

## Central Nervous System (CNS)

- CNS – composed of the brain and spinal cord
- Cephalization
  - Elaboration of the anterior portion of the CNS
  - Increase in number of neurons in the head
  - Highest level has been reached in the human brain

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## The Brain

- Composed of wrinkled, pinkish gray tissue
- Surface anatomy includes cerebral hemispheres, cerebellum, and brain stem

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## Embryonic Development

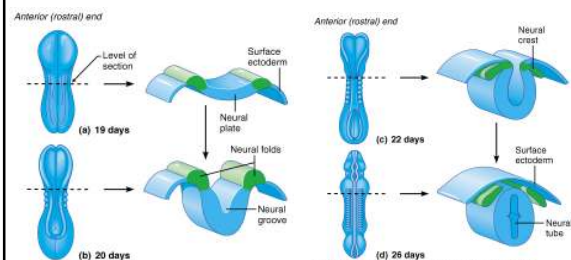
- During the first 26 days of development:
  - Ectoderm thickens along dorsal midline to form the neural plate
  - The neural plate invaginates, forming a groove flanked by neural folds
  - The neural groove fuses dorsally and forms the neural tube

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## Embryonic Development



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4 Figure 12.2

## Primary Brain Vesicles

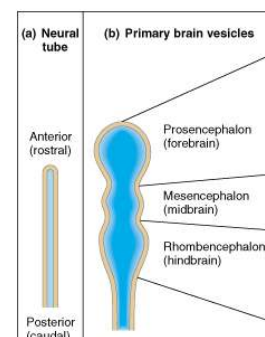
- The anterior end of the neural tube expands and constricts to form the three primary brain vesicles
  - Prosencephalon – the forebrain
  - Mesencephalon – the midbrain
  - Rhombencephalon – hindbrain

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## Primary Brain Vesicles



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6 Figure 12.3a, b

## Secondary Brain Vesicles

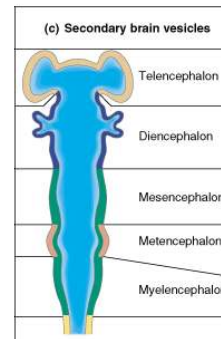
- In week 5 of embryonic development, secondary brain vesicles form
  - Telencephalon and diencephalon arise from the forebrain
  - Mesencephalon remains undivided
  - Metencephalon and myelencephalon arise from the hindbrain

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## Secondary Brain Vesicles



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8 Figure 12.3c

## Adult Brain Structures

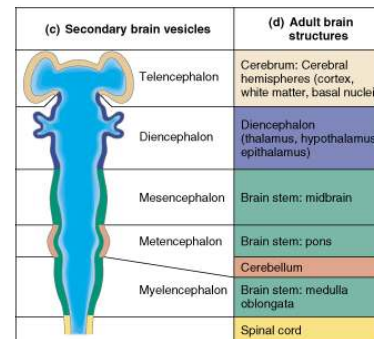
- Fates of the secondary brain vesicles:
  - Telencephalon – cerebrum: cortex, white matter, and basal nuclei
  - Diencephalon – thalamus, hypothalamus, and epithalamus
  - Mesencephalon – brain stem: midbrain
  - Metencephalon – brain stem: pons
  - Myelencephalon – brain stem: medulla oblongata

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## Adult Brain Structures



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10 Figure 12.3c, d

## Adult Neural Canal Regions

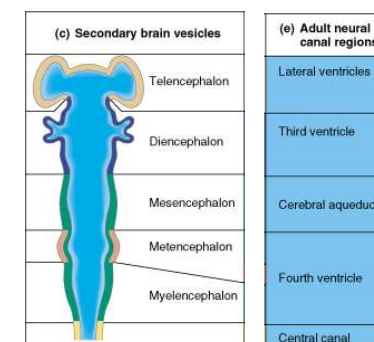
- Adult structures derived from the neural canal
  - Telencephalon – lateral ventricles
  - Diencephalon – third ventricle
  - Mesencephalon – cerebral aqueduct
  - Metencephalon and myelencephalon – fourth ventricle

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## Adult Neural Canal Regions



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12 Figure 12.3c, e

## Basic Pattern of the Central Nervous System

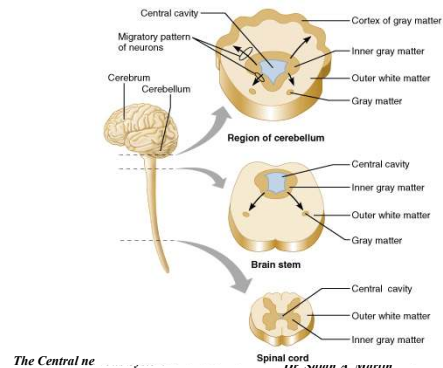
- Spinal Cord
  - Central cavity surrounded by a gray matter core
  - External to which is white matter composed of myelinated fiber tracts
- Brain
  - Similar to spinal cord but with additional areas of gray matter
  - Cerebellum has gray matter in nuclei
  - Cerebrum has nuclei and additional gray matter in the cortex

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## Basic Pattern of the Central Nervous System



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14 Figure 12.5

## Ventricles of the Brain

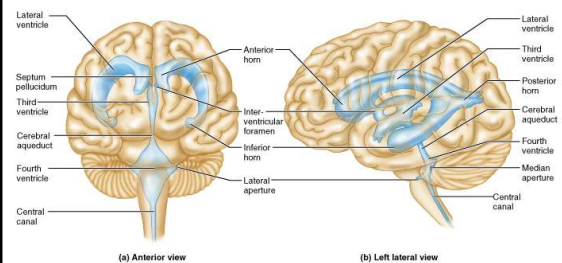
- Arise from expansion of the lumen of the neural tube
- The ventricles are:
  - The paired C-shaped lateral ventricles
  - The third ventricle found in the diencephalon
  - The fourth ventricle found in the hindbrain dorsal to the pons

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## Ventricles of the Brain



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16 Figure 12.6

## Cerebral Hemispheres

- Form the superior part of the brain and make up 83% of its mass
- Contain ridges (gyri) and shallow grooves (sulci)
- Contain deep grooves called fissures
- Are separated by the longitudinal fissure
- Have three basic regions: cortex, white matter, and basal nuclei

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## Major Lobes, Gyri, and Sulci of the Cerebral Hemisphere

- Deep sulci divide the hemispheres into five lobes:
  - Frontal, parietal, temporal, occipital, and insula
- Central sulcus – separates the frontal and parietal lobes
- Parieto-occipital sulcus – separates the parietal and occipital lobes
- Lateral sulcus – separates the parietal and temporal lobes
- The precentral and postcentral gyri border the central sulcus

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## Cerebral Cortex

- The cortex – superficial gray matter; accounts for roughly 40% of the mass of the brain
- It enables sensation, communication, memory, understanding, and voluntary movements
- Each hemisphere acts contralaterally (controls the opposite side of the body)
- Hemispheres are not equal in function
- No functional area acts alone; conscious behavior involves the entire cortex

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## Functional Areas of the Cerebral Cortex

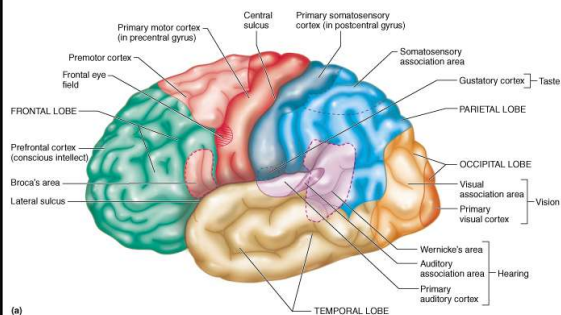
- Three types of functional areas are:
  - Motor areas – control voluntary movement
  - Sensory areas – conscious awareness of sensation
  - Association areas – integrate diverse information

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## Functional Areas: Left Cerebral Cortex



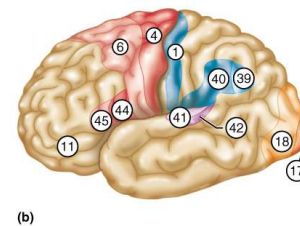
(a)

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21 Figure 12.8a

## Functional Areas: Left Cerebral Cortex



(b)

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22 Figure 12.8b

## Cerebral Cortex: Motor Areas

- Primary (somatic) motor cortex
- Premotor cortex
- Broca's area
- Frontal eye field

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## Primary Motor Cortex

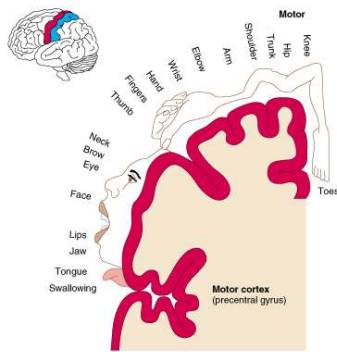
- Located in the precentral gyrus
- Composed of pyramidal cells whose axons make up the corticospinal tracts
- Allows conscious control of precise, skilled, voluntary movements
- Motor homunculus – caricature of relative amounts of cortical tissue devoted to each motor function

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## Primary Motor Cortex



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25 Figure 12.9.1

## Premotor Cortex

- Located anterior to the precentral gyrus
- Controls learned, repetitious, or patterned motor skills
- Coordinates simultaneous or sequential actions
- Involved in the planning of movements

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## Broca's Area and Frontal Eye Field

- Broca's area
  - Located anterior to the inferior region of the premotor area
  - Present in one hemisphere (usually the left)
  - A motor speech area that directs muscles of the tongue
  - Is active as one prepares to speak
- Frontal eye field
  - Located anterior to the premotor cortex and superior to Broca's area
  - Controls voluntary eye movement

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## Sensory Areas

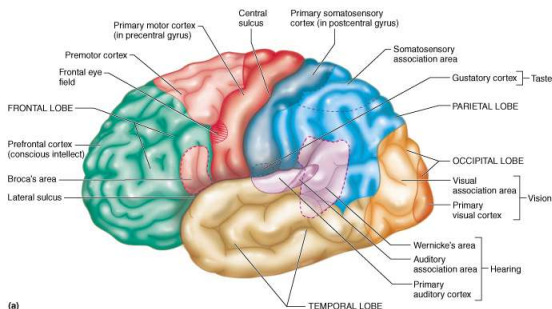
- Primary somatosensory cortex
- Somatosensory association cortex
- Visual areas
- Auditory areas
- Olfactory cortex
- Gustatory cortex
- Vestibular cortex

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## Sensory Areas



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29 Figure 12.8a

## Primary Somatosensory Cortex

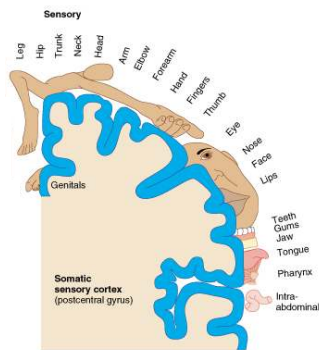
- Located in the postcentral gyrus, this area:
  - Receives information from the skin and skeletal muscles
  - Exhibits spatial discrimination
- Somatosensory homunculus – caricature of relative amounts of cortical tissue devoted to each sensory function

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## Primary Somatosensory Cortex



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31 Figure 12.9.2

## Somatosensory Association Area

- Located posterior to the primary somatosensory cortex
- Integrates sensory information
- Forms comprehensive understanding of the stimulus
- Determines size, texture, and relationship of parts

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## Visual Area

- Primary visual cortex
  - Located on the extreme posterior tip of the occipital lobe
  - Receives visual information from the retinas
- Visual association area
  - Surrounds the primary visual cortex
  - Interprets visual stimuli (e.g., color, form, and movement)

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## Auditory Areas

- Primary auditory cortex
  - Located at the superior margin of the temporal lobe
  - Receives information related to pitch, rhythm, and loudness
- Auditory association area
  - Located posterior to the primary auditory cortex
  - Stores memories of sounds and permits perception of sounds

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## Association Areas

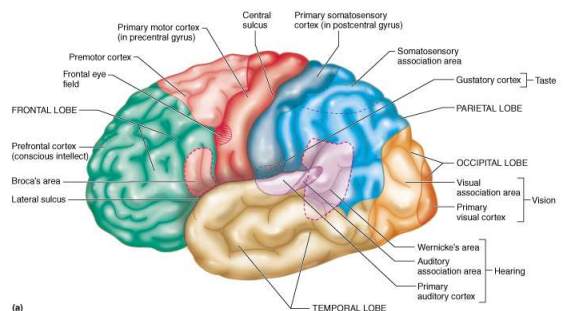
- Prefrontal cortex
- Language areas
- General (common) interpretation area
- Visceral association area

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## Association Areas



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36 Figure 12.8a

## Prefrontal Cortex

- Location – anterior portions of the frontal lobe
- Involved with intellect, cognition, recall, and personality
- Necessary for judgment, reasoning, persistence, and conscience
- Closely linked to the limbic system (emotional part of the brain)

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## Language Areas

- Located in a large area surrounding the left (or language-dominant) lateral sulcus
- Major parts and functions
  - Wernicke's area – involved in sounding out unfamiliar words
  - Broca's area – speech preparation and production
  - Lateral prefrontal cortex – language comprehension and word analysis
  - Lateral and ventral temporal lobe – coordinate auditory and visual aspects of language

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## General (Common) Interpretation Area

- Ill-defined region including parts of the temporal, parietal, and occipital lobes
- Found in one hemisphere, usually the left
- Integrates incoming signals into a single thought
- Involved in processing spatial relationships

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## Visceral Association Area

- Located in the cortex of the insula
- Involved in conscious perception of visceral sensations

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## Lateralization of Cortical Function

- Lateralization – each hemisphere has abilities *not* shared with its partner
- Cerebral dominance – designates the hemisphere dominant for language
- Left hemisphere – controls language, math, and logic
- Right hemisphere – controls visual-spatial skills, emotion, and artistic skills

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## Cerebral White Matter

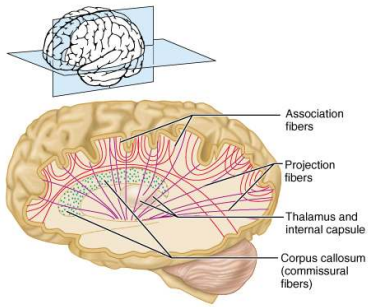
- Consists of deep myelinated fibers and their tracts
- Responsible for communication between the cerebral cortex and lower CNS center, and areas of the cerebrum
- Types include
  - Commissures – connect corresponding gray areas of the two hemispheres
  - Association fibers – connect different parts of the same hemisphere
  - Projection fibers – enter the hemispheres from lower brain or cord centers

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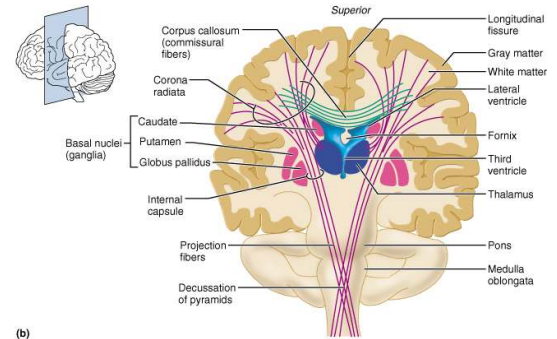
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## Cerebral White Matter



(a)  
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## Cerebral White Matter



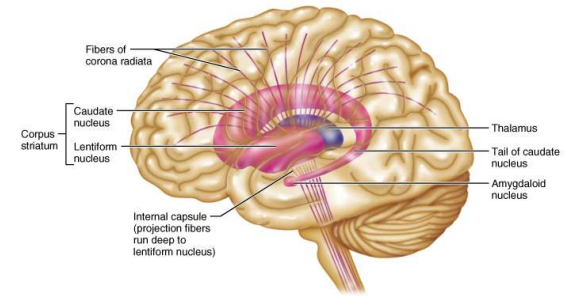
(b)  
The Central nervous System Dr. Salah A. Martin 44 Figure 12.10b

## Basal Nuclei

- Masses of gray matter found deep within the cortical white matter
- The corpus striatum is composed of three parts
  - Caudate nucleus
  - Lentiform nucleus – composed of the putamen and the globus pallidus
  - Fibers of internal capsule running between and through caudate and lentiform nuclei

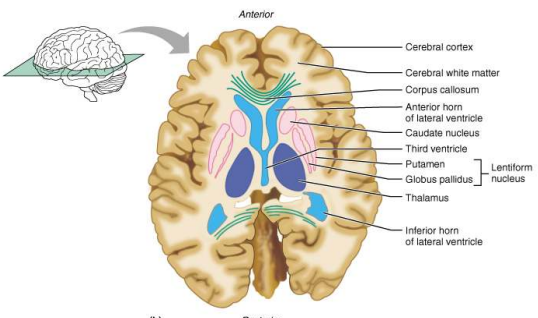
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## Basal Nuclei



(a)  
The Central nervous System Dr. Salah A. Martin 46 Figure 12.11a

## Basal Nuclei



(b)  
The Central nervous System Dr. Salah A. Martin 47 Figure 12.11b

## Functions of Basal Nuclei

- Though somewhat elusive, the following are thought to be functions of basal nuclei
  - Influence muscular activity
  - Regulate attention and cognition
  - Regulate intensity of slow or stereotyped movements
  - Inhibit antagonistic and unnecessary movement

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## Diencephalon

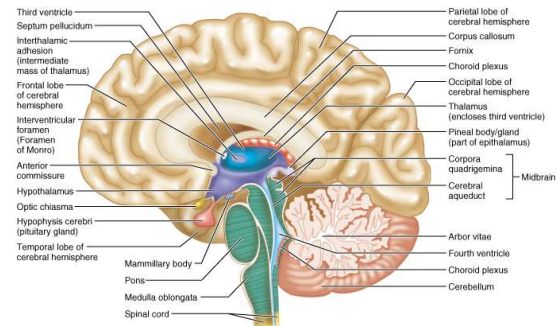
- Central core of the forebrain
- Consists of three paired structures – thalamus, hypothalamus, and epithalamus
- Encloses the third ventricle

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## Diencephalon



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50 Figure 12.12

## Thalamus

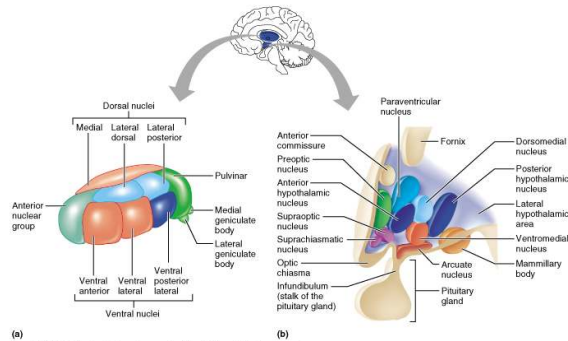
- Paired, egg-shaped masses that form the superolateral walls of the third ventricle
- Connected at the midline by the intermediate mass
- Contains four groups of nuclei – anterior, ventral, dorsal, and posterior
- Nuclei project and receive fibers from the cerebral cortex

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## Thalamus



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52 Figure 12.13a, b

## Thalamic Function

- Afferent impulses from all senses converge and synapse in the thalamus
- Impulses of similar function are “sorted out,” edited, and relayed as a group
- All inputs ascending to the cerebral cortex pass through the thalamus
- Plays a key role in mediating sensation, motor activities, cortical arousal, learning, and memory

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## Hypothalamus

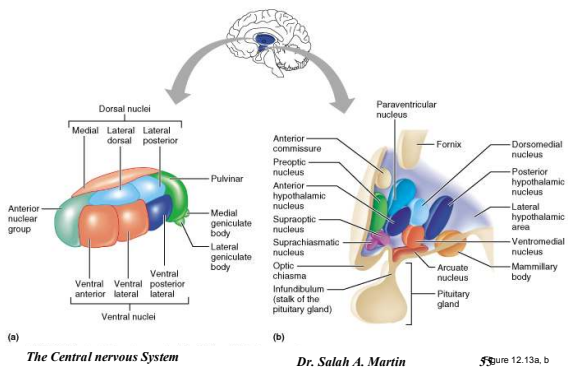
- Located below the thalamus, it caps the brain stem and forms the inferolateral walls of the third ventricle
- Mammillary bodies
  - Small, paired nuclei bulging anteriorly from the hypothalamus
  - Relay station for olfactory pathways
- Infundibulum – stalk of the hypothalamus; connects to the pituitary gland
- Main visceral control center of the body

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## Hypothalamus



## Hypothalamic Function

- Regulates blood pressure, rate and force of heartbeat, digestive tract motility, rate and depth of breathing, and many other visceral activities
- Is involved with perception of pleasure, fear, and rage
- Controls mechanisms needed to maintain normal body temperature
- Regulates feelings of hunger and satiety
- Regulates sleep and the sleep cycle

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## Endocrine Functions of the Hypothalamus

- Releasing hormones control secretion of hormones by the anterior pituitary
- The supraoptic and paraventricular nuclei produce ADH and oxytocin

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## Epithalamus

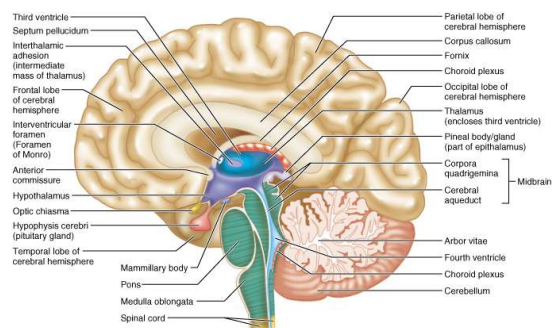
- Most dorsal portion of the diencephalon; forms roof of the third ventricle
- Pineal gland – extends from the posterior border and secretes melatonin
  - Melatonin – a hormone involved with sleep regulation, sleep-wake cycles, and mood
- Choroid plexus – a structure that secretes cerebrospinal fluid (CSF)

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## Epithalamus



## Brain Stem

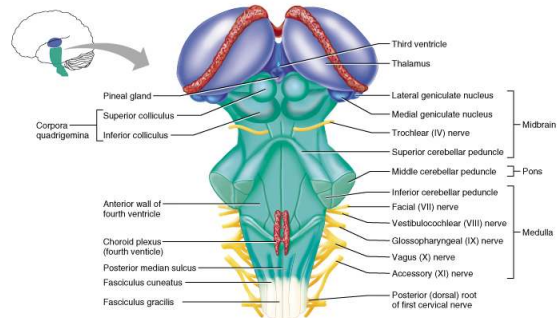
- Consists of three regions – midbrain, pons, and medulla oblongata
- Similar to spinal cord but contains embedded nuclei
- Controls automatic behaviors necessary for survival
- Provides the pathway for tracts between higher and lower brain centers
- Associated with 10 of the 12 pairs of cranial nerves

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## Brain Stem



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61 Figure 12.15

## Midbrain

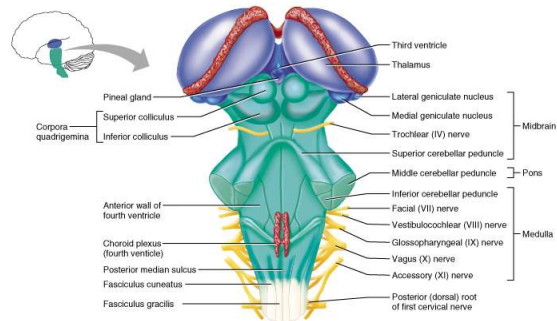
- Located between the diencephalon and the pons
- Midbrain structures include
  - Cerebral peduncles – two bulging structures that contain descending pyramidal motor tracts
  - Cerebral aqueduct – hollow tube that connects the third and fourth ventricles
  - Various nuclei

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## Midbrain



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63 Figure 12.15

## Midbrain Nuclei

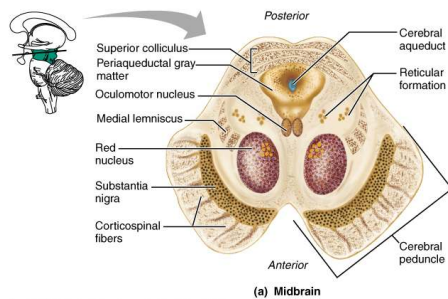
- Nuclei that control cranial nerves III (oculomotor) and IV (trochlear)
- Corpora quadrigemina – four dome-like protrusions of the dorsal midbrain
- Superior colliculi – visual reflex centers
- Inferior colliculi – auditory relay centers
- Substantia nigra – functionally linked to basal nuclei
- Red nucleus – largest nucleus of the reticular formation; red nuclei are relay nuclei for some descending motor pathways

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## Midbrain Nuclei



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65 Figure 12.16a

## Pons

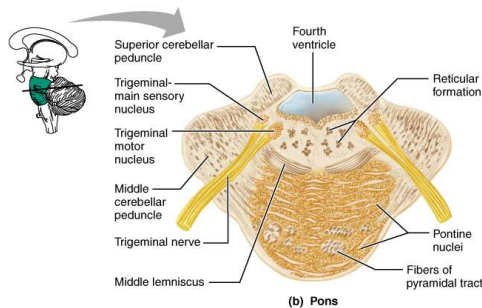
- Bulging brain stem region between the midbrain and the medulla oblongata
- Forms part of the anterior wall of the fourth ventricle
- Fibers of the pons:
  - Connect higher brain centers and the spinal cord
  - Relay impulses between the motor cortex and the cerebellum
- Origin of cranial nerves V (trigeminal), VI (abducens), and VII (facial)
- Contains nuclei of the reticular formation

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## Pons



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67 Figure 12.6b

## Medulla Oblongata

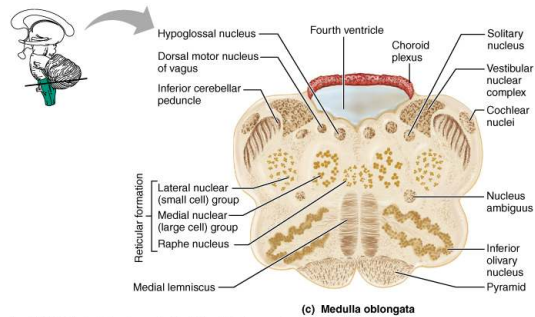
- Most inferior part of the brain stem
- Along with the pons, forms the ventral wall of the fourth ventricle
- Contains a choroid plexus on the ventral wall of the fourth ventricle
- Pyramids – two longitudinal ridges formed by corticospinal tracts
- Decussation of the pyramids – crossover points of the corticospinal tracts

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## Medulla Oblongata



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69 Figure 12.16c

## Medulla Nuclei

- Inferior olivary nuclei – gray matter that relays sensory information
- Cranial nerves X, XI, and XII are associated with the medulla
- Vestibular nuclear complex – synapses that mediate and maintain equilibrium
- Ascending sensory tract nuclei, including nucleus cuneatus and nucleus gracilis
- Cardiovascular control center – adjusts force and rate of heart contraction
- Respiratory centers – control rate and depth of breathing

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## The Cerebellum

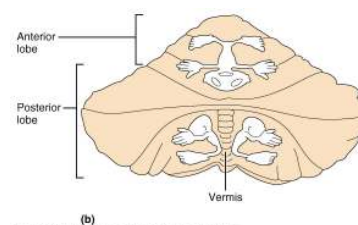
- Located dorsal to the pons and medulla
- Protrudes under the occipital lobes of the cerebrum
- Makes up 11% of the brain's mass
- Provides precise timing and appropriate patterns of skeletal muscle contraction
- Cerebellar activity occurs subconsciously

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## The Cerebellum



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72 Figure 12.17b

## Anatomy of the Cerebellum

- Two bilaterally symmetrical hemispheres connected medially by the vermis
- Folia – transversely oriented gyri
- Each hemisphere has three lobes – anterior, posterior, and flocculonodular
- Neural arrangement – gray matter cortex, internal white matter, scattered nuclei
- Arbor vitae – distinctive treelike pattern of the cerebellar white matter

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## Cerebellar Peduncles

- Three paired fiber tracts that connect the cerebellum to the brain stem
- All fibers in the cerebellum are ipsilateral
- Superior peduncles connect the cerebellum to the midbrain
- Middle peduncles connect the pons to the cerebellum
- Inferior peduncles connect the medulla to the cerebellum

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## Cerebellar Processing

- Cerebellum receives impulses of the intent to initiate voluntary muscle contraction
- Proprioceptors and visual signals “inform” the cerebellum of the body’s condition
- Cerebellar cortex calculates the best way to perform a movement
- A “blueprint” of coordinated movement is sent to the cerebral motor cortex

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## Cerebellar Cognitive Function

- Plays a role in language and problem solving
- Recognizes and predicts sequences of events

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## Functional Brain Systems

- Networks of neurons working together and spanning wide areas of the brain
- The two systems are:
  - Limbic system
  - Reticular formation

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## Limbic System

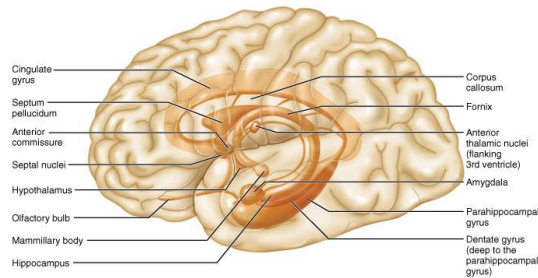
- Structures located on the medial aspects of cerebral hemispheres and diencephalon
- Includes the rhinencephalon, amygdala, hypothalamus, and anterior nucleus of the thalamus
- Parts especially important in emotions:
  - Amygdala – deals with anger, danger, and fear responses
  - Cingulate gyrus – plays a role in expressing emotions via gestures, and resolves mental conflict
- Puts emotional responses to odors – e.g., skunks smell bad

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## Limbic System



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79 Figure 12.18

## Limbic System: Emotion and Cognition

- The limbic system interacts with the prefrontal lobes, therefore:
  - One can react emotionally to conscious understandings
  - One is consciously aware of emotion in one's life
- Hippocampal structures – convert new information into long-term memories

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## Reticular Formation

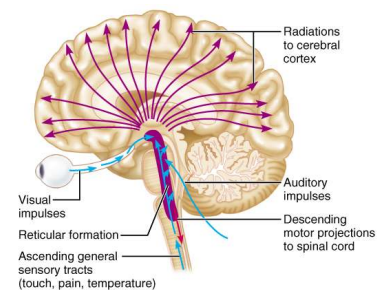
- Composed of three broad columns along the length of the brain stem
  - Raphe nuclei
  - Medial (large cell) group
  - Lateral (small cell) group
- Has far-flung axonal connections with hypothalamus, thalamus, cerebellum, and spinal cord

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## Reticular Formation



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82 Figure 12.19

## Reticular Formation: RAS and Motor Function

- RAS – reticular activating system
  - Sends impulses to the cerebral cortex to keep it conscious and alert
  - Filters out repetitive and weak stimuli
- Motor function
  - Helps control coarse motor movements
  - Autonomic centers regulate visceral motor functions – e.g., vasomotor, cardiac, and respiratory centers

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## Brain Waves

- Normal brain function involves continuous electrical activity
- An electroencephalogram (EEG) records this activity
- Patterns of neuronal electrical activity recorded are called brain waves
- Each person's brain waves are unique

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## Types of Brain Waves

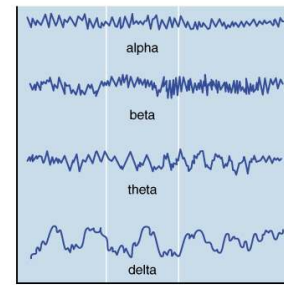
- Alpha waves – low-amplitude, slow, synchronous waves indicating an “idling” brain
- Beta waves – rhythmic, more irregular waves occurring during the awake and mentally alert state
- Theta waves – more irregular than alpha waves; common in children but abnormal in adults
- Delta waves – high-amplitude waves seen in deep sleep and when RAS is damped

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## Types of Brain Waves



(b)

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86 Figure 12.20b

## Brain Waves: State of the Brain

- Brain waves change with age, sensory stimuli, brain disease, and the chemical state of the body
- EEGs can be used to diagnose and localize brain lesions, tumors, infarcts, infections, abscesses, and epileptic lesions
- A flat EEG (no electrical activity) is clinical evidence of death

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## Consciousness

- Encompasses perception of sensation, voluntary initiation and control of movement, and capabilities associated with higher mental processing
- Involves simultaneous activity of large areas of the cerebral cortex
- Is superimposed on other types of neural activity
- Is holistic and totally interconnected
- Clinical consciousness is defined on a continuum that grades levels of behavior – alertness, drowsiness, stupor, coma

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## Types of Sleep

- There are two major types of sleep:
  - Non-rapid eye movement (NREM)
  - Rapid eye movement (REM)
- One passes through four stages of NREM during the first 30-45 minutes of sleep
- REM sleep occurs after the fourth NREM stage has been achieved

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## Types and Stages of Sleep: NREM

- NREM stages include:
  - Stage 1 – eyes are closed and relaxation begins; the EEG shows alpha waves; one can be easily aroused
  - Stage 2 – EEG pattern is irregular with sleep spindles (high-voltage wave bursts); arousal is more difficult
  - Stage 3 – sleep deepens; theta and delta waves appear; vital signs decline; dreaming is common
  - Stage 4 – EEG pattern is dominated by delta waves; skeletal muscles are relaxed; arousal is difficult

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## Types and Stages of Sleep: REM

- REM sleep is characterized by
  - EEG pattern reverts through the NREM stages to the stage 1 pattern
  - Vital signs increase
  - Skeletal muscles (except ocular muscles) are inhibited
  - Most dreaming takes place

## Sleep Patterns

- Alternating cycles of sleep and wakefulness reflect a natural circadian rhythm
- Although RAS activity declines in sleep, sleep is more than turning off RAS
- The brain is actively guided into sleep
- The suprachiasmatic and preoptic nuclei of the hypothalamus regulate the sleep cycle
- A typical sleep pattern alternates between REM and NREM sleep

## Importance of Sleep

- Slow-wave sleep is presumed to be the restorative stage
- Those deprived of REM sleep become moody and depressed
- REM sleep may be a reverse learning process where superfluous information is purged from the brain
- Daily sleep requirements decline with age

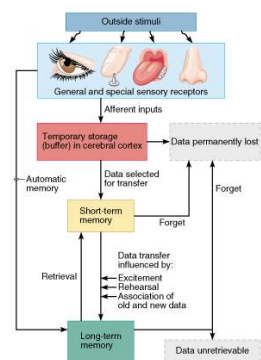
## Sleep Disorders

- Narcolepsy – lapsing abruptly into sleep from the awake state
- Insomnia – chronic inability to obtain the amount or quality of sleep needed
- Sleep apnea – temporary cessation of breathing during sleep

## Memory

- Memory is the storage and retrieval of information
- The three principles of memory are:
  - Storage – occurs in stages and is continually changing
  - Processing – accomplished by the hippocampus and surrounding structures
  - Memory traces – chemical or structural changes that encode memory

## Memory



## Stages of Memory

- The two stages of memory are short-term memory and long-term memory
- Short-term memory (STM, or working memory) – a fleeting memory of the events that continually happen
- STM lasts seconds to hours and is limited to 7 or 8 pieces of information
- Long-term memory (LTM) has limitless capacity

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## Transfer from STM to LTM

- Factors that affect transfer of memory from STM to LTM include:
  - Emotional state – we learn best when we are alert, motivated, and aroused
  - Rehearsal – repeating or rehearsing material enhances memory
  - Association – associating new information with old memories in LTM enhances memory
  - Automatic memory – subconscious information stored in LTM

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## Categories of Memory

- The two categories of memory are fact memory and skill memory
- Fact (declarative) memory:
  - Entails learning explicit information
  - Is related to our conscious thoughts and our language ability
  - Is stored with the context in which it was learned

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## Skill Memory

- Skill memory is less conscious than fact memory and involves motor activity
- It is acquired through practice
- Skill memories do not retain the context in which they were learned

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## Structures Involved in Fact Memory

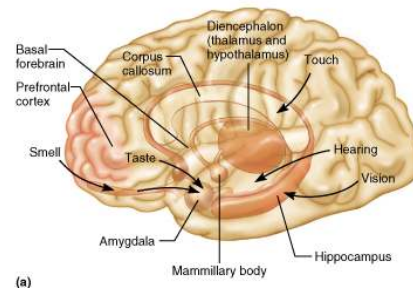
- Fact memory involves the following brain areas:
  - Hippocampus and the amygdala, both limbic system structures
  - Specific areas of the thalamus and hypothalamus of the diencephalon
  - Ventromedial prefrontal cortex and the basal forebrain

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## Structures Involved in Fact Memory



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102 figure 12.22a

## Major Structures Involved with Skill Memory

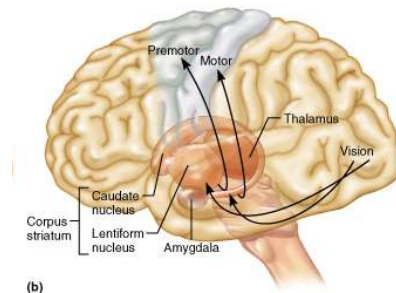
- Skills memory involves:
  - Corpus striatum – mediates the automatic connections between a stimulus and a motor response
  - Portion of the brain receiving the stimulus (visual in this figure)
  - Premotor and motor cortex

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## Major Structures Involved with Skill Memory



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104 figure 12.22b

## Mechanisms of Memory

- The engram, a hypothetical unit of memory, has never been elucidated
- Changes that take place during memory include
  - Neuronal RNA content is altered
  - Dendritic spines change shape
  - Unique extracellular proteins are deposited at synapses involved in LTM
  - Presynaptic terminals increase in number and size, and release more neurotransmitter

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## Protection of the Brain

- The brain is protected by bone, meninges, and cerebrospinal fluid
- Harmful substances are shielded from the brain by the blood-brain barrier

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## Meninges

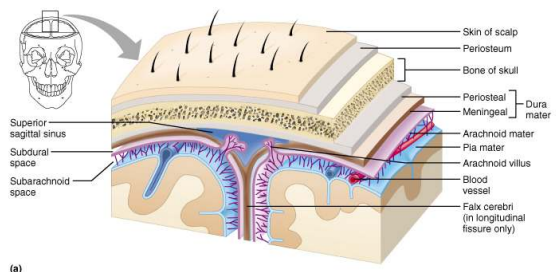
- Three connective tissue membranes that lie external to the CNS – dura mater, arachnoid mater, and pia mater
- Functions of the meninges include:
  - Cover and protect the CNS
  - Protect blood vessels and enclose venous sinuses
  - Contain cerebrospinal fluid (CSF)
  - Form partitions within the skull

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## Meninges



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108 figure 12.23a

## Dura Mater

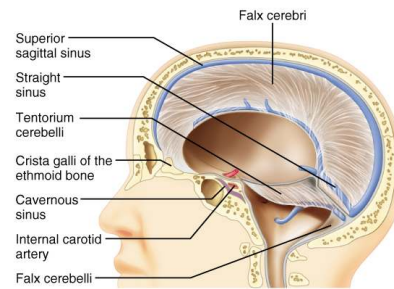
- Leathery, strong meninx composed of two fibrous connective tissue layers
- The two layers separate in certain areas and form dural sinuses
- Three dural septa extend inward and limit excessive movement of the brain
  - Falx cerebri – fold that dips into the longitudinal fissure
  - Falx cerebelli – runs along the vermis of the cerebellum
  - Tentorium cerebelli – horizontal dural fold extends into the transverse fissure

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## Dura Mater



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110 Figure 12.24

## Arachnoid Mater

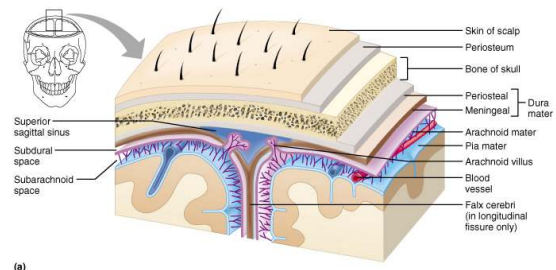
- The middle meninx, which forms a loose brain covering
- It is separated from the dura mater by the subdural space
- Beneath the arachnoid is a wide subarachnoid space filled with CSF and large blood vessels
- Arachnoid villi protrude superiorly and permit CSF to be absorbed into venous blood

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## Arachnoid Mater



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112 Figure 12.20a

## Pia Mater

- Deep meninx composed of delicate connective tissue that clings tightly to the brain

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## Cerebrospinal Fluid (CSF)

- Watery solution similar in composition to blood plasma
- Contains less protein and different ion concentrations than plasma
- Forms a liquid cushion that gives buoyancy to the CNS organs
- Prevents the brain from crushing under its own weight
- Protects the CNS from blows and other trauma
- Nourishes the brain and carries chemical signals throughout it

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## Choroid Plexuses

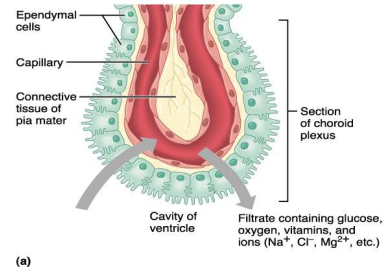
- Clusters of capillaries that form tissue fluid filters, which hang from the roof of each ventricle
- Have ion pumps that allow them to alter ion concentrations of the CSF
- Help cleanse CSF by removing wastes

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## Choroid Plexuses



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116 figure 12.25a

## Blood-Brain Barrier

- Protective mechanism that helps maintain a stable environment for the brain
- Bloodborne substances are separated from neurons by:
  - Continuous endothelium of capillary walls
  - Relatively thick basal lamina
  - Bulbous feet of astrocytes

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## Blood-Brain Barrier: Functions

- Selective barrier that allows nutrients to pass freely
- Is ineffective against substances that can diffuse through plasma membranes
- Absent in some areas (vomiting center and the hypothalamus), allowing these areas to monitor the chemical composition of the blood
- Stress increases the ability of chemicals to pass through the blood-brain barrier

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## Cerebrovascular Accidents (Strokes)

- Caused when blood circulation to the brain is blocked and brain tissue dies
- Most commonly caused by blockage of a cerebral artery
- Other causes include compression of the brain by hemorrhage or edema, and atherosclerosis
- Transient ischemic attacks (TIAs) – temporary episodes of reversible cerebral ischemia

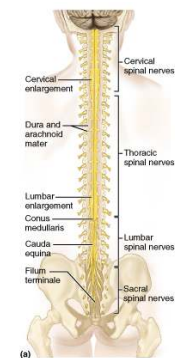
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## Spinal Cord

- CNS tissue is enclosed within the vertebral column from the foramen magnum to L<sub>1</sub>
- Provides two-way communication to and from the brain



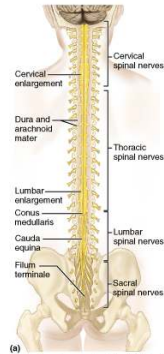
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120 figure 12.26a

## Spinal Cord

- Protected by bone, meninges, and CSF
- Epidural space – space between the vertebrae and the dural sheath (dura mater) filled with fat and a network of veins



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121 Figure 12.26a

## Spinal Cord

- Conus medullaris – terminal portion of the spinal cord
- Filum terminale – fibrous extension of the pia mater; anchors the spinal cord to the coccyx
- Denticulate ligaments – delicate shelves of pia mater; attach the spinal cord to the vertebrae
- Spinal nerves – 31 pairs attach to the cord by paired roots
- Cervical and lumbar enlargements – sites where nerves serving the upper and lower limbs emerge
- Cauda equina – collection of nerve roots at the inferior end of the vertebral canal

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## Cross-Sectional Anatomy of the Spinal Cord

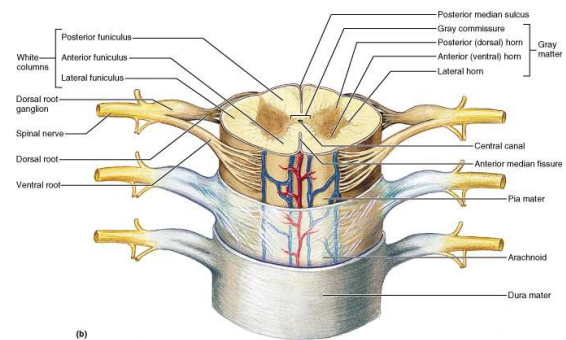
- Anterior median fissure – separates anterior funiculi
- Posterior median sulcus – divides posterior funiculi

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## Cross-Sectional Anatomy of the Spinal Cord



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124 Figure 12.28b

## Gray Matter and Spinal Roots

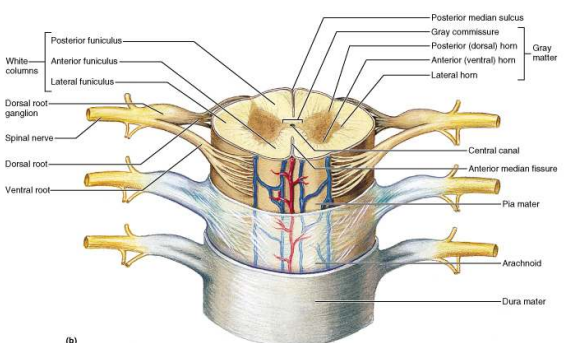
- Gray matter consists of soma, unmyelinated processes, and neuroglia
- Gray commissure – connects masses of gray matter; encloses central canal
- Posterior (dorsal) horns – interneurons
- Anterior (ventral) horns – interneurons and somatic motor neurons
- Lateral horns – contain sympathetic nerve fibers

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## Gray Matter and Spinal Roots



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126 Figure 12.28b

## Gray Matter: Organization

- Dorsal half – sensory roots and ganglia
- Ventral half – motor roots
- Dorsal and ventral roots fuse laterally to form spinal nerves

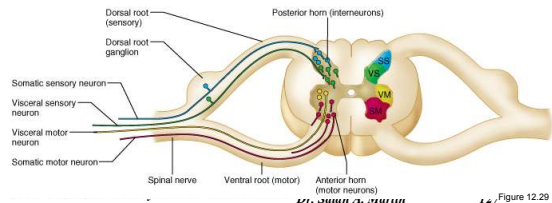


Figure 12.29

## Gray Matter: Organization

- Four zones are evident within the gray matter – somatic sensory (SS), visceral sensory (VS), visceral motor (VM), and somatic motor (SM)

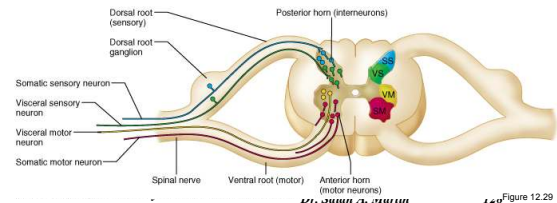


Figure 12.29

## White Matter in the Spinal Cord

- Fibers run in three directions – ascending, descending, and transversely
- Divided into three funiculi (columns) – posterior, lateral, and anterior
- Each funiculus contains several fiber tracts
  - Fiber tract names reveal their origin and destination
  - Fiber tracts are composed of axons with similar functions

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## White Matter: Pathway Generalizations

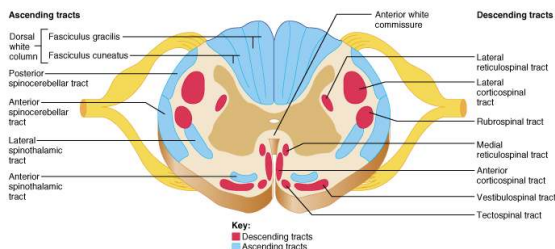
- Pathways decussate
- Most consist of two or three neurons
- Most exhibit somatotopy (precise spatial relationships)
- Pathways are paired (one on each side of the spinal cord or brain)

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## White Matter: Pathway Generalizations



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131 Figure 12.30

## Main Ascending Pathways

- The central processes of first-order neurons branch diffusely as they enter the spinal cord and medulla
- These branches take part in spinal cord reflexes
- Others synapse with second-order neurons in the cord and medullary nuclei
- Pain fibers synapse with substantia gelatinosa neurons in the dorsal horn
- Fibers from touch and pressure receptors form collateral synapses with interneurons in the dorsal horns

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### Three Ascending Pathways

- The nonspecific and specific ascending pathways send impulses to the sensory cortex
- These pathways are responsible for discriminative touch and conscious proprioception
- The spinocerebellar tracts send impulses to the cerebellum and do not contribute to sensory perception

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### Specific and Posterior Spinocerebellar Tracts

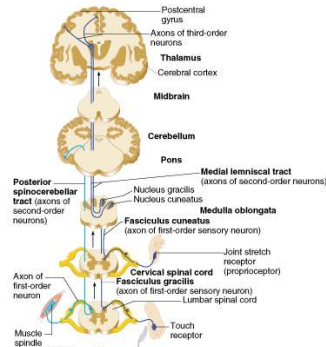
- Specific ascending pathways within the fasciculus gracilis and fasciculus cuneatus tracts, and their continuation in the medial lemniscal tracts
- The posterior spinocerebellar tract

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### Specific and Posterior Spinocerebellar Tracts



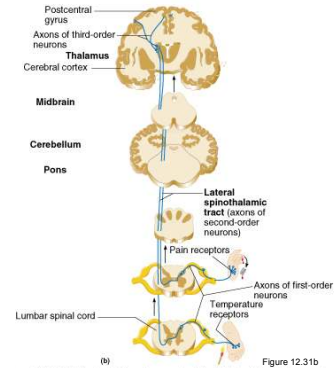
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Figure 12.31a

### Nonspecific Ascending Pathway

- Nonspecific pathway for pain, temperature, and crude touch within the lateral spinothalamic tract



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(b)

Figure 12.31b

### Descending Motor Pathways

- Descending tracts deliver efferent impulses from the brain to the spinal cord, and are divided into two groups:
  - Direct pathways equivalent to the pyramidal tracts
  - Indirect pathways, essentially all others
- Motor pathways involve two neurons (upper and lower)

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### The Direct (Pyramidal) System

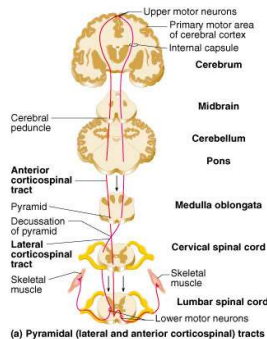
- Direct pathways originate with the pyramidal neurons in the precentral gyri
- Impulses are sent through the corticospinal tracts and synapse in the anterior horn
- Stimulation of anterior horn neurons activates skeletal muscles
- Parts of the direct pathway, called corticobulbar tracts, innervate cranial nerve nuclei
- The direct pathway regulates fast and fine (skilled) movements

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## The Direct (Pyramidal) System



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139 figure 12.32a

## Indirect (Extrapyramidal) System

- Includes the brain stem, motor nuclei, and all motor pathways not part of the pyramidal system
- This system includes the rubrospinal, vestibulospinal, reticulospinal, and tectospinal tracts
- These motor pathways are complex and multisynaptic, and regulate:
  - Axial muscles that maintain balance and posture
  - Muscles controlling coarse movement of the proximal portions of limbs
  - Head, neck, and eye movement

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## Extrapyramidal or Multineuronal Pathways

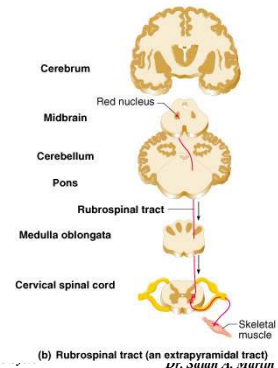
- Reticular nuclei – maintain balance
- Vestibular nuclei – receive input from the equilibrium apparatus of the ear and cerebellum
- Vestibulospinal tracts – control the segmental apparatus during standing
- Red nuclei – control flexor muscles
- Superior colliculi and tectospinal tracts mediate head movements

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## Extrapyramidal or Multineuronal Pathways



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(b) Rubrospinal tract (an extrapyramidal tract)  
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142 figure 12.32b

## Spinal Cord Trauma: Paralysis

- Paralysis – loss of motor function
- Flaccid paralysis – severe damage to the ventral root or anterior horn cells
  - Lower motor neurons are damaged and impulses do not reach muscles
  - There is no voluntary or involuntary control of muscles

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## Spinal Cord Trauma: Paralysis

- Spastic paralysis – only upper motor neurons of the primary motor cortex are damaged
  - Spinal neurons remain intact and muscles are stimulated irregularly
  - There is no voluntary control of muscles

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### Spinal Cord Trauma: Transection

- Cross sectioning of the spinal cord at any level results in total motor and sensory loss in regions inferior to the cut
- Paraplegia – transection between T<sub>1</sub> and L<sub>1</sub>
- Quadriplegia – transection in the cervical region

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### Poliomyelitis

- Destruction of the anterior horn motor neurons by the poliovirus
- Early symptoms – fever, headache, muscle pain and weakness, and loss of somatic reflexes
- Vaccines – Salk and Sabin polio vaccines are available and can prevent infection if used

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### Amyotrophic Lateral Sclerosis (ALS)

- Lou Gehrig's disease – neuromuscular condition involving destruction of anterior horn motor neurons and fibers of the pyramidal tract
- Symptoms – loss of the ability to speak, swallow, and breathe
- Death occurs within five years
- Linked to malfunctioning genes for glutamate transporter and/or superoxide dismutase

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