I. embryonic development of the CNS

A. neurulation is the formation of the CNS in the embryo
- invagination of dorsal ectoderm (outer layer of embryo cells)
- this process is induced (caused) by the notochord

1. neural tube

transverse section of embryo dorsal view of embryo

- the cranial end becomes the brain
- the rest becomes the spinal cord

2. neural crest cells invaginate after neural tube cells and are not incorporated into the tube
- they form the sensory nerve cells

3. cells in the wall of the neural tube proliferate and migrate to surround the tube
   - they form gray matter

4. these cells' axons grow outwards away from the tube
   - they form white matter

B. expansion of the cranial end of the neural tube produces vesicles
   - the walls of vesicles expand and thicken to form solid parts of brain
   - fluid-filled cavities remain inside the vesicles (ventricles)

telencephalon		cerebrum	lateral ventricles
diencephalon		diencephalon	third ventricle
mesencephalon		midbrain	cerebral aqueduct
metencephalon		pons, cerebellum	fourth ventricle
myelencephalon		medulla oblongata	

C. the brain bends to fit into the cranium

- midbrain flexure
- cervical flexure

Why doesn't the cranium just get larger?

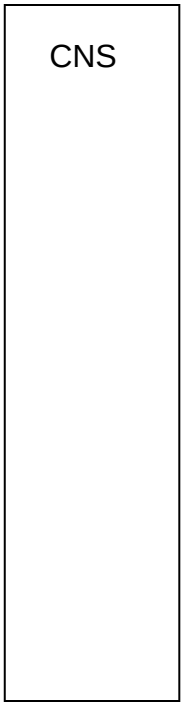
D. during expansion, the cerebrum grows outwards and around the diencephalon

frontal view lateral view

II. spinal cord

A. functions:

- pathway between body and brain
- reflex integration



B. gross anatomy:

- located inside vertebral canal of vertebral column
- extends from formen magnum to L1 or L2
- inferior end – conus medullaris
- filum terminale - filament of c.t. that attaches conus medularis to coccyx
- segments - longitudinal regions (31), each associated with a pair of spinal nerves
- cervical and lumbar enlargements
- cauda equina - bundle of nerve roots below conus medularis
- dorsal median sulcus
- ventral median fissure
- white matter consists of columns of (mostly) myelinated axons that form ascending tracts, descending tracts and commissural tracts
- gray matter consists of columns of cells bodies and unmyelinated axons, deep to white matter; called “horns” in cross section

C. cross section

- central canal - central cavity of neural tube
- white columns: dorsal, lateral, ventral
- gray horns:
  - posterior/dorsal - contain interneurons; receive information from sensory neurons via dorsal roots
  - lateral (thoracic and superior lumbar) - ANS motor neuron cell bodies; leave spinal cord in ventral roots
  - anterior/ventral - somatic motor neuron cell bodies; leave spinal cord in ventral roots
- gray commissure connects left and right sides of spinal cord

III. ventricles

lateral ventricles

interventricular foramen

third ventricle

cerebral aqueduct

fourth ventricle

central canal of spinal cord

lateral and medial apertures lead to subarachnoid space

IV. protection of the CNS

brain	spinal cord

A. meninx/meninges - c.t. membranes that surround brain and spinal cord

1. dura mater - tough fibrous c.t.

a. brain

- cranial dura mater has two layers:
  periosteal - fused to inner surface of cranial bones
  meningeal layer
- layers fused except where there are venous (dural) sinuses

- extends inwards to form partitions:
  falx cerebri
  falx cerebelli
  tentorium cerebelli

b. spinal cord
- spinal dura mater not fused to vertebrae
- meningeal layer only
- epidural space - between spinal dura mater and vertebrae

c. subdural space - between dura mater and arachnoid mater; does not normally contain fluid except as a result of trauma or disease

2. arachnoid mater - middle layer made of thin c.t.
- arachnoid villi project into superior sagittal sinus
- subarachnoid space contains CSF and blood vessels

3. pia mater - inner layer made of very delicate c.t. directly on brain and spinal cord surface
- contains many blood vessels
- dips into convolutions, fissures
- lateral extensions called denticulate ligaments attach spinal cord to vertebrae

B. cerebrospinal fluid (CSF)
fills all CNS cavities and subarachnoid space

1. functions:
   - floats brain (reduces weight by 97%)
   - cushions brain and spinal cord
   - delivers nutrients and removes wastes

2. composition = similar to plasma; less protein, more Na and Cl

3. formation - choroid plexuses (one in each ventricle)
   - a choroid plexus consists of a group of capillaries covered by ependymal cells
   - they project into the ventricles (one in each ventricle)
   - the ependymal cells actively transport solutes from brain tissue fluid into ventricles, water follows by osmosis

   - solutes and water come from blood in brain capillaries

4. volume at any one time = 100 -160 ml
   total production ~ 500 mL/day

5. circulation: ventricles into central canal and subarachnoid space

6. reabsorption: through arachnoid villi into dural sinuses

C. blood-brain barrier controls composition of brain tissue
keeps unwanted molecules out of brain tissue
allows needed molecules to enter and wastes to leave
tight junctions between capillary endothelial cells restrict permeability

blood	brain tissue fluid	CSF

during prolonged physical or emotional stress the barrier becomes leaky, allowing inappropriate molecules (including some that might be toxic) and pathogens to enter brain tissue

V. overview of major regions of the brain

cerebrum
cortex (gray matter)
tracts (white matter)
nuclei (gray matter)
diencephalon
epithalamus
thalamus
hypothalamus
brainstem
midbrain
pons
medulla oblongata
cerebellum
cortex (gray matter)
white matter (arbor vitae)
nuclei (gray matter)

VI. brain stem

A. medulla oblongata

- inferior to pons; superior to and continuous with spinal cord
- floor of fourth ventricle
- pyramids are ridges on ventral surface formed by pyramidal tracts (corticospinal tracts; originate in primary motor cortex); axons decussate (cross to opposite side of CNS)
- inferior cerebellar peduncles connect medulla oblongata to cerebellum
- cranial nerve nuclei VIII – XII
  - cochlear and vestibular nuclei [sensory] - termination of cranial nerve VIII
- reticular formation – network of gray matter, includes:
  - cardiovascular reflex centers (heart rate, heart strength, blood pressure)
  - respiratory reflex centers (breathing, coughing, sneezing)
  - digestive reflex centers (swallowing and others)

B. pons

- inferior to midbrain, superior to medulla oblongata, anterior to cerebellum
- floor of fourth ventricle
- cranial nerve nuclei V, VI, VII
- bridge between brain stem and cerebellum
- middle cerebellar peduncles connect pontine motor nuclei to cerebellum

C. midbrain

- inferior to diencephalon and superior to pons
- cerebral aqueduct runs through center
- dorsal tectum contains corpora quadrigemina
  - superior colliculi - visual reflexes
  - inferior colliculi - auditory reflexes
- ventral midbrain contains cerebral peduncles (corticospinal tracts)
- superior cerebellar peduncles connect midbrain to cerebellum
- periaqueductal gray matter
- cranial nerve nuclei III and IV
- substantia nigra - motor nucleus

VII. cerebellum

inferior to occipital lobe, posterior to brain stem
forms roof of fourth ventricle
2 hemispheres connected by vermis
superficial layer is cerebellar cortex (gray matter)
surface is convoluted: folia (ridges) and fissures (grooves)
white matter is deep to cortex – called arbor vitae
cerebellar nuclei are embedded in white matter
coordinates movement, maintains posture and balance

VIII. diencephalon - medial and inferior to cerebrum

A. epithalamus
superior and posterior to thalamus
forms roof of third ventricle
contains choroid plexus
consists of pineal body and other nuclei

B. thalamus
forms lateral wall of third ventricle
consists of many nuclei that relay information to the cerebral cortex
massa intermedia (intermediate mass) joins left and right thalamus
processes and edits information going to cerebrum

C. hypothalamus
anterior and inferior to thalamus
forms lower walls of third ventricle (funnel-shaped)
consists of several nuclei with specific functions:
1. controls autonomic nervous system
2. coordinates physical responses to emotion
3. regulates body temperature
4. regulates hunger and thirst
5. motivational behavior
6. regulates sleep/wake cycle – suprachiasmatic nucleus is biological clock
7. controls some endocrine glands
8. memory
pituitary gland and mammillary bodies project from inferior surface

IX. cerebrum – 83% of total brain mass

A. surface features

hemisphere = lateral half of cerebrum

longitudinal fissure = partially separates hemispheres
transverse fissure = separates cerebrum from cerebellum

convolutions - increase surface area of cerebral cortex

sulcus/sulci = grooves on surface of cerebrum
gyrus/gyri = ridges between sulci

lobes = 5 major divisions of cerebral cortex
frontal
parietal
temporal
occipital
insula

central sulcus separates frontal and parietal lobes
parieto-occipital sulcus separates parietal and occipital lobes
lateral sulcus separates temporal lobe from frontal and parietal lobes

B. layers:

1. cerebral cortex
    - 2-4 mm thick
    - 6 layers of cell bodies and dendrites
    - 40% of brain mass
    - subdivided into functional areas (refer to handout)
        - sensory areas allow perception of sensation
        - association areas integrate and store information
        - motor areas control voluntary movement
    - some areas show spatial organization (somatotopy)
        - primary motor cortex
        - primary somatosensory cortex
    - size of cortical area associated with body area represents
        - motor: degree of innervation, precision of control
        - sensory: sensitivity or accuracy

2. cerebral white matter
    - deep to cortex
    - mostly superficial to basal nuclei
    - made of myelinated axons
    - form tracts that connect different areas
        - association
        - commissural
            - corpus callosum
                - passes superior to lateral ventricles
                - connects cerebral hemispheres
        - projection
            - internal capsule
                - passes between thalamus and basal nuclei
                - contains sensory and motor tracts

3. deep gray matter
    - various nuclei embedded in white matter
        a. basal ganglia
            - caudate nucleus
            - putamen
            - globus pallidus
            - involved in regulation of voluntary movement
        b. basal forebrain nuclei
            - functions are arousal, learning, memory, motor control

X. functional brain systems

A. limbic system = emotional brain
- interconnected structures in cerebrum and diencephalon:
  - fornix – links components together
  - amygdala – response to fear
  - hippocampal formation (hippocampus + parahippocampal gyrus)
    - encodes, consolidates and retrieves memories of facts and events
- output is through hypothalamus and reticular formation
- causes physical response to emotion
- modulated by prefrontal cortex

B. reticular formation
- network of gray matter located in brain stem
- axons project to thalamus, cerebellum, spinal cord
- sensory input keeps RF neurons active, then RF maintains brain alertness and consciousness (function called reticular activating system)
- filters sensory input

XI. sensory and motor pathways (tracts)

- contain multi-neuron pathways connecting brain to body
- most decussate at some point

1. sensory/ascending
   a. general structure
      - first order: receptor to spinal cord or medulla oblongata
      - second order: spinal cord or medulla oblongata to thalamus
      - third order: thalamus to cerebral cortex
   b. tracts
      - dorsal column (faciculus cuneatus and faciculus gracilis) - somatic sensory information to primary somatosensory cortex
      - spinothalamic - somatic sensory information to primary somatosensory cortex
      - posterior and anterior spinocerebellar - proprioception to cerebellum

2. motor/descending
   a. anterior and lateral corticospinal (pyramidal) - primary motor cortex to motor neurons controlling skeletal muscles (cranial nerve motor nuclei and spinal cord ventral gray horn)
   b. extrapyramidal pathways (subconscious and postural somatic motor activity)
      - tectospinal - superior colliculus to motor neurons for neck muscles
      - vestibulospinal - vestibular nuclei to motor neurons
      - rubrospinal - red nucleus to motor neurons
      - reticulospinal - reticular formation to motor neurons