Section 1 Anatomy

Chapter 1

Structure and Function of the Brain and Spinal Cord

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Key Points

- The CNS can be organized into five anatomical regions: cerebral hemispheres, diencephalon, brain stem, cerebellum, and spinal cord.
- The anterior two-thirds of the spinal cord are supplied by the anterior spinal artery. This portion of the spinal cord contains lower motor neurons in the ventral horn, descending corticospinal tracts, and ascending spinothalamic tracts.
- The supra-tentorial compartment includes the cerebral hemispheres and the diencephalon. More than 80% of people are left-hemisphere dominant for speech and language function.
- The infra-tentorial compartment contains the brain stem, cerebellum, and cranial nerves 3–12.
- The basal ganglia include caudate, globus pallidus, putamen, and amygdala.

Abbreviations

CNS Central nervous system
CSF Cerebrospinal fluid

Contents

Introduction

The CNS can be divided grossly into five anatomical regions (Figure 1.1):

(1) spinal cord
(2) cerebral hemispheres
(3) diencephalon
(4) brain stem, consisting of the medulla, pons, and midbrain
(5) cerebellum

For practical purposes, many surgeons divide the intracranial compartment into supra-tentorial and infra-tentorial compartments. The supra-tentorial compartment contains the cerebral hemispheres and the diencephalon, while the infra-tentorial compartment includes the brain stem and cerebellum.

The CNS is bathed in CSF. CSF is created in the ventricles by the choroid plexus at a rate of about 15–20 ml/h in adults (Figure 1.2a) and circulates through the ventricular system to the subarachnoid space. The subarachnoid space is found between the pia mater, which is attached to the brain and spinal cord tissue, and the arachnoid mater, which is a delicate, spiderweb-like connective tissue (Figure 1.2b). Outside the arachnoid is the tough dura mater. Collectively, the pia, arachnoid, and dura mater form the meninges.

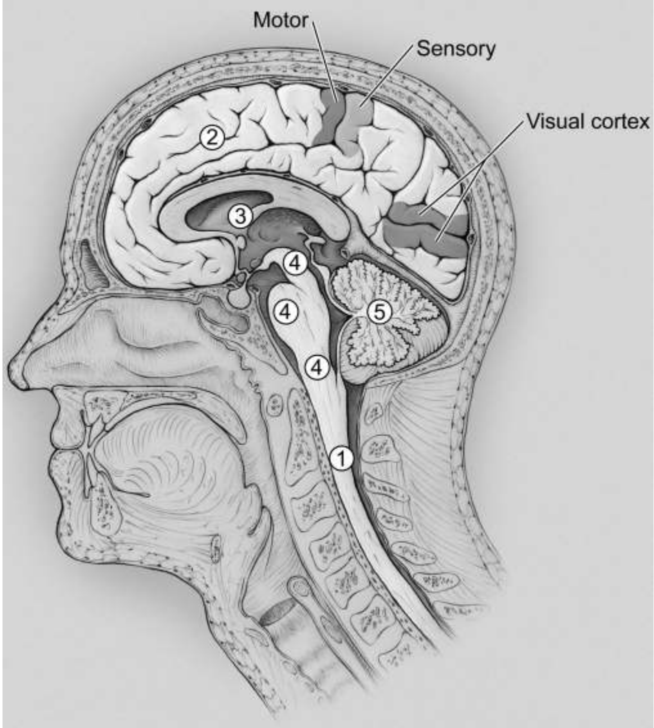

Figure 1.1 Sagittal image showing relationships of (1) spinal cord; (2) cerebral hemispheres; (3) the diencephalon; (4) the brain stem, consisting of the medulla, pons, and midbrain; and (5) the cerebellum.

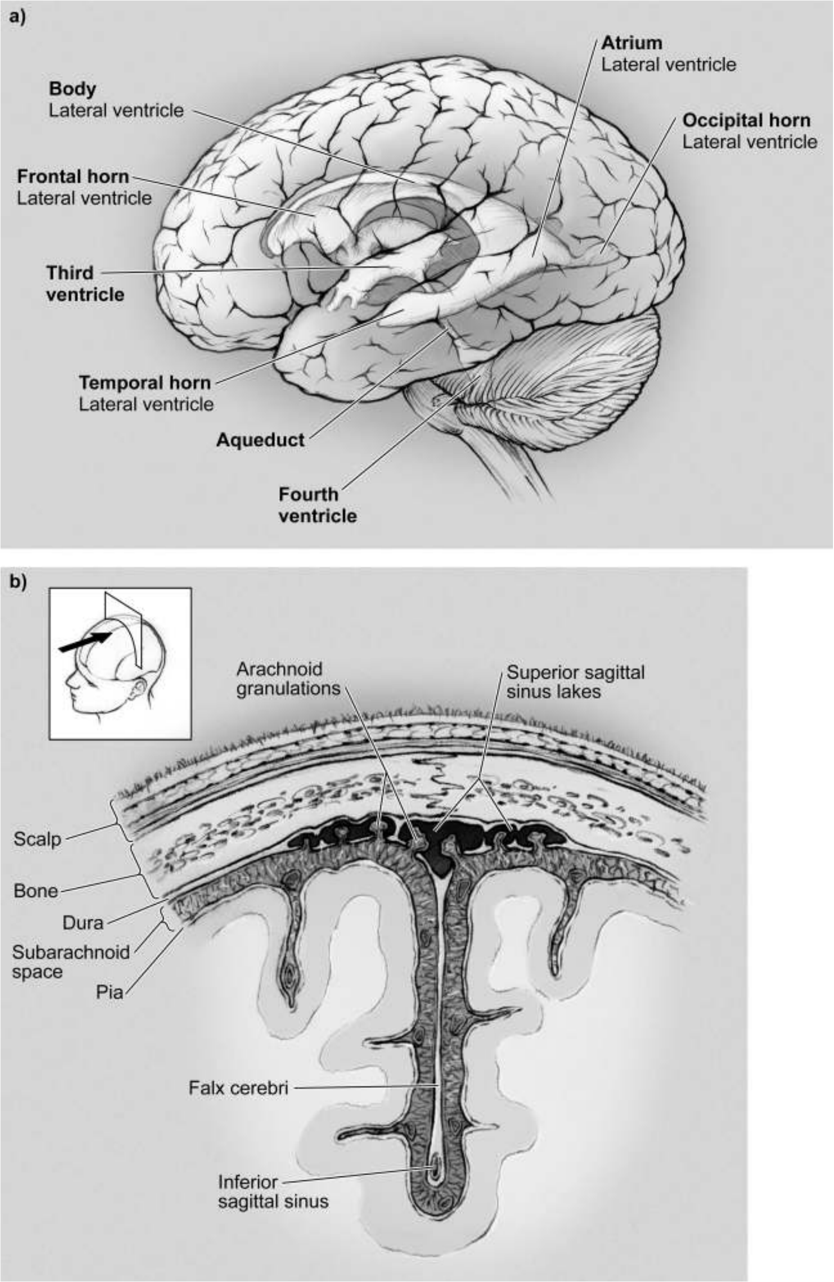

Figure 1.2 (a) Position of the lateral, third and fourth ventricles, and connection pathways. The lateral ventricle is divided into frontal horn, body, atrium, and occipital and temporal horns. Choroid plexus is found in floor of body of ventricle and roof of temporal horn and in the third and fourth ventricles (b) Coronal section showing relationship of arachnoid granulations to superior sagittal sinus.

Spinal Cord

The spinal cord extends from the base of the skull and tapers down to the conus, becoming the filum terminale between T12 and L2 (Figure 1.3). The principal functions of the spinal cord are threefold. First, in its central gray matter lie the cellular circuitry underlying the motor function of most of the body (except for the face, tongue, and mouth), including the anterior horn cells and the indirect pathways which regulate them (reflex loops).

Second, the spinal cord receives sensory input from the peripheral nerves and transmits these to higher structures. The primary ascending tracts are the posterior columns and the lateral spinothalamic tract (Figure 1.4). The posterior columns transmit fine touch, vibration, and proprioception. The lateral spinothalamic tract conveys contralateral pain and temperature. Pain fibers from the dorsal roots ascend or descend one to three segments before synapsing in the spinal cord.

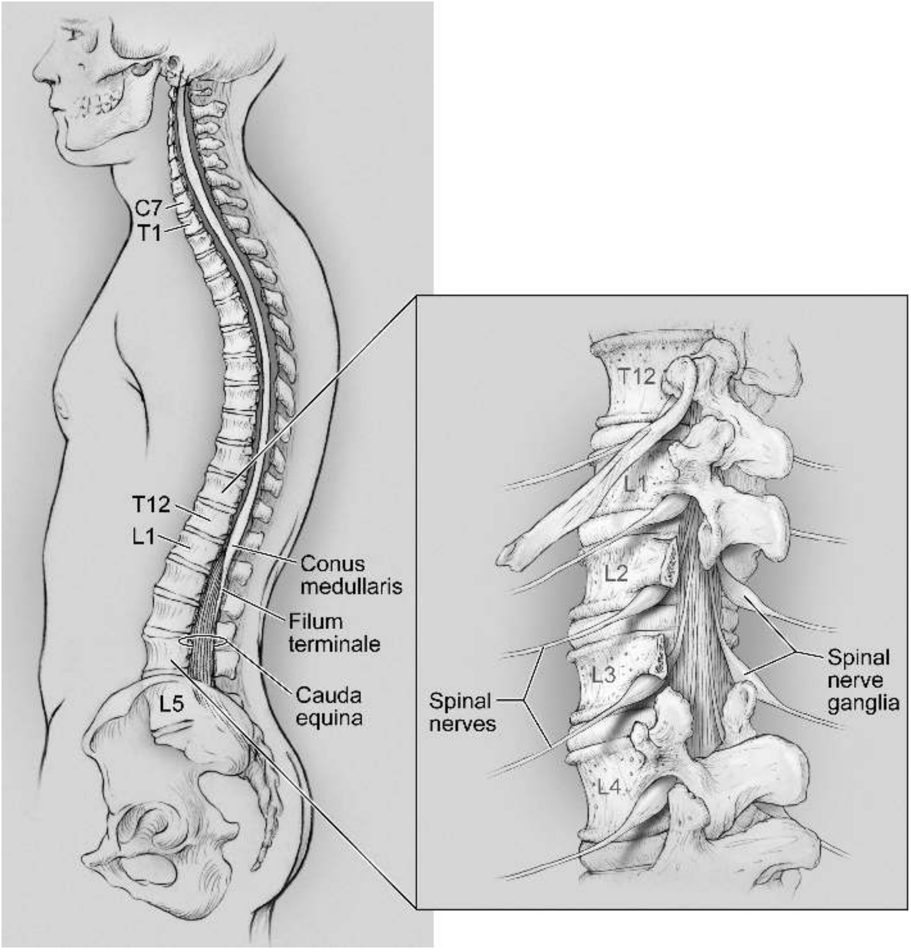

Figure 1.3 Sagittal image of spine and spinal cord with close-up of cauda equina and compound spinal nerves. The spinal cord extends from the base of the skull and tapers down to the conus, becoming the filum terminale between T12 and L2.

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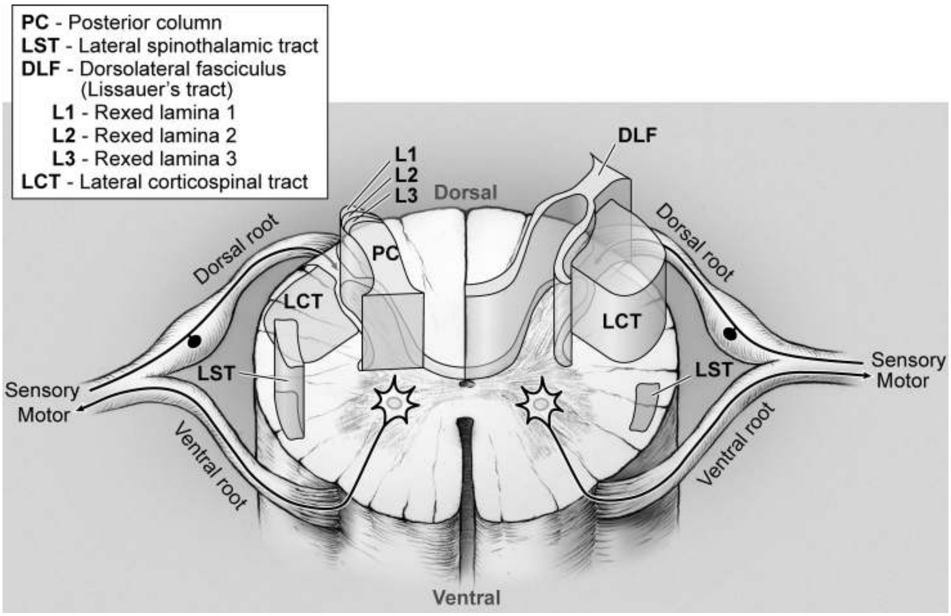

Figure 1.4 Axial schematic representation of ascending and descending tracts and dorsal horn.

Third, the spinal white matter contains several descending tracts, which are utilized by the higher CNS structures to regulate spinal cord function either by directly stimulating cells or by regulating interneurons that increase or decrease signalling efficiency. The most clinically important of these is the lateral corticospinal tract (Figure 1.4) which conveys voluntary, skilled movement from the contralateral cerebral hemisphere. Many other motor pathways originate from cortical and brainstem structures to control posture and movement. Additionally, there exist descending pathways responsible for the regulation of pain fibers.

The blood supply to the spinal cord comes via paired posterior spinal arteries and a single anterior spinal artery. While the posterior arteries supply the dorsal horns and white matter columns, the anterior spinal artery supplies the anterior two-thirds of the cord. There are six to eight prominent radicular arteries that supply the anterior spinal artery network, most numerous in the cervical region and least in the thoracic. The artery of Adamkiewicz, the main thoraco-lumbar radicular vessel, supplies the spinal cord from T8 to the conus. This artery arises in the T9–L2 region and mostly from the left side of the aorta. Spinal artery perfusion pressure is an important consideration especially in the prone position where intravenous pressures are elevated.

The Supra-Tentorial Compartment

The Cerebrum and Neocortices

The cerebral hemispheres consist of the cerebral cortex, white matter projections, and a few deep structures including the basal ganglia and hippocampus. The cortex is highly

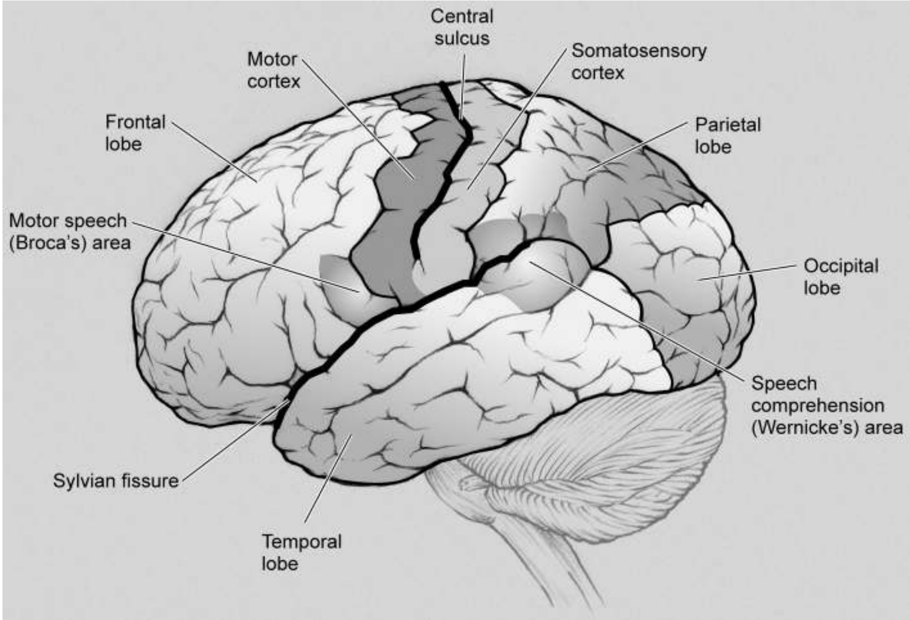

Figure 1.5 The cortex is highly convoluted with infoldings called sulci and bumps or ridges called gyri. Each hemisphere is divided into four major lobes: the frontal, parietal, temporal, and occipital. Motor (Broca's) and receptive (Wernicke's) language areas are shown in the frontal and temporal/parietal lobes, respectively.

convoluted with infoldings called sulci and bumps or ridges called gyri. Each hemisphere is divided into four major lobes: the frontal, parietal, temporal, and occipital (Figure 1.5). The hemispheres are principally defined by the midline interhemispheric fissure, the central sulcus in the posterior frontal lobe, and the large lateral Sylvian fissure.

Not all cortex is created equal, such that some regions can be removed with impunity, while others will cause neurological deficits if injured. Thus, it is essential to understand the location of the so-called eloquent brain regions, as non-eloquent regions are the preferred operative path for most lesions. The eloquent brain regions include the primary motor and sensory cortices, the speech areas (Broca's and Wernicke's areas), the primary visual cortex, the thalamus, the brainstem reticular activating system, the deep cerebellar nuclei, and to some extent the anterior parietal lobes. Many of these lie near or directly adjacent to the Sylvian fissure.

The primary motor cortex and somatosensory cortex straddle the central sulcus. Both the motor and sensory cortex represent the opposite side of the body in a precise topological fashion (Figure 1.6). The visual cortex is in the occipital lobe, primarily on the medial aspect of the hemisphere above and below the calcarine sulcus.

The left hemisphere is dominant for language in nearly all right-handed patients; about 80% of left-handed are still left-hemisphere language dominant with bilateral dominance and right side dominance in about 15% and 5% of patients, respectively. Wernicke's area is behind the primary auditory cortex in the posterior superior temporal lobe. Lesions of Wernicke's area lead to problems with language comprehension, classically causing a fluent aphasia (normal sentence length and intonation, speech devoid of meaning). Broca's area is

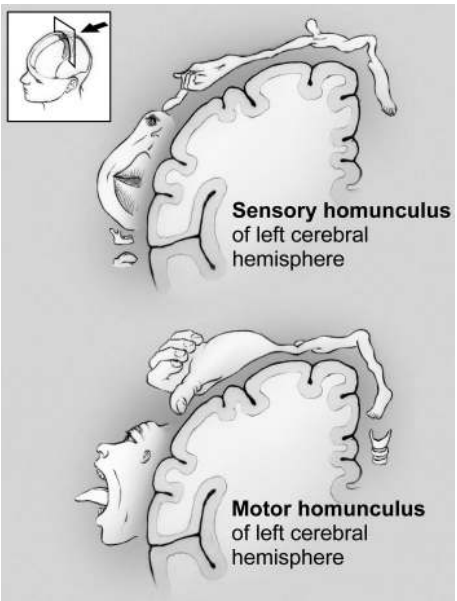

Figure 1.6 Approximate representation of the motor and sensory areas in pre- and post-central sulcus.

located in the frontal lobe premotor cortex and is important for word formation; Broca's area lesions lead to a non-fluent aphasia (faltering, broken speech).

The Diencephalon

The diencephalon sits above the midbrain and consists of the thalamus and hypothalamus. The thalamus is "an information relay station." All sensory modalities except olfaction pass through the thalamus, and there are many reciprocal connections between the thalamus and cerebral cortex as well as with the cerebellum. The thalamus is important for motor control, wakefulness, and sensory information processing. Thalamic lesions thus can produce coma, tremors, and other motor difficulties, as well as sensory problems including pain syndromes.

The hypothalamus, located just inferior to the thalamus, controls endocrine, autonomic, and visceral function. The hypothalamus is connected to the pituitary gland by the infundibulum, which continues as the pituitary stalk (Figure 1.7). The pituitary gland sits within the sella, which is just behind and inferior to the optic chiasm. Hence, tumors of the pituitary can compress the chiasm, producing visual problems (e.g., bitemporal hemianopsia). Hypothalamic releasing and inhibitory factors regulate pituitary hormone release. Vasopressin (or antidiuretic hormone) is made by hypothalamic cells and is transported to the posterior pituitary for release.

The hypothalamus also originates descending fibers which influence the sympathetic and parasympathetic autonomic nervous system. There are discrete nuclei within the hypothalamus which are critical to body homeostasis. Thermoregulation, satiety, and arousal are partially controlled in the hypothalamus. For instance, experimental lesions of the lateral hypothalamus produce anorexia, while medial lesions cause overeating.

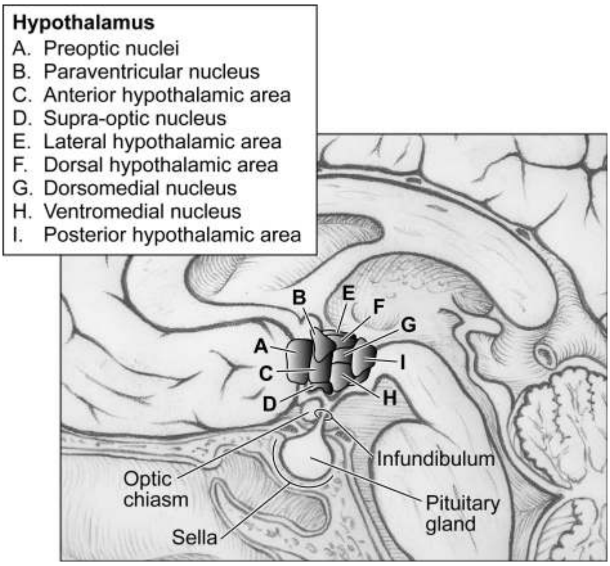

Figure 1.7 Locations of hypothalamic nuclei in the diencephalon.

The Infra-Tentorial Compartment

The Brain Stem

The medulla, pons, and midbrain comprise the brain stem, a highly complex and clinically critical region of the CNS (Figure 1.1). Unlike any other region of the brain, it is at the same time the anatomic substrate of consciousness, a regulator of autonomic function, the origin and target of numerous different descending regulatory fiber tracts and a few ascending ones, a thoroughfare for tracts having no functional relation to it, the home of 10 of the 12 cranial nerves with their attendant input and output nuclei, and the location of a number of clinically relevant reflexes.

Probably the most clinically important function of the brain stem is its role in maintaining consciousness. Significant injuries to the brain stem lead to stupor and coma, due to injury to the reticular activating system. The brainstem reticular formation consists of a set of interconnected nuclei in the core of the brain stem which mediate the level of alertness.

Equally important are the respiratory control centers located in the medulla and pons. The respiratory control neurons are involved in rhythm generation as well as processing afferent information from central and peripheral chemoreceptors and various lung receptors. Focal medullary injury or edema can lead to life-threatening respiratory arrest.

Many ascending and descending fiber tracts pass through the brain stem. Other tracts, such as the corticobulbar, trigeminothalamic, central tegmental tract, and medial longitudinal fasciculus, have their origin or termination within the brainstem nuclei. For instance, the nuclei for cranial nerves 3 to12 (CNIII–CNXII) are in the brain stem (Table 1.1). Importantly, many of these tracts have close analogues in the spinal cord, and a lack of concordance of deficits between face and body (e.g., a right facial weakness and left hemiparesis) strongly suggests a lesion in the brain stem.

Brainstem function can be grossly tested in comatose patients using the pupillary, corneal, and gag/cough reflexes. The pupillary (light) reflex assesses function at the

Table 1.1 Cranial Nerves and Function

Cranial Nerve	Function	Defined Nucleus Location
I	Smell	Uncus, septal area
II	Vision	Lateral geniculate nucleus
III	Extraocular movement; lid elevation	Midbrain tectum (superior)
IV	Eye movement; down and in	Midbrain tectum (inferior)
V	Sensory to skin of face: Motor to muscles for chewing (V3)	Pons (motor, sensory), medulla, cervical cord (sensory)
VI	Lateral eye movement	Pons (dorsal)
VII	Facial movement; sense of taste (anterior 2/3 tongue)	Pons (ventral)
VIII	Hearing; balance	Pons (dorsal-lateral)
IX	Palate movement/sensation; taste posterior 1/3 tongue	Medulla
X	Vocal cords; parasympathetic supply to viscera	Medulla
XI	Trapezius, sternomastoid supply	Medulla
XII	Muscles of tongue	Medulla

midbrain level, as well as the integrity of the optic and oculomotor nerves. The corneal (blink) reflex assesses brainstem function at the level of the pons. Its afferent limb is the trigeminal nerve and efferent limb is the facial nerve. The gag reflex tests the lower brain stem, or medulla, as well as the glossopharyngeal and vagus nerves.

The vomiting reflex passes through the medulla. Stimulation of certain neurons of the reticular formation leads to impulses descending to lower motor neurons causing contraction of the diaphragm and abdominal muscles.

The Cerebellum

The cerebellum is found in the posterior cranial fossa (Figure 1.1). It is attached to the brain stem by the three cerebellar peduncles at the level of the fourth ventricle. The tentorium, a transverse fold of dura, stretches over the superior part of the cerebellum, separating it from the occipital lobe of the cerebral hemispheres. This intimate relationship between cerebellum and brain stem puts the patient's life in danger in cases of acute cerebellar edema.

The oldest part, the archicerebellum, lies in the antero-inferior flocculonodular lobe, receives input from the vestibular nuclei, and regulates control of eye movements. The paleocerebellum consists of the midline vermis and processes proprioceptive input from the ascending spinocerebellar tracts where it controls axial posture via neocortical projections. The neocerebellum is primarily made up of the lateral hemispheres which receive neocortex input via the middle peduncle and sends processed output back to the neocortex via the thalamus.

Lesions of the cerebellum typically produce deficits ipsilateral to the lesion. This is because the output of the cerebellum is crossed, and it affects primarily the descending motor pathways, which are also crossed. Typical symptoms include ataxia and truncal tremor (titubation), with paleocerebellum (medial) lesions, or limb ataxia or action tremor, with neocerebellum (lateral) lesions.

The Extrapyramidal Organs

The extrapyramidal organs are structures linked not by spatial proximity, but by functional and neuroanatomic similarity. Both structures can be thought of as a form of consultant to the rest of the CNS: receiving and processing input from the neocortex and/or spinal cord, relaying this processed input back to external targets commonly the thalamus, where it modulates motor, emotional, and cognitive function. As a result, damage to the extrapyramidal organs classically causes tremor and incoordination (known as extrapyramidal signs), not paralysis.

The Basal Ganglia

Within the cerebral hemisphere lie the basal ganglia (Figure 1.8). The principal components are the caudate nucleus, putamen, globus pallidus, and amygdala. These organs contain many interconnections as well as reciprocal connections with other brain regions including

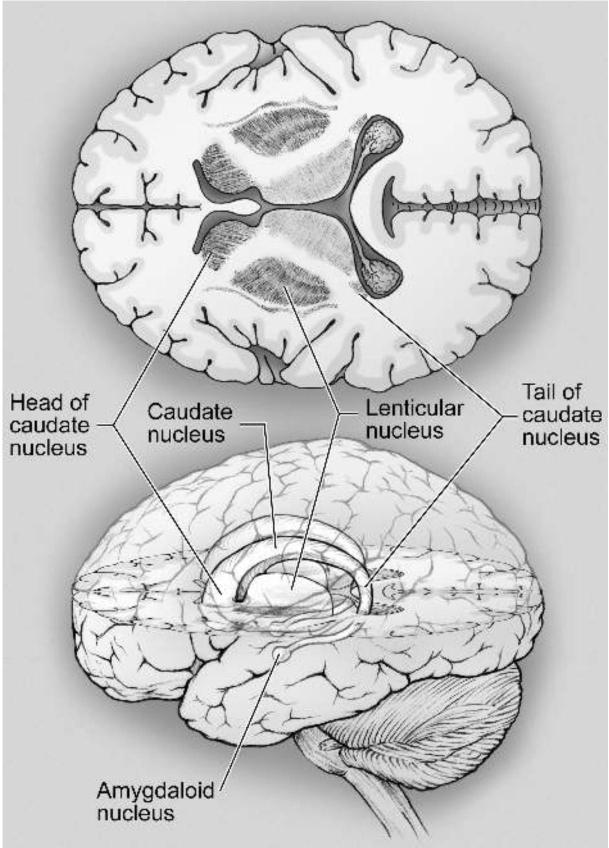

Figure 1.8 Axial and 3D representation of the basal ganglia.

the midbrain, diencephalon, and cerebral cortex. Functionally, these connections can be classified into oculomotor, skeletomotor, limbic, and cognitive circuits, each with different inputs and targets.

Basal ganglia diseases, such as Parkinson's and Huntington's disease, lead to abnormal motor control, alterations of muscular tone, and emergence of irregular, involuntary movements. These diseases can cause emotional and cognitive disturbances, depending on the degree of involvement of the emotional and cognitive circuits.

Further Reading

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