Lecture 9

General Medicine_3rd semester

MICROSCOPIC STRUCTURE AND DEVELOPMENT OF THE CENTRAL AND PERIPHERAL NERVOUS SYSTEM

- Structure of gray matters in the CNS: Iso- and allocortex, cerebellar cortex, spinal cord
- Meninges
- Ganglia and peripheral nerves
- Overwiev of development of the brain and spinal cord including histogenesis of the neural tube

two divisions of the nervous system are distinguished:

- the **central nervous system** (CNS) - includes the spinal cord and brain

- the **peripheral nervous system** (PNS) - involves peripheral nerves and ganglia = small aggregations of neurons associated with cerebrospinal or autonomic nerves

Histologically, the nervous system consists of three structurally different components:

- the **nerve tissue**
- **blood vessels**: capillaries, arterioles and venues that densely penetrate the nerve tissue,
- the **connective tissue** that serves to protection; it may be differentiated into:
  - **meninges** - forming envelopes of the CNS
  - **epi-, peri-** and **endoneurium** - connective tissue occurring within nerves or on their surfaces
  - **capsules** surrounding the ganglia

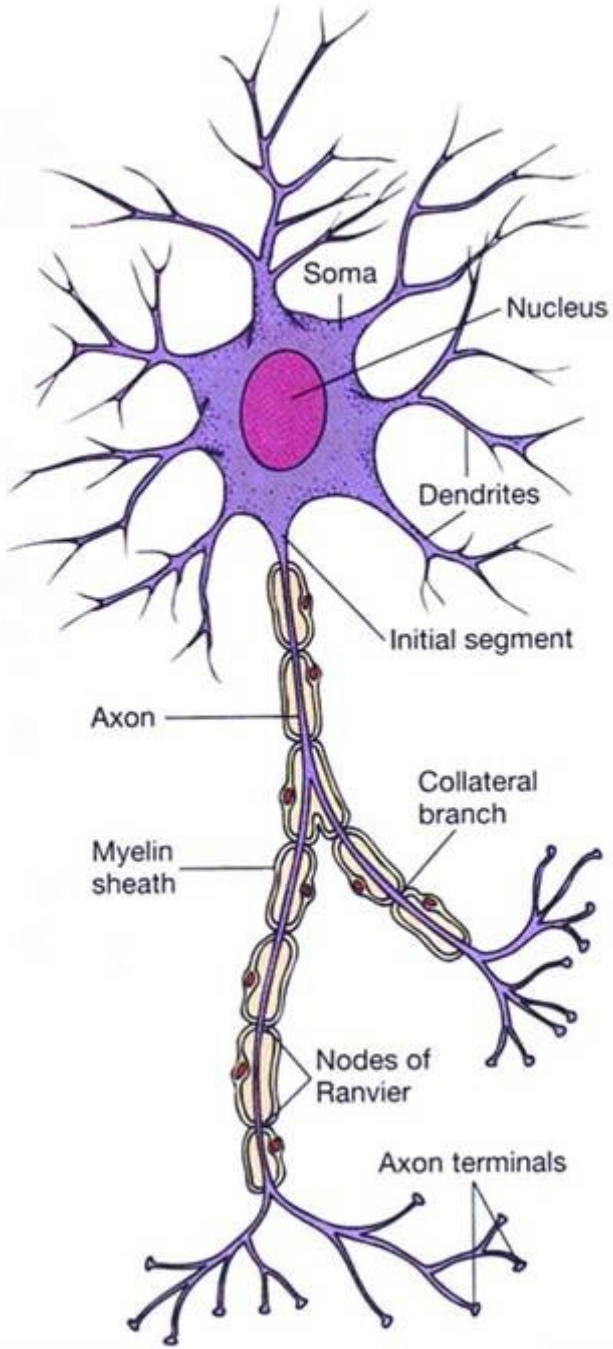
Basic structural characteristics of the nerve tissue

it is composed of
the nerve cells or **neurons** and special supporting cells called **neuroglia**

neurons - cells in which two properties of protoplasm are developed to a great degree: **irritability** (the capacity for response to physical and chemical agents with the initiation of an impulse), **conductivity** (the ability to transmit impulses from one locality to another)

- the cell body or **perikaryon**
- **dendrites** (their number varies in a great range, theoretically from one to several hundreds; they are usually short and conduct impulses to the perikaryon)
- the **axon** (neurite) - it is mostly very long and **always single**, it conducts the impulses away from the respective cell.
- twig-like branchings or **arborizations** (**telodendria**) that touch the perikarya, dendrites or axons of one or more neurons

synapses



Synapses

unidirectional transmission of signals

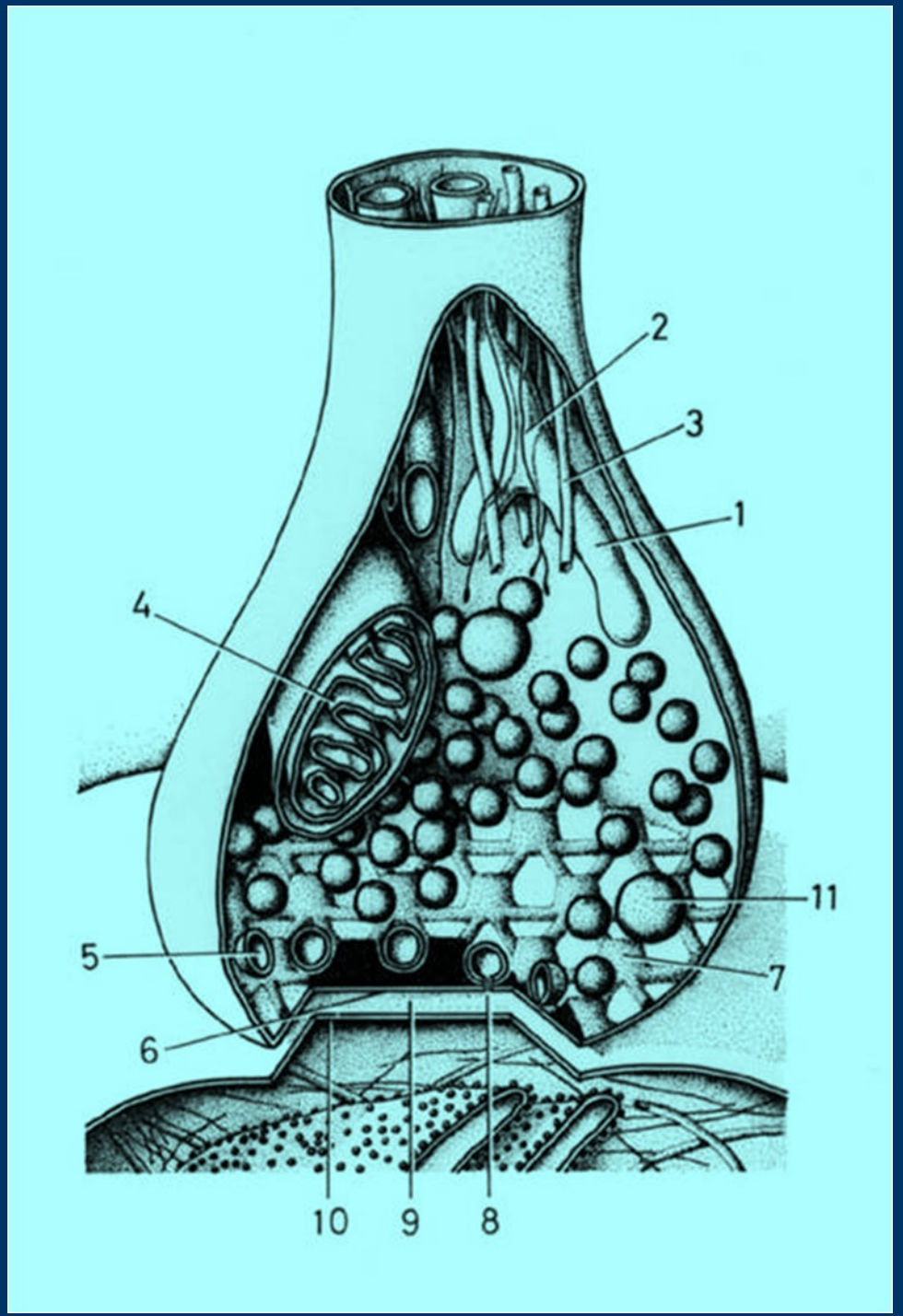
synapses

chemical

electric

Chemical synapse

- **presynaptic terminal (knob)**
- **synaptic cleft**
- **postsynaptic terminal (membrane)**



neuroglial cells are classified

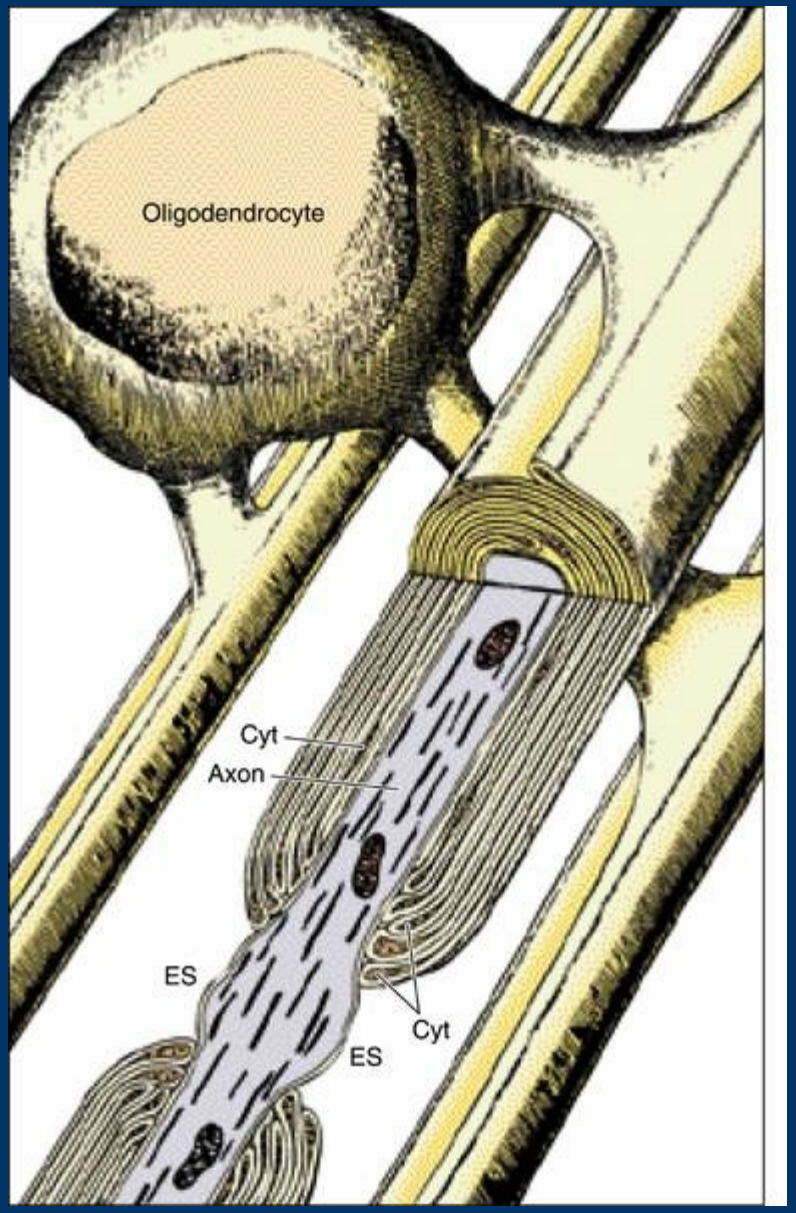
- **central glia:**
  astrocytes, oligodendrocytes, microglia and ependyma
- **peripheral glia:** cells of Schwann, satellite cells

Astrocytes - are the largest of neuroglial cells, are the protoplasmic and the fibrous ones, both cell types send off numerous processes that extend to blood vessels and to neurons where they expand (**end feet**)

hematoencephalic barrier

the protoplasmic astrocytes prevail in gray matter while the fibrous ones in white matter

Oligodendrocytes - are found in particular in white matter where are arranged in rows between the myelinated fibres
oligodendrocytes produce the myelin of myelinated axons in white matter

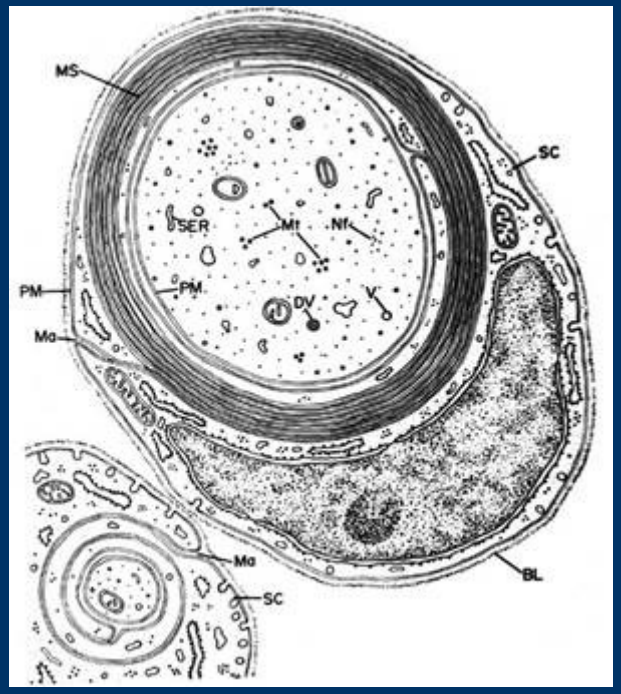


Microglia - are the smallest of all glial cells
they have smaller and elongated cell bodies that are continuous with one or two thick processes that branch freely in gray matter

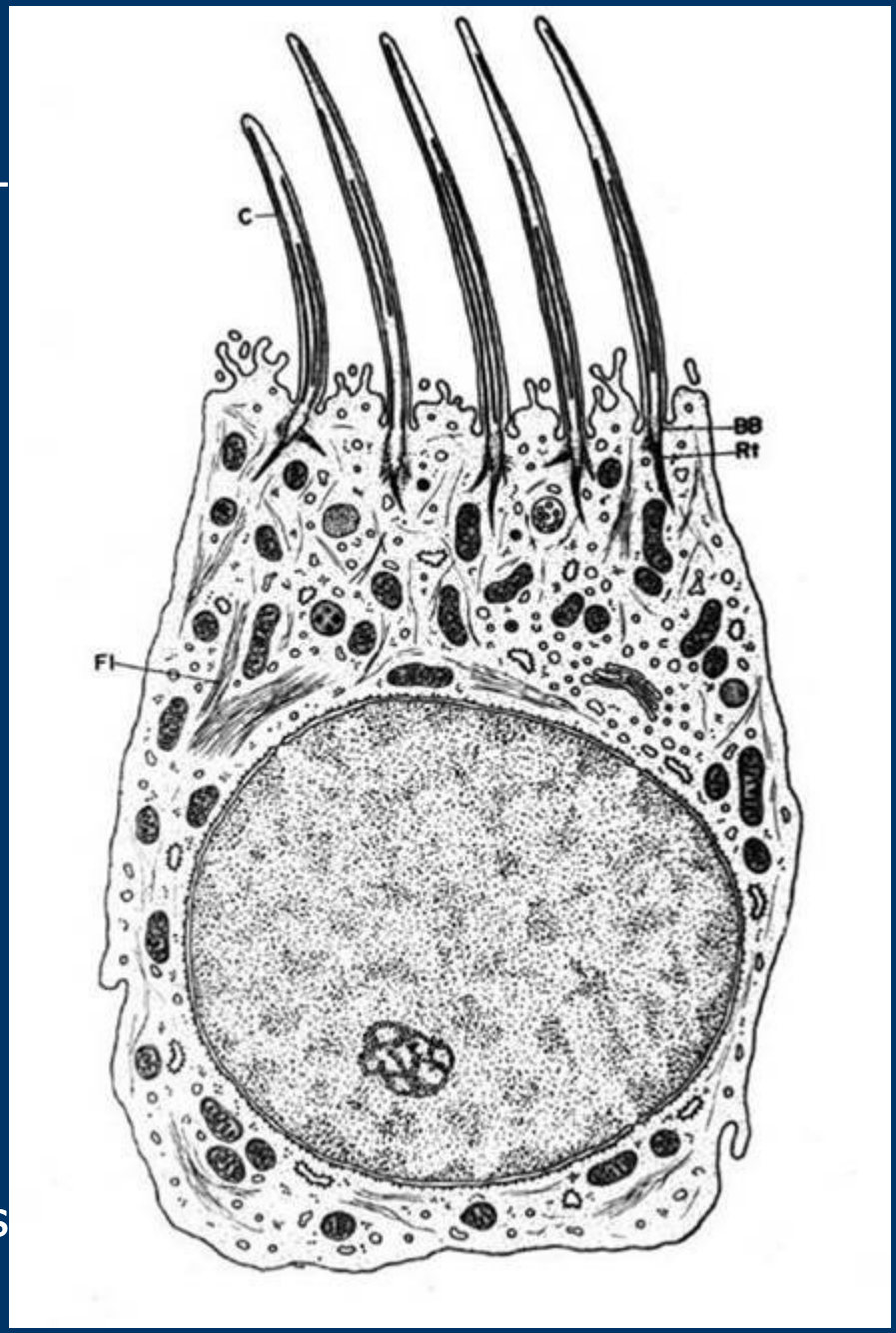
is of mesenchymal origin and is **phagocytic**

Ependyma - forms a lining of ventricles and the spinal canal
it consists of cubical or columnar cells
the eponym is closely associated with pia mater that is extremely vascular and forms so-called **choroids plexus**

Schwann's cells - accompany myelinated fibres in peripheral nerves



Satellite cells - are found in spinal or autonomic ganglia where surround cell bodies of neurons in a single layer



THE CENTRAL NERVOUS SYSTEM

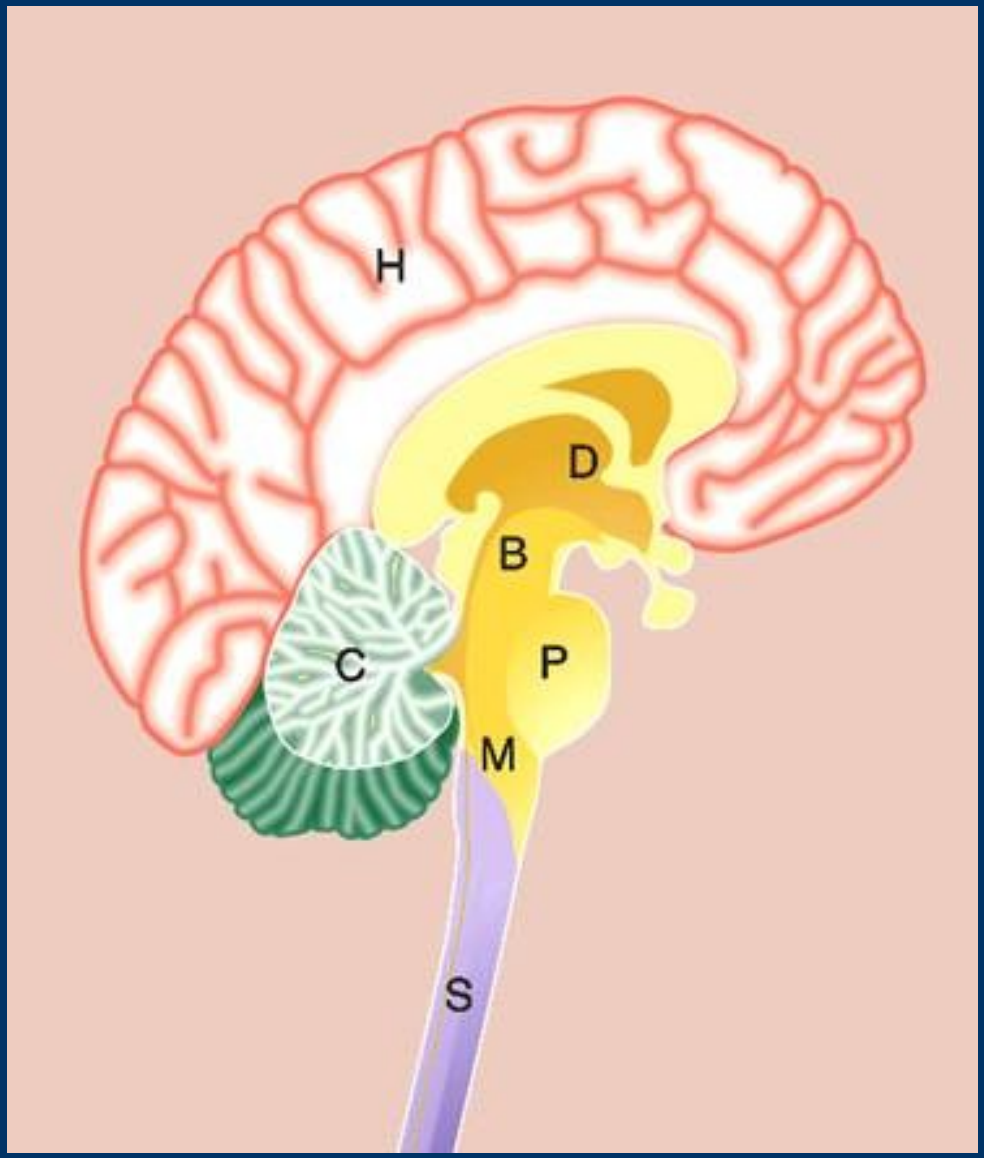
CNS involves the spinal cord and brain

brain:

- brain stem (myelencephalon, metencephalon, mesencephalon, diencephalon)
- cerebellum
- telencephalon

are consisted of two matters differing in the appearance and structure

the **gray** and
the **white matter**



the **gray matter** contains cell bodies, nonmyelinated fibres, associated neuroglial cells (astrocytes, microglia) and very dense capillary network

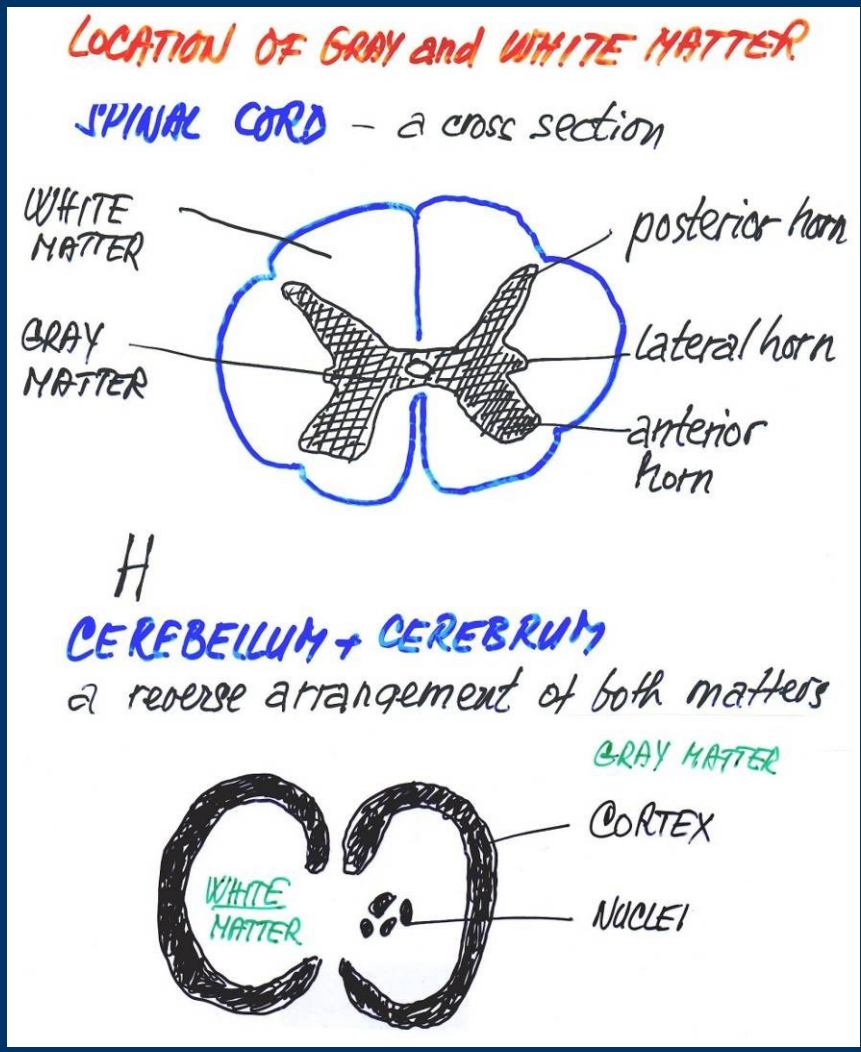
the **white matter** is composed of only myelinated axons of nerve cells plus oligodendrocytes and blood capillaries (lesser than in gray matter)

Distribution of the gray and white matter

spinal cord - the gray matter occurs in the core of the organ, resembling the general form of an H on cross sections (the white matter is peripherally)

cerebrum and cerebellum - the gray matter is superficially forming an outer cover designated as the **cortex**, the white one occupies the inner core

islands of the gray matter scattered the white matter in the centre are **nuclei**



Description of gray matters in the CNS

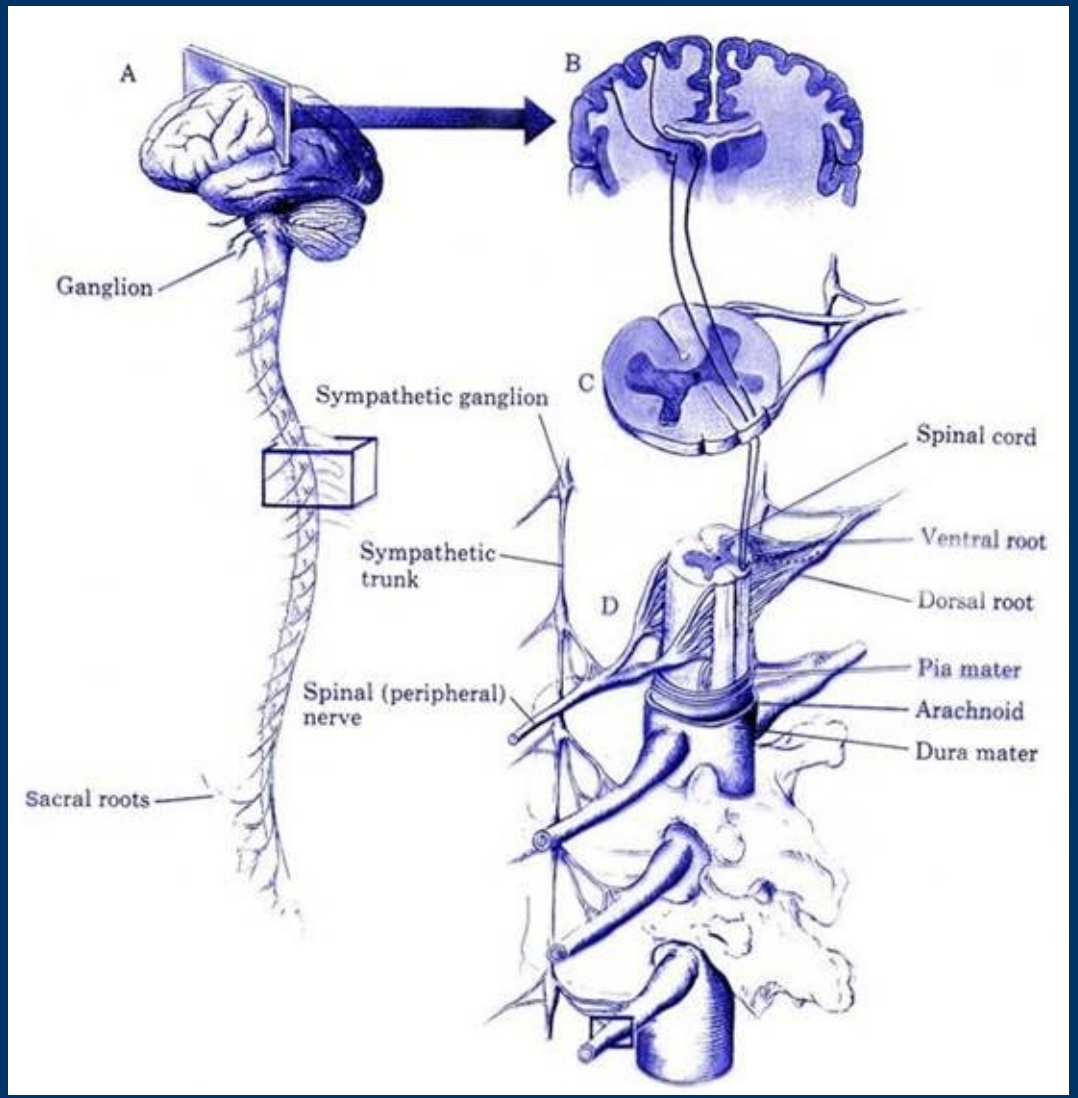
4 locations: as the gray matter of the spinal cord, as the cerebellar cortex, as the cerebral cortex (telencephalon), and as the cerebellar and cerebral nuclei

SPINAL CORD

the gray matter is placed centrally and resembles the H-shaped area on each side, the limbs of the capital H are termed the **anterior** and **posterior horns**

in addition, extending throughout the thoracic segments and first lumbar ones, there are **lateral horns** of gray matter

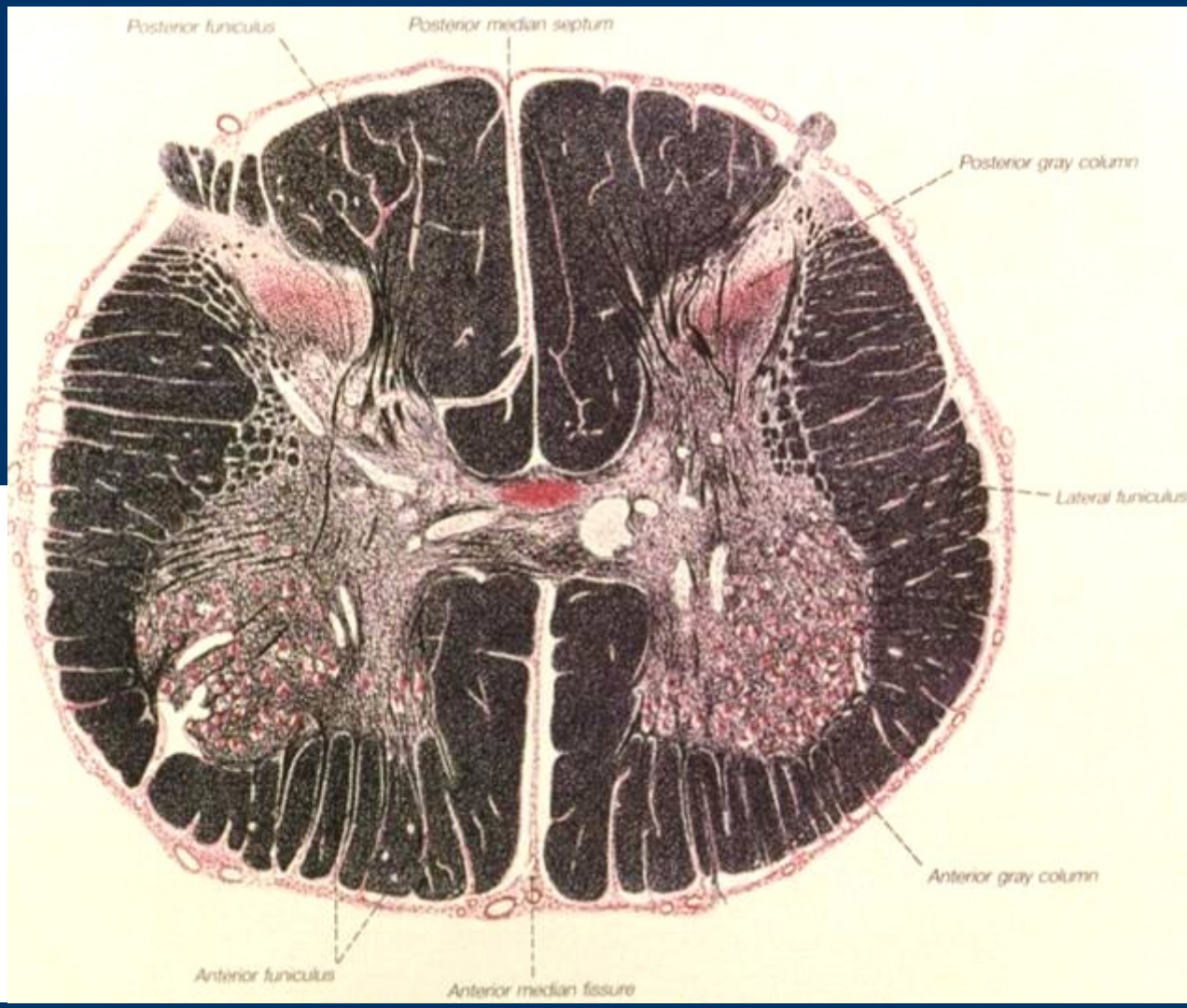
central canal, lined by ependyma, is situated in the horizontal bar of the H



the **gray matter**

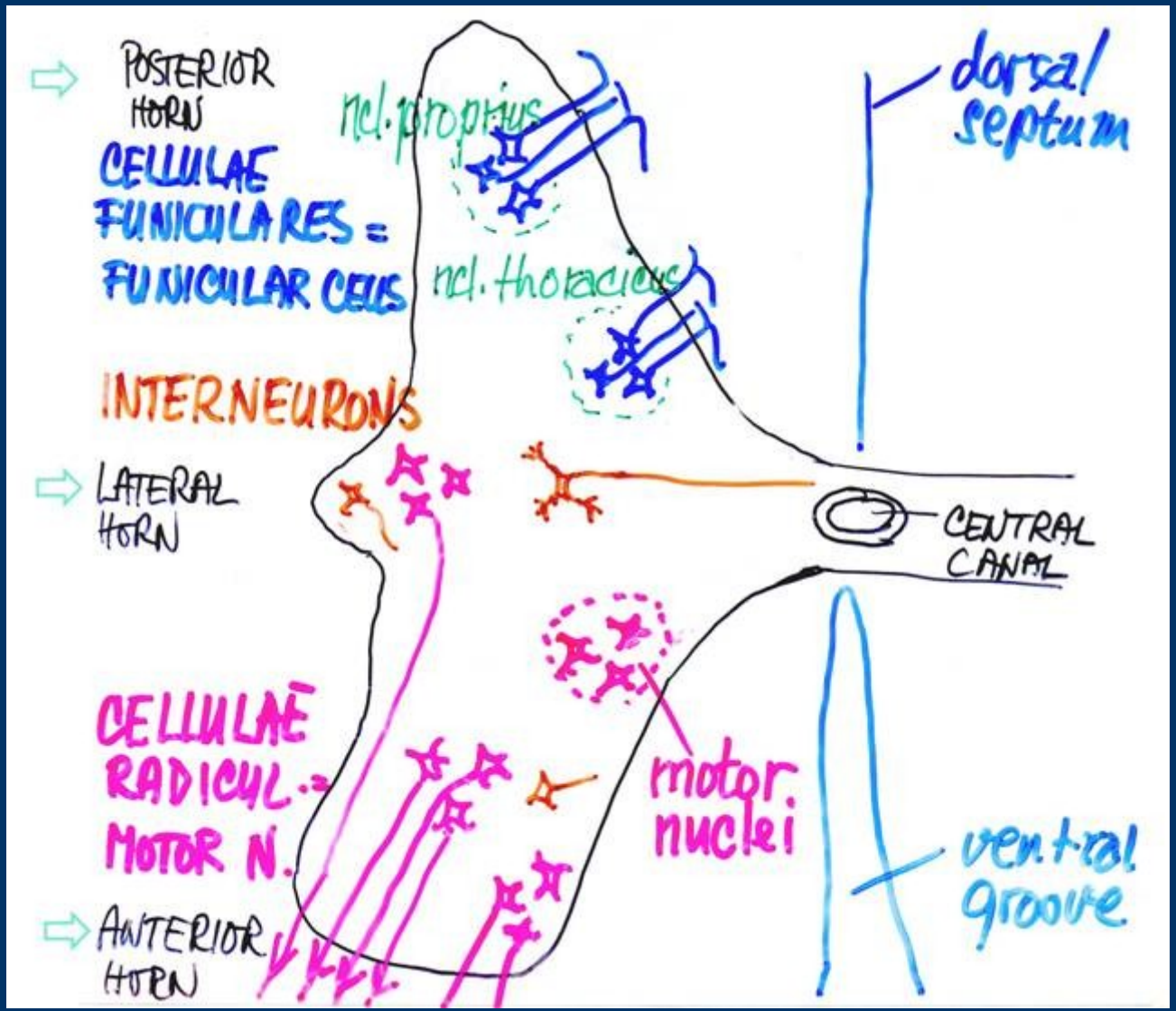
the **white matter**

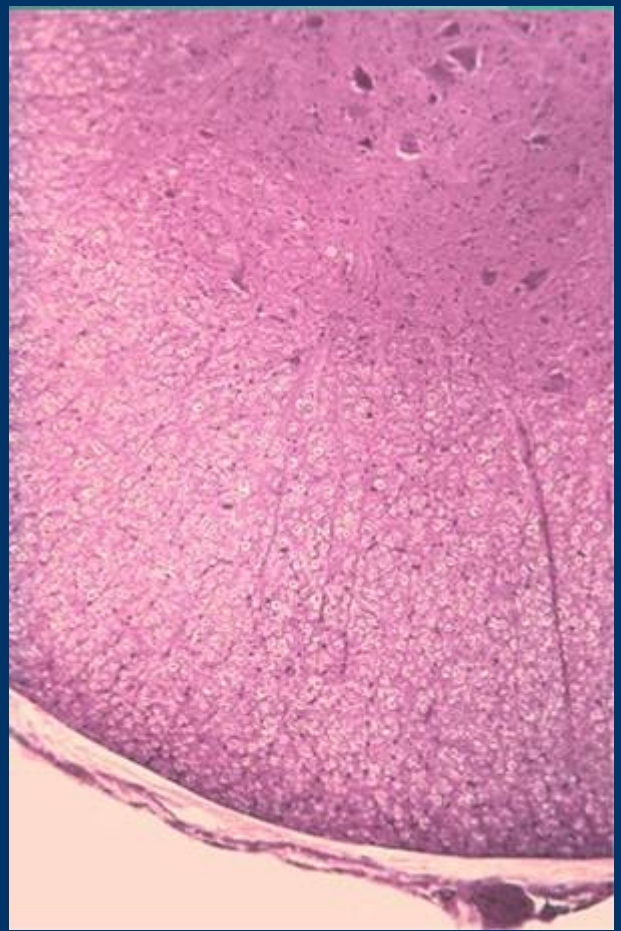
- 3 fasciculi (anterior, lateral and posterior)

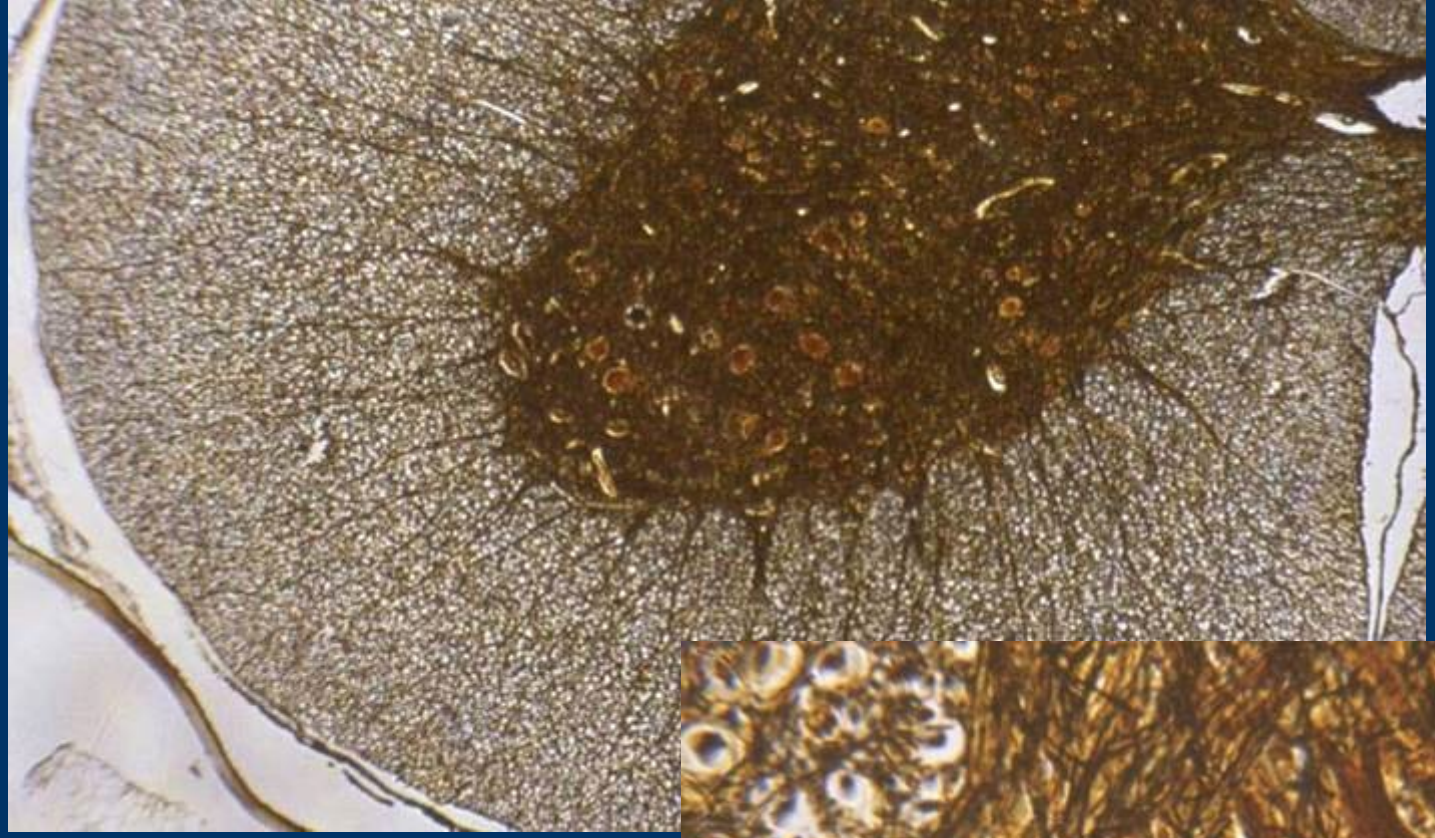


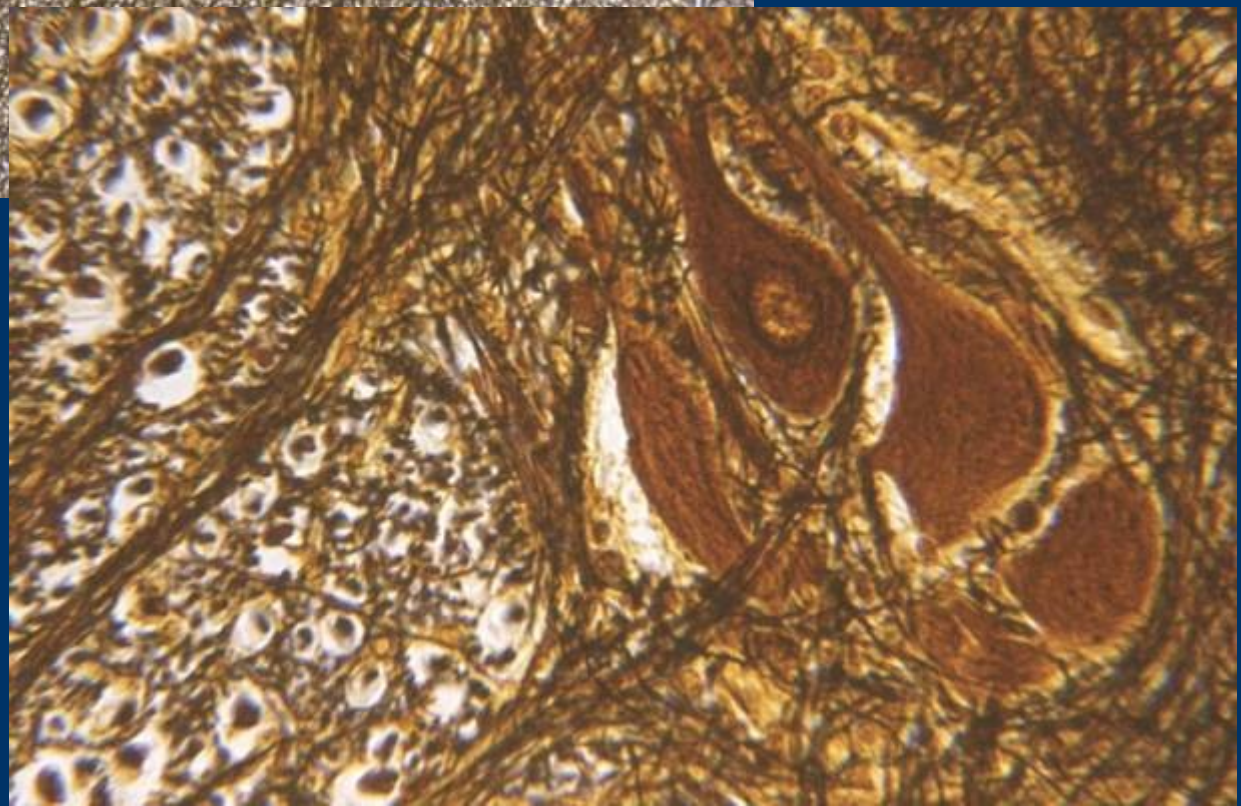
Nerve cells of the gray matter are multipolar and of 3 types:

- **motor neurons** - in the anterior (ventral) horns; stellate shape, 150 um in diameter and send off long and myelinated axons ending on muscle fibres of striated voluntary muscles
- **funicular cells** (cellulae funiculares) - mainly in the posterior horns; the axons of the funicular cells enter the white matter and run to the brain stem where end
- **interneurons** (intercalated neurons) - small neurons diffusely distributed among motor and funicular cells









CEREBELLUM

vermis and 2 hemispheres

surface area is cca 0,10 - 0,15 m^2

gray matter occurs in 2 locations:

a thin **cortex** at the surface of cerebellar hemispheres

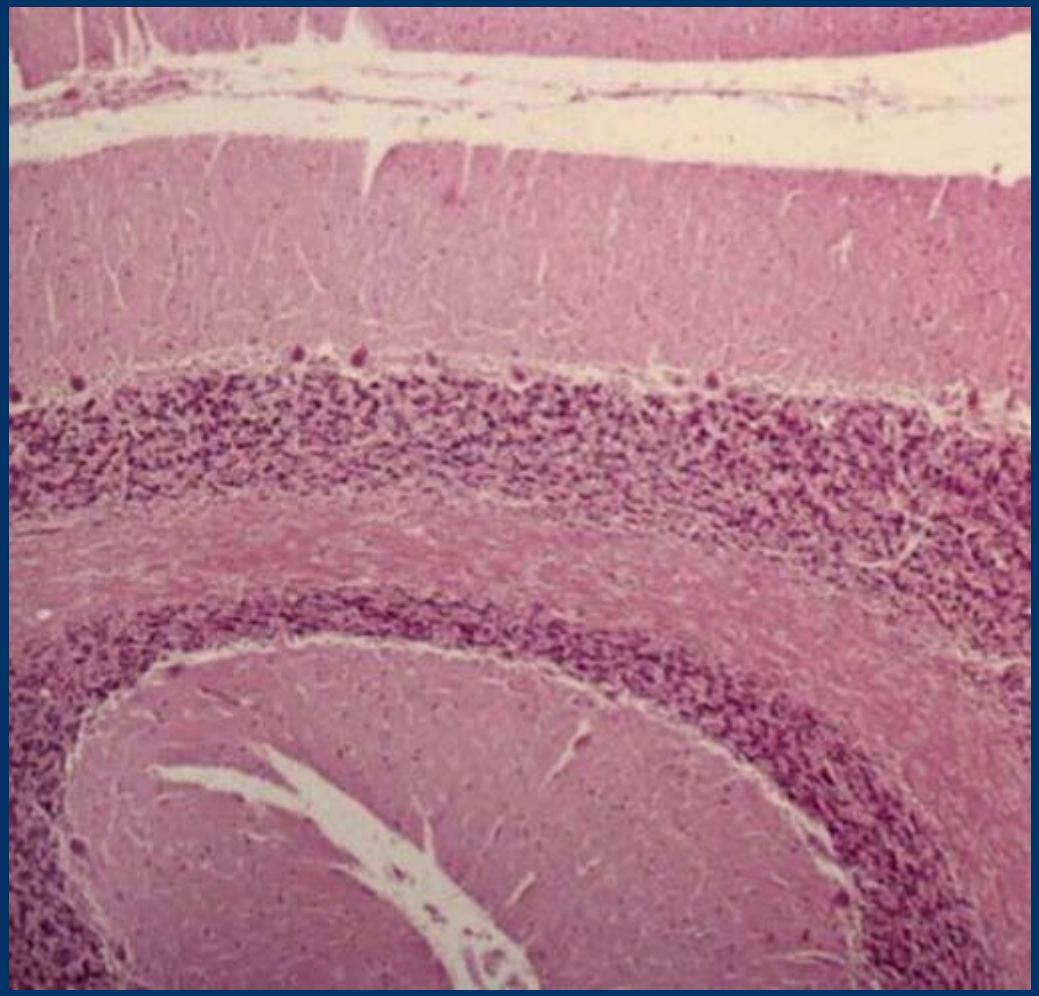
and within the centrally placed white matter where forms several small collections of nerve cells called the **cerebellar nuclei**

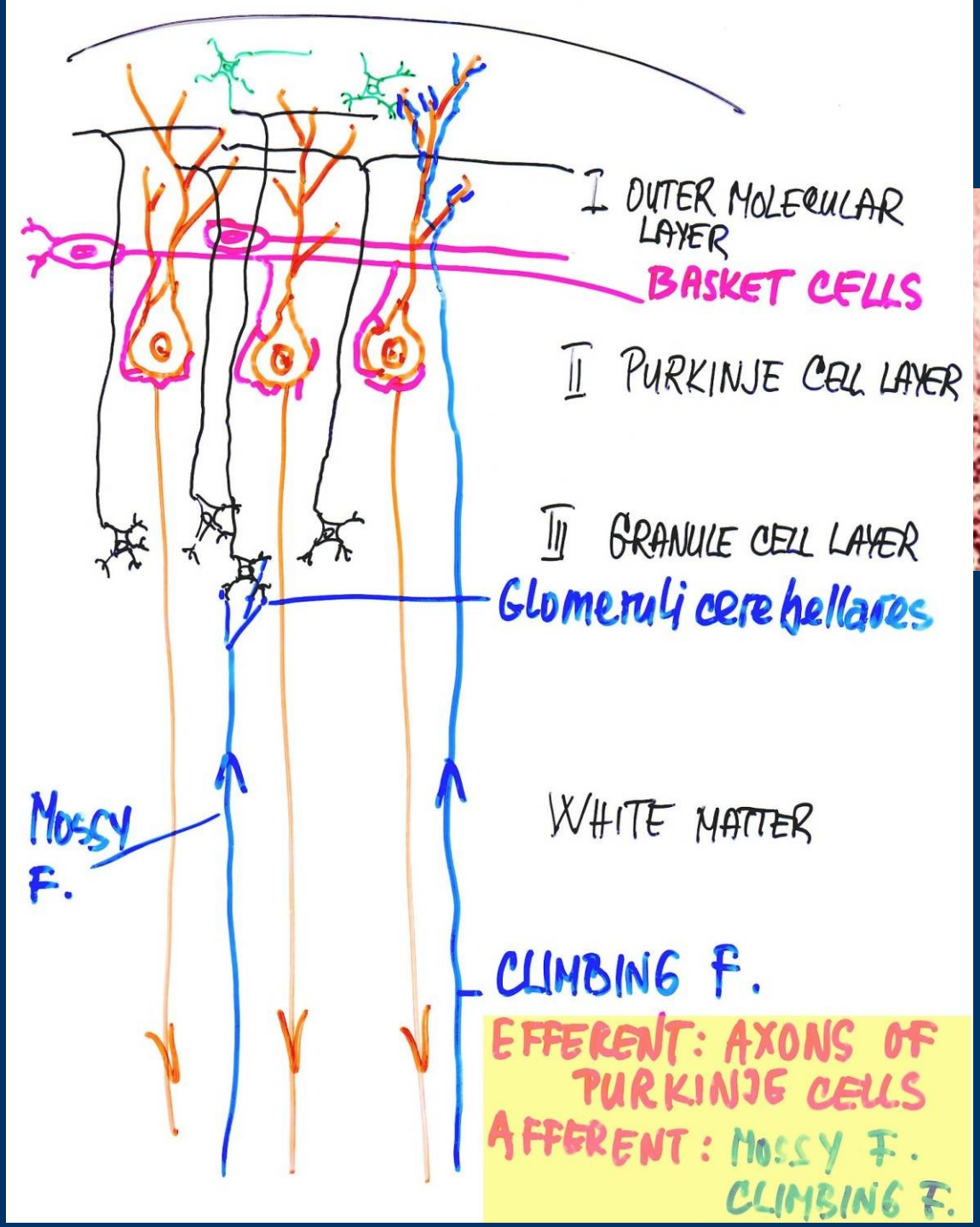
white matter: fills spaces between cortex and nuclei

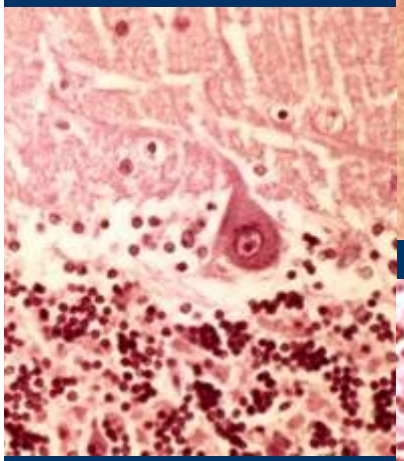
on sections, it forms „arbor vitae"

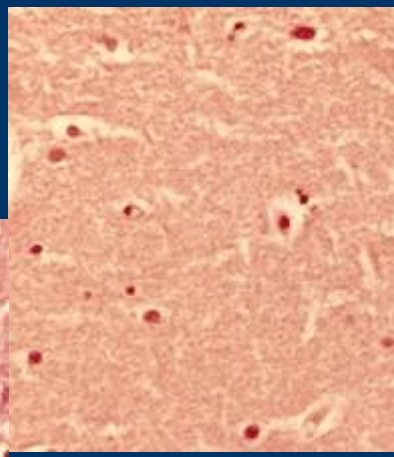
in sections, the cerebellar cortex shows 3-layered structure:

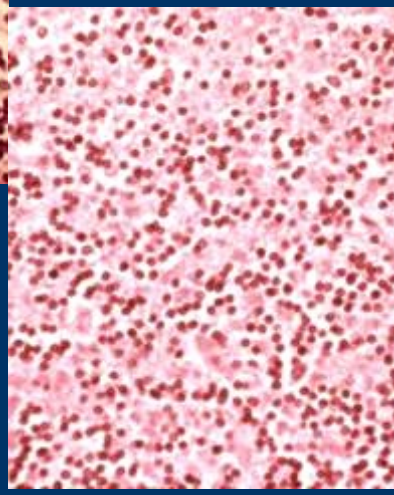
- an **outer molecular layer** (stratum moleculare)
- **Purkinje cell layer** (stratum gangliosum)
- **granule cell layer** (stratum granulosum)











efferent fibers - axons of Purkinje cells

afferent fibers of 2 types:

- **mossy fibres** (they form synapses on cells of granule cell layer)
- **climbing fibers** (take part in synapses on dendrites of Purkinje cells)

TELENCEPHALON

gray matter:

- **cortex telencephali** (on the surface)
- **nuclei**

thicknes of the cortex 1,5 - 5 mm, area 0,20 – 0,25 m^2

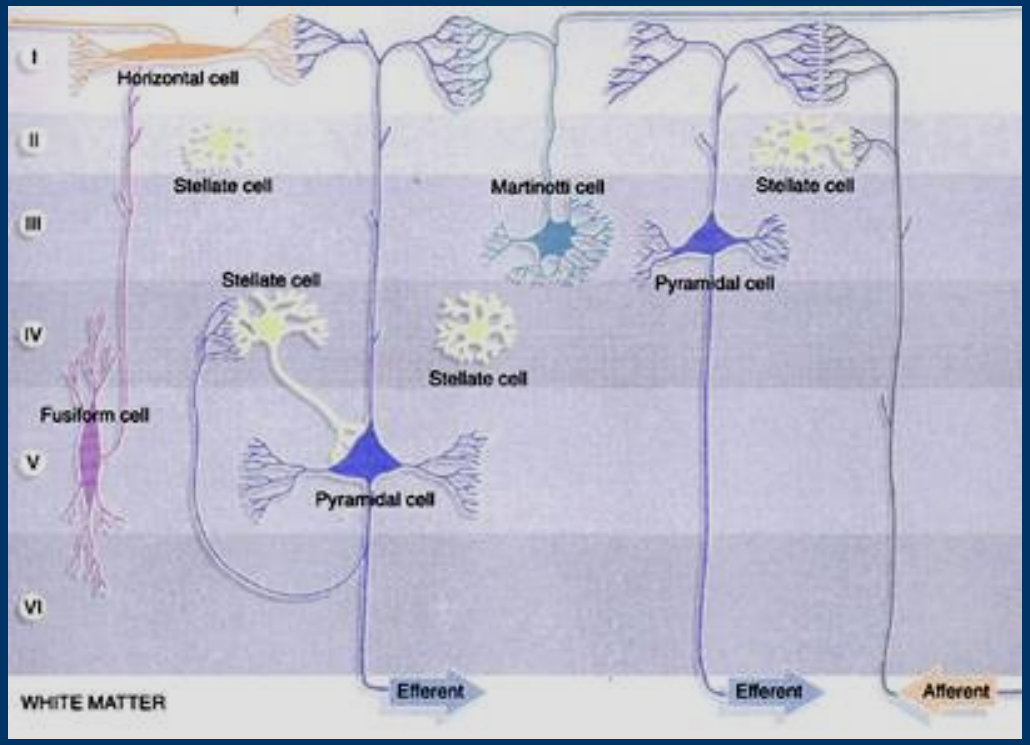
white matter: between cortex and nuclei

Cortex telencephali/cerebri)

- **isocortex** - asi 11/12
- **allocortex**

Isokortex (neocortex)

8–9 milliard cells



Neurons:

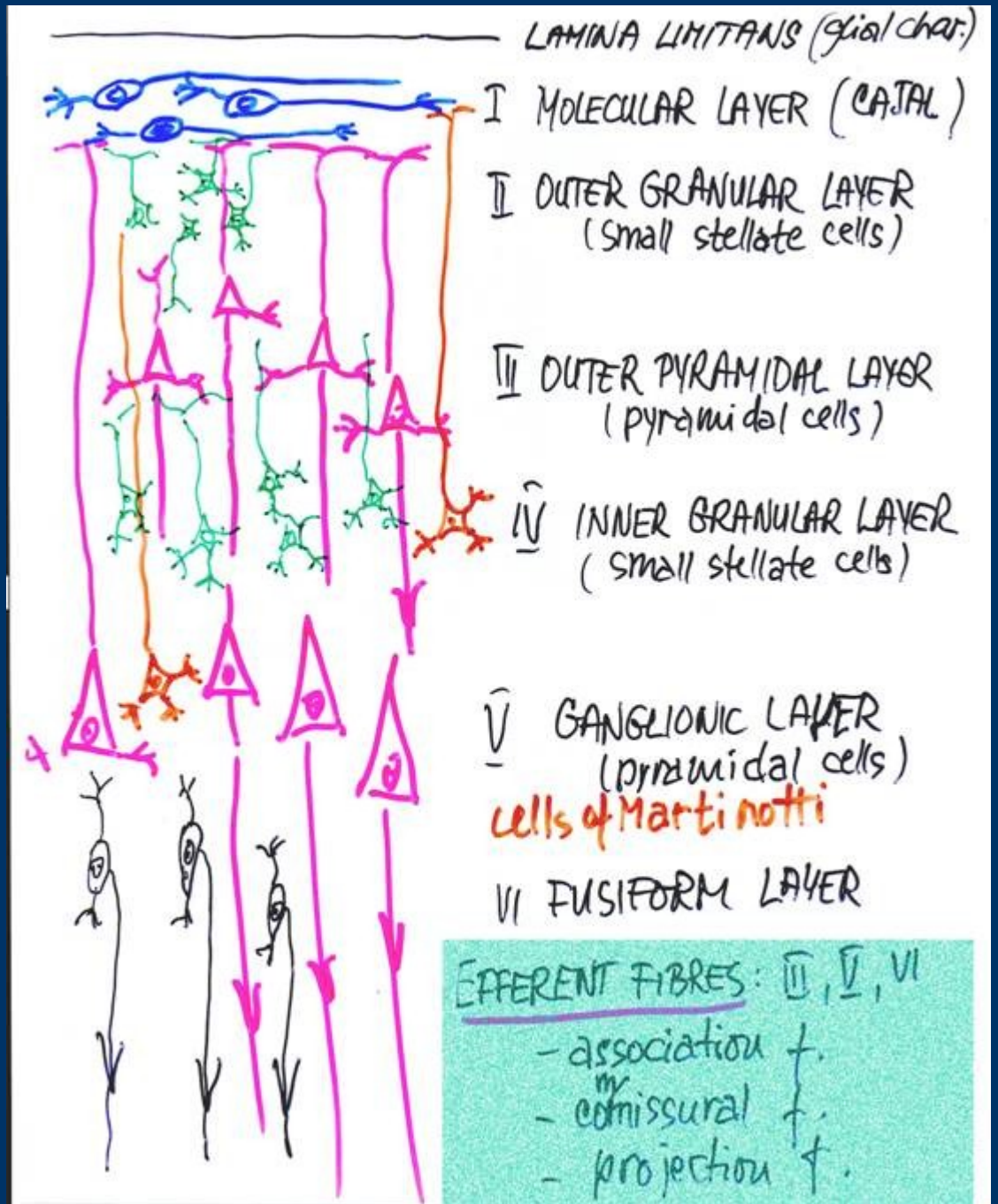
- pyramidal cells

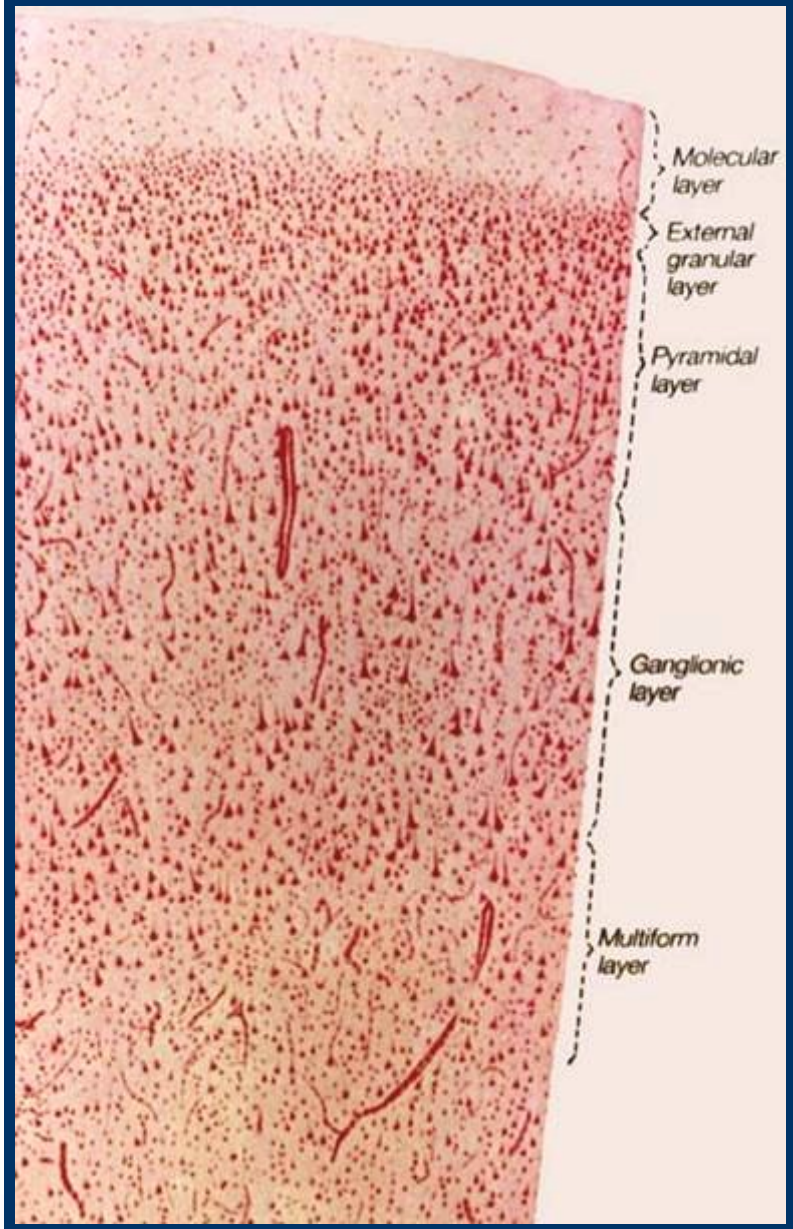
- fusiform cells

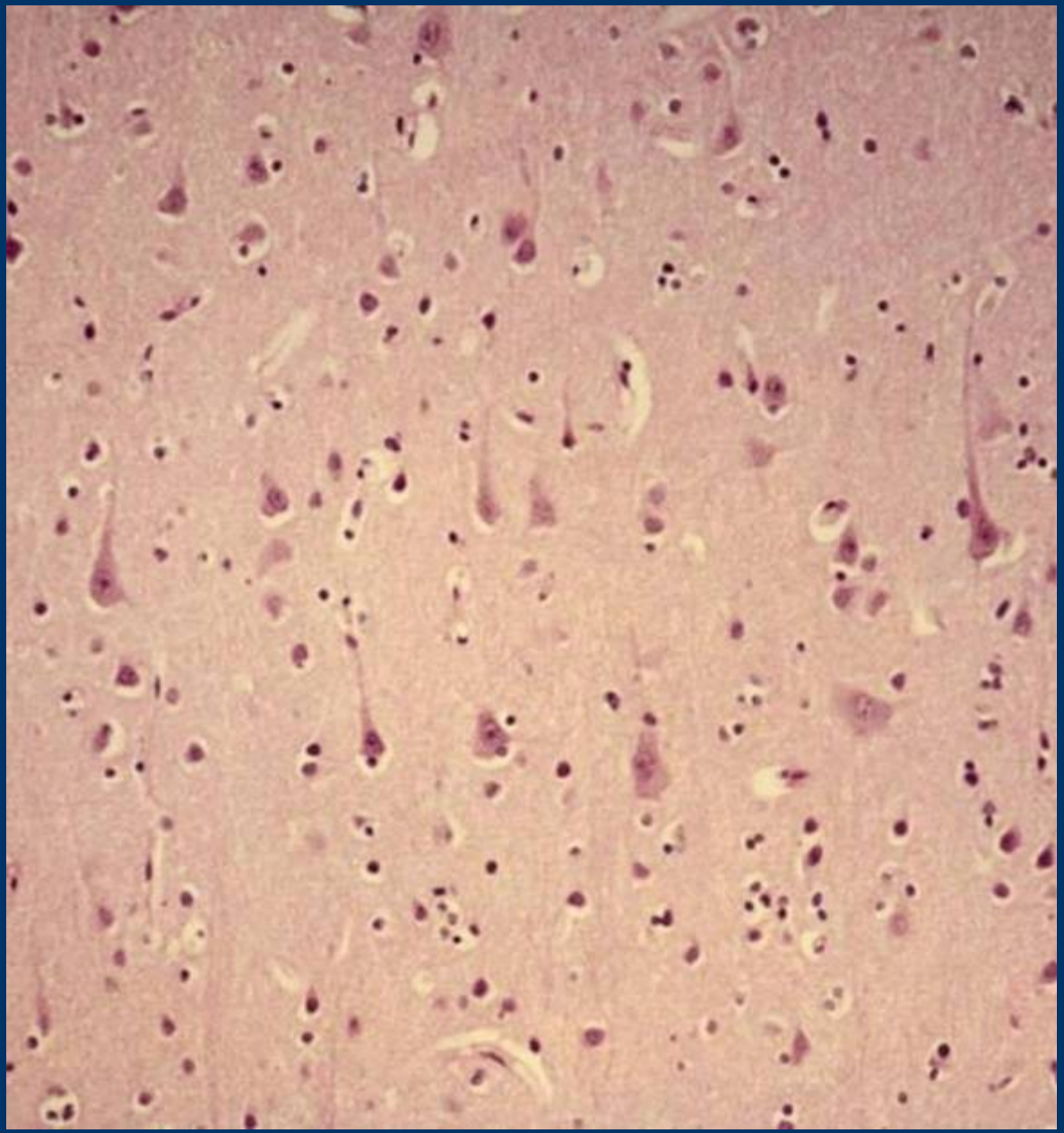
- stellate (granule) **cells**

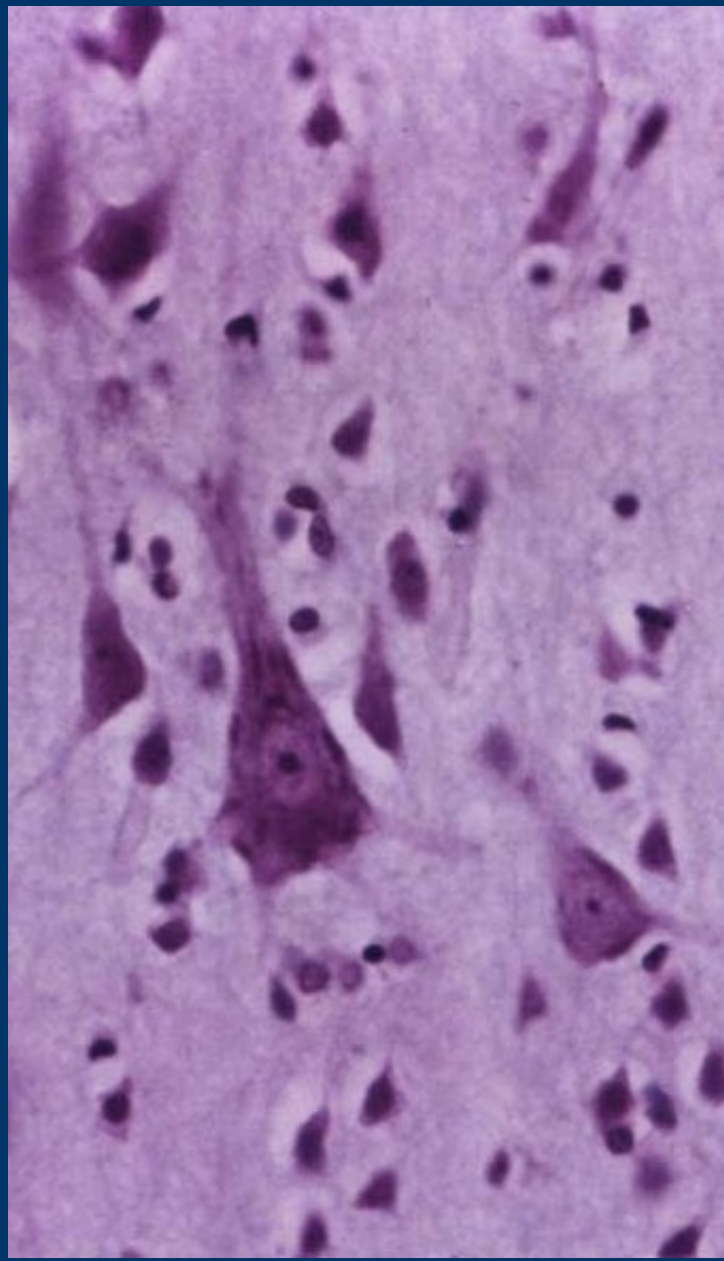
- special neurons: horizontal cells (cells of Cajal) and **vertical cells (cells of Martinotti)**

neurons are organized by a laminated manner in 6 layers









The axons of cells in the outer pyramidal layer, ganglionic layer and polymorphic (fusiform) layer leave the cortex, enter the white matter and connect different regions of the cortex
in the same hemisphere - **association** fibres or connect areas of the cortex of one hemisphere with corresponding areas of opposite hemisphere
- **commissural** fibres
or connect the cortex with lower nervous centres - **projection** fibres

Maps of the izocortex

Although 6-layered organization is found in the whole isocortex, the thickness of individual layers and their relative proportions as well as density (total number) of neurons, glial cells, fibers and blood vessels in them show more or lesser conspicuous differences among cerebral lobes and gyruses

the differences have been extensively studied in 30 and 40 years of last century on serial sections of cerebral hemispheres and resulted in construction of **special maps of the isocortex**

Maps are termed according to information involved in them as follows:

- **cytoarchitectural maps -** describe the density of perikarya,
- **myeloarchitectural maps -** show the density of myelinated fibers,
- **glioarchitectural maps** - concern the type and density of glial cells,
- **angioarchitectural maps** - describe the density of blood capillaries or vascu-larization,
- **synaptoarchitectural maps** - show the density synapses in the isocortex

Allocortex

shows more simple structure than the isocortex, it approximately corresponds to primitive part of telencephalon known as the **rhinencephalon**

MENINGES

The CNS is protected from the external trauma by bony encasements (skull and vertebral column) and by three membranous investments.

- the outermost, robust **dura mater**
- the middle, spider web-like **arachnoid** and
- the innermost, delicate, vascular **pia mater**

Dura mater

includes: a) the cranial dura, b) the spinal dura

The cranial dura consists of two layers:
- an outer **endosteal layer** of dense connective tissue, adhering to the inner surface of the bones of the skull
- an inner **meningeal layer**, consisting of a thinner fibrous tissue membrane, which is covered on its inner surface by mesothelial cells.

These two layers separate each other at certain locations to form the extensive **venous (dural) sinuses**.

The spinal dura is a continuation of the inner layer of the cranial dura.

Arachnoid

is a delicate, avascular membrane lying immediately beneath the dura

it consists of 2 components:
- a thin, **connective tissue component** being in contact with the dura
- a network of delicate **trabeculae**, which insert to the pia mater

they are covered with flat or low cuboidal epithelium

the cavity between the arachnoid and pia mater is a **subarachnoid space** and is filled with cerebrospinal fluid (CSF)

Pia mater

the innermost layer is highly vascularized, adheres closely to the brain and spinal cord and follows all of their surface irregularities
- **inner layer** of elastic and reticular fibers, which are firmly attached to the under-lying nervous tissue,
- **superficial layer** receiving the trabeculae from the arachnoid

iIts external aspect is covered with simple squamous cells of mesodermal origin

Cerebrospinal fluid (CSF) - is a filtrate of blood; it is produced in choroid plexus (folds of pia mater and blood vessels covered with the ependymal cells), located in the ventricles of the brain

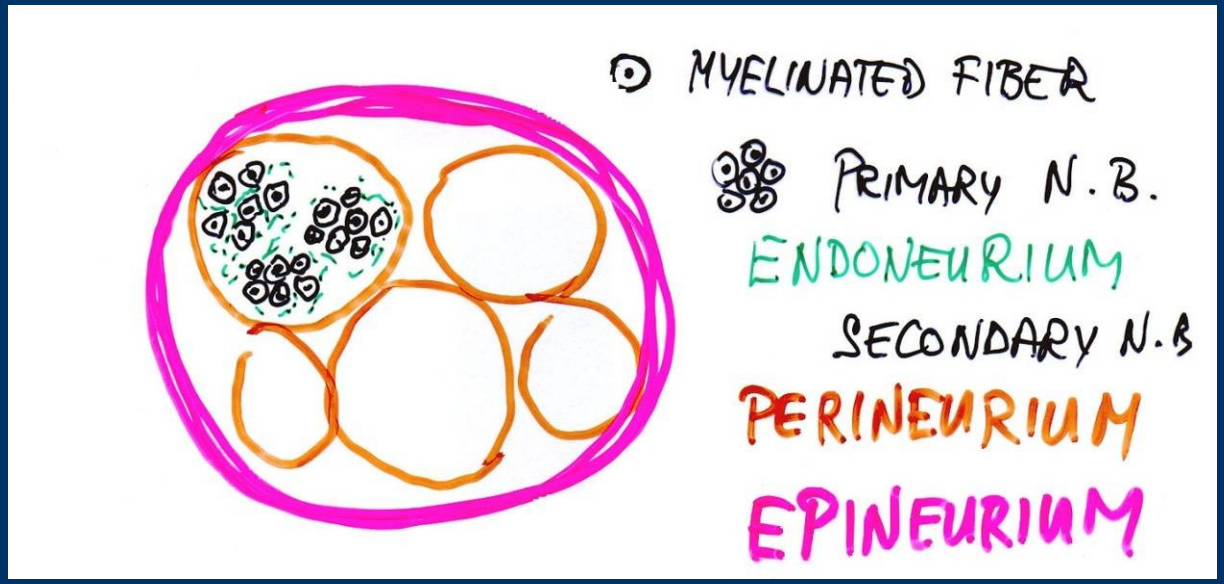
THE PERIPHERAL NERVOUS SYSTEM

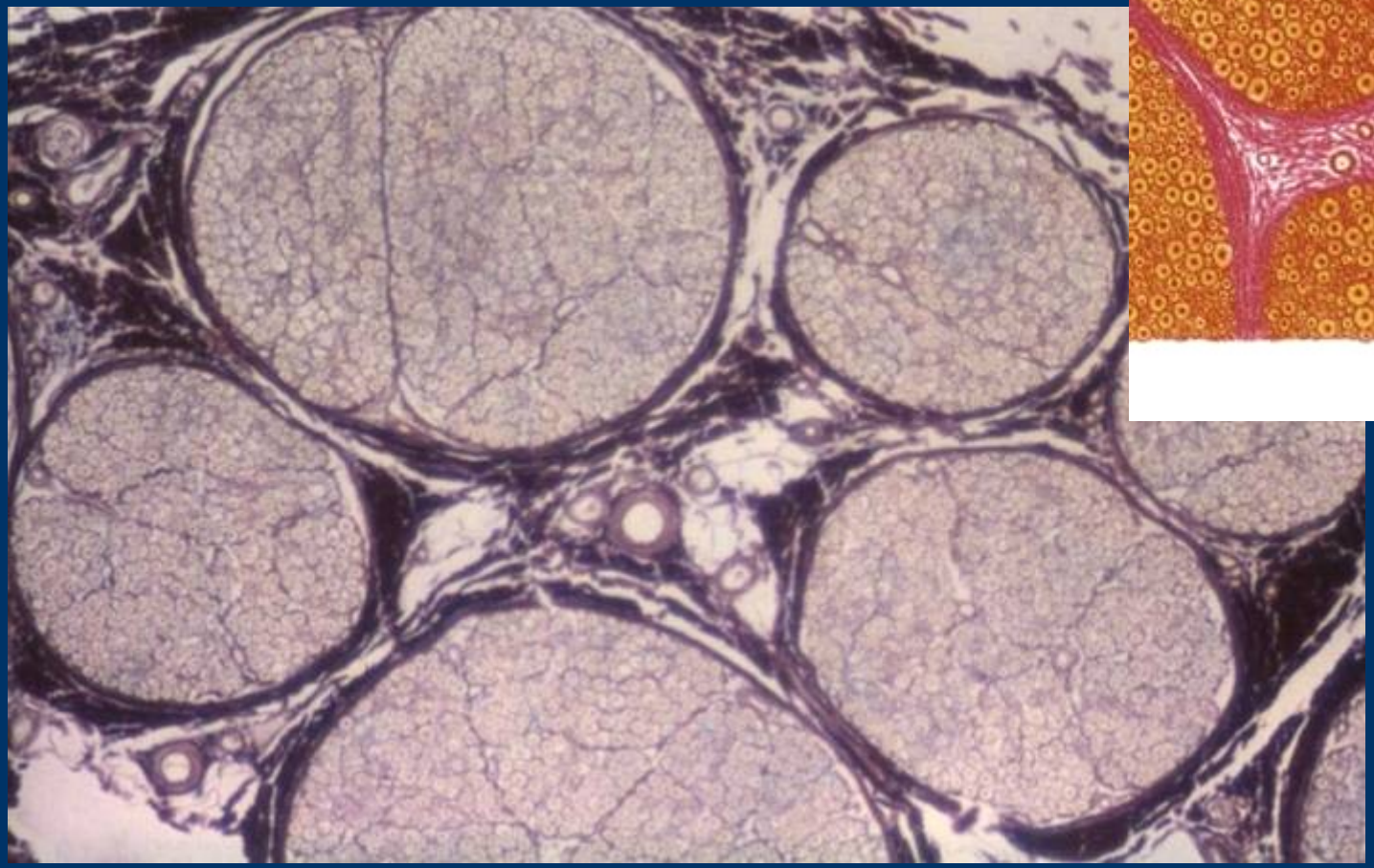
includes nerves and ganglia of the peripheral nerves

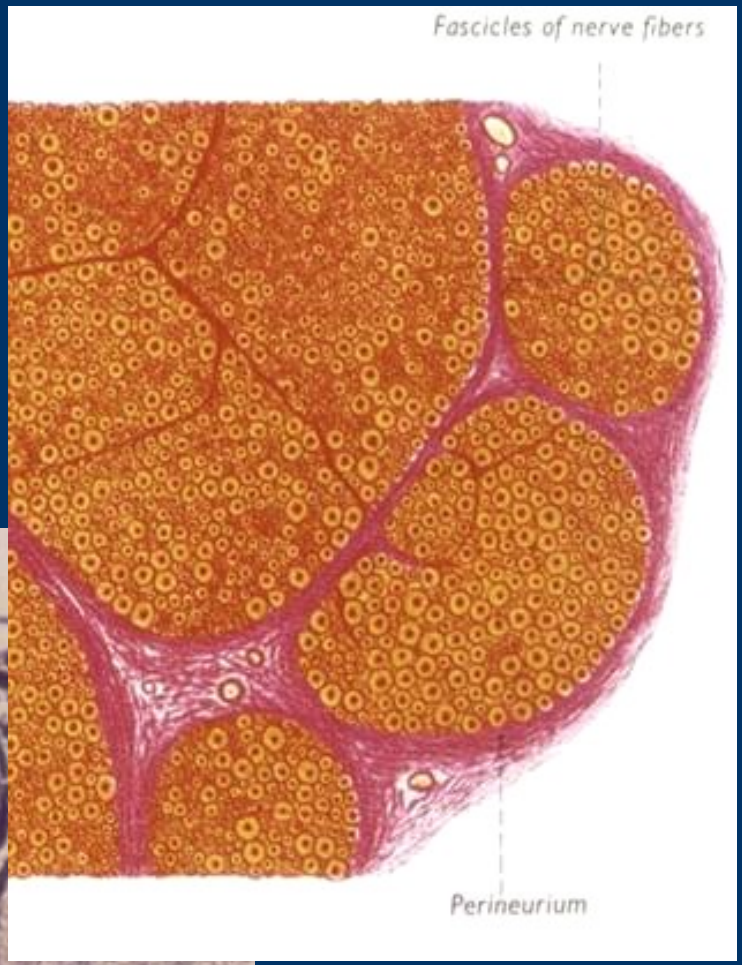
NERVES

are composed of parallel running nerve fibres and intervening connective tissues

are grouped in thin **primary nerve bundles** with a small amount of loose connective tissue - **endoneurium**
several primary bundles unite to form a **secondary nerve bundle** surrounded by **perineurium**
in accordance with thickness of the nerve, a few to several tenth of secondary nerve bundles are integrated in the proper **nerve** enveloped by **epineurium** that consists of dense connective tissue



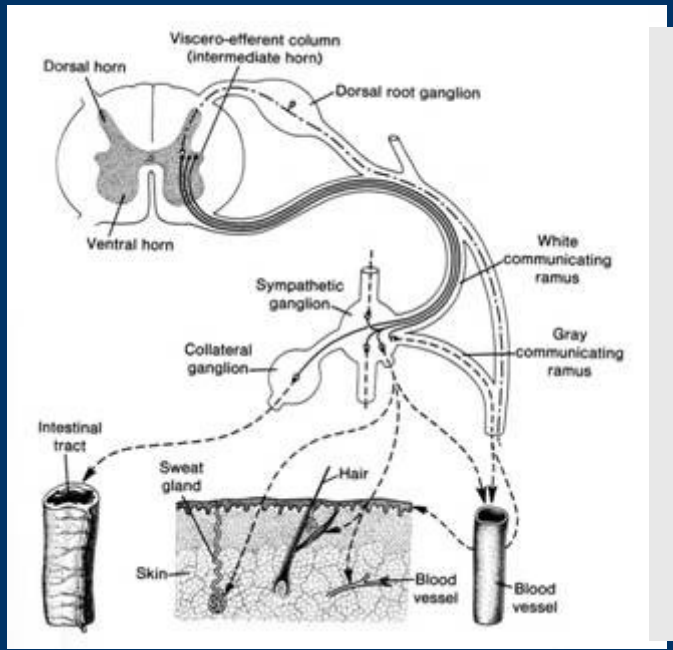


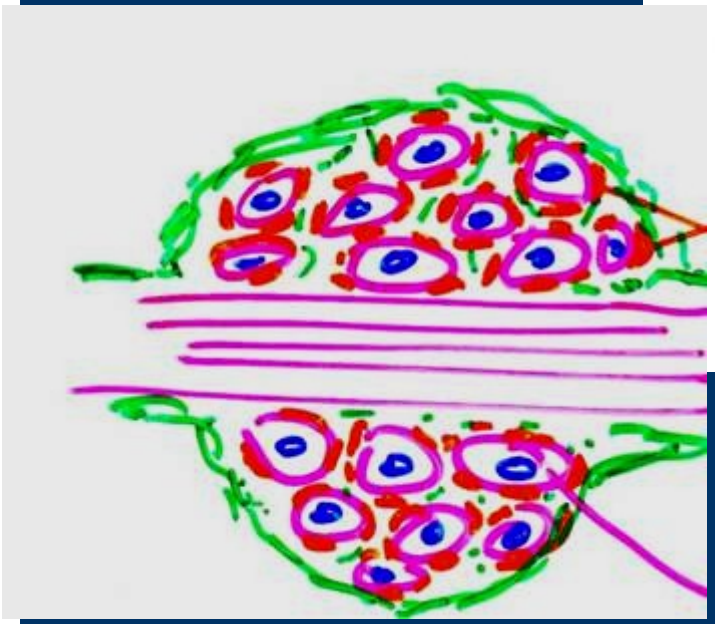

Fascicles of nerve fibers
Perineurium

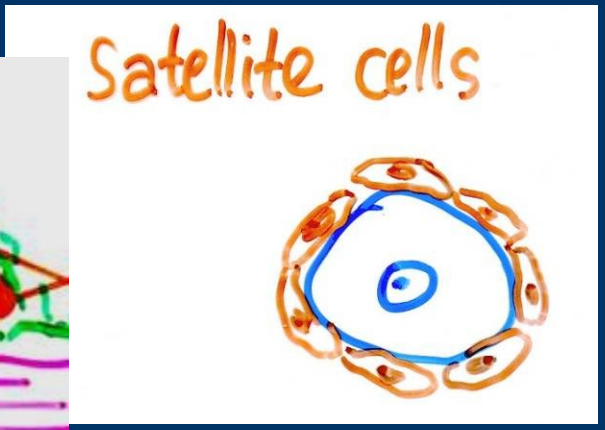
GANGLIA

ganglia are usually ovoid structures encapsulated similar as nerves by a dense connective tissue
two types of ganglia:
- **dorsal root ganglia (sensory)** - are interposed in the course of the dorsal (posterior) roots of the spinal nerves and in some cranial nerves
- **autonomic ganglia** - are associated with nerves of the autonomic nervous system

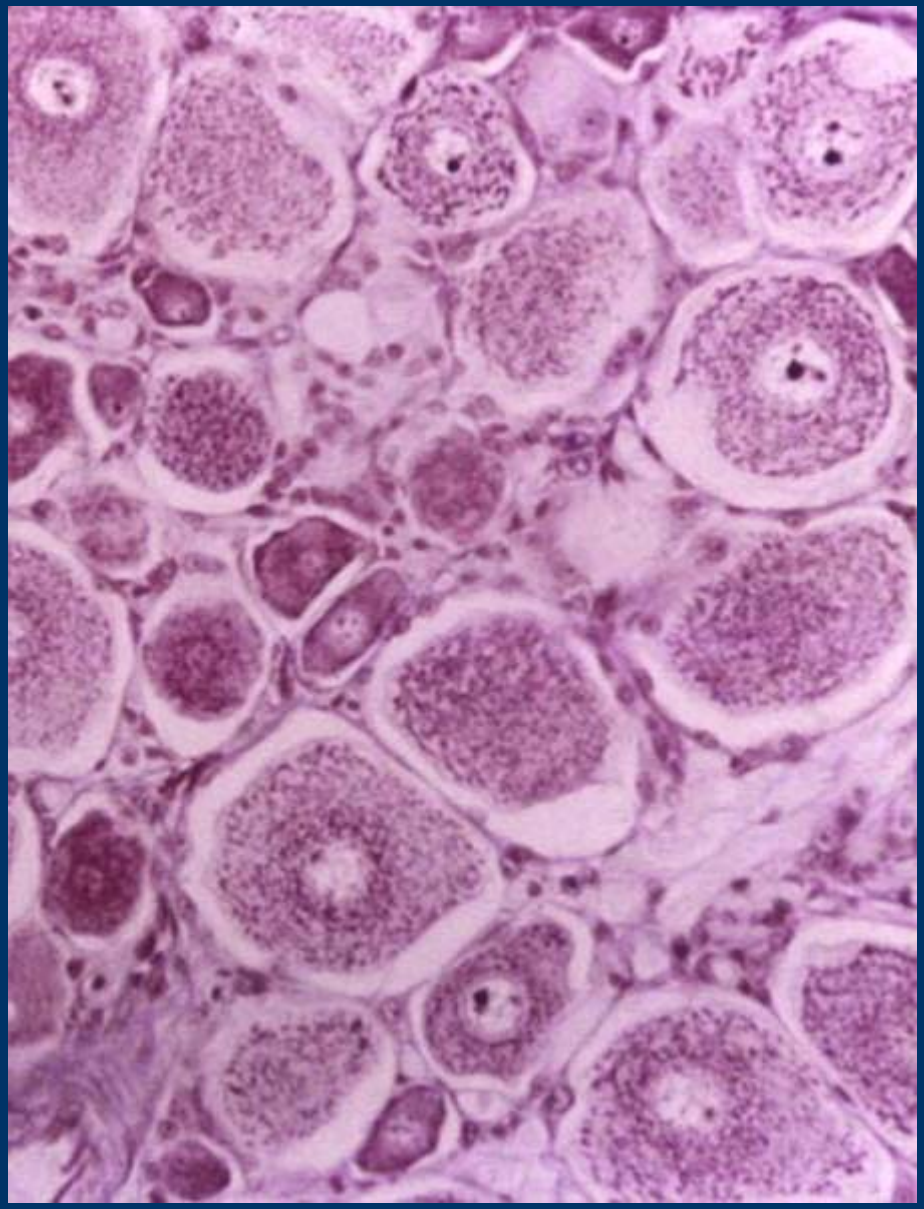
dorsal root ganglia contain the **pseudounipolar neurons**
autonomic ganglia medium-sized **multipolar neurons**
perikarya of neurons are enveloped by a layer of small flat or cuboidal glial cell known as **satellite cells**



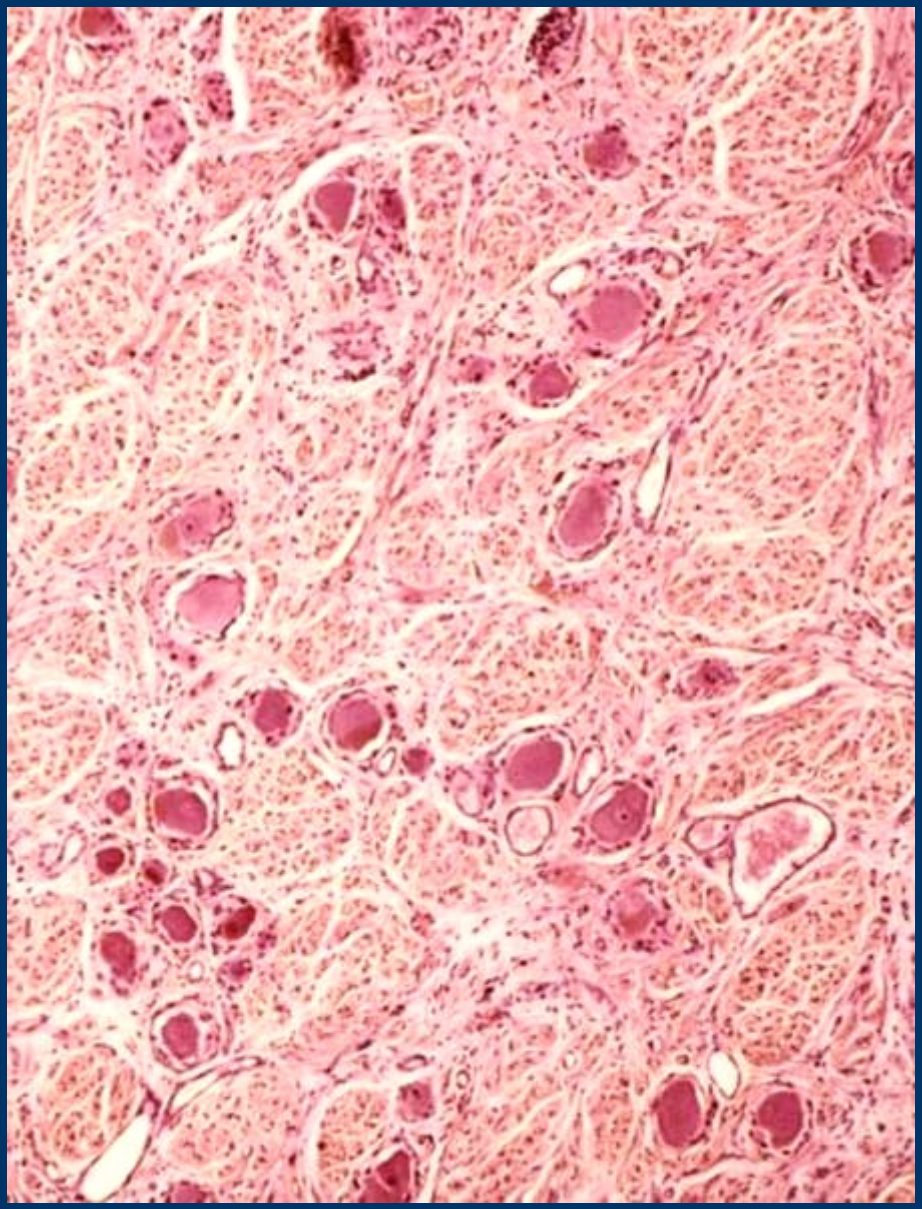




dorsal root ganglion:

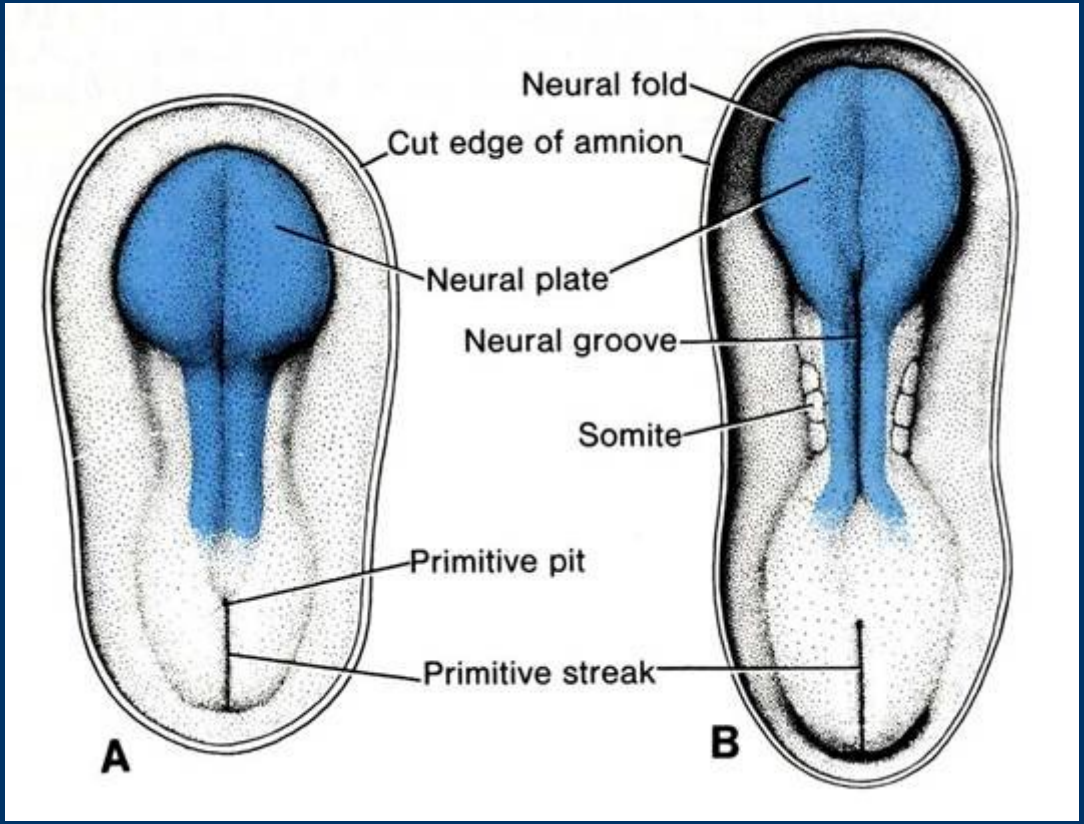


autonomic ganglion:

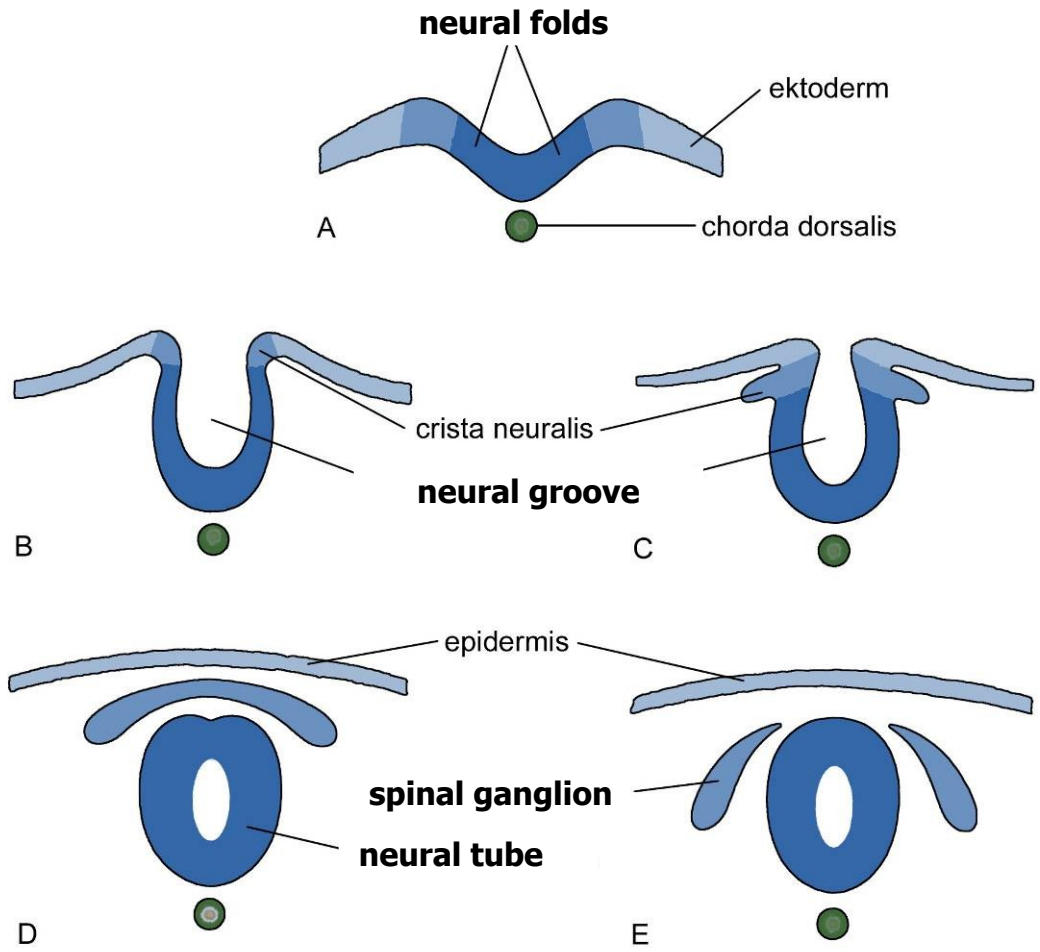


Overwiev of development of the brain and spinal cord including histogenesis of the neural tube

it develops from a thickened area of the embryonic ectoderm - **neural plate**
it occurs very early on the dorsal aspect of the embryonic disc cranially to the primitive knob reaching to the oropharyngeal membrane over the notochord



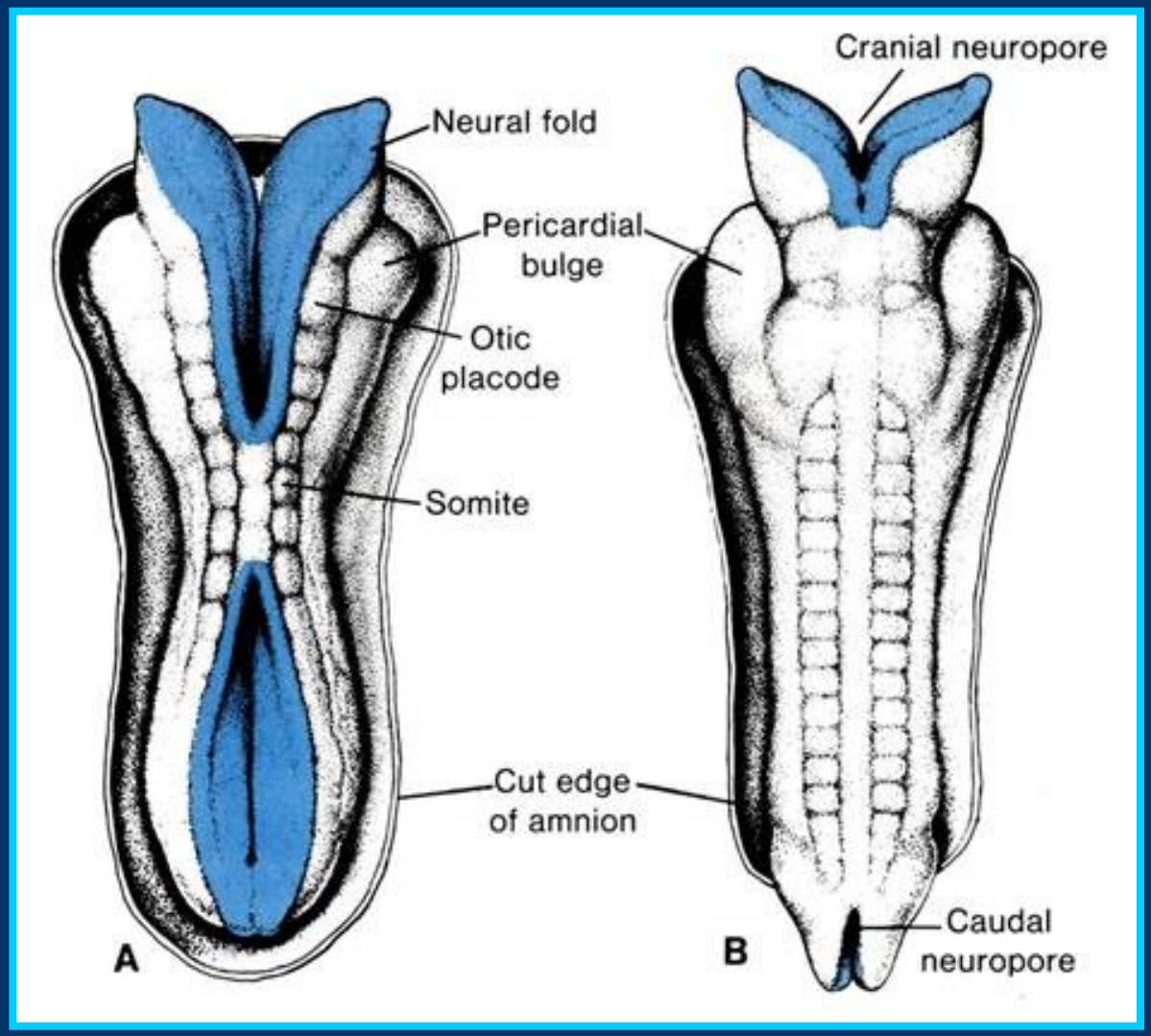
on about day 18, the neural plate begins to invaginate along the cranio-caudal axis and forms **neural groove** limited with **neural folds** on each side
by the end of the third week, the neural folds become to move together and fuse into a **neural tube**
the neural tube separates from the ectoderm and is then located between it and notochord



at the time when the neural folds fuse, some neuroectodermal cells separate from them and form along the dorsal aspect of the tube single cord - called the **neural crest**; it soon divides in the left and right parts that migrate to the dorsolateral aspect of the neural tube

neural crest cells give rise to cells of the **spinal ganglia** and cells of the **autonomic ganglia**

from the beginning, the proximal segment of the neural tube is broadened and corresponds to future **brain**
the narrower caudal one develops in the **spinal cord**



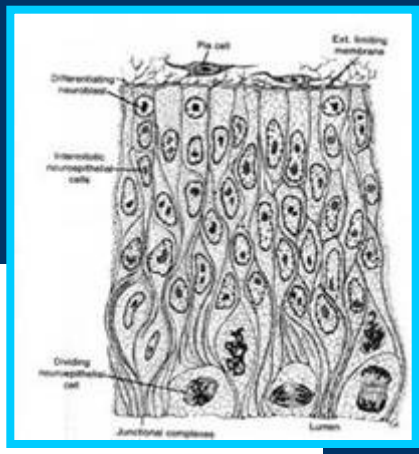
Histogenesis of the neural tube

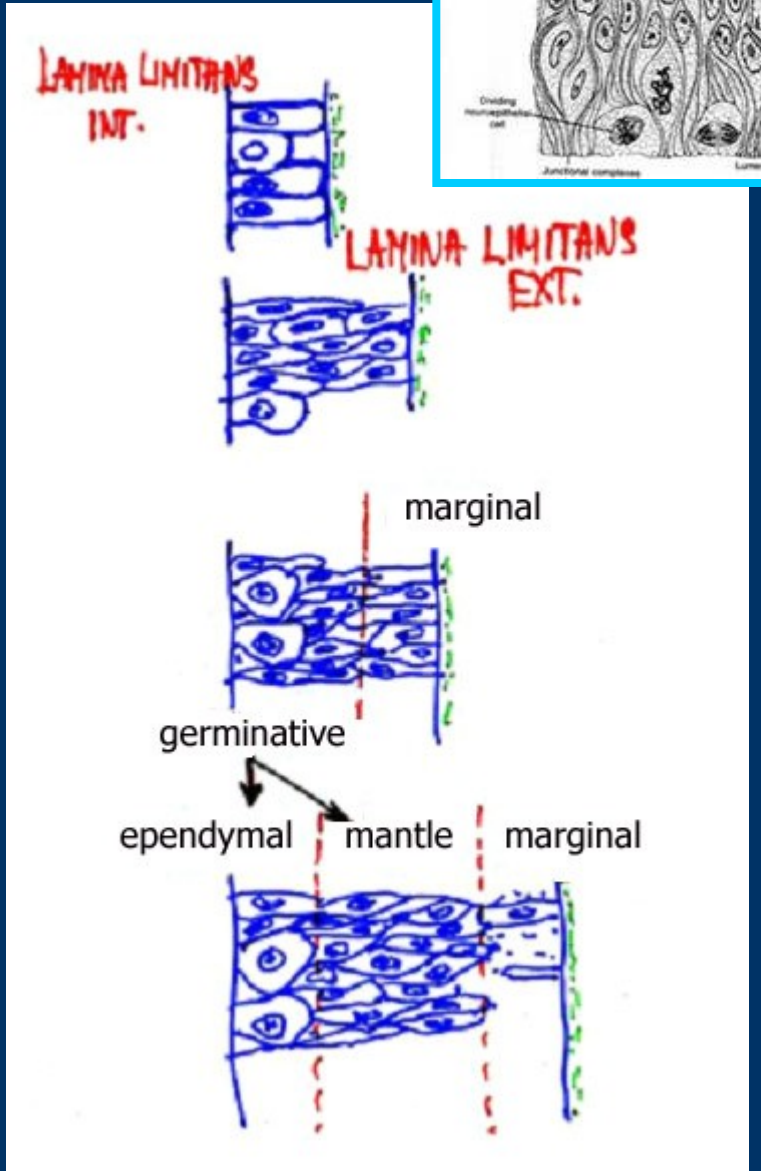
the wall of the neural tube is initially composed of a thick, pseudo-stratified columnar epithelium cells then rapidly proliferate in entire thickness of the wall, but later the mitotic activity is reduced only on cells situated near the luminal aspect of the neural tube; as a result of this process, the wall of neural tube differentiates into 2 zones: the inner **germinative** and the outer **marginal ones**

in the germinative zone the cells continue in their mitotic activity and migrate peripherally.

finally, the wall of neural tube shows 3-layered structure:

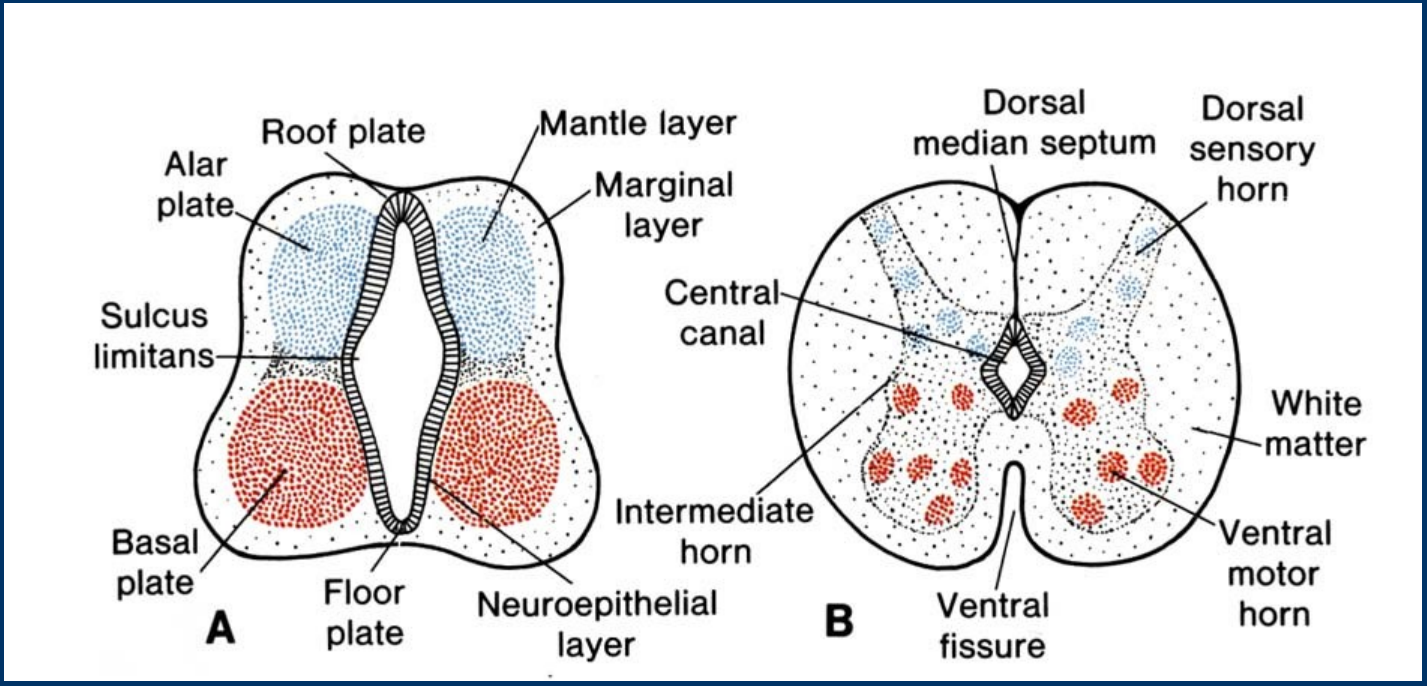
- the **ependymal** layer = ependyma,
- the **intermediate** or **mantle** layer= gray matter -cells of mantle layer soon differentiate into primitive neurons - neuroblasts and spongioblasts (glioblasts),
- the **marginal** layer = white matter (contains no cells)





DEVELOPMENT OF THE SPINAL CORD

it develops from the caudal portion of the neural tube
in contrast with lateral walls of the neural tube, where cells rapidly proliferate, the dorsal and ventral aspects remain thin
longitudinal groove - sulcus limitans - divides both lateral walls in the dorsal part - **alar plate** and ventral part - **basal plate**
cells of mantle layer rapidly proliferate and differentiate in the gray matter
Remember:
The alar plate - gives rise to **dorsal horn, the basal plate -** to **ventral horn**



Positional changes of the spinal cord
Initially, the spinal cord extends the entire length of the vertebrate canal
during further development, the vertebrate canal grows rapidly than spinal cord and its caudal end gradually comes to lie at relatively higher levels
in adults, it usually terminates at the inferior border of the first lumbar vertebra

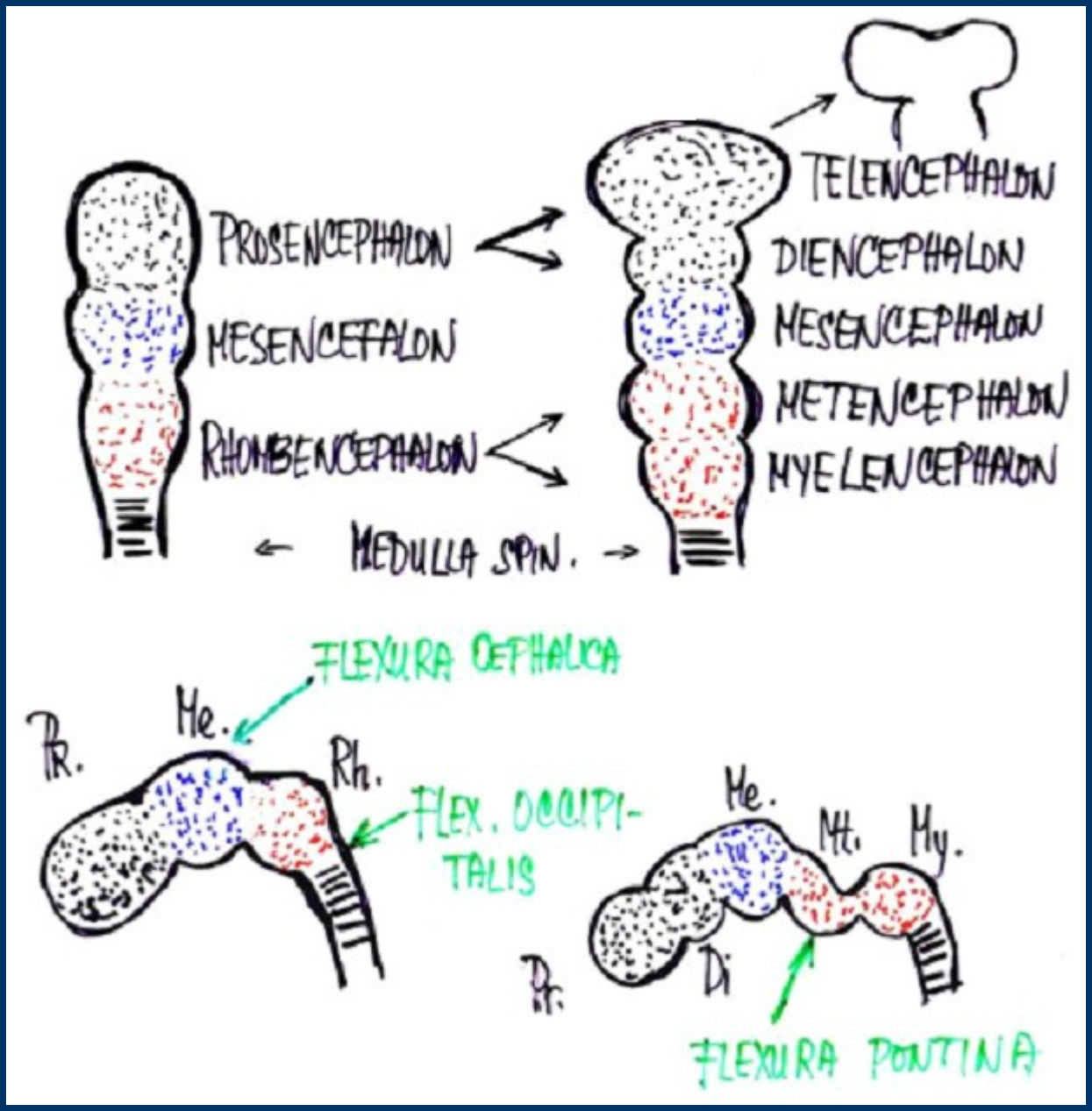
DEVELOPMENT OF THE BRAIN

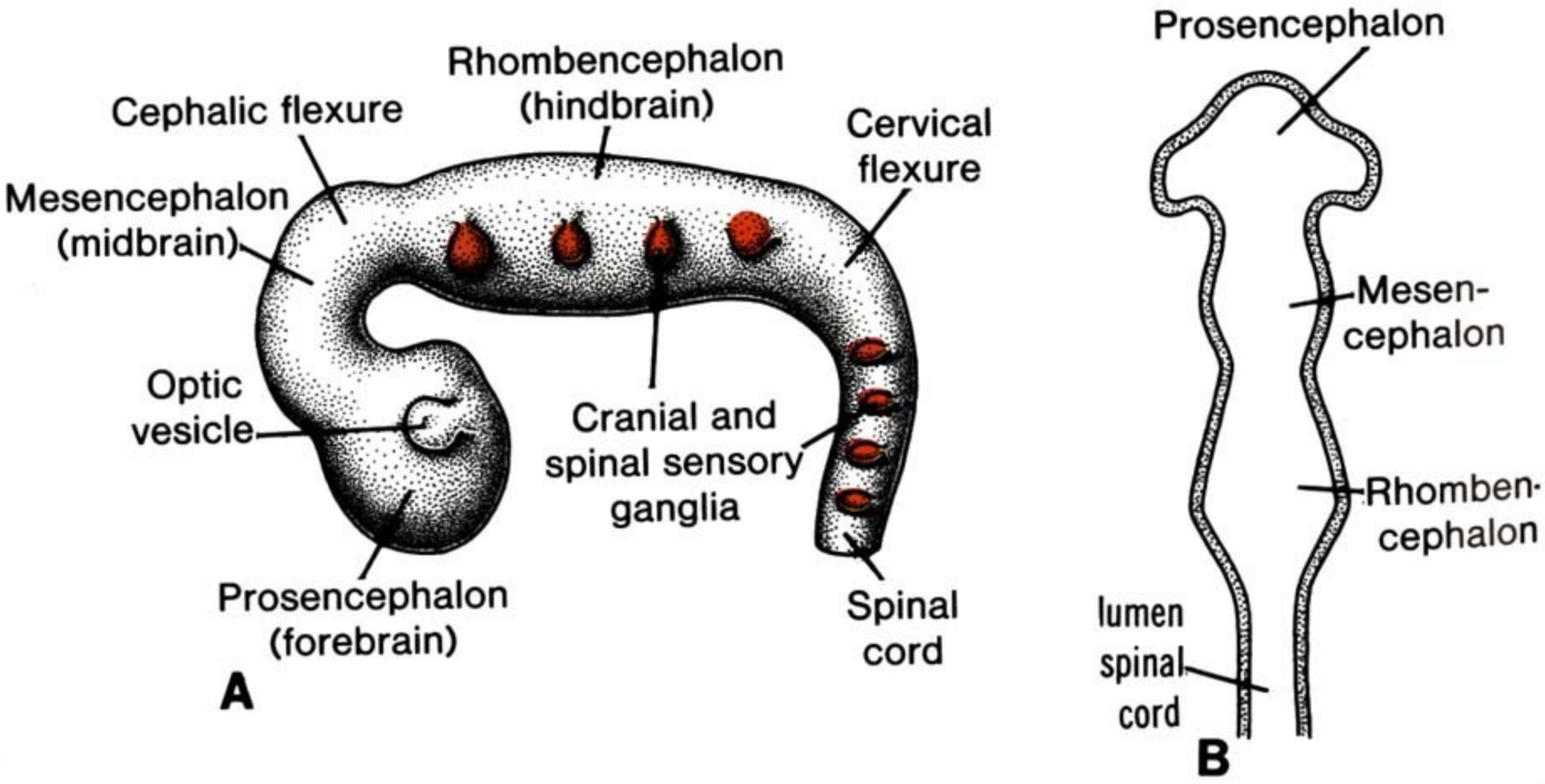
the brain develops from the cranial part of the neural tube

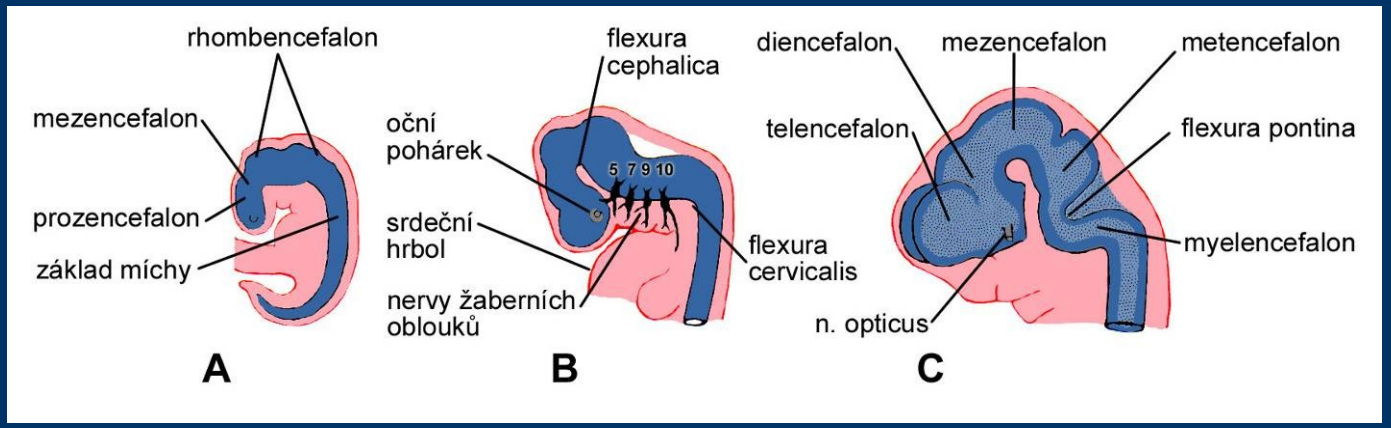
at the fourth week,three primary brain vesicles occur:

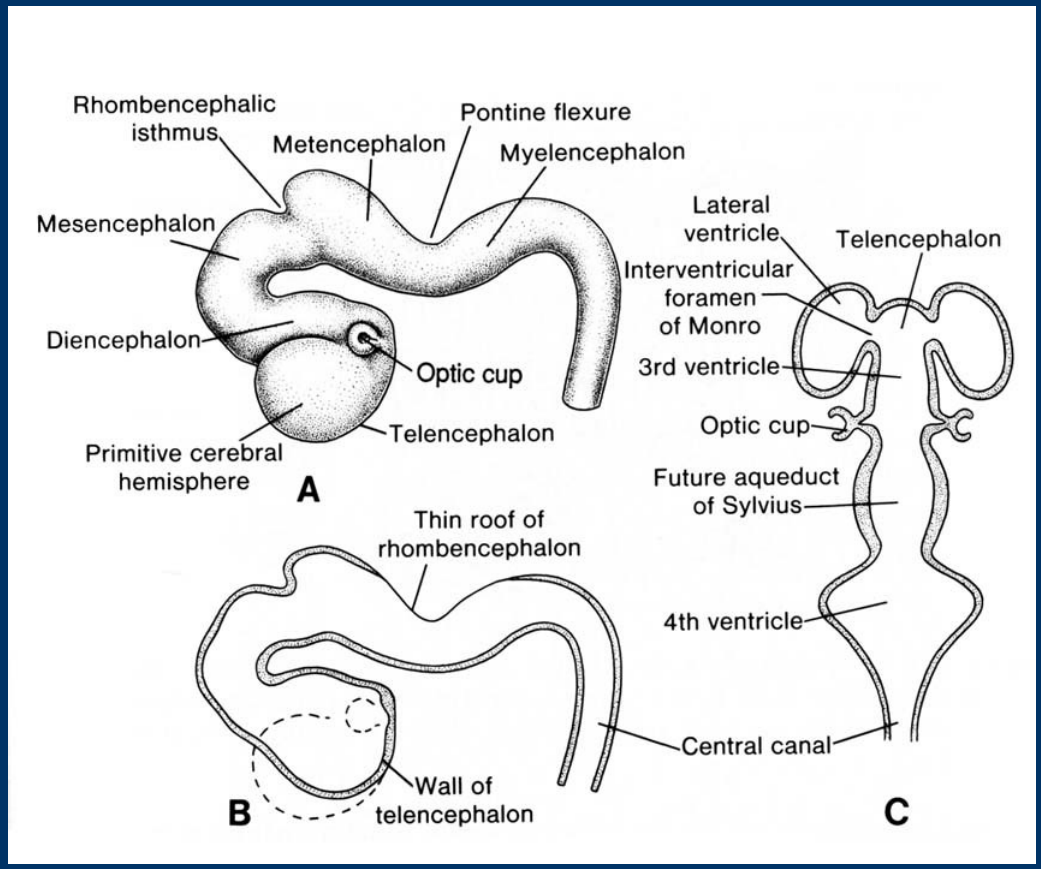
- **the forebrain - prosencephalon**
- **the midbrain - mesencephalon**
- **the hindbrain - rhombencephalon**

During the fifth week, the forebrain and hindbrain divides so that
5 secondary vesicles arise:
see diagram (it includes information concerning the development of cavities)


PROSENCEPHALON
MESENCEFALON
RHOMBENCEPHALON
TELENCEPHALON
DIENCEPHALON
MESENCEPHALON
METENCEPHALON
MYELENCEPHALON
MEDULLA SPIN.
FLEXURA CEPHALICA
He.
Pr.
Rh.
FLEX. OCCIPI-
TALIS
He.
Mt.
My.
Di
Pr.
FLEXURA PONTINA


Rhombencephalon
(hindbrain)
Cephalic flexure
Cervical
flexure
Mesencephalon
(midbrain)
Optic
vesicle
Cranial and
spinal sensory
ganglia
Prosencephalon
(forebrain)
Spinal
cord
A
Prosencephalon
Mesen-
cephalon
Rhomben-
cephalon
lumen
spinal
cord
B


rhombencefalon
mezencefalon
prozencefalon
základ míchy
A
flexura cephalica
oční pohárek
5 7 9 10
srdeční hrbol
nervy žaberních oblouků
flexura cervicalis
B
diencefalon
mezencefalon
metencefalon
telencefalon
flexura pontina
myelencefalon
n. opticus
C


Rhombencephalic isthmus
Metencephalon
Pontine flexure
Myelencephalon
Mesencephalon
Diencephalon
Optic cup
Telencephalon
Primitive cerebral hemisphere
A
Thin roof of rhombencephalon
Wall of telencephalon
B
Lateral ventricle
Telencephalon
Interventricular foramen of Monro
3rd ventricle
Optic cup
Future aqueduct of Sylvius
4th ventricle
Central canal
C

PROSENCEPHALON

MESENCEPHALON

RHOMBENCEPHALON

TELENCEPHALON VENTRICULI LAT.CEREBRI

DIENCEPHALON VENTRICULUS TERTIUS

MESENCEPHALON AQUAEDUCTUS CEREBRI

METENCEPHALON

VENTRICULUS QUARTUS

MYELENCEPHALON