Detailed Section of Physiology Overview For PDD Lifelong Students of the Science

(Part 2)

Mark Handler and Joel Reicherter

I. INTRODUCTION

See Overview for Introduction.

II. PHYSIOLOGICAL AND CHEMICAL BACKGROUND

A. Chemical level of organization

1. The basic structure of an atom- The structure of an atom consists of the nucleus, which contains the protons and the neutrons tightly bound together. Protons have a positive electrical charge and neutrons are neutral. Protons and neutrons have about the same mass, which is designated as one atomic mass unit. Each proton and each neutron is one atomic mass unit. Electrons have a negative electrical charge and are small in comparison to protons or neutrons. Electrons have about 1/2000 of the mass that a proton or neutron has and are usually designated as zero atomic mass units.

2. Ions are important in cell signaling- An ion is an atom with a positive or negative electrical charge. Calcium (Ca++), Potassium (K+), Chlorine (Cl-) and Sodium (Na+) are all involved in nerve impulse conduction. Ion flow across the membrane conducts the nerve impulse.

3. Molecule- When two or more atoms combine chemically, they form a molecule. Molecules can consist of two or more of the *same* atoms (hydrogen or H_2) or they can form compounds, which are molecules of *different* atoms (H_2O or water).

III. HUMAN BODY ORGANIZATION -cells-tissues-organs-systems-organism

A. CELLS

1. The cell is the basic structural and functional unit of a living organism.

2. There are three generalized regions of human cells and their functions-

a. The *nucleus* lies near the center of the cell and manages the cell's activities through its DNA construction.

b. The cell or plasma *membrane* separates the cell from its internal environment of a watery mix of ions and nutrients, often referred to as extracellular or interstitial fluid. The membrane serves as a regulator of what substances will enter the cell and what will be excreted. Many specialized cells have unique molecules known as receptors, which regulate the movements of certain ions into or out of the cell. As a result of this regulation, cells can have more positive ions on the outside of the cell membrane, which will establish a charge difference between the outside and inside of the cell. This is known as a resting potential. Specialized cells in the nervous and muscular systems can use resting potential to conduct impulses or action potentials. These signals are sent to the organ systems, instructing specific physiological activity.

c. The *cytoplasm* is the fluid-filled region between the nucleus and the plasma membrane. It contains numerous small structures called organelles that in effect are the machinery performing the cell's specialized activities.

3. The plasma (or cell) membrane separates the cell into two areas:

a. Intracellular, and

b. extracellular.

4. *Interstitial fluid* is an extracellular fluid that bathes our cells. It is derived from our blood and contains the many substances needed for metabolism. Cells extract the nutrients they need from this fluid through a process known as selective permeability. The process of selective permeability allows needed nutrients to enter the cell while keeping out undesirable material.

5. *Diffusion* across a cell membrane occurs when ions and molecules scatter to equalize their concentration in an environment. Ions and molecules tend to move from higher concentrations to lower concentrations. This process is called diffusing down their concentration gradients.

a. *Simple diffusion* is one of two basic diffusions that occurs when substances are able to cross the cell membrane without having to use a channel. This happens with such things as oxygen and carbon dioxide. Oxygen concentrations are always higher in the blood than inside the tissue cell, so oxygen constantly enters the cell by diffusing down its concentration gradient. Carbon dioxide (CO_2) is one of the "waste products" produced by the cells and it is in higher concentrations inside the cell than outside. CO_2 diffuses down its concentration gradient by the process of simple diffusion.

b. Facilitated diffusion is the second basic diffusion. It involves the movement of substances across the membrane that are either too large to pass through passively, or, are lipid-phobic (meaning they are insoluble to the lipid bilayer that forms the cell membrane). Facilitated diffusion uses proteins that construct passageways or pores through the membrane.

c. Osmosis is a special type of diffusion. Osmosis is the net movement of a liquid (usually water) across a selectively permeable membrane when there is a difference in concentration of solutes on either side of the membrane. The liquid is driven by the difference in solute concentrations on the two sides of the membrane. A selectively permeable membrane is one that allows unrestricted passage of water, but not solute molecules or ions, so only the water moves from one side to the other.

The different concentrations of the solute results in different concentrations of "free" water molecules on each side of the semi-permeable membrane. On the side of the membrane with higher free water concentration (i.e., a lower concentration of solute), more water molecules are available to bounce around and hit the pores in the membrane. More hitting of the membrane results in more molecules passing through the pores, which in turn results in net diffusion (movement) of free water from the compartment with high concentration of free water to that with low concentration of free water.

6. *Active transport* is an important process to cell membranes. Sometimes substances cannot passively navigate through the cell membrane. This may be due to size, charge, or because it cannot dissolve through the bi-lipid (fatty) layers of material that make up the cell walls. Active transport uses proteins called *transport systems* to move ions "uphill" against their concentration gradient. One very important transport system is the sodium-potassium (Na+ - K+), which helps keep the proper concentration in intracellular and extracellular. The concentration gradients of sodium and potassium are essential for our muscle and nerve cells to function properly.

7. *Vesicular transport* is a process whereby large particles and molecules can be transported across cell membranes inside of small sacs called vesicles. This process is called exocytosis. One way cells communicate with one another is by the release of chemicals called neurotransmitters. The little sacs attach to the inside of the membrane, fuse with it, and spill out the neurotransmitter so it can contact the adjacent cell. The sacs are reabsorbed by the cell, and recycle themselves to be used again.

8. *Membrane potential*, or voltage, is the amount of electrical potential energy across a membrane. In cells, the plasma membrane separates oppositely charged particles. If there are more positively than negatively charged particles gathered on one side (e.g., the outside of the cell membrane), the difference results in *membrane potential*, much like a battery. If

there becomes a way for the charged particles to flow, a current will arise. All cells are said to be polarized because they establish a membrane potential with the inside of the cell membrane being more negatively charged than the outside of the membrane. Cells use this membrane potential to communicate by opening channels that allow current to flow in or out of the cell. This will be discussed later in the section on the nervous system.

9. *Chemical signaling* is a primary way cells in the nervous system, and hormones in the endocrine system, communicate using neurotransmitters. Different cells respond in different ways to the same neurotransmitter or hormone. Some transmitters can increase the activity in one cell and decrease the activity in another. The end result depends upon the receiving target cell.

B. TISSUE

1. *Tissue*- Groups of similar cells that combine to perform a related function are called tissue. There are four types of primary tissue that form the body: epithelial, connective, muscle, and nervous.

2. *Epithelia* – Epithelia forms the boundaries between different environments for an organism. Epithelium provides protection, absorption, filtration, excretion, secretion, and sensory pathways.

3. *Connective Tissue* – Connective tissue "connects" body parts. Functions of connective tissue include support, storage, and protection of the body. Skin, blood, bone, ligaments, and cartilage are all examples of connective tissue.

4. *Muscle Tissue* – Muscle tissue has the unique ability to shorten or contract. The three types of muscle tissues are skeletal, cardiac, and smooth. Smooth muscle is found in the walls of hollow organs like our blood vessels and stomach. It is called smooth because it has no striations or stripes. Smooth muscles can contract (constrict) or dilate (enlarge) and can be used to adjust the movement of substances. Smooth muscles are highly involved in the adjustment of blood pressure.

C. ORGAN and ORGAN SYSTEMS

1. *Organ*- An organ is a discrete structure that performs a specific function composed of different tissue types.

2. *Organ system*- Organ systems are composed of organs working together for a common purpose. There are 11 organ systems in the human body. They are: cardiovascular, respiratory, nervous, integumentary, muscular, skeletal, digestive, endocrine, lymphatic, urinary, and reproductive systems.

3. In PDD, we are primarily concerned with the respiratory, cardiovascular, nervous, and integumentary systems. These systems contribute to the physiologic measurements we collect during PDD exams. A basic understanding of the physiologic properties underlying the measurements is essential for a sound foundational knowledge base.

a. Respiratory system- (air movement through the nasal cavity, pharynx, larynx, trachea, bronchus, lung). This system removes carbon dioxide and continually supplies blood with oxygen.

b. Cardiovascular system- (heart, blood vessels). The heart pumps our blood and our blood vessels transport it throughout the body to all cells. Blood carries oxygen, carbon dioxide, nutrients, waste and more throughout the body.

c. Nervous system- (brain, spinal cord, nerves). This is the control system of the body. It responds to internal and external changes, and activates muscles and glands.

d. Integumentary system- (skin, hair, nails). This system forms the external body covering and protects deeper tissues from injury. It houses cutaneous receptors, sweat glands, oil glands, and synthesizes (makes) vitamin D.

D. ORGANISM

1. *Organism*- The living organism (animal or plant) that represents the sum total of all organ systems working together.

E. HOMEOSTASIS & ALLOSTASIS

1. *Homeostasis*- Homeostasis is a term used within the scientific community to describe

the maintenance of the internal viability of organisms. The word homeostasis is derived from the Greek homeo, which means "same," while stasis means "stable;" thus, "remaining stable by staying the same." American physiologist Walter Cannon coined the term "homeostasis" to refer to the processes by which constancy of the fluid matrix is maintained. It is used to describe the maintenance of internal parameters within a relatively narrow window. Homeostasis is maintained through the "integrated" actions of numerous body systems. For example, sufficient nutrients must be present in the blood and the cardiovascular system must be functioning properly to provide those nutrients to all of the cells in the body. Waste products, like CO_2, must not be allowed to accumulate in the cells and must be continuously removed. The core temperature of a healthy person is maintained within a relatively narrow band in spite of the changing climates.

2. *Homeostatic mechanism of actions*- Homeostatic reflexes adjust to maintain a constant set point or level, much like a thermostat in a home. Homeostasis involves a *negative feedback loop* because it waits for something to happen before acting. A feedback loop involves a central control module which receives input regarding a condition, processes it, and then sends an output signal to maintain a set point. The central control center in a negative feedback system sends a correction to reverse the change from a set point to maintain a constant or fixed state. Positive control feedback systems enhance a stimulus that is already present. The classic feedback control model of homeostasis in psychophysiology describes compensatory responses to restore detected imbalances rather than enhancing what is already there and thus is considered negative. Homeostasis describes the regulation of the body to a balance, by single point tuning such as blood pressure, blood oxygen level, blood glucose, or blood pH. Baroreceptor reflex in blood pressure is the classic, prototypic homeostatic system whose inputs, outputs, and controls are well characterized. But blood pressure set points can, and do, change depending on the circumstances. Additionally, blood pressure can be changed through a variety of ways, not necessarily through one simple negative feedback system.

3. *Allostasis*- Allostasis is the process of achieving stability, or homeostasis, through physiologic or behavioral change. This term is derived from the Greek: *allo* meaning change, and *stasis* meaning "stable". That is, some changes are necessary to maintain stability or viability. These changes are presumed to be aimed at ensuring the overall viability of the organism. Allostasis encompasses both behavioral and physiologic processes directed towards maintaining adaptive states of the internal environment. One common example is the ever changing relative blood pressure in a person over the course of the day. Researchers have found mean arterial blood pressure will fluctuate to meet demands, or in an anticipation of a demand.

4. *Allostasis as a feed-forward regulatory process*- The allostatic model acknowledges the organism can use prior information to predict demand and adjust proactively before the demand is needed. Cannon recognized the body can respond in anticipation of a disturbance or agitation. For example, blood pressure typically rises slightly during the moments just before a person stands after having been sitting or relaxing. The anticipatory increase in blood pressure is adaptive, and serves to prevent lightheadedness by preventing the gravitational pull of blood to the feet by this positional change. The anticipatory increase in blood pressure is not in response to environmental or physiologic feedback, but can be thought of as a form of adaptive learning from past experiences with the action of standing. If a subject takes medication which blocks these blood pressure changes, the feed forward action can be blocked and the subject becomes dizzy.

F. ANATOMICAL NOMENCLATURE

1. The standard body position known as the *anatomical position*- A position in which the body is standing erect, feet slightly apart, palms facing forward with the thumbs pointing away from the body. The terms "right" and "left" are used with reference to the body being described and not the person observing that body.

2. *Sagittal plane*- A sagittal is a vertical plane that divides the body section being viewed into right and left. Mid-sagittal describes a sagittal

plane directly down the middle of the part viewed. Imagine splitting your body from the top of your head down through your crotch and then being able to look into either the left or right half of your body.

3. *Frontal* or *Coronal* plane- A frontal or coronal plane splits a body into anterior (front) and posterior (back) views. Imagine splitting your body from the top of your head through both shoulders, down to your feet and looking at the front half or back half of your body.

4. *Horizontal* or *Transverse* plane- A horizontal or transverse plane runs across and separates the body viewed into superior and inferior planes. These are sometimes referred to as cross-sectional planes. Imagine cutting straight across your stomach and being able to look at the upper or lower half of your body.

a. Superior (cranial)- A direction towards the head or upper end of the structure.

b. Inferior (caudal)- A direction away from the head end and towards the lower part of the structure.

c. Posterior (dorsal)- A direction towards the back or behind.

d. Anterior (ventral)- A direction towards the front or in front of something.

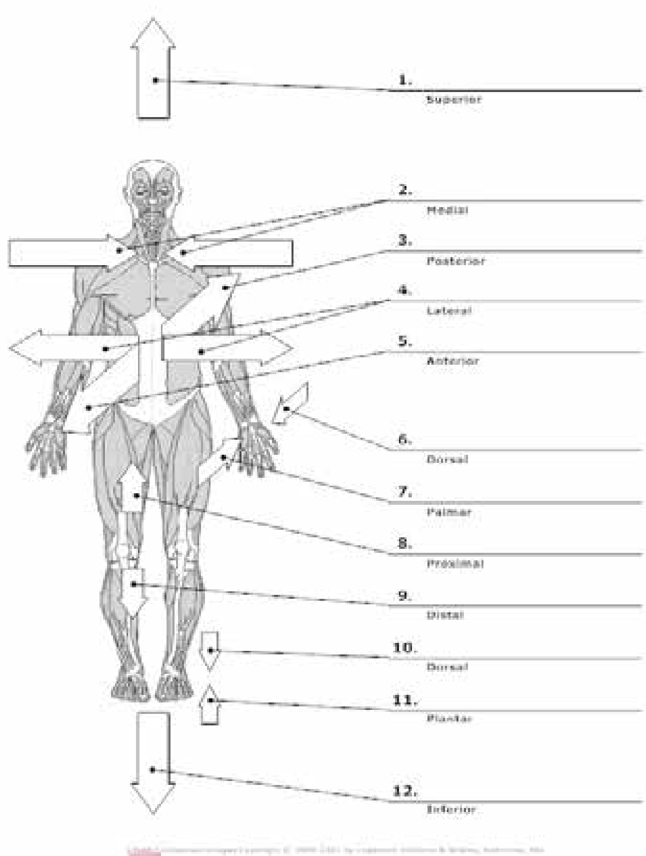
e. Medial- On the inner side or towards the center.

f. Lateral- On the outer side or away from the middle.

g. Proximal- Closer to the origin of the body part or the point of attachment.

h. Distal- Farther from the origin of the body part or point of attachment.

5. View orientation and anatomical planes below:



6. The *dorsal body cavity* and the two subdivisions- The dorsal body cavity encases the organs that comprise the central nervous system, the brain and the spinal cord.

7. The *ventral body cavity* and the two major subdivisions- The two major subdivisions of the ventral body cavity are the thoracic cavity and the abdominopelvic cavity.

8. The *thoracic cavity*- The thoracic cavity contains the pleural cavities which encase the lungs and the medial mediastinum. The mediastinum encloses the thoracic organs as well as the pericardial cavity, which surrounds the heart.

9. The *diaphragm*- The diaphragm is a dome shaped muscle that is extremely important for breathing. It separates the thoracic cavity from the inferior abdominopelvic cavity.

10. The *abdominopelvic cavity*- The abdominopelvic cavity contains two parts. The superior abdominal cavity contains the stomach, liver, spleen and intestines, as well as related organs.

11. The pelvic cavity lies inferior and contains some reproductive organs, the bladder, and the rectum.

IV. THE NERVOUS SYSTEM

A. The basic functions of the nervous system-

1. The nervous system monitors information about changes inside and outside of the body. It perceives or senses the information about change and forms decisions.

2. It causes muscles, glands, organs, and additional portions of the nervous system to respond (monitor, interpret and command). The nervous system is the master control/coordinator system in the body. Control/coordination is accomplished through:

   a. Monitoring changes inside and outside body sensory input

   b. Integrating sensory input and determining output

   c. Affecting responses (motor output)

3. The Nervous system partners with the endocrine system. Nervous system responses are quick and short lived, while endocrine responses are slower and longer lasting.

B. The structural and functional divisions of the nervous system-

1. The nervous system can be broadly separated into two primary divisions, the central nervous system (CNS) and the peripheral nervous system (PNS).

2. The CNS consists of the brain and spinal cord and can be considered the command center of the body. The CNS receives information, interprets the information, and then commands actions based on the interpretation. The PNS can be thought of as the system that carries messages to and from the CNS.

3. The *subdivisions of the PNS*-

   a. The PNS can be broken down into two subdivisions, one that carries information into the CNS (the sensory or afferent division) and one that carries the impulses away from the CNS (motor or efferent system).

      i. Sensory fibers from all over the body, such as the eyes, ears, nose, mouth, skin, joints, internal organs, and muscles send impulses to the CNS via the afferent or sensory division of the PNS.

   b. The motor or efferent division transmits commands from the CNS to all body parts, which are called effector organs, because nerve impulses affect them. Effector organs then respond to the commands of the CNS to perform functions the CNS has determined are necessary.

4. The *motor division of the PNS*-

a. The motor division can be thought of as having two major parts, the somatic nervous system and the autonomic nervous system (ANS).

b. The somatic nervous system is often called the voluntary nervous system because the nerve fibers control voluntary movement of skeletal muscles. For example, we use these nerves to command our fingers to type on a computer keyboard, or to pick up a book to study.

c. The ANS consists of nerves that regulate the activity of smooth muscles (like blood vessels, cardiac muscles, and glands). These activities are generally considered outside of our control and so this system is sometimes referred to as the involuntary nervous system. The ANS has two functional subdivisions, the sympathetic branch and the parasympathetic branch.

5. The historical view of the functional division of the ANS-

a. The purpose of *sympathetic* branch of the autonomic nervous system has been thought to be related to mobilizing the body systems for stressful or emergency situations; the fight or flight response. The *parasympathetic* branch has been proposed to support conservation of energy, nonemergency functions, "resting and digesting," etc.

i. These descriptions of function are often based on the seminal work of Walter Cannon in the first half of the 20th century. Cannon and others analyzed the function of the ANS in experimental animals and developed theories that drive our current conceptual approach to the ANS.

ii. Cannon coined the phrase "homeostasis," which he used to describe the coordinated physiological processes that maintain a steady state within the organism. Cannon believed the sympathetic nervous system was primarily responsible for maintaining homeostasis. Cannon also believed the sympathetic nervous system acted broadly (all at once and hence the name sympathetic) to restore imbalances in homeostasis. He believed there was a widespread and diffuse output aimed at returning the body's internal state to the narrow band needed to support life.

iii. In contrast, the parasympathetic branch functions were considered to be more discreet, having greater specificity. Cannon believed the effects of the sympathetic and parasympathetic nervous systems were generally opposite in the same organ and his ideas of an all or nothing sympathetic defense response and a specific restorative parasympathetic nervous system have influenced the conception of the functionality of the ANS.

6. A *current* view of the functional division of the ANS-

a. Wilfrid Janig, a modern physiologist, points to a number of inconsistencies in the historical functional separation of the divisions of the ANS. Janig makes a very convincing case for the idea that the separation between the sympathetic and parasympathetic branches of the ANS is anatomical as opposed to functional.

b. The parasympathetic outflows are cranial (from the head area) and sacral (from the lower spine area) while the sympathetic braches originate in the thoracolumbar (from the thoracic and lumbar parts of the spinal column).

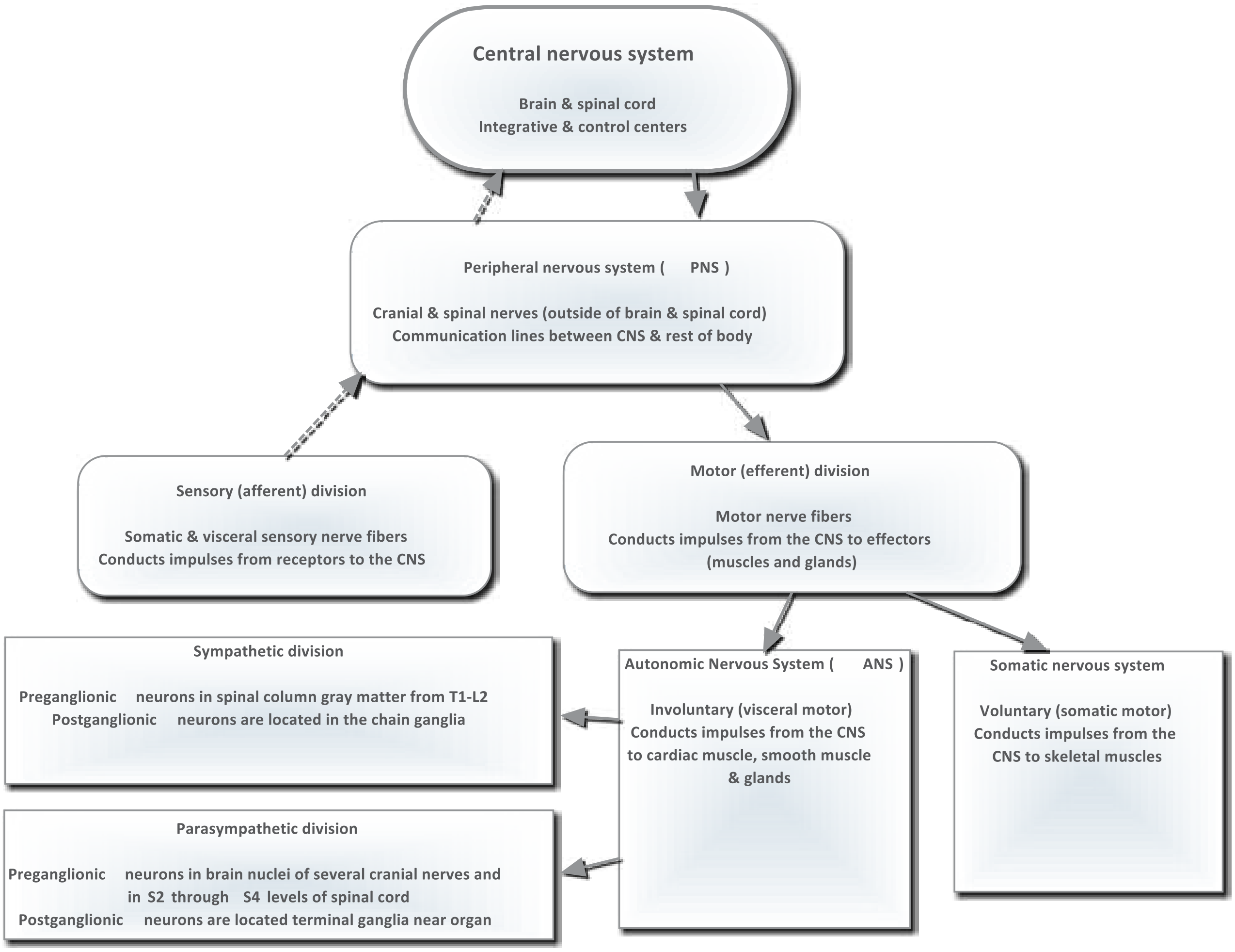
c. Some organs are "dually innervated" meaning they are innervated by both branches of the ANS and these innervation actions are antagonistic. The end result however is a coordinated, and conceivably larger or more "fine-tuned" response. Dual innervation allows the CNS to activate both the sympathetic and parasympathetic branches of the ANS, which can act synergistically to improve the response. Heart rate is an example. Parasympathetic activation may result in slowing the heart while sympathetic innervation will speed the heart. A coordinated (integrative) action comprised of a reduction of parasympathetic innervation and increase in sympathetic innervation can result in a potentially greater and faster response.

d. Janig points out that modern evidence more strongly supports a theory of integrative actions of the ANS, as opposed to a simple all or nothing action of one branch or the other.

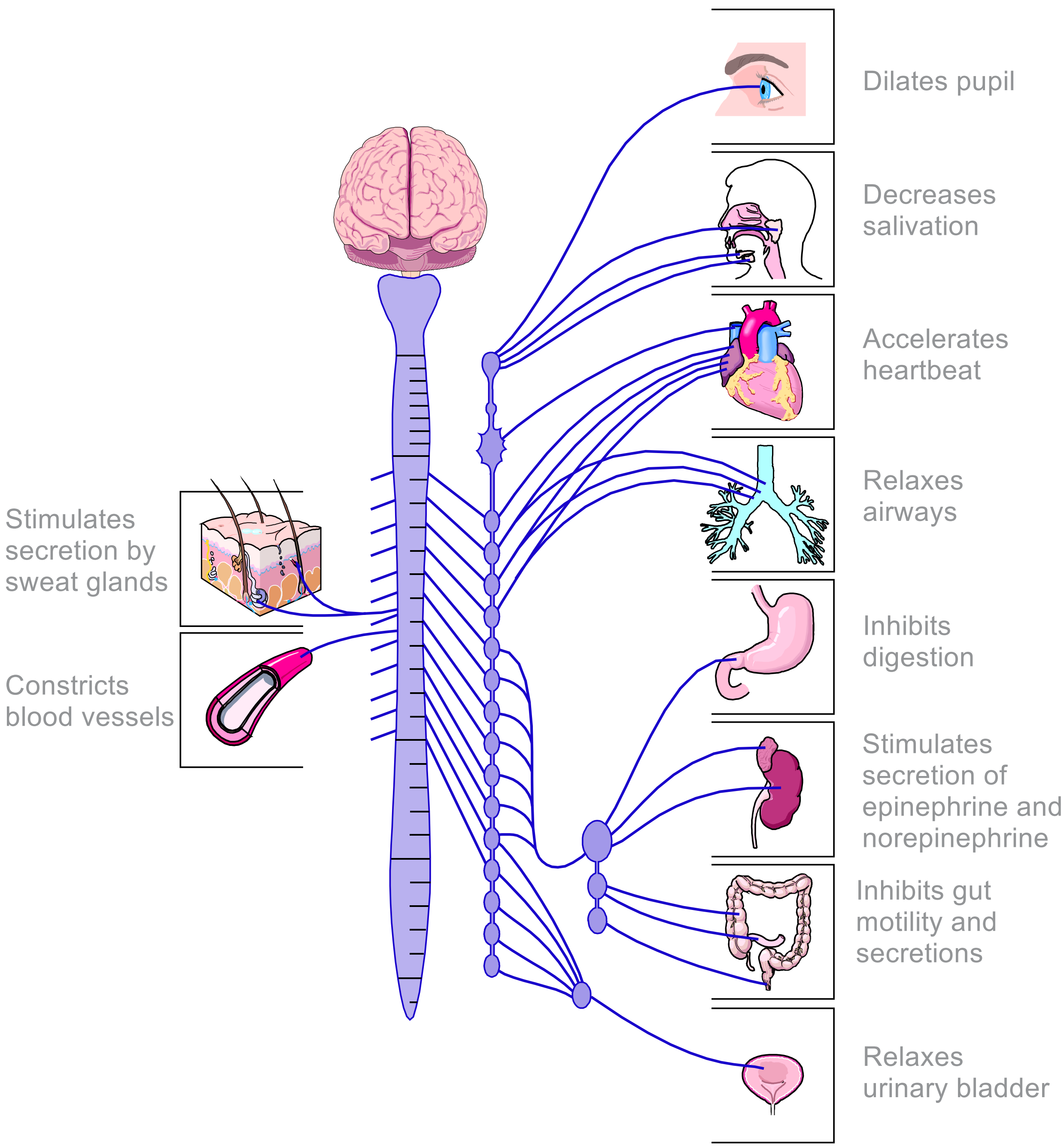
e. Berntson and Cacioppo have also questioned the historical doctrine of the two branches being functionally opposing systems. They point out that both branches can have similar effects on certain organs. They have shown that in some cases, one system activates at certain times, while the other system activates at other times. For example, at higher blood pressures, heart rate is controlled primarily by vagal (parasympathetic) activity, while at lower blood pressures, by sympathetic activity.

    i. Berntson and Cacioppo proposed a multidimensional model of autonomic regulation to account for conditions where the two systems are not reciprocal, but instead uncoupled (not acting at the same time) or coactive.

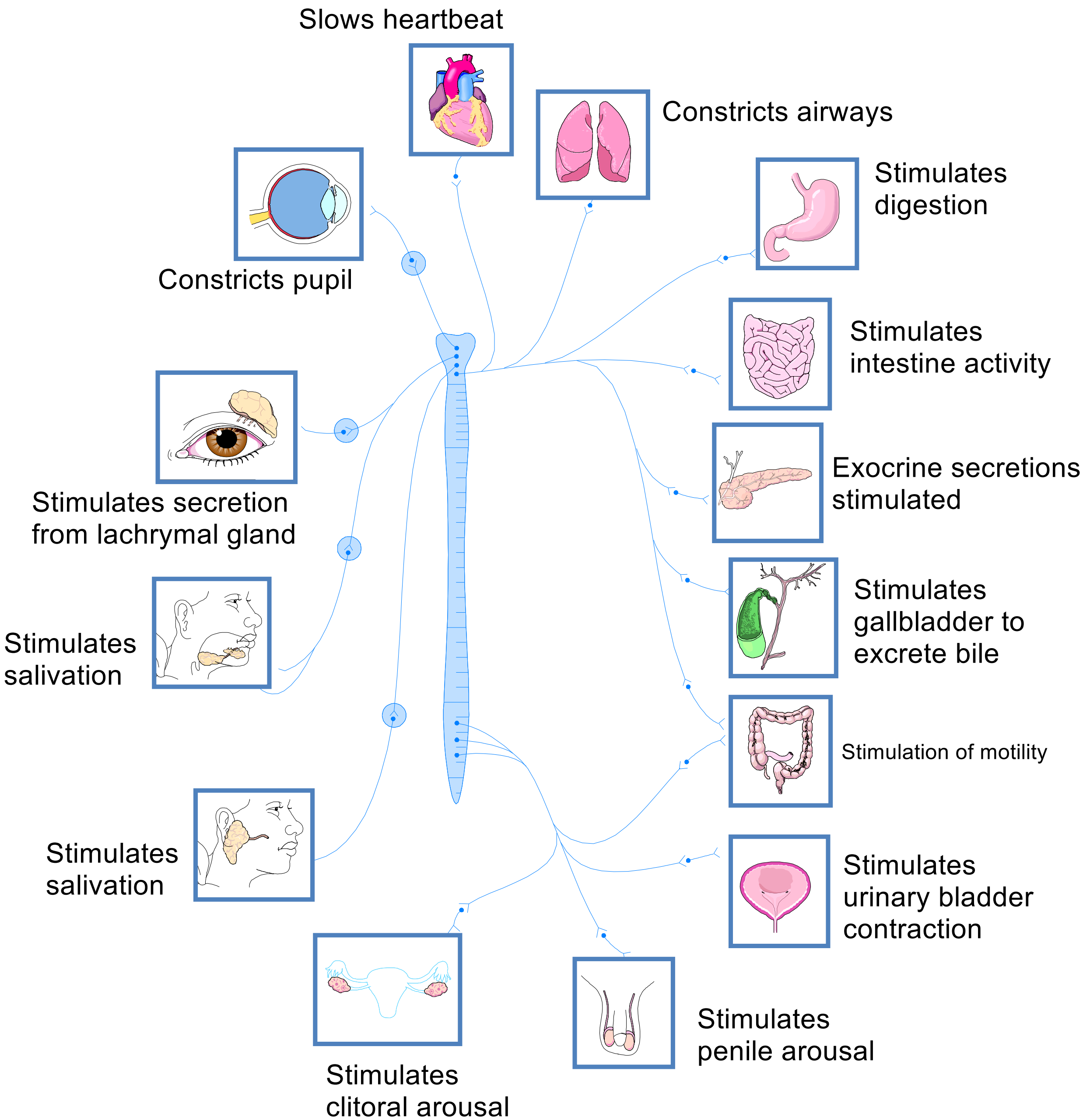
7. A general outline of the nervous system



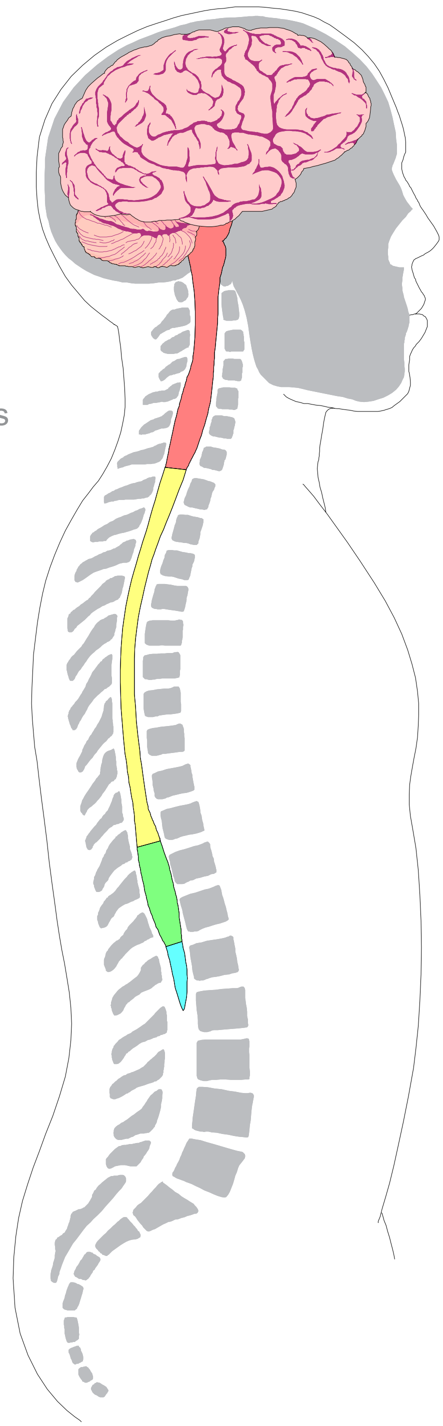
8. Organs innervated by the parasympathetic nervous system.



9. Organs innervated by the parasympathetic nervous system.



10. The location of the CNS-



Lateral view of figure showing central nervous system and its associated encasing skeletal structure.

11. The two principle types of nervous cells

    a. Nervous system tissue can be essentially divided into two main types of cells: neurons, the nerve cells that transmit signals, and neuroglia or supporting cells that surround, assist, and support the neurons.

    b. Some of the functions of neuroglia- Neuroglia or "glial" are support cells that make up about 85-90% of all brain cells. There are five main different types of neuroglia cells.

    c. In the CNS there are four different "glial" cells; astrocytes, microglia, ependymal, and oligodendrocytes.

    d. The glial cells of the PNS are Schwann cells. All glial have unique functions but one important purpose is to provide support for neurons by keeping them separate from one another. Also, some glial cells improve communication between cells by wrapping themselves around a portion of the neuron, thus insulating it. This results in faster conduction, much the same as wrapping a leaking garden hose with duct tape moves the water faster from one end of the hose to the other by reducing leakage.

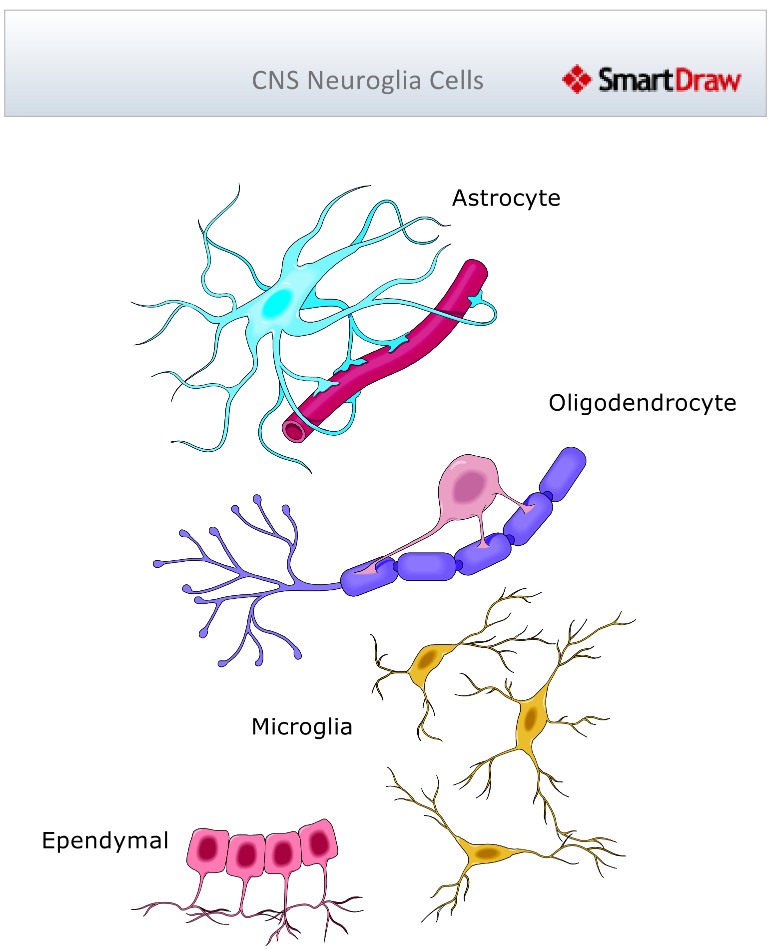


Image showing the four types of CNS neuroglia cells.

12. The basic parts of the neuron and a description of their purposes-

    a. Cell body- The cell body (or soma) contains the *nucleus* and other organelles involved in the biosynthetic activities to support cell life and function.

    b. Dendrites- The dendrites comprise the main input or receptive areas of the cell. They receive incoming information from numerous sources and convey this information on towards the cell body.

    c. Axons- Each neuron has a single axon that projects from a part of the neuron called the axon hillock. Once the axon leaves the axon hillock, it narrows to a relatively uniform diameter for the remainder of its length. Axons can range in length from non-existent to several feet. Axons are usually a single process for most of their length, though they can have branches or collaterals. At the end of axons, there are numerous (thousands) of terminal branches called axon terminals. Axons are the conducting component of the neuron during its communication with other neurons. Axons transmit nerve impulses away from the cell body to the axon terminals.

    d. Axon Terminals- Axon terminals are the knob-line bulbs at the terminal end of the axon. They contain the secretory component of the neuron. Upon reaching the terminals, an impulse causes chemicals (neurotransmitter) stored there to be released from the axon terminals. These neurotransmitters interact with adjacent cells and can cause those cells to become excited or inhibited.

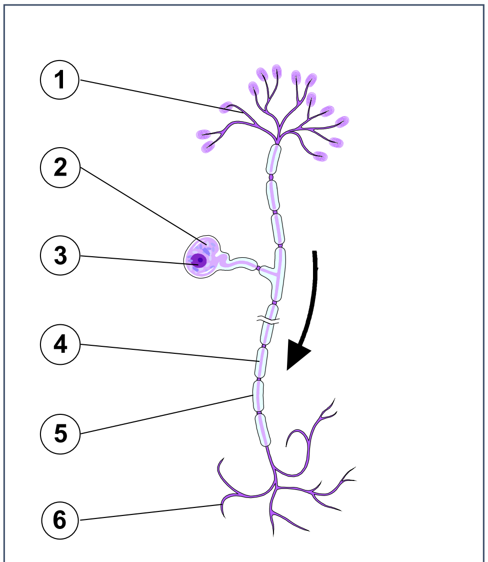
    e. Myelin- Myelin is a white colored, fatty tissue that covers some axons. Myelin protects the axon and insulates the axon from others. Myelinated fibers are able to conduct nerve impulses faster than those that are unmyelinated.

        i. Myelin in the PNS is composed of Schwann cells and myelin in the CNS is composed of oligodendrocytes. In the PNS, Schwann cells wrap around the axon but leave small gaps called Nodes of Ranvier. These gaps occur at regular intervals along the axon because of the size of the Schwann cell providing the myelination. The gaps contribute to the increased speed of conduction.

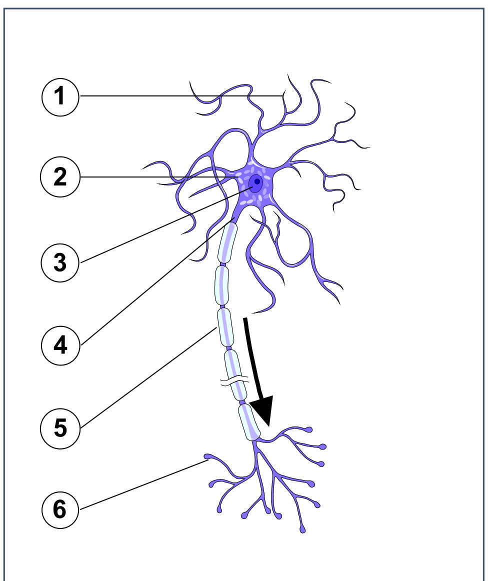
13. Major parts of the sensory or motor “model neuron”

NERVOUS SYSTEM

Types of Neurons



SENSORY NEURON



MOTOR NEURON

1. DENDRITE/RECEPTOR...
a slender, branched projection of a neuron, which conducts the electrical stimulation received from other cells to and from the cell body, or soma, of the neuron from which it projects.

2. CELL BODY (SOMA)...
the bulbous end of a neuron, containing the nucleus and is where most protein synthesis occurs.

3. NUCLEUS...
controls chemical reactions within the cytoplasm and stores information needed for cellular division.

4. AXON...
a long slender projection of a neuron which conducts electrical impulses away from the neuron's cell body.

5. MYELIN SHEATH...
an electrically insulating phospholipid layer that surrounds the axons of many neurons, composed of about 80% lipid fat and about 20% protein. It helps prevent the electrical current from leaving the axon and causing a short circuit in the brain.

6. AXON TERMINAL...
a specialized structure at the end of the axon that is used to release neurotransmitter and communicate with target neurons.

KMG Kurtsdale Medical Group

14. *Action potentials*- An action potential is the conductance of an electrical impulse along the length of an axon. The way most excitable neurons communicate is through action potentials.

    a. Recall our discussion about cells. The cell membrane has a potential (voltage difference) across it like a battery. This negative membrane potential (more negative inside the cell membrane compared to the outside of the cell membrane) results from the ion concentration. An action potential results in a brief (a couple of milliseconds or thousandths of a second) depolarization of the membrane and this continues along the axon until it reaches the terminals where the neurotransmitters are released.

    b. Action potentials are not graded; they keep the same strength from start to finish. If a neuron is sufficiently stimulated, it can transmit an action potential or nerve impulse. The propagation of the action potential comes from opening gates on the axon that are sensitive to voltage changes and that allow certain ions to pass through because of the decrease in voltage.

    c. Remember when we discussed sodium and potassium earlier and mentioned they were ions involved in neuronal communication. Changes in voltage open and close gates along the axon that allows ions to enter or leave. This lowers the voltage of the adjacent section of the axon and gates open and close there allowing more ion movement and this decreases the voltage of the next adjacent part of the axon. This "chain reaction" of depolarization and opening of gates allows a current to move down the axon to the axon terminals where it ultimately results in the release of the neurotransmitter from the terminal bulbs.

15. The two types of *gated membrane ion channels*- Plasma or cell membranes contain two basic types of gated ion channels: *chemically gated* and *voltage gated*. The term gated is used to describe the idea that there is a gate in the membrane that is open or closed.

    a. Chemically gated or neurotransmitter gated channels open or close when the appropriate neurotransmitter binds there. It can be visualized as a locked open or closed gate and only when the correct key (neurotransmitter) is used can the gate become unlocked and then change from opened to closed or visa-versa.

    b. Likewise, voltage gated ion channels open or close based on membrane potential.

        i. Each ion channel is generally selective for just which ion or ions it will allow to pass when open. Once opened, ions pass very quickly through the gate based on the electrical charge and chemical or concentration gradient. Ions will move away from an area of similar charge towards an area of opposite charge which is along their electrical potential. Ions will flow from areas of higher to lower concentration, which is called the concentration gradient. Together the electrical and concentration gradients are referred to electrochemical gradients and they are what effect ion movement across open ion channels. Ions will tend to balance out based on the electrochemical gradients.

16. The action of neurotransmitters- Neurotransmitters are chemicals that neurons release that stimulate or inhibit other neurons or effector cells.

    a. Neurons use neurotransmitters and their electrical signals to communicate with other cells (neurons, glands, and muscle). The cell releasing the neurotransmitter is called the presynaptic cell and the cell upon which it acts is called the postsynaptic neuron.

    b. The neurotransmitter is released into a small fluid filled gap between the neuron and the effector cell which is called the synaptic cleft. This functional space or point of close contact between two neurons or between a neuron and an effector cell is called the synapse. Some neurons release only one neurotransmitter at a synapse but most make and/or release more than one neurotransmitter. Some of the neurotransmitters we will discuss are;

        i. Acetylcholine (ACh)- This was the first neurotransmitter to be identified and probably the most studied. ACh is released at neuromuscular junctions, which are where neurons synapse with muscle cells for movement. In the ANS, ACh is the presynaptic neurotransmitter for all preganglionic neurons both sympathetic and parasympathetic. ACh is the postsynaptic neurotransmitter for all parasympathetic postganglionic fibers. It is also the neurotransmitter for postganglionic fibers for the eccrine sweat glands which are a member of the sympathetic nervous system and are responsible for the electrodermal activity measured in polygraph.

        ii. Norepinephrine (NE) - An excitatory or inhibitory neurotransmitter, depending on the receptor. NE is found in the CNS and the PNS. In the PNS, NE is the main postganglionic cells of the sympathetic nervous system.

        iii. GABA- This is the principle CNS inhibitory neurotransmitter in the brain. Alcohol and antianxiety drugs of the benzodiazepam class enhance GABAs effect. GABA manifests its inhibitory effect on cells by opening chloride channels and allowing extra negatively charged chloride to enter the cell. This extra negative charge hyperpolarizes the cell, bringing it further away from threshold and making it harder for the cell to fire and initiate an action potential. It tends to make the cells less active.

        iv. Glutamate- This is a principle excitatory CNS neurotransmitter in the brain. Glutamate is very important for learning and memory because of its action in the medial temporal lobe of the brain. A little goes a long way, however, as excess glutamate leads to excitotoxicity. This occurs when neurons literally excite themselves to death, and is common during strokes. Some medical treatments for stroke now include drugs to combat the excessive glutamate released during strokes to prevent cell death in the brain.

17. The *spinal cord*- This bundle of nervous tissue runs from the base of the brain stem to somewhere between the first to the third lumbar region and it provides the afferent (to the brain) and efferent (away from the brain) conductance pathways.

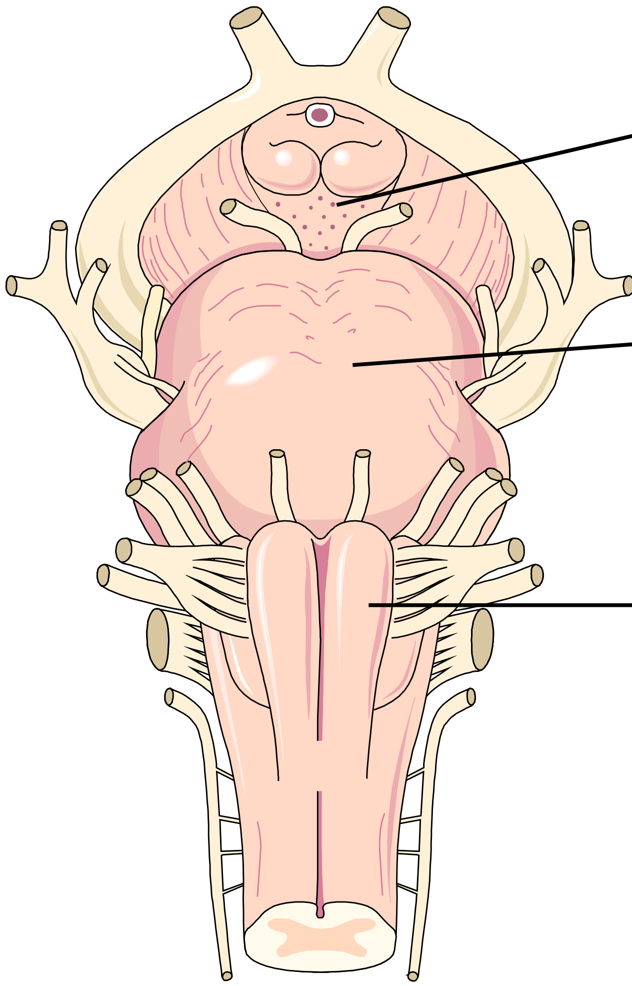
    a. The spinal cord is composed of *"white matter" and "gray matter."* The *gray matter* consists mostly of neuron cell bodies and neuroglia, and is shaped like a butterfly or the letter H. The gray matter can be divided into a dorsal half (in the back) which is generally the sensory input and a ventral half (in the front), which is generally the motor output.

    b. The sensory afferent fibers enter through the dorsal half where they connect to the sensory cell bodies in an area known as the dorsal root ganglion. The cell bodies for the motor output mostly lie in an area called the ventral horn, sending their fibers out through the ventral roots.

    c. White matter in the spinal cord is composed of nerve fibers, both myelinated and unmyelinated. There are fibers that ascend to the brain, carrying sensory input, and fibers that descend for motor output. Additionally, there are fibers that cross from one side of the spinal cord to the other called transverse or commissural fibers. The white matter is the communication transport section of the spinal cord, much like phone lines for telecommunication.

18. The *brain stem*- Working from an inferior to superior direction, the brain stem is comprised of the medulla oblongata, pons, and midbrain.

    a. The brain stem contains many important nuclear groups that result in the automatic behavior programs necessary for survival. The brainstem provides a pathway for fiber tracts running between the higher and lower brain center.



Anterior view of the brainstem. Midbrain (mesencephalon), pons, medulla oblongata and spinal cord are visible.

19. The functions provided by the *cerebellum*- The cerebellum is a large structure located dorsal to the pons and medulla. It processes inputs from the cortical areas responsible for motor actions, sensory receptors, and brain stem inputs. The cerebellum is concerned with coordination of movements.

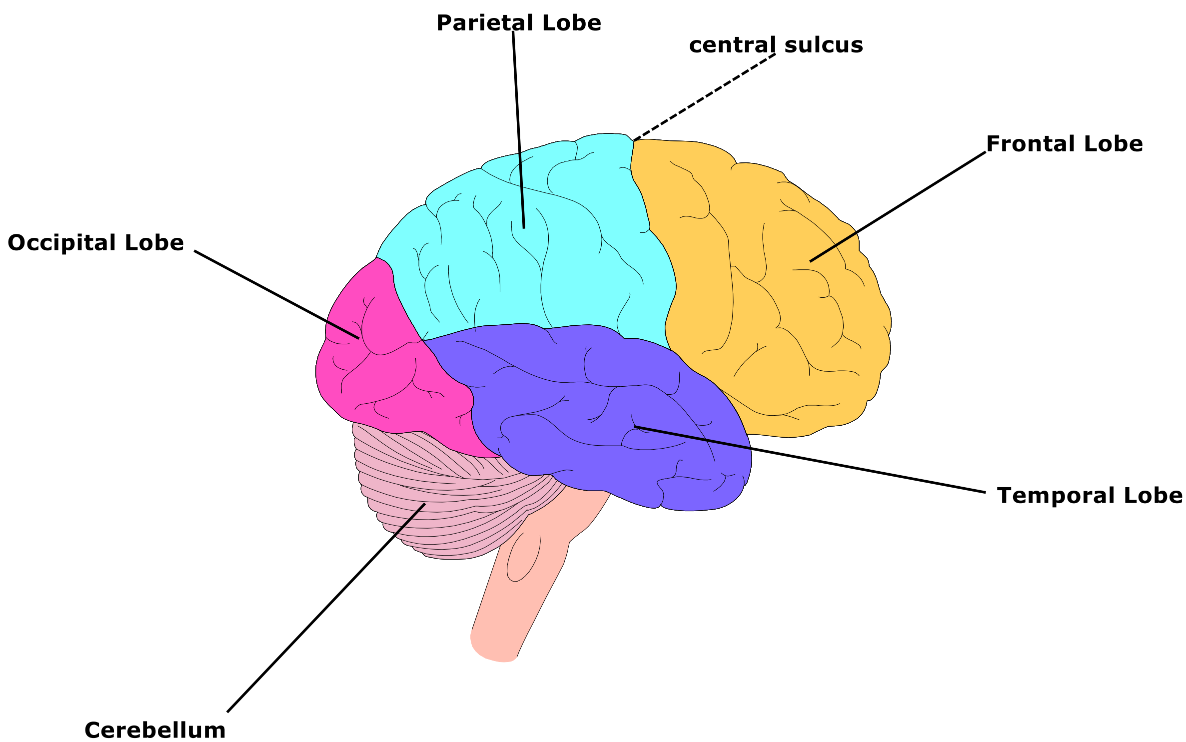
20. The *lobes* of the human brain- The hemispheres of the brain are subdivided into five major lobes on the basis of some of the major grooves.

    a. The *frontal lobe* consists of the area in front of what is known as the central sulcus and is the largest of all lobes. It contains important motor and language related areas in posterior part and many functions related to social behavior and higher mental activities towards the frontal part.

    b. The *parietal lobe* is located parallel to the central sulcus and contains much of the somatosensory related cortex.

    c. The *occipital lobe* is primarily related to visual functions and is located at the back of the brain.

    d. The *temporal lobe* contains many different regions including sensory areas for auditory and olfactory functions. This lobe contains two very important structures related to memory and emotion called the amygdala and the hippocampus.



Lateral view of the brain with the different lobes depicted with color.

21. The *diencephalon* and some functions - The diencephalon forms the central portion of the forebrain and consist of the thalamus, the hypothalamus, and the epithalamus.

    a. The thalamus is the largest part of the diencephalon and contains about fifty smaller nuclei which each have their own functional specialty. Thalamus is a Greek word meaning "inner room." It receives virtually all inputs to the brain including sensory, emotional, and motor related input. The only sensory input that bypasses the thalamus is the olfactory system. The *Thalamus* plays a key role in integrating and mediating motor activity, sensation, cortical arousal, learning, and memory. The thalamus is the means by which almost all information gets to the cortex to be processed.

    b. The hypothalamus is named for its position directly below the thalamus (hypo means lower). In spite of its small size, the *hypothalamus* is the grand conductor of homeostatic control of the body. Hypothalamus is part of the autonomic control center, the emotional response control center, and directs life supporting behaviors such as food and water intake and sleep. The hypothalamus controls the release of hormones from the endocrine system which also helps maintain homeostatic balance of the body.

    c. The *epithalamus* consists of the pineal gland, which helps regulate sleep, and the choroid plexus, which manufactures cerebrospinal fluid.

22. Psychophysiology concepts relating to the CNS. The concept of the *"limbic system"* from a historical, anatomical, and present day perspective-

    a. Around 1939, an American anatomist named James Papez proposed that the central parts of the brain including the hypothalamus, parts of thalamus, the cingulate gyrus, the hippocampus, and their interconnections, form a "harmonious mechanism" by which all emotion is generated, and from which emotional expressions result. Following Papez' proposal, the size and structures attributed to this "limbic system" have expanded to include a substantial portion of the brain. Modern neuroscientists seem to agree there is no scientific justification for a "limbic system." Many of the so-called limbic structures have multiple purposes that go beyond emotion. Indeed, some do contribute to generation and expression of emotion, but this poorly reasoned association does not justify a specific "system" of the brain dedicated solely to emotion.

V. EDA AND THE INTEGUMENTARY SYSTEM-

A. The Integumentary System

1. The skin consists of a complex set of organs called the integumentary system, which serves a protective function. We will limit our discussion of skin to predominately those aspects related to understanding the mechanisms of electrodermal activity (EDA).

    a. Skin protects the body from environmental threats such as temperature, chemical, mechanical, and infectious microorganisms.

    b. From a sensory standpoint, skin houses various receptors to provide afferent information related to touch, pain, and temperature.

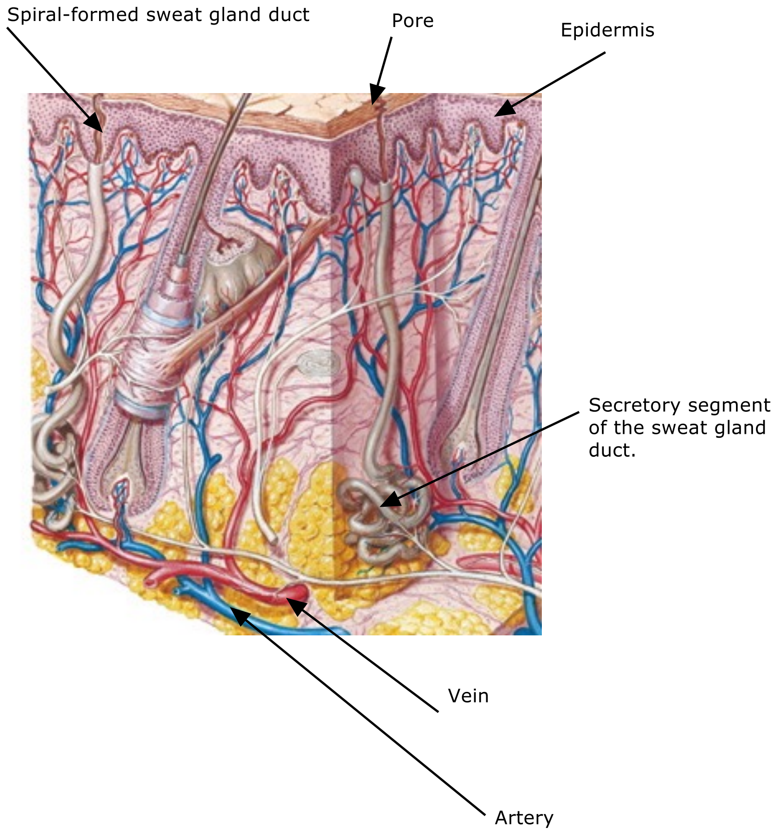
    c. Skin participates in

perspiration, which keeps the skin moist and allows the body to excrete fluids. Skin can be hairy or glabrous (hairless).

2. A typical cross section of the skin and some of the important features-

   a. Skin is composed of various characteristic layers, though all layers are not uniformly found in all skin. Skin essentially consists of two main layers; an outer layer called the epidermis, and a thicker lower layer, the dermis.

   b. The epidermis is composed of five layers with each layer becoming progressively hornier (tough and calloused). The outer layer of the epidermis is the stratum corneum. The epidermis, the layering most important to EDA, consists of regularly arranged cells that become drier as they move towards the stratum corneum. The glabrous skin found on the palms (palmer) and soles of the feet (plantar) has a thick epidermis and also a relatively thick stratum corneum. The stratum corneum has a very important role in producing the EDA we measure in polygraph.



3. The action of sweating of the *eccrine* sweat glands-

    a. Sweat glands secrete directly onto the skin surface. The greatest density of sweat glands is found on the forehead, the palms, and the soles.

    b. The sweat glands of the palm are considered eccrine sweat glands, which means the secretions do not contain something called cytoplasm.

    c. The sweat glands can be subdivided into the secretory portion and the duct. The secretory section is located deep within the skin and is comprised of an irregularly coiled duct. The duct extends from the secretory section to the sweat gland pore opening on the surface of the skin.

    d. Efferent fibers from the sympathetic nervous system innervate the eccrine sweat glands. These are referred to as sudorisecretory fibers. The sudorisecretory fibers use acetylcholine to innervate the secretory part of the sweat gland.

    e. The hypothalamus is generally regarded as the controlling center for all ANS function including sweat gland innervation. Hypothalamic sympathetic activity can be elicited by a number of brain structures, not the least of which includes the cerebral cortex. A variety of mental functions have been found to demonstrate the ability to activate the eccrine sweat glands and cause an EDA reaction.

4. A mechanism of sweating and how that contributes to EDA-

    a. Human sweat contains a certain amount of sodium and chloride ions. The precursor of sweat in humans has a considerably higher concentration of both. As sweat makes its way up through the duct, it loses some of the sodium and chloride ions. This is the theory behind NaCl reabsorption, that reabsorption may prevent excessive loss of NaCl. Sweat does not continuously flow out of the sweat duct but rather is ejected in pulses. Rhythmic contractions of the secretory and sweat duct portions are thought to be the source of pulses that are suspected of being the force that drives sweat up and out of the ducts.

5. *"Emotional sweating"*- Increased sweating as a result of mental activity, especially during emotional arousal, is referred to as "emotional sweating." Emotional sweating occurs primarily on the glabrous skin on the palmer and plantar surfaces of the body and is likely activated via the hypothalamus. EDA reactions during polygraph testing can be a result of emotional sweating.

6. Some of the putative CNS origins of EDA-

    a. EDA can be elicited by higher level CNS processes (cortical) but can also come from structures considered to be subcortical. The hypothalamus seems to be one of the primary initiators of EDA reactions from an emotional standpoint. A part of the brain called the basil ganglia may contribute to EDA responses in preparation for motor actions.

7. Some of the suggested biological roles of EDA-

    a. Sweating may be a biologically adaptive function that serves a number of purposes. Hydration provides optimal friction and tactile sensitivity. One is able to feel and grip better when their hands are slightly moist. Footing is arguably better when the feet are slightly moist or tacky. Skin is also less likely to sustain injury when slightly moist.

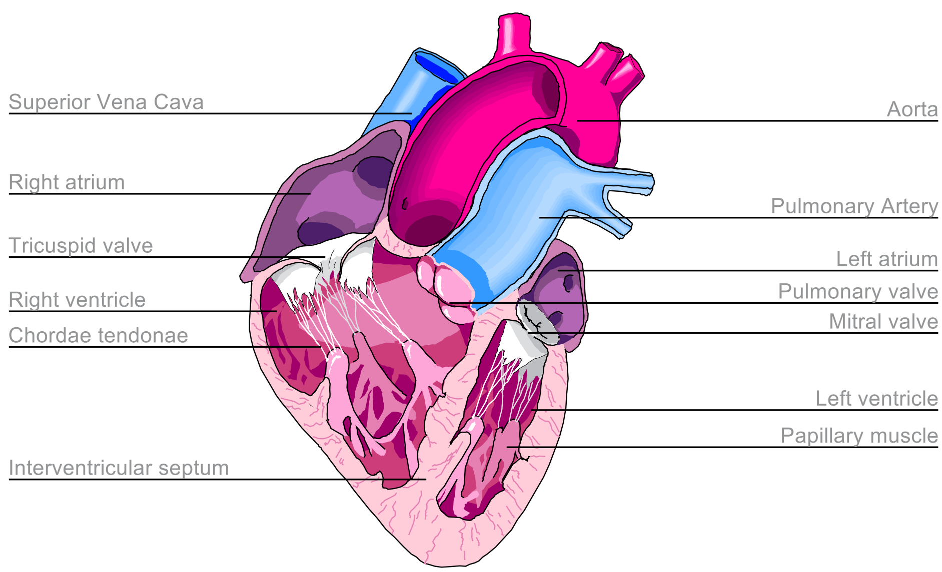
b. Skin is more resistant to abrasion and cutting when moist then when dry.

VI. THE CARDIOVASCULAR SYSTEM

A. The chambers of the heart-

1. The heart has four chambers, two ventricles and two atria. The ventricles are the discharge chambers and discharge blood to the body (left ventricle) or to the lungs (right ventricle). The atria are the receiving chambers for blood returning from the body (right atria) or the lungs (left atria).

Parts of the Internal Heart



B. The major heart valves-

1. There are two atrio-ventricular (AV) valves, one on each side of the heart, which separate the atria from the ventricle, preventing back flow.

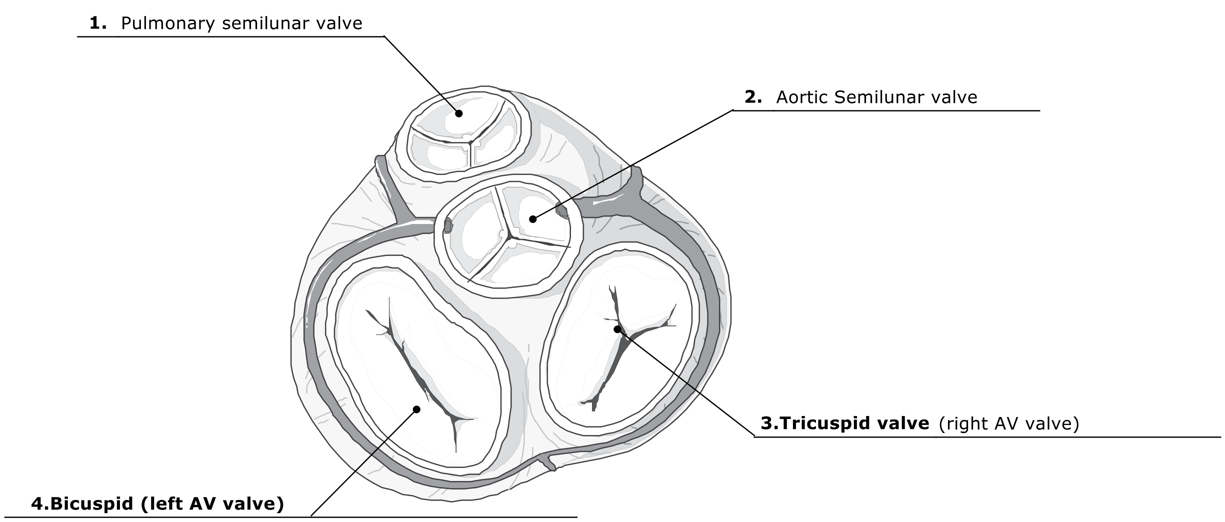
2. The right AV valve is called the tricuspid valve because it has three flexible cusps or flaps. The left AV valve is called the bicuspid valve because it has only two cusps or flaps.

a) The bicuspid valve is sometimes referred to as the mitral valve as it is said to resemble a miter, the hat worn by a bishop.

3. There are two semilunar valves (SL), one at the discharge site of each ventricle. The SL valves guard against backflow by flattening out and slamming shut when pressure is higher on the discharge side.

a) SL valves are so named because of their three crescent moon shaped cusps.

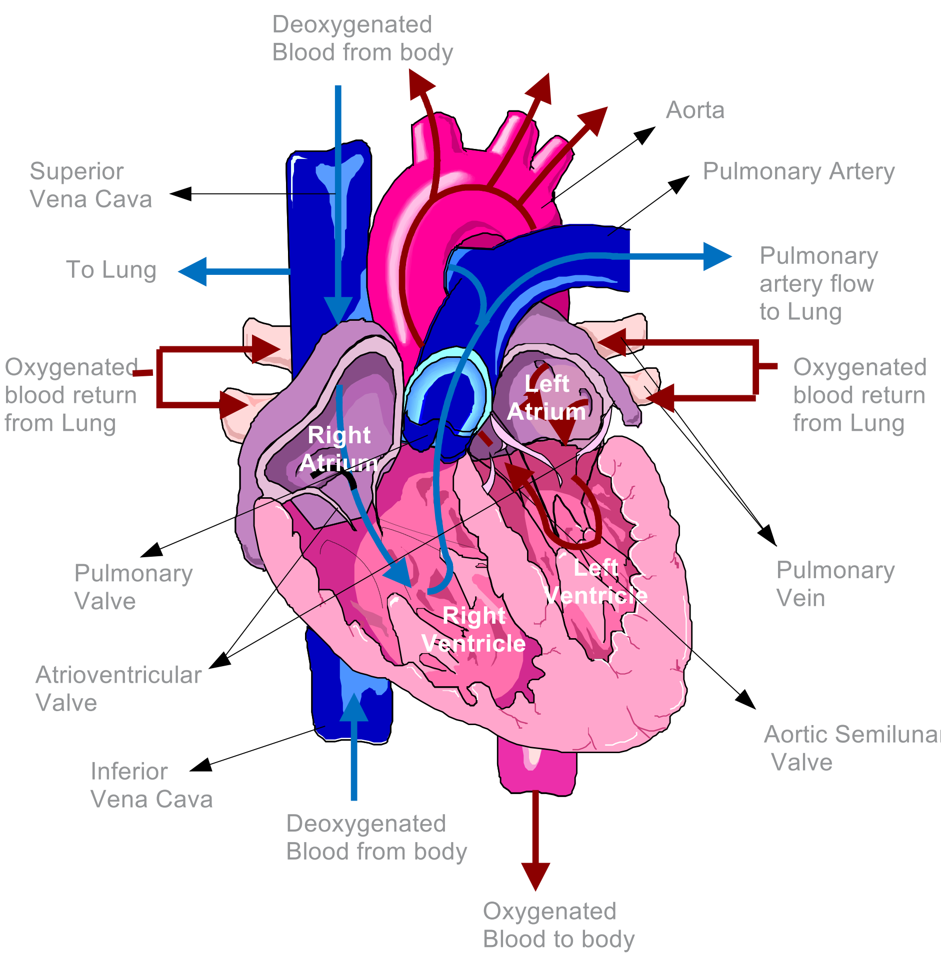
Heart Valves



C. The pathway of blood flow through the heart-

1. The right side of the heart is the *pulmonary circuit* which directs carbon dioxide rich blood to the lungs. Returning blood enters and fills the right atria. The right atria contracts, forcing blood through the tricuspid valve and into the right ventricle. The right ventricle compresses, sending blood out the pulmonary semilunar valve to the lungs via the pulmonary arteries. It is here that carbon dioxide is exchanged for oxygen.

2. The left side of the heart is the *systemic circuit* pump. It is responsible for transportation of blood through the cardiovascular system. The freshly oxygenated blood is returned to the left atria of the heart via the pulmonary veins. The left atria contracts and directs blood through the bicuspid or mitral valve to the left ventricle, which pumps blood out of the aortic semilunar valve into the aorta.



D. The purpose of the *cardiovascular system*-

1. The cardiovascular system is a completely closed structure consisting of the heart muscle, arteries, capillaries, and veins. A primary purpose of the cardiovascular system is to transport nutrients and oxygen to body tissues and remove metabolic wastes and carbon dioxide from the body tissues.

E. Blood pressure and how is it measured-

1. Blood pressure is a measurement of force per unit of area exerted on a blood vessel wall. It is typically expressed in units of millimeters of mercury, written "mmHg." Blood pressure is usually expressed medically in terms of systolic pressure over diastolic pressure.

2. In polygraph testing, the cardiograph waveform depicts changes in relative blood pressure throughout the examination. For the sake of our paper, when we discuss blood pressure, we refer to systemic blood pressure as measured at the monitoring site, unless otherwise stated.

F. Peripheral resistance-

1. Blood flow occurs within the body's closed circulatory system and is normally expressed in milliliters per minute, written as "ml/min." Peripheral resistance is a term used to describe the overall restriction to blood flow within the blood vessels and it is a function of blood viscosity, vessel length, and vessel diameter. Thicker blood, longer vessels, or smaller diameter vessels each increase resistance to flow.

G. How cardiac output and peripheral resistance effect blood pressure-

1. Blood pressure is determined by cardiac output and peripheral resistance. Cardiac output is the amount of blood the heart is pumping for a given time period. Cardiac output is a function of stroke volume times the number of beats per minute.

2. Stroke volume is how much the heart pumps (ml/beat) and is a function of how hard the heart beats (contractile force) and how much blood is available to pump (end diastolic volume, or EDV**).**

3. EDV is the volume of blood in a ventricle at the end of filling. The greater the EDV, the greater the distention (stretching) of the ventricle. An increase in EDV increases the preload on the heart. It increases the amount of blood ejected from the ventricle, during systole, through the Frank-Starling mechanism. EDV is generally controlled by venous return or the blood returned to the venae cavae prior to being delivered to the right atrium.

4. Additionally, a physiologist named Bainbridge observed that right atrial distention produced an increase in heart rate. Bainbridge found the reflex arc responsible for this tachycardia was mediated through an increase in sympathetic effect and a decrease in parasympathetic effect.

5. There are two primary factors that increase venous return: the respiratory pump and the muscular pump. The respiratory pump describes pressure changes in the venae cavae that result from breathing. As we inhale, chest pressure decreases, negative pressure is generated, and blood is "sucked" back towards the heart. The greater the depth or length of inhalation, the

greater the amount of negative pressure influence created for venous return. The muscular pump describes the manner in which the skeletal muscle contraction presses against veins to force blood back towards the heart.

6. Peripheral resistance affects blood pressure by increasing or decreasing the <u>pressure</u> against which the heart pumps. The greater the overall vasoconstriction, the greater the pressure. As vasodilation occurs, blood pressure decreases.

7. In summary, there are several factors affecting blood pressure. Cardiac output increases by accelerating the heart rate, contractile force, or end diastolic volume. Altering the diameter of the blood vessel increases or decreases peripheral resistance to flow. Any combination of these factors can result in a rise in blood pressure.

H. The *electrical conduction system* through the heart-

1. The heart is able to contract (beat) without influence from outside nervous systems. There is, however, a great deal of neural input to the heart, which coordinates the heart's activities with that of other systems that support life.

2. Electrical conduction begins at the sinoatrial (SA) node in the right atria, which intrinsically generates impulses at the rate of about 75 times per minute. This small mass is known as the "pacemaker," as it sets the cadence that is known as sinus rhythm.

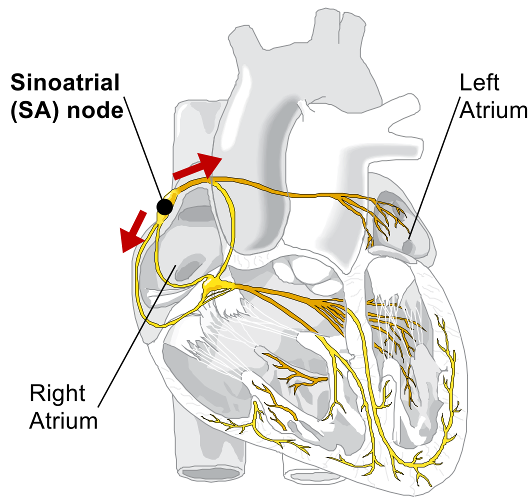
3. From the SA node, the signal is sent through intermodal fibers into both atrial muscle walls, and then into the atrioventricular node located near the tricuspid valve. This node holds the signal for a moment, allowing the atria to fully contract before it passes the signal on.

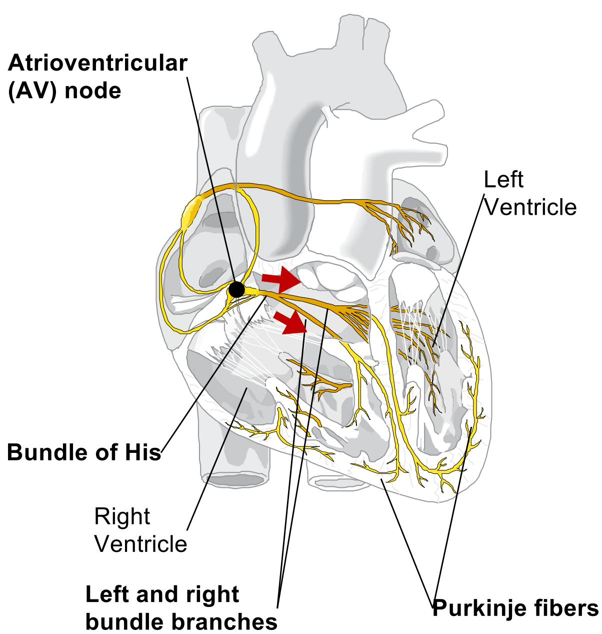
4. From the AV node, the signal progresses to the atrioventricular (AV) bundle, which is located in the upper portion of the septum that separates the ventricles. This is sometimes called the bundle of HIS, named after its discoverer.

5. From the bundle of HIS, the signal splits into the right and left bundle branches as they progress down the septum. The right and left bundle branches send the impulses to the Purkinje fibers that are located in the ventricles. The left ventricle has a thicker muscular wall due to greater pressure requirements needed to pump blood through the increased resistance of the entire body than the right ventricle has pumping just to the lungs.

Electrical Conduction System of the Heart

(cardiac conduction system)





The heart's electrical system controls all the events that occur when your heart pumps blood. Each beat of your heart begins with an electrical signal from the sinoatrial node, called SA node.

The signal is generated as the two vena cavae fill your heart's right atrium with blood from other parts of your body. The signal spreads across the cells of your heart's right and left atria. This signal causes the atria to contract. This action pushes blood through the open valves from the atria into both ventricles.

The signal arrives at the AV node near the ventricles, where it slows for an instant to allow your heart's right and left ventricles to fill with blood. The signal is released and moves to the His bundle located in the walls of your heart's ventricles.

The signal is released and moves next to the bundle of His located in your heart's ventricles. From the bundle of His, the signal fibers divide into left and right bundle branches which run through your heart's septum.

The signal leaves the left and right bundle branches through the Purkinje fibers that connect directly to the cells in the walls of your heart's left and right ventricles.
As the signal spreads across the cells of your heart's ventricle walls, both ventricles contract, but not at exactly the same moment. The left ventricle contracts an instant before the right ventricle. This pushes blood through the pulmonary valve (for the right ventricle) to your lungs, and through the aortic valve (for the left ventricle) to the rest of your body.

As the signal passes, the walls of the ventricles relax and await the next signal.

Source: National Heart Lung and Blood Institute, National Institutes of Health. nhlbi.nih.gov

VII. THE RESPIRATORY SYSTEM

A. The function of *respiration-*

1. The primary function of the respiratory system is to supply the cells of the body with oxygen, and to vacate the body of carbon dioxide.

2. Pulmonary ventilation (breathing) describes the collective actions that move air into and out of the lungs.

3. External respiration describes the exchange of oxygen for carbon dioxide in the alveoli, the microscopic air sacs in the lungs.

4. Internal respiration describes the exchange of oxygen for carbon dioxide between blood and tissues.

5. Cellular respiration describes the cellular metabolic reactions that consume oxygen to produce energy molecules and carbon dioxide.

Respiratory System

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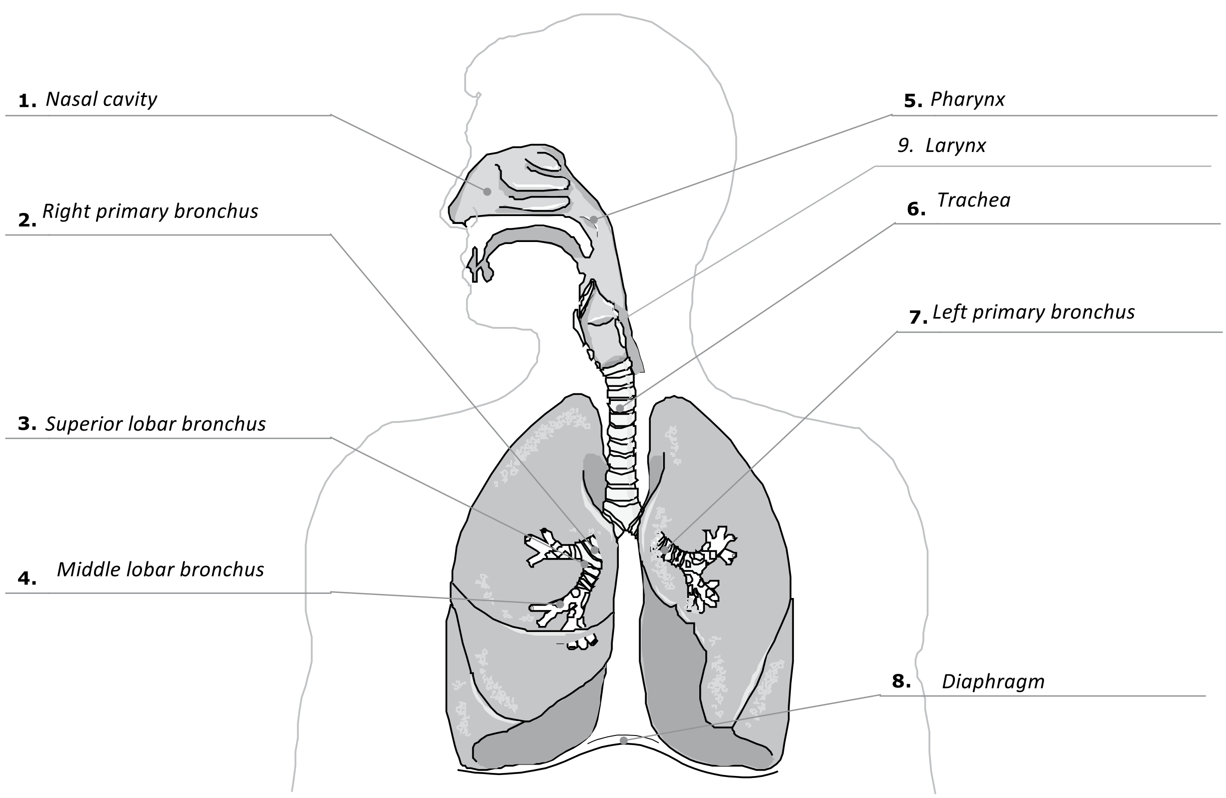


B. Describe *breathing*-

1. Breathing involves moving air through the airway (dead air space) composed of the nasal cavity, pharynx, larynx, trachea, bronchi bronchial tree, then into the lungs.

2. The airway, through which the air travels, warms, humidifies, and cleans the air before directing it to the lungs.

3. The nasal passageway contains olfactory receptors which are unusual in that their input bypasses the thalamus and is sent directly to cortical and limbic system areas of the brain that stimulate memory.

4. The pharynx connects the nasal cavity and mouth to the larynx.

5. The larynx is composed primarily of cartilage, vocal cords, and other connective tissue, and connects the pharynx to the trachea.

6. The trachea, composed of C shaped cartilaginous rings, is a flexible tube that connects the larynx to the bronchi.

7. The bronchi enter the lungs and branch out to form secondary and tertiary bronchi leading to terminal bronchioles and finally into alveoli air sacs.

8. Pulmonary capillaries surround the alveoli sacs providing the pathway for blood flow to and away from them. It is at this junction the exchange of oxygen for carbon dioxide takes place.

C. The mechanics of breathing-

1. The mechanics of breathing generates a pressure differential between the inside and outside of the lungs, causing air to move one direction or the other.

2. Air, as with fluids, moves from areas of higher pressure to lower pressure regions. Just before inspiration, the differential pressure between the inside and outside of the lungs (intrapulmonary pressure) is zero. At zero, there is no air movement.

3. The act of breathing causes the pressure inside of the lungs to be lower than that outside and thus air flows inward (Boyle's Law), similar to the concept of drawing a fluid up into a syringe. This negative intrapulmonary pressure is made possible by the expansion of the lungs resulting from the ventilation dynamics of the diaphragm and intercostal muscles.

4. The muscles of normal, quiet inspiration (eupnea) include the diaphragm and the external intercostals. The diaphragm is a large, domed shaped muscle that separates the abdominal cavity from the thoracic cavity. The diaphragm is attached to the sternum and is the muscle most responsible for eupneic breathing. During normal quiet breathing the diaphragm contracts, causing it to descend about one half inch into the abdominal cavity. This results in stretching the thoracic cavity downward, increasing its volume.

5. Simultaneously, contraction of the external intercostal muscles lift the rib cage and pull the sternum outward, like a handle on a bucket. The external intercostal muscles are innervated by nerves leaving the first through the eleventh thoracic segments of the spinal column.

6. The lungs are passive. They have no capacity to expand or contract on their own and are subject to external forces, much like a sponge absorbs and releases water. Each lung is encased by one continuous serous tissue folded over itself called the pleural membrane. The parietal pleura portion is attached to the outer wall of the thoracic cavity with the visceral pleura bonding directly to the lungs. This creates a small space between the two pleurae which is called the interpleural space, or pleural cavity. Both pleurae secrete a fluid into the cavity which reduces friction between them. Just prior to inspiration, the pressure within the pleural cavity is about 4mmHg below atmospheric pressure. This negative pressure between the pleura membranes keeps the lungs sucked to the chest wall thus preventing them from collapsing inward. As the thoracic cavity expands, the lungs are pulled into an expanded mode, reducing the pressure in the alveoli (intrapulmonic pressure), resulting in air being pulled into the lungs.

7. The combination of the contractions of the diaphragmatic and intercostal muscles results in an action that increases the thoracic cavity by approximately 500 milliliters. This increase causes a drop of intrapulmonary pressure of about 1-2 mmHg and air rushes into the lungs.

8. Expiration during eupneic breathing is passive and is accomplished through the elastic nature of the lungs and relaxation of the inspiratory muscles. As the muscles relax and the lungs recoil, the volume of the thoracic cavity decreases and there is no longer a difference in pressure between the inside and outside of the lungs. Additionally, alveoli ducts and bronchioles have elastic fibers that recoil inward, expelling air. Finally, inward pull resulting from the surface tension of water vapor in the alveoli also contributes to lung volume decrease. The intrapulmonary pressure rises to about 1 mmHg above atmospheric pressure to force air out of the lungs.

D. The regulatory control of breathing-

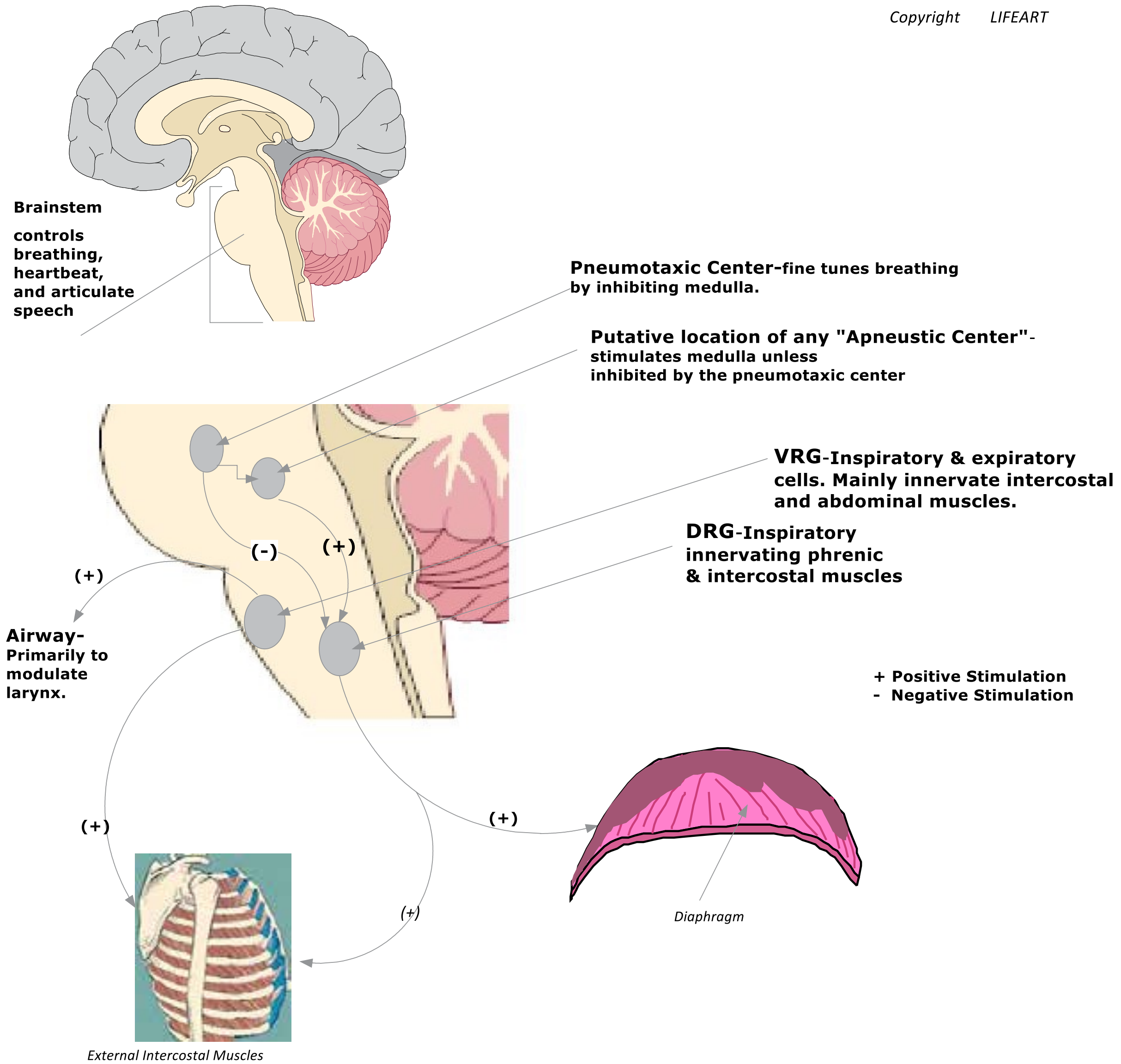
1. Vegetative regulations of visceral body organs, including breathing dynamics, are controlled in part by nuclei and centers in the brain stem.

2. The respiratory rhythmicity centers are located in the lower brain stem, medulla oblongata, with refining regulatory centers in the pons.

3. In the medulla, the rhythmic respiratory center is comprised of two distinct respiratory areas known as the dorsal respiratory group (DRG) and the ventral respiratory group (VRG). The DRG neurons are the primary innervators of the phrenic nerve and thus the diaphragm muscle.

4. The VRG, a column of individual nuclei stacked upon one another, contains mostly expiratory neurons and receives drive input from the DRG. The VRG is also involved in innervating the larynx and pharynx via vagal motoneurons, which assists in maintaining airway patency. During inhalation, the VRG innervates the external intercostal muscles and has some connection to the phrenic nerve. Expiratory neurons, originating in the VRG, project to the internal intercostal muscles and abdominal muscles. These muscles, however, function mostly during intense and rapid exhalation, such as during exercise when passive exhalation would take too long.

5. Modulatory centers such as the pontine respiratory group (formerly called the pneumotaxic) and a putative "apneustic center," located in upper area of the pons, appear to be associated with phase-related activity. If nuclei exist that form an apneustic center it seems they may function as a "cut off switch," terminating inspiration. While this center has not been positively identified, it is presumed to be located at about the same level as the pontine respiratory group. Investigators who have experimentally transected the brain stem at this level have been able to produce apneusis (inspiratory spasms or cramps), but only if they also serve the vagus nerve. This suggests any "apneustic center" that exists receives input via the vagus nerves in order to prevent apneusis. While not well defined, the function of the respiratory related neurons in the pons seems to be to "fine tune" the action of eupneic respiration, helping to provide a smooth transition between inspiration and expiration. The ponto-medullary respiratory rhythmicity center, however, can be influenced by the emotional limbic system centers as well as the cognitive cerebral cortical areas.



General locations of central nervous system nuclei responsible for rhythmic regulatory control of breathing. DRG and VRG generalized location and effects on the diaphragm and intercostal muscles during eupneic breathing. Copyright LIFEART and reprinted with permission of LIFEART and SmartDraw, Inc.

E. The major reflexes that affect the breathing cycle-

1. A number of reflexive (automatic) actions can have an effect of the depth and rate of breathing.

2. Stretch receptors within the airways have the potential to influence the respiratory cycle. One such stretch receptor reflex, known as the Hering-Breuer inflation reflex, can result in decreased respiration drive. As the lungs expand through pulmonary inflation, it activates the sensors of these stretch receptors, which project via the vagus nerve to the DRG and the pontine respiratory group. The end result is bronchial dilation and increased expiration time, resulting in a decrease in respiration rate. This seems to be a protective reflex, which has developed to prevent the lungs from over-expanding.

3. Irritant receptors are located throughout the airway and can be activated by certain chemicals, gasses, smoke, dust, and very cold air. Activation by these vectors is transmitted primarily by the vagus nerve and can result in bronchial constriction, which functions to protect the airways from the noxious agent.

4. Chemoreceptors are located centrally in the medulla and peripherally in the great vessels of the neck. The central chemoreceptors are exquisitely sensitive to carbon dioxide, which is the most tightly controlled chemical factor. Carbon dioxide diffuses into the cerebral spinal fluid and forms carbonic acid, which liberates hydrogen ions, resulting in a drop in the pH of the cerebral spinal fluid. It is these hydrogen ions that actually excite the central chemoreceptors in the medulla, which in turn stimulates ventilation. The peripheral chemoreceptors, however, are more responsive to oxygen levels in the blood. Chemoreceptors sensitive to oxygen are located in the aortic and the carotid bodies. If the circulating level of oxygen drops substantially, these act to stimulate respiration rate and depth. Under normal conditions, oxygen levels in the blood affects breathing only indirectly by enhancing the sensitivity of the central carbon dioxide sensors.

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