MENINGES AND CEREBROSPINAL FLUID

MENINGES

General Anatomy of the Cranial and Spinal Meninges

The brain and spinal cord are enclosed within three meninges (membranes): ***the dura mater, arachnoid and pia mater.*** Of these, the pia mater is the innermost layer, in contact with the brain and spinal cord. The dura mater is the outermost layer while the arachnoid lies between the other two membranes.

Dura mater

In the cranial cavity, the dura mater adheres to the periosteum lining the inner surface of the cranial wall. In the neural canal, it is separated from the periosteum by the epidural space. The dura is the thickest of the meninges. Histologically, it consists mainly of rather avascular dense connective tissue.

Arachnoid

The arachnoid is a thin membrane which is pressed against the dura mater by the pressure of the cerebrospinal fluid. Reflected from it are numerous fine filaments, which blend with the pia mater. These filaments resemble a spider's web, hence its name. Histologically the arachnoid consists of a lamina of delicate collagenous connective tissue, coated on both sides by a squamous mesothelium

Pia Mater

The pia mater is a thin membrane which covers the brain and spinal cord. Its outer surface blends with the filaments of the arachnoid; its inner surface is fused to the brain and spinal cord. Histologically, it consists of connective tissue covered on its outer aspect by a squamous mesothelium. Midway between successive spinal roots the pia and arachnoid are firmly attached to the dura mater, forming the denticulate ligament: this ligament suspends the cord within the dura mater.

Because they are continuous with each other by means of the fine filaments (and at the filum terminale), the pia mater and arachnoid are often collectively named pia-arachnoid (leptomeninges), and regarded as a single entity.

ANATOMY OF THE MENINGES AROUND THE SPINAL NERVE ROOTS

The dura mater and arachnoid mater are extended around both the dorsal and the ventral roots in the form of tubular sleeves which prolong the subarachnoid space and therefore contain cerebrospinal fluid. In the dog, these tubular sleeves reach to the intervertebral foramina.

SPACES AROUND THE MENINGES

Three spaces are associated with the meninges, namely ***the epidural space, the subdural space and the subarachnoid space.***

i. ***The epidural space*** is present in the neural canal but not in the cranial cavity. In the neural canal, it lies between the dura mater and the periosteum. It contains loose areolar connective tissue, containing a certain amount of fat which is semi-fluid at body temperature. The epidural space also contains the longitudinal spinal venous sinuses.

ii. ***The subdural space*** lies between the dura and arachnoid mater. In life this is really only a potential space containing no more than a thin film of clear yellow fluid.

iii. **The subarachnoid space** lies between the arachnoid and pia mater, and contains cerebrospinal fluid (CSF). This space is continued around the larger vessels where they penetrate the surface of the brain and spinal cord. But it fails to reach as far as the capillaries which arise from these vessels, and therefore does not extend around individual neurons.

THE CISTERNS

The subarachnoid space is narrow, except in few places where it expands to from cisterns. There two main cisterns:

i. ***The cisterna magna or cerebellomedullary cistern:*** This is a large expansion of the subarachnoid space between the caudal aspect of the cerebellum and dorsal surface of the medulla oblongata. This cistern is used in the dog for obtaining samples of CSF with a needle and can also be used for the same purpose (usually under general anaesthesia) for the ox, sheep, horse and cat.

ii. ***The lumbar cistern***: In the dog this cistern is limited to the region of the first sacral vertebra. Lumbar puncture here produces only a few drops of CSF, not enough for analysis. In the ox, the lumbar cistern is under the lumbosacral junction. At this point the cistern itself is about 3 to 4mm deep. It can be entered by lumbar puncture and this provides an adequate volume of CSF for testing. In man, the lumbar cistern can be entered between the 3^{rd} and 4^{th} lumbar vertebrae and provides sufficient volume for testing. The chemical and cellular constituents of the cerebrospinal fluid and also its pressure may change in diseases of the CNS and meninges, thus analysis of these changes may be helpful in diagnosis.

RELATIONSHIP OF BLOOD VESSELS TO THE MENINGES

The arteries and veins travelling on the surface of the brain and spinal cord are suspended in the filaments which pass between the pia and arachnoid.

THE FILUM TERMINALE (TERMINAL FILAMENTS OF THE SPINAL CORD)

The filum is a tubular strand of tissue which tethers the end of the cord to the coccygeal vertebrae. It has no practical importance, but is of minor theoretical interest because it causes the dura mater to be continuous with the periosteum, and the arachnoid to be continuous with the pia mater.

CEREBROSPINAL FLUID

Formation of the CSF

Cerebrospinal fluid is formed from two main sources:

i. *From the small arteries, arterioles and capillaries* suspended in the filaments of the pia and arachnoid
ii. *From the choroid plexuses.* Direct observations on the living tissues have shown that CSF accumulates in drops on an exposed choroid plexus.

The Choroid Plexuses

There are four, located in the left and right lateral ventricles, the third ventricle, and the fourth ventricle. Of these, the plexus in the fourth ventricle adds a relatively large volume. A choroid plexus comprises of:

- A tuft of arterioles
- A coat of pia mater suspending these vessels, and
- A non-nervous epithelium consisting of cuboidal glandular cells, thrown into extensive folds to increase the surface area. The single layer of epithelial cells represents a persistence of the neural tube in its embryonic form.

Mechanism of Formation of CSF

CSF is probably produced mainly by dialysis, with some active secretion by the cuboidal glandular cells of the choroid plexus. The process of dialysis resembles the formation of tissue fluid, aqueous humour, synovial fluid, and glomerular filtrates. The dialysed fluid, however, has to pass through the cuboidal epithelium of the plexus (in order to enter a ventricle of the brain) and may then be modified by secretory processes of these glandular cells.

Total Volume of CSF

It is difficult to estimate the total volume accurately, but a figure of 200ml has been given for the horse. In humans with a damaged cranium and an exposed subarachnoid space, volumes of up to about 200ml have been collected daily.

Circulation of CSF

The CSF formed by the choroid plexus of the lateral ventricle escapes via the interventricular foramen into the third ventricle. Here the flow is augmented by the plexus of the third ventricle. After passing caudally through the cerebral aqueduct (aqueduct of Sylvius), the flow is again augmented, this time to a relatively greater extent by the product of the plexus of the fourth ventricle.

The CSF in the fourth ventricle may enter the central canal of the spinal cord. Most of it, however, escapes into the subarachnoid space through a pair of openings to the lateral walls of the fourth ventricle; these openings are called the left and right lateral apertures of the fourth ventricle. These apertures occur in mammals generally. In the higher primates, including man, there is a third opening in the mid-line; this is the median aperture of the fourth ventricle.

Having thus entered the subarachnoid space around the medulla oblongata, the CSF circulates in all directions throughout the subarachnoid space of the cranial and spinal meninges.

Obstruction to the flow of CSF can occur by narrowing the interventricular foramen, of the cerebral aqueduct, or of the lateral apertures (and median in man) of the fourth ventricle. This causes internal hydrocephalus, which is the distension of the ventricles above the obstruction. This distension gradually destroys the surrounding brain tissue by pressure from within (pressure atrophy).

Drainage of CSF

There are no lymphatics within the tissues of the brain and spinal cord. CSF is removed by three main routes, its speed of removal being rapid; a dye injected into the CSF appears in venous blood within 30seconds.

i. By absorption into the veins which are suspended in the subarachnoid space by the filaments of the pia and arachnoid. This absorption is governed by essentially the same forces as those controlling the absorption of tissue fluid by the venous end of the capillary bed: it is therefore due primarily to the osmotic pressure of the venous blood.
ii. By the arachnoid villi (evaginations of the arachnoid into the venous sinuses of the dura mater). In the arachnoid villi, the barrier between CSF and blood is reduced to the arachnoid mater plus the endothelium of the sinus. **There is doubt as to the importance of the arachnoid villi in the removal of CSF. The presence of villi has been confirmed in man, sheep and some other mammals, but it is uncertain whether villi are typical of mammal generally. It is commonly believed that they exist in the dog but this has been disputed. In some species which do have arachnoid villi, the electron microscope revealed valve-like perforations in the wall of the villi, bringing the CSF into direct continuity with venous blood.*
iii. A less important route of drainage is into the lymphatics of the roots of the cranial and spinal nerves.

Failure of the drainage mechanisms produces accumulation of CSF in the subarachnoid space, causing external hydrocephalus. This compresses the brain externally.

Functions of the Cerebrospinal Fluid

The CSF has three main functions:

i. Protection of the brain and spinal cord against impact upon their surrounding bony walls.
ii. Nutrition of the brain and spinal cord. CSF may have significant metabolic functions.
iii. To permit variations in the volume of blood inside the cranial cavity. Since the cranial cavity has bony walls and is therefore not distensible, an increase in blood volume can only occur if some other content of the cranial cavity is

proportionately reduced in volume; reduction of CSF permits a reciprocal increase of blood volume and vice versa.

BLOOD-BRAIN BARRIER

Certain substances (including dyes like trypsin blue) which normally pass freely from the blood through the tissue fluid in the body generally are unable to penetrate the capillary walls in the brain. This fact has led to the hypothesis of the blood-brain barrier. Nevertheless, the barrier is certainly not total since many substances like water, gases, electrolytes [Na^+, K^+, Cl^-], glucose, and amino acids do pass freely across the tissues of the brain.

The mechanism of the barrier is not fully understood. The cellular components of the CNS are so tightly packed together that the extracellular space is unusually small (perhaps as low as 5 to 15% of the total volume of the brain), but this is quite enough room for substances in solution to travel freely. The main elements of the barrier seem to lie in the capillaries of the brain. In contrast to capillaries elsewhere in the body, their endothelial cells have very few pinocytotic vesicles and possess true zonulae occludens at their junctions. In addition the outer surface of the basal lamina of nearly all the capillaries of the brain is covered by the perivascular feet of the astrocytes(about 85% of the total capillary surface is estimated as being covered in this way), and this may contribute to the barrier. The function of the barrier may be to protect the brain from invasion by toxic compounds.