Chapter 13
Anatomy and Physiology of the Nervous System

The nervous system regulates the activities of most of the other body systems.

- Consciousness, thought, memory, language, sensation and movement all originate in the NS.
- Ability to comprehend learn and respond to stimuli is a result of the integrated functioning of the NS.

I. Overview of the Organization of the Human Nervous System

A. Two anatomic divisions: CNS and PNS

1. Central nervous system (CNS)
   a. consists of the brain and spinal cord
   b. encased in bone.
   c. Surrounded / protected by meninges and CSF
   d. Fxn: Highly sophisticated; Processes, integrates, stores, and responds to information from PNS. Produces ideas and emotions, that are not the automatic consequences of information input.

2. Peripheral nervous system (PNS)

   a. PNS consists of nervous tissue outside of the CNS,
      (1) consists of nerves and ganglia.
      (a) ganglia are collections of nerve bodies located outside the CNS
      (2) 43 pairs of nerves originating in the CNS make up the PNS
      (a) 12 cranial nerves - pass through foramina in the skull
      (b) 31 pair of spinal nerves - pass through intervertebral foramina
      (3) Fxn: The PNS detects stimuli and transmits to and receives information from the CNS.

b. Anatomic Divisions of the PNS (sensory and motor)
   (1) afferent or sensory division (ascending pathways)
      (a) transmits action potentials to the from sensory organs to the CNS
      (b) consists of single neurons with cell bodies in ganglia.
      i) ganglia are located outside the spinal cord or within cranial nerves.
   (2) efferent or motor division (descending pathways)
      (a) carries action potential away from the CNS
      (b) effects muscle (skeletal/ smooth) and glands. (Effector organs)

c. Functional (clinical) subdivisions of PNS (somatic motor and ANS)

   (1) Somatic - motor nervous system
      (a) It consists of motor and sensory pathways that regulate voluntary motor control of skeletal

   (2) Autonomic nervous system (ANS)
      (a) also consists of motor and sensory components.
      (b) responsible for regulating the bodies internal organs.
      (c) innervates cardiac muscle, smooth muscle, and glands.
      (d) called involuntary nervous system (can be controlled to some degree through mental practice)
      (e) two neurons between the CNS and effector organs.
      i) The first neuron has its cell body in CNS, and the second neuron has its cell body within autonomic ganglia and extends to effector

   (1)
organ.

(3) Two (functional) divisions of ANS:

(a) **Sympathetic** - T1-L2 - ganglia are near spinal cord
   
i) SANS increases heart and respiratory rates and decrease activity of the GI tract
   ii) prepares body for stress

(b) **Parasympathetic** - Cranial nerves and S2-S4 - ganglia are in or near organ affected.
   
i) PANS - decreases heart and respiratory rate and increases activity in the GI tract.

II. **Cells of the Nervous system**

   A. **Neuroglia**
      1. Neuroglia - (nerve glue) supporting cells for neurons
      2. Microglia -
         a. Phagocytic cells - digest and ingest tissue debris
      3. Ependymal cell
         a. - production and movement of CSF
         b. - line the cerebral ventricles
      4. Astroglia
         a. Provide essential nutrients to neurons
         b. Maintain electrical potentials
         c. May form part of the blood brain barrier
      5. Oligodendrocyte
         a. Form the myelin within the CNS
         b. May wrap around several axons
      6. Schwann cell -
         a. Form the myelination in the PNS
         b. Speeds conduction along axon through saltatory conduction.
         c. Myelination provides structural support and protection for the nerve.
         (1) **Neurilema** - delicate cytoplasmic membrane formed by Schwann cells.
         d. Demyelinating diseases such as multiple sclerosis (MS) demonstrate the importance of myelinization.

   B. **Neurons**
      1. Nerve cell is the basic anatomic and functional unit of the nervous system
      2. $10^{11}$ neurons in the human brain
      3. Vary considerably in size, shape and length of process.
      4. Anatomical components
         a. Cell body (soma)
         b. Dendrites - conduct information toward the cell body
         c. Axons - only one
            (1) conductive projection carries nerve impulses away from the cell body.
            (2) may have some branches - colaterals
            (3) branch profusely near termination site - telodendria
(4) synaptic boutons - enlargement on the end of each telodendria
(5) axon hillock - cone shaped area where axon leaves the cell body - action potentials are generated here.
(6) typically covered with myelin sheath

5. Neurons are classified on the basis of the number of processes extending from the cell body
a. Unipolar - single process - found in the eye
b. Pseudounipolar - unipolar sensory neurons
c. Bipolar - two processes - retinal neurons.
d. Multipolar - several dendrites and one axon - most neurons in CNS

6. Convergence and Divergence
a. Divergence = ability of the axon to influence many different neurons
b. Convergence = numerous neurons converge to influence one neuron.

7. Neurotransmitters

C. Nerve injury and Regeneration in the PNS
1. When an axon is severed, a complex series of degenerative and regenerative events occurs
   a. Distal to cut on the axon (wallerian degeneration).
      (1) a characteristic swelling appears within the portion of the axon distal to the cut.
      (2) the neurofilaments (cell scaffolding) hypertrophy
      (3) the myelin sheath shrinks and disintegrates
      (4) the axon degenerates and disappears.
      (5) the myelin sheath reforms as Schwann cells line up in a column between the cut and the effector organ.
   b. Proximal to the cut
      (1) similar changes occur but only back to the next node of Ranvier
      (2) swelling occurs
      (3) cell increases its metabolic activity and protein synthesis.
      (4) 7-14 days after the injury, a new axon will sprout from the end of the severed axon.
2. Because no neurilemma exists in the CNS little or no regenerative potential exists for CNS neurons.
   a. Damaged areas within the CNS fill with glial cells (primarily astrocytes) forming gliotic scars.
3. Nerve regeneration depends on many factors
   a. location and type of injury, the inflammation response, the scarring process
   b. injuries close to the cell body may destroy the nerve cell and it will not regenerate
   c. Crushed nerves regenerate better than cut nerves.

III. The Nerve Impulse
   A. Neurons generate and conduct electrical impulses by generating an action potential.
      1. All or none response to stimulus.
   B. The Synapse
         a. presynaptic terminals - The enlarged ends of the axon that contain synaptic vesicles.
b. **postsynaptic membranes** - contain receptors for the neurotransmitter and are found on other neurons, muscles or glands.

c. **synaptic cleft** - the space that separates the presynaptic and postsynaptic membranes.

### 2. **Synaptic transmission**

a. An action potential arriving at the presynaptic terminal causes Ca++ gates to open

b. Ca++ ions diffuse into the synaptic terminal

c. Ca++ causes synaptic vesicles containing the neurotransmitter to bind to the synaptic membrane releasing the neurotransmitter,

d. The neurotransmitter diffuses across the synaptic cleft and binds to the receptors of the postsynaptic membrane.

e. Binding of a ligand to the receptor invokes a response in the postsynaptic cell.

### 3. **Neurotransmitter inactivation** (three methods):

a. The neurotransmitter is broken down by an enzyme
   (1) Eg. acetylcholinesterase

b. The neurotransmitter is taken up by the presynaptic terminal.
   (1) Epinephrine is taken up repackaged in vesicles and reused or inactivated within the presynaptic terminal by monoamine oxidase (MAO).

c. The neurotransmitter diffuses out of the synaptic cleft.

### 4. **Receptor molecules in synapses**

a. Receptors for neurotransmitters are specific.

b. A single neurotransmitter may bind to several different receptor types
   (1) Therefore a neurotransmitter can be stimulatory (depolarize) in one synapse and inhibitory (hyperpolarize) in another, depending on the type of receptor present.

c. Some presynaptic terminals have receptors.
   (1) Release of norepinephrine (NE) can bind to presynaptic receptors which decrease the release of NE. (modifies its own release).
   (2) Opiate are known to modify the release of other neurotransmitters by acting presynaptically

### C. **Neurotransmitter and Neuromodulators**

1. Neurotransmitters are substances released at a synapse that affect another cell.

2. Once thought that each neuron contained only one neurotransmitter.
   a. Some neurons can secrete more than one type of neurotransmitter.
   b. A neuron makes use of the same combination of chemical messengers at all of its synapses.
   c. **Contrary to book**, neurons can release one neurotransmitter in greater abundance compared to another neurotransmitter.
      (1) Size of versicle and frequency of action potential.

3. Neuromodulators influence the likelihood that an action potential in a presynaptic terminal will result in an action potential in a postsynaptic cell.
   a. Can influence the release of other neurotransmitters.

4. Neurotransmitters are produced by a presynaptic neuron, released into the synaptic cleft and active receptors found on the postsynaptic neuron.
   a. Cannot work backwards - since receptors are found on the postsynaptic neuron only.
   b. Binding does one of two things: creates a **excitatory post synaptic potential** or an (IPSP) in the postsynaptic neuron.
c. The postsynaptic neuron then sums the signals sent to it to determine if it will produce an action potential.

d. released at the axon terminal

(1) must be reabsorbed or broken down within the synapse
(2) each neuron may release more than one transmitter.
(3) Terms:
   (a) hyperpolarization
   (b) depolarization
   (c) threshold
   (d) action potential -all or none
   (e) connection to neurotransmitter release.

5. Types of Neurotransmitters. See table 13-2

<table>
<thead>
<tr>
<th>Substance</th>
<th>Location</th>
<th>Effect</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Small molecule</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetylcholine</td>
<td>Used by motor neurons in spinal cord and at all nerve skeletal muscle junctions. Widespread use throughout the brain and in ANS synapses</td>
<td>Excite or inhibit</td>
<td>Alzheimer’s disease - decrease in Ach release / Ach producing neurons. Myasthenia gravis - (weakness in skeletal muscle) decrease in ACH receptors.</td>
</tr>
<tr>
<td>2. Biogenic Amines</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dopamine</td>
<td>ANS synapses and parts of brain</td>
<td>excite</td>
<td>Parkinson’s (depression for voluntary control of motor control) dopamine neuron destruction drugs that increase D induce schizophrenia/vomiting.</td>
</tr>
<tr>
<td>Norepinephrine</td>
<td>brain and sympathetic ANS synapses</td>
<td>excitatory / inhibitory</td>
<td>Amphetamines / cocaine - increase epi. And result in overstimulation of postsynaptic neurons.</td>
</tr>
<tr>
<td>Epinephrine</td>
<td></td>
<td>excitatory / inhibitory</td>
<td></td>
</tr>
<tr>
<td>Serotonin</td>
<td>Many areas of the brain and spinal cord</td>
<td>Inhibitory</td>
<td>Mood anxiety sleep, elevated in schizophrenia (delusions, hallucinations, and withdrawl)</td>
</tr>
<tr>
<td>Histamine</td>
<td></td>
<td>inhibitory</td>
<td>arousal from sleep and thermoregulation, pituitary hormone secretion, cerebral circulation</td>
</tr>
</tbody>
</table>
### 3. Amino Acids

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Target</th>
<th>Effect/Mode</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>GABA gamma-aminobutyric acid</td>
<td>most neurons in the CNS</td>
<td>major inhibitory trans. (IPSP)</td>
<td>Used to treat epilepsy (decreases excessive discharge of neurons)</td>
</tr>
<tr>
<td>Glycine</td>
<td>spinal cord</td>
<td>Inhibitory</td>
<td>blocked by strychnine</td>
</tr>
<tr>
<td>Glutamate aspartate</td>
<td>Widespread in brain and spinal cord</td>
<td>excitatory</td>
<td>drugs that block glutamate and asp. prevent seizures.</td>
</tr>
</tbody>
</table>

### 4. Neuropeptides (Over 50 have been identified.)

<table>
<thead>
<tr>
<th>Neuropeptide</th>
<th>Location</th>
<th>Type</th>
<th>Function/Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opioids (enkephalin / endorphin)</td>
<td>widespread in CNS hypothalamus</td>
<td>inhibitory</td>
<td>regulate pain, reproduction, thermoregulation and maternal behaviors morphine and heroine bind to opioid receptors. Block pain by blocking the release of neurotransmitters.</td>
</tr>
<tr>
<td>Tachykinins</td>
<td>Substance P,</td>
<td>excitatory</td>
<td>regulate sex, pain transmission, release is blocked by opioids</td>
</tr>
<tr>
<td>Gastrins (CCK, Galanin)</td>
<td>both depending on receptor type.</td>
<td></td>
<td>regulate sex and maternal behaviors</td>
</tr>
<tr>
<td>Neurohypophyseal</td>
<td></td>
<td></td>
<td>vassopressin, oxytocin, neurophysins</td>
</tr>
<tr>
<td>Secretins</td>
<td></td>
<td></td>
<td>glucagon, VIP, Growth Hormone RH, histidine</td>
</tr>
<tr>
<td>Insulins</td>
<td>regulate blood sugar levels and growth</td>
<td></td>
<td>insulin, insulin-like growth factors</td>
</tr>
</tbody>
</table>
IV. **The Brain**

A. Enables individuals to reason, function intellectually, express personality, mood and interact with the environment.

1. 2% of the total body weight
2. 20% cardiac output
3. 20% of O\textsubscript{2} consumption
4. Most energy consuming organ of the body.
   a. Demand is constant
5. Tissue is fragile
6. Consciousness is lost in as little as 10 seconds once blood flow is stopped.
   a. Lapse of a few minutes can cause irreversible damage.
7. Integration and coordination center of the body.
8. Understanding the functional specificity or the brain is very useful to clinical personnel especially when attempting to localize pathologic conditions in the nervous system.
   a. Ascribing specific functions to various regions is often difficult because many functions are not localized to just one area.

B. **Brain Stem**

1. **Brainstem** is made up of the medulla oblongata, pons and midbrain
   a. Many lesions of the brain stem can be detected through evaluation of the cranial nerves.
   b. Connects to the spinal cord and rest of the brain.
   c. Damage to small regions of the brainstem often cause death
      (1) Contain reflexes necessary for survival are integrated in brainstem
      (2) All but 2 cranial nerves (optic and olfactory) enter or exit the brainstem.
2. **Medulla oblongata**
   a. continuous with the spinal cord
   b. Contains several nuclei of cell bodies (unlike spinal cord)
      (1) contains ascending and descending nerve tracts.
      (2) **The pyramids**
          (a) Found on inferior / anterior surface between hypoglossal nerves.
          (b) Descending nerve tracts controlling voluntary muscle movement.
          (c) Some nerve fibers cross (decusate) to other side of brain.
              i) accounts for ½ of brain controlling opposite side of body
      (3) **The olives**
          (a) Lateral to superior margin of pyramids. (Between hypoglossal and vagus nerves).
          (b) function in equilibrium, coordination and modulation of sound from the inner ear.
      (4) **Medullary nuclei regulate:**
          (a) the heart, blood vessels, respiration, swallowing, vomiting, coughing, sneezing, and hiccuping.
      (5) The nuclei of cranial nerves V (trigeminal) and IX-XII are in the medulla.
          (trigeminal, glossopharyngeal, vagus, accessory and hypoglossal).
(6) **Fasciculus gracilis and Fasciculus cuneatus**
(7) carry pressure, vibration, proprioception and two point touch discrimination

3. **Pons**
   a. superior to the medulla.
   b. Ascending and descending nerve tracks pass through the pons.
   c. Pontine nuclei (anterior portion of pons) **regulate sleep and respiration** (along with nuclei in medulla).
   d. The nuclei of that regulate cranial nerves V-IX are in the pons. (Trigeminal, abducens, facial, vestibulocochlear, and glossopharyngeal).

4. **Midbrain** (mesencephalon) is superior to the pons.
   a. Smallest region of the brainstem
   b. Contains the nuclei for cranial nerves III, IV, and V.
   (1) Oculomotor, trochlear and trigeminal
   c. Includes the Tectum, Tegmentum, cerebral peduncle, substantia nigra and Reticular formation.
   (1) **Tectum**
      (a) - posterior portion of the midbrain (copora quadrigemina - bodies of four twins)
      (b) consists of four nuclei that form mounds on the surface of the brainstem called colliculi.
         i) two **inferior colliculi** are involved in hearing,
            a) auditory pathways of brain.
         ii) two **superior colliculi** are in visual reflexes.
            a) neurons project to oculomotor, trochlear and abducens cranial nerves.
            b) stimulate motor neurons leading to the muscles of neck and eyes to control head and eye movement.
            c) important in visual tracking of objects.
   (2) **Tegmentum** (floor of the midbrain) contains ascending tracts and the red nuclei, which are involved in motor activity.
      (a) Red nuclei named for pinkish color.
      (b) Aids in unconscious regulation and coordination of muscle movement.
   (3) **Cerebral peduncles**
      (a) (foot or column) are the major descending motor pathway.
      (b) Inferior (anterior) to the tegmentum
   (4) **Substantia nigra** (black substance)
      (a) Black mass between the tegmentum and the cerebral peduncle
      (b) connects to the basal nuclei (caudate / putamen) which carry motor information from the cortex.
      (c) involved with muscle tone and movement.
      (d) Lesions of the substantia nigra produce muscular rigidity, fine tremor at
rest, slow shuffling gate.
i) Parkinson’s disease involves the dopamine releasing neurons in the substantia nigra.

d. **Reticular formation** consists of nuclei scattered throughout the brainstem.
   (1) The reticular activating system extends to the thalamus and cerebrum
   (2) maintains **consciousness and sleep-wake cycle**.
   (3) Regulates **vital reflexes** such as cardiovascular function and respiration.

C. **Cerebellum**
1. The cerebellum has three parts that **control balance, gross motor coordination, and fine motor coordination.**
2. All functions are below the level of conscious thought.
3. The cerebellum functions to correct discrepancies between intended movements and actual movements.
4. The cerebellum can “learn” highly specific complex motor activities.

D. **Diencephalon**
1. The diencephalon is located between the brainstem and the cerebrum
   a. Consists of the thalamus, subthalamus, hypothalamus and epithalamus.
2. **Thalamus** consists of two lobes connected by the intermediate mass. The thalamus functions as an **integration center**.
   a. Most **sensory input** synapses in the thalamus
      (1) **Medial geniculate** - auditory impulses
      (2) **Lateral geniculate** - visual impulses synapse
   b. Influences **mood and body movements** associated with emotions such as fear and rage.
      (1) Anterior and medial nuclei connect to limbic system and are involved in mood modification
   c. The thalamus also has some **motor functions**.
      (1) Ventral anterior and ventral lateral nuclei are connected to the motor cortex
3. **Subthalamus**
   a. inferior to the thalamus
   b. involved in **motor function** and
   c. contains part of red nuclei and substantia nigra.
4. **Epithalamus** is
   a. superior and posterior to the thalamus and
   b. contains the habenular nuclei and pineal body.
      (1) habenular nuclei influence **emotions through the sense of smell**.
      (2) pineal body may play a role in the **onset of puberty**, sleep-wake cycle. (Research not conclusive)
5. **Hypothalamus**, the most inferior portion of the diencephalon contains **several nuclei** and tracts.
   a. The mamillary bodies are reflex centers for olfaction.
   b. The hypothalamus regulates many **endocrine functions**
      (1) (e.g., metabolism, reproduction, response to stress, and urine production).
   c. The pituitary gland attaches to the hypothalamus.
   d. The hypothalamus regulates body temperature, hunger, thirst, satiety, swallowing,
emotions, stress, reproduction, sex, urine production
e. Receives input from visceral organs, taste receptors, limbic system (olfaction), nipples, genitalia, and prefrontal cortex where mood is generated.
f. Send fibers to the autonomic nervous system, infundibulum to regulate posterior pituitary function, skeletal muscle attached to the lower vertebrae.
g. Sexual pleasure, feeling relaxed, feeling full after a meal, rage, fear are all related to hypothalamic function.

E. Limbic System
1. The limbic system includes parts of the cerebral cortex, basal nuclei, thalamus, hypothalamus, and the olfactory cortex.
2. The limbic system controls visceral functions through the autonomic nervous system and the endocrine system and is also involved in emotions and memory.

F. Cerebrum
1. Largest portion of the brain (1200g in females and 1400g in males).
2. Divided into left and right hemispheres by the longitudinal fissure.
3. The cortex of the cerebrum is folded into ridges called gyri and grooves called sulci or fissures.
5. Each hemisphere has five lobes.
   a. **Frontal lobes** are involved in smell, voluntary motor function, motivation, aggression, and mood.
      (1) **Prefrontal area** - goal oriented behavior (ability to concentrate), short term memory, elaboration of thought and inhibition of the limbic system (emotions)
      (2) **Premotor area** - programming motor movements
      (3) **Frontal eye field** - controls eye movement.
      (4) **Primary motor area** (precentral gyrus) - primary voluntary motor area
         (a) somatotopic organization of homunculus
            i) Arranged topographically according to the general plan of the body.
            ii) feet most superior and Taste inferior surface of the frontal lobe.
         (b) **Corticospinal tracts** decussate to control the opposite side of the body (contralateral control)
            i) Each cerebral hemisphere controls and receives input from the opposite side of the body.
            ii) The right and left hemispheres are connected be commissures. The largest commissure is the corpus callosum, which allows sharing of information between hemispheres.
            iii) In most people the left hemisphere is dominant, controlling speech and analytic skills. The right hemisphere controls spatial and musical abilities.
      (5) **Broca’s area** - (left hemisphere only) controls motor aspects of speech
         (a) gets input from Wernicke’s area in the temporal lobe
   b. **Parietal lobes** contain the major sensory areas receiving general sensory input, taste, and balance.
      (1) **Postcentral gyrus** - receives sensory input
(2) **Somatic sensory association area** - communication with motor area, storage analysis and interpretation of stimuli
c. **occipital lobes** contain the **visual centers**.
   (1) Receives **visual input** and contains **visual association areas**.
d. **temporal lobes** receive olfactory and auditory input, and are involved in memory, abstract thought, and judgement.
   (1) **Wernicke’s area** - reception and interpretation of speech
6. Nerve tracts connect areas of the cortex
   a. **association fibers** within the same hemisphere
   b. **commissural fibers** between different hemispheres
c. **projection fibers** between other parts of the brain and the spinal cord.

V. **Spinal Cord**
A. General structure
   1. Thirty-one pairs of spinal nerves exit the spinal cord.
      a. Sections:
         (1) cervical
         (2) thoracic
         (3) lumbar
         (4) sacral
         (a) Conus medullaris
         (b) Cauda equina
         (5) coccogeal
         (a) Filum terminale

B. Cross Section
   1. The cord consists of peripheral white matter and central gray matter.
   2. White matter is organized into funiculi, which are subdivided into fasciculi of nerve tracts, which carry action potentials to and from the brain.
   3. Gray matter is divide into horns.
      a. The dorsal horns contain sensory axons that synapse with association neurons. The ventral horns contain the neuron cell bodies of somatic motor neurons, and the lateral horns contain the neuron cell bodies of the autonomic neurons.
      b. The gray and white commissures connect each half of the spinal cord.
   4. The dorsal root conveys sensory input into the spinal cord, and the ventral root conveys motor output away from the spinal cord.

VI. **Spinal Reflexes**
A. Stretch reflex
   1. Muscle spindles detect stretch of skeletal muscles and cause the muscle to shorten reflexively.
B. Golgi Tendon Reflex
   1. Golgi tendon organs respond to increased tension within tendons and cause skeletal muscles to relax.
C. Withdrawal Reflex
1. Activation of pain receptors causes contraction of muscles and the removal of some part of the body from a painful stimulus.
2. Reciprocal innervation causes relaxation of muscles that would oppose the withdrawal movement.
3. In the crossed extensor reflex, during flexion of one limb caused by the withdrawal reflex, the opposite limb is stimulated to extend.

VII. Spinal Pathways

A. Ascending pathways
1. Ascending pathways carry conscious and unconscious sensations.
2. Spinothalamic system
   a. Lateral spinothalamic tracts carry pain and temperature sensations.
   b. Anterior spinothalamic tracts carry light touch, pressure, tickle, and itch sensations.
   c. Both tracts are formed by primary neurons that enter the spinal cord and synapse with secondary neurons. The secondary neurons cross the spinal cord and ascend to the thalamus, where they synapse with tertiary neurons that project to the somatic sensory cortex.
3. Dorsal column/medial lemniscal system
   a. Dorsal column/medial lemniscal system carries the sensations of two-point discrimination, proprioception, pressure and vibration.
   b. Primary neurons enter the spinal cord and ascend to the medulla, where they synapse with tertiary neurons that extend to the somatic sensory cortex.
4. Spinocerebellar system and other tracts.
   a. Spinocerebellar tracts carry unconscious proprioception to the cerebellum from the same side to the body.
   b. Neurons of the dorsal column/medial lemniscal system synapse with the neurons that carry proprioception information to the cerebellum.
   c. The spinoolivary tract contributes to coordination of movements, the spinotectal tract to eye reflexes, and the spinoreticular tract to arousing consciousness.

B. Descending Pathways
1. Upper motor neurons are located in the cerebral cortex, cerebellum, and brainstem. Lower motor neurons are found in the cranial nuclei are the ventral horn of the spinal cord gray matter.
2. The direct pathways maintain muscle tone and control fine, skilled movements in the face and distal limbs. The indirect pathways control conscious and unconscious muscle movements in the trunk and proximal limbs.
3. The corticospinal tracts control muscle movements below the head.
   a. About 75%-85% of the upper motor neurons of the corticospinal tracts cross over in the medulla to form the lateral corticospinal tracts in the spinal cord.
   b. The remaining upper motor neurons pass through the medulla to form the anterior corticospinal tracts, which cross over in the spinal cord.
   c. The upper motor neurons of both tracts synapse with association neurons that the synapse with lower motor neurons in the spinal cord.
4. The corticobular tracts innervate the head muscles. Upper motor neurons synapse with association neurons in the reticular formation that, in turn, synapse with lower motor neurons.
neurons in the cranial nerve nuclei.
5. The indirect pathways include the rubrospinal, vestibulospinal, and reticulospinal tracts and fibers from the basal nuclei.
6. The indirect pathways are involved in conscious and unconscious trunk and proximal limb muscle movements, posture, and balance.
7. Some axons form the somatic sensory cortex synapse with secondary and tertiary neurons of the ascending sensory system and modify their activity.

VIII. Coverings of the brain and spinal cord
A. Bone - cranium
1. Dura mater (pachymeninx) - tough inelastic leather like tissue composed of two layers.
   1. Outer endosteal dura - forms the periosteum of the skull
   2. Inner meningeal dura - forms barriers between brain tissues
      b. Falx cerebelli - separates the cerebellar hemispheres.
      c. Tentorium cerebelli - separates cerebrum from cerebelli
   3. Venous sinuses
      a. are found between the 2 layers of the dura.
      b. Drain blood from head
B. Arachnoid membrane (with pia considered the leptomeninges)
   1. Thin fine avascular, fibrous membrane
   2. Subarachnoid space
      a. - enlargement of space is called a cistern
      b. L3 and L4 (or L4 -L5) enlargement used for spinal taps.
C. Pia mater
   1. Continuous with the brain and follows its contour.
E. Pathologies
   1. Hematoma
      a. extradural / epidural hematoma - between the bone and the dura
         (1) The inner table of the skull contains grooves in which lie the anterior middle and posterior meningeal arteries.
      b. Subdural hematoma - bleeding between meningeal dura and arachnoid
      c. Subarachnoid hematoma - between the arachnoid and pia mater
IX. Vascular supply of the brain and spinal cord
A. The CNS relies on an adequate supply of blood for nutrients and to remove metabolic waste
B. The vascular supply to the brain is highly interconnected to ensure adequate blood supply to cells
   1. Ie. Circle of willis
C. Carotid Arterial Supply
   1. Internal and external carotid branch from the common carotid
      a. External supplies: face thyroid, tongue, pharynx
         (1) branch to middle meningeal artery - supplies deep structures of the face and dura
mater.

b. Carotid sinus - detect changes in blood pressure.

c. **Internal carotid** enters skull and feeds:
   (1) **anterior cerebral arteries** - caudate, putamen internal capsule, corpus callosum frontal and parietal lobes (including somestheitic and motor cortices.
      (a) occlusion - contalateral hemiplegia (paralysis) that is greater in leg than arm
   (2) **middle cerebral arteries** - temporal, parietal and frontal lobes over the lateral surface
      (a) major blood supply to precentra and postcentral gyrus
      (b) auditory, somesthetic, motor and premotor cortecies
      (c) occlusion: severe aphasia (speech loss), contralateral sensory loss and severe contralateral hemiplegia (paralysis) predominantly in the upper extremities.
   (3) **opthalmic arteries** - supply the orbit and eye, nose and sinuses
      (a) occlusion results in monocular blindness

D. Vertebral-Basilar arterial supply
   1. Rt and left vertebral originate from the subclavian arteries
   2. Fuse to form the basilar artery
   3. Basilar divides into the posterior cerebral arteries which joins the circle of Willis
   4. **Basilar Feeds**:
      a. the Medulla, pons cerebellum, midbrain and part of the diencephalon
   5. **Posterior cerebral artery**
      a. Diencephalon, occipital and temporal lobe, Cochlear apparatus and vestibular organs.
      b. Branch - to **calcarine artery** - supplies the occipital lobe
         (1) occlusion results in a blindness in one region of the visual field.
   c.

E. Arterial circle of Willis
   1. Provides interconnection of internal carotids and basilar arteries.
      a. Safety feature in case of dramatic changes in arterial blood pressure.

F. Conducting and penetrating Arteries
   1. Conducting arteries - form an extensive vascular network over the surface of the brain
      a. Ie internal carotid, anterior, middle and posterior cerebral arteries.
   2. Penetrating
      a. Nutrient vessels derived from the conducting arteries
      b. Enter the brain at right angles and provide blood to deep cerebral structures
         (1) eg. Lentiform (Striate) arteries- occlusion interrupts motor pathways and results in paralysis
   c.

G. Venous Drainage of the Brain
   1. Drainage is via deep veins draining into superficial venous plexuses and into dural sinuses
   2. Dural sinuses include:
      a. Superior and inferior sagital sinus and the transverse and sigmoid sinus
      b. Eventually drain into the jugular veins.
   3. Skull fracture: must consider damage to the sinuses, may result in subdural hematoma.
X. Ventricles and Cerebrospinal Fluid.

A. Ventricles
1. Series of 4 interconnected cavities in the brain
2. They are filled with CSF
   a. CSF provides a protective fluid cushion around the CNS
   b. produced by ependymal cells that form the choroid plexus within the ventricles.
3. Ventricles and connecting structures (given in order of flow)
   a. Lateral ventricles
      (1) foramina of Monro - leads to 3rd ventricle
   b. Third ventricle - in diencephalon
      (1) Cerebral aqueduct (aqueduct of Sylvius)
   c. Fourth ventricle
      (1) foramina of Luschka (x2) - exits from lateral wall of 4th ventricle
      (2) foramen of Magendie - exits to sub archnoid space from below the cerebellum.
   d. Central canal
4. CSF, once in subarchnoid space, is reabsorbed into the blood through the arachnoid villi (granulations) near the superior sagittal venous sinus.
5. Total volume of CSF is ~125 ml
   a. 500-750ml produced / day
   b. CSF pressure is result of rate of production and resistance to reabsorption.
      (1) measured by lumbar puncture
      (2) averages 130 mm H$_2$O (13 mmHg)