12 Meninges, Cerebrospinal Fluid, and Neural Tube

Competencies

AN56.1: Describe and identify the various layers of the meninges with their extent and modifications.

AN56.2: Describe circulation of the cerebrospinal fluid with its applied anatomy.

AN64.2: Describe the development of the neural tube.

AN64.3: Describe the various types of open neural tube defects with its embryological basis.

Q1a. Classify dural folds. (AN56.1)

Classification

The four folds of dura mater are the following (**Fig. 12.1**):

- Falx cerebri.
- Falx cerebelli.
- Tentorium cerebelli.
- Diaphragma sellae.

Q1b. Describe the falx cerebri. (AN56.1)

Falx Cerebri

- Large, sickle-shaped fold of the dura mater (**Fig. 12.1**).
- Location: median longitudinal fissure between two cerebral hemispheres.

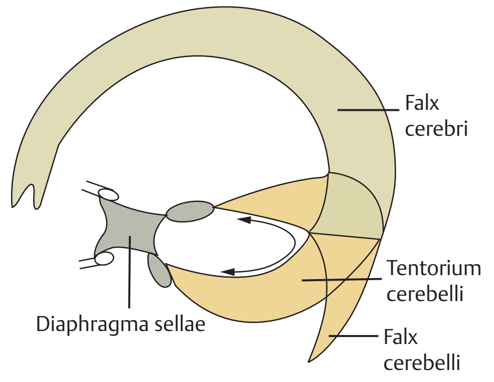


Fig. 12.1 Dural folds.

Ends

- Anterior: narrow—attached to the crista galli.
- Posterior: broad—attached to the superior surface of the tentorium cerebelli in its midline. It contains straight sinus.

Margins

- Superior: convex—attached to the lips of the sagittal sulcus. It lodges suerior sagittal sinus.
- Inferior: concave—free. It lodges inferior sagittal sinus.

Surfaces

- Right and left: related to the medial surface of the cerebral hemispheres.

Q1c. Write a short note on the tentorium cerebelli. (AN56.1)

Tentorium Cerebelli

- Tent-shaped fold of the dura mater (**Fig. 12.1**).
- Forms the roof of the posterior cranial fossa.
- Separates the cerebellum from the occipital lobes of the cerebrum.
- Divides the cranial cavity into supra- and infratentorial compartments.

Margins

- Free:
  - Anterior.
  - **U**-shaped.

- Ends of “U” attached to the anterior clinoid process.
- Boundary for the tentorial notch: the midbrain and superior vermis (anterior part) of cerebellum pass through it.

- Attached:
  - Convex.
  - Posterolaterally attached to the lips of the transvers sulcus on the occipital bone and on the posteroinferior angle of the parietal bone. It contains transverse sinus.
  - Anterolaterally attached to the superior border of the petrous temporal bone and the posterior clinoid process. It contains superior petrosal sinus.
- Crossing of free and attached margins:
  - At the apex of the petrous temporal bone.
  - Anterior to the point of crossing lies the triangular posterior part of roof of cavernous sinus, that is, pierced by the third and fourth cranial nerves.

Trigeminal/Meckel’s Cave

- Recess of the dura mater in the attached margin of tentorium cerebelli.
- Formed by evagination of the inferior layer of the tentorium cerebelli over the trigeminal impression on the petrous temporal bone.
- Contains the trigeminal ganglion.

Surfaces

- Superior surface:
  - Convex.
  - Slopes to either side from midline.
  - Falx cerebri is attached in the median plane.
  - Straight sinus lies along the attachment of the falx cerebri.
  - Related to occipital lobes of the cerebrum.
- Inferior surface:
  - Concave.
  - Falx cerebelli is attached in the posterior part.

Q1d. Describe the coverings of the spinal cord. (AN56.1)

Coverings of the Spinal Cord

There are three layers of meninges covering the spinal cord.

- Dura mater:
  - Only meningeal layer, with no endosteal layer.
  - Extent: from the foramen magnum to S2 vertebra.
  - Attachments:
    - Cranial: to margins of the foramen magnum.
    - Caudal: incorporates the filum terminale, extends up to the coccyx (Co1) vertebra and blends with its periosteum.
    - Sides: give a sheath to the roots of the spinal nerves that passes through the intervertebral foramen and covers the nerve trunk. The teeth like ligamenta denticulata are attached to the dura.
  - Nerve supply: recurrent branches of the spinal nerves.
- Arachnoid mater of the spinal cord:
  - Extent:
    - Foramen magnum to S2.
    - Subdural and subarachnoid spaces extend laterally along the roots of the spinal nerves up to the end of the intervertebral foramen.
- Pia mater: it is the inner most layer. Closely attached to the brain.

Q2. Write briefly on the arachnoid villi and granulations. (AN56.1)

Arachnoid Villi and Granulations

- Arachnoid villi are blind projections of the arachnoid mater and subarachnoid space into the dural venous sinuses through which cerebrospinal fluid (CSF) passes into the blood vascular system (**Fig. 12.2**).
- The arachnoid mater is separated from the blood in the sinuses by the endothelium.
- When small (in children), they are called arachnoid villi and when enlarged and calcified (old age), they are called arachnoid granulations/Pacchionian bodies. Arachnoid granulations increase in size and number with age and are numerous in relation to the superior sagittal sinus. The enlarged arachnoid granulations produce depressions in the skull.
- The arachnoid granulations resorb CSF into the vascular system and are occasionally seen as radiolucent structures on either side of the sagittal suture.

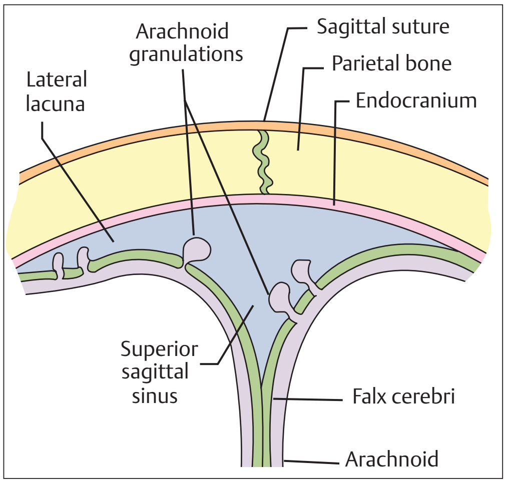


Fig. 12.2 Arachnoid villi and granulations.

Q3a. What are the modifications of pia mater? (AN56.1)

- Extent of spinal pia mater:
  - Complete investment.
  - Laterally, along the roots of the spinal nerves, it extends up to the end of the interventricular foramen and becomes continuous with the perineurium.

Modifications of Pia Mater

- Subarachnoid septum: in posterior median sulcus.
- Filum terminale: extension distal to conus medullaris.
- Denticulate ligaments: lateral extensions.
- Linea splendens: in anterior median fissure.

Q3b. Write short notes on the filum terminale. (AN56.1)

Filum Terminale

- Slender non-nervous filament of the pia mater that extends beyond the conus medullaris (**Fig. 12.3**).
- Length: 20 cm.

Parts

- Filum terminale internum: the part inside the dural sac and is the proximal 15 cm.
- Filum terminale externum: distal 5 cm. It lies outside the dural sac.

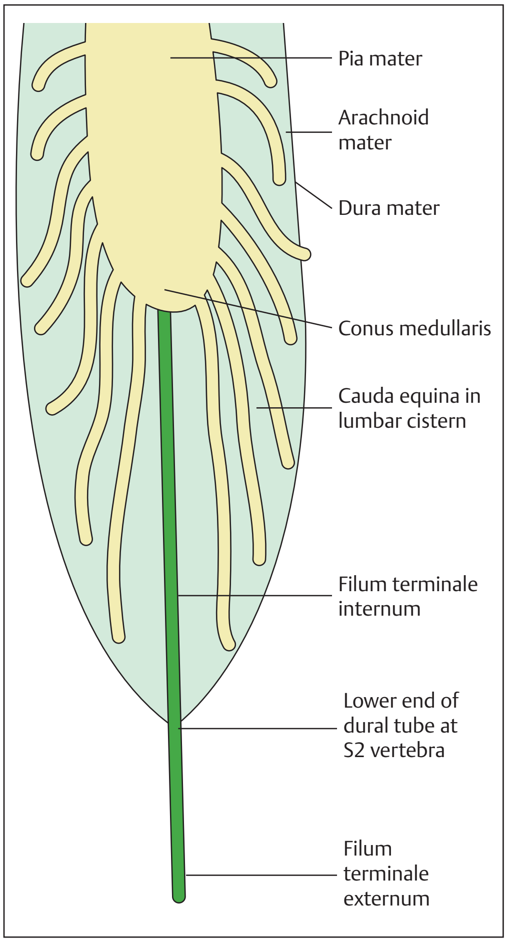


Fig. 12.3 Filum terminale.

Extent

- Above: at L1 (lower border) continuous with the tip of the conus medullaris.
- At S2: pierces the dura and arachnoid—receives dural prolongation.
- Leaves sacral hiatus.
- At Co1: blends with the periosteum.

Q3c. Write briefly on the ligamenta denticulata. (AN56.1)

Denticulate Ligaments

- Bilateral extensions of pia mater of spinal cord between ventral and dorsal roots (**Fig. 12.4**).
- Twenty-one pairs of triangular teeth like processes that are attached to the dura mater.

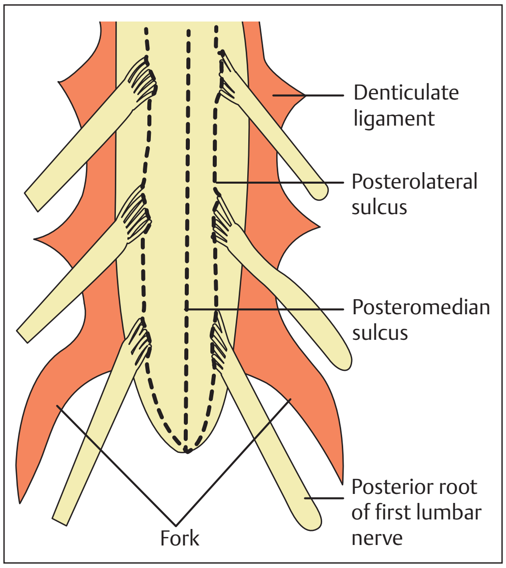


Fig. 12.4 Ligament denticulate.

- First tooth is at the level of the foramen magnum. Last tooth is at the oblique extension between roots of T12 (above) and L1 (below) nerves.
- Function: keep the spinal cord in position.
- Importance: helps neurosurgeon in tractotomy (selective).

Q4a. Name the spaces of spinal meninges. (AN56.1)

Spaces between Meninges

The spaces between different layers of the meninges are the following:

- Extradural space.
- Epidural space.
- Subdural space.
- Subarachnoid space.

Q4b. Write briefly on the extradural space. (AN56.1)

Extradural Space

- The space between the outer periosteal layer of the dura mater and the inner surface of the cranial bone.
- This space is not seen in normal conditions. In pathological condition of rupture of the blood vessels, the blood separates the periosteal layer away from the skull bone.

Clinical Importance

Extradural hemorrhage: collection of blood into this space following head injury causes fracture of the skull bone. The extravasated blood separates the dura from the skull bone. Compression of the brain due to increased accumulation of blood causes drowsiness and unconsciousness.

Q4c. Write briefly on the epidural space. (AN56.1)

Epidural Space

- The cranial epidural space is between the endosteal and meningeal layers of the dura mater. The spinal epidural space is the space between the spinal dura mater and the inner surface of the periosteal lining of the vertebral canal.
  - It runs along the entire length of the spinal cord, vertically and to the intervertebral foramina laterally.
  - The space is at a distance of 4.5 to 5.0 cm from the skin.
- Contents: this space contains spinal nerve roots, loose connective tissue, epidural fat, small arteries, lymphatics, and internal vertebral venous plexus.

Clinical Importance

Spinal epidural anesthesia is given to relieve pain, in obstetric practice for painless labor and delivery of the fetus, and to relief pain in cancer patients.

Q5a. Write briefly on subarachnoid cisterns. (AN56.1)

Subarachnoid Cisterns

- The pia mater is closely adherent to the surface of the cerebrum, and it follows the convexities and concavities of the cerebrum (**Fig. 12.5**).
- The arachnoid does not follow the irregular surfaces of the cerebrum. Instead, it bridges over the concavities resulting in subarachnoid spaces

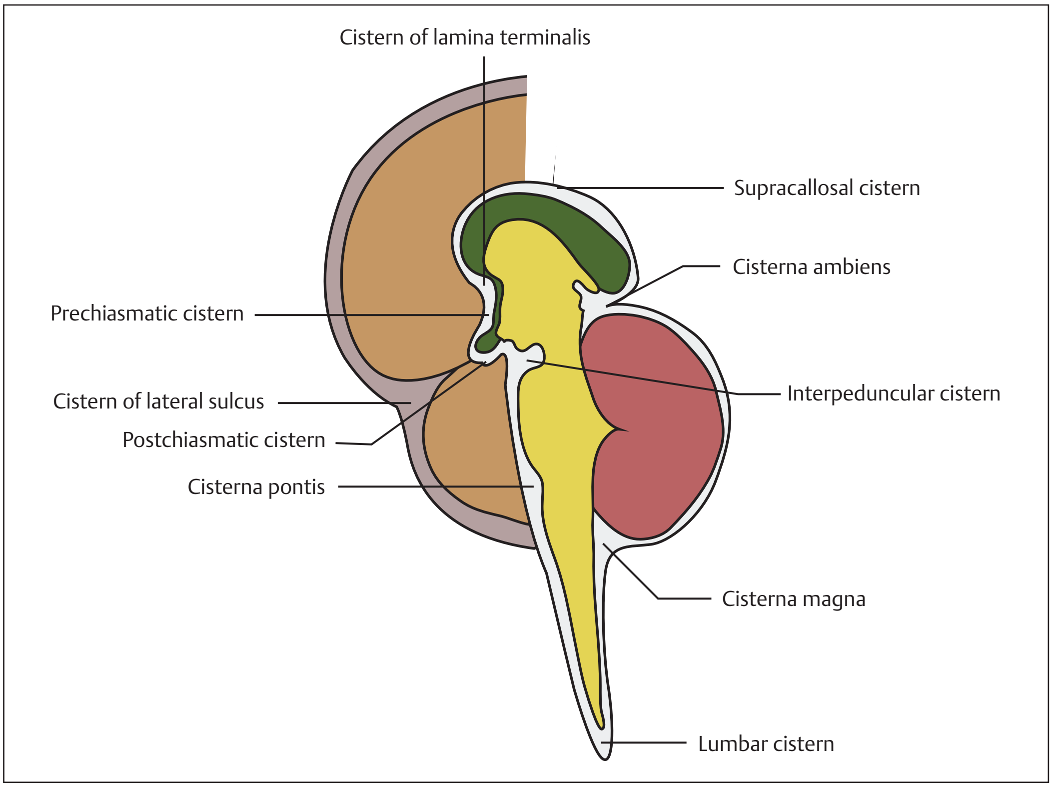


Fig. 12.5 Subarachnoid cisterns.

of variable depths containing the CSF and blood vessels that are known as the subarachnoid cistern.

- The subarachnoid space communicates with the fourth ventricle by means of three foramina. Two lateral foramina of Luschka open into the subarachnoid space at the cerebellopontine angle, and one median foramen of Magendie opens into the cisterna magna.
- The various subarachnoid cisterns of cerebrum that communicate with one another are the following:
  - Major cisterns:
    - Cisterna magna/cerebellomedullary cistern: largest of the cisterns.
    - Interpeduncular cistern: located on the inferior surface of cerebrum and contains circle of Willis.
    - Pontine cistern: on the ventral surface of pons and contains basilar artery.
    - Cisterna ambiens: is located on the posterior surface of midbrain and contains great cerebral vein.
  - Minor cisterns:
    - Cistern of lateral sulcus.
    - Pre- and postchiasmatic cisterns.
    - Cistern of lamina terminalis.
    - Supracallosal cistern.

Q5b. Write short notes on cisterna magna.

- Largest of the cisterns.
- Location and contents: it is between the inferior surface of the cerebellum and the posterior surface of the medulla. It contains vertebral arteries and 9th–11th cranial nerves.
- Communication: it communicates
  - Below: with the spinal subarachnoid space.
  - Above: with the fourth ventricle.

Clinical Importance

Cisternal puncture: although usually sample CSF is obtained from the spinal subarachnoid space by lumbar puncture, it can also be obtained sometimes for laboratory investigation from cisterna magna. A needle is passed through the interval between the atlas and the axis vertebrae and through the posterior atlanto-occipital membrane to enter this cistern. This method is preferred in infants and young children.

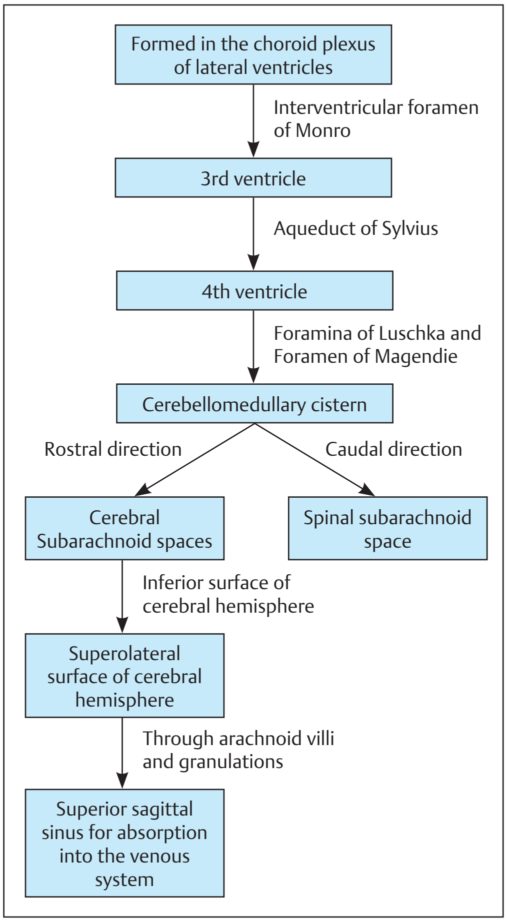
Q5c. Describe the production, circulation, and absorption of the CSF. Add a note on its clinical importance. (AN56.1 and AN.56.2)

Circulation of CSF and its Applied Anatomy

- The CSF is a clear, colorless, odorless fluid that fills the ventricular system and the subarachnoid space.
- Formation and circulation: its flow is unidirectional in ventricles and multidirectional in subarachnoid spaces (**Flowchart 12.1** and **Fig. 12.6**).
- Arachnoid granulations act like valve to control the flow of CSF into the vascular system, preventing its backflow.
- Factors facilitating CSF circulation are pressure gradients. Flow of CSF is pulsatile corresponding to the systolic pulse wave in choroidal arteries. If there is higher pressure in choroid plexus and low pressure in ventricles and subarachnoid spaces, it will lead to lowest pressure in dural venous sinuses.
- CSF pressure: postural variations:
  - Supine position: 80 mm of water.
  - Sitting position: 300 to 400 mm of water (in lumbar region) and zero in the cerebellomedullary cistern and negative side in the ventricles.
- Rate of flow of CSF is 1 drop/second.

Clinical Importance

- Collection of CSF and examination for diagnosis: CSF is collected by a procedure called lumbar puncture and is subjected to biochemical and microbiological investigations in diseases of brain, infections (meningitis, tuberculosis), intracranial bleeding (cerebral hemorrhage), and cancer (primary brain tumors, metastases).
- Hydrocephalus: excessive accumulation of CSF in the subarachnoid cisterns or in the ventricular system.
- Pneumoencephalography: a procedure to identify space-occupying tumors in the cranial cavity by withdrawing CSF by lumbar puncture and replacing it with air.
- Ventriculography: in the cases where there is contraindication for lumbar puncture, the air is introduced directly into the ventricular system.
- Myelography: injection of contrast media replacing the CSF to visualize the subarachnoid cisterns.



Flowchart 12.1 Circulation of the cerebrospinal fluid.

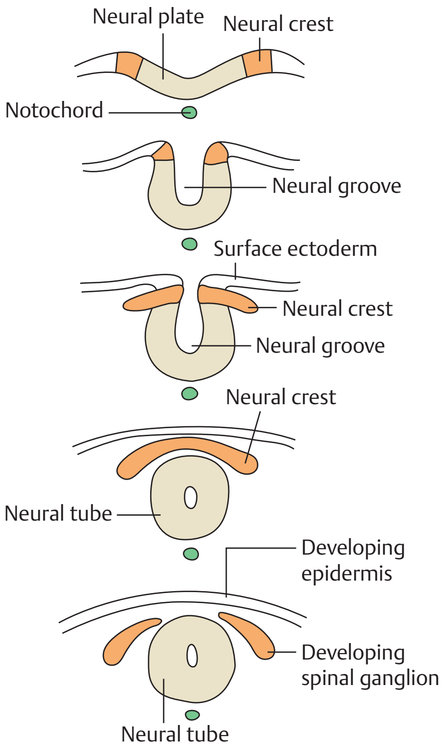


Fig. 12.6 Development of the neural tube.

Q6a. Describe the formation of the neural tube, subdivisions, and foldings of the neural tube. (AN64.2, AN64.3)

Formation of Neural Tube

- Sixth day to 20th day of development: The neurectoderm in the midline on the dorsal aspect of the developing embryonic disk is converted into neural plate (**Fig. 12.6**) under the inductive influence of the notochord.
- Twentieth day/21st day of development: The neural groove appears in the midline of the neural plate. On either side of the neural groove, the raised neural plate is called the neural fold.
- Twenty second day to the 25th day of development: The neural folds get approximated in the midline and fuse, forming the neural tube. The cranial and caudal end of the neural tube presents the openings of the anterior and posterior neuropores, respectively. The closure of the neural tube begins in the middle and extends cranially and caudally. The anterior neuropore closes earlier (25th day) than the posterior neuropore (28th day).

Subdivisions of the Neural Tube and their Derivatives

It is divided into enlarged cranial part and tubular caudal part. Each part encloses a cavity. Derivatives of these parts and the cavities of brain and spinal cord are shown in **Table 12.1** and **Fig. 12.7**.

Folding of the Neural Tube

- Initially, the three primary brain vesicles are in horizontal line (**Fig. 12.8**).
- With the formation of flexures, the linear arrangement changes.
- The flexures of neural tube are the following:
  - Cervical flexure: develops at the junction of the rhombencephalon and spinal cord.
  - Mesencephalic flexure: appears in the midbrain.
  - Pontine flexure: develops in the middle of the rhombencephalon dividing it into metencephalon and myelencephalon.
  - Telencephalic flexure: appears between telencephalon and diencephalon.
- The flexures and differential growth of the brain vesicles result in formation of different parts of the brain as in adults.

Q6b. Write short notes on neural tube defects. (AN64.3)

Neural Tube Defect

These are serious anomalies of the brain and the spinal cord:

- Fusion of neural folds and closure of neuropores completes by the 4th week of development. Failure of fusion of neural folds and closure of neuropores result in an opening in the spinal cord or the brain or both.
- The neural tube has an inductive effect on the development of vertebral arches. Failure of fusion of neural folds influences not only the development of the central nervous system but also that of the vertebral arches that lie above it.
- Failure of closure of the anterior neuropore is called *cranial dysraphism*. Failure of closure of the posterior neuropore is known as *spinal dysraphism (rachischisis).*

Table 12.1 Subdivisions of the neural tube and their adult derivatives

Neural tube division	Primary brain vesicles	Secondary brain vesicles	Adult derivatives	Cavities
Cranial part: cerebrum/ brain	Prosencephalon	Telencephalon	▪ Cerebral hemispheres ▪ Corpus striatum	Lateral ventricle
		Diencephalon	▪ Thalamus ▪ Hypothalamus ▪ Epithalamus	Third ventricle
	Mesencephalon	Mesencephalon	Midbrain	Cerebral aqueduct
	Rhombencephalon	Metencephalon	▪ Pons ▪ cerebellum	Fourth ventricle
		Myelencephalon	Medulla oblongata	
Caudal part: spinal cord	Spinal cord			Central canal

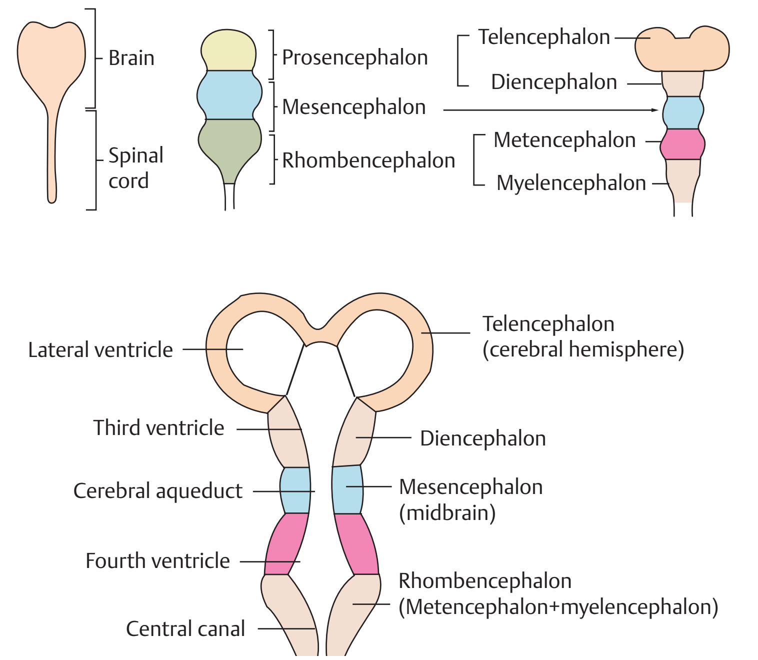


Fig. 12.7 Subdivisions of the neural tube.

- Types of neural tube defect (NTD): open and closed (**Fig. 12.9**).
- Closed neural tube defects are rare.

Open Neural Tube Defects

These are more common than the closed type. These result from a defect in the skull or vertebra that exposes the brain and the spinal cord. There will be nonfusion of the cranial or caudal part of the neural tube (brain or spinal cord) or the overlying skull bones or vertebrae.

Types

- *Encephalocele*: saclike protrusion of brain and meninges covering it through a defect in the skull (usually the occipital area). Large occipital encephaloceles are incompatible with life because of damage to the brainstem.

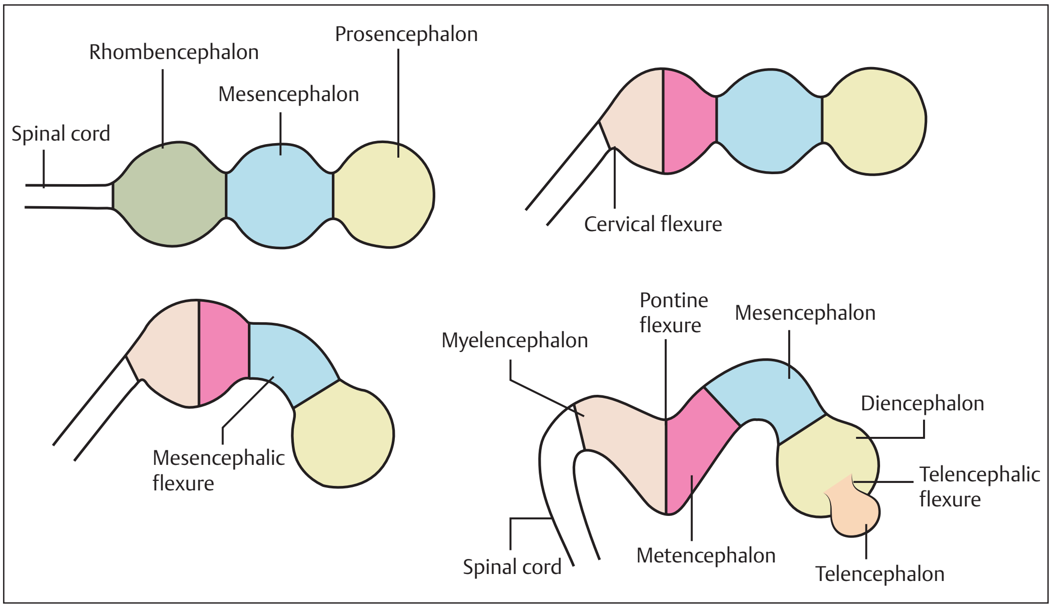


Fig. 12.8 Foldings of the neural tube.

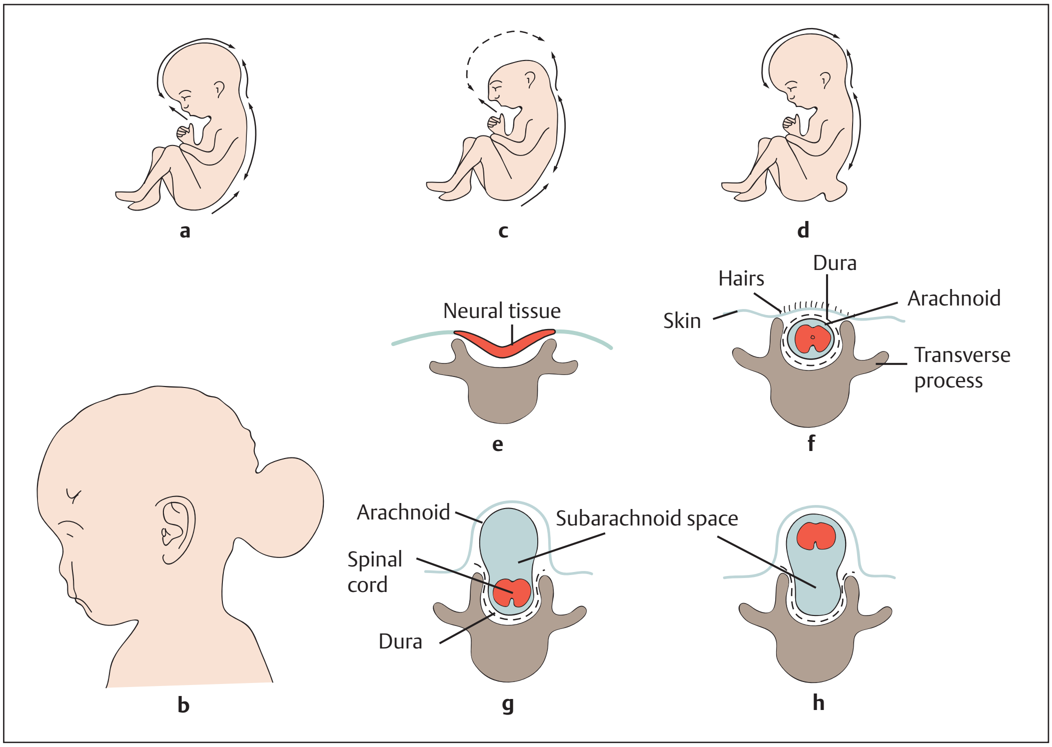


Fig. 12.9 Neural tube defects. **(a)** Normal. **(b)** Encephalocele. **(c)** Anencephaly. **(d)** Spina bifida. **(e)** Spina bifida rachischisis. **(f)** Spina bifida occulta. **(g)** Spina bifida with meningocele. **(h)** Spina bifida with meningomyelocele.

- *Anencephaly*: failure of closure of the anterior neuropore. Neural folds do not fuse in the cranial region.
- *Craniorachischisis*: the fusion fails for the entire neural tube and is a lethal defect.
- *Spina bifida*: opening of the vertebral canal and failure of closure of the posterior neuropore. Depending on the number of nonfused neural arches and other structures that are affected, there are different types:
  - Spina bifida occulta (means hidden): it is a closed neural tube defect.
    - Spinal cord is normal.
    - Nonclosure of the osseous vertebral arch. The spinal cord, its coverings, and overlying skin are normal. Sometimes a **tuft of hair** indicated the site where the osseous structures are missing.
  - Spina bifida aperta (means visibly present):
    - Spina bifida with meningocele: protrusion of meninges through the vertebral defect.
    - Meningomyelocele: the spinal cord with coverings protrudes through the defect.
  - Myeloschisis: the spinal cord is directly exposed.

Q6c. Describe the formation of various layers in the wall of the neural tube and the structural organization. (AN64.2)

- The neural tube presents a lumen that forms ventricles/central canal.
- The developing neural tube shows dorsoventral differentiation forming the following (**Fig. 12.10**):
  - Roof/alar plate.
  - Floor/basal plate.

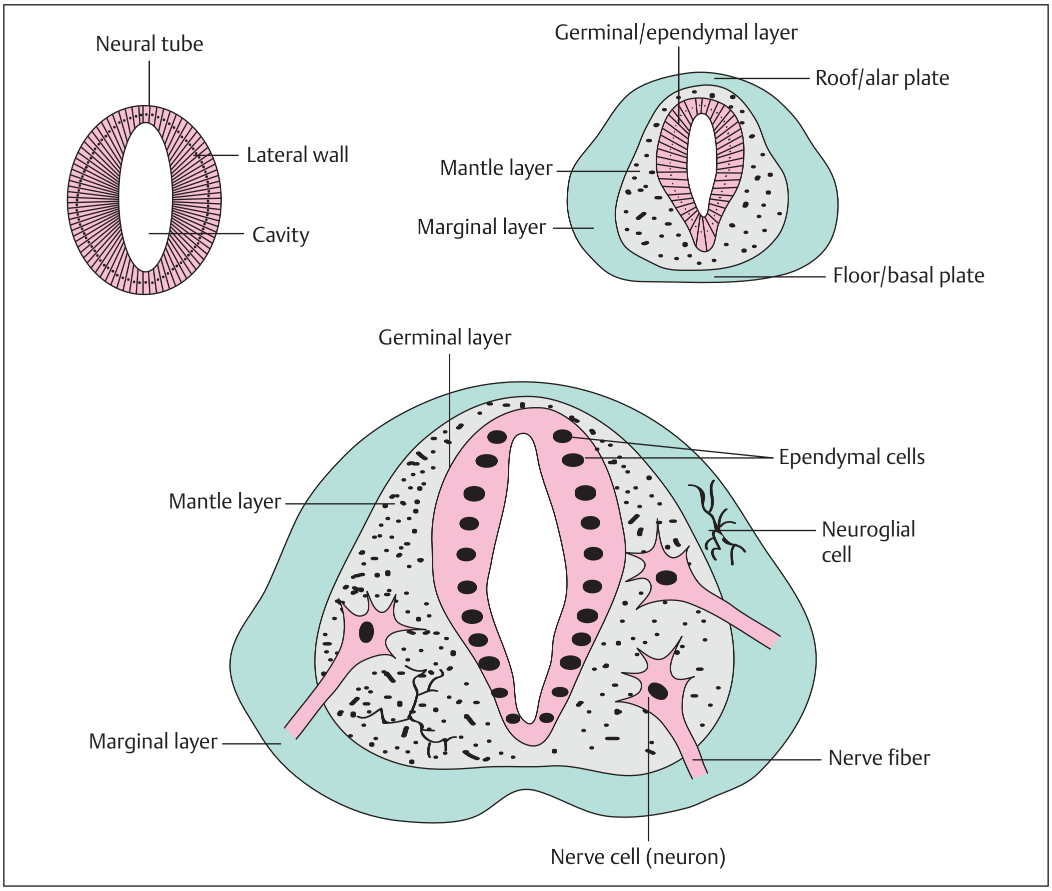


Fig. 12.10 Differentiation of the wall of the neural tube.

- Initially the wall of the neural tube presents a single layer of columnar neuroepithelial cells that later become pseudostratified and extend between two limiting membranes, external and internal. The neuroepithelial cells form the neurons, neuroglial, and ependymal cells.
- Later the wall of the neural tube presents three layers:
  - *Matrix/ependymal layer*: It is toward the lumen of the neural tube and the cells give rise to neuroblasts and spongioblast (neuroglia). The ependymal cells first form the neuroblasts. After completion of differentiation of neuroblasts, neuroglia develop and with the stoppage of formation of neuroblasts, the cells close to the lumen become ependymal cells.
  - *Mantle layer*: The middle layers contains migrated neuroblasts that differentiate into nerve cells and forms the gray matter.
  - *Marginal layer*: The outer layer has no nerve cells. It contains processes of the nerve cells and neuroglial cells and forms the white matter.
- Stages in the formation of nerve cells from the neuroblast (**Fig. 28.1, Volume 1**):
  - *Apolar neuroblast*: The cells of the germinal layer pass to the mantle layer and form the apolar neuroblasts.
  - *Bipolar neurons:* Two processes develop and the apolar neuroblasts are converted to bipolar neurons.
  - *Unipolar neurons:* One process of the bipolar neuroblast disappears and it becomes a unipolar neurons.
  - *Multipolar neurons:* the remaining process of the unipolar neuroblast elongates and a number of small processes develop around the cell and are converted to a multipolar neurons. The long process becomes axon and the multiple small processes become dendrites.
  - *Pseudounipolar neurons:* these develop from neural crest cells. These have a single process that bifurcates like the letter T.