CUNNINGHAM'S TEXTBOOK OF ANATOMY

ELEVENTH EDITION

EDITED BY

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It is possible that the ascending spinocortical fibres in the pyramid form the sensory pathway for these reflexes.

Efferent fibres from the cerebral cortex have already been described passing to other parts of the brain, e.g., corpus striatum, tectum of the midbrain, red nucleus, cerebellum, and reticular formation, through which the cerebral cortex can have indirect effects on the motor cells of the brain stem, and spinal medulla. These pathways form part of an extensive system, known as the **extrapyramidal system,** because the pathways involved do not pass through the pyramid. It is concerned with complex movements of a more automatic nature, such as the maintenance of balance during movements, the correct distribution of muscle tone necessary for normal movements, etc. The long descending pathways of the extrapyramidal system are the reticulospinal, the vestibulospinal, the rubrospinal, and the tectospinal tracts. These are almost certainly reinforced by many other paths consisting of chains of short neurons, such as those which connect the hypothalamus and subthalamus with the reticular formation. The extrapyramidal system is, anatomically, extremely complicated and the method by which its numerous parts interact is not clear. It is characterized by multiple feedback systems linking its several parts. The major parts of this system have already been described, but it should be realized that the separation of the pyramidal and extrapyramidal systems is completely artificial, and that the two systems are complementary parts of the normal nervous system.

THE MENINGES

The meninges form the protective coverings of the central nervous system and separate it from the bony elements which surround it, the skull and vertebral column. They consist of an external, thick, fibrous **dura mater,** or pachymeninx, and a mass of delicate tissue, the leptomeninges, believed to be developed from the neural crest (Horstadius, 1950). The latter is partly split into two layers (arachnoid mater and pia mater) by the presence within it of the **subarachnoid space,** filled with the clear, watery **cerebrospinal fluid.** The external of these two layers, the **arachnoid mater,** is applied to the internal surface of the dura mater, but separated from it by a capillary interval, the **subdural space.** The adjacent surfaces of the arachnoid and dura are covered with a flattened layer of mesothelial cells so that the subdural space forms a large bursa which surrounds the central nervous system and allows of movement of the nervous system and leptomeninges on the dura. Every structure, blood vessels, nerves, etc., passing to or from the brain and spinal medulla must cross the subdural space, and it is only where such structures cross it that the continuity of the subdural space is interrupted.

The external surface of the arachnoid is everywhere applied to the deep surface of the dura and its shape is therefore the same as that of the dura. On the other hand, the **pia mater** immediately invests the central nervous system, following its every contour. The blood vessels running on the nervous system are adherent to the external surface of the pia mater. Thus the branches of these vessels which pierce the nervous system carry a sleeve of pia mater with an extension of the subarachnoid space passing for a short distance into the nervous tissue, the **perivascular space.** Where the shape of the dural sac differs from that of the underlying nervous system, the distance between the pia and arachnoid mater is altered and hence the depth of the subarachnoid space, which forms deep spaces or **cisterns** in some situations and is relatively shallow in others. Apart from variations in its depth, the subarachnoid space also contains a variable number of delicate strands of tissue lying in the cerebrospinal fluid. These join the arachnoid to the pia and form a delicate web, from which the arachnoid obtains its name.

The meninges, as protective coverings of the central nervous system, have two entirely different mechanical problems to overcome:

1. The protection of the relatively firm spinal medulla within the moving vertebral column, by slinging it in a fluid-filled tube, protected externally by fat and venous spaces.

2. The support and protection of the voluminous, soft brain within the skull. This is achieved by the formation of rigid compartments within the skull and a special fluid-filled 'sponge' immediately surrounding the brain.

The Spinal Meninges

The spinal dura mater forms a long tubular sheath extending from the margin of the foramen magnum to the upper part of the sacrum. It is not of uniform width throughout, being widest in the cervical region and narrowest in the thoracic region where the sac is closest to the spinal medulla. Throughout the length of the vertebral canal it is separated from the periosteum lining the bony elements of the vertebral canal by a variable amount of soft fat and a considerable number of venous spaces, the **internal vertebral venous plexus.** The fat is found mostly over its dorsal surface forming a buffer between it and the moving laminae, and, though a few venous channels are present on this surface, the largest extradural veins form channels on either side extending the length of the vertebral canal. These communicate with the intersegmental veins through the intervertebral foramina, and with the basivertebral veins anterior to the posterior longitudinal ligament. Principally in the thoracic region, the dural sac is lightly attached to the posterior longitudinal ligament by fine collagenous strands which hold the sac close to the posterior surface of the vertebral bodies and thus to the axes of vertebral movements.

Throughout its length the spinal dura mater is lined by arachnoid while the pia mater forms a thick, tough membrane on the surface of the spinal medulla. It is thickened into a glistening ribbon, the **linea splendens,** which runs anterior to the anterior median fissure and the anterior spinal artery. The pia is also markedly thickened to form a linear fold extending laterally from the surface of the spinal medulla between the ventral and dorsal roots. This flange of the pia mater has a thick, rounded, lateral border which forms the free edge of a scalloped or toothed ligament, the **ligamentum denticulatum** [FIG. 872], which passes laterally between the points of emergence of the spinal nerve roots, forming a sharp point attached to the dura mater through the arachnoid. The ligamentum denticulatum thus suspends the spinal medulla within the spinal subarachnoid space at some twenty to twenty-two points on each side, and allows for a

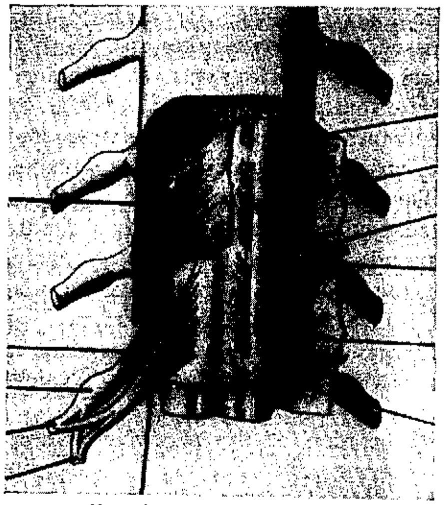

FIG. 872 Membranes of spinal medulla and mode of origin of spinal nerves. The lowest spinal nerve on the left is shown semi-diagrammatically dissected, to indicate the participation of both roots in the formation of each ramus.

considerable range of movement of the dura without a corresponding movement of the spinal medulla. The spinal subarachnoid space is relatively wide with only a few delicate strands connecting the arachnoid to the pia on the posterior surface of the spinal medulla.

The spinal medulla ends immediately below the first lumbar vertebra, but the dural and arachnoid sheaths extend inferiorly covering the cauda equina and carrying the subarachnoid space to the second part of the sacrum. Here the **filum terminale**, the thread-like continuation of the spinal medulla and its covering of pia mater, pierce the arachnoid and dura and, carrying off a sheath from them, pass to be attached to the dorsal surface of the coccyx, thus holding down the caudal part of the dural sheath [FIGS. 730 and 731].

At its cranial end, the dural sheath tends to be more firmly attached to the second and third cervical vertebrae and at the foramen magnum becomes continuous with the cranial dura mater which, unlike the spinal part, is fused with the periosteum lining the skull. Also at its cranial end the ligamentum denticulatum is continued into the cranial cavity just anterior to the spinal accessory nerve and is attached to the dura posterior to the hypoglossal canal.

The Cranial Meninges

The Cranial Dura Mater. This is closely applied to the interior of the skull without any intervening fat, and is fused with the periosteum except where the venous sinuses of the dura mater intervene or the dura is folded inwards between the parts of the brain. The combined periosteum and dura mater, sometimes erroneously called the outer and inner layers of the dura mater, are less firmly adherent over the cranial vault than they are at the base of the brain, where both periosteum and dura mater are continued through the various foramina, the one to become continuous with the periosteum on the external surface of the skull, the other with the fibrous sheaths of the nerves. The **venous sinuses of the dura mater** are endothelial tubes lying in the same layer as the internal vertebral venous plexus (between the dura and the periosteum) and are continuous with it through the foramen magnum. Like the internal vertebral venous plexus, the venous sinuses of the dura mater communicate:

1. With veins outside the skull:
   (i) Through the various foramina for the cranial nerves.
   (ii) Through emissary foramina.
2. With the diploic veins in the cranial bones.

The method of growth of the brain, whereby its three main masses, two cerebral hemispheres and the cerebellum, expand separately into the surrounding tissues, results in the formation of three separate pockets in that tissue, pockets which communicate with each other in the plane of the original brain tube. In this fashion an incomplete septum of tissue, the **falx cerebri,** is left between the two hemispheres and a similar septum, the **tentorium cerebelli,** lies between the cerebellum below and the occipital lobes of the hemispheres above. These two septa meet in a λ-shaped arrangement in the midline posteriorly where the two occipital lobes and the cerebellum come closest together. A similar but much smaller fold **(falx cerebelli)** extends anteriorly from the internal occipital crest between the cerebellar hemispheres; another, the **diaphragma sellae,** roofs over the hypophysis in the sella turcica. Each of these septa is in the form of a fold of dura mater with the arachnoid applied to its cerebral or cerebellar surface. *In situ*, the falx cerebri and tentorium cerebelli form rigid structures which act as baffles within the cranial cavity, the former preventing, to some extent, side-to-side movement of the brain, while the tentorium tends to prevent downward displacement of the occipital lobes and holds the cerebellum in position.

The **falx cerebri** [FIGS. 873 and 874] is a sickle-shaped structure lying in the median plane, attached to the cerebral surface of the cranial vault from the crista galli of the ethmoid to the internal occipital protuberance. It passes into the longitudinal fissure between the hemispheres, increasing in depth from before backwards so that its free, inferior margin comes close to the splenium of the corpus callosum posteriorly. Here its inferior edge joins the anterior extremity (apex) of the tentorium cerebelli, while anteriorly its free edge lies some distance from the genu of the corpus callosum [FIG. 874]. Within its fixed border, enclosed between its diverging surfaces and the periosteum, lies the superior sagittal sinus, the lateral lacunae of which separate the dura and periosteum further laterally. Between the layers of its free, concave border lies the inferior sagittal sinus which is joined by the great cerebral vein where that border meets the tentorium. The straight sinus, so formed, passes postero-inferiorly in the line of junction of the tentorium and the falx to reach the internal occipital protuberance. The anterior part of the falx, and the dura mater of the superior sagittal sinus and its lacunae are perforated or cribriform. The cribriform parts of the superior sagittal sinus allow the superior cerebral veins and extensions of the underlying arachnoid **(arachnoid villi** and **granulations)** to pass through the dura and come into association with the endothelial lining of the sinus and its lacunae.

The **tentorium cerebelli** [FIGS. 873 and 874] is a large, crescentic, transversely placed fold of dura mater which roofs

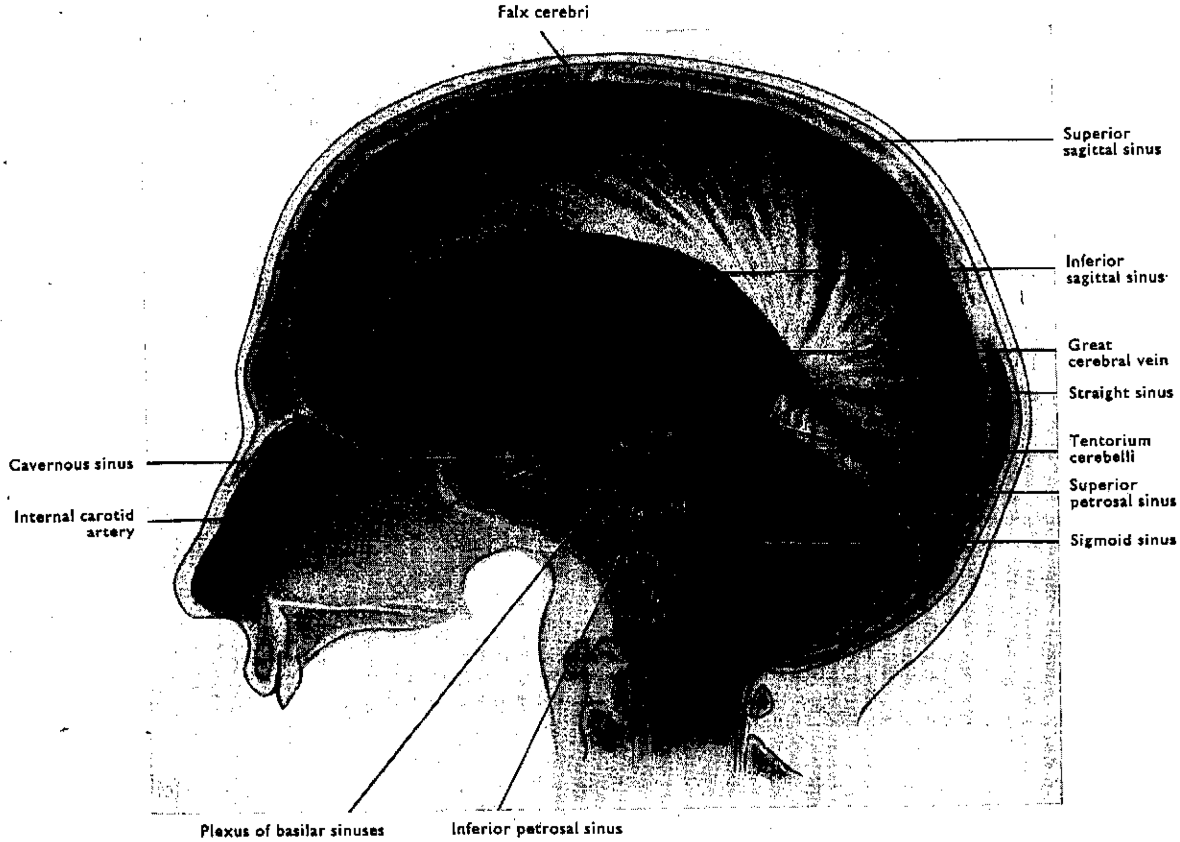

FIG. 873 Sagittal section of skull, a little to the left of median plane, to show arrangement of dura mater. Cranial nerves are indicated by numerals.

in the posterior cranial fossa and is shaped like a tent, the apex of which lies at its meeting with the free edge of the falx cerebri, posterosuperior to the splenium of the corpus callosum. It is accurately fitted to the superior surface of the cerebellum and every part of it slopes inferiorly from its apex towards its fixed margin. The **fixed margin** passes from the posterior clinoid process of the sphenoid bone, posterolaterally along the margin of the petrous temporal bone which separates the middle and posterior cranial fossae and carries the superior petrosal sinus. Passing over the mastoid part of the temporal bone to the postero-inferior angle of the parietal bone, it straddles a broad groove formed by the transverse sinus, and is pierced from above by inferior anastomotic and other inferior cerebral veins passing to the transverse sinus. The attached margin then sweeps medially along the transverse sinus to the internal occipital protuberance where it meets the fixed margin of the falx cerebri. The **free margin** forms the anterosuperior border of the tentorium and clasps the midbrain, thus forming the **tentorial notch.** The free margin is attached antero-inferiorly to the anterior clinoid processes from which it passes posteriorly as a slightly raised ridge, lateral to the oculomotor nerve, to cross the fixed margin of the tentorium lateral

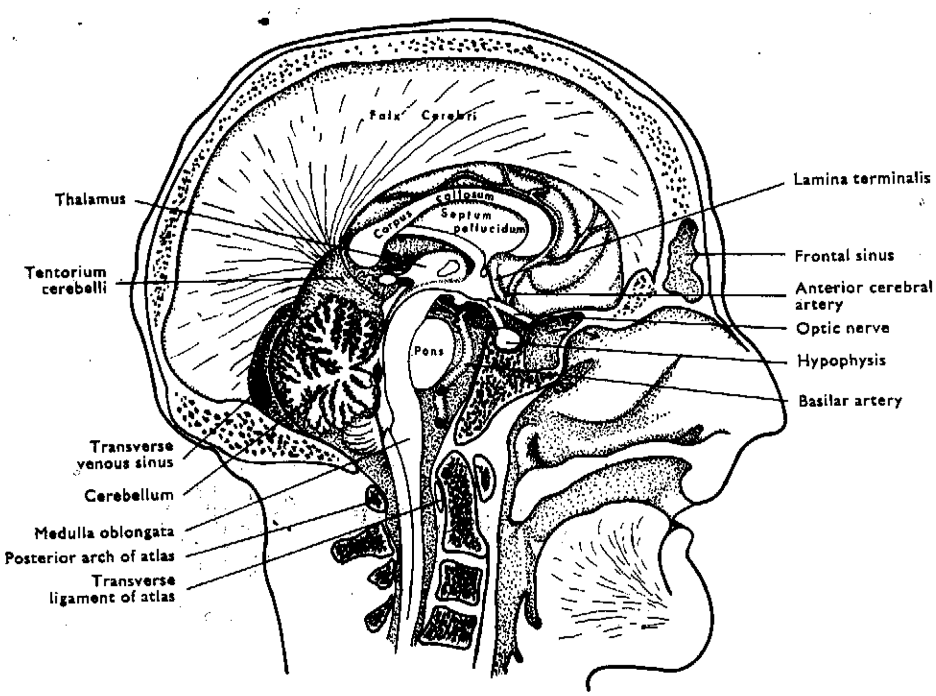

FIG. 874 Drawing prepared from a photograph of a section (supplied by Professor R. Walmsley) to show the relation between the skull, meninges, and brain. The brain stem is slightly displaced posteriorly, the pons normally lies closer to the clivus.

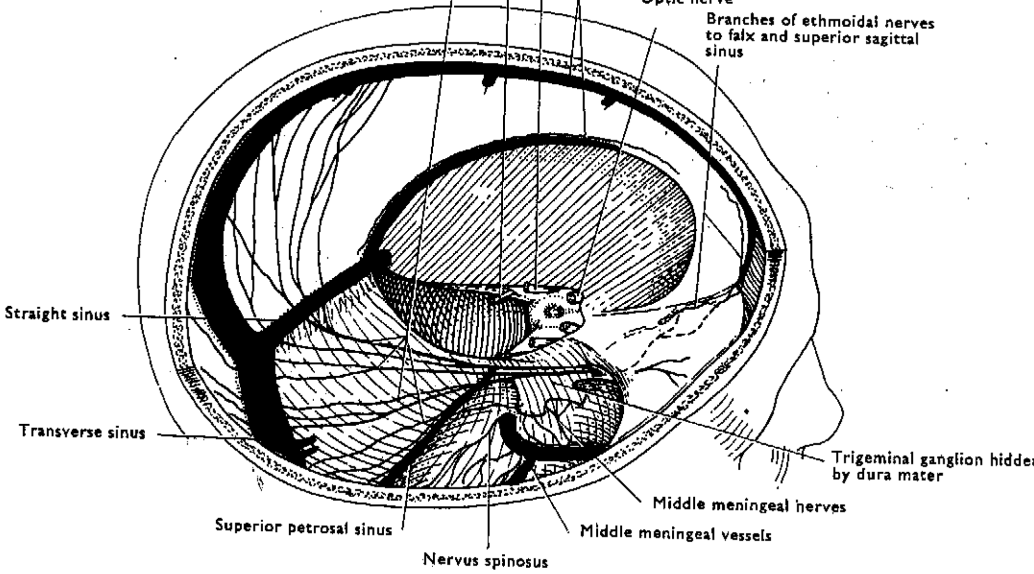

FIG. 875 Distribution of sensory nerves to dura mater of anterior and middle cranial fossae, falx cerebri, and tentorium cerebelli. (After Penfield and McNaughton, 1940.)

to the posterior clinoid process. Above the anterior part of the free edge lies the medial side of the temporal lobe, and further posteriorly the posterior cerebral artery, while below this margin lies the trochlear nerve and the superior cerebellar artery. This relation of the temporal lobe to the tentorium results in the uncus being displaced downwards medial to it when there is any space-occupying lesion in the supratentorial compartment of the skull.

The Innervation of the Dura Mater. The cranial dura mater is innervated by branches of the trigeminal, vagus, and by sympathetic nerves on the meningeal arteries which supply the dura mater and skull but play no part in the vascular supply of the brain. The anterior cranial fossa and the anterior part of the falx cerebri are supplied by the anterior (and posterior) ethmoidal nerves, passing from the cribriform plates of the ethmoid. The middle cranial fossa is supplied by branches of the maxillary and mandibular divisions of the trigeminal nerves, one of which (the nervus spinosus) is a recurrent branch of the mandibular nerve entering by the foramen spinosum. The tentorium and the posterior part of the falx cerebri are supplied by recurrent tentorial branches of the ophthalmic divisions of the trigeminal nerves, which run backwards near the free margin of the tentorium [FIG. 875]. The posterior cranial fossa receives a recurrent meningeal branch of the vagus which enters the skull through the jugular foramen.

The spinal dura mater is supplied by the recurrent meningeal branches of the spinal nerves.

The Cranial Arachnoid Mater. This differs from the spinal arachnoid in two ways:

1. On the cerebral and cerebellar hemispheres it is connected by a dense meshwork of processes to the pia mater. The interstices of this mesh are filled with cerebrospinal fluid which thus forms a sort of fluid-filled sponge which may act as a cushion preventing, in part, injury to the brain when the head is suddenly moved.

2. **Arachnoid villi and granulations** [FIGS. 876 and 877]. Along the line of the superior sagittal sinus, where the venous pressure is at its lowest, finger-like prolongations of the arachnoid pass through the fenestrations in the dura and project into the sinus and its lateral lacunae. These arachnoid villi are present but very small in the new-born but enlarge progressively throughout life until in elderly individuals they may be so large as to indent the overlying bone (foveolae granulares). The villi and granulations are covered on their vascular surfaces by the endothelium of the sinus which becomes continuous with capillary-like tubules leading through these structures to become continuous with the subarachnoid space. In the villi and granulations the tubules are surrounded by the subarachnoid meshwork which becomes distended with

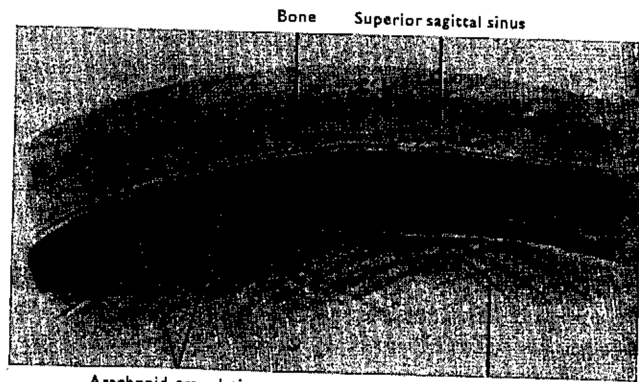

FIG. 876 Median section through cranial vault in parietal region (enlarged). Displays a portion of the superior sagittal sinus and the arachnoid granulations protruding into it.

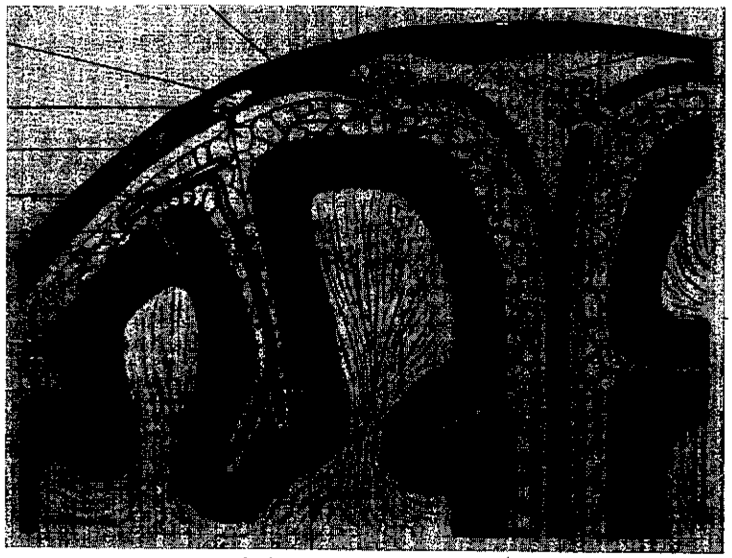

FIG. 877 Diagram to show relation of meninges to brain and of subarachnoid space to arteries, neuronal elements, and venous channels of dura mater. The necks of the villi are fused with the dura mater, and there is no continuity between the venous sinus and the subdural space.

cerebrospinal fluid when the pressure of that fluid is greater than the pressure in the sinus. The strands of the meshwork hold open the tubules which discharge cerebrospinal fluid directly into the sinus or its lacunae. When the venous pressure exceeds that of the cerebrospinal fluid, the villi or granulations collapse, the tubules are closed, and blood cannot pass into the subarachnoid space (Jayatilaka, 1965). Thus these structures are valvular openings from the subarachnoid space into the venous system, and they prevent increases in intracranial pressure. This arrangement explains the great increase in intracranial pressure which follows clotting (thrombosis) of the blood in the superior sagittal sinus.

The Cranial Subarachnoid Space. Because the brain and skull show marked differences in shape, there are several situations where the subarachnoid space is deep, forming a series of subarachnoid cisterns within the skull. These are found particularly on the base of the brain, and in them the trabeculae joining arachnoid to pia mater are very much reduced so that the arachnoid can easily be lifted away from the pia.

The largest of the **cisterns** is the **cerebellomedullary** which lies between and behind the cerebellum and medulla oblongata. It can readily be entered by a needle introduced immediately below the posterior margin of the foramen magnum and passed upwards **(cisternal puncture).** In its depth lies the median aperture of the fourth ventricle. It is continuous inferiorly with the spinal subarachnoid space, and around the sides of the medulla oblongata with a shallower but extensive cistern surrounding the pons and medulla oblongata. This pontine cistern is continuous anteriorly on the base of the brain with a deep **interpeduncular cistern,** formed by the arachnoid mater bridging across between the temporal lobes. The interpeduncular cistern contains the arterial circle of the base of the brain, and extensions of this cistern follow the main branches of this circle:

1. With the posterior cerebral arteries around the superior part of the midbrain at the margin of the tentorium, cisterna ambiens.

2. With the middle cerebral artery into the lateral sulcus and its branches, the **cistern of the lateral fossa.**

3. With the anterior cerebral arteries, surrounding the superior and inferior surfaces of the optic chiasma, the **cisterna chiasmatis.** Within the lateral sulcus the middle cerebral artery is so closely surrounded by brain tissue that, it is believed, the pulsations of the artery drive the cerebrospinal fluid laterally from the interpeduncular fossa over the lateral surface of the hemisphere. Possibly the other major arteries have similar effects in causing directional flow of cerebrospinal fluid in the subarachnoid space.

The Formation and Circulation of Cerebrospinal Fluid. The bulk of the cerebrospinal fluid is formed in the choroid plexuses of the lateral ventricles and in lesser amounts in the third and fourth ventricles. It is probably also produced by ependyma throughout the ventricular system and some may even be derived from the capillaries on the surface of the brain and spinal medulla. It is a clear, protein-free fluid which contains two or three lymphocytes per $mm.^3$ and is in osmotic equilibrium with blood plasma, principally because of a higher concentration of chlorides. The normal course of the fluid is from the lateral ventricles through the interventricular foramen to the third ventricle, thence through the midbrain in the **cerebral aqueduct** to the fourth ventricle. Here the cerebrospinal fluid escapes through the median and the two lateral apertures [p. 601] into the subarachnoid space, entering the cerebello-medullary and pontine cisterns respectively. From this site the fluid may pass downwards around the spinal medulla, but most of it flows slowly through the tentorial notch and spreads over the cerebral hemispheres, partly aided by the active pulsations of the cerebral arteries, to reach the arachnoid granulations where it can pass into the

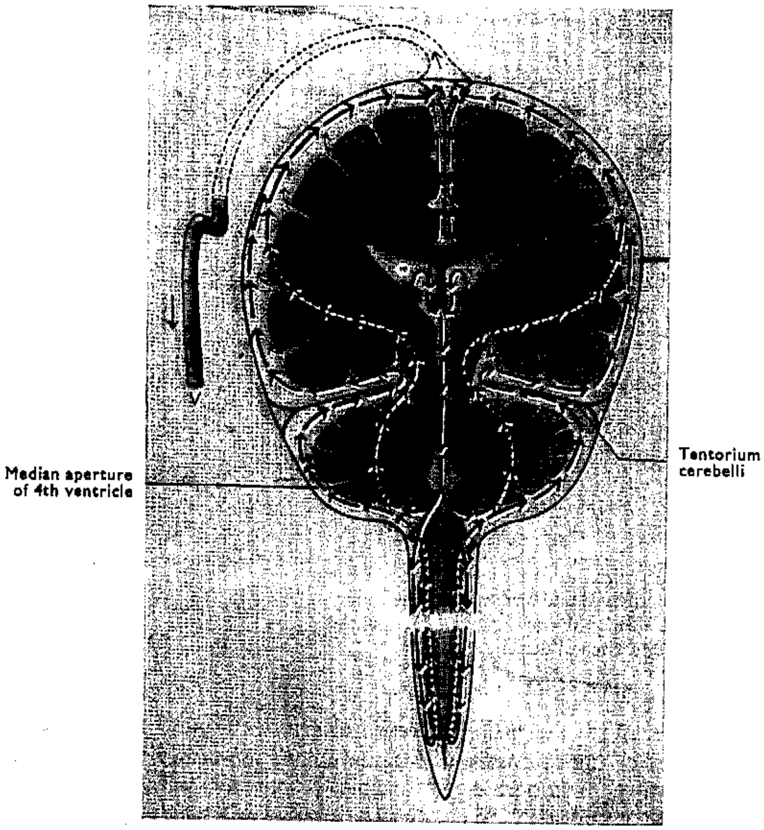

FIG. 878 Diagram to show the main points relating to the production, course, and absorption of the cerebrospinal fluid. (After N. M. Dott (1928) *Edinb. med. J.*, 35, 182.)

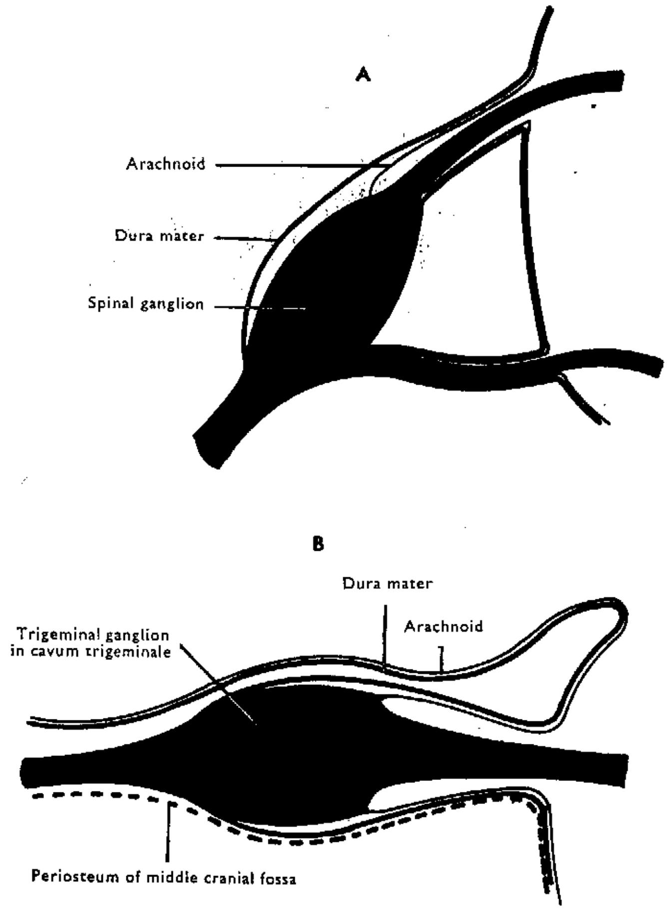

FIG. 880 Diagram to indicate the meningeal relation of A, a spinal nerve, and B, the trigeminal ganglion in the cavum trigeminale.

venous system [FIG. 878]. Absorption has been shown to occur into the perineural lymph vessels and the veins on the spinal nerves. In particular, cerebrospinal fluid passes into :

1. The orbital lymph vessels, by passing along the sub-arachnoid sheath which surrounds the optic nerve to the lamina cribrosa of the sclera.

2. The lymph vessels of the nose from the region of the olfactory bulb, also along the vestibulocochlear and facial nerves. At one time it was thought that every branch of the arteries in the subarachnoid space carried a sleeve of the space with it to its terminal ramifications in the brain, and that such spaces communicated with perineuronal spaces in the brain. This is now known not to be the case, since no such spaces are visible under the electron microscope and the peri-vascular spaces only accompany the larger vessels for a short distance as they pierce the nervous system.

The Pia Mater of the Brain. In most situations this is a much more delicate membrane than its spinal counterpart, though over the medulla oblongata it is thick and firmly adherent. Elsewhere it forms the intimate covering of the brain, dipping into every sulcus. In certain places it lies in apposition with the ependymal lining of the brain, i.e., in the roofs of the fourth and third ventricles and in the medial walls of the lateral ventricles. Here it is known as the **tela choroidea,** and forms the vascular connective tissue core of the choroid plexuses, being in-vaginated into the ventricle with a covering of ependyma in these situations [pp. 600 and 653].

The Relation of the Meninges to the Nerves. [FIG. 880] In the spinal nerves the dura mater is prolonged separately over the ventral and dorsal roots to fuse with the epineurium at the distal part of the spinal ganglion. The arach-noid also forms a separate sheath for both roots, the subarachnoid space extending to the

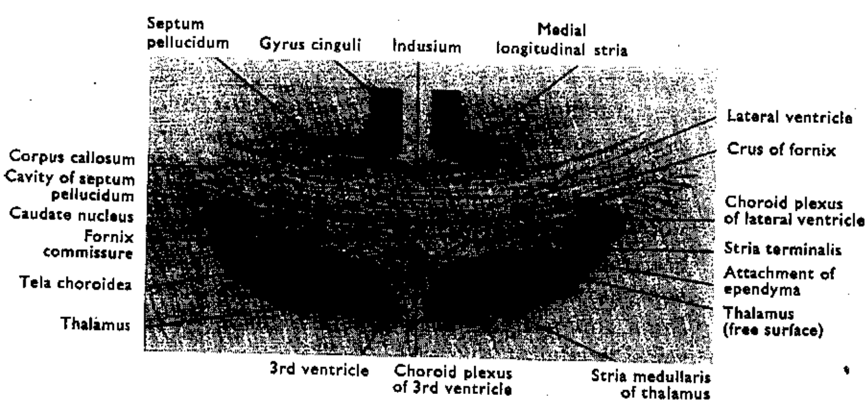

FIG. 879 Diagram of coronal section through tela choroidea of third ventricle.

proxima part of the spinal ganglion. It is in this region that reabsorption of cerebrospinal fluid is believed to occur. Exactly the same arrangement is present in the cranial nerves, the dura fusing with the distal part of the ganglia and the arachnoid with their proximal parts. The arrangement around the trigeminal ganglion is the same as that of spinal ganglia, only in this case the dura mater is folded over it, forming the floor of the middle cranial fossa, so that the cavum trigeminale has two layers of dura mater superior to it, but is otherwise the same as the space surrounding any spinal ganglion. The pia mater is continuous with the perineurium.

CRANIOCEREBRAL TOPOGRAPHY

The relationship between the brain and the internal cranial base is readily visualized. In the midline [FIG. 874] the medulla and pons lie on the clivus with the upper border of the pons reaching almost to the dorsum sellae and its anterior surface separated from the bone by the basilar venous plexus [FIG. 1119], the meninges, and the basilar artery in the subarachnoid space. The optic chiasma does not lie in the sulcus chiasmatis of the sphenoid bone but considerably posterior to this, almost vertically above the hypophysis. From the chiasma the optic nerves pass forwards, above the hypophysis in the sella turcica and below the corresponding anterior cerebral artery, to reach the optic canal immediately lateral to the sphenoidal air sinus. In the anterior cranial fossa lies the crista galli and the attachment of the falx cerebri to the ethmoid bone. Immediately on either side of this, the olfactory bulb lies on the cribriform lamina of the ethmoid which, together with the dura mater and nasal epithelium, separate it from the nasal cavity. Further laterally the orbital surface of the frontal lobe lies in contact with the orbital part of the frontal bone and the lesser wing of the sphenoid. The orbital part of the frontal bone separates the brain from the ethmoidal air sinuses medially and the orbit laterally. It is a thin plate of bone which is in close apposition to the surface of the frontal lobe and is marked with ridges and impressions corresponding to the sulci and gyri overlying it. Medially it slopes inferiorly to overlie the ethmoid as far as the lateral edge of the cribriform lamina, while posteriorly it is continuous with the lesser wing of the sphenoid, the sharp concave posterior edge of which is inserted into the lateral sulcus and overlies the extreme anterior part of the temporal lobe. The floor of the anterior cranial fossa is very thin throughout, except for the occasional extension of the frontal air sinus posteriorly between the inner and outer tables of the orbital part of the frontal

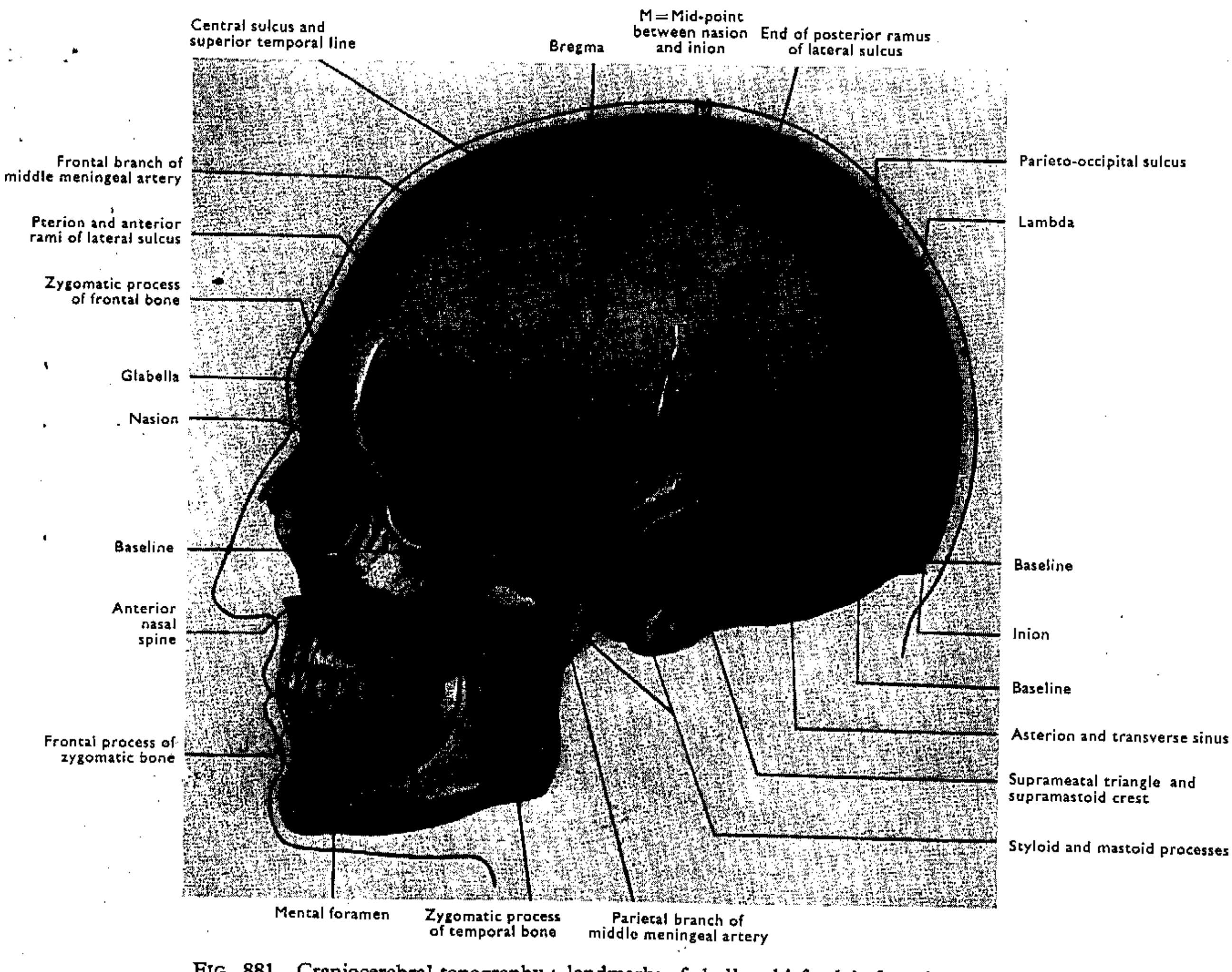

FIG. 881 Craniocerebral topography : landmarks of skull ; chief sulci of cerebrum ; transverse and sigmoid venous sinuses ; middle meningeal artery.