) of the corpus striatum.
- ⊙ The striatum receives fibers mainly from the cerebral cortex, thalamus, and substantia nigra. The globus pallidus sends fibers to the thalamus, subthalamus, substantia nigra, reticular formation, and red nucleus.
- ⊙ Different pathways involve different neurotransmitters, which include dopamine, acetylcholine, glutamate, and  $\gamma$ -aminobutyric acid (GABA).
- ⊙ Claustrum is a thin saucer-shaped mass of grey matter situated between the putamen and insula.
  - ⊙ Its significance is not known
- ⊙ Amygdaloid body is an almond-shaped mass of grey matter in the temporal lobe, lying anterosuperior to the tip of inferior horn of lateral ventricle. It is situated deep to uncus, which serves as a surface landmark for its location.
- ⊙ The fibers arising from amygdaloid body form stria terminalis, which follow the inner curve of the caudate nucleus and terminate into septal area, anterior perforated substance, and anterior hypothalamic nuclei. The stria terminalis is the main efferent tract of the amygdaloid body.
- ⊙ Developmentally it is related to the basal nuclei but functionally it is included in the limbic system, and therefore, shares its functions

⊙ The functions of the basal nuclei are as follows:

1. Concerned with planning and programming of voluntary movements.
2. Determine how rapidly a movement is to be performed and how large the movement must be.
3. Decrease muscle tone and inhibit unwanted muscular activity.
4. Regulate the muscle tone and thus help in smoothening the voluntary motor activities of the body.
5. Control automatic associated movements, like swinging of arms during walking.
6. Control group of movements responsible for emotional expression.
7. Control reflex muscular activity.

⊙ **Lesions of basal ganglia:** The lesions of basal ganglia result in various forms of unwanted involuntary movements and disturbance in the muscle tone. These disorders include Parkinsonism chorea, athetosis, and ballismus. The Parkinsonism being the commonest disorder is described in detail in the following text.

⊙ **Parkinsonism** (also called Parkinson's disease/paralysis agitans): This disease usually occurs after 50 years of age due to deficiency of the neurotransmitter dopamine in the corpus striatum following a lesion in substantia nigra and/ or its nigrostriate fibers.

⊙ *Characteristic features of Parkinsonism:*

- Resting tremors.
- Lead-pipe or cogwheel type of muscular rigidity.
- Pill-rolling movements of hands.
- Mask-like face or loss of facial expression.
- Stiff, shuffling gait.
- Stooped posture.
- General slowing-down of movements and absence of associated movements, such as arm swinging during walking.

## Limbic system

- ⊙ The word *limbus* means ring, the term **limbic system** is applied to the parts of the cortical and subcortical structures that form a ring around the upper end of the brainstem.
- ⊙ The limbic region was formerly called **rhinencephalon** because of its association to olfaction, but only a small part of it is actually concerned with smell.
- ⊙ Phylogenetically, limbic cortex is the oldest part of the cerebral cortex and is made up of primitive type of cortical tissue called **allocortex**, which consists of only three layers and surrounds the hilum of the cerebral hemisphere.
- ⊙ The limbic system plays a vital role in **abstract functions** such as emotions, behavior, drive, and memory.
- ⊙ The limbic system is functionally associated with the following neural activities:
  1. Emotional aspects of behavior together with visceral responses accompanying these emotions, particularly the reactions of fear and anger, and emotions associated with sexual behavior which are necessary for:
    - (a) survival of an individual including procuring of food and eating behavior, and
    - (b) survival of the species including the sexual behavior.
  2. Brain mechanisms responsible for recent memory.
  3. Integration of olfactory, visceral, and somatic impulses reaching the brain.
    - ⊙ **N.B.** Because of visceral responses to activities in the limbic system, it is also known as *visceral brain*. The main object of limbic system is to meet the needs of primitive life, i.e., food and sex.

## Components of the limbic system

- ⊙ A large number of structures of the brain are included in the limbic system. However, a fairly accepted list of these is:

## Regions of Grey Matter in Limbic System

### a. Cortical Structures

### b. Subcortical Nuclei

#### a. Cortical Structures

1. **Limbic lobe**, consisting of cingulate gyrus, isthmus, parahippocampal gyrus, and uncus (anterior part of the parahippocampal gyrus).
2. **Hippocampal formation**, which includes hippocampus (cornu ammonis), dentate gyrus, gyrus fasciolaris, and indusium griseum

#### b. Subcortical Nuclei

1. Amygdaloid nuclear complex (also called *amygdaloid body*).
2. Septal region and nuclei.
3. Olfactory areas.
4. Hypothalamus especially the mammillary bodies.
5. Anterior nucleus of thalamus.

## Fiber Bundles of the Limbic System

1. Fornix.
2. Mammillothalamic tract.
3. Stria terminalis.
4. Anterior commissure.

Amygdaloid nuclear complex consists of lateral, central, and basal nuclei. It is an almond-shaped mass of grey matter underlying the rostral part of the parahippocampal gyrus on the anterior most part of the roof of the inferior horn of lateral ventricle.

- ⊙ Posteriorly, amygdaloid body becomes continuous with the tail of the caudate nucleus and stria terminalis.

### ⊙ CONNECTIONS

Afferents: Main afferents to amygdaloid body are from

- ⊙ primary olfactory regions.

Efferents: **Stria terminalis** forms the main efferent tract of

- ⊙ the amygdaloid body. It takes a circuitous route along with (but not functionally related to) the tail of caudate nucleus in close relation to the lateral ventricle until the level of anterior commissure, where majority of its fibers terminate in the septal area and anterior portion of the hypothalamus. The others join the anterior commissure and are distributed to the contralateral amygdaloid body.
- ⊙ In general, amygdaloid body plays an important role in controlling the somatic responses to internal needs, drives or instincts. Since part of it receives olfactory input, it is believed that the amygdaloid body plays an important role in smell mediated sexual behavior.
- ⊙ Stimulation of amygdaloid body produces excitability, fear, and rage. Bilateral damage of amygdaloid body reduces fear and increases sexual activity.
- ⊙ **N.B.** People in late sixties become pervasive in their sexual behavior, probably due to atrophy of amygdaloid bodies.

### The hippocampal formation

- ⊙ The hippocampal formation consists of
- ⊙ (a) hippocampus,
- ⊙ (b) dentate gyrus,
- ⊙ (c) indusium griseum, gyrus fasciolaris
- ⊙ and
- ⊙ (d) medial and lateral longitudinal striae.

Hippocampus (also called **Ram's horn** or **Ammon's horn**) is an area of cerebral cortex which has rolled into the floor of the inferior horn of the lateral ventricle during fetal life.

In an adult brain, it forms a longitudinal elevation in the floor of inferior horn of the lateral ventricle and is continuous medially with the subiculum and parahippocampal gyrus.

The name "hippocampus" meaning "sea horse", is derived from its appearance in coronal section.

- ⊙ In the frontal section the hippocampus is C-shaped and its outline bears a resemblance to a Ram's horn, hence the name **Ram's horn**. It is also called **Ammon's horn** after an Egyptian deity with Ram's head. Its anterior extremity is expanded and bears few grooves and intervening ridges. Because of its resemblance to an animal's paw it is termed **pes hippocampi** (pes = foot). Traced posteriorly the hippocampus gradually narrows and ultimately ends beneath the splenium of corpus callosum. The ventricular surface of the hippocampus is covered by a thin layer of white fibers called **alveus**. The fibers of alveus originate in the hippocampal cortex, course towards the medial border of hippocampus where they converge to form a narrow strip of white matter, the **fimbria of hippocampus**.



- ⊙ Afferents: Hippocampus receives fibers mainly from entorhinal area (area 28).
- ⊙ Efferents: The fornix is the main efferent tract of the hippocampus.
- ⊙ The fibers leaving the hippocampus pass to:
  - (a) the opposite hippocampus through the *commissure of fornix/hippocampal commissure*,
  - (b) the septal and anterior hypothalamic regions, and
  - (c) the mammillary body, which sends impulses to cingulate gyrus through anterior nucleus of thalamus.

1. Formerly hippocampus was regarded as the part of olfactory system but it has no direct connections with the sense of smell in man.

2. In man it is an integrative center, which influences endocrine and visceral functions and emotional states through its connections with hypothalamus, septal nuclei, and the cingulate gyrus.

- ⊙ It plays an important role in *recent memory*.
- ⊙ In the fetal brain, the **dentate gyrus** develops as a further extension of the hippocampus and occupies the interval between the hippocampus and the parahippocampal gyri, lying deep to fimbria. Its surface is toothed, hence the name **dentate gyrus**.

When traced anteriorly, dentate gyrus runs medially across the inferior surface of the uncus. This part is called **tail of dentate gyrus**. The posterior end of dentate gyrus is continuous with the **splenial gyrus or gyrus fasciolaris**, which continues as a thin layer of grey matter over the corpus callosum called **indusium griseum**.

The indusium griseum is the vestigial grey matter and contains two delicate longitudinal bands of fibers buried in it, the **medial and lateral longitudinal striae**.

**The fornix** is a large bundle of projection fibers, which connects the hippocampus with the mammillary body. It constitutes the sole efferent system of the hippocampus.

On the medial surface of the cerebral hemisphere, it is seen as an arched prominent bundle of white fibers below the corpus callosum, along the lower border of septum pellucidum. There is one fornix in each cerebral hemisphere but two are so closely related/fused beneath the middle of the body of corpus callosum that they are usually described as a single structure. The fibers of fornix arise mainly from the pyramidal cells of the hippocampus and form a thin layer of white fibers on its ventricular surface called **alveus**.

The **fibers of alveus** collect on the medial margin of hippocampus to form a narrow strip of white matter, the **fimbria**, lying flat over the dentate gyrus. The fimbria becomes a rounded band, the **crus of fornix** as it arches upwards, medially and forwards underneath the splenium of corpus callosum. The two crura, one of each hemisphere, curving over the thalamus, converge and unite in the midline beneath the trunk of corpus callosum to form the **body of fornix**.

Anteriorly, the body of fornix divides into two columns, the **columns of fornix**. Each column of fornix arches downwards towards the anterior commissure, and forms the anterior boundary of interventricular foramen. Then it curves posteriorly through the hypothalamus to end in the mammillary body. These fibres being located posterior to anterior commissure are referred to as **postcommissural fornix**. Some fibers of column pass in front of anterior commissure to end in the septal area and anterior hypothalamic region, etc. to constitute the **precommissural fornix**.

- To summarize, the main parts of the fornix are fimbria, crura, body, and anterior columns.
- Mammillothalamic tract, also called, Félix Vicq d'Azyr, is a prominent bundle of fibers, which carry impulses from mammillary body to the anterior, nucleus of the thalamus. (1-10)

## 2. The cerebral arteries (*Arteriae encephali*)

### The anterior choroidal artery (*A. choroidea anterior*)

Arises from the internal carotid artery, near the origin of the posterior communicating artery. It passes posterolaterally above the medial part of the uncus, along the optic tract, curves laterally to reach the lateral side of the geniculate body. Further it is oriented laterally, it crosses the optic tract again and reaches the level of the lateral geniculate body which gives it several branches (*Rr. corporis geniculati lateralis*). Finally, enters the inferior horn of the lateral ventricle through the choroidal fissure and ends in the choroid plexus.

The **anterior choroidal artery** supplies globus pallidus, caudate nucleus, amygdala, hypothalamus, tuber cinereum, anterior perforated substance, red nucleus, posterior limb of the internal capsule, optic radiation, optic tract, optic chiasm, hippocampus, and the fimbria of the fornix.

Branches of the anterior choroidal artery:

- Choroidal branches to lateral ventricle (*Rr. choroidei ventriculi lateralis*);
- Choroidal branches to third ventricle (*Rr. choroidei ventriculi tertii*);
- Branches to the anterior perforated substance (*Rr. substantia perforatae anterioris*);
- Chiasm branches (*Rr. chiasmatici*);
- Optic tract branches (*Rr. tractus optici*);
- Branches to genu of the internal capsule (*Rr. genu capsulae internae*);
- Branches to posterior limb of the internal capsule (*Rr. cruris posterior capsulae internae*);
- Branches to retrolenticular portion of the internal capsule (*Rr. partis retrolentiformis capsulae internae*);
- Globus pallidus branches (*Rr. globi pallidi*);
- Branches to caudate nucleus „tail“ (*Rr. caudae nuclei caudati*);
- Distal branches (*Rr. uncales*);
- Hippocampus branches (*Rr. hippocampi*);
- Branches to amygdala body (*Rr. corporis amygdaloidei*);
- Tuber cinereum branches (*Rr. tuberis cinerei*);
- Hypothalamic nuclei branches (*Rr. nucleorum hypothalami*);
- Thalamic nuclei branches (*Rr. nucleorum thalami*);
- Substantia nigra branches (*Rr. substantiae nigrae*);
- Red nucleus branches (*Rr. nuclei rubri*);
- Cerebral peduncle branches (*Rr. cruris cerebri*).

### Anterior cerebral artery (*Arteria cerebri anterior*)

It is the smallest terminal branch of the internal carotid artery. Arises from the internal carotid artery and is part of the circle of Willis; it is oriented antero-medially above the optic nerve in the longitudinal fissure. The left and right anterior cerebral arteries are connected by the anterior communicating artery. The anterior cerebral artery is divided into proximal or precommunicating (A-1) segment and distal or postcommunicating (A-2) segments by the anterior communicating artery.

From the precommunicating segment (*Pars precommunicalis; Segmentum A1*), anteromedial central arteries arise (*Aa. centrales anteromediales*):

- proximal medial striate artery (*Aa. striatae mediales proximales*);
- supraoptic artery (*A. supraoptica*);
- anterior perforated artery (*Aa. perforantes anteriores*);
- preoptic artery (*Aa. preopticae*).

The anterior communicating artery is seldom a distinct vessel but more often has a duplication with the following branches:

- suprachiasmatic artery (*A. suprachiasmatica*);
- arteries of the anterior commissure (*A. commissuralis mediana*);
- median artery of the corpus callosum (*A. callosa mediana*).

The postcommunicating segment (*Pars postcommunicalis; Segmentum A2*) vascularizes the olfactory lobe, right gyrus, medial orbital gyrus, corpus callosum, cingulate gyrus, medial frontal gyrus, paracentral lobe, superior frontal gyrus, middle frontal gyrus, upper portion of precentral gyrus, precuneus and adjacent lateral surface. Has the following branches:

- distal medial striate artery (*A. striata medialis distalis*);
- Orbitofrontal artery (medial frontal basal) (*A. frontobasalis medialis A. orbitofrontalis medialis*);
- Frontopolar artery (polar frontal) (*A. polaris frontalis*);
- callosal marginal artery (*A. callosomarginalis*), with the following branches:
  - o anteromedial frontal branch (*R. frontalis anteromedialis*);
  - o intermediomedial frontal branch (*R. frontalis intermediomedialis*);
  - o posteromedial frontal branch (*R. frontalis posteromedialis*);
  - o cingular branch (*R. cingularis*);
  - o paracentral branches (*Rr. paracentrales*).
- pericallosal artery (*A. pericallosa*), with the following branches:
  - o paracentral branches (*Rr. paracentrales*);
  - o precuneal branches (*Rr. precuneales*);
  - o parietooccipital branches (*Rr. parietooccipitales*).

### **Middle cerebral artery (*Arteria cerebri media*)**

It is the largest terminal branch of the internal carotid artery. Arises from the internal carotid and continues into the lateral sulcus having a horizontal, sphenoidal segment where it then branches and projects to many parts of the lateral cerebral cortex. It is divided into a proximal (M-1) segment and a distal (M-2) segment by the middle cerebral artery bifurcation.

The sphenoidal segment (*Pars sphenoidalis; Pars horizontalis; Segmentum M1*):

- two anterolateral central arteries (*Aa. centrales anterolaterales*), with the following branches
  - o lateral striate arteries or lenticulostriate (*Rr. proximales laterales striati*) which vascularizes the caudate nucleus;
  - o Distal lateral striate branches (*Rr. distales laterales striati*) which vascularizes the caudate nucleus and the internal capsule.
- Temporopolar artery (*A. polaris temporalis*);
- Uncal artery (*A. uncalis*);
- Anterior temporal artery (*A. temporalis anterior*).

The insular segment (*Pars insularis; Segmentum M2*) : insular arteries (*Aa. insularis*), inferior cortical branches and superior cortical branches.

The inferior cortical branches (*Rr. terminales inferiores; R. corticales inferiores*):

- anterior temporal artery (*R. temporalis anterior*);
- middle temporal artery (*R. temporalis media*);
- posterior temporal artery (*R. temporalis posterior*);
- temporo-occipital branch (*R. temporooccipitalis*);
- angular gyrus branch (*R. gyri angularis*).

The superior cortical branches (*Rr. Terminales superiores; Rr. corticales superiores*):

- lateral frontobasal artery (*A. frontobasalis lateralis; A. orbitofrontalis lateralis*);
- prefrontal artery (*A. prefrontalis*);
- the artery of precentral sulcus (*A. sulci precentralis*);
- the artery of central sulcus (*A. sulci centralis*);
- the artery of postcentral sulcus (*A. sulci postcentralis*);
- anterior parietal artery (*A. parietalis anterior*);
- posterior parietal artery (*A. parietalis posterior*).

Cortical branches vascularize the inferior and middle frontal gyrus, the lateral portion of the orbital surface of the frontal lobe, the precentral gyrus, the postcentral gyrus, the lower portion of the superior parietal lobe, the entire inferior parietal lobe, and the lateral face of the temporal lobe.

### **Posterior communicating artery (*Arteria communicans posterior*)**

The posterior communicating artery arises from the internal carotid artery. It passes backwards above the oculomotor nerve and anastomoses with the posterior cerebral artery. Vascularizes the medial surface of the thalamus, the walls of the third ventricle, the optic chiasm, the tuber cinereum, the hypothalamus, the Mammillary bodies and the oculomotor nerve. Has the following branches:

- Posteromedial central branches (*Aa. centrales posteromediales*):
  - o anterior branches (*Rr. anteriores*);
  - o posterior branches (*Rr. posteriores*).
- Chiasmatic branch (*R. chiasmaticus*);
- Tuber cinereum artery (*Aa. tuberis cinerei*):
  - o Medial branches (*Rr. mediales*);
  - o Lateral branches (*Rr. laterales*).
- Talamotuberal artery (*A. thalamotuberalis*);
- Hypothalamic branch (*R. hypothalamicus*);
- Mammillary arteries (*Aa. mammillares*);
- Oculomotor nerve branch (*R. nervi oculomotorii*).

### **Posterior cerebral artery (*Arteria cerebri posterior*)**

The two posterior cerebral arteries (right and left), is the terminal branch of the basilar artery, arises at the level of the upper edge of the pons. From its origin curves laterally receiving the posterior communicating artery completing the arterial circle of Willis. The posterior cerebral artery supplies the temporal and occipital lobes.

The precommunicating segment (P1) (*Pars precommunicalis; Segmentum P1*):

- posteromedial central branches (*Aa. centrale posteromediales*) which, together with the posteromedial arteries of the posterior communicating artery, supplies the anterior portion of the thalamus, the lateral wall of the third ventricle and globus pallidus;
- thalamoperforating artery (*A. thalami perforans*) supplies the thalamus;
- collicular artery (*A. collicularis A. quadrigeminalis*) supplies the quadrigeminal colliculus;
- short circumferential arteries (*Aa. circumferentiales breves*).

The postcommunicating segment (P2) (*Pars postcommunicalis; Segmentum P2*):

- posterolateral central arteries (*Aa. centrales posterolaterales*);
- thalamogeniculate artery (*A. thalamogeniculata*);
- medial posterior choroidal branches (*Rr. choroidei posteriore mediales*);
- lateral posterior choroidal branches (*Rr. choroidei posteriore laterales*);
- peduncular perforating branches (*Rr. pedunculares*).

These branches supply the posterior thalamus, pineal gland, medial geniculate body, lateral geniculate body, participates in the formation of the choroid plexuses of the third ventricle.

Cortical branches: medial and lateral occipital branches.

Lateral occipital artery (*A. occipitalis lateralis; Segmentum P3*) with the following branches:

- anterior temporal branches (*Rr. temporales anteriores*);
- intermediate temporal branches (*Rr. temporales intermedii; Rr. temporales medii*);
- posterior temporal branches (*Rr. temporales posteriores*).

Medial occipital artery (*A. occipitalis medialis; Segmentum P4*) with the following branches:

- the dorsal branch to corpus callosum, posterior pericallosal branch (*R. corporis callosi dorsalis*);
- parietal branches (*R. parietalis*);
- parietooccipital branches (*R. parietooccipitalis*);
- calcarine branches (*R. calcarinus*);
- occipitotemporal branches (*R. occipitotemporales*).

The temporal branches supply the uncus, parahippocampal, medial and lateral occipitotemporal gyri. The occipital branches supply the cuneus, lingual gyrus, and posterolateral surface of the occipital lobe. The parieto-occipital branches supply the cuneus and precuneus and the calcarine branches the calcarine sulcus and its adjacent areas.

### **Cerebral arterial circle (*Cercus arteriosus cerebri*)**

The cerebral arterial circle (The circle of Willis) is formed from the arteries that provide the vascularization of the brain:

- Internal carotid artery (*A. carotis interna*) with the following branches:
  - o Anterior cerebral artery (*A. cerebri anterior*) and anterior communicating artery (*A. communicans anterior*);
  - o Middle cerebral artery (*A. cerebri media*);
  - o Posterior communicating artery (*A. communicans posterior*);

- Basilar artery (*A. basilaris*) with the posterior cerebral artery (*A. cerebri posterior*).

### The cerebral veins (*Venae encephali*)

The **cerebral veins** are divisible into superficial **cerebral veins** and deep **cerebral veins**

#### Superficial cerebral veins (*Venae superficiales encephali*)

Three groups:

- Superior cerebral veins (*Vv. superiores cerebri*) numbering 8-12, drain the superior, lateral, and medial surfaces of the hemispheres, they can be found in the sulci between the gyri. They drain into the superior sagittal sinus. The superior veins are:
  - o Prefrontal veins (*Vv. prefrontales*);
  - o Frontal veins (*Vv. frontales*);
  - o Parietal veins (*Vv. parietales*);
  - o Temporal veins (*Vv. temporales*);
  - o Occipital veins (*Vv. occipitales*).
- Middle cerebral veins and ends in the cavernous or the sphenoparietal sinus. An upper anastomotic vein (*V. anastomotica superior*) connects the cavernous sinus with the superior sagittal sinus, and an inferior anastomotic vein (*V. anastomotica inferior*) connects the middle cerebral vein to the transverse sinus.
- Inferior cerebral vein (*Vv. inferiores cerebri*):
  - o Orbital vein (*Vv. orbitae*);
  - o Vein of uncal (*V. uncalis*);
  - o Temporal veins (*Vv. temporales*).

The orbital veins drain into the superior sagittal sinus, through the superior cerebral veins, and the uncal vein and the temporal veins flow into the basal vein, the cavernous sinus, the superior petrosal sinus, and the transverse sinuses.

#### Deep cerebral veins (*Venae profundae cerebri*)

The basal vein (*V. basalis*) is formed at the anterior perforated substance by the following veins:

- o Anterior cerebral veins (*Vv. anteriores cerebri*);
- o Deep middle cerebral veins (*V. media profunda cerebri*) which receives tributaries from the insula (*Vv. insulares*);
- o thalamostriate veins (*Vv. thalamostriatae inferiores*).

The basal vein passes around the cerebral peduncle, and ends in the great cerebral vein; it receives the following tributaries:

- o Vein of olfactory gyrus (*V. gyri olfactorii*);
- o Inferior ventricular vein (*V. ventricularis inferior*) inferior horn of the lateral ventricle
- o peduncular veins (*Vv. pedunculares*) cerebral peduncles;
- o inferior choroid vein (*V. choroidea inferior*) choroid plexus of the third ventricle;

- The great cerebral vein (*V. magna cerebri*) is formed by the union of the two internal cerebral veins (*Vv. internae cerebri*), passes around the splenium, receives the basal vein and drains into the straight sinus.
- The internal cerebral vein is formed by the union of the thalamostriate (*V. thalamostriata superior; V. terminalis*), choroid veins (*V. choroidea superior*) and the vein of the septum pellucidum.
- The thalamostriate superior vein passes between the thalamus and the caudate nucleus and receives the following branches:
  - anterior vein of the septum pellucidum (*V. anterior septi pellucidi*);
  - posterior vein of the septum pellucidum (*V. posterior septi pellucidi*);
  - medial vein of the lateral ventricle (*V. medialis ventriculi lateralis*);
  - lateral vein of the lateral ventricle (*V. lateralis ventriculi lateralis*);
  - caudate nucleus veins (*Vv. nuclei caudati*).
- Corpus callosum posterior vein (*V. posterior corporis callosi; V. dorsalis corporis callosi*) drain the posterior part of the corpus callosum.



## 3. The brainstem

### General aspects

The hind-brain (rhombencephalon) is situated in the posterior cranial fossa, inferiorly to tentorium cerebelli and consists of the myelencephalon, the metencephalon and the isthmus rhombencephali. The myelencephalon consists of medulla oblongata and the inferior part of fourth ventricle, the metencephalon comprises the pons, cerebellum and the intermediate part of the fourth ventricle and the isthmus rhombencephali consists of superior cerebellar peduncles, the anterior medullary velum, and the superior part of the fourth ventricle.

The brainstem is the encephalon division that connects the forebrain (diencephalon and cerebrum) with the spinal cord. Brainstem consists of three parts, which from inferiorly to superiorly are:

1. Medulla oblongata,
2. Pons Varolii,
3. Midbrain (mesencephalon).

Each part communicates with the cerebellum through cerebellar peduncles (superior, middle and inferior). Brainstem also establishes connections with the cerebrum through the cerebral peduncles.

The brainstem consists of nerve fibers mostly disposed longitudinally as tracts in the spinal cord and also of nerve cells disposed mostly into nuclei: nuclei of cranial nerves III-XII and other nuclei (substantia nigra, olivary nuclei, red nucleus etc). The brainstem comprises also a diffuse system called reticular formation with vital functions.

The last ten pairs of cranial nerves reach surface at the level of brainstem: the third and fourth cranial nerve (III – oculomotor, IV – trochlear) at the level of midbrain, the next four pairs (V – trigeminal, VI – abducens, VII – facial, VIII – vestibulocochlear) at the level of pons and the last four pairs of cranial nerves (IX – glossopharyngeal, X – vagus, XI – accessory, XII – hypoglossal) arise at the level of medulla oblongata.

#### Limits:

The inferior limit is represented by the horizontal plane that passes through the inferior part of pyramidal decussation and that can be found superiorly to the origin of the first pair of cervical nerves.

The superior limit which separates the brainstem from diencephalon is represented antero-laterally by the level at which cerebral peduncles are crossed by the optic tracts and posteriorly by the horizontal line that passes superiorly to the superior quadrigeminal colliculi.

Brainstem has a cone trunk shape flat from anterior to posterior with the large base superiorly and an oblique direction towards anterior and superior. Brainstem consists of 2 surfaces (antero-lateral and posterior) with a total length of 9 cm, distributed equally to medulla oblongata, pons and midbrain.

## MEDULLA OBLONGATA (SPINAL BULB)

Medulla oblongata is the inferior part of brainstem, pyramidal in shape, with its inferior narrower extremity continuous with the medulla spinalis, which begins at the foramen magnum and ends at the level of bulbo-pontine sulcus (a groove marking the boundary between the two structures). Medulla oblongata lies almost vertically between the clivus anteriorly and the vallecule of the cerebellum posteriorly.

Medulla oblongata extends from the lower margin of the pons to a plane passing transversely inferiorly to the pyramidal decussation and superiorly to the first pair of cervical nerves, which corresponds to the superior border of the atlas and the middle of the odontoid process of the axis. Superiorly, medulla oblongata is separated from the pons by the bulbo-pontine sulcus (sulcus bulbopontinus) where the apparent origin of cranial nerves VI, VII, VII bis and VIII can be found. This sulcus can be found only on the anterior and lateral surfaces.

The central canal of the medulla spinalis extends into the inferior part of medulla oblongata in order to open in the cavity of the fourth ventricle, hence the two parts of medulla oblongata: one inferior part comprising the central canal (closed part) and one superior part corresponding to the fourth ventricle (open part).

Physiologically, the medulla has an extremely important role regulating the heartbeat and blood pressure through its cardiac and vasomotor centers, but also regulating the rate and depth of respirations through its respiratory centers. Other centers include speech, salivation, vomiting, sneezing and sweating.

### EXTERNAL FEATURES

The medulla is divided into two halves by **the anterior median fissure** and **posterior median sulcus**.

The antero-lateral surface is divided into two symmetrical and elongated parts by the **anterior median fissure** (fissure mediana anterior; ventral or ventromedian fissure), which contains a fold of pia mater. The anterior median fissure is continuous inferiorly with the corresponding fissure of medulla spinalis and is interrupted in the inferior part of it by the pyramidal decussation where bundles of fibers cross obliquely from one side to the other. Some fibers called the anterior external arcuate fibers emerge from the fissure superiorly to the pyramidal decussation and after having a superior and lateral trajectory reach the inferior peduncle. The anterior median fissure ends superiorly through foramen cecum, which represents a small depression situated at the inferior border of the pons.

**The posterior median sulcus** is well represented only in the inferior half of the medulla, because superiorly its borders diverge and form the inferior part of rhomboid fossa.

Because of the superficial origins of the cranial nerves, each half of the medulla oblongata can be further divided into three areas/districts: **anterior, middle and posterior**, which appear to be continuous with the corresponding funiculi of the medulla spinalis, but not necessarily containing the same fibers. The division is made by **two sulci: the antero-lateral sulcus** which extends along the lateral border of the pyramid and where the roots of the hypoglossal nerve reach the surface **and postero-lateral sulcus** between the olive and the inferior cerebellar peduncle. Both sulci are continuous with the corresponding ones from the medulla spinalis.

## Features of the ventral part:

On both sides of the anterior median fissure can be found the **bulbar pyramids** (pyramis medullae oblongatae) which represent the **anterior district**, found between the anterior median fissure and antero-lateral sulcus. The two pyramids are produced by the underlying motor fibers that descend from the brain to medulla oblongata and medulla spinalis, called the corticobulbar and corticospinal (pyramidal) tracts, 90% of them crossing over the midline at the level of pyramidal decussation and then reach the posterior part of the lateral funiculus as the lateral cerebrospinal fasciculus. As a result, one side of the brain will control the muscles from the contralateral part of the body. The fibers from the lateral part of the pyramid do not decussate and form the anterior cerebrospinal fasciculus which pass inferiorly to the anterior funiculus on the same side.

**The lateral district** is found between antero-lateral and postero-lateral sulci and comprises superiorly a prominent oval mass named **the olive** produced by the inferior olivary nucleus and inferiorly the lateral funiculus of the medulla spinalis seems to be continuous directly with medulla oblongata. Only a portion of the lateral funiculus is continuous with the district of medulla oblongata, since the lateral cerebrospinal fasciculus reach the other side pyramid and the dorsal spinocerebellar fasciculus reach the inferior peduncle in the posterior district. The ventral spinocerebellar fasciculus is continuous with the lateral surface of medulla oblongata, it passes inferiorly to external arcuate fibers, dorsal to the olive and ventral to the roots of X and XI cranial nerves and then passes along the dorso-lateral edge of the lateral lemniscus. The remaining lateral funiculus represent the lateral proper fasciculus.

The olives are structures situated laterally to pyramids and are separated from them by the pre-olivary sulcus (antero-lateral sulcus, sulcus anterolateralis) where the roots of the hypoglossal nerve emerge. The fibers of the hypoglossal nerve (XII) are considered a continuation of the anterior nerve roots.

Posteriorly, the ventral spinocerebellar fasciculus separates the olives from the retro-olivary sulcus (postero-lateral sulcus, sulcus retro-olivaris).

Superiorly to the olives a depression called the supra-olivary fossette can be found, where the apparent origin of cranial nerve VII is.

Posteriorly to the lateral cord there is the postero-lateral sulcus (sulcus posterolateralis) where the **cranial nerves IX, X, XI** are attached and they correspond to the posterior nerve roots. Superiorly to lateral cord cranial nerve VIII reach the surface.

## Features on the Dorsal Aspect

The posterior surface of medulla oblongata forms the posterior district which can be found posteriorly to the postero-lateral sulcus and has two different parts: a superior open part and an inferior closed part.

**The inferior closed part (extraventricular part)** has less than one cm and it resembles spinal cord. This part presents the posterior median sulcus which is bordered by two fasciculi which end superiorly at the level of obex: fasciculus gracilis (of Goll) situated medially and fasciculus cuneatus (of Burdach) situated laterally. The third most lateral elongation visible on the surface of the closed part is the inferior cerebellar peduncle, also called restiform bodies. Gracilis and cuneatus fasciculi have a vertical trajectory and before reaching the level of rhomboid fossa and

diverging in V-shaped manner, each presents an elevation: clava or gracile tubercle for the fasciculus gracilis which is formed by the gracilis nucleus and cuneate tubercle corresponding to fasciculus cuneatus formed by the cuneatus nucleus. Posterior district of medulla oblongata presents in the inferior part, laterally to fasciculus cuneatus a third elongation formed by the substantia gelatinosa of Rolando. This elongation is separated from the surface of medulla oblongata by the spinal root of V cranial nerve and ends by expanding and forming tuber cinereum, inferiorly to the pons.

**At the level of the superior open part (ventricular part)** the cords are separating and thus forming taenia of the fourth ventricle. The floor of fourth ventricle (rhomboid fossa) has a rhomboid shape with a corresponding bulbar triangle situated inferiorly and a pontine triangle situated superiorly. The rhomboid fossa contains the median sulcus which divides the floor of the fourth ventricle into two halves. On the sides of the sulcus, the medial eminence can be found, which is bordered laterally by the sulcus limitans. Superiorly, in the **pontine triangle**, the medial eminence forms the colliculus facialis, whereas in the bulbar triangle it will form the trigonum hypoglossi. In the superior pontine triangle, sulcus limitans presents the locus caeruleus, a blue area. At the level of colliculus facialis the sulcus limitans become a depressed area called superior fovea and in the inferior part of the fossa will form the vagus triangle which contains the dorsal nucleus of vagus nerve. Laterally to this 2 areas area vestibularis can be found. Area vestibularis extends laterally until it reaches the tuberculum acusticum. From the inferior peduncle can be followed the striae medullares until they disappear into the median sulcus. Stria medullares are a part of the cochlear division of the VIII cranial nerve.

**The bulbar triangle** consists of three other small triangles.

The first superior triangle is the hypoglossal triangle (trigonum hypoglossale) which presents as a transversally rounded prominence of triangular shape, with the base superiorly and the apex at the level of inferior angle of ventricle. This triangle has a ventricular crest which will separate it into a medial part with relations to the nucleus of XII cranial nerve and a lateral part with relations to Staderini intercalate nucleus. Laterally, the triangle is bordered by sulcus limitans.

The second inferior triangle is the vagus triangle (fovea inferior, ala cinerea) with the base oriented inferiorly which contains the dorsal nucleus of vagus nerve.

The third triangle (area vestibularis) has the base superiorly and corresponds to the nuclei of Deiters, Schwabe and Bechterew. This third triangle is crossed transversally by fasciculi coming from median sulcus to lateral angle of rhomboid fossa. These fasciculi present the acoustic striae which can be followed until they reach the auditory tubercle.

## **PONS**

The pons (L. *pons*= bridge) is the middle part of the brainstem situated between midbrain and the medulla and anteriorly to cerebellum from which is separated by the fourth ventricle. Inferiorly the pons is separated from the medulla oblongata by the ponto-medullary junction where from medial to lateral the cranial nerves VI, VII and VIII reach the surface. Superiorly, the limit between pons and the midbrain is marked by cerebral peduncles and the interpeduncular fossa. The pons is connected to cerebellar hemispheres via middle cerebellar peduncles, on either side.

Similar to medulla oblongata, it has an antero-lateral surface (ventral surface) and a posterior (dorsal) surface and also 2 borders: inferior and superior. The borders

have important relations with the cerebellar arteries: the superior cerebellar arteries curve along the superior border and AICA (anterior inferior cerebellar arteries) curve around the inferior border.

### **Features on the Ventral Aspect**

The antero-lateral surface is very prominent and it rests on the clivus. This surface presents the **basilar groove** (sulcus basilaris) which lodges the **basilar artery**, therefore the artery is interposed between the clivus and the pons, which represents an important aspect in head traumas. On the sides of the basilar groove the **pontine pyramids** can be found. These pyramids present parallel transverse striations which are continuous at the level of middle cerebellar peduncles (pedunculus cerebellaris medius) due to underlying ponto-cerebellar fibers.

**The trigeminal nerve** (formed by a larger lateral sensitive root and a smaller medial motor root) has the apparent origin at the level of pontine pyramids, near the superior border of the pons. The vertical line drawn posteriorly to the apparent origin of the V cranial nerve is considered to be the limit between the pons and the middle cerebellar peduncle.

### **Features on the Dorsal Aspect**

Posterior surface of the pons is covered by the cerebellum and between them the cavity of the fourth ventricle can be found. This surface has a triangular shape and it corresponds to superior segment of the floor of fourth ventricle (pontine triangle of rhomboid fossa), which consists of 3 different zones: eminentia teres (internal zone), fovea superior (middle zone) and an external zone.

Eminentia teres (colliculus facialis) is a rounded protuberance which is continuous superiorly through a cord called funiculus teres. Both structures are intraventricular protuberances of the nucleus of abducens nerve, which is surpassed by the ascending portion of the facial nerve.

Fovea superior represents the widening of sulcus limitans into a depression and it corresponds to the motor nucleus of trigeminal nerve (V).

External zone corresponds to superior part of vestibular area. In the lateral part of pontine triangle, sulcus limitans represents the lateral limit of the rhomboid fossa and it presents a blue-greyish area called locus coeruleus, where the superior root of trigeminal nerve ends.

### **MIDBRAIN (MESENCEPHALON)**

The midbrain is the shortest, constricted and superior part of brainstem which connects the pons and the cerebellum with the diencephalon and cerebrum, without a strict delimitation superiorly. Anteriorly has a poorly delimitation, the limits being superiorly the diencephalon, laterally optic tracts, posteriorly the superior borders of superior quadrigeminal colliculus. Inferiorly the midbrain is separated from the pons by the ponto-peduncular groove, which is less evident posteriorly.

Midbrain consists of: an antero-lateral surface composed of the cerebral peduncles, a dorsal surface consisting of 4 structures called corpora quadrigemina

and the cerebral aqueduct of Sylvius, which is the cavity of the midbrain that connects 3<sup>rd</sup> and 4<sup>th</sup> ventricle.

On cross section, the midbrain presents 3 floors:

1. Inferior floor represented by the cerebral peduncles
2. Middle floor also called tegmentum (ventral to the aqueduct)
3. Superior floor also called tectum (roof of midbrain, dorsal to the aqueduct): corpora quadrigemina

The limit between tegmentum and tectum is marked by the cerebral aqueduct of Sylvius.

### Features on the Ventral Aspect

Antero-lateral surface consists anteriorly of **the two cerebral peduncles** (pedunculus cerebri) which are two divergent structures covered by the cerebral temporal lobes, which must be drawn aside for them to be visualized. The inferior part of the peduncles are called **crus cerebri**. Between the peduncles there is a depressed area called the **interpeduncular fossa** which presents: an apex at the level of the median part of the ponto-peduncular sulcus, a base superiorly at the level of the optic chiasm and optic tracts and 2 lateral borders represented by the cerebral peduncles. The vast majority of the structures that can be found at the level of the interpeduncular fossa belong to diencephalon: superiorly the pituitary stalk and mammillary bodies and inferiorly the posterior perforated substance, pierced by small apertures for the passage of blood vessels. The anterior surface of each peduncle has connections with superior cerebellar and posterior cerebral arteries, being crossed from medial to lateral by them. On the median line **tuber cinereum** can be found, which is a grey zone where the pituitary stalk (infundibulum) starts. Inferiorly, the cerebral peduncles are surrounded by the **IIIrd pair of cranial nerves** that can be found in the oculomotor sulcus, which is the lateral boundary of the interpeduncular fossa. Laterally the apparent origin of the **IVth pair of cranial nerves** can be observed, which come from the posterior surface of brainstem and also fibers from the lateral lemniscus reach the surface in the lateral sulcus.

### Features on the Dorsal Aspect

Posterior surface of midbrain is represented by tectum and can be visualized only after sectioning tentorium cerebelli and removing the occipital lobes. It presents the **corpora quadrigemina** (quadrigeminal plate, tectal plate) formed by the 2 superior and 2 inferior quadrigeminal colliculi, which are laterally continuous with the brachium colliculi. The corpora quadrigemina represent 4 rounded structures (*colliculi= little hills*) situated superiorly and anteriorly to anterior medullary velum and superior peduncle and inferiorly and posteriorly to the third ventricle and posterior commissure. They are covered by the splenium of corpus callosum and partly covered by the pulvinar. The quadrigeminal colliculi are arranged in 2 pairs and they are separated by a **cruciform sulcus** which consists of a horizontal part (which separates the superior colliculi from the inferior colliculi) and a vertical part with an anterior large component where the **pineal gland** sits. When traced inferiorly, the vertical part of the sulcus is continuous with the **frenulum veli**. **The IVth cranial**

**nerve** emerge one on each side of the upper part of frenulum veli. The brachium represents a white band structure spreading from the lateral part of each colliculus to the lateral and medial geniculate bodies. The superior brachium connects the superior colliculus with the lateral geniculate body and optic tract, passing between pulvinar and medial geniculate body and consists of optic tract fibers. The inferior brachium connects the inferior colliculus with the medial geniculate body and consists of auditory fibers.

**The cerebral aqueduct of Sylvius** is a narrow canal connecting the third and fourth ventricle, situated between tectum and tegmentum.

## INTERNAL MORPHOLOGY OF BRAINSTEM

Brainstem bears some resemblance with the spinal cord regarding the internal structure: grey substance is covered by white substance. Brainstem's white substance consists mainly of numerous fasciculi disposed in a horizontal fashion, whereas fasciculi of the medulla spinalis are disposed longitudinally. Grey substance is composed of three types of structures: the cranial nerves nuclei, brainstem's proper nuclei and reticular formation.

Grey substance suffers several changes from the grey substance of spinal cord, because of pyramidal decussation, sensitive decussation, enlargement of central canal forming the fourth ventricle, internal arcuate fibers and biotaxis, phenomena which will determine a different aspect of grey substance of brainstem in comparison to the one of medulla spinalis.

- 1. Pyramidal decussation (motor pathway decussation):** will split the anterior horn of grey substance into 2 longitudinal columns: one from the base of anterior horn initially attached to the rest of grey substance and one from the head of anterior horn and completely separated from the rest of the grey substance
- 2. Decussation of the lemniscus (sensitive pathway decussation):** is situated in the middle third of medulla oblongata and separates the posterior horns in 2 longitudinal columns: one from the head of the posterior horn and one from the base of the posterior horn. Decussation of the lemniscus represents the crossing over of fasciculi gracilis and cuneatus at the level of posterior surface of medulla oblongata and then, posteriorly to cortico-spinal tracts will form a ribbon-like band called medial lemniscus (*lemniscus: lemn= ribbon+ iscus= little*).  
Because of these two decussations, grey substance is fragmented in 4 longitudinal columns disposed on either side of median line.
- 3. Enlargement of central canal of medulla spinalis at the level of posterior surface of medulla oblongata to form the floor of fourth ventricle.** This will determine the movement of central columns: the base of anterior horn will move posteriorly, the base of posterior horn will move posteriorly but laterally to the base of anterior horn, the head of posterior horn will move laterally and will appear on the posterior surface of medulla oblongata and the head of anterior horn will move slightly medial and will remain deep into medulla oblongata, being surrounded by white substance.

4. **Internal arcuate fibers** will pass through white substance columns and will fragment them from superiorly to inferiorly in a series of superimposed nuclei which represent the real origin of cranial nerves.
5. **Quantitative modification of white matter.** Anterior funiculi will have larger dimensions superiorly to the level of pyramidal decussation, posterior funiculi will end at the level of medulla oblongata and lateral funiculi will have smaller dimensions because they do not contain pyramidal fasciculi and spino-cerebellar fasciculi end superiorly to medulla oblongata.
6. **Biotaxis** represent a neuronal characteristic through which neurons with same functions are attracted which explains the forming of nuclei. This process tries to explain the apparition of vegetative nuclei through which internal arcuate fibers do not pass.

Therefore, isolated nuclei will arise and they will be disposed into longitudinal cords, six cords on each side: two motor cords, two visceral cords and two sensitive cords.

1. **From the anterior somatic motor cord derived from the head of the anterior horn** will arise the ambiguous nucleus (real origin of IX, X, XI cranial nerves), motor nucleus of facial nerve (VII) and motor nucleus of trigeminal nerve (V)
  - a. **Ambiguous nucleus.** This nucleus is situated at the level of medulla oblongata and is formed from inferiorly to superiorly by the motor nuclei of accessory cranial nerve (XI), vagus nerve (X) and glossopharyngeal nerve (IX), being the continuation into the medulla oblongata of the dorso-lateral cell group of the anterior column of the medulla spinalis. Ambiguous nucleus consists of large multipolar neurons similar to those of the anterior column of the medulla spinalis and its axons will form the motor component of IX, X, XI nerves. The trajectory of the axons leaving the ambiguous nucleus is firstly towards rhomboid fossa and then curve anteriorly and laterally to join the fibers from the dorsal nucleus. Fibers reach the surface in the retro-olivary sulcus. Activity of the nucleus is controlled by fibers from motor cortex of frontal lobe via cortico-nuclear fasciculus.
  - b. **Motor nucleus of facial nerve (nucleus facialis).** This nucleus is situated at the level of antero-lateral part of inferior third of pons. Motor nucleus of facial nerve innervates mimic muscles. The trajectory of its fibers is extremely tortuous in the substance of the pons. At first, they have a posterior direction until they reach the rhomboid fossa. Here, they are collected into a bundle that cross over the VIth nucleus forming a bend called geniculum of facial nerve (colliculus facialis). Furthermore, it bends again and arches laterally before reaching the surface at the level of supra-olivary fossette, found between the olive and the inferior peduncle of medulla oblongata. The nucleus has connections with motor cortex of frontal lobe via cortico-nuclear fasciculus and with motor nuclei of extrapyramidal system, with functions in reflex activity of face muscles.
  - c. **Motor nucleus of the trigeminal nerve** is also called the masticator nucleus because of its function. This nucleus is a small one situated inferiorly to facial nucleus, along the line of the lateral margin of the fourth ventricle. Axons of masticator nucleus group themselves into a compact



fasciculus which reach the surface of the pons at the limit of anterior surface of the pons and antero-lateral surface of middle cerebellar peduncle. Masticator nucleus activity is controlled by fibers from frontal lobe motor cortex.

As a general rule, each of these nerves is a nerve corresponding to a brachial arch: trigeminal nerve is the nerve of the first brachial arch, facial nerve innervates the second brachial arch, glossopharyngeal innervates third brachial arch and vagus nerve is the nerve of fourth brachial arch. Therefore, these nerves will innervate the muscles derived from the corresponding brachial arch.

2. **From the posterior somatic motor cord derived from the base of the anterior horn will arise** the motor nuclei of III (oculomotor), IV (trochlear), VI (abducens), XII (hypoglossal) cranial nerves
  - a. **Hypoglossal nucleus** is situated in medulla oblongata and innervates the tongue muscles. This nucleus projects onto ventricular floor at the level of medial area of hypoglossal triangle. This nucleus consists of large multipolar neurons similar to those in the anterior column of the medulla spinalis and the axons form the roots of XII cranial nerve. The fibers pass anteriorly between white and gray reticular formation and between inferior olivary nucleus and medial accessory olivary nucleus and reach the bulbar surface at the level of pre-olivary sulcus (antero-lateral sulcus).
  - b. **Abducens nucleus** is situated in the inferior third of pons, close to rhomboid fossa, superiorly to striae medullares and it innervates the lateral rectus muscle. The nucleus of VIth cranial nerve will form eminentia teres which is a rounded structure on the pontine triangle from the roof of fourth ventricle. The abducens nucleus lies laterally to the ascending part of the facial nerve (colliculus facialis). Axons of abducens nucleus reach the brainstem surface at the level of bulbo-pontine sulcus, superiorly to anterior pyramid of medulla oblongata. Abducens nucleus receives motor fibers through cortico-nuclear fasciculus and fibers from superior and inferior quadrigeminal colliculi which ensures optical, ocular and acustico-ocular reflexes. Its association with the nuclei of III, IV, XI and vestibular part of VIII cranial nerves explains the oculocephalogyric and vestibulo-ocular reflexes.
  - c. **Trochlear nucleus** is situated in mesencephalon, inferiorly to oculomotor nucleus, at the level of a plane carried transversely superiorly to the inferior colliculus. Trochlear nerve is the only nerve with the apparent origin at the level of posterior surface of brainstem. It innervates superior oblique muscle and has the same connections as the oculomotor nerve.
  - d. **Oculomotor nucleus** can be found in mesencephalon and innervates superior rectus muscle, inferior rectus muscle, medial rectus muscle, inferior oblique muscle and levator palpebrae superioris muscle. This nucleus consists of a complex of nuclei spread from posterior white commissure to trochlear nucleus, inferiorly to the superior colliculus. Cortical connections are with frontal lobe cortex and visual area of occipital lobe cortex. Other connections are made with vestibular nuclei, acoustic nuclei, reticular formation.

3. **From the visceral motor cord derived from the anterior part of lateral and intermediate zone** will arise the dorsal nucleus of vagus nerve (X), inferior salivatory nucleus (IX), superior salivatory nucleus (VII bis), naso-muco-lacrimal nucleus (V, VII), pupillary nuclei of Edinger Westphall (III), central nucleus of Perlia (III)
  - a. **Dorsal nucleus of vagus nerve (cardiopneumoenteric nucleus)** is situated in medulla oblongata and it is a vital nucleus with a cardiac, respiratory and digestive functions. Preganglionic fibers from the nucleus follow vagus nerve trajectory and have the first synapse in perversal plexus ganglia and intramural plexus ganglia from thorax and abdomen. Therefore, the activity of vagus nerve consists of controlling the motor functions of esophagus, bronchia, stomach and intestines and also it has an inhibitory cardiac action. It stimulates the secretion of gastric, duodenal, intestinal glands and also hepatic and pancreatic secretion. It lowers the blood pressure by vasodilation of periphery.
  - b. **Inferior salivary nucleus** is situated at the level of medulla oblongata and it ensures parotid gland secretion.
  - c. **Superior salivary nucleus** is situated in pons and ensures the submaxillary and sublingual glands secretion.
  - d. **Naso-muco-lacrimal nucleus** is situated in pons, inferiorly to the floor of fourth ventricle, laterally to eminentia teres and medially to acustico-vestibular nuclei complex. It ensures lacrimal and nasal fossas mucosal secretion.
  - e. **Edinger Westphall nucleus** represents the center of pupillary contraction and accommodation. Cranial extremity is larger and it is responsible for the photomotor reflex. Caudal extremity is the convergence reflex and distance accommodation center.
    - i. Afferent fibers of photomotor reflex reach the retina via optic tracts then they reach medial geniculate body without making a synapse. The next station is superior quadrigeminal nuclei and lastly, they reach cranial pole of Edinger Westphal nuclei.
    - ii. Afferent fibers of accommodation reflex consist of IIIrd cranial nerve nuclear complex connection with occipital lobe cortex.
    - iii. Efferent fibers remain the same for both reflexes. Preganglionic fibers follow IIIrd cranial nerve pathway until they reach the orbit, then they reach the branch for inferior oblique muscle. From here they reach the ganglion via motor root of ciliary (ophtalmic) ganglion. They do a synapse with ganglia cells, then postganglionic fibers reach pupillary sphincter via short ciliary nerves. Pupillary sphincter contraction ensures contraction of iris and ciliary muscle contraction ensures lens accommodation.
  - f. **Median nucleus of Perlia** is a single midbrain nucleus having a role in ocular convergence.
4. **From the sensory visceral cord derived from the posterior part of lateral and intermediate zone** will arise the dorsal nucleus of vagus nerve (X). This nucleus is situated in medulla oblongata and receives information from jugular, plexiform ganglia and ganglia of perversal and intramural plexuses. This nucleus ensures interoceptive reception of information from thorax and abdomen and makes possible the interoceptive reflexes through its connections with visceromotor and somato-motor nuclei.

5. **From the anterior somatic sensory cord derived from the base of posterior horn** will arise the sensory nucleus of trigeminal nerve (V). This nucleus is situated in pons and it consists of two roots: one ascending root towards midbrain for proprioceptive sensibility of mastication and mimics muscles and one descending root towards medulla oblongata for protopathic sensibility (pain, temperature and pressure sensations).
6. **From the posterior somatic sensory cord derived from the head of posterior horn** will arise the solitary nucleus (VII bis, IX, X) and acoustic tubercle (VIII).
  - a. **Solitary nucleus** is situated in bulbo-pontine sulcus, corresponding to sensitive and sensory parts of VII bis, IX, X cranial nerves. The superior 2/3ds of the nucleus receive via VII bis and IX gustatory information from lingual mucosa thus the name gustatory nucleus of Nageotte.
  - b. **Acoustic tubercle** is the origin of vestibulocochlear nerve (VIII). This nerve consists of an acoustic branch with origin in cochlear nuclei and a vestibular branch with origin in vestibular nuclei of Schwalbe, Deiters and Bechterew. Vestibular nuclei can be found on the floor of fourth ventricle, at the level of vestibular area. Connections of vestibular nuclei are important for orientation and equilibrium reflexes. Afferent fibers come from vestibular component of VIII cranial nerve and from cerebellum. Efferent fibers reach cerebellum, spinal cord and brainstem. Acoustic nuclei are ending nuclei for the axons of first acoustic neurons from Corti's ganglion. Afferent fibers represent the axons of the first acoustic neurons. Efferent fibers follow pathways in relation to the nucleus of origin.

### **Brainstem nuclei**

Brainstem nuclei have distinctive functions and do not represent cranial nerves origins or terminations. They represent relays on cerebellar and extrapyramidal descending pathways, with the exception of Goll, Burdach and von Monakov nuclei. Brainstem proper nuclei are different from medulla oblongata to pons to midbrain. As the cerebral hemispheres have evolved and have acquired coordination functions, tectal structures remained reflex centers.

#### **1. Nuclei of medulla oblongata**

- a) **Gracilis (Goll's nucleus), cuneatus (Burdach's nucleus) and cuneatus accessories (von Monakov nucleus)** represent the nuclei of posterior column and relay stations of ascending tracts being part of conscious proprioceptive pathway. They are situated in postero-inferior part of medulla oblongata. Cuneatus nucleus is situated laterally to gracilis nucleus, whereas cuneatus accessorius nucleus is situated postero-laterally to cuneatus nucleus. The fibers from this nuclei synapse with nerve fibers (second-order) that decussate and form the medial lemniscus, which is a ribbonlike structure. Efferent fibers of gracilis and cuneatus reach thalamus synapsing there with third-order neurons via medial lemniscus, whereas efferent fibers von Monakov's nucleus connect medulla oblongata to cerebellum via inferior cerebellar peduncles.
- b) **The olivary nuclei and paraolives (n. olivaris inferior, n. olivaris accessories medialis et posterior)** are situated on the lateral surface of medulla oblongata, being also called olivary complex. They represent a relay between cerebellum and spinal cord. The inferior olivary nucleus represent a wavy layer of gray substance and is the largest nucleus from the complex, occupying the olive.

Olivary nuclei are situated on the antero-lateral surface of medulla oblongata and posteriorly and laterally to bulbar pyramids where they form a bulge of 1 cm height. The medial accessory olivary nucleus is situated between the inferior olivary nucleus and the pyramid. The dorsal accessory olivary nucleus is the smallest and lies posteriorly to the inferior olivary nucleus. On cross section they have the shape of a horseshoe with the concavity directed towards posterior, aspect given by the distribution of small neurons with numerous dendritic arborizations. Each olive is flanked on its sides by a discoid structure called paraolive, one lateral and one medial.

Afferent fibers from the olivary nuclei are represented by:

- Talamo-olivary tract (main tegmental tract), but also fasciculi from red nucleus, superior and inferior quadrigeminal colliculi, trigeminal nucleus with the chief function of controlling olivary nuclei
- Dento-olivary and cerebello-olivary fibers which come from cerebellar cortex and dentate nucleus via inferior cerebellar peduncles

Efferent fibers are represented by:

- Olivo-cerebellar fibers represented by the axons of the olivary nuclei decussate with those from the opposite olive in the raphe and reach opposite cerebellar cortex via the opposite inferior cerebellar peduncle
  - Olivo-spinal tract (of Helweg) which descend to cervical medulla spinalis
- Bulbar olives are an important chain in the extrapyramidal circuit, having connections with cerebellum and having the main function of regulating muscle and postural tone.

## 2. Nuclei of pons

- Nuclei of pons** are small oval shape structures situated in the antero-lateral side of pons between white substance. Because of these nuclei and their fibers, the main motor pathway is being fragmented into small fasciculi. Fibers originating from these nuclei cross over on median line and reach cerebellar cortex via middle cerebellar peduncles. Afferent fibers come from cerebral cortex via cortico-pontine tracts (fronto-pontine, temporo-pontine, parieto-pontine and occipito-pontine fasciculi). Efferent fibers group into small transverse fasciculi forming the ponto-cerebellar fasciculus which cross over on median line and reach opposite cerebellar cortex via middle cerebellar peduncles. The arcuate nuclei are nuclei of the pons who have migrated into pyramids of medulla oblongata,
- Superior olivary nucleus** is situated laterally from the nucleus of trapezoid body. Receives cochlear afferent fibers via vestibulocochlear nerve and sends efferent fibers to organ of Corti, having the chief functions of sound localization.
- Nucleus of trapezoid body** is situated in inferior and lateral third of pons. Receives fibers from opposite acoustic nuclei and send fibers to lateral lemniscus.

## 3. Nuclei of midbrain

- Red nucleus (nucleus ruber):** is a large pale pink-colored nucleus due to its vascularization and content of iron. Red nucleus can be found posteriorly to substantia nigra and inferiorly to quadrigeminal plate, in the anterior part of the tegmentum, continued superiorly into the posterior part of the subthalamic region. Nucleus ruber consists of two different parts: one central part situated antero-superior and parvocellular which forms neorubrum and one postero-inferior which

forms paleorubrum. Paleorubrum represent a relay station of muscular tone control via extrapyramidal pathway and neorubrum is on the descending extrapyramidal pathway with cortical origin. On cross section at the level of superior colliculus the appearance is the one of a round mass crossed by the fibers of the oculomotor nerve.

Afferent fibers of red nucleus are represented by:

- Cortico-rubric fibers from areas 4 and 6 from frontal lobe and areas 3 and 5 of parietal lobe, for parvocellular part
- Strio-rubric fibers from lenticular nucleus either directly either having a relay station in substantia nigra
- Talamo-rubric fibers
- Reticulo-rubric fibers from reticular nuclei from midbrain and pons with the main role of controlling the influxes from red nucleus
- Tecto-rubric fibers which connect quadrigeminal colliculi with red nucleus
- Dento-rubric fibers from dentate nucleus; as these fibers reach midbrain via superior cerebellar peduncle, they cross over opposite ones and stop at the level of parvocellular but also magnocellular of red nucleus
- Vestibulo-rubric fibers from vestibular nuclei

Efferent fibers are represented by:

- Rubro-tectal and rubro-spinal fibers from paleorubrum which reach quadrigeminal colliculi and motor neurons from spinal cord
- Rubro-olivary, rubro-reticular, rubro-striate, rubro-thalamic fibers from neorubrum which reach bulbar olive, bulbar reticular formation, striate nuclei, antero-lateral nuclei of thalamus

Red nucleus has important functions regarding coordination and distribution of muscular tone (fine motor control) being under cortical control and extrapyramidal centers control.

**b) Substantia nigra (substantia nigra Sommering, locus niger)** represents a layer of grey substance comprising multipolar neurons intensely pigmented due to its melanin content, being the largest nucleus of midbrain tegmentum differentiated from reticular formation. Substantia nigra is situated in the antero-lateral part of midbrain, spread on the entire height of midbrain, from the oculomotor sulcus to the lateral sulcus. It has a connection with the III cranial nerve, its fibers traversing the medial part of substantia nigra, where the substantia is also thicker. On cross section substantia nigra has a semilunar aspect with the concavity directed posteriorly. The main function consists of regulating automate movements associated to voluntary movements. Substantia nigra divides the midbrain into 2 parts: the peduncle of the midbrain and the midbrain tegmentum which extends to quadrigeminal plate.

Afferent fibers are represented by:

- Strio-nigric fibers from caudate nucleus and lenticular nucleus
- Cortico-nigric fibers from areas 4,6,8 of frontal lobe

Efferent fibers are represented by:

- Nigro-bulbar fibers
- Nigro-spinal fibers

Substantia nigra is considered a part of extrapyramidal system, with the main function of regulating autonomic movements associated with voluntary movements by suppressing unwanted muscle contractions. Substantia nigra is affected in Parkinson disease, where uncontrollable muscle tremors can be seen.

- c) Preinterstitial nucleus** is a small nucleus situated at the level of superior extremity of midbrain. Afferent fibers come from substantia nigra, globus pallidus and vestibular nuclei. Efferent fibers reach reticular formation, thalamus, subthalamic nuclei and spinal cord. Its chief function is represented by the coordination of extrapyramidal motor activity.
- d) Interstitial nucleus of Cajal (nucleus interstitialis)** represent a cluster of neurons situated superiorly to the oculomotor nerve nucleus and inferiorly to the opening of cerebral aqueduct in the third ventricle. Its chief function is the coordination of pupillary reflexes and oculocephalogyric movements. Afferent fibers come from visual cortex, retina and superior colliculi. Efferent fibers reach Edinger Westphal nucleus via medial longitudinal fasciculus.
- e) Interpeduncular nucleus of Gudden (nucleus interpeduncularis)** is situated anteriorly to substantia nigra, in between the cerebral peduncles, in the posterior perforated substance; it represents a relay station between brainstem and limbic system. Interpeduncular nucleus has connections with epithalamus and its efferent fibers reach midbrain tegmentum via central tegmental tract.
- f) Superior quadrigeminal colliculi (anterior)** form together with inferior colliculi the roof of midbrain also called tectum. Superior colliculi consist of layers of white substance alternating with 4 layers of grey substance, the covering layer (stratum zonale) being formed by white fibers mainly derived from the optic tract. The next inner layer consists of stratum cinereum, a grey substance structure comprising numerous small multipolar neurons in a network of nerve fibers. The next layer is stratum opticum with large multipolar neurons. Stratum lemnisci is deeper to stratum opticum and contains fibers from the lemniscus and from the cells of the superior layer. The inner most strata are the grey-white layers. The 3 striae medullaris (external, middle, internal) represent the real midbrain cortex.

Afferent fibers are represented by:

- Cortico-tectal/ occipito-tectal fibers from occipital cortex with the function of controlling reflex movements of the eyes, accommodation and convergence reflexes, object projection onto macula.
- Optic fibers represented by retina pupillary fibers which arrive via optic tracts and anterior conjunctival brachium with a role in forming the images onto macula reflexes.
- Spino-tectal fibers
- Fibers from vestibular nuclei and sensory nucleus of trigeminal nerve

Efferent fibers are represented by:

- Ascending fibers towards habenular ganglion, thalamus, occipital lobe of the cerebrum
- Descending fibers towards spinal cord represented by tecto-spinal fasciculus which cross over at the level of Meynert decussation (fountain decussation of Meynert)

- Descending fibers towards brainstem: tecto-bulbar, tecto-pontine, tecto-midbrain, tecto-reticular fibers

Because of these efferent fibers, superior quadrigeminal colliculi coordinate eye and head movements and reflex movements of limbs and trunk which have an optic stimulus. Quadrigeminal colliculi have a role in vertical synergic movements of rising and lowering the eyeballs.

**g) Inferior quadrigeminal colliculus (posterior)** has a simpler structure: at the surface presents a white substance layer derived from the lateral lemniscus. The deep layer consists of grey substance which represents the grey nucleus of inferior quadrigeminal colliculus.

Afferent fibers are represented by:

- Tectal contingent of lateral lemniscus

Efferent fibers are represented by:

- Tecto-spinal, tecto-bulbar, tecto-pontine descending fibers which have a role in reflex movements caused by an acoustic stimulus (turning the head and the eyes towards the sound direction)
- Tecto-geniculate fibers which reach medial geniculate body through posterior conjunctival brachium
- Tecto-tectal fibers which connect the superior and inferior colliculi and also inferior colliculi between them

Inferior quadrigeminal colliculus represents an acoustic reflex center, without interfering with acoustic perception.

#### **4. Reticular formation (formation reticularis)**

Reticular formation represents a loosely organized network of fibers and nuclei present at all brainstem levels and with connections with many areas of cerebrum. The reticular formation surpasses the brainstem superiorly going into diencephalon and inferiorly going towards spinal cord.

Nervous fibers of reticular formation cross over one another mainly on the median line of medulla oblongata. Usually the fibers are short, connecting closely to different neuronal clusters. This clusters will form more than one hundred small nuclei present at each level of the brainstem.

Reticular formation has an essential role in transmitting the nervous impulses, but it also has functions in: somatic motor control (maintaining tone, balance, posture by integrating visual, auditory and vestibular stimuli), cardiovascular control (through its cardiac, vasomotor and respiratory centers), pain modulation (through descending analgesic fibers), sleep and consciousness (reticular formation injury results in irreversible coma) and habituation. Because the large number of neurons that it contains, the conducting speed in reticular formation is very low.

There are 4 cords of nuclei present at the level of reticular formation of midbrain: dorsal, lateral, central and median.

- **Dorsal nuclei** are small nuclei found below the posterior surface of medulla oblongata and pons. Functionally, they have a role in regulating vegetative mechanisms regarding the respiration, deglutition, salivation and vomiting. At the level of medulla the respiratory center can be found, which is connected with the apneustic pontine center. Pneumotaxic pontine center has an inhibitory action on apneustic center. Also, at the level of the medulla the inhibiting cardiac center and

vasoconstricting and vasodilating centers can be found. These nuclei are connected with spinal cord, hypothalamus and cerebral cortex.

- **Median nuclei** are also called nuclei of raphe and are situated around aqueduct of Sylvius and they are formed by bulbo-pontino-mesencephalic activating reticular formation. These nuclei receive afferent fibers from all sensory pathways that cross the midbrain. Efferent fibers go to cerebral cortex either directly either through thalamic or hypothalamic relay stations.
- **Central nuclei** are situated on the sides of median nuclei. Their afferent fibers start from cortex and cross striatum. In these nuclei there are two types of reticular formation: one mesencephalo-pontine activating and one and bulbar descending inhibiting. From the activating one posterior reticulo-spinal tract leaves whereas from the inhibiting one the anterior reticulospinal tract leaves.
- **Lateral nuclei** are best represented at the level of medulla and pons. Lateral nucleus of medulla has connections with the cerebellum and it represents a relay station between medulla oblongata and cerebellum. Lateral nucleus of pons is a relay station of central acoustic pathway.

## 5. White substance

White substance consists of myelinated fibers organized into:

- Arcuate fibers of medulla oblongata
- Transverse fibers of the pons
- Decussations of brainstem
- Ascending pathways (lemniscus)
- Descending pathways (cortical and extrapyramidal)
- Association pathways
- Afferent cerebellar pathways

**Arcuate fibers of medulla oblongata** are classified into external and internal arcuate fibers. External arcuate fibers are direct fibers situated posteriorly and crossed fibers situated anteriorly. The posterior external arcuate fibers have the origin at the level of Goll and Burdach's nuclei and they reach dentate nucleus and cerebellar cortex through inferior cerebellar peduncle of the same side. The anterior external arcuate fibers arise also from gracile and cuneate nuclei, decussate in the middle line, reach the surface and then arch backward over the pyramid, enclosing the nucleus arcuatus, then over the olive and lateral district of the medulla oblongata and enter the inferior peduncle. The anterior external arcuate fibers connect the cerebellum with the gracile and cuneate nuclei of the opposite side, hence the name of crossed fibers. Internal arcuate fibers are crossed fibers from the gracilis and cuneatus nuclei of the opposite side. They connect bulbar olives with dentate nucleus and cerebellar cortex via inferior cerebellar peduncle, forming the larger part of the inferior cerebellar peduncle

**Transverse fibers of the pons** can be classified into superficial and deep fibers and fibers of trapezoid body. Superficial transverse fibers start from anterior surface of the pons and reach inferior cerebellar peduncles. Deep transverse fibers from the basilar part of the pons are a part of middle cerebellar peduncles and ponto-cerebellar pathways.

**Decussations of brainstem** are represented by pyramidal decussation and decussation of lemniscus. Pyramidal decussation (*of Mistichelli*) is formed by the lateral cortico-spinal tracts in the inferior third of medulla oblongata, at the level of anterior median fissure. Decussation of lemniscus (*of Spitzka*) represent the



sensitive decussation formed by internal arcuate fibers coming from gracilis and cuneatus nuclei and spinal nucleus of trigeminal nerve, situated superiorly and posteriorly to pyramidal decussation. These fibers form medial lemniscus (*Reil's band*). Anterior tegmental decussation (*of Forel*) consists of crossed fibers of rubro-spinal tract and it is situated in the inferior part of midbrain tegmentum. Posterior tegmental decussation (*of Meynert*) consists of tecto-spinal and tecto-bulbar tracts and can be found at the level of superior colliculi. Trochlear's nerve decussation is situated at the level of superior medullary velum. Cortico-bulbar and cortico-tectal decussation, trapezoid body decussation and decussation of cerebellar afferent and efferent fibers (olivo-cerebellar, ponto-cerebellar and cerebello-vestibular) are other important decussations.

**Ascending pathways** start from spinal cord or brainstem and are represented by medial and lateral lemniscus, trigeminal lemniscus and spinal lemniscus. Medial lemniscus has the origin in gracilis and cuneatus nuclei through internal arcuate fibers which decussate and finally reaches thalamus. Lateral lemniscus is formed at the level of trapezoid body being continuous with the axons of the neurons of accessory acoustic nucleus. Spinal lemniscus represents the spinothalamic tracts and it is found laterally to medial lemniscus. Trigeminal lemniscus with the origin in sensory trigeminal nuclei unite its fibers with the ones of medial lemniscus.

**Descending pathways** are pyramidal pathways starting from cortex or cortical or subcortical extrapyramidal pathways.

<b>CORTICAL DESCENDING PATHWAY</b>	<b>EXTRAPYRAMIDAL DESCENDING PATHWAY</b>
<b>Cortico-spinal tract</b>	<b>Cortico-ponto-cerebellar pathway</b>
<b>Cortico-bulbar tract</b>	<b>Tecto-spinal tract</b>
<b>Cortico-pontine tract</b>	<b>Nigro-bulbo-spinal tract</b>
<b>Cortico-rubral tract</b>	<b>Rubro-spinal tract</b>
<b>Cortico-tectal tract</b>	<b>Vestibulo-spinal tract</b>
	<b>Olivo-spinal tract</b>
	<b>Reticulo-spinal tract</b>

**Association pathways** are grouped into a central tegmental tract and a medial and dorsal longitudinal fasciculi. Central tegmental tract is also called thalamo-olivary tract and it consists of fibers coming from thalamus, hypothalamus, quadrigeminal colliculi and red nucleus which end at the level of olives. Medial longitudinal fasciculus is situated between diencephalon and spinal cord and it has the origin in interstitial nucleus of Cajal and posterior commissural nucleus, consisting of direct and crossed fibers with a complex structure: ascending, descending, internuclear, vestibular, extrapyramidal fibers. Its chief function consists of coordination of eyes and head and neck movements in stimulation of vestibulocochlear nerve. Dorsal longitudinal fasciculus is situated posteriorly to medial longitudinal fasciculus and consists of ascending and descending fibers with the chief function of connecting the hypothalamus with cranial nerves autonomic nuclei.

**Afferent cerebellar pathways** are represented by posterior and anterior spino-cerebellar tract, olivo-cerebellar tract, vestibulo-cerebellar tract, cuneo-cerebellar tract, ponto-cerebellar tract and arcuate-cerebellar tract.

## Vascularization

The arteries belong to the vertebral system. Vertebral artery connects with the opposite vertebral artery at the level of anterior surface of pons forming the basilar artery which can be found in the basilar sulcus. At the level of superior border of pons the 2 posterior cerebral arteries arise, which communicate with the carotid system via posterior communicating arteries. The basilar artery has the following branches: antero-medial, lateral and posterior.

The medulla is supplied by the two vertebral arteries. basilar artery, anterior and posterior spinal arteries. and anterior and posterior inferior cerebellar arteries.

The pons is supplied by the pontine arteries that arise from the basilar artery and anterior inferior cerebellar artery.

The midbrain is supplied by direct branches from basilar artery and posterior cerebral and superior cerebellar arteries and branches of posterior communicating and anterior choroidal arteries.

To summarize, 3 large arterial territories can be identified with corresponding vascular syndromes:

1. **Anteromedial territory of brainstem** consists of:
  - a. Medial part of motor pathways mainly the geniculate fasciculus (only at the level of midbrain) and corticospinal tract (especially the fibers for spinal cord)
  - b. Medial part of sensory pathway (tactile and deep sensibility)
  - c. Motor nuclei of cranial nerves which extend the base of anterior horn of spinal cord (III, IV, VI, XII)
2. **Lateral territory of brainstem** consists of:
  - a. Lateral part of sensory pathways (pain and thermal sensibility)
  - b. Motor nuclei of cranial nerves which extend the head of anterior horn

Between anterior and lateral territories there is a less vascularized zone corresponding to lateral part of sensory pathways.

3. **Posterior territory of brainstem** (constant only at the level of midbrain) consists of:
  - a. Tectal region with its annexes in midbrain
  - b. Gracilis, cuneatus and vestibular nuclei in medulla oblongata.

Veins of the pons and medulla oblongata form superficial plexuses which drain into adjacent sinuses and freely communicate with longitudinal veins of spinal cord. Midbrain veins drain into basal vein.

## 4. The diencephalon (*Diencephalon*)

The diencephalon is a part of prosencephalon which develops from the primary cerebral vesicle. The diencephalon is formed by the following components:

- Thalamus;
- Metathalamus;
- Subthalamus;
- Epithalamus;
- Hypothalamus;

### Thalamus (*Thalamus*)

#### **External morphology (*Morphologia externa*)**

Thalamus represents an ovoid nuclear mass, with a 4 cm length, that borders the third ventricle. Thalamus has an oblique disposition; its anterior pole being oriented towards median line forming the posterior border of interventricular foramen. Its narrow anterior part forms the anterior thalamic tubercle (*Tuberculum anterius thalami*) and its larger posterior pole represents the pulvinar (*Pulvinar thalami*). External surface of thalamus is covered by a thin layer of white substance called stratum zonale, which extends laterally to the reflection line of thalamic taenia (*Taenia thalami*), forming the roof of third ventricle. The lateral border of the superior surface is represented by stria medullaris (*Stria medullaris thalami*). Laterally, a thin layer of white substance called the lateral medullary lamina (*Lamina medullaris lateralis*) separates the body of thalamus from the reticular nucleus. The medial surface of thalamus forms the dorso-superior part of the lateral wall of third ventricle, being connected with the medial surface of thalamus from the opposite side by the interthalamic adhesion (*Adhesio interthalamica*), which is situated posteriorly to the interventricular foramen.

#### **Internal morphology (*Morphologia interna*)**

Thalamus is mainly formed by grey substance (*Substantia grisea thalami*), covered superiorly and laterally by thin layers of white substance— stratum zonale, respectively lateral medullary lamina. The interior of thalamus is incompletely divided by the white substance disposed in a Y shape- medial medullary lamina (*Lamina medullaris medialis*).

The nuclei of thalamus are divided into anterior, dorsal, intralaminar, medial, median, posterior and ventral nuclei.

**The anterior nuclei (*Nuclei anteriores thalami*)** are situated between the structures of medial medullary lamina and are represented by:

- Antero-dorsal nucleus (*Nucleus anterodorsalis*);
- Antero-medial nucleus (*Nucleus anteromedialis*);
- Antero-ventral nucleus (*Nucleus anteroventralis*);

Afferent fibers of the anterior nuclei:

The mammillo-thalamic fasciculus (*Fasciculus mamillothalamicus*). Mammillary nuclei receive fibers from the hippocampal formation via fornix. Medial mammillary nuclei send impulses to antero-ventral and antero-medial nuclei on the same side and lateral mammillary nuclei send impulses to antero-dorsal nucleus bilaterally.

Efferent fibers of the anterior nuclei:

The anterior nuclei project onto medial surface of cerebral hemispheres, including anterior limbic zone, corpus callosum, cingulate gyrus and parahippocampal gyrus.

### **Dorsal nuclei (*Nuclei dorsales thalami*)**

There are three dorsal nuclei:

- The lateral dorsal nucleus (*Nucleus dorsalis lateralis*): is the most anterior nucleus from this group, its anterior pole being in contact with medial medullary lamina. This nucleus receives subcortical afferent fibers from pretectum and superior colliculi. It is connected with cingulum and posterior parahippocampal cortex;
- The posterior lateral nucleus (*Nucleus lateralis posterior*): receives subcortical afferent fibers from superior colliculi. It is connected with the parietal lobe (5th area of Brodmann) and with medial parahippocampal cortex;
- Pulvinar nuclei: (*Nuclei pulvinare*):
  - o Anterior pulvinar nucleus (*Nucleus pulvinares anterior*);
  - o Inferior pulvinar nucleus (*Nucleus pulvinares inferior*);
  - o Lateral pulvinar nucleus (*Nucleus pulvinares lateralis*);
  - o Medial pulvinar nucleus (*Nucleus pulvinares medialis*).

Pulvinar nuclei have uncertain afferent fibers, probably coming from the superior colliculi. Efferent fibers reach temporo-parietal cortical association areas, visual areas from occipital lobe, striate and extra-striate cortex of occipital lobe, inferior parietal cortex, prefrontal cortex and orbitofrontal cortex.

### **The intralaminar nuclei (*Nuclei intralaminares thalami*)**

These nuclei are grouped inside of medial medullary lamina in five nuclei:

- Lateral central nucleus (*Nucleus centralis lateralis*);
- Medial central nucleus (*Nucleus centralis medialis*);
- Centromedian nucleus (*Nucleus centromedianus*);
- Paracentral nucleus (*Nucleus paracentralis*);
- Parafascicular nucleus (*Nucleus parafascicularis*);

Their main role is mediating cortical activity of reticular formation and integrating sensitive and motor activity.

### **The medial nuclei (*Nuclei mediales thalami*)**

The medial nuclei are represented by medio-dorsal nucleus and medio-ventral nucleus.

- The mediodorsal nucleus (*Nucleus mediodorsalis*) is situated between medioventral nucleus medially and medial medullary lamina laterally. This nucleus has 3 parts:
  - Medial magnocellular part (*Pars magnocellularis medialis*), which receives olfactory afferent fibers and fibers from the amygdala. This part projects onto anterior and medial prefrontal cortex, mainly at the level of posterior lateral and posterior central olfactory zone of the orbital surface of frontal lobe;
  - Lateral parvocellular part (*Pars parvocellularis lateralis*) receives afferent fibers from globus pallidus and is connected with dorso-lateral and dorso-medial prefrontal cortex and cingulate gyrus. Injury of lateral parvocellular part produces anxiety, tension, aggression, obsessive thoughts, amnesia and confusion;
  - Paralamina part (*Pars paralamina*) is connected with parietal cortex;
- Medioventral nucleus (*Nucleus medioventralis*) is connected with medial prefrontal cortex and cingulate gyrus.

### **The median nuclei (*Nuclei mediani thalami*)**

There are four median nuclei:

- Paratenial nucleus (*Nucleus paratenialis*);
- Paraventricular nuclei (*Nuclei paraventricularis thalami*):
  - Anterior paraventricular nucleus (*Nucleus paraventricularis anterior*);
  - Posterior paraventricular nucleus (*Nucleus paraventricularis posterior*);
- Reuniens nucleus (*Nucleus reuniens*);
- Rhomboid commissural nucleus (*Nucleus commissuralis rhomboidalis*).

Afferent fibers of median nuclei come from:

- hypothalamus;
- spinal cord via spinothalamic tract;
- reticular formation of medulla oblongata and pons;
- locus caeruleus.

Efferent fibers of median nuclei project onto:

- hippocampal formation;
- amygdala;
- accumbens nucleus;
- orbito-frontal cortex.

### **Posterior nuclei: (*Nuclei posteriores thalami*)**

There are three posterior nuclei:

- Nucleus limitans (*Nucleus limitans*);
- Posterior nucleus (*Nucleus posterior*);
- Supragenulate nucleus (*Nucleus supragenulates*).

These nuclei are connected with prefrontal cortex and parahippocampal gyrus.

## **Ventral nuclei (*Nuclei ventrales thalami*)**

- Basal ventral nuclei (*Nuclei ventrobasales*):
  - o Posterolateral ventral nucleus (*Nucleus ventrales posterolaterales*);
  - o Posteromedial ventral nucleus (*Nucleus ventrales posteromediales*);
- Medial ventral nuclei (*Nuclei ventrales mediales*):
  - o Medial ventral basal nucleus (*Nucleus basalis ventralis medialis*);
  - o Main medial ventral nucleus (*Nucleus principalis ventralis medialis*);
  - o Submedial nucleus (*Nucleus submedialis*);
- Inferior posterior ventral nucleus (*Nucleus ventrales posterior inferior*);
- Lateral ventral nuclei (*Nuclei ventrales lateralis*):
  - o Ventrolateral anterior nucleus (*Nucleus anterior ventrolateralis*);
  - o Ventrolateral posterior nucleus (*Nucleus posterior ventrolateralis*);
- Anterior ventral nucleus (*Nucleus ventrales anterior*):
  - o magnocellular part (*Pars magnocellularis*);
  - o main part (*Pars principalis*);
- Intermediate ventral nucleus (*Nucleus ventralis intermedius*);
- Posterolateral ventral nucleus (*Nucleus ventrali posterolateralis*);
- Internal posterior ventral nucleus (*Nucleus ventralis posterior internus*);
- parvocellular ventro-posterior nucleus (*Nucleus ventroposterior parvocellularis*);

Afferent fibers of ventral nuclei originate from:

- cerebellar nuclei;
- internal segment of globus pallidus;
- spinal cord via spinothalamic tract;
- vestibular nuclei;
- substantia nigra;
- somatosensitive fibers, which at the level of lateral part receive the medial lemniscus (*Lemniscus medialis*) and spinothalamic pathway;
- trigeminal nucleus via trigemino-thalamic pathway

Efferent fibers of ventral nuclei reach:

- striate zone;
- anterior parietal cortex;
- premotor area;
- primary motor cortex;
- frontal lobe (uncertain);
- primary somatic sensitive cortex of postcentral gyrus and secondary somato-sensitive area from parietal operculum.

White substance of thalamus (*Substantia alba thalami*)

White substance of thalamus form cortico-thalamic tracts and thalamo-cortical tract which are grouped into radiations;

- Anterior radiation (*Radiatio anterior thalami*);
- Central radiation (*Radiatio centralis thalami*);
- Inferior radiation (*Radiatio inferior thalami*);
- Posterior radiation (*Radiatio posterior thalami*);

Cortical projection of acoustic pathway forms the acoustic radiation (*Radiatio acustica*) and cortical projection of optic pathway forms the optic radiation (*Radiatio optica*) of Gratiolet.

The fibers coming from the colliculi from:

- The superior colliculi (*Brachium colliculi superioris*;)
- The inferior colliculi (*Brachium colliculi inferioris*).

Intra-thalamic connections are made through intra-thalamic fibers (*Fibrae intrathalamicae*). Some fibers are disposed around third ventricle and are named periventricular fibers (*Fibrae periventriculares*). The thalamus receives afferent fibers from all sensitive and sensorial pathways with the exception of olfactory pathway, here being situated the third neuron of the pathway.

The lenticular fasciculus (*Fasciculus lenticularis*) represents the dorsal division of palidofugal fibers which cross the internal capsule.

Lenticular ansa (*Ansa lenticularis*) has a complex origin and arises from both parts of globus pallidus as well as from putamen.

The thalamic fasciculus (*Fasciculus thalamicus*) is a complex of fibers from the pre-rubric field which crosses zona incerta and reach ventral thalamic nuclei. This fasciculus contains fibers from the lenticular fasciculus, lenticular ansa, dento-thalamic fibers, rubro-thalamic fibers and thalamo-striated fibers. It ends at the level of H1 fields of Forel.

The subthalamic fasciculus (*Fasciculus subthalamicus*) represents a double pathway, both efferent and afferent, which cross the internal capsule to connect subthalamic nuclei with globus pallidus and putamen.

Thalamic connections:

<b>Afferent fibers</b>	<b>Efferent fibers</b>
Anterior spinothalamic tract Lateral spinothalamic tract The medial lemniscus Spinal lemniscus ( <i>Lemniscus spinalis</i> ) Trigeminal lemniscus ( <i>Lemniscus trigeminalis</i> ) - anterior trigeminothalamic tract (anterior trigeminothalamic tract) - posterior trigeminothalamic tract (posterior trigeminothalamic tract) Brachium colliculi superioris Brachium colliculi inferioris Lateral lemniscus ( <i>Lemniscus lateralis</i> ) The mamilo-thalamic fasciculus Corticothalamic fibers The dento-rubro-thalamic tract The thalamic fasciculus	Cingulate gyrus The motor cortex The premotor cortex The prefrontal cortex The sensitive cortex The association cortex The limbic structures of the temporal lobe Parahippocampal gyrus

## Metathalamus (Methalamus)

### External morphology

The metathalamus consists of the lateral geniculate body (*Corpus geniculatum laterale*) and the medial geniculate body (*Corpus geniculatum mediale*). The medial geniculate body is situated inferiorly to the posterior pole of thalamus and has an emerging part through which it connects to inferior colliculi brachium. Lateral geniculate body has an ovoid shape and it is situated laterally and posteriorly to the medial geniculate body.

### Internal morphology

The lateral geniculate body presents the following nuclei:

- Dorsal nucleus of the lateral geniculate body (*Nucleus dorsalis corporis geniculati lateralis*) which has three layers:
  - o coniocellular layer (*Stratum koniocellulare*);
  - o magnocellular layer (*Stratum magnocellulare*);
  - o parvocellular layer (*Stratum parvocellulare*);
- Ventral nucleus of lateral geniculate body (*Nucleus ventralis corporis geniculati lateralis*).

Afferent fibers of the lateral geniculate body come from optic pathway (here reaching most of the retina impulses) and from the cortex. Efferent fibers reach the visual cortex and extra-striate areas from occipital lobe.

The medial geniculate body has the following nuclei:

- Ventral nucleus (*Nucleus ventralis*);
- Dorsal nucleus (*Nucleus dorsalis*);
- Magnocellular medial nucleus (*Nucleus medialis magnocellularis*).

Afferent fibers of the medial geniculate body come from the auditory system. Efferent fibers reach the auditory cortex.

## Subthalamus (*Subthalamus*) or ventral thalamus

Subthalamus consists of reticular nucleus, zona incerta, Forel fields and pregeniculate nucleus. Subthalamic nucleus (*Nucleus subthalamicus*) is considered part of the basal nuclei because of its connections.

The subthalamic tracts are:

- Medial, spinal, trigeminal and solitario-thalamic lemnisci which reach the thalamic nuclei;
- Contralateral dento-thalamic tract, accompanied ipsilaterally by rubro-thalamic fibers;
- Fasciculus retroflexus;
- Fasciculi from the pre-rubral fields (H Forel fields);
- Continuation of the lenticular fasciculus (in the H2 Forel fields);
- Thalamic fasciculus (H1 Forel fields).



### **Reticular nucleus (*Nucleus reticularis thalami*)**

The reticular nucleus is considered a thalamic nucleus by Nomina Anatomica. It has the shape of a slide which surrounds the lateral border of thalamus and it is separated from it by the lateral medullary lamina. Anteriorly, the reticular nucleus surrounds the rostral pole of thalamus, being situated between it and the prethalamic nuclei. The reticular nucleus is crossed over by fibers passing from thalamus to cortex and hence the reticular aspect. Afferent fibers come from all the cortico-thalamic, thalamo-cortical, thalamo-striate and palido-striate pathways that cross over it. The reticular nucleus also receives afferent fibers from cuneiform nucleus. Efferent fibers reach thalamus.

### **Pregeniculate nucleus (*Nucleus pregeniculatus*)**

Nomina Anatomica considers this nucleus as a part of metathalamus.

Afferent fibers originate from retina, visual cortex, superior colliculi, cerebellum, vestibular nuclei and locus caeruleus (uncertain).

Efferent fibers are destined for superior colliculi, pretectal nuclei, pontine nuclei and hypothalamus, but also for pulvinar, dorsal nucleus of lateral geniculate body and thalamic intralaminar nuclei. Pregeniculate nucleus is supposed to have an important role in visual sensitivity and motor ocular processes.

### **Zona incerta and Forel fields**

Between the ventral part of lateral medullary lamina and cerebral peduncles a group of small cells called Zona incerta (*Zona incerta*) can be found. Medially there is a group of cells contained in a fibrous tissue which is called H fields of Forel. Some of the cells aggregate forming the nucleus of medial field (*Nucleus campi medialis H*)

Dorsally to zona incerta, H<sub>1</sub> fields of Forel can be found. These also present the nucleus of dorsal field (*Nucleus campi dorsalis H<sub>1</sub>*). Ventrally, between zona incerta and subthalamic nucleus H<sub>2</sub> fields of Forel can be found, which present the nucleus of ventral field (*Nucleus campi ventralis H<sub>2</sub>*). These three nuclei represent the nuclei of perizonal fields (*Nuclei campi perizonalis H, H<sub>1</sub>, H<sub>2</sub>*).

Zona incerta receives afferent fibers from sensitive and motor cortex, pregeniculate nucleus, cerebellar nuclei, trigeminal nuclear complex and spinal cord. Efferent fibers reach spinal cord and pretectal area. The function of zona incerta remains unknown

The nuclei from the perizonal fields receive afferent fibers from the internal segment of globus pallidus, spinal cord and reticulate formation. Efferent fibers reach spinal cord. Function of these nuclei is yet to be established.

### **Epithalamus (*Ephithalamus*)**

#### ***External morphology***

Epithalamus consists of: habenula (*Habenula*), stria medullaris of thalamus (Nomina Anatomica includes stria medularis in thalamus), posterior/ epithalamic commissure

(*Commissura posterior* *Commissura epithalamica*), pineal gland (*Glanda pinealis*) and pretectal area (*Area pretectala*). The trigone of habenula (*Trigonum habenulare*) is a small triangular– shaped depression situated anteriorly to superior colliculi and medially to pulvinar and it is separated from pulvinar by the habenular sulcus. (*Sulcus habenulare*).

### ***Internal morphology***

#### **Habenular nuclei**

There are two habenular nuclei:

- medial habenular nucleus (*Nucleus habenularis medialis*);
- lateral habenular nucleus (*Nucleus habenularis lateralis*).

These nuclei are situated posteriorly to dorso-medial thalamic angle. From the ventral border of the nuclei a thin band of white matter called the habenulo-interpeduncular tract or retroflexus fasciculus (*Tractus habenulointerpeduncularis Fasciculus retroflexus*) arises. Laterally, these nuclei are bordered by a lamina in which the retroflexus fasciculus enters. Posteriorly, the habenular nuclei are bordered by the habenular commissure. (*Commissura habenularum*).

Afferent fibers of habenular nuclei cross thalamic stria medullaris of thalamus and come from:

- prepiriform cortex (bilaterally);
- basal nucleus of Maynert;
- hypothalamus;
- pars compacta of substantia nigra;
- tegmental lateral dorsal nucleus.

Most of the afferent fibers reach lateral habenular nucleus, whereas afferent fibers from septofimbrial nucleus reach medial habenular nucleus.

Efferent fibers from habenular nuclei reach:

- interpeduncular nucleus;
- nucleus of the raphe;
- mesencephalic reticular formation;
- ventral tegmental zone;
- hypothalamus.

Stria medullaris cross over thalamus supero-medially and contains fibers for ipsilateral habenular nuclei. Other fibers cross over at the level of habenular commissure in order to reach contralateral habenular nuclei. The main habenular tract reach the interpeduncular nucleus, mediodorsal thalamic nucleus, tectum and reticular formation, the best represented fasciculus being the fasciculus retroflexus.

### **Posterior (epithalamic) commissure**

Posterior commissure is a fiber complex that cross over inside posterior pineal lamina. Posterior commissure is associated with interstitial nucleus of posterior commissure, dorsal nucleus of posterior commissure (Darkschewitz) and interstitial nucleus (Cajal). Fibers coming from these nuclei cross over at the level of posterior commissure. Fibers from dorsal thalamic nuclei, pretectal nuclei, superior colliculi, connections between tectal nuclei and habenular nucleus are also part of posterior commissure. The destination of these fibers is yet to be established.

### **Pretectal area (*Area pretectalis*)**

Pretectal area is situated at the junction of mesencephalon with diencephalon and extends from a dorso-lateral position at the level of posterior commissure towards superior colliculi. At this level pretectal area is partially continuous with the posterior commissure.

Pretectal area contains the following pretectal nuclei (*Nuclei pretectales*):

- anterior pretectal nucleus (*Nucleus pretectalis anterior*);
- optic tract nucleus (*Nucleus tractus optici*);
- olivary pretectal nucleus: (*Nucleus pretectalis olivaris*);
- posterior pretectal nucleus (*Nucleus pretectalis posterior*).

Pretectal area receives afferent fibers from visual cortex via superior quadrigeminal brachium, lateral root of optic tract and superior colliculi. Efferent fibers reach both oculomotor nuclei, pulvinar and deep lamina of superior colliculi.

### **Pineal gland (*Glanda pinealis*)**

Is situated between superior colliculi on median line, and is tied to habenula through pineal pedicle. The pineal gland consists of pineal cells and glial cells and has important connections with hypothalamus. Its secretion controls the cyclic functions dependent of light-darkness.

## 5. Cerebellum

Cerebellum or the little brain is situated in the posterior cranial fossa, posteriorly to medulla oblongata and pons. Between these structures can be found the fourth ventricle. Cerebellum weighs 150 grams and it has a spherical shape with the transverse axis (8-12 cm) longer than the vertical axis (6-7 cm) and the anterior-posterior axis (4-5 cm).

The surface of cerebellum is called cerebellar cortex and it is formed of grey substance of 1 mm thickness with a trilaminar structure. White substance can be found inside the cerebellum and it forms the cerebellar medullary body (corpus medullare cerebelli). Cerebellar nuclei are grey substance structures found around the fourth ventricle, embedded in the white substance.

Cerebellum consists of a median narrow structure called the vermis (Vermis cerebelli) and two cerebellar hemispheres (Hemispherium cerebelli), situated on the sides of the vermis. The cerebellar hemispheres are separated from the vermis through the paramedian sulcus. Posteriorly, the two cerebellar hemispheres are separated through the posterior cerebellar fissure which contains Falx cerebelli. Inferiorly, the cerebellum has relations with the internal surface of squama of occipital bone and anteriorly and laterally with the posterior surface of petrous part of the temporal bone. The cerebellum is covered by tentorium cerebelli.

Phylogenetically the cerebellum consists of:

- archicerebellum, which represents the control center of static and dynamic balance
- paleocerebellum, with the main role in regulating the postural tone of the antigravitational muscles
- neocerebellum which controls voluntary motility, regarding the degree, force and speed of movements

A functional division of the cerebellum was first described by Herrick and then by Larsell and states that the flocculonodular lobe has connections with the vestibular nuclei and they form Vestibulocerebellum (Vestibulocerebellis). Moreover, a part of Corpus cerebelli has connections with the spinal cord and they form Spinocerebellum (Spinocerebellis). Lastly, another part of Corpus cerebelli has connections with the pons and they form Pontocerebellum (Pontocerebellis)

### ***External morphology***

The cerebellum has a superior and an inferior surface, separated by the horizontal fissure (Fissura horizontalis, Fissura intercruralis). The horizontal fissure goes along the postero-lateral border of each cerebellar hemisphere, from the middle cerebellar peduncle to posterior cerebellar fissure. The cerebellum consists of three lobes: anterior, posterior and flocculonodular lobe, which are further subdivided into lobules, separated by cerebellar fissures (Fissurae cerebelli).

The anterior cerebellar lobe is separated from the posterior one by the primary fissure (Fissura prima, Fissura preclivalis), which is also the deepest fissure of cerebellum.

**The anterior cerebellar lobe (Lobus cerebelli anterior)** is further subdivided by superficial grooves into lobules. Each lobule from vermis has two corresponding lobules from the hemispheres, with one exception: the lingula- which has only the velum.

At the level of vermis, the anterior lobe presents the following lobules from anterior to posterior:

- lingula (Lingula cerebelli), with the corresponding velum
- central lobule (Lobulis centralis II et III) presents an anterior part (Pars anterior Pars ventralis II) and a posterior part (Pars posterior Pars dorsalis III). This lobule has as a corresponding part on the hemispheres called the wing of central lobule (Ala lobulis centralis) which presents an inferior (ventral) part (Pars inferior Pars ventralis II H) and a superior (dorsal) part (Pars superior Pars dorsalis III H). The limit between the lingula and the central lobule is represented by the precentral (postlingual) fissure (Fissura precentralis Fissura postlingualis).
- culmen (Culmen IV et V) has an anterior part (Pars anterior Pars ventralis IV) and a posterior part (Pars posterior Pars dorsalis V) divided by the intraculminal fissure (Fissura intraculminalis). Culmen has as a corresponding part on the cerebellar hemispheres the anterior quadrangular lobule (Lobulus quadrangularis anterior H IV et H V), which presents an anterior part (Pars anterior Pars ventralis H IV) and a posterior part (Pars posterior Pars dorsalis H V). The limit between central lobule and the culmen is marked by the preculminal (postcentral) fissure (Fissura preculminalis Fissura postcentralis).

**The posterior cerebellar lobe (Lobus cerebelli posterior)** is separated from the anterior cerebellar lobe by the primary fissure. The posterior cerebellar lobe presents at the level of vermis the following lobules:

- declive (Declive VI) with its corresponding posterior quadrangular lobule (Lobulus quadrangularis posterior H VI). At this level, there is no strict delimitation between the vermis and the cerebellar hemispheres so the declive and the corresponding posterior quadrangular lobules are called simplex lobule (Lobulus simplex H VI-VI).
- folium vermis (Folium vermis VII A) with its corresponding superior semilunar lobule (Lobulus semilunaris superior Crus primum lobuli ansiformis H VII A). Folium vermis is separated from declive by the superior posterior fissure also called postclival fissure (Fissura posterior superior Fissura postclivalis).
- tuber (Tuber VII B) has the inferior semilunar lobule (Lobulus semilunaris inferior Crus secundum lobuli ansiformi H VII A) and gracilis lobule (Lobulus gracillis Lobulus paramedianus H VII B) as corresponding parts on the cerebellar hemispheres. These two lobules are separated by the lungogracilis fissure (Fissura lungogracillis Fissura ansoparamedianus). Tuber is situated on the inferior surface of cerebellum and it is separated from the folium vermis by the horizontal fissure (Fissura horizontalis Fissura intercruralis)
- pyramis (Pyramis VIII) has as a corresponding lobule on the cerebellar hemispheres the biventral lobule (Lobulus biventer H VIII). The biventral lobule has a lateral part (Pars lateralis lobuli biventralis Pars copularis lobuli paramediani H VIII) and a medial part (Pars medialis lobuli biventralis Pars parafloccularis dorsalis H VIII B) separated by the intrabiventral fissure (Fissura intrabiventralis Fissura anterior inferior). The pyramis is separated

from tuber by the pre-biventral fissure also called the pre-pyramidal fissure (Fissura prebiventralis Fissura prepyramidalis).

- Uvula (Uvula IX) has as a corresponding lobule on the cerebellar hemispheres the tonsil (Tonsilla cerebelli Paraflocculus ventralis H IX). Uvula is separated from the pyramis by the secondary fissure also called the post-pyramidal fissure (Fissura secunda Fissura postpyramidalis)..

**The flocculonodular lobe (lobus flocculonodularis)** presents at the level of vermis the nodulus (Nodulus X) which has as a corresponding part at the level of the cerebellar hemispheres the flocculus (Flocculus H X). The nodulus lobule is separated from the uvula by the postero-lateral fissure (Fissura posterolateralis). The flocculus and the tonsil are connected through the accessory paraflocculus of Henle. The nodulus is the last division of the vermis and at the level where its cortex ends the taenia of the roof of fourth ventricle can be found. Laterally from the nodulus the floor of the paramedian sulcus is formed by the posterior medullary velum, which consists of a thin layer of white substance between the nodulus and the flocculus. The inferior surface of the posterior medullary velum is represented by the ventricular ependyma and its external surface is covered by pia mater.

#### Transversal section of cerebellum

Vermis	Cerebellar hemispheres	Cerebellar lobe
Lingula	Velum	Anterior lobe
Central lobule - Anterior part - Posterior part	Ala of central lobule - Anterior part - Posterior part	Anterior lobe
Culmen - Anterior part - Posterior part	Anterior quadrangular lobule - Anterior part - Posterior part	Anterior lobe
Declive	Posterior quadrangular lobule	Posterior lobe
Folium vermis	Superior semilunar lobule	Posterior lobe
Tuber	Inferior semilunar lobule Gracilis lobule	Posterior lobe
Pyramis	Biventer lobule - Lateral part - Medial part	Posterior lobe
Uvula	Cerebellar tonsil	Posterior lobe
Nodulus	Flocculus	Flocculonodular lobe

The cerebellum has a superior surface and an inferior surface.

Superior surface has the following lobules:

- lingula and velum
- central lobule and ala of central lobule
- culmen and anterior quadrangular lobule
- declive and posterior quadrangular lobule
- folium vermis and superior semilunar lobule

Inferior surface has the following lobules:

- tuber and inferior semilunar lobule and gracilis lobule
- pyramis and biventer lobule
- uvula and cerebellar tonsil
- nodulus and flocculus

### ***Internal morphology***

The Cerebellum consists of grey substance and white substance, which are further divided into lamellae, giving the appearance of tree of life (Arbora vitae) on section.

### **Grey substance**

The grey substance can be found on the surface of cerebellum forming the cerebellar cortex, but also inside the cerebellum where it forms the cerebellar nuclei.

Cerebellar cortex (Cortex cerebelli) has three distinct cellular layers:

- granular layer (Stratum granulosum): is deeply situated, with the main function of reception and it is formed by Golgi II cells and small cells
- Purkinje cells layer (Stratum purkinjense) has a single layer of large pear-shape cells- the Purkinje cells which are effector cells
- Molecular layer (Stratum moleculare) consists of external and internal stellate cells and has an association role

Cerebellar nuclei (Nuclei cerebelli)

The cerebellar nuclei represent the origin of all the cerebellar efferent fibers. The cerebellar cortex has an inhibiting role for the cerebellar nuclei, through the axons of neurons from the Purkinje layer. There are four cerebellar nuclei:

- Dentate nucleus/ lateral nucleus (Nucleus dentatus Nucleus lateralis cerebelli), has the main function of programming and synchronizing the movements. Efferent signals travel to the thalamic nuclei and red nuclei via the superior cerebellar peduncles. Inferior and medial, the grey substance of the dentate nucleus is slightly distanced forming the hilum of dentate nucleus. (Hilum nuclei dentati)
- Emboliform nucleus or the anterior interposed nucleus (nucleus interpositus anterior Nucleus emboliformis), is situated medially to the dentate nucleus and has the role of correcting the limb movements. Axons leaving the emboliform

nucleus reach the red nucleus and thalamic nuclei through the superior cerebellar peduncles.

- Globose nucleus or the posterior interposed nucleus (Nucleus interpositus posterior Nucleus globosus) is situated medially to the emboliform nucleus with the main function of correcting the limb movements. Its efferent fibers reach thalamic nuclei, red nucleus and medulla oblongata via superior cerebellar peduncles.
- Fastigial nucleus or the medial nucleus (Nucleus fastigii Nucleus medialis cerebelli) is situated medially, at the level of vermis, superiorly to the fourth ventricle. The fastigial nucleus has the main function of maintaining the posture and balance but also it has a role in ocular reflex movements. It receives input from vestibular nuclei and reticular formation of brainstem via inferior cerebellar peduncles.

### **White substance**

The white substance forms:

- Inside cerebellum: the cerebellar medullary body, which at the level of the roof of the fourth ventricle forms two white substance laminae: superior and inferior medullary velum
- Externally: three pairs of cerebellar peduncles (Pedunculi cerebelli), through which the cerebellum makes its connections

Inferior cerebellar peduncle (Pedunculus cerebellaris inferior) consists of a posterolateral tract of fibers called the restiform body (Corpus restiforme) and a medial tract of fibers called juxtarestiform body (Corpus juxtarestiforme). The restiform body receives afferent fibers from spinocerebellar, trigeminocerebellar, cuneocerebellar, reticulocerebellar and olivocerebellar tracts. The juxtarestiform body is mainly efferent, but it also consists of vestibulocerebellar fibers.

Middle cerebellar peduncle (Pedunculus cerebellaris medius) is the largest and the most lateral peduncle. This peduncle is mainly formed by the fibers from the pons basal nuclei and some fibers from the nuclei from the tegmental part.

Superior cerebellar peduncle (Pedunculus cerebellaris superior) receives fibers from dentate, emboliform and globose nuclei, and a small part of fibers from fastigial nucleus. Some spinocerebellar fibers reach cerebellum via superior cerebellar peduncle.

Fibers which cross inside the white substance form the cerebellar commissure (Commissura cerebelli), which consist of an efferent part and an afferent part. The efferent part contains crossed fibers from fastigial nucleus and the afferent part contains fibers from the restiform body and from the middle cerebellar peduncle.

### **Cerebellar connections:**

Afferent fibers:

- Posterior spinocerebellar tract: ends ipsilaterally into the granular layer of vermis, into the lateral part of the anterior lobe and bilaterally in pyramis lobule and in its corresponding lobule of cerebellar hemispheres



- Anterior spinocerebellar tract: the fibers cross again in cerebellar commissure and they end at the level of granular layer of anterior lobule
- Rostral spinocerebellar tract: end ipsilaterally at the level of culmen, simplex lobule and posterior part of pyramis lobule.
- Olivo-cerebellar fibers: the majority of fibers coming from different sub-nuclei of inferior olive end at the level of Purkinje cells of cerebellar cortex. Some fibers reach the fastigial, emboliform and globose nuclei. Fibers coming from the main olive reach the contralateral hemisphere with some collaterals in dentate nucleus.
- Vestibulo-cerebellar fibers: primary fibers end into the granular layer of nodulus, caudal part of uvula, anterior part of the anterior lobe and into the deep fissure of vermis via the juxtarestiform body. Secondary fibers end in the same way as the primary fibers, at which it is added the projection at the level of flocculus.
- Cuneo-cerebellar tract: end at the level of culmen, simplex lobule and posterior part of pyramis lobule.
- Trigemino-cerebellar tract: represents the projection of trigeminal nucleus at the level of granular layer of cerebellar cortex.
- Reticulo-cerebellar fibers: Lateral reticular nucleus projects bilaterally onto the vermis and onto the hemispheres. The dorsal part of nucleus projects at the level of hemispheres, whereas the ventral part of the nucleus projects at the level of vermis. Some fibers are sent to fastigial and emboliform nuclei and to the medial part of the globose nucleus. Medial reticular nucleus projects at the level of the entire cerebellum with the exception of paraflocculus. Tegmental reticular nucleus projects at the level of anterior lobe cortex, simplex lobule, tuber, vermis, semilunar lobuli, lateral part of globose nucleus, having a complementary projection with the one of lateral reticular nucleus.
- Cortico-ponto-cerebellar tract: visual projection is made at the level of paraflocculus, folium, tuber, uvula and vermis, whereas auditory projection is made at the level of paraflocculus.
- Tecto-ponto-cerebellar tract: From superior and inferior colliculi this tract reaches the dorso-lateral part of the pons and from there to vermis in declive and folium vermis lobuli.

#### Efferent fibers:

Efferent fibers of cerebellum consist of the inhibitory projection of Purkinje neurons on cerebellar nuclei but also of the efferent connections of cerebellar nuclei. The cerebellar nuclei are connected with the motor cortex through thalamus. Their effect is always indirect, because there are no direct connections between cerebellar nuclei and motor neurons. Vermis` connections with motor neurons are mediated by vestibular nuclei via a pathway with multiple synapses including fastigial nucleus, vestibular nuclei and reticular formation. Connections of cerebellar hemispheres, dentate nucleus, emboliform nucleus and globose nucleus are made through red nucleus, thalamus and motor cortex.

- Fastigial nucleus: this nucleus is bilaterally connected with the vestibular nuclei and reticular formation of pons and medulla oblongata. Some fibers travel to midbrain and diencephalon and then they descend towards medulla spinallis. Nucleo-olivary fibers end in the accessory medial olive. The uncinata tract is the major efferent pathway of fastigial nucleus. Its fibers cross at the

anterior level of the cerebellar commissure and then cross the superior cerebellar peduncle to enter laterally into the vestibular nuclei. Direct fastigo-bulbar fibers reach vestibular nuclei via juxtarestiform body. Uncinate tract and direct fastigo-bulbar fibers pass through the vestibular nuclei and spread to medial reticular formation. One small fasciculus of fibers from fastigial nucleus has an ascending direction through the superior cerebellar peduncles, towards the thalamus, ending in ventro-lateral and intra-laminar nuclei.

- Emboliform nucleus: axons of neurons from emboliform, globose and dentate nuclei run through superior cerebellar peduncle, from lateral to medial, their disposition being globose nucleus, emboliform nucleus and dentate nucleus. The emboliform nucleus projects onto lateral part of ventro-lateral nucleus of thalamus, which is connected with the caudal motor cortex. The pyramidal tract has its origin in the motor cortex and ends at the level of the motor neurons from spinal cord, on the same side or on the other side. The effect of the emboliform nucleus on the ipsilateral extremities is achieved through two different pathways - the corticospinal tract and the rubrospinal tract: Efferent nucleo-olivary fibers reach the anterior half of the dorsal accessory olive. Emboliform nucleus does not participate in the recurrent cycle cerebellum-midbrain-olives.
- Globose nucleus: sends efferent fibers to the fastigial nucleus, these two nuclei sharing their projection at the level of the spinal cord and the superior colliculi. Nucleo-olivary efferent fibers reach the anterior half of medial accessory olive.
- Dentate nucleus: Its fibers reach red nucleus, thalamus and oculomotor nucleus. Central tegmental tract has its origin in the parvocellular red nucleus and it ends at the level of main olivary nucleus. Thalamic projection of dentate nucleus is made at the level of ventro-lateral nucleus but it also extends in the medial part of nucleus, which projects onto the premotor area of frontal lobe.

### ***Blood supply of cerebellum***

Arteries:

Arterial blood supply of cerebellum consists of the following arteries:

- Posterior inferior cerebellar artery: (A. inferior posterior cerebelli) arises from the intracranial part (Pars intracranialis) of the vertebral artery (A. vertebralis). It vascularizes the posterior-inferior part of cerebellum and gives rise to a tonsillar branch (R. tonsillae cerebelli) for the cerebellar tonsil and to a choroidal branch (R. choroideus ventriculi quarti) for the choroid plexus of fourth ventricle.
- Anterior inferior cerebellar artery (A. inferior anterior cerebelli) arises from the basilar artery (A. basilaris) and it vascularizes the antero-inferior part of cerebellum.
- Superior cerebellar artery (A. superior cerebelli) arises from the terminal part of basilar artery and it gives rise to a medial branch (R. medialis) and to a lateral branch (R. lateralis) which vascularize the superior surface of the cerebellar hemispheres. The medial branch gives rise to the superior artery of vermis (A. vermis superior) for the superior surface of vermis.

## Veins:

The cerebellum has a venous network at its surface which is continuous with cerebellar veins: (Venae cerebelli)

- Superior vein of vermis (V. superior vermis)
- Inferior vein of vermis (V. inferior vermis)
- Superior cerebellar veins (Vv. superiores cerebelli)
- Inferior cerebellar veins (Vv. inferiores cerebelli)
- Precentral vein of cerebellum (V. precentralis cerebelli)
- Petrosal vein (V. petrosa)

Cerebellar vein drain venous blood from cerebellum in the following dura mater sinuses:

- Transverse sinus (Sinus transversus)
- Occipital sinus (Sinus occipitalis)
- Sigmoid sinus (Sinus sigmoideus)
- Straight sinus (Sinus rectus)
- Inferior petrous sinus (Sinus petrosus inferior)

## 6. The ventricular system

The ventricular system had been recognized since ancient history, around third century BC, when the first human dissections were done. Their work led to a better understanding of the ventricles and gave full anatomic description of four “small stomachs”, the ventricles, and their communications. However, they believed that the function of these ventricles was to convert the vital spirit. Only in 1774, Domenico Felice Antonio Cotugno was the first anatomist to discover cerebrospinal fluid and to describe the continuity between the ventricles and subarachnoid space.

The ventricular system of the brain contains four freely communicating, cerebrospinal fluid (CSF) filled cavities: the two lateral ventricles (left and right), the third ventricle, Sylvius’ aqueduct; the fourth ventricle and the central canal of the spinal cord.

CSF is produced by ependymal cells of the choroid plexus, circulating through the entire ventricular system, firstly it will spill through Sylvius’ aqueduct in fourth ventricle. At this level, the lateral orifices of Luschka and Magendie ensure communication with the subarachnoid spaces where the CSF is diffused, they return to the circulation through the arachnoid granulations.

The cavities of the ventricular system have different volumes, corresponding to the volume of the component in which they are included, so that the lateral ventricles will be the largest. The entire ventricular system has a volume of less than 30 cubic centimetres.

### The lateral ventricles

The **lateral ventricles** are paired C-shaped cavities filled with CSF in the cerebrum. They are larger than the third or fourth ventricles, but can be asymmetrical. Each lateral ventricle communicates with the third ventricle with a common interventricular foramen or foramen of Monro. The lateral ventricles are divided into five divisions, including three horns that project into the lobe after which they are named:

- body/ central part
- anterior/frontal horn
- inferior/temporal horn
- posterior/occipital horn
- trigone/atrium

**The atrium** communicates with the frontal horn, dorsally with the occipital diverticle, and caudally, ventrally and laterally with the inferior horn.

**The body** of the lateral ventricle is **elongated** anteroposteriorly from interventricular foramen to splenium of corpus callosum. It is divided into a **roof**, **floor**, and a **medial wall**; the roof and floor meet on the lateral aspects.

The boundaries are:

- internal wall: septum pellucidum and body of fornix
- roof: inferior aspect of the body of corpus callosum
- lateral wall: medial part of the body of the caudate nucleus
- floor: thalamus medially and body of caudate nucleus laterally and in between these two striae terminalis and thalamostriate vein.

**The anterior horn or frontal horn** extends forward into the frontal lobe in front of interventricular foramen. Has a triangular shape

The boundaries are:

- internal wall: septum pellucidum
- roof, anterior wall and floor: anterior wrapping of the corpus callosum
- lateral wall: the posterior edge of the caudate nucleus.

**The inferior horn or temporal horn** or is the largest component projecting from the posterior end of central part runs downward and **anteroinferiorly** into the **temporal lobe**. The **anterior end** reaches close to the uncus of the cerebrum.

It is formed by:

- floor: hippocampus or pes hippocampus and caudally the collateral eminence (prominence formed by the T4–T5 sulcus)
- roof: inferior aspect of the thalamus, tail of the caudate nucleus and deep white matter of the temporal lobe,
  - internal wall: choroidal fissure and choroid plexus clinging to the fimbria which is the initial portion of the anterior crus fornix and to the inferior aspect of the hemisphere.
- The anterior extremity is situated just behind the amygdaloid nucleus.

**The posterior horn or occipital horn** of the lateral ventricle extends **posteromedially** into the **occipital lobe**, and like other parts of the lateral ventricle has a **roof, lateral wall** and a **medial wall**.

The walls are formed by:

- internal wall: two prominences formed cranially and inferiorly by the fibers of the splenium of the corpus callosum (bulbar prominence) and the deep part of the calcarine sulcus (calcar avis),
- *roof and lateral wall are formed by the fibers of the tapetum of the corpus callosum, overlaid laterally by the optic radiations*

## **The Third Ventricle**

The third ventricle is a narrow vertical cavity of the diencephalon which lies between the two thalami. Dimensions: 4 cm in length, 3 cm in height and 1 cm in width. Has a rectangular shape, transversally flattened with the basis situated superiorly, lateral walls are almost touching. It communicates anterosuperiorly on each side with lateral ventricles through interventricular foramen (Monro foramen) and posteriorly, with the fourth ventricle through aqueduct of Sylvius. The choroid plexuses of ventricle III continue the choroid plexuses of the lateral ventricles. Neurons and fibers that connect the two thalami may cross the third ventricle.

The third ventricle has two lateral walls, a superior wall (roof), a floor and two sides – anterior and posterior, some authors call these sides the anterior and the posterior walls.

The lateral walls are formed superiorly by thalamus and below of the hypothalamic sulcus (a groove that extends from foramen of Monro anteriorly to aqueduct posteriorly) by hypothalamus. The interventricular foramen of Monro is seen on lateral wall just behind the column of fornix.

The anterior wall is formed from the lamina terminalis which is a small layer of gray matter in the telencephalon that stretch posterior to from the corpus callosum, superior to the optic chiasma and forms the median portion of the rostral wall of the third ventricle of the cerebrum.

The posterior wall of formed by the pineal gland which is attached to the posterior portion of the brainstem by two commissures, the habenular commissure superiorly and the posterior commissure inferiorly. It forms a space between them, the pineal recess.

The roof of the third ventricle is arched shape and extends from interventricular foramen (Monro foramen) to the suprapineal recess. The roof is composed of four layers.

The tela choroidea is the main part since it forms two out of four layers. It consists of two thin membranes derived from the pia mater, interconnected by loosely organized trabeculae. The final layer in the roof is the vascular layer, this includes the medial posterior choroidal arteries and the internal cerebral veins. The upper layer of the tela choroidea is attached to the inferior surface of the fornix and the hippocampal commissure. There might be some kind of space above the velum interpositum, between the hippocampal commissure and splenium, what is called the cavum vergae.

The floor has an arch shape with the end facing downwards and is called the infundibulum. It is formed by the hypothalamus and presents 3 formations: the optic recess (recessus opticus), the infundibulum (*recessus infundibularis*) and the orifice of the aqueduct which separates an anterior infundibulotuberian and supraoptic sector and a mammillary sector.

## THE FOURTH VENTRICLE

The 4th ventricle is an expansion of the central canal, diamond shape. It is also named the rhomboid fossa, lies posterior/dorsal to the pons and medulla (of the brainstem) and anterior/ventral to the cerebellum. On the inferior side it communicates with the central canal of brainstem and superior with the aqueduct of Sylvius. The vertical axis measures 3.5 cm while the the transversal axis measures approximate 2 cm. Its surface is lined by an epithelial layer called the ependyma, and is filled with cerebrospinal fluid (CSF).

The fourth ventricle has an anterior/ventral floor and a posterior/dorsal tent-shaped roof. CSF produced and/or flowing into the fourth ventricle can exit to the subarachnoid space through lateral apertures foramen of Luschka and a single median aperture foramen of Magendie located in the inferior portion of the roof.

The floor of the tent is formed by the pons and medulla. The roof is oriented posteriorly and separated in a superior and inferior roof, at a point named the fastigium. Each part of the tent has a corresponding cerebellar part. The superior one corresponds to tentorial surface of the cerebellum and the inferior one to the suboccipital surface. The floor is formed by the pons and the medulla, related to the petrosal surface of the cerebellum. The surgical approaches to the fourth ventricle are performed through the inferior part of the roof.

The superior roof of the fourth ventricle has thick neural structures, the superior cerebellar peduncles. They are localized on the lateral wall of the superior roof and are the extension of the dentate nuclei. The dentate nuclei are above the superior pole of the tonsils.

Inferior roof is formed by two thin membranes, the tela choroidea and the inferior medullary velum which stretch laterally and forms the peduncle of the flocculus at the level of the lateral recess. The space between the superior cerebellar peduncle and the inferior medullary velum is called the superolateral recess. The tela choroidea, when seen from anteriorly, resembles the letter T. It extends laterally to form the floor of the two lateral recesses and extends inferiorly from the inferior medullary velum to attach to the inferolateral edges of the floor of the fourth ventricle along the taenia, which are narrow white ridges that meet at the obex.

The inferior portion of the suboccipital surface of the cerebellum covers the inferior roof of the fourth ventricle. The tonsil and the biventral lobule cover the tela choroidea and the lateral recess. The uvula is in the midline and covers the nodule. The cerebellomedullary fissure is a natural space between the cerebellum and the medulla, it is continuous with the vallecula, the space between both tonsils.

The lateral recess extends laterally below the cerebellar peduncles to open into the cerebellopontine cistern through the foramina of Luschka. The lateral recess may be divided into a peduncular and a floccular part. The peduncular part is formed by the inferior cerebellar peduncle anteriorly and the peduncle of the flocculus posteriorly. The floccular part is formed by the rhomboid lip anteriorly and by the flocculus posteriorly. The rhomboid lip is a thin sheet of neural tissue located posteriorly to the glossopharyngeal and vagus nerves. The tela choroidea forms the floor of both parts of the lateral recess.

The floor of the fourth ventricle: Pontine part of the floor has a triangular shape, with its apex continuous with the aqueduct. The base is represented by an imaginary line which follows with the lower margin of the cerebellar peduncles. The medullary part has the same triangular form, but its apex points downwards to the obex, it's base has the same imaginary line along the site of attachment of the tela choroidea to the tenia below the lateral recess.

The floor is divided in two halves by the median sulcus. Parallel to the median sulcus is the sulcus limitans. The sulcus limitans does not mark the median, but it has two distinct depressions along its way. The superior depression is the superior fovea, located laterally to the facial colliculus. The inferior depression is the inferior fovea, located laterally to the hypoglossal triangle. The motor nuclei of the cranial nerves are located medially to the sulcus limitans, whereas the sensory nuclei are located laterally. The median eminence contains the facial colliculus and three triangular areas on its inferior end: hypoglossal triangle, vagal triangle, and area postrema. The inferior part of the fourth ventricle is called the calamus scriptorius, because these three triangular areas are grouped together near the median sulcus on the inferior part of the floor, giving a configuration of a feather or pen nib.

## 7. SPINAL CORD (*Medulla spinalis*)

### GENERAL ASPECTS

The spinal cord is the elongated part of the central nervous system and from a phylogenetic point of view it represents the oldest component of the central nervous system. It is situated in the vertebral canal, occupying the two superior thirds. Its limits are superiorly: a plan that passes through the anterior tubercle of atlas, the middle of the odontoid process and the superior border of the anterior arch of atlas and inferiorly: a plan that passes through the intervertebral disk between L1-L2. The spinal cord does not occupy entirely the vertebral canal, being spread between foramen magnum and the second lumbar vertebrae. Superiorly it is continuous with the medulla oblongata and inferiorly it gets narrower and forms a conical enlargement called Conus medullaris (coned shape) with its prolongation-a delicate filament called Filum Terminale, which ends at the level of first coccygian vertebrae. Distal to this end the cauda equina can be found, which represents a collection of nerve roots with a horsetail-like appearance. Cauda equina innervates the pelvic organs and lower limbs.

The spinal cord is covered by the three protective membranes called meninges, which are continuous with the ones from the brain: Dura mater spinalis, Arachnoidea mater spinalis and Pia mater spinalis. Between the dura mater and the subjacent arachnoid, the subdural space can be found, which is filled with a small quantity of lymph fluid. Between arachnoid and pia mater the subarachnoid cavity can be found, which contains cerebrospinal fluid. The epidural space represents the space between the spinal cord covered in meninges and the bony walls of the vertebral canal. This space contains venous plexuses and loose areolar tissue and because of it, the spinal cord never gets in contact with the bony elements of the vertebral canal.

Medulla spinalis has 3 large functions:

1. **Reflexes:** represent involuntary responses to stimuli. Medulla spinalis is a center of reflexes, but it also needs the brain and the peripheral nerves to carry out a reflex.
2. **Conduction:** at the level of medulla spinalis different bundle of nerve fibers can be found which either will connect different segments of the spinal cord, either will connect the spinal cord with different structures of the brain.
3. **Locomotion:** the alternating movements of the legs (the act of putting one foot in front of the other with the help of the repetitive muscle contractions) is coordinated by the central pattern generators in the spinal cord.

### EXTERNAL MORPHOLOGY

The spinal cord has a cylindrical shape, being flattened from anterior to posterior with a length of a 40-45 cm, depending on the gender and height of the subject. Filum Terminale has almost 20 cm, the first 15 cm being called the dural part of Filum Terminale (Pars duralis or filum terminale internum) which extends to S2. This part is surrounded by the nerves of cauda equina is easily recognizable because of its bluish color. The last 5 cm of Filum terminale represents the pial part of Filum Terminale (Pars Pialis or filum terminale externum) which extends to C1.



The spinal cord follows the curvatures of the vertebral column hence the cervical curvature which is convex anteriorly and the thoracic curvature which is convex posteriorly.

The spinal cord presents 2 enlargements, corresponding to the origin of the spinal nerves that innervate the lower (lumbar plexus) and upper limbs (brachial plexus):

- **Cervical enlargement:** more pronounced, origin of the spinal nerves C5-T1, which innervates the upper limbs; it extends from C3 to T2 and the maximum diameter of 38 mm is at the level of attachment of the 6<sup>th</sup> pair of cranial nerves
- **Lumbosacral enlargement:** origin of the spinal nerves L1-S3, which innervates the lower limbs; it extends from T9; the maximum diameter of 33 mm can be found at the level of T12

Because of these enlargements, the spinal cord can be divided into 5 parts:

1. **Superior part:** from medulla oblongata to the cervical enlargement which contains the origin of the first 3 pairs of cervical nerves
2. **Cervical enlargement:** from C3 →T2 with the origin of the last 5 cervical nerves and the first thoracic nerve
3. **Thoracic part:** between T2→T10, with the last 11 thoracic nerves
4. **Lumbar enlargement:** between T10→L2 which will send the nerves which form the lumbar plexus; it is continuous inferiorly with filum terminale
5. **Conus medullaris (medullary cone, the terminal cone)**

The spinal cord has a slower development than the one of the vertebral column and that's why there is an apparent process of medullar ascension. The spinal nerve roots which initially were horizontal will become more oblique trying to get to their emergent foramen from above downward, and the last ones (lumbar and sacral nerves) will even become almost vertical to reach their points of exit. These nerves are collectively called Cauda Equina and they are surrounding Filum Terminale. Thus, there are 8 spinal nerves but 7 cervical vertebrae and there is no spinal cord inferiorly to L2, which permits us to do lumbar punctures, without having the risk of producing medullar damage.

The external morphology of the spinal cord consists of a number of fissures and sulci. The anterior median fissure and the posterior median sulcus incompletely divides the medulla into two halves, connected in the midline by a commissural band. These fissures and sulci are:

- **Anterior median fissure (*fissura mediana anterior*):** extends the length of the anterior surface, containing a double fold of pia mater; its floor consists of the anterior white commissure, which is a transverse band of white substance
- **Posterior median sulcus (*sulcus medianus posterior*):** a shallow sulcus that can be found on the posterior surface,
- **Postero-lateral sulcus:** situated at the level of the posterior surface, on either side of the posterior median sulcus, where the posterior rootlets of the spinal nerves enter the spinal cord attached along a vertical furrow
- **Posterior funiculus:** the part of medulla spinalis between the postero-lateral sulcus and the posterior median sulcus

- **Postero-intermediate sulcus:** the posterior funiculus has a characteristic disposition in the cervical and the superior thoracic regions, forming a longitudinal furrow called the posterior-intermediate sulcus
- **Fasciculus gracilis and cuneatus:** both fascicles represent parts of the posterior funiculus subdivided by a septum at the level of the postero-intermediate sulcus; fasciculus gracilis is situated medially, whereas fasciculus cuneatus is situated laterally;
- **Antero-lateral sulcus:** not that well represented, because the anterior nerve roots are not attached in linear series; can be found on each side of the anterior median fissure, where the anterior roots of the spinal nerve exist the spinal cord.
- **Antero-lateral region:** the region of medulla spinalis situated in front of the postero-lateral sulcus. This region is separated by the most lateral anterior nerve roots` bundle into:
  - **Anterior funiculus:** between the most lateral of the anterior nerve roots and the anterior median fissure
  - **Lateral funiculus:** between the postero-lateral sulcus and the exit of these roots
- **Central canal:** internally, the spinal cord has a central canal surrounded by gray and white substance

Because of this characteristic disposition, the spinal cord presents funiculi, divided by vertical sulci:

- **Anterior funiculus:** (one on each side) between anterior median fissure and antero-lateral sulcus,
- **Posterior funiculus:** between posterior median sulcus and postero-lateral sulcus; in the cervical and superior thoracic part posterior intermediate sulcus can be found, which will divide each posterior column into 2 fascicles: gracilis (or Goll`s fascicle, situated medially) and cuneatus (or Burdach`s fascicle, situated laterally)
- **Lateral funiculus:** between antero-lateral sulcus and postero-lateral sulcus

## The spinal nerves

The spinal nerves are 31 pairs of nerves (8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal). The first pair of the spinal nerves pass superiorly to the first cervical vertebrae and the rest of them will pass to the corresponding intervertebral foramina. Each spinal nerve presents one anterior (ventral) motor root and one posterior (dorsal) sensitive root which they unite after exiting the cord forming a trunk, which will exit through the corresponding intervertebral foramen. The posterior root is easily distinguishable because of an enlargement called the spinal ganglion. Each root is attached to the spinal chord through some radicular fillets. The roots of the lumbar and spinal nerves together with Filum Terminale form Cauda Equina.

The posterior root innervates the skin and the deep muscles of the back, whereas the anterior roots will form plexuses: cervical, brachial, lumbar and sacral; and the intercostal and subcostal nerves.

The spinal nerves are mixed nerves and contain:

- Sensory fibers: their cell bodies can be found in the dorsal root ganglion
- Motor fibers: their cell bodies can be found in the anterior horn of the spinal cord
- Preganglionic sympathetic fibers: their cell bodies can be found in the intermedio-lateral cell column of the lateral horn of the spinal cord T1-T2
- Preganglionic parasympathetic fibers: their cell bodies can be found in the intermedio-lateral cell column of the lateral horn of the spinal cord S2-S4

Conventionally, the spinal cord is formed by superimposed spinal segments, also called **neuromeres**. Even though there is no segmentation visible on the external morphology of the spinal cord, a neuromere is considered to be the region supplied by each pair of spinal nerves. Hence, the spinal segments have different lengths:

- In the cervical region: 13 mm
- Thoracic region: 26 mm
- Lumbar region: 15 mm
- Sacral region: 4 mm (even though the spinal cord ends superior to the sacrum, it is called like that because of the level of the vertebral column from which the spinal nerves emerge)

### Structures associated with the spinal cord

1. **Cauda Equina:** located in the subarachnoid space inferiorly to the conus medullary. It floats in the cerebrospinal fluid and it is not damaged during lumbar punctures.
2. **Denticulate ligaments:** represent 21 pairs of thin processes (toothpick-like) which are a lateral extensions of the pia mater spinalis towards the dura mater, between the anterior and posterior roots of the spinal nerves. Their main role is to keep the medulla spinalis in position within the subarachnoid space.
3. **Filum Terminale:** represents an extension of the pia mater, surrounded by cauda equina. It ends at the level of S2 by attaching to the apex of the dural sac (filum terminale internum). Filum terminale externum (filum of the dura mater of the coccygeal ligament) attaches to the dorsum of the coccyx.

### INTERNAL MORPHOLOGY

On examining a cross section of the spinal cord, it is seen to consist of grey substance disposed internally and white substance disposed externally. On this transverse section, the grey substance has a butterfly shape (or an H shape) consisting of an anterior horn, a posterior horn and a lateral horn, corresponding to the longitudinal columns. The grey substance is surrounded by the white substance. Between them the reticular substance can be found. The grey substance consists of 3 columns: anterior, posterior and intermediate column. The intermediate column contains the central canal and around it the central gelatinous substance.

### GREY SUBSTANCE (*Substantia grisea centralis*)

The grey substance represents the superposition of some comparable segments called myelomers which contain a territory (called metamere) formed by skin (dermatome), muscle (myotome), blood vessels, organs etc. The grey substance got its name because of the dull color of the poor myelinated structures that can be found inside it (bodies of the neurons, dendrites and proximal parts of the axons of neurons)

The grey substance consists of 2 symmetrical parts (right and left), one in each half of the spinal cord. On transverse section, the 2 symmetrical parts are disposed from anterior to posterior in a comma or crescent-like shaped with the concavity situated laterally, united by a transverse commissure of grey substance which is called the grey commissure.

Inside the grey substance, centrally, the ependymal canal (central canal) can be found, which is also visible to the naked eye. The central canal extends throughout the entire length of the spinal cord, which opens superiorly inside the fourth ventricle and inferiorly it extends until it reaches the middle part of Filum Terminale. The central canal is collapsed in most areas of the adult spinal cord, but it remains open in some regions-filled with cerebrospinal fluid and in young children. It represents a remnant of the lumen of the neural tube.

The two longitudinal crescent-like shaped parts present one anterior motor component and one posterior sensitive component. Both components have a somatic and an autonomic (formerly known as vegetative) part. The autonomic part of the spinal cord extends from one lateral horn to the other and it also contains the grey commissures. These parts contain visceromotor neurons situated in the anterior part of the intermediate part and viscerosensitive neurons in the posterior part. On a coronal plane at the level of the central canal, the longitudinal crescent-like shaped parts are divided into columns or horns, as it follows.

#### **Anterior column** (*columna anterior; anterior cornu*)

The anterior column is larger and has a quadrangular shape, consisting of a head and a base towards the intermediolateral zone, without a strict differentiation between the head and the base. The anterior column is separated by the surface of the spinal cord by a layer of white substance where the anterior nerve roots pass. In the thoracic region, the anterior column presents with a lateral projection of a triangular shape called the lateral column. Its nuclei have the shape of columns of somatomotor cells that have developed throughout the spinal cord unequally. The nuclei are:

- Antero-medial nucleus: C1→S4
- Antero-lateral nucleus
- Postero-lateral nucleus. These lateral nuclei are less developed than the antero-medial nucleus and they will give fibers from C1-C4 to form the medullary root of accessory nerve
- Postero-medial nucleus, less developed
- Central nucleus of the head of the anterior horn: present only at the level of cervical and lumbar enlargements

The medial nuclei innervate the proximal muscles of limbs and axial muscles. The lateral nuclei innervate the distal muscles of the limbs and the parietal muscles of the trunk. In each nucleus the cells for the extensor's muscles are situated anteriorly to those of the flexors.

#### **Posterior column** (*columna posterior; posterior cornu*)

The posterior column is slightly more elongated and thinner than the anterior horn and presents a head, a neck and a base. The head of the posterior horn extends almost as far as the postero-lateral sulcus and it is separated from the surface of the spinal cord through a thin layer of white substance called the marginal

zone of Lissauer (the tract of Lissauer), inside of which we can find the Waldeyer's layer. The apex of the posterior column almost reaches the postero-lateral sulcus. Surrounding the apex there is a V-shaped structure that contains translucent neuroglia called substantia gelatinosa of Rolando. The base of the posterior column is directly continuing the base of the anterior horn.

These 2 structures contain the second neuron of the tactile or protopathic exteroceptive sensibility and the second neuron of the pain and temperature sensibility at the level of the head of the nucleus of Waldeyer.

At the base of the posterior horn can be found: the Stilling-Clarke nucleus medially and Bechterew nuclei, laterally, which represent the second neuron of the unconscious proprioceptive sensitivity.

### **Central canal (*Canalis centralis*)**

The central canal can be found inside the grey substance throughout the entire length of the spinal cord. The central canal divides the grey matter surrounding it into an anterior part called the anterior gray commissure and a posterior part called the posterior gray commissure. The anterior gray commissure is thinner and it is directly in contact with the anterior white commissure. The posterior gray commissure extends from the central canal to the posterior median septum. The central canal extends superiorly into the inferior part of the medulla oblongata opening into the fourth ventricle and inferiorly it has a dilatation called the terminal ventricle. The central canal is lined with ependymal cells and it contains cerebrospinal fluid.

### **Intermediolateral zone**

The intermediolateral zone contains the autonomic motor and sensitive centers grouped into columns. From T1 to L3 an internal and an external intermediolateral column can be found.

The sympathetic autonomic centers of the spinal cord can be found at the level of the lateral column, which at the thoracic level form the lateral horn. The sympathetic central neurons grouped at the level of lateral horn send their axons (preganglionic fibers) through the anterior root of the spinal nerve and through the white communicating ramus to make synapse with the neurons of the paravertebral sympathetic ganglions.

The sympathetic autonomic centers are:

- Irido-dilatatory center of Budge: between C8-T3
- Cardio-acceleratory center: T1-T4
- Bronhopulmonary center: T3-T5
- Pilomotor, Sweat and vaso-motor centers: T2-12
- Abdominal splanchnic centers: T6-L2
- Pelvic splanchnic centers: L1-L4

The medial autonomic column is situated externally to the central canal and contains sympathetic structures.

The autonomic parasympathetic centers are present only at the sacral level:

- Micturition center
- Defecation center
- Erection and ejaculation center

The preganglionic fibers exit the cord through the sacral nerves as pelvic splanchnic nerves or erector and they synapse with the neurons from the hypogastric ganglion.

Grey substance consists of neuron`s bodies, unmyelinated nervous fibers, glial tissue and blood vessels. There are 5 types of neuros that can be found here:

1. Alfa neurons: are large multipolar neurons situated inside the head of the anterior horn; here arrive the fibers of the pyramidal, extrapyramidal fascicles and fibers that come through the posterior root. They send a large axon to the neuro-muscular junctions of the striated muscles through the anterior root of the spinal nerve.
2. Gamma neurons: are smaller neurons inside the head of the anterior horn; here arrive the fibers of the pyramidal, extrapyramidal fascicles and reticulospinal fibers and peripheric fibers. They send a small axon to the neuromuscular junctions of the intrafusal muscular fibers through the anterior root of the spinal nerve. They have a role in defense reflexes.
3. Sympathetic visceromotor neurons: small neurons spread through the entire autonomic zone of the spinal cord. They send an axon through the anterior root of the spinal nerve inside the trunk of the spinal nerve and they make synapse with the paravertebral sympathetic neurons.
4. Parasympathetic visceromotor neurons: are present only at the level of sacral cord. The axons of these neurons exit the cord through the anterior roots S2-S4 and then pass to hypogastric ganglion through the erectors or pelvic nerves.
5. Columnar neurons: situated at the level of posterior horn, they exist the grey substance in order to arrive at the level of anterior and lateral white substance columns. Ipsilateral axons= the axons pass on the same side of the white substance, without decussation (the origin and destination of the fibers are on the same side). Contralateral= the axons pass on the opposite side of the white substance (the origin and destination of the fibers are on opposite sides). Decussation is a process through which fibers from one part of the body cross over on the other side. As a result, the left side of the brain will sense and control the right side of the body and vice-versa. Clinically, a stroke that involves for instance the motor centers of the left side of the brain will cause paralysis on the right limbs.

### **WHITE SUBSTANCE** (*Substantia alba medulla spinalis*)

The white substance contains myelinated axons, hence the bright, white appearance. It contains bundles of axons called tracts that carry information connecting the spinal cord with other structures of the central nervous system. These bundles are arranged in three pairs called funiculi or columns.

At the level of the white substance can be found:

- **Anterior, posterior and lateral funiculi** which contain long ascending fibers (centripete) and long descending fibers (centrifuge) with a peripheric disposition. The anterior funiculus is situated between the anterior median fissure and the most lateral of the anterior nerve roots. The posterior funiculus can be found between the posterior median and postero-lateral sulci. The lateral funiculus is disposed between the most lateral of the anterior nerve roots and postero-lateral sulcus.
- Short fibers of association which have the role of connecting different parts of the spinal cord

Long fibers have a vertical trajectory and connects the spinal cord with the encephalon or they connect different myelomers.

Short fibers can be found nearby the grey substance and they form the reflex center of the spinal cord.

Fibers from the spinal cord which have a similar origin, destination and function will occupy the same part in the cord. The origin can be:

- From the encephalon: axons of the neurons from the cortex or brainstem nuclei
- From the spinal cord: axons from the grey substance of the spinal cord
- From outside the central nervous system: axons of the spinal ganglion cells.

There are 3 types of fascicles, in relationship to their function:

1. **Sensitive tracts (fascicles):** are formed by long vertical fibers which will ascend towards the encephalon from the cord's cells or the spinal ganglion cells.
2. **Motor tracts (fascicles):** are formed by long vertical fibers which will descend from the encephalon to the motor cells of the spinal cord
3. **Association tracts (fascicles):** are long, middle or short fibers which will ascend or descend from a myelomer to another myelomer

Usually, the fascicles are grouped together, with the exception of some of the extrapyramidal fascicles. The white substance cords spread throughout the entire medulla spinalis, but have a different development regarding the medullary level considered.

Ascending tracts carry sensory signals up the spinal cord and are easily recognizable by the prefix spino- + a root for the destination of the fibers in the brain. It involves 3 neurons from their origin in the receptors to their brain destination (sensory areas)

- The gracile fasciculus
- The cuneate fasciculus
- The spinothalamic tract
- The dorsal and ventral spinocerebellar tracts

Descending tracts carry motor signals to the brainstem and spinal cord and they are easily distinguishable because of the suffix -spinal. Descending tracts involve 2 neurons: an upper motor neuron and a lower motor neuron.

- The corticospinal tracts
- The tectospinal tract
- The lateral and medial reticulospinal
- The vestibulospinal tract

At the level of the **Lateral Funiculus** the following tracts can be found:

- Descending Fasciculi:
  - Crossed pyramidal tract (lateral cerebro-spinalis tract)
  - Rubro-spinal fasciculus (of von Monakow; prepyramidal tract)
  - Olivo-spinal fasciculus (of Helweg)
- Ascending Fasciculi:
  - Direct spino-cerebellar tract (posterior spino-cerebellar tract of Flechsig): for the unconscious muscle sense
  - Crossed spino-cerebellar tract (anterior spino-cerebellar tract of Gowers)
  - Lateral spino-thalamic fasciculus: conducts impulses of pain, temperature
  - Spino-tectal fasciculus
  - Lateral vestibulo-spinal tract
- Tecto-spinal tract (of Lowenthal)
- Reticulo-spinal tract
- Spino-olivary tract
- Spino-vestibular tract

At the level of **Posterior Funiculus**, the following tracts can be found:

- Fasciculus gracilis (tract of Goll) and Fasciculus cuneatus (tract of Burdach), which conduct: impulses of conscious and unconscious muscle sense and impulses of tactile discrimination.
  - Gracilis fasciculus: vibration, visceral pain, deep and discriminative touch (touch whose location one can precisely identify), proprioception from the midthoracic and lower parts of the body. (Proprioception represents the sense of the position and movements of the body)
  -
- Posterior proper fascicles:
  - Septo-marginal fascicle
  - Comma-shaped fasciculus in the lateral part of the fasciculus cuneatus: in the cervical and superior thoracic regions
  - Triangular strand in the posterior-medial part of the fasciculus gracilis: in the conus medullaris
  - Dorsal peripheral band on the posterior surface of the funiculus: in the inferior thoracic region

At the level of the **Anterior Funiculus**, the following 5 tracts can be found:

- 3 descending tracts (*descending fasciculi*):
  - Direct pyramidal tract (anterior cerebro-spinal fasciculus of Turck and Barnes)
  - Anterior vestibulo-spinal fasciculus
  - Anterior tecto-spinal fasciculus (of Lowenthal)
- 2 ascending fasciculi:
  - Anterior reticulo-spinal fasciculus



- Anterior spino-thalamic fasciculus: pain, temperature, pressure, tickle, itch, and light or crude touch (*Light touch represents the sensation produced by stroking the skin with a feather, without indenting the skin; crude touch represents non-discriminative touch= feeling a touch without being able to localize it*)

The motor fascicles are less important as they descend and the sensitive ones are more important as they ascend: in the superior part of the spinal cord the white substance is better represented whereas in the inferior part (below 4) the grey substance is better represented.

## **VASCULARIZATION**

The arterial blood supply of the spinal cord consists of 2 arterial systems with distinct embryological origin. The first arterial system comprises the anterior and posterior spinal arteries (with origin in the vertebral artery) which are parallel to the spinal cord axis. The second arterial system consists of the radicular arteries, which have a transverse disposition. Between these two systems multiple anastomoses can be found.

There are 4 spinal arteries: 2 anterior spinal arteries and 2 posterior spinal arteries. The anterior ones form anterior spinal trunk which pass through the anterior median fissure and end at the level of C5 and C6. The two posterior spinal arteries are united by anastomoses and form arterial circles around the spinal cord and vascular columns.

The radicular arteries follow the course of the spinal nerve roots inside their corresponding foramen. The spinal cord is very well vascularized at the level of the enlargements, hence the cervical enlargement artery and the lumbosacral enlargement artery.

The veins are disposed just like the arteries into 2 vascular systems: an intramedullary system and one system surrounding the spinal cord.

The anterior spinal veins and the posterior spinal veins form a network around the spinal cord which follow the spinal nerve roots. The veins drain into the anterior internal vertebral venous plexus and into the posterior internal vertebral venous plexus, which can be found in the epidural space. These plexuses have many anastomoses on the posterior surface of the vertebral bodies.

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