Chapter 35: The meninges and blood supply

Three membranes form a protective covering around the brain and spinal cord, an outer dense fibrous dura mater, an intermediate delicate avascular arachnoid and an inner delicate vascular pia mater. The dura and arachnoid are separated by a potential subdural space and the arachnoid and pia by a wider subarachnoid space containing cerebrospinal fluid. The arachnoid and pia can be looked on as different parts of one enclosing membrane, the pia-arachnoid.

The Dura Mater

Cranial

The cranial dura mater is in two layers. The outer (endocranial) layer is the periosteum on the inner surface of the cranial bones and is thus continuous with the periosteum on the outer surface of the skull through the foramina and sutures. The inner (cerebral) layer of dura mater is continuous with that of the spinal cord. In most areas the two layers are firmly adherent but in places they are separated to enclose the venous sinuses. The inner layer is folded to form the falx cerebri and the tentorium cerebelli, and is stretched between the clinoid processes as the diaphragma sellae.

The falx cerebri lies in the midsagittal plane and separates the two cerebral hemispheres. It is attached to the vault of the skull from the crista galli to the internal occipital protuberance. It is sickle-shaped, narrower at its anterior end, and posteriorly blends with the upper surface of the tentorium cerebelli. The inferior sagittal sinus lies within the lower free border and the superior sagittal sinus within the attachment of the fold to the vault of the skull.

The tentorium cerebelli roofs in the posterior cranial fossa and separates the cerebral hemispheres from the cerebellum. Anteriorly is a U-shaped hole for the midbrain. It thus has attached and free borders. The attached border extends from each posterior clinoid process along the superior border of the petrous temporal bone and then round to the internal occipital protuberance. The free border is at a higher level then the attached; it runs around the lateral and posterior aspects of the midbrain and can be followed forwards to the anterior clinoid processes. The superior petrosal and transverse venous sinuses lie along the attached border of the fold. In the midline the straight sinus passes backwards in the line of union of the falx cerebri to the tentorium cerebelli.

The diaphragma sellae is attached to the four clinoid processes and forms a roof for the hypophyseal fossa. In the midline it is evaginated and closely surrounds the pituitary fossa.

The cerebral layer of dura forms a sheath around the cranial nerves as they leave the skull. The sheath so formed around the optic nerve extends to the sclera of the eyeball.

The cranial dura mater receives its blood supply from anterior ethmoidal, middle meningeal, internal carotid and vertebral arteries. It is innervated by meningeal branches of
the trigeminal, glossopharyngeal, vagal and upper three cervical nerves from before backwards.

The dura lining the vault is much less firmly attached to the bones than is the dura over the base of the skull. Fractures of the base usually rupture the dura, and cerebrospinal fluid can escape. Fractures of the vault may injure the middle meningeal vessels. In this situation the blood clot is extradural, ie outside the inner layer of dura, and this usually remains intact.

Spinal

The spinal dura mater is continuous at the foramen magnum with the cerebral layer of cranial dura and extends downwards to the level of the second sacral vertebra. It lies within the vertebral canal separated from its walls by extradural fat and the internal vertebral venous plexus. It is pierced by the ventral and dorsal roots of the spinal nerves and the filum terminale, and ensheaths these structures and the mixed spinal nerves as far as the intervertebral foramina. The spinal nerves and filum terminale help to stabilise the dural sac within the vertebral canal.

The Arachnoid

This is closely applied to the inside of the cranial and spinal dura mater and fine trabeculae pass from it to the pia mater. In places the arachnoid herniates through the dura mater, forming arachnoid villi which come into contact with the endothelium of the cranial venous sinuses, especially the superior sagittal sinus and its lateral recesses. The clusters of villi seen in later life are known as arachnoid granulations. Through these villi cerebrospinal fluid is returned to the blood in the venous sinuses.

The Pia Mater

This is closely applied to the surface of the brain and spinal cord. It extends into the sulci of the brain and the anterior median fissure of the cord and invests the cranial and spinal nerves, their roots and the filum terminale. On each side of the spinal cord the pia forms a serrated fold, the ligamentum denticulatum. The ligament runs the whole length of the cord and is attached to the dura mater, between the spinal nerves, by its serrations which pierce the arachnoid. The ligament helps to stabilise the spinal cord within the dural sheath.

Grey and white matter are absent over the roof of the third and fourth ventricles and the medial wall of the lateral ventricle. In these regions the pia mater lies in contact with the ependymal lining of the ventricles. The two layers fuse and are invaginated into the cavities by blood vessels. The folds so formed are known as choroid plexuses. The ependymal cells take on a secretory appearance and are concerned with the production of cerebrospinal fluid. A forward projecting fold of pia extends into the transverse fissure below the corpus callosum and is known as the tela choroidea. Choroidal arteries and the great cerebral vein lie in the tela. Lateral and inferior extensions of the tela invaginate the lateral and third ventricles forming their choroidal plexuses. Median and the lateral apertures in the pia and ependyma of the roof of the fourth ventricle allow cerebrospinal fluid to pass from the ventricular system to the subarachnoid space.
The subarachnoid space is filled with cerebrospinal fluid and is narrowest over the cerebral hemispheres. In some regions, where the arachnoid stretches over subdivisions of the brain, larger spaces (cisterns) are formed. The larger of these are the cerebellomedullary cistern (cisterna magna) in the angle between the cerebellum and the medulla, the interpeduncular between the cerebral peduncles, and the pontine in front of the pons. The cerebellomedullary cistern can be drained by a hollow needle inserted through the posterior atlanto-occipital membrane and the dura. The lumbar cistern, caudal to the end of the spinal cord, contains the cauda equina. A hollow needle can be pushed forwards in the midline between the spines of the lower lumbar vertebrae and after passing through the interspinous ligaments, it enters the extradural space. The needle then pierces the dura and arachnoid and enters the subarachnoid space. In this way a sample of cerebrospinal fluid can be aspirated for examination, the procedure being known as a lumbar puncture. A local anaesthetic can be introduced through such a needle into the subarachnoid space to produce regional anaesthesia; the procedure is known as spinal anaesthesia. Air, or other contrast media, may be introduced into the subarachnoid space to help radiological diagnosis. The subarachnoid space extends along the bundles of olfactory nerves which pierce the cribriform plate, and along the optic nerve as far as the eyeball. Some effects of increased intracranial pressure can be observed by inspection through an ophthalmoscope of the optic disc.

Circulation of the cerebrospinal fluid

Most of the cerebrospinal fluid is produced by the choroid plexuses of the ventricles by active secretion of the modified ependymal cells. It flows through the cavities of the brain and then through the apertures in the roof of the fourth ventricle into the subarachnoid space. The fluid circulates around the outside of the brain and spinal cord, and is returned to the blood stream either through the arachnoid villi and granulation or directly to the small veins. Some fluid may be absorbed into perineural lymph vessels. Interference with the circulation of cerebrospinal fluid produces a condition known as hydrocephalus. If the blockage is within the ventricular system (such as with pressure from a tumour) the ventricle will become dilated proximal to the level of obstruction - a condition known as internal hydrocephalus. Blockage of the arachnoid granulations (as with infection) produces communicating (external) hydrocephalus.

The Blood Supply of the Brain

Owing to the unyielding nature of the skull and spinal dura, and the relative incompressibility of the brain and cerebrospinal fluid, the vascular system is very susceptible to changes in intracranial pressure. The pattern of the vessels and the rate of flow through them can be investigated radiologically after the injection of contrast medium into the large arteries in the neck. Local cerebral ischaemia, occurring as a result of cerebral or general degenerative arterial disease, may produce variable degrees of muscle weakness, speech disturbance, somatosensory and visual loss, the condition being known as a 'stroke'. Similar symptoms may be produced by pressure on a cortical area resulting from injury, local inflammation or a tumour. Occasionally, an aneurysm of a cerebral artery in the subarachnoid space ruptures (a subarachnoid haemorrhage) or a meningeal vessel may be torn by a fracture of the skull. In both cases the patient shows the signs of increasing intracranial pressure.
Arterial supply

The brain receives its blood from the two internal carotid and the two vertebral arteries.

Internal carotid artery

This enters the cranial cavity through the carotid canal in the petrous temporal bone, traverses the cavernous sinus, piercing its roof near the anterior clinoid process, and then divides into anterior and middle cerebral arteries.

Branches

(i) anterior cerebral artery - passes forwards towards the midline and then upwards around the genu of the corpus callosum. It divides into two terminal branches which run backwards on the corpus callosum and in the cingulate sulcus. The artery supplies the medial aspect of the frontal and parietal lobes as far back as the parieto-occipital sulcus, and a small part of the adjacent lateral surface. The two anterior cerebral arteries are united near their origin by the short anterior communicating artery.

(ii) middle cerebral artery - passes laterally into the lateral sulcus in which it crosses the temporal pole and insula and turns upwards and backwards across the lateral aspect of the hemisphere. The artery supplies the inferior surface of the frontal lobe, the insula and all save the periphery of the lateral surfaced of the hemisphere.

(iii) ophthalmic artery - see in the previous chapters.

(iv) anterior choroidal artery - arises in the subarachnoid space, passes backwards with the optic tract and contributes to the blood supply of the choroid plexus in the inferior horn of the lateral ventricle.

(v) posterior communicating artery - passes backwards in the subarachnoid space to the posterior cerebral artery.

(vi) branches to the pituitary gland, meninges and trigeminal ganglion.

Vertebral artery

This enters the cranial cavity through the foramen magnum, passes forwards, upwards and medially on to the basal part of the occipital bone and, uniting with its fellow of the opposite side at the lower border of the pons, forms the basilar artery.

Branches

(i) anterior spinal artery - a single vessel is formed by the union of branches from both vertebral arteries. It descends in front of the medulla and reaches and supplies the spinal cord.
(ii) **posterior inferior cerebellar artery** - passes posteriorly and supplies the posterolateral part of the medulla, the lower cerebellum, a choroidal branch to the fourth ventricle, and a posterior spinal branch which descends to the spinal cord.

**Basilar artery**

This ascends in front of the pons and divides near its upper border into the two posterior cerebral arteries.

**Branches**

(i) **anterior inferior cerebellar artery** - passes backwards to its named area.

(ii) **pontine branches**.

(iii) **labyrinthine artery** - passes through the internal acoustic meatus to the inner ear.

(iv) **superior cerebellar artery** - passes backwards around the cerebral peduncles and supplies the superior surface of the cerebellum.

(v) **posterior cerebral artery** - passes backwards around the cerebral peduncles and supplies the medial surface of the occipital lobe. Branches supply the inferior surfaces of the occipital and temporal lobes and the adjacent lateral surface. Its **posterior choroidal** branch passes into the tela choroidea and supplies the choroid plexus of the third and lateral ventricles.

**Circle of Willis**

The principal arteries supplying the forebrain form an anastomotic ring, the circle of Willis, around the optic chiasma and the pituitary gland. It is formed by the stem of the anterior and middle cerebral arteries of each side anterolaterally, the posterior cerebral arteries posteriorly, the anterior communicating artery uniting the two anterior cerebral arteries, and the posterior communicating arteries uniting the corresponding posterior cerebral arteries to the middle cerebral or internal carotid arteries. The pattern of this anastomosis, however, is variable. A number of branches from the circle and its larger tributaries pass upwards into the nuclear masses of the forebrain, entering the brain mainly through the anterior and posterior substances. These perforating vessels supply the internal capsule and the adjacent thalamus and basal nuclei. The anterior cerebral artery supplies the upper part of the sensorimotor cortex (leg and foot areas). The middle cerebral artery supplies the remainder of the sensorimotor cortex and also the auditory, speech and gustatory areas. The posterior cerebral artery supplies the visual area (the striate calcarine cortex).

**Venous Drainage**

The veins draining the hemispheres may be divided into superficial and deep groups which anastomose freely and drain to the cranial venous sinuses.
Superficial group

(i) the superior cerebral veins, passing to the superior sagittal sinus.

(ii) the superficial middle cerebral vein passing in the lateral sulcus to the cavernous sinus.

(iii) the inferior cerebral veins passing to the transverse sinus. Superior and inferior anastomotic veins join the superficial middle cerebral vein to the superior sagittal and transverse sinuses respectively.

Deep group

(i) the anterior cerebral vein, draining the region supplied by its artery, joins

(ii) the deep middle cerebral vein, lying deeply in the lateral sulcus and forms the basal vein. This passes backwards round the midbrain and joins the great cerebral vein near the pineal gland.

(iii) each internal cerebral vein receives the thalamostriate vein, draining the caudate nucleus and thalamus, and the choroidal veins of the lateral and third ventricles.

(iv) the great cerebral vein, formed when the two internal cerebral veins join, lies in the tela choroidea in the transverse fissure and opens into the straight sinus.

The Cranial Venous Sinuses

These lie either between the two layers of cranial dura mater or within a fold of the cerebral layer. The sinuses receive venous blood from adjacent parts of the brain and communicate via other sinuses and emissary veins with the exterior of the skull. The sinuses may be unpaired or paired.

Unpaired Sinuses

(i) superior sagittal sinus - passes backwards in the upper border of the falx cerebri and reaches the internal occipital protuberance where it usually joins the right transverse sinus. Its walls are invaginated by many arachnoid granulations, as are the lateral recesses of the sinus.

(ii) inferior sagittal sinus - passes backwards in the lower border of the falx cerebri and joins the straight sinus at the attachment of the falx to the tentorium.

(iii) straight sinus - runs downwards within the tentorium cerebelli to the internal occipital protuberance, usually joining the left transverse sinus.

(iv) basilar sinus - is a network of sinuses lying on the basal part of the occipital bone and uniting the two inferior petrosal sinuses.
(v) **intercavernous sinuses** - unite the cavernous sinuses anterior and posterior to the pituitary gland.

**Paired Sinuses**

(i) **transverse sinus** - commences at the internal occipital protuberance, the right usually continuous with the superior sagittal sinus and the left with the straight sinus. Each runs along the attached border of the tentorium, grooving the occipital and parietal bones, to the lateral part of the petrous temporal bone where it becomes the sigmoid sinus. The two transverse sinuses often communicate at the internal occipital protuberance and form the confluence of the sinuses.

(ii) **sigmoid sinus** - is a continuation of the transverse sinus and is formed at the lateral end of the superior border of the petrous temporal bone. It curves downward and then forwards, grooving the inner surface of the mastoid process, and reaches the jugular foramen where it becomes the internal jugular vein.

(iii) **cavernous sinus** - lies on the body of the sphenoid bone lateral to the pituitary gland. It is traversed by the internal carotid artery, the oculomotor, trochlear and abducens nerves and the ophthalmic and maxillary branches of the trigeminal nerve. It extends from the apex of the petrous temporal bone and the opening of the carotid canal forwards to the superior orbital fissure. Its roof is in contact with the diaphragma sellae which lies under the hypothalamus and it is pierced in front by the internal carotid artery. Its lateral wall is related to the temporal lobe of the brain and within this wall lie the oculomotor, trochlear, ophthalmic and maxillary nerves. Posteriorly the wall is related to the trigeminal ganglion. The internal carotid artery passes upwards and forwards through the sinus and pierces its roof near the anterior clinoid process. The abducent nerve passes forwards and downwards through the sinus lateral to the artery. The maxillary nerve is only in the sinus for a short distance. All the nerves and the artery, though inside the dural cleft, are outside the endothelial lining of the sinus.

The sinus receives the ophthalmic veins, the sphenoparietal sinus, the superficial middle cerebral vein and smaller veins from the adjacent parts of the brain. It drains via emissary veins to the pterygoid venous plexus, and via the superior and inferior petrosal sinuses to the transverse sinus and internal jugular vein respectively. The two sinuses communicate via the intercavernous sinuses.

(iv) **inferior petrosal sinus** - arises from the cavernous sinus, descends over the petro-occipital suture, passes through the jugular foramen and joins the internal jugular vein.

(v) **superior petrosal sinus** - passes along the superior border of the petrous temporal bone uniting the cavernous and transverse sinuses.

(vi) **sphenoparietal sinus** - runs along the edge of the lesser wing of the sphenoid bone to the cavernous sinus.

(vii) **occipital sinus** - passes from the transverse sinus near the internal occipital protuberance, around the foramen magnum to the sigmoid sinus.
Emissary veins

These pass through most foramina of the skull and unite the intracranial venous sinuses with the veins outside the skull. They include the condylar, parietal and mastoid veins, and veins passing through the foramen ovale, foramen lacerum and hypoglossal foramen.

Diploic veins

These are present in the frontal, parietal and occipital bones. They drain the diploë and communicate with the veins of the scalp and the dura.

Blood Supply of the Spinal Cord

**Arterial supply** - is from a single anterior spinal artery (derived from both vertebral arteries) and two posterior spinal arteries (branches of the posterior inferior cerebellar arteries). The anterior artery descends in the anterior median fissure and each posterior artery behind the posterior spinal nerve rootlets. These three arteries are reinforced in different regions by branches passing through the intervertebral foramina from the vertebral, deep cervical, posterior intercostal, lumbar and lateral sacral arteries. The lumbar arteries provide a rich supply to the lumbar enlargement.

**Venous drainage** - is via midline anterior and posterior spinal veins, and smaller channels near the emergence of the rootlets. They drain to the internal vertebral venous plexus.