

## Unit 2 – The Central Nervous System

### Evolution of Nervous Systems

- First multicellular animals to develop neurons were *Cnidaria*, the jellyfish and sea anemones
  - o Nervous system consists of a nerve net composed of sensory neurons, connective interneurons and motor neurons
  - o No identifiable control centre
- Flatworms have a rudimentary brain
  - o The distinction between central nervous system and peripheral nervous system is not clear
  - o “Brain” consists of a cluster of nerve cell bodies concentrated in the head (cephalic) region
  - o Nerve cords come off the “brain” and lead to a nerve network that innervates distal regions
- Segmented worms (annelids) have an advanced nervous system
  - o Cluster of cell bodies no longer restricted to cephalic region
  - o Cell bodies also occur in fused pairs, called ganglia
  - o Each segment of the worm contains a ganglion, simple reflexes can be integrated without input from the brain
- Advantages of cephalic brains
  - o Head is the part of the body that first contacts the environment
  - o As brains evolved, they became more associated with cephalic receptors such as eyes, ears and taste
- In higher arthropods, such as insects and octopus, specific regions of the brain are associated with particular functions
  - o More complex brain → more complex behaviours

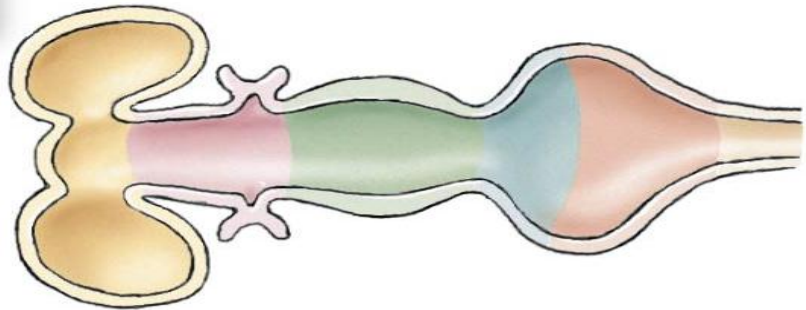
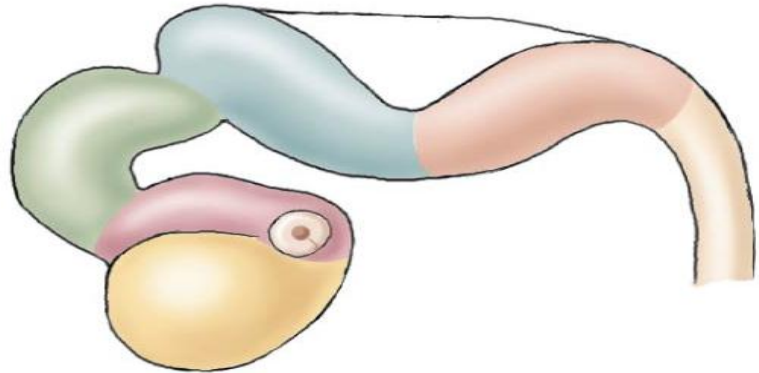
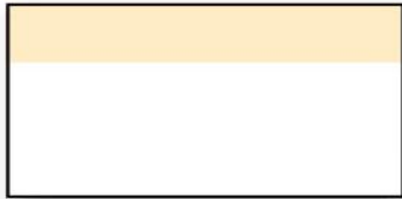
### Evolution of Brains in Vertebrates

- Most dramatic change is seen in the forebrain region, which includes the **cerebrum**
- Cerebrum is the part of the brain that makes humans, human
  - o Responsible for reasoning and cognition

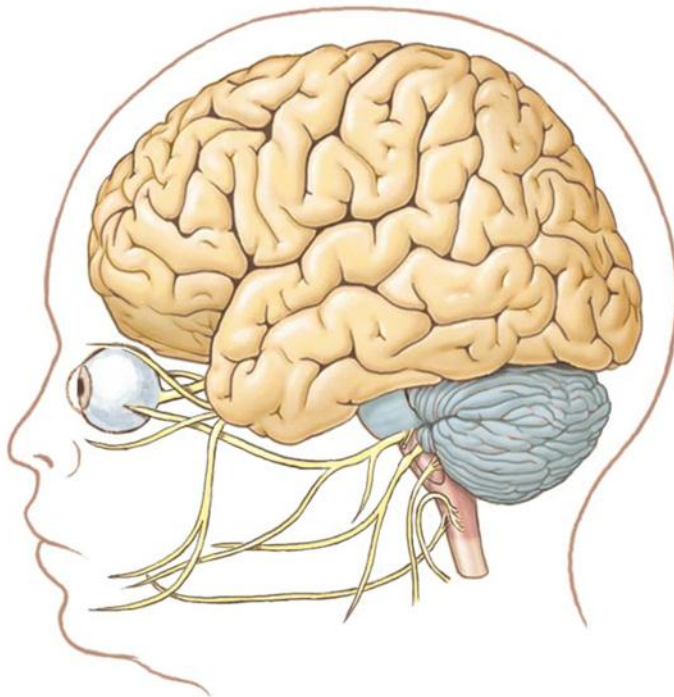
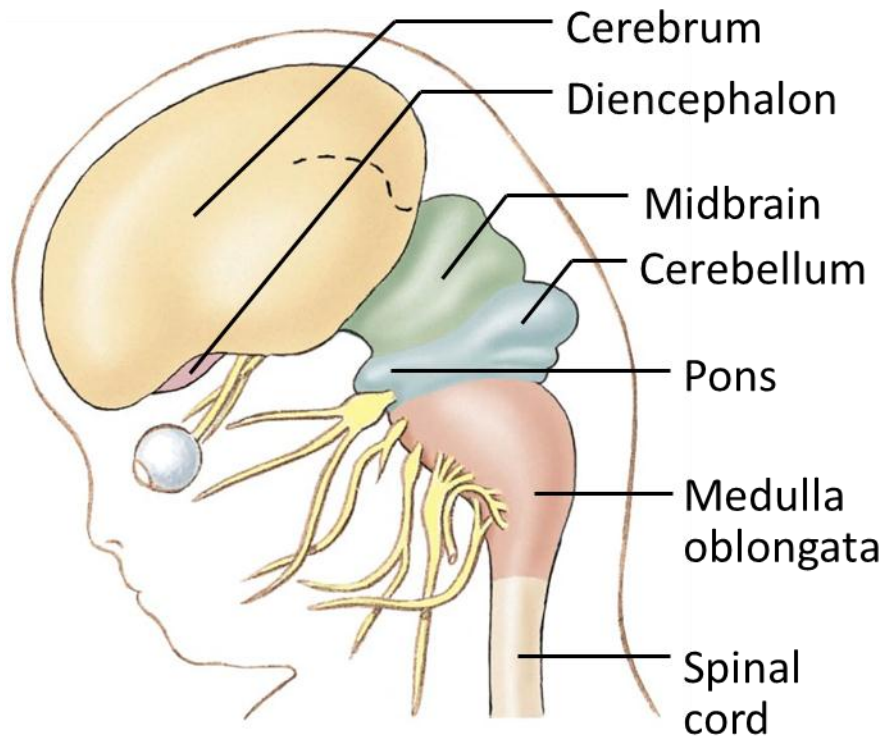
### Development of the Vertebrate CNS

- 1) Cells that will become the nervous system lie in a flattened region called the **neural plate**
  - a. Convergence of the neural plate occurs, a neural tube forms which will eventually form the CNS
  - b. Outer layer of the neural tube will become neurons and the glia of the CNS
  - c. Neural crest cells will become the sensory and motor neurons of the PNS
- 2) At week 4, the anterior portion (cephalic region) of the neural tube specializes into the forebrain, midbrain and hindbrain
- 3) At week 6, the CNS has formed 7 major divisions that present at birth
  - a. Cerebrum
  - b. Diencephalon
  - c. Midbrain

- d. Cerebellum
- e. Pons
- f. Medulla oblongata
- g. Spinal cord
- h. The lumen of the neural tube enlarges to form the hollow ventricles of the brain

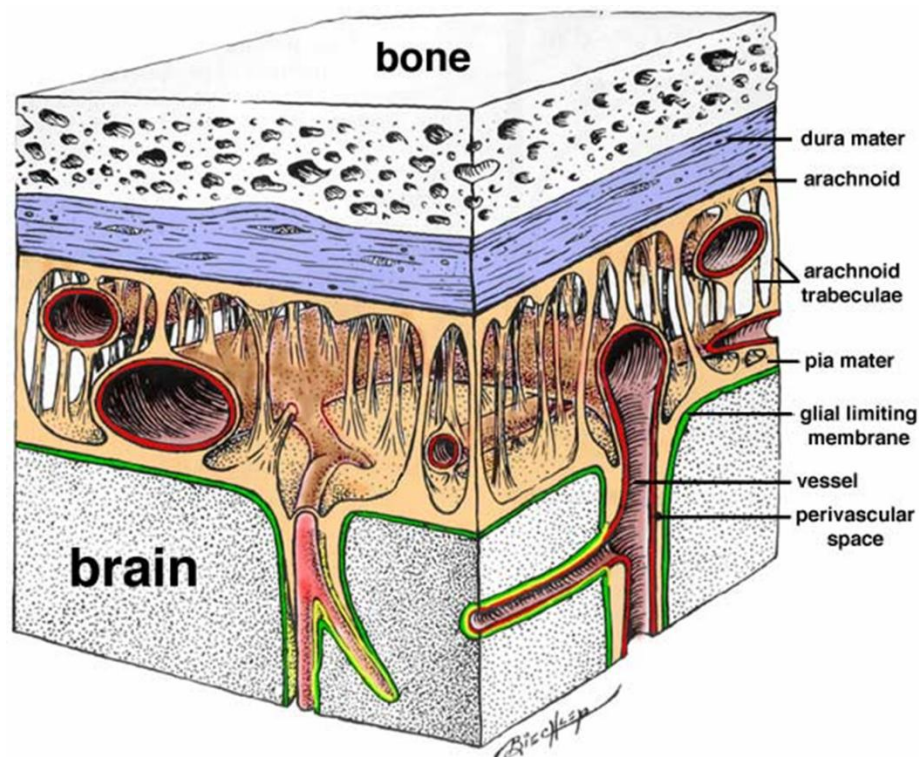


- 4) At week 11, the growth of the cerebrum is noticeably more rapid than that of the other divisions of the brain
- a. Cerebrum surrounds diencephalon, midbrain, pons, leaving only the cerebellum and medulla oblongata visible below it. Convoluted surface of cerebrum caused to rapid growth in confined space



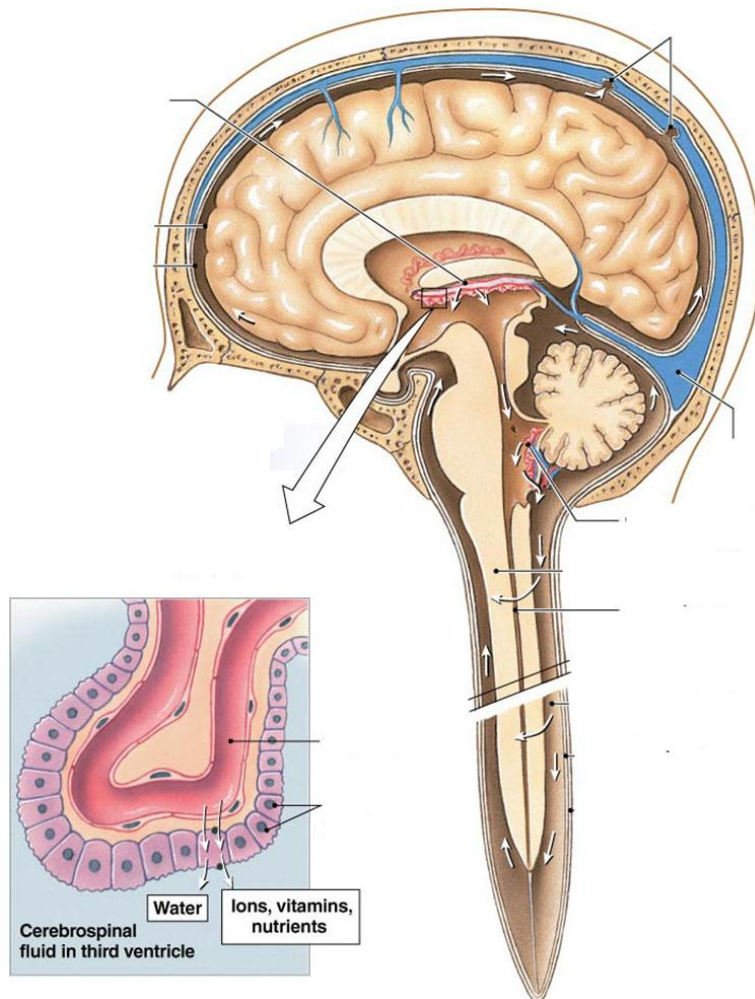
### Organization of the Adult CNS

- Brain encased in bony skull (cranium)
- Spinal cord runs through a canal in the vertebral column
- Body segmentation can be seen in bony vertebrae which are stacked on top of one another and separated by disks of connective tissue
- Three layers of membrane, called the **meninges** lie between the bones and tissues of the CNS – they help stabilize neural tissue and protect it from bruising against bones of the skeleton
  - o Membranes are:
  - o Dura mater – thickest of the three membranes, associated with veins that drain blood from the brain through vessels or sinuses
  - o Arachnoid membrane – loosely tied to inner membrane, leaving a subarachnoid space between 2 layers
  - o Pia mater – the most inner membrane and adheres to the surface of the brain and spinal cord, arteries that supply the brain are associated with this layer



## Cerebrospinal Fluid

- Solution continuously secreted by the choroid plexus, a specialized region on the walls of ventricles
- It is similar to kidney tissue
- Choroid plexus pump sodium and other solutes from plasma into ventricles
  - o ventricles within brain, hollow central canal within spinal cord
  - o two lateral ventricles, two descending ventricles that extend through in brain stem
  - o CSF in ventricles continuous with fluid in central canal of spinal cord
- CSF then flows into **subarachnoid space**, surrounding the entire brain and spinal cord in fluid



## Roles of CSF

- Provide physical protection
  - o Buoyancy of CSF reduces the weight of the brain 30 fold, thus resulting in less pressure on blood vessels and nerves
  - o CSF helps to cushion the brain

- Provide Chemical protection
  - o CSF creates a closely regulated extracellular environment for neurons
  - o Choroid plexus is selective about which substances it transports into the ventricles
- A spinal tap, or lumbar puncture can be done to analyze the components of CSF. Blood cells or proteins in the CSF suggests an infection
- Compared to blood, has lower  $K^+$ ,  $Ca^{2+}$ ,  $HCO_3^-$ , glucose, pH, similar  $Na^+$  levels as blood
- Choroid plexus produces about 500mL of CSF daily, enough to replace the CSF 4 times a day
- CSF is reabsorbed into **venous blood** by **arachnoid villi**
- Choroid plexus is composed of **ependymal cells**

### Circulation of CSF

- 1) Lateral ventricles
- 2) Third ventricle
- 3) Fourth ventricle
- 4) Subarachnoid space, central canal of spinal cord
- 5) Arachnoid villi
- 6) Superior sagittal sinus
- 7) Venous return to heart

### Blood-Brain Barrier

- Functional barrier between interstitial fluid and the blood
- Protects the brain against harmful substances and harmful bacteria
- Endothelial cells form tight junctions with one another that prevent solute movement between cells
- Astrocytes cause tight junction formation
- Lipid soluble molecules cross readily , water soluble molecules cannot cross
- Hydrophilic substances (ions, amino acids, peptides, proteins) will only cross if specific transporters/carriers are present on endothelial cells of capillaries within CNS

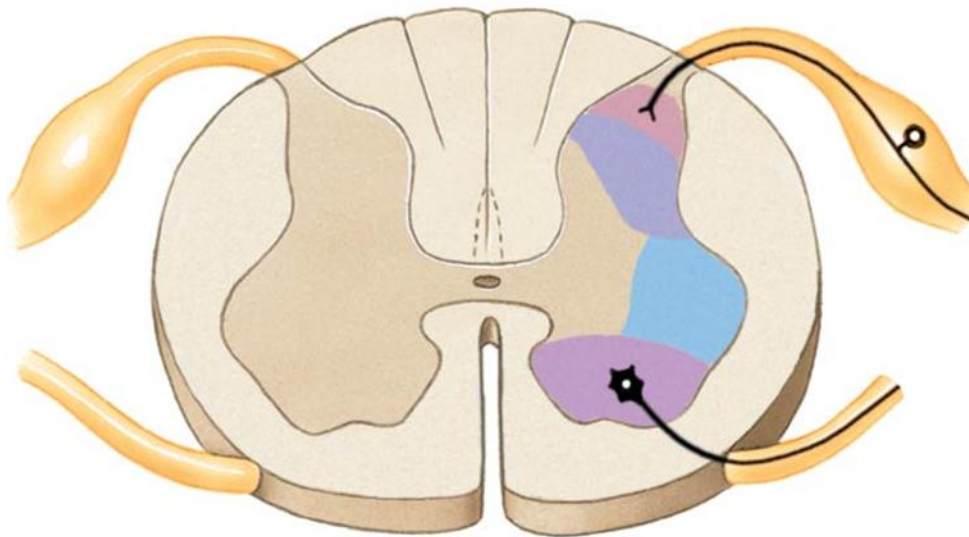
### Quirks of Neural Tissue

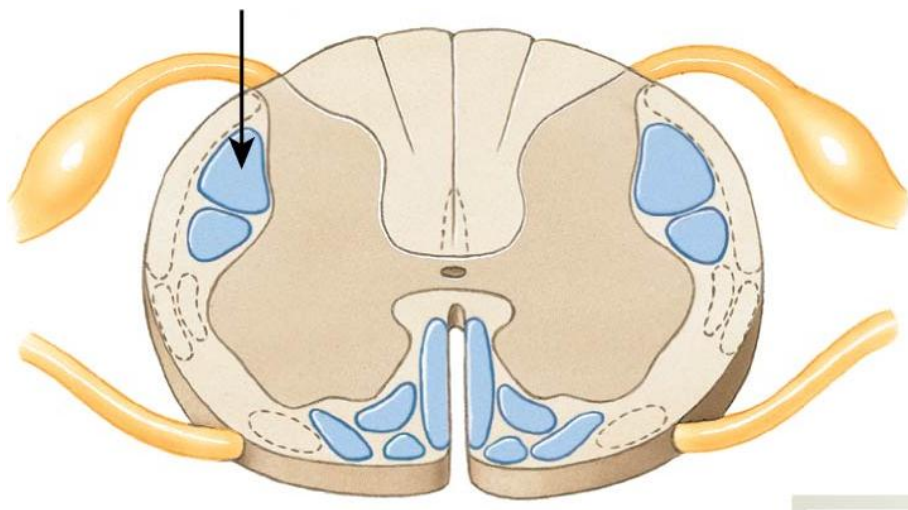
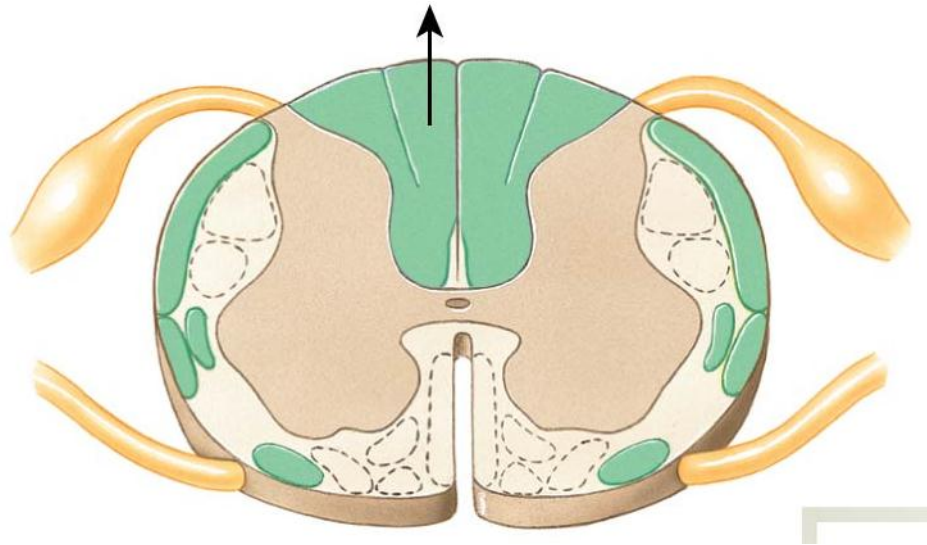
- Neurons are obligate aerobes – unable to switch to anaerobic metabolism
- Oxygen readily crosses blood brain barrier
- Capillaries of CNS express high levels of glucose transporters to provide adequate levels of glucose
- Brain responsible for about half of body's glucose consumption
- About 15% of cardiac output received by brain
  - o Critically dependant on adequate oxygen and glucose

### The Spinal Cord

- Major path for information flow between CNS and skin, joints, muscles
- Contains neural networks involved in locomotion
- Divided into 4 regions → each of which is divided into segments
  - o Each segment gives rise to pair of spinal nerves
  - o Just before a spinal nerve joins the spinal cord, it divides into two branches called roots

- Dorsal Root of spinal nerve
  - o Specialized to carry incoming sensory information
  - o The dorsal root ganglia, swellings found on the dorsal roots just before they enter the cord, contain cell bodies of **sensory neurons**
- Ventral Root of spinal nerve
  - o Carries information from the CNS to muscles and glands
- Cross section of spinal cord
  - o Has a butterfly shaped core of grey matter and surrounding rim of white matter
    - White matter → myelinated axons, white colour occurs due to fatty layer. Bundles of axons connecting CNS regions → Tracts
    - Grey matter → unmyelinated axons, mostly cell bodies and dendrites.
      - Cluster of cell bodies within CNS → nuclei
      - Cluster of cell bodies outside CNS → ganglia
- Sensory fibres from the dorsal roots synapse with interneurons in the **dorsal horns** of the grey matter
  - o Dorsal horn cell bodies are organized into 2 distinct nuclei, one for somatic information, one for visceral information
- **Ventral horns** of grey matter contain cell bodies of motor neurons that **carry efferent** signals to muscles and glands
  - o Ventral horns are organized into somatic and autonomic nuclei.
- White matter is divided into columns composed of tracts of axons that transfer information up and down the cord
  - o Ascending tracts take sensory information up to the brain
  - o Descending tracts carry mostly efferent (motor) signals from the brain to the cord
    - They occupy the ventral and interior lateral portions of the white matter

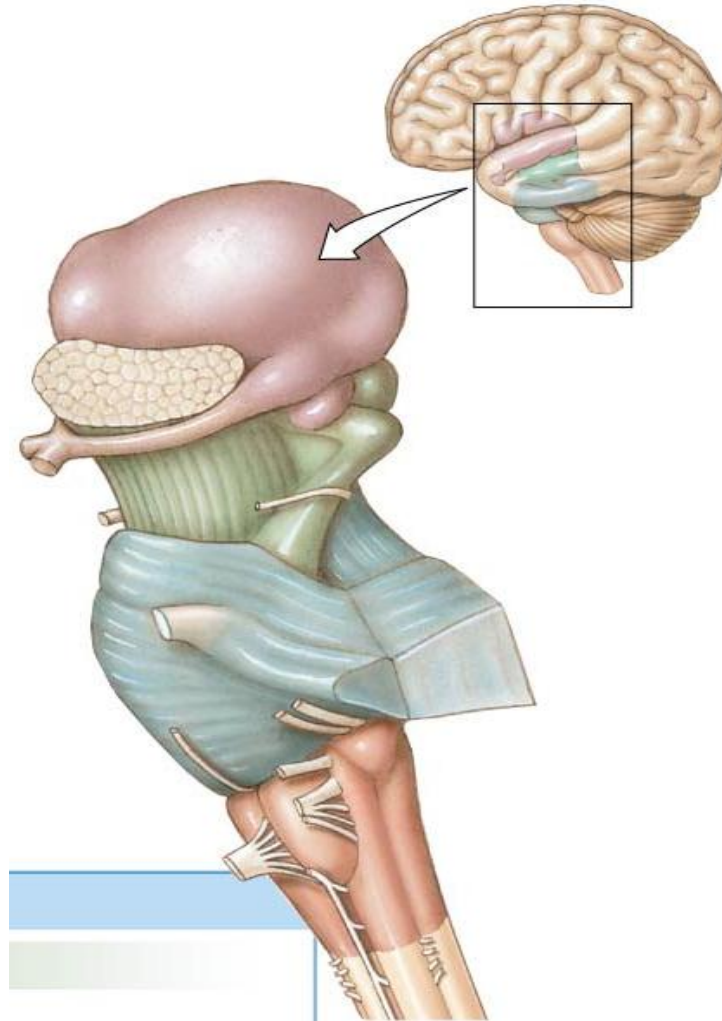




### The Brain Stem

- The brain stem consists of the medulla, the pons and the midbrain
- It is the oldest and most primitive part of the brain
  - o Contains structures derived from embryonic hind and midbrain
- Organized much like the spinal cord
  - o Organized into grey matter and white matter
  - o Some ascending tracts from the spinal cord pass through the brain stem, while others synapse there
  - o Descending tracts pass through the brain stem on their way to the spinal cord
- 11 out of the 12 **cranial nerves** originate from the brain stem
  - o The first cranial nerves originates from the forebrain

- Cranial nerve 10 is the **vagus** nerve, which is responsible for all parasympathetic, efferent activity signals
- Located throughout the brain are discrete groups of nerve cell bodies which are associated with **reticular formation**
  - Diffuse network of neurons involved in processes such as arousal/sleep, muscle tone, coordination of breathing, blood pressure and modulation of pain



### Functions of Brain Stem Structures

#### Medulla

- Transition from the spinal cord into the brain proper
- White matter contains ascending **somatosensory tracts** that bring sensory information to the brain and descending **corticospinal tracts** that convey information from the cerebrum to the spinal cord
- Site of decussation (crossing over) for most neurons in the corticospinal tracts

### Pons

- Bulbous protrusion on ventral side of brainstem just above the medulla
- Primary function is to act as a relay station for information transfer between the cerebellum and the cerebrum
- Pons also coordinates the control of breathing with centers in the medulla.

### Midbrain

- Also called the mesencephalon
- Responsible for coordination of eye movement
- Relays signals for auditory and visual reflexes

### The Cerebellum

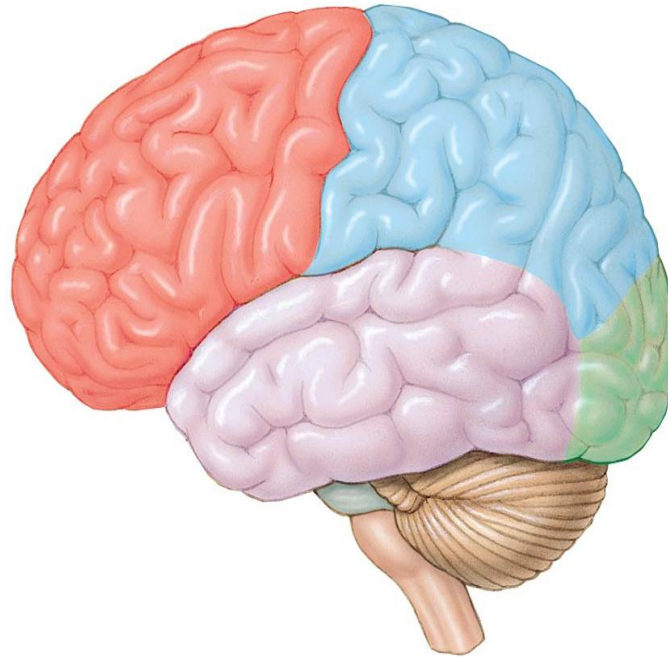
- Responsible for coordination of movement
- Sensory input comes from somatic receptors and from receptors for equilibrium in the inner ear

### The Diencephalon

- Lies between brain stem and cerebrum
- Composed of two main sections and two endocrine structures
  - The thalamus – receives sensory fibers from the optical tract, ears and spinal cord as well as motor information from the cerebellum. Information is then projected to the cerebrum
  - The hypothalamus – lies beneath the thalamus. It is the centre from homeostasis; contains centres related to hunger, thirst, satiety. Also influences autonomic responses such as endocrine functions
  - Pituitary gland – regulated by hypothalamus (will be covered later in course)
  - Pineal gland – secretes melatonin, which is involved in circadian and seasonal rhythms (monitoring day length etc.)

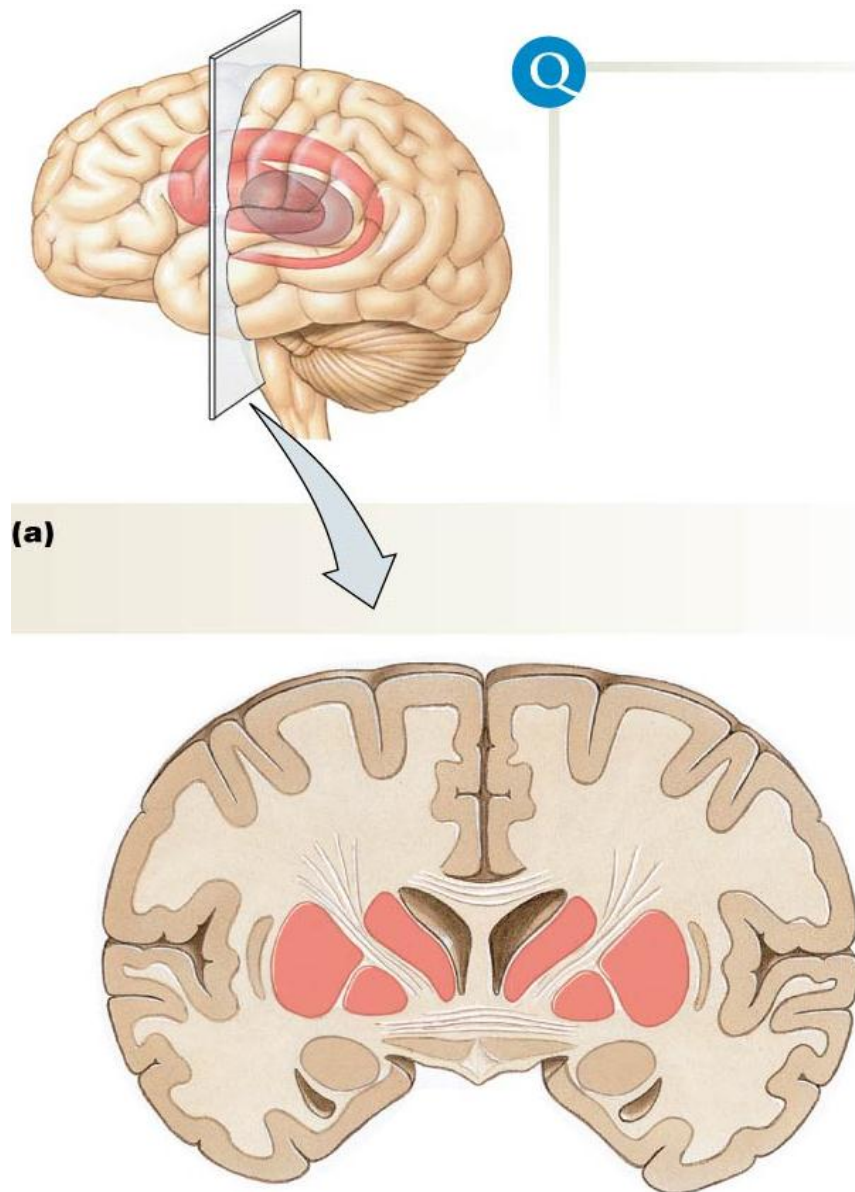
### The Cerebrum

- Site of higher brain functions, it is the largest and most distinctive part of the brain in higher primates
- Composed of two hemispheres connect primarily at the corpus collosum
  - Each cerebral hemisphere is divided into four lobes: Frontal, parietal, temporal and occipital lobe
  - Furrow or groove → sulcus
  - Convolution → gyrus
- The degree of folding is related to the capacity for higher processing in a species, thus less advanced mammals will have smoother brains



### Organization of the Cerebrum

- Cerebral grey matter can be divided into three major regions: the cerebral cortex, the basal ganglia and the limbic system
  - o Cerebral cortex – the most outer layer of the cerebrum, only a few mm thick and responsible for higher brain functions
  - o Basal ganglia – Should really be called the basal nuclei, since it resides inside the CNS, it is responsible for the coordination of movement
  - o Limbic system – surrounds the brain stem. Represents the most primitive region of the cerebrum. Acts as a link between higher cognitive functions such as reasoning and primitive emotions such as fear. Major areas of the limbic system include
    - Amygdala → emotion and memory
    - Cingulate gyrus → emotion and memory
    - Hippocampus → learning and memory
- White matter in the cerebrum is found mostly in the interior
- Cerebral cortex is the terminus of ascending information and the starting point of descending tracts



### Brain Function

- Brain function can be somewhat compared to the simple neural reflex pathway
  - o However, what makes the brain more complicated than this pathway is its ability to generate information and output signals **in the absence of external input**
  - o **Sensory information, cognitive system and behavioural state system** all influence output by motor systems of the body

### Functional Areas of the Cerebral Cortex

- Cerebral cortex serves as an integrating centre for sensory information and a decision making region for many types of motor output
- The functional areas of the cerebral cortex do not necessarily correspond to the anatomical lobes of the brain
  - o Functional specialization is not symmetrical across the cerebral cortex; each lobe has special functions not shared by matching lobe on the opposite side
    - This cerebral lateralization of function is referred to as **cerebral dominance**
- Can be divided into three specializations
  - o Sensory areas – receive sensory input and translated into perception (awareness)
  - o Motor areas – which direct skeletal muscles movement
  - o Association areas – integrate information from sensory and motor areas

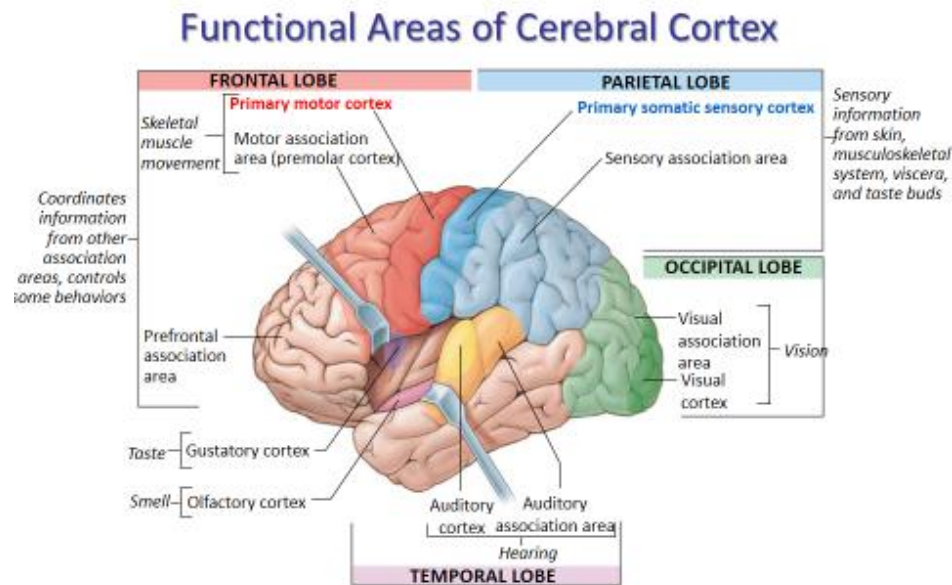


Fig 9.13

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### Primary Motor and Somatosensory Cortices

- Primary motor cortex
  - o On ridge anterior to central sulcus (or precentral gyrus)
  - o Consists of cell bodies of descending 'upper' or 'first order' motor neurons
- Primary somatosensory cortex
  - o On ridges posterior to central sulcus (or precentral gyrus)

- Consists of terminals of ascending sensory pathways from skin, musculoskeletal system viscera.
- Carry information about touch, temperature, pain, itch and body position
- Special senses have devoted regions
  - Visual cortex, auditory cortex, olfactory cortex, gustatory cortex
    - Visual cortex → information from eyes
    - Auditory → information from ears
    - Olfactory → information from chemoreceptors in nose
    - Gustatory → information from taste buds
- Neural pathways extend from sensory areas to association area, which integrate stimuli into perception
- Lips, tongue and finger tips occupy more space in the cerebellum and also have a high density of sensory neurons → larger projection areas is somatosensory cortex

### **Wilder Penfield**

- Founding director of Montreal Neurological Institute
- Pioneer of neurosurgical technique for epilepsy → The Montreal procedure

### **Neural Pathways for Voluntary Movement**

