OBJECTIVES

Following a review of this material, the student should be capable of:

1. Discussing the components of the meninges and their specific anatomical relations.
2. Identifying the ventricles and describing their anatomical boundaries.
3. Describing the process of cerebrospinal fluid (CSF) production as well as the route of CSF drainage.
4. Appreciating the significance of CSF composition as a reflection of health or disease.

I. The Meninges

The brain is invested by three non-neuronal membranes within the bony encasement of the skull. The cranially located meninges are both comparable to and continuous with those investigating the cord, however, the cerebral membranes do possess modifications and specializations not found in the cord.

A. Dura Mater - consists of two layers, an external, endosteal, and an internal, meningeal, layer. These two layers are grossly indistinguishable; however, their bilaminar nature is apparent in those regions where they are separated by the large cerebral venous sinuses (these will be discussed in a later lecture).

1. The external or endosteal layer - serves as the periosteum of the inner table of the skull and is rich both in blood vessels and nerves. Injury to these blood vessels may result in hemorrhage or hematoma in the epidural space. Besides contributing to the cranial periosteum, this external layer of the cerebral dura also provides sheaths for the cranial nerves as they exit the skull at their respective foramina.

2. The internal or meningeal layer - sends four processes or septa internally and these septa divide the cranial cavity into incomplete compartments. These septa are:

   a. Falx cerebri - a sickle shaped structure which lies in the longitudinal fissure between the two cerebral hemispheres.

   b. Tentorium cerebelli - forms the roof over the posterior cranial fossa and thus supports the occipital lobes of the cerebral cortex, while it covers the cerebellum. Its anterior concave border is free and together with the dorsum sellae of the sphenoid bone, form the boundary of the tentorial notch.
c. **The diaphragma sellae** - a circular, horizontal structure which forms the dural roof of the sellae turcica and which, in turn, is perforated by the stalk of the pituitary.

d. **Falx cerebelli** - a small septa that partially divides the cerebellar hemispheres.

3. **The vascular supply of the cerebral dura** - is chiefly from the middle meningeal artery.

The innervation of the cerebral dura is discussed in reference to two anatomical planes:

a. The supratentorial portion - sensory innervation is provided by branches of the trigeminal nerve.

b. The infratentorial portion - sensory innervation is provided by the meningeal branches of the vagus and by the meningeal branches of the first three cervical nerves.
4. **Spinal dura** - Corresponds to the internal layer of the cerebral dura, and is continuous with its cerebral counterpart at the foramen magnum. The spinal dura consists only of this one layer as the vertebrae have their own separate periosteum.

B. **Arachnoid** - this membrane, together with the underlying pia, is frequently described as the leptomeninges.

* Link to Netter Image 1.41A
* Link to Netter Image 1.41B

1. In the cerebral region, the arachnoid, a thin, delicate non-vascular, membrane is usually adherent to the overlying dura.

2. In the cerebral region the arachnoid passes over the sulci without dipping into them.

3. The cerebral arachnoid membranes possess many fine filamentous extensions (trabeculae) which extend from it to attach to the underlying pia. That region or space which lies between the arachnoid membrane and the pia and which is transversed by the arachnoid trabeculae, is filled with cerebrospinal fluid, a clear, watery substance. This space is referred to as the subarachnoid space. Communication between this subarachnoid space and the ventricular compartments which occupy the internal core of the brain is established both by the foramen of Magendie which lies in the roof of the fourth ventricle and by the two foramina of Luschka which lie in the lateral recesses of the fourth ventricle.

* Link to Netter Image 1.44

4. In the cranial cavity, the extent of the subarachnoid space shows many local variations due to the irregular contour of the brain's surface. At various points the arachnoid is widely separated from the underlying pia creating large spaces filled with cerebrospinal fluid. These large fluid filled spaces or pools are called subarachnoid cisterns. The cisterns most commonly identified are the cisterna magna, pontis, superior, interpeduncular, chiasmatic and ambiens.

* Link to Netter Image 1.44

5. The cerebral arachnoid sends tufted prolongations, called the arachnoid granulations, through the inner layer of the dura into the superior sagittal sinus. It is through these granulations that the cerebrospinal fluid passes into the venous blood.

C. **Pia Mater** - This constitutes the innermost membrane of the meninges and lies in direct apposition to both the brain and spinal cord.

1. The pia of the spinal cord, itself, is composed of an inner intimal layer (membranous) and an outer epipial layer (loose collagen fibers). Around the brain the epipial layer is poorly developed, consequently superficial arteries and veins
of the cortex lie on the intimal pia in the subarachnoid space. This is of clinical importance as these vessels are exposed to the CSF and thus, alterations therein can elicit vascular change. The presence of blood in CSF due to aneurysmal bleeding or other causes can trigger reactive vascular change leading to vasospasm. This decreases cerebral blood flow with serious CNS consequences. In the spinal cord, the blood vessels run within the epipial tissue.

2. The pia mater follows all the convolutions of the brain and spinal cord, dipping into all the sulci.

II. The Ventricular System
* Link to Netter Image 1.42A

As noted, the internal core of the brain is occupied by the cerebrospinal fluid-containing ventricular compartment. The ventricular compartment is composed of two lateral ventricles, a midline third ventricle communicating with the midline fourth ventricle via the aqueduct of Sylvius. As noted previously, the fourth ventricle communicates with the outlying subarachnoid space via the foramina of Magendie and Luschka. The location of the four above named ventricles is as follows:

A. The Lateral Ventrices - exist as paired structures which occupy the internal substance of the cerebral hemispheres. Each lateral ventricle has a body and an anterior (or frontal), a posterior (or occipital) and an inferior (or temporal) extension which is commonly referred to as a horn. Communication between the two lateral ventricles and the third ventricle is established through the paired interventricular foramina of Monro.

The anatomical boundaries of the lateral ventricles are as follows:

1. The anterior horn is roofed by the corpus callosum. Its medial wall is formed by the septum pellucidum, while the floor and lateral wall are formed by the head of the caudate nucleus.

2. The body of the lateral ventricle has a roof formed by the corpus callosum and a medial wall formed by the septum pellucidum. Its floor contains portions of the fornix, choroid plexus, the lateral dorsal surface of the thalamus, while the caudate nucleus and stria terminalis form the lateral wall.

3. The posterior horn lies within the occipital lobe. Fibers of the corpus callosum form its roof, while its medial wall is formed by the calcar avis.

4. The inferior horn enters the temporal lobe. Cortical white matter forms the roof while the stria terminalis and tail of caudate form the lateral wall. The floor and media wall of the inferior horn of the temporal lobe are formed by the hippocampus.
B. **The Third Ventricle** - a thin space in the midline of the diencephalon, bounded by the thalami and hypothalami.

C. **The Fourth Ventricle** - a midline cavity whose floor is formed by the substance of the medulla and the pons and whose roof is formed by the cerebellum.

* [Link to Netter Image 1.43A](#)
* [Link to Netter Image 1.43B](#)
D. **Ventricular Lining** - The ventricles are lined by ependymal cells which are modified glial cells. As these cells are not fused by tight junctions, free exchange exists between the cerebrospinal fluid containing ventricles and the extracellular space of the brain. Typically, this situation permits the washout of many products of brain metabolism down a concentration gradient from the brain into the ventricular cerebrospinal fluid (CSF). This sink-like effect explains why study of the CSF provides a functional window on the brain in both health and disease.

E. **Cerebrospinal Fluid Production** - The choroid plexuses - Within the lateral, third and fourth ventricles, vascular tufts are found which are responsible for the production of CSF. These tufts, the choroid plexuses, consist of choroidal epithelial cells overlying a capillary bed. The capillary bed is fenestrated and freely permeable to circulating materials; however, the choroidal epithelial cells, joined by tight junctions, regulate the entrance of various solutes into the CSF front, while they
actively produce the CSF. The epithelial cells demonstrate many of the properties shown by the brain's vascular endothelial cells (Refer to the blood-brain barrier section) and, as such, carrier-mediated transport and diffusion into the CSF have been demonstrated. Additionally, active transport of metabolites from the CSF has been shown. Lastly, unique to the choroidal epithelial cells, a Na, K-ATPase pump located at the apical (CSF) surface actively drives Na\(^+\) into the CSF and K\(^+\) into the cell. Bicarbonate (HC\(O_3^-\)) and chloride (Cl\(^-\)) also move into the CSF, while H\(^+\) and K\(^+\) move in the opposite direction. Due to the osmotic gradient created by the NaCl passage into the CSF, water flows into the CSF. This process involves carbonic anhydrase which regulates the hydration of CO\(_2\) to supply the H\(^+\) and HC\(O_3^-\) ions. Based upon these properties, the choroidal epithelial cells rigorously control CSF composition. Its barrier properties exclude the same substances excluded by the blood-brain barrier, while its pump systems create a NaCl filtrate that resembles extracellular fluid and thus is compatible with the extracellular compartment of the brain. In general, 500 ml of CSF are produced daily. This exceeds by several fold the total volume of the ventricular and subarachnoid compartment (150 ml). Thus, drainage of CSF is mandatory to preclude a build up of fluid, with an attendant rise in intracranial pressure (ICP).

F. Cerebrospinal Fluid Drainage * Link to Netter Image 1.44 - In general, CSF produced in the lateral ventricles drains through the foramina of Monro to reach the third ventricle. Fluid from this ventricle drains via the cerebral aqueduct into the fourth ventricle. Here, the fluid moves through the foramen of Magendie and the paired lateral foramina of Luschka to reach the subarachnoid space approximating the brain stem. From here, the fluid travels upward in the subarachnoid space over the cortical convexities to reach the arachnoid granulations which protrude directly into the superior sagittal sinus or its related lacunae. In general, the CSF is under a 5-10 mm/Hg pressure, while the sinus pressure approximates 0. This pressure difference creates transcellular channels in arachnoid villi and allows the CSF to move into the venous return. Should venous pressure rise, CSF outflow would be impeded. In addition to this CSF flow pattern, some CSF moves downward in the spinal subarachnoid space, where it is partially resorbed. Alternate CSF drainage pathways have also been identified in subhuman primates. Cranial and spinal nerve routes, with significant drainage along the nasal olfactory system, have been described. However, their clinical significance is unknown and a matter of debate.

G. CSF Composition - As noted, CSF composition is highly regulated by the active transport and regulatory properties of the choroidal epithelium. It is an essentially NaCl solution which is low in protein and virtually acellular. Its composition related to serum is as follows:
As the CSF composition is so rigorously controlled, changes in CSF composition strongly suggest disordered CNS function or disease. Typically, by performing a lumbar tap between the L3 and L4 spinous processes, CSF can be sampled in the lumbar cistern which is continuous with that bathing the ventricular and superficial brain surfaces. Examples of CSF change and their related disease states are:

![Table 1](https://example.com/table1.png)

As the CSF composition is so rigorously controlled, changes in CSF composition strongly suggest disordered CNS function or disease. Typically, by performing a lumbar tap between the L3 and L4 spinous processes, CSF can be sampled in the lumbar cistern which is continuous with that bathing the ventricular and superficial brain surfaces. Examples of CSF change and their related disease states are:
<table>
<thead>
<tr>
<th>CSF Change</th>
<th>Disease State</th>
</tr>
</thead>
<tbody>
<tr>
<td>RBC's</td>
<td>Subarachnoid hemorrhage from ruptured aneurysm</td>
</tr>
<tr>
<td>WBC's</td>
<td>Bacterial or fungal meningitis</td>
</tr>
<tr>
<td>Lowered glucose</td>
<td>Bacterial or fungal meningitis</td>
</tr>
<tr>
<td>Elevated gamma globulins most likely IgG - discrete subfractions forming oligoclonal bands</td>
<td>Multiple sclerosis</td>
</tr>
</tbody>
</table>

* Netter Presenter Image Copyright 2004 Icon Learning Systems. All rights reserved.