Section 1 Fundamentals of neurocritical care

Chapter 1

Neuroanatomy

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Overall structure and organization

The structure of the central nervous system (CNS) is organized into five distinct parts comprising the cerebrum, diencephalon (thalamus and hypothalamus), brainstem, cerebellum and spinal cord. There is a complex interplay of signals, which are transmitted among each component of the CNS to control consciousness, sensation, motor activity, autonomic nervous function and coordinate speech and movement.

Cerebrum

The cerebrum is composed of the cerebral hemispheres and processes the higher-order functions of the nervous system. It also supplies neuronal connections to nervous system outlets to the voluntary/involuntary muscles and diencephalon, and receives sensory inputs from the peripheral nervous system. The right and left cerebral hemispheres are separated by a central meningeal reflection called the falx cerebri. Posteriorly, the tentorium separates the cerebrum from the intratentorial compartment, which contains the cerebellum and brainstem. Crevices and folds of the cerebrum are referred to as sulci and gyri, respectively. Anatomical boundaries formed by sulci divide the cerebrum into four lobes: frontal, parietal, occipital and temporal. The central sulcus forms the boundary between the frontal and parietal lobes, whereas the Sylvian fissure separates the frontal/parietal lobes from the temporal lobe. The occipital lobe is located posterior to the parietal.

Interhemispheric connections are formed by the corpus callosum, genu and splenium. Deep within the cerebral hemispheres, cavities form the lateral ventricles of the ventricular system, which subsequently drain into the 3rd ventricle.

Importantly, the cerebrum is organized into distinct areas which are responsible for higher-order neurological functions. Nearly 100% of people who are right handed, are left hemisphere dominant, meaning that the language centres are located unilaterally in the left hemispehere. Approximately 75% of

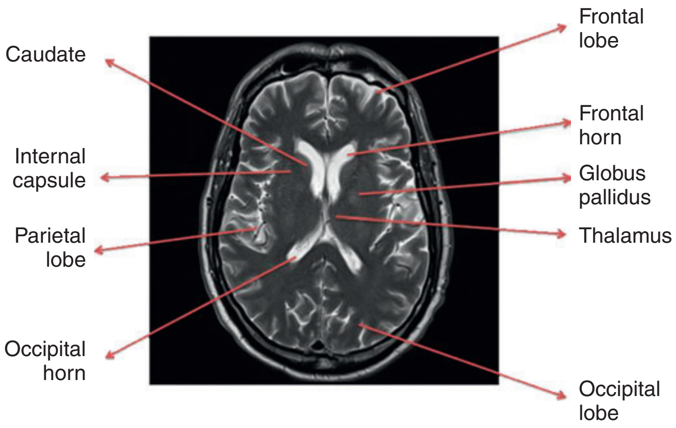

Figure 1.1 MRI axial. An axial MRI slice revealing the appearance of the deep cerebral structures such as the thalami, basal ganglia, internal capsules. Also shown are the frontal and occipital horns of the ventricular system.

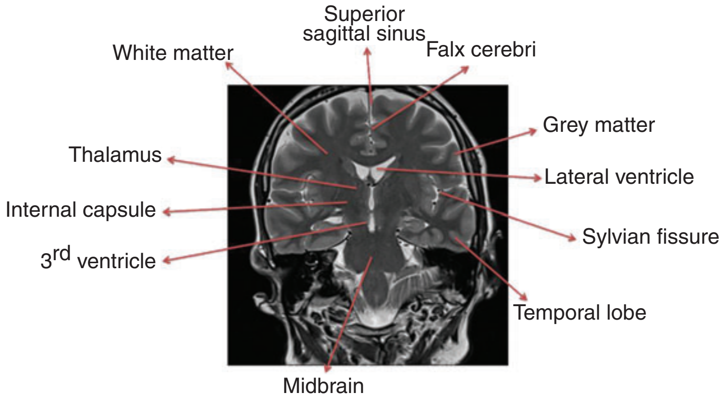

Figure 1.2 MRI coronal. A coronal slice of an MRI demonstrating the appearance of the cerebral hemispheres, cortex and deeper structures such as the thalami and basal ganglia.

left-handed people are also left hemispehere dominant, while the remainder are bilaterally or right-side dominant. The motor area is located immediately anterior to the central sulcus in the major gyrus of the frontal lobe. Alternately, the sensory strip is located in the parietal lobe, in the major gyrus directly opposite to the motor strip. The body's reflection in the sensory and motor strips are organized in the homunculus, which is an anatomical projection in the cerebrum. Centrally, the motor and sensory functions of the feet and lower extremities are located. Moving laterally, the torso, hands and face are anatomically located along the respective gyri.

The speech areas are divided into two distinct regions. Broca's area, which is responsible for expressive speech, is located laterally in the frontal lobe and is bordered by the Sylvian fissure and motor strip. Wernicke's area, which controls receptive speech functions, is located in the temporal and parietal lobes, traversing the Sylvian fissure, and is bordered posteriorly by the occipital lobe.

Diencephalon (thalamus and hypothalamus)

The diencephalon is composed of the deeper structures in the cerebral hemispheres: hypothalamus and thalamus. The thalami, which are located adjacent to the lateral ventricles deep within each cerebral hemisphere serve as a relay centre for sensory input from the body. Sensory neuronal pathways have a connection within the thalami prior to giving rise to the final neuron, which terminates in the sensory cortex of the parietal lobe. The thalamus also has many important connections which regulate the function of the basal ganglia, hypothalamus and cerebellum. Its blood supply arises from the medial and lateral lenticulostriate arteries. It also has a watershed blood supply from the posterior circulation.

The hypothalamus, which is derived from the autonomic nervous system, contains many individual nuclei, each of which has important functions in wakefulness, satiety, hormone production and thermoregulation. Anatomically, it is located superior to the optic chiasm and is connected to the pituitary by the hypophyseal stalk. The hypothalamus is the site of antidiuretic hormone production, which is ultimately stored and released from the posterior pituitary. It is also the site of corticotrophic, thyrotrophic, gonadotrophic and growth hormone releasing hormone production/secretion.

Mesencephalon (brainstem)

The brainstem is composed of three distinct regions: the midbrain, pons and medulla. It is located between the cerebrum and is continuous with the spinal cord caudally. The cerebellum forms its posterior border, making cerebellar pathology a dangerous site of injury if the brainstem is compressed or compromised. The brainstem relays sensory and motor functions between cerebral

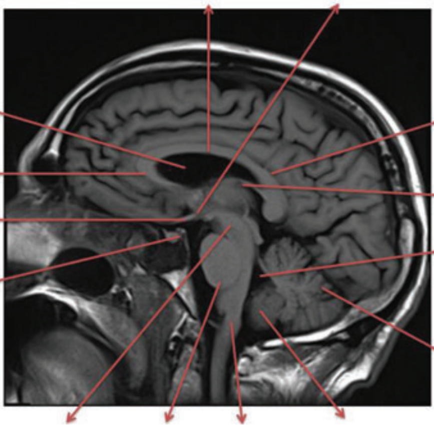

Figure 1.3 MRI sagittal. A sagittal MRI showing the appearance of the corpus callosum, hypothalamus, pituitary and ventricular system. Also shown is the connection between the diencephalon and mesencephalon with the proximity of the cerebellum to brainstem structures in the posterior fossa.

cortex and spinal cord. Additionally, it houses the nuclei of ten of the 12 cranial nerves, which are responsible for important somatic and visceral functions in the body. The reticular activating system is located throughout the brainstem and is principally responsible for wakefulness and arousal. Finally, the respiratory center, which modulates the drive to initiate respiratory effort, is located in the medulla. Complete and irreversible damage to the brainstem and all its functions is determined by clinical examination in the absence of confounders or ancillary tests, and defines brain death.

Cerebellum

The cerebellum is located inferiorly and separated from the occipital lobe by the tentorium. It is divided into hemispheres by a central vermis and is connected to the brainstem via three cerebellar peduncles bilaterally, which carry important neuronal fibres to the peripheral nervous system, cranial nerve nuclei, the diencephalon and basal ganglia. The 4th ventricle and its drainage apertures are located anterior to the cerebellum, making pathology in the cerebellum an important cause of obstructive hydrocephalus if a lesion blocks the ventricular drainage system. The functions of the cerebellum include control of eye movements, speech fluency, coordination of movement and a contribution to proprioception.

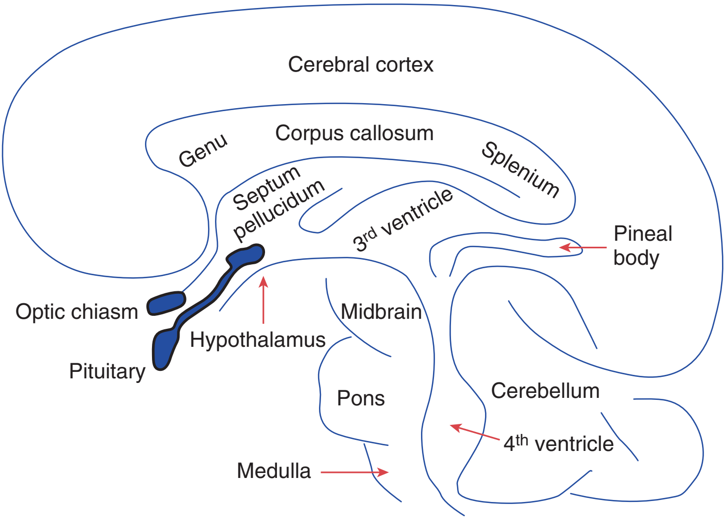

Figure 1.4 Sagittal anatomy of the cerebrum and brainstem. The anatomy of the ventricular system is demonstrated alongside major anatomical structures of the central nervous system. Importantly, the 4th ventricle lies between the cerebellum and brainstem, a narrow area where obstruction to CSF flow can occur, resulting in non-communicating hydrocephalus.

Spinal cord

The spinal cord begins its path caudally from its origin at the medulla and terminates in the conus medullaris at the level of the second or third lumbar vertebral body. The cauda equina extends from the conus as a free standing collection of nerves which exit the spinal column in the lumbosacral region. A cross-section of the spinal cord reveals a butterfly shaped appearance of grey matter which contains cell bodies of motor neurons and important decussating neurons of the spinothalamic tract. In the centre of the cord, the spinal canal is located, which contains cerebral spinal fluid.

The spinal cord is composed of ascending and descending neuronal tracts which carry distinct functions to the peripheral nervous system. Sensory pathways such as the dorsal columns are located posterior to the grey matter and transmit sensations of proprioception, light touch and vibration. The spinothalamic tracts, which carry pain and temperature, have their first-order neuron cross-over in the spinal cord on its ascent in the spinal cord. The major motor tracts, the medial and lateral corticospinal tracts, carry voluntary motor neurons to skeletal muscle. The muscles of the head and neck are carried by the cranial nerves and do not traverse the spinal cord.

Central nervous system blood supply

The brain has dual arterial blood supply from the carotid arteries and vertebrobasilar system. The carotid arteries supply the anterior circulation (frontal, temporal and majority of the parietal lobes). The vertebrobasilar system gives rise to posterior cerebral arteries, which mainly supply the occipital lobes, brainstem and cerebellum.

The right common carotid artery emerges from the brachiocephalic artery and the left common carotid originates directly from the aortic trunk. Both vessels enter the neck and run alongside the internal jugular veins. The common carotid bisects into the internal and external carotid arteries. The external carotid supplies the main extracranial structures of the head and neck. The internal carotid continues its path and eventually enters in the intracranial space via the carotid canal and while running through the cavernous sinus. Once in the intracranial vault, the ICA trisects into the anterior cerebral, middle cerebral and posterior communicating arteries, forming the circle of Willis.

The anterior cerebral artery runs along the base of the frontal lobes and each ACA joins another by the anterior communicating artery. The ACAs supply the medial aspect of the frontal lobe circulation and basal ganglia. The MCA, which is the largest intracerebral artery, runs laterally through the Sylvian fissure and supplies the lateral parts of the frontal and parietal lobes. It also supplies the temporal lobe circulation. Importantly, the lenticulostriate arteries emerge from the MCA proximal to its exit into the Sylvian fissure and supply the deep cerebral structures such as the lateral basal ganglia, internal capsules and thalamus.

The vertebral arteries traverse the spinal column through the intravertebral canals after their origin from the subclavian arteries. Upon exiting the canals, they give rise to the anterior spinal artery, which travels caudally and supplies the anterior two-thirds of the spinal cord. Shortly thereafter, the vertebral arteries join to form the basilar artery at the pons. The posterior inferior and anterior inferior cerebellar arteries originate from the basilar to supply the inferior cerebellum. As the basilar artery travels superiorly, the pontine arteries exit and supply the pons as well as superior midbrain. Finally, the superior cerebellar artery originates from the basilar prior to the basilar artery terminating by giving rise to the posterior cerebral and posterior communicating cerebral arteries in the circle of Willis.

The spinal cord blood supply originates from the vertebral arteries by branches from both forming the anterior spinal artery, which travels caudally to supply the anterior two-thirds of spinal cord. The posterior one-third of the

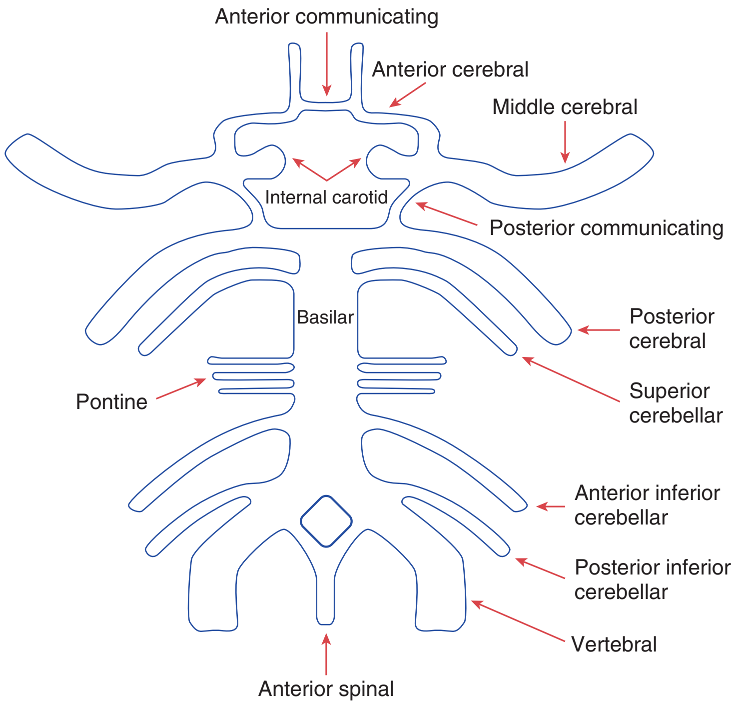

Figure 1.5 Diagram of circle of Willis and cerebral vasculature. The circle of Willis is a confluence of vasculature of the anterior and posterior circulation of the cerebral parenchyma and brainstem. It provides an ability for a source of backup circulatory flow if one source is compromised. The vertebral arteries originate from each subclavian artery and the anterior circulation is provided from the carotid arteries. Branches of the basilar artery supply the entire brainstem and cerebellum.

spinal cord is supplied by the posterior spinal artery, which is supplied by perforators from the intercostal arteries. At the thoracolumbar junction, the artery of Adamkowiez gives rise to the blood supply for the anterior spinal cord. This artery directly originates from the descending aorta.

The venous vasculature of the intracranial space is organized into large venous sinuses, which eventually drain into the internal jugular veins. The superior and inferior sagittal sinus receives venous supply from cortical veins. Interestingly, the superior sagittal sinus also contains arachnoid villi, which absorb CSF into the venous vasculature, the main method of CSF drainage from intracranial space. This large sinus runs along the top of the cerebrum

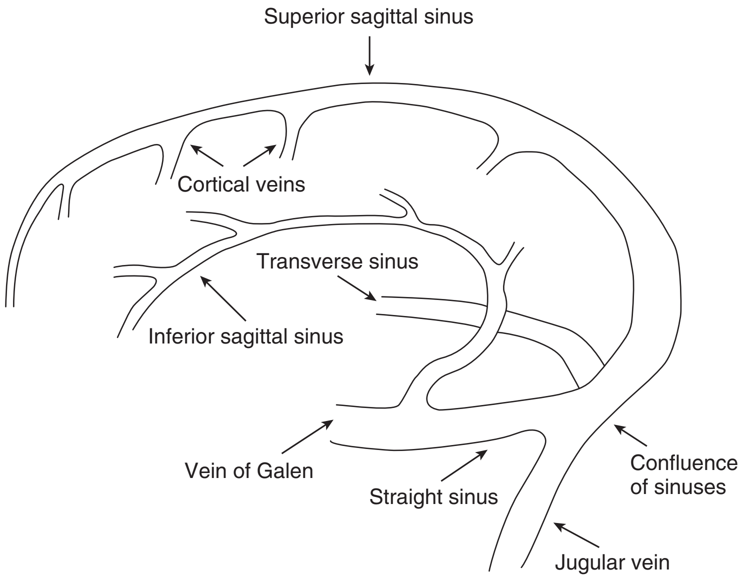

Figure 1.6 **Cerebral venous sinus anatomy**. Cortical veins drain into both superior and inferior sagittal venous sinuses. The transverse and sigmoid sinuses provide venous drainage from the inferior aspects of the frontal, parietal, occipital and temporal lobes. The vein of Galen drains the deep cerebral structures and forms the straight sinus once joined by the inferior sagittal sinus. Ultimately, all sinuses converge at the confluence of sinuses which leads into the internal jugular veins.

between a fold of dura mater, eventually terminating at the confluence of sinuses located posteriorly. The inferior sagittal sinus drains venous blood from inferior aspects of the frontal and parietal lobes and also terminates in the straight sinus. The transverse sinuses retrieve venous blood from the temporal lobes and run along the tentorium to the confluence of sinuses. The vein of Galen receives venous return from the deep cerebral structures and drains into the straight sinus, which in turn terminates in the confluence of sinuses. From the confluence of sinuses, each internal jugular vein originates and exits the intracranial space via the jugular foramen.

In the cerebral capillaries, the cerebral vasculature exhibits a unique property of a tight barrier function between the intraluminal vascular space and parenchyma. This is termed the “blood–brain barrier” and is formed by numerous tight junctions between the endothelial cells that establish a tightly controlled passage system of substances between the vessels and brain. In states of disease (traumatic brain injury, ischemia, inflammation, infection), the blood–brain barrier can be compromised and leave the brain at risk of edema formation and increased intracranial pressure.

Summary

- The central nervous system is comprised of the cerebrum, diencephalon, brainstem, cerebellum and spinal cord.
- The cerebrum is divided into two hemispheres and controls the high-order functions of the nervous system.
- The brainstem is responsible for transmitting neuronal signals to and from the cerebrum. It also controls wakefulness and contains the respiratory center.
- The cerebellum, located in the posterior fossa, is responsible for balance and cordination.
- The spinal cord is contained within the spinal column and relays messages between the central and peripheral nervous systems.
- The diencephalon is composed of the thalamus and hypothalamus, both of which are situated deep within in the cerebral hemispheres.

Suggested readings

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3. Menon DK. Cardiovascular Physiology. London, BMJ Publishing. 1999.
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Chapter 2

Essential neurophysiology

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Monro–Kellie doctrine

"The cranial cavity is a closed rigid box and that therefore a change in the volume of one of the intracranial compartments can only occur as a result of a compensatory decrease in another compartment(s)."

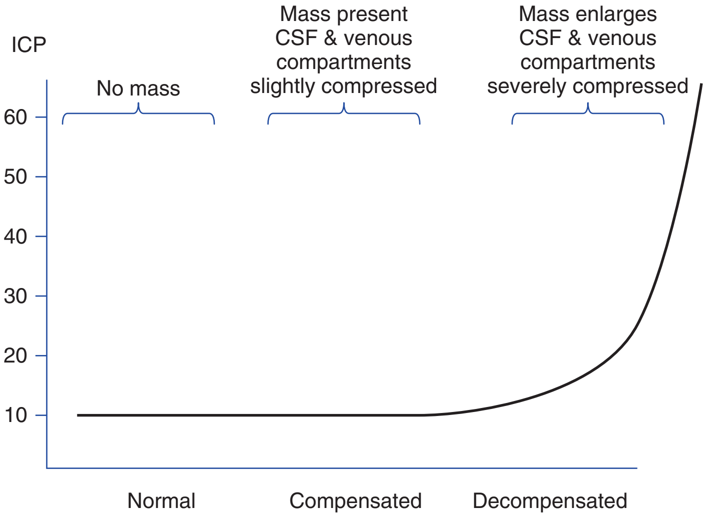

Figure 2.1 **Effect of a mass-expanding lesion on intracranial compartment volume and pressure**. As the volume of a space occupying lesion increases within the rigid cranium, the CSF and venous vascular compartments gradually decrease to maintain a normal intracranial pressure (ICP). Once these compensatory mechanisms are exhausted, the intracranial pressure rises precipitously and results in herniation. (Adapted from *Textbook of Pediatric Intensive Care, 1996*.)