Wilderness Medicine Training Center

WMTC

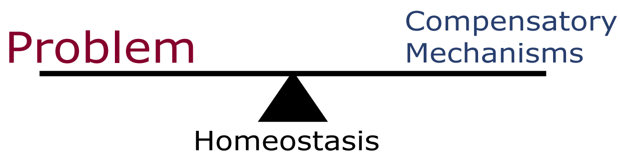
International

General Concepts in Human Anatomy & Physiology

General Concepts in Human Anatomy & Physiology

Introduction

Human anatomy is the study of the physical parts of the human body and their relationship to each other; human physiology is the study of their functions. The collective goal for each of the body's systems is to maintain a balance between the body and its environment. Biologically, this balancing act is known as homeostasis. Built into each complex body system are numerous compensating mechanisms that work to correct problems before they become critical. If any problem overwhelms the body's compensatory mechanisms, outside intervention is necessary to tilt the balance in favor of healing.



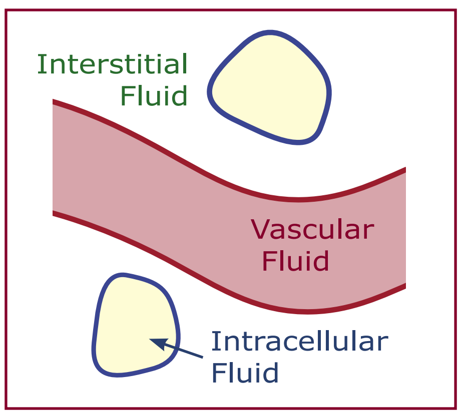
Levels of Organization

The human body contains many parts, both small and large; all are interdependent, and damage to one part affects the entire system. At the chemical level, atoms make up molecules. The shape of each molecule determines its function. Molecules can be organic or inorganic and combine to form the individual parts of a cell (organelles). As such, a change in body chemistry may alter cell function. Cells are the smallest living components of the human body; they behave like tiny organisms and act independently to maintain homeostasis with the body's internal environment. Similar cells working together form tissue. Tissue function, like cellular function, is specialized. Multiple types of tissue work together to form organs, while multiple organs work together to form organ systems. Organ systems work together to make up the body. Each level of organization has its own specific, and somewhat restricted, set of functions.

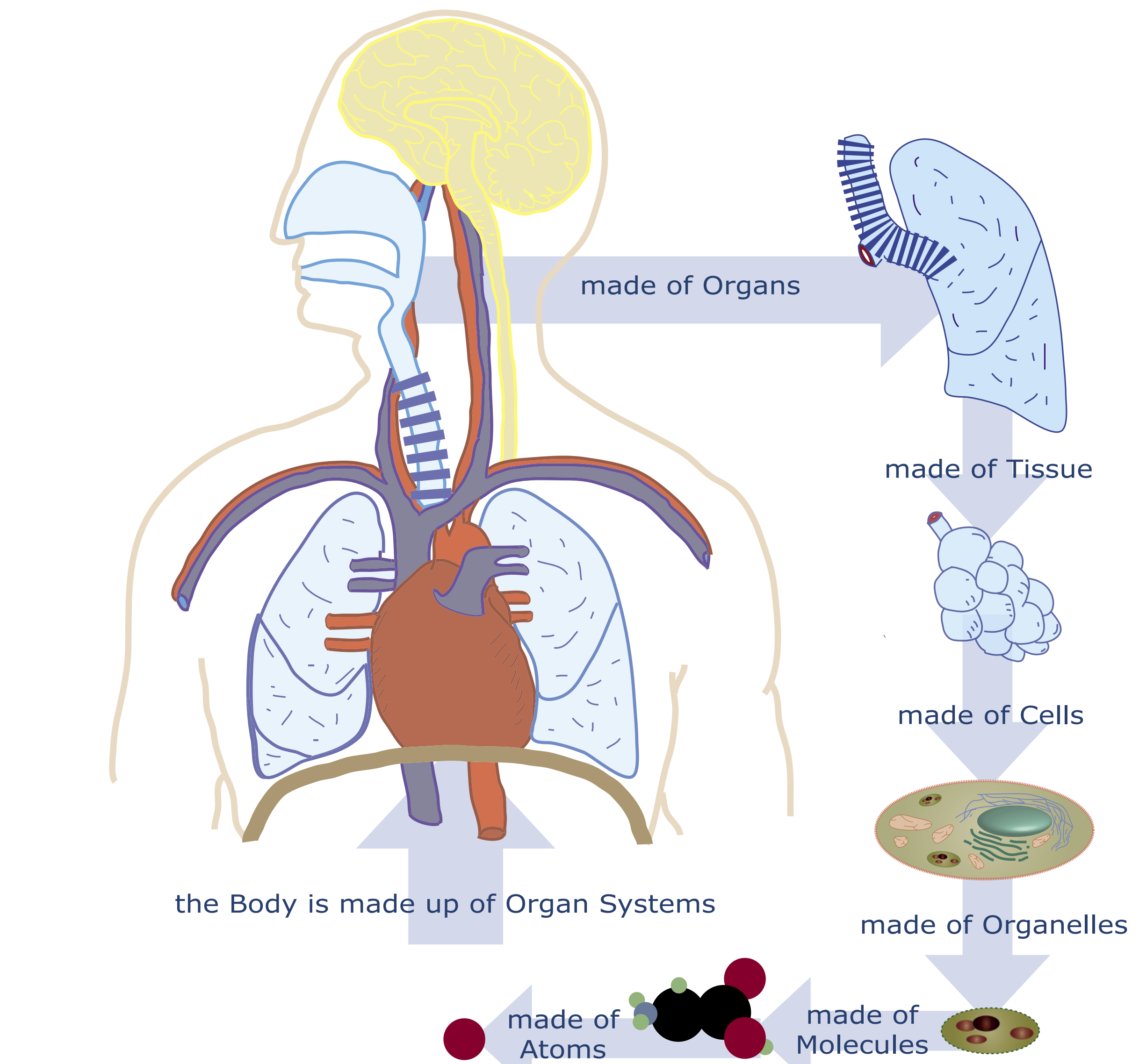
In general, gross functions are carried out by individual organs and organ systems. Structurally, fluids and gases are transported between organs and systems via tubes. Blood, for example, travels throughout the body in the tubes of the circulatory system. Oxygen enters and carbon dioxide leaves the body through air tubes, as part of the respiratory system. Digestive, excretory, and reproductive systems all rely on tubes for transporting both fluids and solids. Control and integration are provided by the brain, as its messages are conducted throughout the body via nerves. ***In its simplest form, the major components of the human body are organs, tubes, and nerves.***

Water, Fluid Spaces, & Stuff Sacks

All living cells are in contact with body fluids, and all body fluids contain water. As such, water accounts for approximately 65% of the body's total weight and is arguably its most important compound. The majority of the body's chemical reactions take place in water. Water is an excellent solvent capable of dissolving numerous chemical compounds. Water is also an essential reactant in and by-product of cellular metabolism. It is both an input in chemical reactions that break down specific compounds in the cell, as well as a by-product of cellular reactions that build the specialized compounds required for life. The chemical reactions necessary to maintain life occur within a narrow temperature range. Since water has an enormous capacity for holding and transferring heat, it plays a key role in regulating body temperature. Water retains its liquid form throughout a broad range of temperatures. This property, combined with the small size of its molecules, enables it to pass freely through most body membranes and effectively transport molecular compounds , such as nutrients, wastes, and toxins, throughout the body.



There are three basic types of fluid and fluid spaces within the human body: vascular, tissue, and cellular. Vascular spaces contain blood, plasma, and lymph; tissue spaces are filled with interstitial



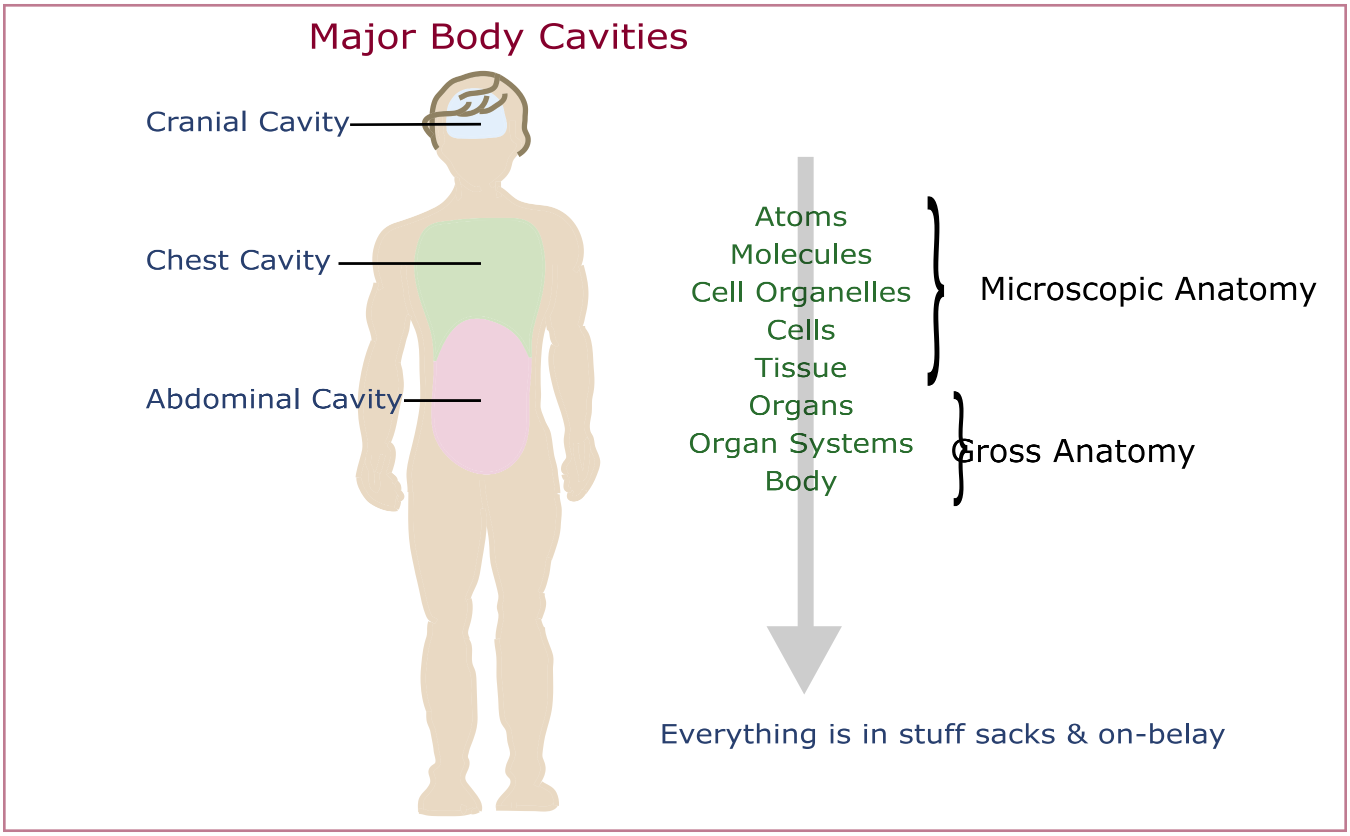
Levels of Organization

Each level has its own specific—and somewhat restricted—set of functions.

fluid; and, cells contain intracellular fluid. Solutes and structures contained in each of the three fluid matrices are slightly different and help to define the density and characteristics of each. Blood, plasma, and lymph have the consistency of vegetable juice, interstitial fluid is syrupy, while intracellular fluid is gel-like. Extracellular fluid (vascular and extracellular fluid) contains high levels of sodium (Na^+) and chloride (Cl^-) ions, while intracellular fluid contains high levels of potassium (K^+) and protein (A^-) ions. Any significant change in the volume or chemical composition of the fluids in any of the spaces will affect overall body chemistry and homeostasis.

Each of the body's components—cells, tissues, organs, body cavities—and the body collectively and individually, is surrounded by a membrane. Structural proteins attach each component to one another. Essentially, everything in the body is in "stuff sacks" and "on-belay." Membranes serve to separate, contain, and protect. Increases in membrane permeability encourage fluid or gas movement across the membrane in accordance with the pressure and concentration gradients.

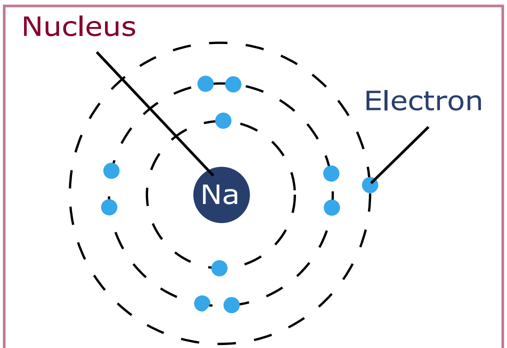
Swelling indicates structural damage and is caused by one of two mechanisms: bleeding or edema. Bleeding occurs when blood vessels are broken. Blood leaks from the damaged vessels into the local tissue spaces until the pressure is equalized



and is referred to as a hematoma or bruise. Edema occurs when plasma (not blood cells) leaks into tissue spaces due to an increase in vascular permeability. Numerous mechanisms, each discussed in depth in your course and handbook, may lead to increased vascular permeability and subsequent edema: altitude, a weak heart, poor muscle tone, inflammatory response, etc. If the structures of the body are viewed as cells, tissue, organs, and organ systems, where fluids and gases are transported through tubes, the concept of "stuff sacks" has clinical significance. If a rupture or leak occurs in any tube or stuff sack, the leak is contained within the next largest stuff sack. *This idea is perhaps the single most important concept in understanding the pathophysiology of most traumatic injuries (Section VI).*

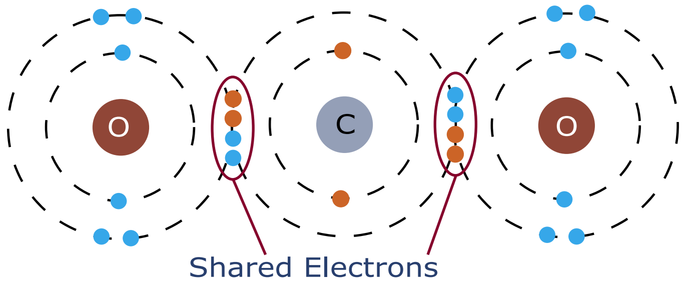
Basic Chemistry

Atoms are the smallest components of matter and can chemically bond to one another to create molecules. Chemical reactions between molecules alter the shape and properties of matter while leaving the atoms essentially unaffected. Atoms are comprised of neutrons, protons, and electrons. Neutrons and protons make up the nucleus, or core, of the atom. Electrons orbit around the nucleus in a prescribed cloud or shell. Each electron shell holds a fixed number of electrons. If the outermost shell is full, the atom will NOT react with other atoms. ONLY atoms with space in their outermost electron shell are available to participate in chemical reactions. Atoms bond to one another by sharing electrons with another atom, accepting electrons from another atom, or donating electrons to another atom. Once their outermost electron shell is full, they are unavailable for further reactions.



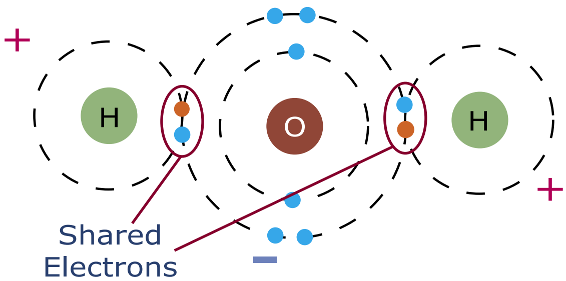
The sodium atom has only one electron in its outer shell and is available to react with another atom.

Energy is stored in chemical bonds. Cells break the chemical bonds in food to release energy. They



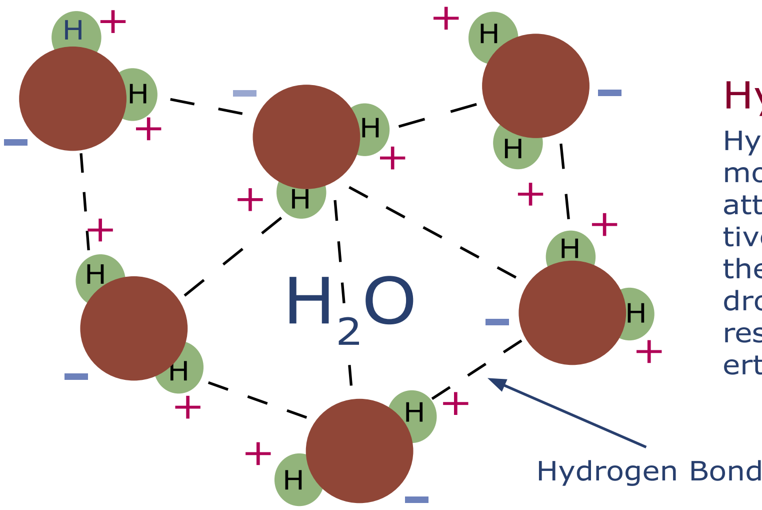
Covalent Bond

In carbon dioxide (CO_2), the electrons are equally shared and the atoms remain electrically neutral.



Polar Covalent Bond

In water (H_2O), the electrons are NOT shared equally and spend more time orbiting the oxygen atom than the hydrogen atoms. As a result, the oxygen atom becomes slightly negatively charged and both hydrogen atoms become slightly positively charged.



Hydrogen Bonds

Hydrogen bonds form between water molecules because of the electrical attraction between the weak negative charge of the oxygen atom and the weak positive charge of the hydrogen atom. This hydrogen bond is responsible for the evaporative properties and surface tension of water.

capture and use the energy to construct many of the molecules necessary to create and maintain life. Excess energy is released as heat.

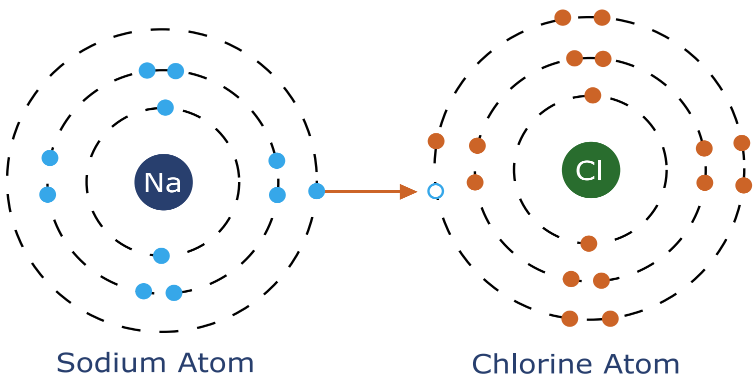
There are three types of chemical bonds: covalent bonds, hydrogen bonds, and ionic bonds. When atoms share electrons, they form covalent bonds. Covalent bonds are the strongest of the three types of atomic bonds and therefore store the most energy; the more electrons shared, the stronger the bond. Covalent bonds are formed and broken in the process of cellular metabolism. Metabolism provides cells with the energy required to grow and to maintain homeostasis.

Most atoms in covalent bonds remain electrically neutral because the electrons are shared equally. In some cases, water is one example, unequal sharing of the electrons results in slight electrical charges within the molecule known as a polar covalent bond. The weak charges are not strong enough to create separate new molecules. However, they can alter the shape of a given molecule and are sufficient to pull other charged molecules together. When hydrogen forms polar covalent bonds with oxygen, the hydrogen bonds that form between water molecules are responsible for the unique surface tension of water and its rather slow evaporative properties.

Protons have a positive electrical charge, electrons have a negative electrical charge, and neutrons have no charge. Atoms are electrically neutral as long as the number of protons equals the number of electrons. Atoms or molecules become electrically charged when they give up or receive electrons. Atoms or molecules with an electrical charge are called ions. An ionic bond is formed when one atom donates one or more electrons to another. The atom donating the electron becomes positively charged while the atom receiving the electron becomes negatively charged. The two atoms remain next to each other after the electron transfer because the opposing electrical charges attract one another. Ionic compounds break into their individual ions when dissolved in water. The slight electrical charges within each water molecule, a result of the polar covalent bonds that form the molecule, keep them apart as long as they remain in solution.

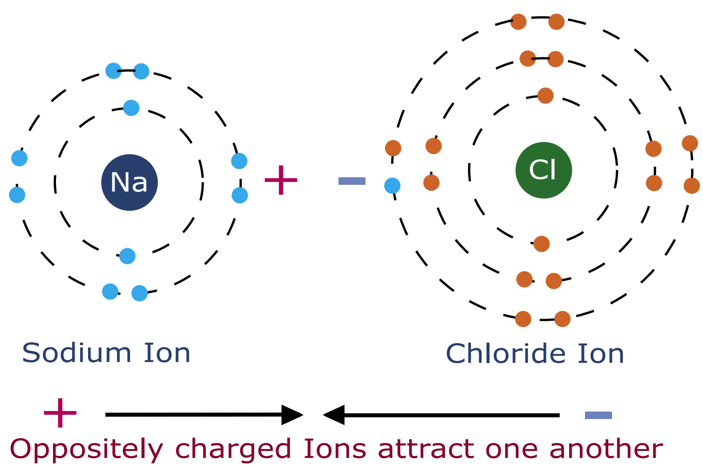
Mineral Salts & Electrolytes

Mineral salts are inorganic ionic compounds, excluding acids and bases, that disassociate in water to release their respective ions. They are naturally occurring elements and work with enzymes to maintain homeostasis. During digestion, they are coated with a protein molecule (chelated) to aid in their absorption. Large amounts of fiber eaten along with mineral salts inhibit the chelating process and restrict mineral absorption.

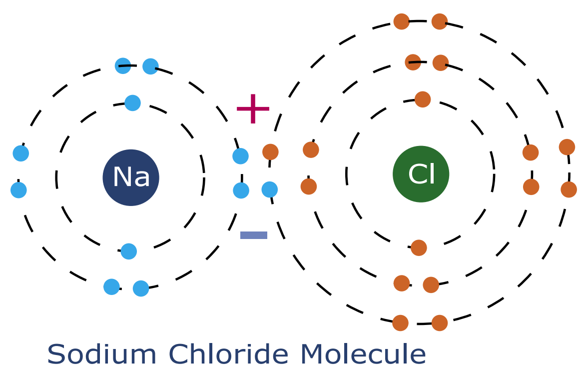


Ionic Bond

The sodium atom donates an electron to the chloride atom leaving the outer electron shells of both atoms full.

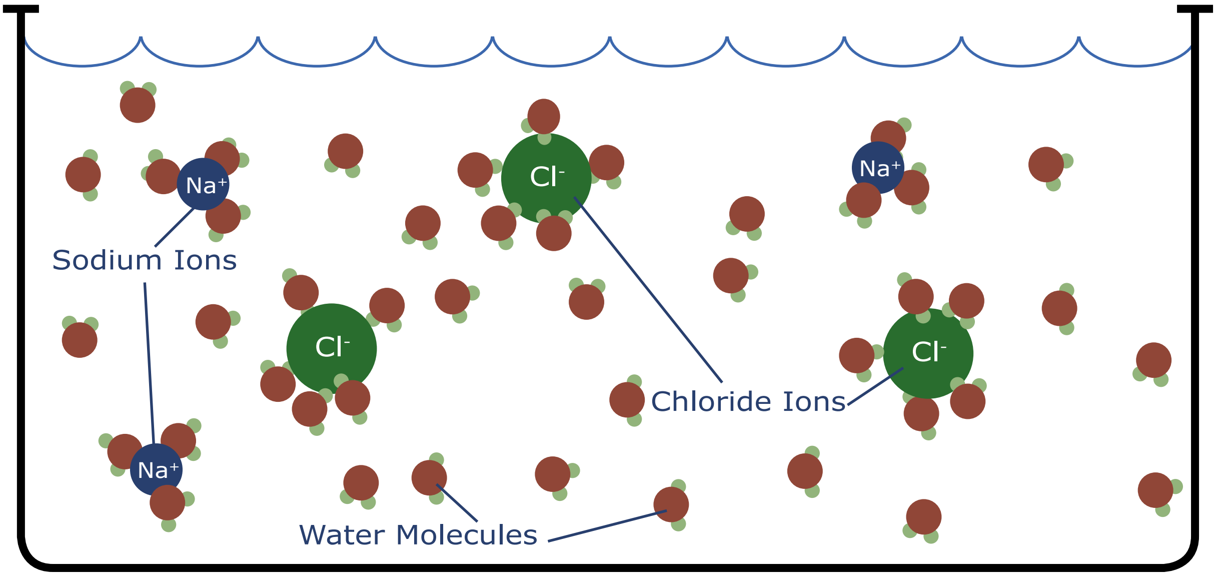


After donating an electron, the sodium atom has a positive charge because it has one more proton than electrons. After receiving an electron, the chloride atom has one more electron than proton giving it a negative charge and becoming the chloride ion.



Opposite charges attract creating the sodium chloride molecule. The molecule disassociates when dissolved in water. The weak negative charges in the oxygen atoms of water are attracted to the positive charges in the sodium ion and the weak positive charges in the hydrogen atoms of water are attracted to the negatively charged chloride ion. The difference in electrical charges keeps the ions apart as long as they remain in solution.

Sodium Chloride Ions in Water



Required Mineral Salts

Bulk Minerals

- Chlorine (Cl)
- Sulfur (S)
- Potassium (K)
- Sodium (Na)
- Magnesium (Mg)
- Phosphorus (P)
- Calcium (Ca)

Trace Minerals

- Fluorine (F)
- Cobalt (Co)
- Chromium (Cr)
- Copper (Cu)
- Iodine (I)
- Iron (Fe)
- Manganese (Mn)
- Selenium (Se)
- Zinc (Zn)

Common Ions in Solution

Positive Ions

- Sodium (Na^+)
- Potassium (K^+)
- Calcium (Ca^{2+})
- Magnesium (Mg^{2+})
- Hydrogen (H^+)

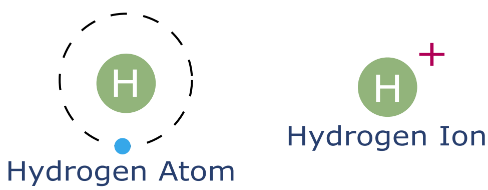
Negative Ions

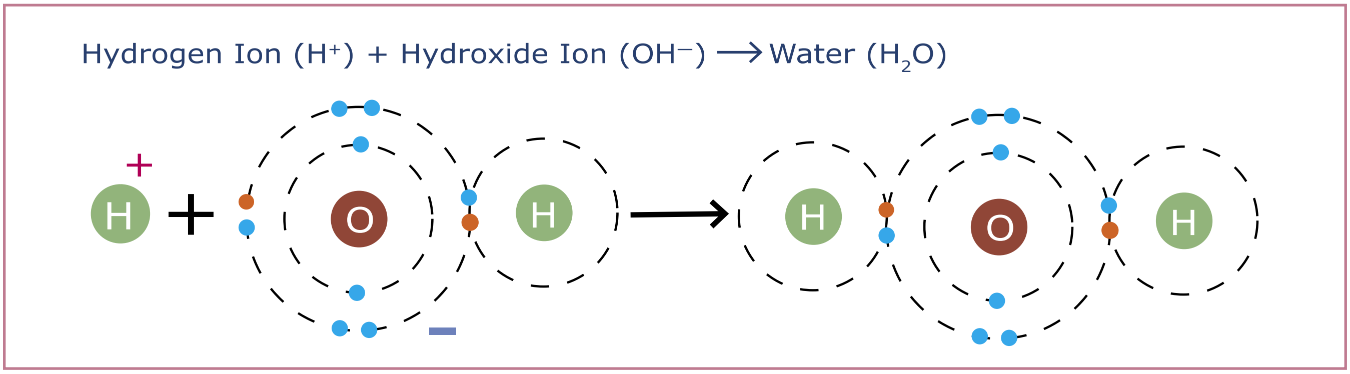
- Chloride (Cl^-)
- Bicarbonate HCO_3^-)
- Biphosphate (HPO_4^{2-})
- Sulfate (SO_4^{2-})
- Hydroxide (HO^-)

Ions capable of carrying an electrical charge when in solution are called electrolytes. All mineral salts are electrolytes. Changes in the concentration of electrolytes in the extra and intracellular fluids will disrupt all body functions and, if severe, lead to death. While calcium and phosphate ions are stored in bone, most mineral salts are excreted in urine and require frequent replacement. Many diseases may be traced to a lack of specific minerals and the adverse-effects reversed if detected early. Sodium is the primary electrolyte in the extra cellular fluid, while potassium is the primary electrolyte in the intracellular fluid. Both are crucial materials for maintaining water balance within the body and hence, neurological function. Together with glucose, which is required for electrolyte absorption, sodium and potassium are the major components in all oral rehydration salt (ORS) preparations used to treat dehydration. (Dehydration and ORS preparations are discussed in more detail in your handbook)

Acids, Bases, & pH

Hydrogen has only one electron in its electron shell and regularly donates it to other atoms creating an EXTREMELY reactive positive ion with one proton. ***Acids are compounds that break down in solution to release hydrogen ions, while bases bind with hydrogen ions and remove them from solution.***

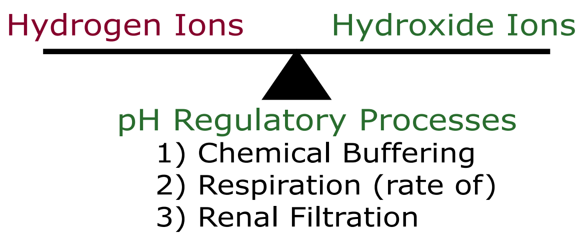




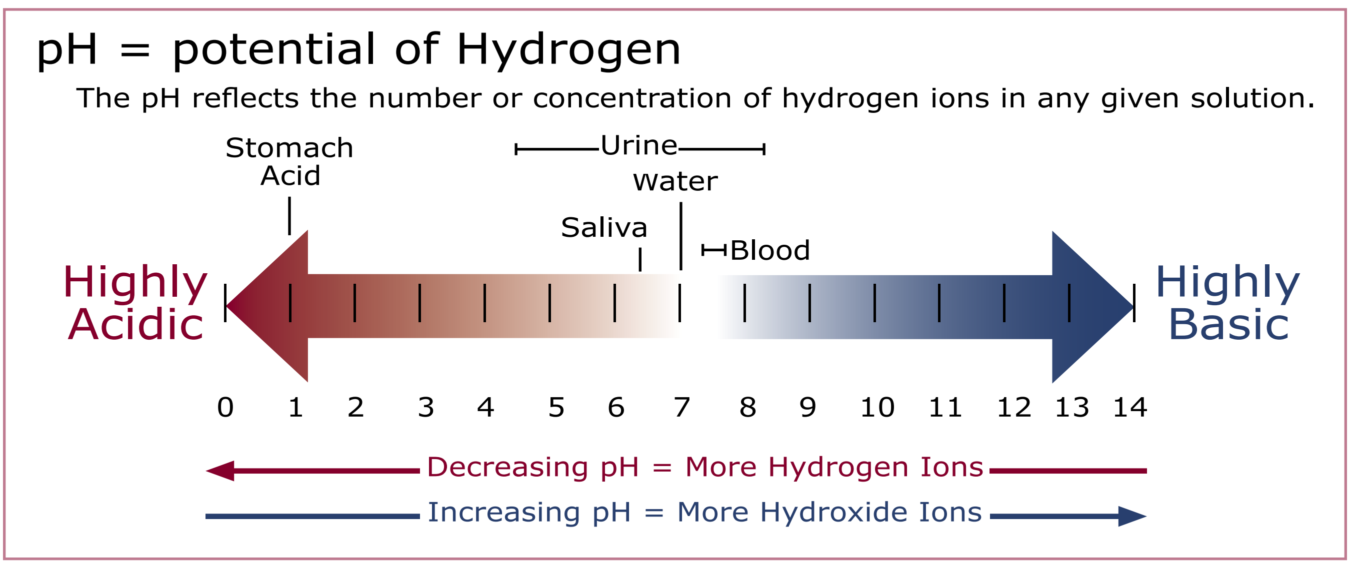
Many common bases dissociate in solution to form a hydroxide ion (OH^-); hydroxide ions readily combine with hydrogen ions (H^+) to form water ($OH^- + H^+ \longrightarrow H_2O$).

pH is an abbreviation that stands for "potential of Hydrogen." The pH of a solution is measured by a logarithmic scale designed so that the large values of the hydrogen ions present in a given solution correspond to small values in the scale. The scale varies from 0 to 14. The lower the number, the greater the concentration of hydrogen ions present in the solution. Each change in pH value represents a tenfold change in the concentration of hydrogen ions. Therefore, small changes in pH reflect huge changes in the number of ions present. The pH of water is 7 and the number of hydrogen ions in solution equals the number of hydroxide ions. Solutions having pH lower than 7 are acidic and those having pH above 7 are considered basic. ***An excess of hydrogen ions (acid) can upset the stability of cell membranes, break chemical bonds, and change the structure of proteins.*** Normal blood pH varies between 7.35 and 7.45; variation of 0.5 pH units outside this normal range can be fatal.

In order for the body to remain in balance the concentration of hydrogen ions in the body fluids (pH) must be carefully regulated. There are three processes responsible for balancing pH in the human body: chemical buffering, respiration, and renal (kidney) filtration.



Carbon Dioxide (CO_2), a byproduct of cellular metabolism, combines with water to produce carbonic acid, which promptly dissociates in solution to release a hydrogen ion and a bicarbonate ion ($H_20 + CO_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$); excess CO_2 in the blood produces more hydrogen ions and lowers blood pH (the blood becomes acidic). Buffering compounds in the blood, tissues, and cells chemically stabilize pH by removing or replacing hydrogen ions. This buys time for the lungs and kidneys to reestablish normal body chemistry. The lungs respond to



decreasing pH levels by increasing respirations and exhaling CO_2, essentially removing the excess acid. A prolonged increase in respiration rate, for instance, as experienced at high altitude or by a medical condition, blows off too much acid and raises blood pH. The kidneys respond to pH changes in both directions by either excreting hydrogen or bicarbonate ions as needed and by producing either acidic or basic urine respectively. Problematic changes in pH are either metabolic or respiratory in nature and treated by correcting the underlying cause.

Organic Compounds

The numerous organic compounds in the body fall into six major classes: carbohydrates, lipids, proteins, nucleic acids, high-energy compounds (ATP), and vitamins; all contain carbon and hydrogen atoms, and most contain oxygen.

Carbohydrates

Carbohydrates are the body's primary energy source. Simple sugars, including glucose, are relatively small molecules whose covalent bonds are quickly broken to provide energy. Two simple sugars combine to form disaccharides. Large complex carbohydrate molecules called polysaccharides, starches are one example, are either plant or animal based and do not dissolve in water. Animal starch (glycogen) is composed of a large chain of glucose molecules and is stored in liver and muscle cells. Stored glycogen is broken down into glucose when energy demands are high. Excess sugar is stored as fat.

Lipids

Lipids are fats, waxes, or oils; most are insoluble in water and require special transport proteins to carry them in the blood. There are four basic types of lipids: fatty acids, fats, steroids, and phospholipids. Each has a slightly different molecular shape specific to its individual function. Fatty acids provide an alternate energy source to carbohydrates and are subdivided into saturated and unsaturated fatty acids. Fatty acids, stored in triglyceride chains, are the building blocks of fat molecules. Saturated fats tend to come from animal sources and are solid at room temperature, while unsaturated fats are usually plant-based and liquid at room temperature. A diet high in saturated fats increases the risk of arteriosclerosis and related circulatory system problems. In addition to providing an emergency energy source, fats also offer subcutaneous insulation and organ protection. Steroids, such as cholesterol, and phospholipids are the primary components of cell membranes. Their water insolubility helps maintain the integrity of the cell and the specific concentrations of the extracellular and intracellular fluids. Cholesterol is also required to manufacture many of the body's messenger hormones.

Proteins

Proteins make up the largest group of organic compounds in the human body. They are composed of long chains of amino acids and are responsible for most of the physical structure of the body and its numerous components. The number and order of the amino acids in a protein determine its shape and function. Minor changes in the concentration of ions, temperature, and pH in the surrounding environment can cause proteins to denature—irreversibly break down. Denaturation ultimately leads to death as tissues, organs, and organs systems fail.

Nucleic Acids

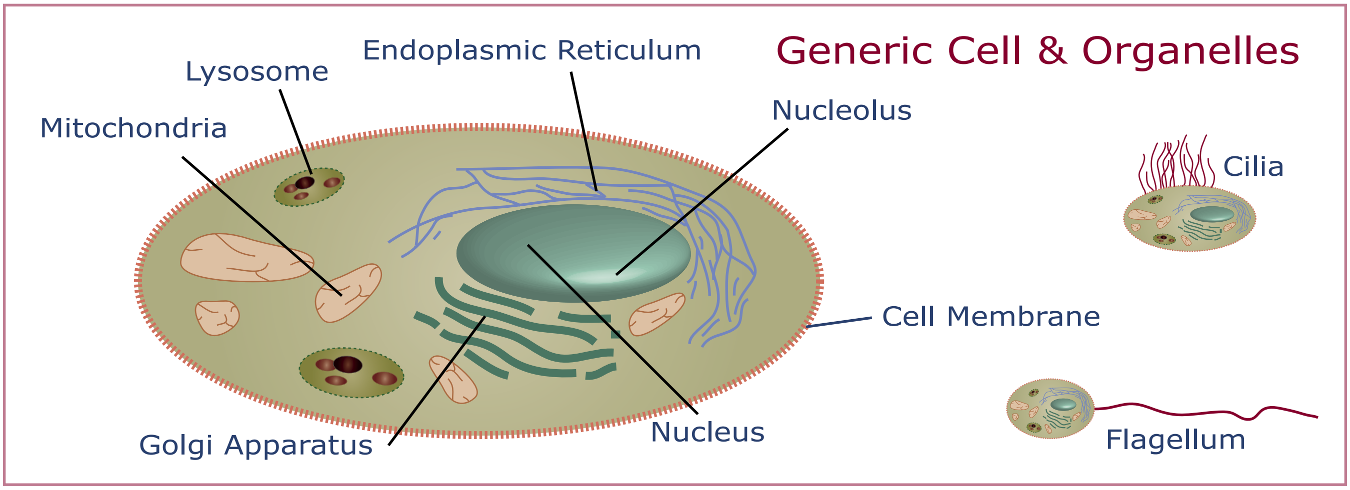
Nucleic acids—DNA and RNA—store and process all the genetic information responsible for our individual characteristics. Both DNA and RNA are composed of nucleotide chains. Both work together to direct the synthesis of proteins in the body. As such, they directly control cellular metabolism.

High Energy Compounds

As previously discussed, cells break the covalent bonds in food to release energy. Much of the released energy is captured by creating high energy phosphate bonds; the remainder emerges as heat. Cells add a phosphate group to adenosine diphosphate (ADP) creating adenosine triphosphate (ATP). The reaction is completely reversible. When cells need energy, the bond is broken under controlled conditions within the cell, leaving the ADP and phosphate group intact for future storage: ATP $\longleftrightarrow$ ADP + phosphate group + energy.

Vitamins

Vitamins are organic nutrients related to lipids and carbohydrates; they work with enzymes to facilitate chemical reactions and maintain homeostasis. Vitamins B and K are produced by bacteria in the intestinal tract; vitamin D is manufactured by skin cells when exposed to sunlight; beta-carotene is converted into vitamin A by the body; and the B com-



plex vitamins, along with vitamin C, are absorbed through the intestinal tract from outside sources. Vitamins are broken down into two major categories: fat soluble and water soluble. Fat-soluble vitamins: A, D, E and K, bind to and are transported with lipids. While fat-soluble vitamins may be stored for long periods of time within muscle tissue and specialized liver cells, water-soluble vitamins must be replaced frequently. Most water-soluble vitamins, such as B complex and C, are excreted by the body within four days. Numerous diseases may be traced to a lack of specific vitamins. Often the disease process may be reversed with early assessment and treatment using the appropriate supplements.

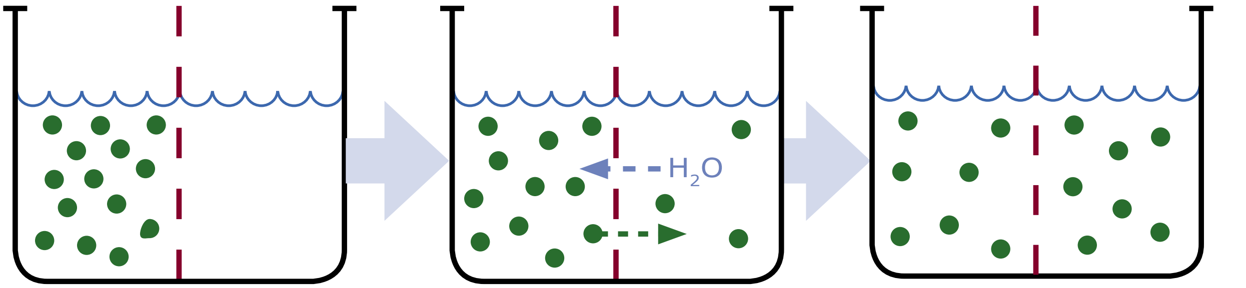
Required Vitamins

Fat Soluble	Water Soluble
Vitamin A	Vitamin C
Vitamin D	All B Vitamins
Vitamin E	
Vitamin K	

Cell Structure & Physiology

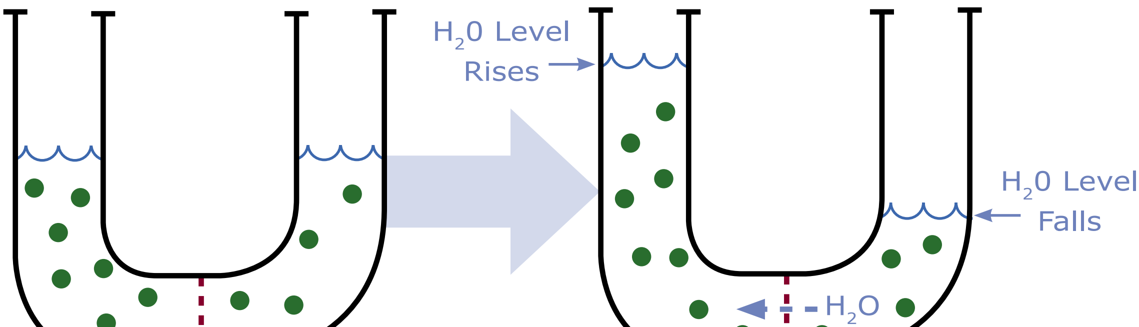
Cells are the smallest form of life and, as the basic building blocks for the human body, they are responsible for creating tissues, organs, and organ systems. While there are numerous types of cells within the body, all respond to internal and external stimuli in order to maintain homeostasis. The shape of a cell reflects its function. Each cell is surrounded by a lipid membrane (stuff sack) that separates the contents of the cell from the extracellular fluid and contains the cell's organelle. Each organelle has its own stuff sack and is held in place by structural proteins. Additional proteins are embedded in the cell membrane and act as receptors, channels, enzymes, molecular carriers, anchors, or identifiers. Individual organelles are responsible for specific functions within each cell: mitochondria process glucose and store energy as ATP. The endoplasmic reticulum synthesizes and stores proteins, carbohydrates, and lipids. Lysosomes are responsible for digestion, defense, and recycling. Golgi apparatus package secretions and enzymes in small vesicles and maintain the cell membrane. The nucleus controls metabolism, reproduction and protein synthesis. Some cells produce hair-like extensions of their cellular membrane to increase their surface area and speed absorption (microvilli), to move liquids across their surface (cilia), or to move through tissue and body fluids (flagella).

In order to perform efficiently, all cells require a constant supply of nutrients and the steady elimination of waste products. Both nutrients and wastes are transported to and from the cells via the circulatory system. They are either suspended within the blood or lymph as solutes or bound to carrier cells. They must be able to freely pass through the semipermeable membranes of the capillaries and cells. Passage generally depends on a combination of their molecular size, shape, electrical charge and lipid solubility. It is through the extracellular fluid that the cells either absorb nutrients or dispose of wastes. Movement of both nutrients and wastes across the cell membranes takes place by filtration, diffusion, active transport or vesicular transport. Filtration happens when particles are forced through the cell membrane by hydrostatic pressure. Diffusion occurs when solutes move across a membrane from an area of higher concentration to



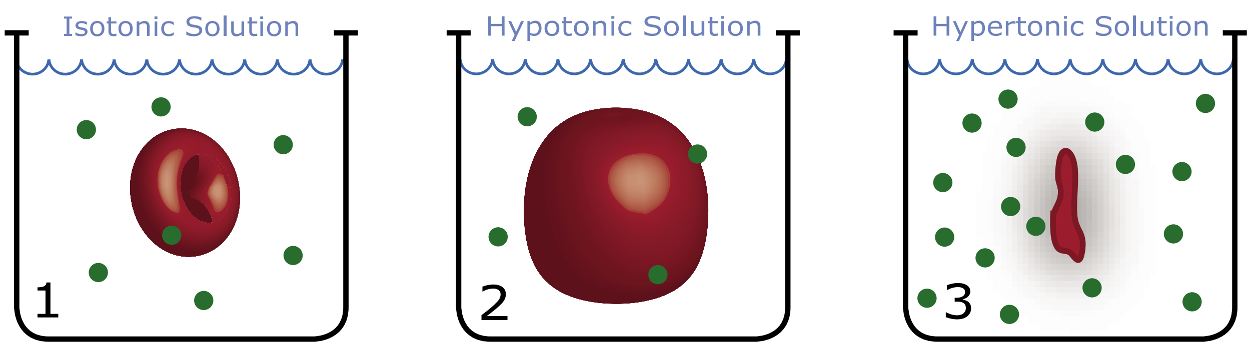
Diffusion

In a freely permeable membrane, solutes and water diffuse through the membrane until they are equally distributed on both sides.

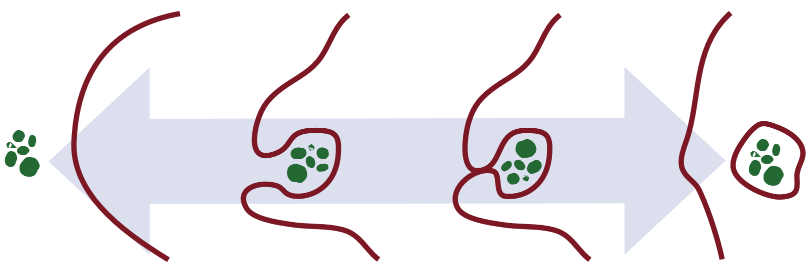


Osmosis

In a semi-permeable membrane, where the solutes are too large to pass through the membrane, water moves across the membrane to dilute the solutes until the concentrations are equal or until an opposing pressure halts the process.

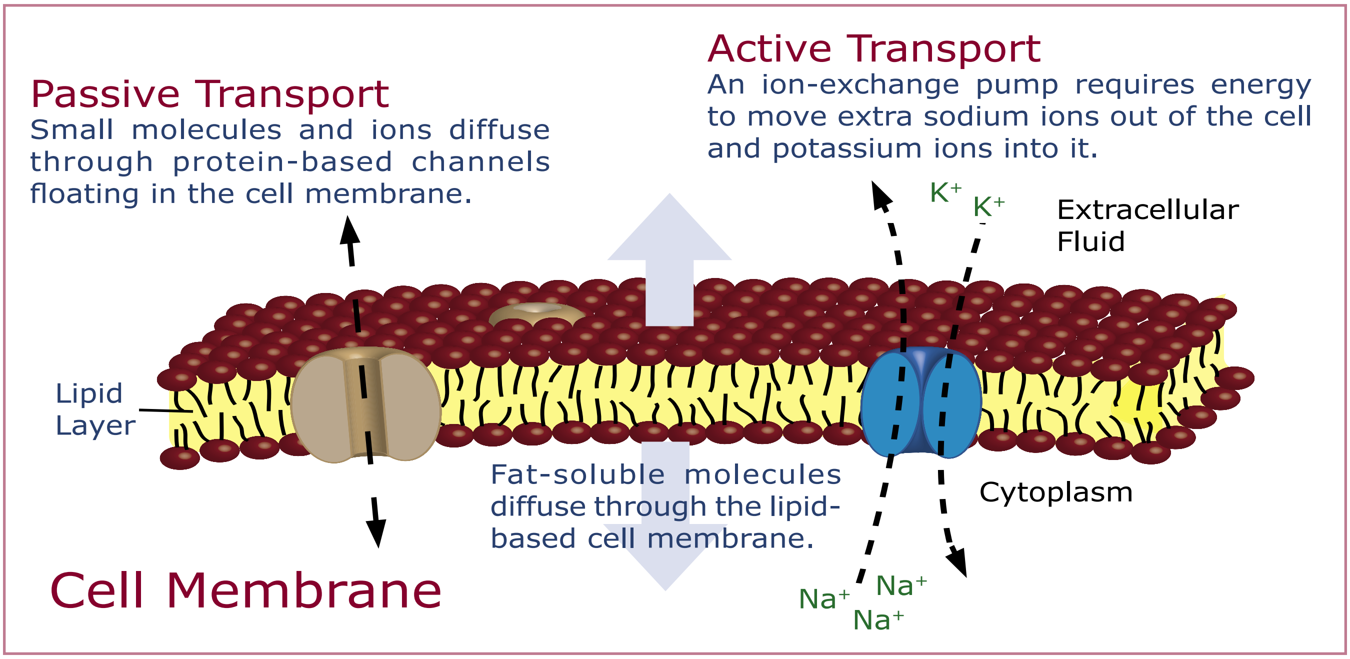


Water moves towards the highest concentration of solute via osmosis. 1. Solutes are equal inside cell and in solution (isotonic solution). 2. A higher concentration of solute is inside of the cell than in the solution (hypotonic solution). 3. A lower concentration of solute is inside of the cell than in the solution (hypertonic solution).



Vesicular Transport

In order to import material into the cell, the cell membrane extends to surround extracellular fluid and the material, and then fuses, to form a vesicle. The reverse happens to export cellular products and/or debris.



an area of lower concentration. Carbon dioxide and oxygen are transported across cell membranes by diffusion. Glucose is also transported across the cell membrane by diffusion; however, its entry is facilitated by the presence of the hormone, insulin. Osmosis is a form of diffusion, wherein water, not a solute, diffuses through a semipermeable membrane to equalize the concentration on each side of the membrane. A working knowledge of osmosis is necessary to prevent, assess, and treat heat-related illnesses.

Active transport occurs when a cell uses energy, that is, converts ATP into ADP, to move solutes across its membrane, often against the concentration gradient. Sodium, potassium, other ions, and proteins are often carried into and out of cells by active transport (shown in the diagram above).

In vesicular transport, nutrients, products, waste, or pathogens are packaged in extensions of the cell membrane for transport into or out of the cell.

As stated previously, all cells require oxygen and glucose in order to survive. Cells break down glucose to produce chemical energy, primarily in the form of ATP, and heat: $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + ATP$. The energy is used by the cell to carry out its functions. A cell deprived of oxygen and glucose will eventually die. Carbon dioxide is a waste product of cellular metabolism. It is picked up by the blood and eliminated through the lungs. Other cellular waste must be transported to the kidneys for removal. If waste products build to toxic levels, cellular function will decrease and the cell will die. ***In order for the transportation of both nutrients and wastes to be effective, fluid levels within the human body must remain within tight parameters. Cellular function will significantly decrease or stop if fluids fall below acceptable levels.***

Body Systems

The Circulatory System

The function of the circulatory system is twofold: it picks up nutrients from the proper organs and delivers them to all the cells of the body; and, of equal importance, it picks up cellular wastes and delivers them to the proper organs for removal. Medically, this transportation process is known as perfusion. Without perfusion, cellular function decreases or ceases altogether as the affected cells are denied access to the nutrients they need to support life or as toxic wastes begin to poison them. Both nutrients and waste are carried by the blood through an interconnected series of tubes to all the cells of the body. The blood is forced through the tubes by a powerful muscular pump. The circulatory system may be structurally divided into three major components: the heart or pump; the vessels or tubes; and the entire fluid volume of the body: blood, plasma, intracellular fluid, and lymph. A problem that disrupts the function of any one of the components of the circulatory system will affect the function of the entire system, and subsequently the entire body.

Severe problems with the circulatory system usually lead to a systemic decrease in cellular perfusion (shock) and death.

The Heart

The heart is a single organ comprised of two pumps, known as ventricles, and two receiving chambers, known as atria. The larger of the two pumps, the left ventricle, pumps blood to the body while the smaller pump, the right ventricle, pumps blood to the lungs. Oxygen-poor blood returning from the body is collected in the larger of the two receiving chambers, the right atrium, and oxygen-rich blood returning from the lungs is collected in the smaller chamber, the left atrium. Each chamber is separated by independent valves, and the timing of these valves, as well as the contraction of each ventricle, is critical to functional circulation. The characteristic "lub-dub" sounds associated with a heartbeat are the opening and closing of the four paired valves that regulate blood flow between the atria and ventricles and its exit from the heart. The heart contains specialized cardiac nerves that are responsible for generating and coordinating the electrical impulses necessary for efficient pumping. The rate and strength of cardiac contractions is dependent upon both the specialized cardiac nerves and signals from the autonomic nervous system. Cardiac perfusion is accomplished via the coronary arteries and veins.

The Vessels

The blood and lymphatic vessels create a system of tubes that carry fluids to and from all the cells of the body. Arteries are muscular blood vessels that carry blood away from the heart and are responsible for the pickup and delivery of nutrients—vitamins, minerals, amino acids, glucose, etc.—from the gastrointestinal system and liver, and oxygen from the lungs. They also deliver cellular waste to the kidneys for elimination. Because they are under increased pressure due to their proximity to the heart, arteries have thicker and more muscular walls than either veins or lymph vessels. Veins and lymphatic vessels return blood and lymph, which is similar to plasma, back to the heart. They are also responsible for delivering carbon dioxide to the lungs for oxygen exchange. All vascular muscles are under the control of the autonomic nervous system and capable of vasoconstriction or vasodilation when properly stimulated.

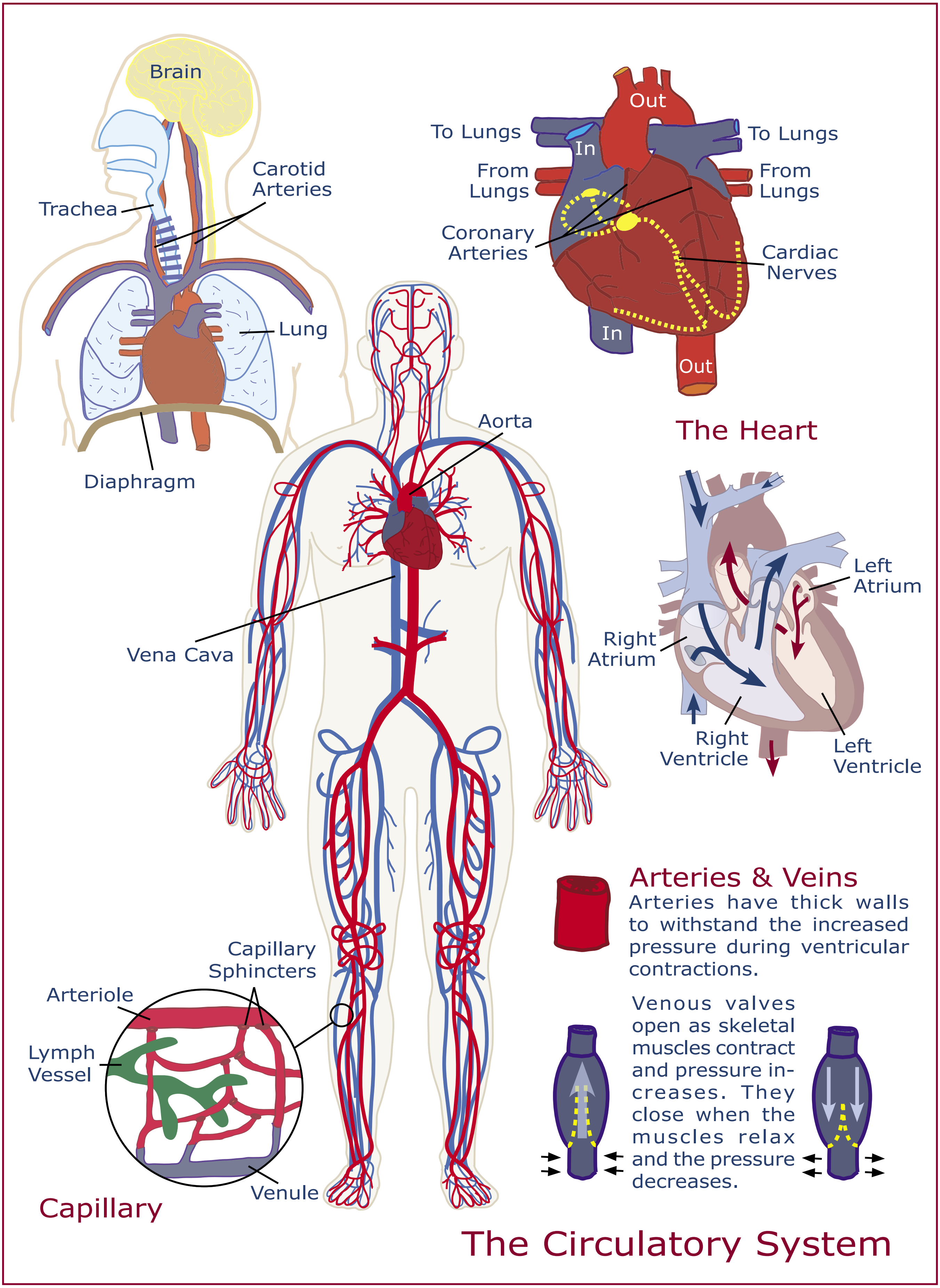
Upon leaving the heart, arteries continually divide and subdivide until they form an interwoven web of microscopic tubes called capillaries. Capillaries form the link between the circulatory system and the cells of the body and are found within all body tissues. Nutrients suspended in blood plasma move through the thin permeable walls of the capillaries to bathe and nourish individual cells. Waste products are released into the extracellular fluid, picked up by the capillaries and lymph vessels, and eventually removed from the blood by the kidneys. Small sphincters surround the entrance to each capillary and dilate or contract in response to autonomic nervous system commands to control the amount of blood entering each capillary.

Blood leaving the capillaries returns to the heart via veins. Movement of venous blood towards the heart is driven by the muscular contraction of the surrounding striated muscle groups, especially those in the legs, by "squeezing" the blood back to the heart. Since the blood pressure is lower on the venous side, the veins contain one-way valves to aid the return of deoxygenated blood to the heart and to prevent it from pooling in the extremities.

Lymph vessels also pick up extracellular fluid and wastes and pass it through lymph nodes, where most of the white blood cells (WBC) in the body are located, before returning it to general circulation via the central veins. WBCs are an integral part of the body's defenses and leave the lymph nodes to fight systemic infections. Fluid moves through the lymphatic vessels in the same manner as venous blood returns to the heart—through contractions of the surrounding muscle groups. Of the blood leaving the capillaries, about one fifth is picked up by the lymph vessels; the remainder is reabsorbed at the venous end of the capillaries. Lymph nodes become enlarged during an infection, when the flow of WBCs *into* the node exceeds the rate of outflow.

Blood, Plasma, and Fluids

Blood is made up of approximately equal proportions of blood cells, including platelets, and plasma. Under normal circumstances, the overwhelming majority of blood cells are red blood cells (RBCs) responsible for binding with and carrying oxygen to all the tissues of the body. The spleen is


Brain
Trachea
Carotid Arteries
Lung
Diaphragm
To Lungs
Out
To Lungs
In
From Lungs
From Lungs
Coronary Arteries
Cardiac Nerves
In
Out
The Heart
Aorta
Vena Cava
Left Atrium
Right Atrium
Right Ventricle
Left Ventricle
Arteries & Veins
Arteries have thick walls to withstand the increased pressure during ventricular contractions.
Venous valves open as skeletal muscles contract and pressure in-creases. They close when the muscles relax and the pressure decreases.
Capillary Sphincters
Arteriole
Lymph Vessel
Venule
Capillary
The Circulatory System

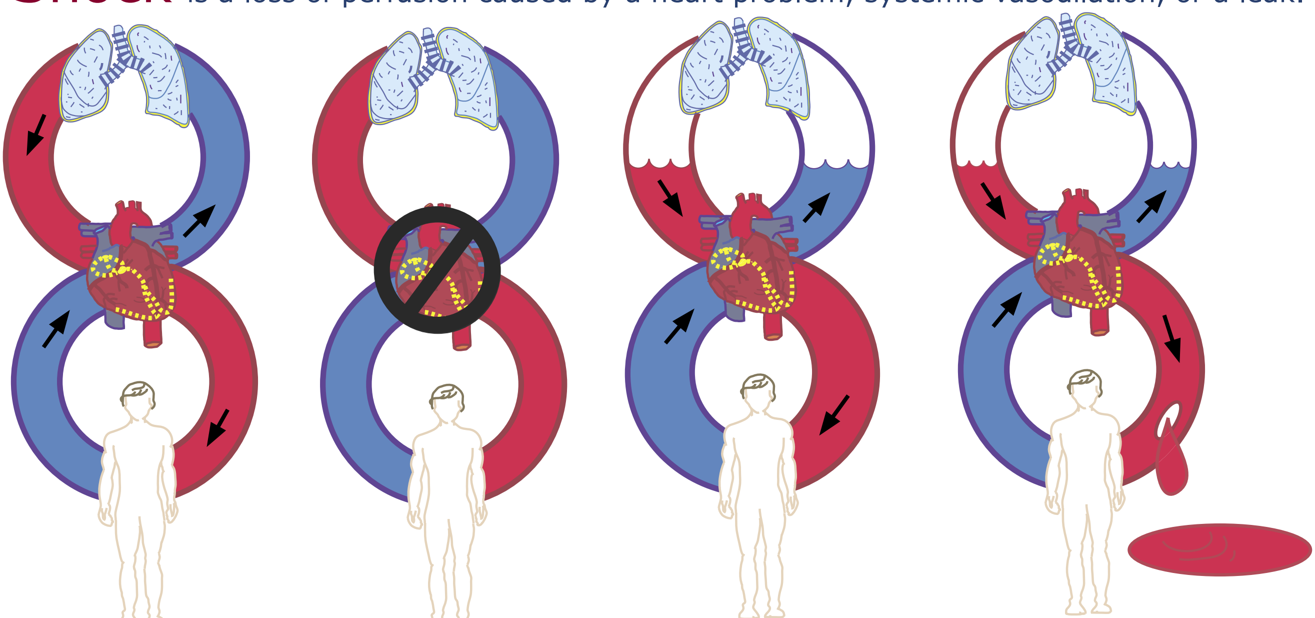
responsible for recycling old RBCs while new red blood cells are formed by stem cells within bone marrow. Unless an infection is present, relatively few white blood cells (WBCs) are present in general circulation. Platelets are also present in small numbers and are responsible for clotting. Plasma is a water-based, nutrient-rich solution containing the salts, sugars, proteins, vitamins, and minerals required by the body's cells for normal functioning. Because of their large size, blood cells remain within the capillary network, while the vital nutrients held within the plasma are able to pass through the semipermeable walls of the capillaries to nourish individual cells. Lymph is similar to plasma in that it does not contain blood cells. Each type of fluid contains a slightly different combination of nutrients and waste products, and each fluid has a unique electrical charge depending upon the needs of the local tissue. Sodium is the predominant ion in the extracellular fluid, while potassium dominates the intracellular fluid or cytoplasm. Because sodium and potassium ions are small enough to pass through the channel proteins in the cell membrane, they freely diffuse into and out of the cytoplasm. In order to maintain the correct ion concentration levels, cells utilize a protein-based ion-exchange pump to move each ion against the concentration gradient. The respective concentrations of sodium and potassium in the extracellular and intracellular fluid are particularly important because, as illustrated earlier, water follows salt, diffusing in or out of the cell, according to the concentration gradient.

Shock

Shock is the major life-threatening problem of the circulatory system. It is medically defined as a loss of systemic perfusion. There are three basic types of shock: heart shock (cardiogenic shock), volume shock (hypovolemic shock), and vascular shock (septic shock, anaphylactic shock and spinal shock). Each is directly related to a failure in one of the major components of the circulatory system. All forms of shock, regardless of the mechanism, may lead to death.

Failure of the pump (heart shock) may be caused by a variety of mechanisms, all resulting in a drop in perfusion pressure and arrest. Medical mechanisms involving the heart usually disrupt the heart's intrinsic electrical system by blocking one or more of the coronary arteries and depriving cardiac cells of oxygen and nutrients (heart attack).

Shock is a loss of perfusion caused by a heart problem, systemic vasodilation, or a leak.



Normal circulation follows a Figure-8 pattern from heart to body and lungs, and back again.

In Cardiogenic Shock, a heart problem stops circulation.

In Vascular Shock, systemic vasodilation leads to a drop in perfusion pressure.

In Volume Shock, a leak in the circulatory system leads to a drop in perfusion pressure.

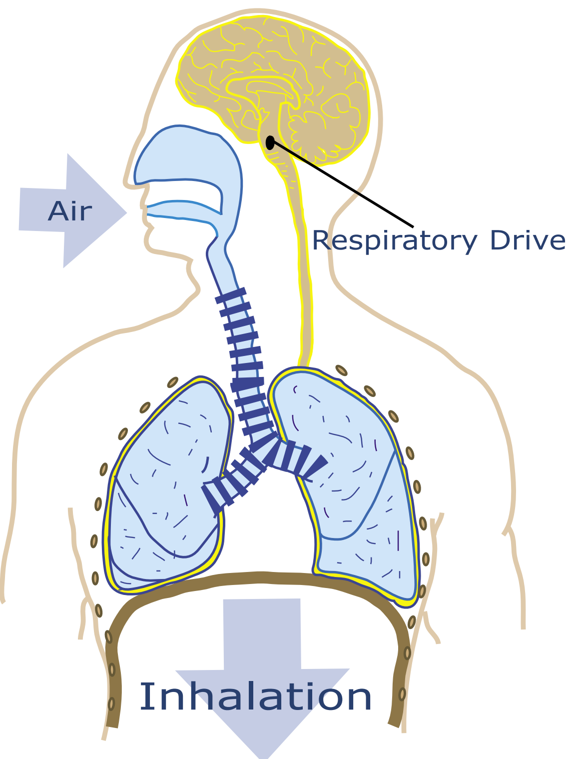
In addition, infection may damage the heart muscle or any of its various components. Trauma can directly impair the heart's electrical system or injure the organ itself. Environmental mechanisms, such as lightning, may disrupt the electrical system directly, while drowning affects the heart indirectly by damaging the respiratory system and depriving the heart of oxygen.

A break in any vessel causes an immediate fluid loss at the site of the break. If the vessel is an artery, the amount of fluid loss is increased because of the arterial pressure. Fluid loss may also be caused by an increase in the permeability of the walls in the capillary beds (inflammatory response). Any loss of red blood cells causes an immediate decrease in the oxygen carrying capacity of the blood. A loss of water (dehydration) causes an immediate decrease in the efficiency of the circulatory system's delivery system. Both cause a decrease in cellular function, as the delivery of nutrients and the removal of wastes slow. Large amounts of fluid loss (blood, plasma, water), regardless of the cause, will cause a systemic loss of perfusion (volume shock).

Problems with the vessels that affect the entire circulatory system tend to be those that cause systemic vasodilation (anaphylaxis, spinal shock, and septic shock). All may lead to a loss of perfusion pressure (vascular shock).

The Respiratory System

The function of the respiratory system is to supply the blood with oxygen and to remove carbon dioxide. The removal of carbon dioxide helps to balance blood pH. When the amount of carbon dioxide in the blood becomes too high, or the oxygen level too low, chemical receptors in the brainstem signal the diaphragm and intercostal muscles to contract and begin inhalation. The muscular contractions enlarge the intrathoracic space, expand the lungs, and cause a negative pressure to develop internally. In a process similar to that of an expanding bellows, air is pulled into the body through the mouth or nose by the negative pressure. It passes through a series of smaller and smaller tubes (trachea, bronchi, bronchioles) until it fills microscopic air sacs (alveoli) and the pressure is equalized. The alveoli are enveloped by capillary beds; it is through the



Breathing
Air is drawn into the lungs as the diaphragm moves down and intercostal muscles move up and out. When they relax, air is pushed out. Inhalation is active, while exhalation is passive.

thin walls of the alveoli and the adjacent capillaries that the gas exchange takes place. While inhalation is an active process, expiration is passive. During expiration, the muscles relax, intrathoracic pressure increases, and air is expelled. Normal respirations are smooth, easy, and quiet.

For diagnostic purposes, the respiratory system may be structurally divided into five major components: the respiratory drive located in the brainstem; the upper airway; the lower airway; the air sacs or alveoli; and the musculoskeletal structure consisting of the chest wall, diaphragm, and pleura (the stuff sacks surrounding each lung). Any problem that disrupts the function of any of the components will affect the function of the entire system and subsequently the entire body. Problems with the respiratory system decrease or stop the gas exchange, causing systemic cellular hypoxia (lack of oxygen) and often death.

The Respiratory Drive

All cells require oxygen to produce energy and do work; carbon dioxide and water are waste products of the metabolic process. An increased demand for work from individual organs, increases the oxygen requirement of their cells. Chemical receptors located in the brainstem monitor blood pH, carbon dioxide, and oxygen levels. When the blood pH falls too low (becomes more acidic) due to increasing levels of carbon dioxide or the oxygen levels fall too low, the chemical receptors stimulate the diaphragm and intercostal muscles to contract. This begins a breathing cycle. The respiratory drive regulates the rate and depth of the body's respirations to facilitate oxygenation and assist the kidneys with balancing blood pH. It is the interface between the nervous system and the respiratory system.

The Upper Airway

The upper airway consists of the nasal and oral pharynges. Both are hollow tubes surrounded by soft tissues that intersect at the back of the throat; both are capable of carrying air. Air entering the nose is filtered before entering the lungs, while air entering the mouth may contain particulate matter. Food is prevented from entering the main air tube, called the trachea, by the contraction of a muscular flap, called the epiglottis. During swallowing, the epiglottis lowers, directing food or liquids into the esophagus. Large contaminants or foreign bodies are removed from the upper airway by sneezing and coughing. Directly below the epiglottis is the larynx or voice box. The upper airway ends at the larynx.

The Lower Airway

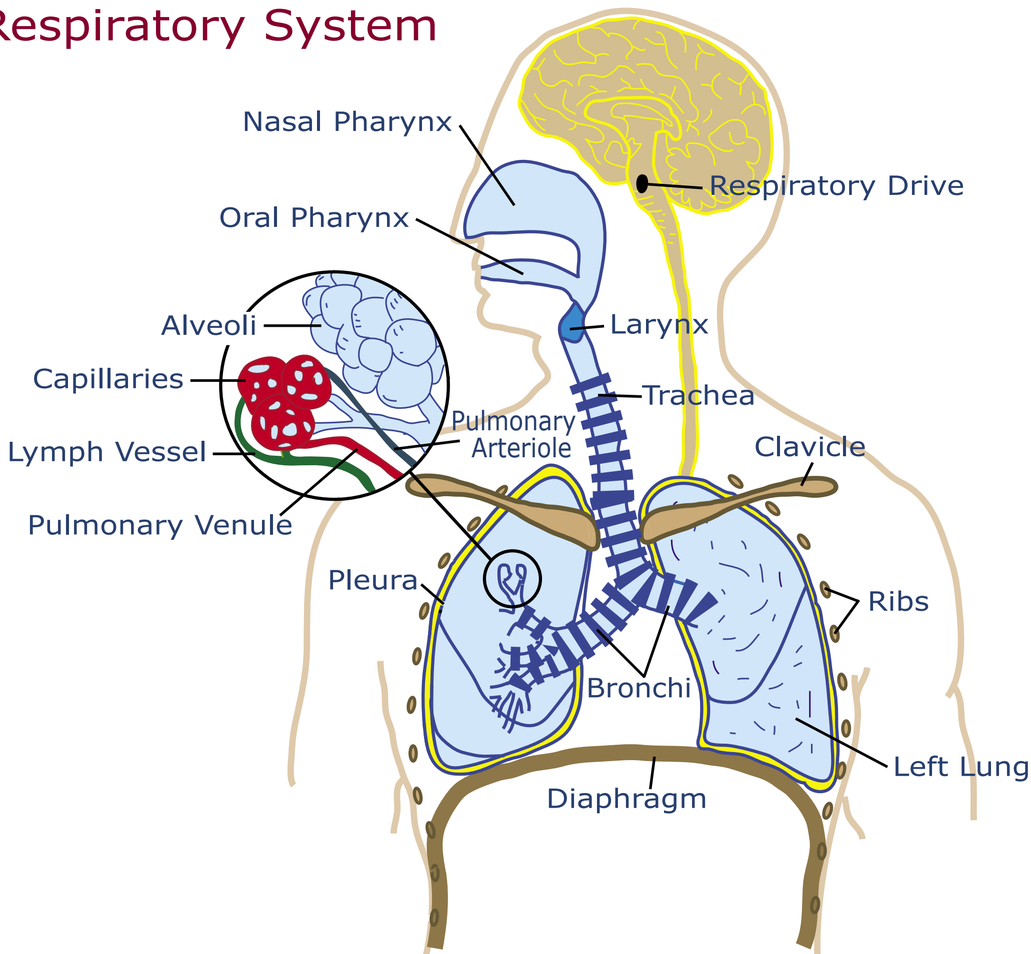
The lower airway is a series of air tubes that begin with the trachea. Immediately below the larynx, the trachea divides into bronchi, then subdivides into secondary bronchi, then again into tertiary bronchi, and then finally into bronchioles, before terminating in the alveoli. The walls of the larger tubes, the trachea and bronchi, are supported by cartilage and are lined with smooth muscle and ciliated mucosa; cilia are small hair-like fibers that help remove tiny particulate matter from the bronchi. The smaller bronchioles consist almost entirely of smooth muscle and are covered by a mucous membrane. Within the lower airway, large particulate matter is removed by coughing while smaller particles are trapped by the mucous layer and expelled by ciliary action. An extensive lymphatic network within the lining of all the tubes is responsible for the removal of microscopic particles and organisms. The lower airway ends at the alveoli.

The Alveoli

The alveoli are microscopic air sacs or chambers completely enveloped by a capillary network. In structure, each air sac resembles a grape clustered with other grapes. It is through the alveolar walls that oxygen is exchanged for carbon dioxide. The alveoli are the interface between the respiratory system and the circulatory system. Both systems must be functioning to ensure the oxygenation of cells.

The circulatory system is responsible for transporting oxygen and carbon dioxide between the alveoli and cells. Once oxygen has diffused through the thin alveolar and capillary walls, it is quickly dissolved in the plasma. Because plasma can only hold a small amount of gas in solution, most of the oxygen binds with hemoglobin molecules in the red blood cells for transportation. Upon reaching its destination, the oxygen is released into the plasma, passes through the capillary walls into the tissue, and then diffuses into the cells where it is used to produce energy. Simultaneously, carbon dioxide diffuses from

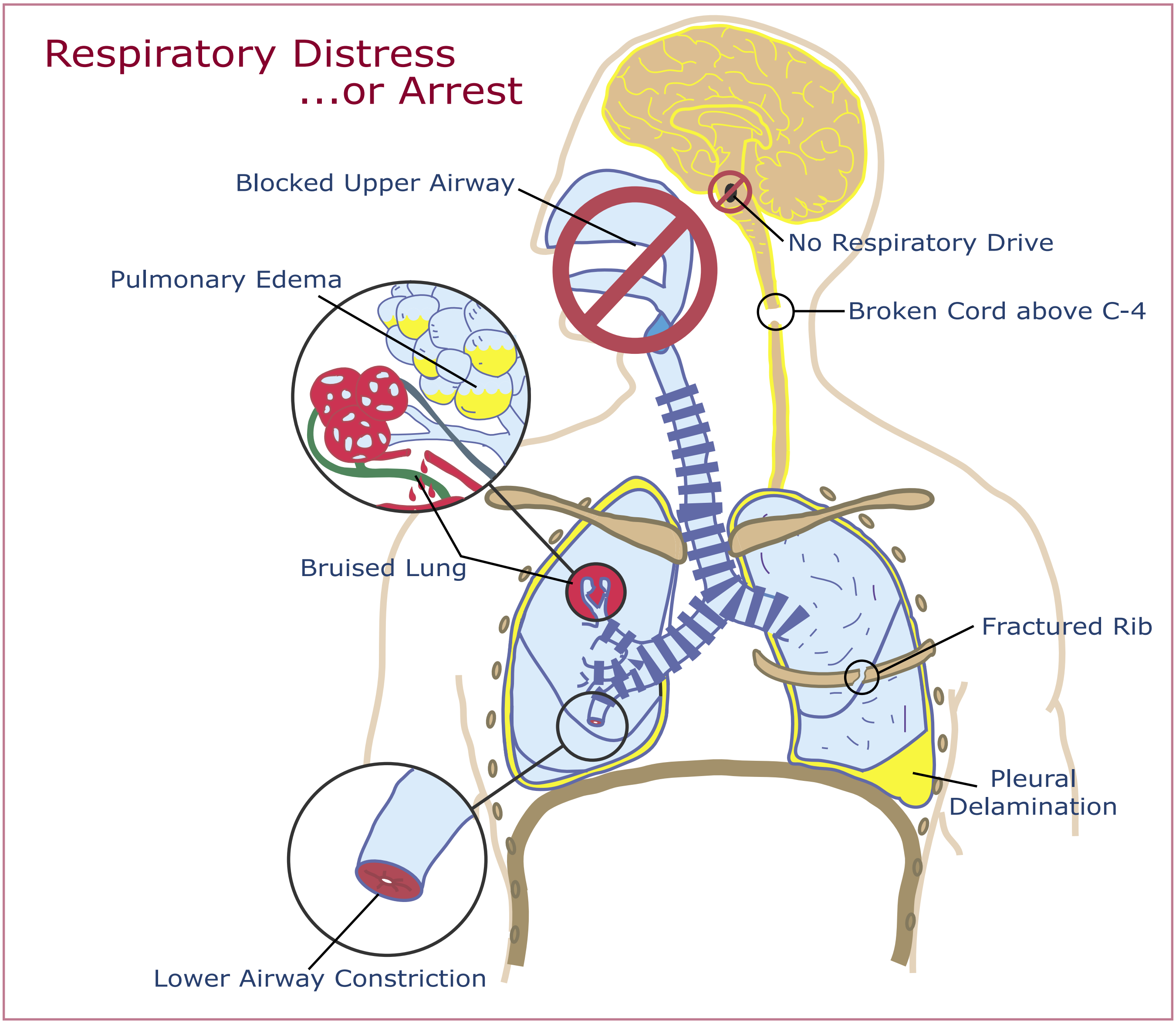
The Respiratory System



the cells into the adjacent capillaries. Carbon dioxide is carried by the blood in three ways: a small amount remains dissolved in the plasma as a solute; approximately one third combines with hydrogen ions and is carried in the red blood cells as carbonic acid; and, the remainder, over half, is carried in the plasma as a bicarbonate ion. Once in the lungs, the carbonic acid breaks down into water and carbon dioxide, diffuses into the alveoli, and is exhaled. The breakdown of carbonic acid and the elimination of the resulting water and carbon dioxide decreases the acidity of the blood (increases blood pH). Prolonged rapid respirations (hyperventilation) may lead to respiratory alkalosis if too much carbon dioxide is lost.

The Musculoskeletal Structure

The musculoskeletal structure of the respiratory system includes the sternum, ribs, and thoracic vertebrae; the diaphragm and intercostal muscles; and, the lungs and their pleura. The bone and cartilage of the sternum, ribs, and thoracic vertebrae provide support, while the intercostal muscles allow for movement. Together, these components form the chest wall. As the intercostal muscles contract, the ribs pivot along the spine and lift anteriorly, causing the chest to expand both externally and internally. The diaphragm is a large muscle that separates the chest cavity from the abdominal cavity. When stimulated, it contracts downward pushing the abdominal organs out of the way to internally expand the chest cavity. Movement of the diaphragm can be seen as an expansion in the upper abdominal quadrants (aka: belly breathing). The interior of the chest wall, or thoracic cavity, and diaphragm are lined with a smooth resilient membrane, known as the parietal pleura. The lungs are enclosed by a second membrane, the visceral pleura, that lies against the parietal pleura separated only by a lubricating fluid. The parietal and visceral pleuras separate the lungs from the middle section of the thoracic cavity (mediastinum) that contains



the heart. The lungs contain the lower airway, the alveoli and the blood vessels that are responsible for the delivery of oxygen and the removal of carbon dioxide. In their most basic form, the lungs are a series of air tubes and sacs tied to a second series of tubes containing blood and surrounded by a stuff sack. It is the integrity of the individual pleura and the surface tension of the fluid between them that permits the lungs to expand with the contraction of the chest and the diaphragm.

Respiratory Distress & Arrest

The major problems of the respiratory system are a complete or partial failure of the system's ability to supply the blood with oxygen and remove carbon dioxide. Partial failure of any of the system's components may cause respiratory distress, while complete failure will cause respiratory arrest and potentially death.

The respiratory drive may be damaged by head trauma, toxins, lack of oxygen (hypoxia), electricity, stroke, altitude, etc. Serious damage leads to a decrease in the patient's level of consciousness and a decreased respiratory rate that is rapidly followed by respiratory arrest. Problems in the upper airway are usually related to a complete or partial blockage. Blockage may occur from foreign objects (usually food or gum), localized swelling, fluids (typically blood or vomitus), or simply poor positioning of an unresponsive patient. Lower airway problems are usually related to the constriction of the smooth muscular lining of the respiratory tree due to a bronchial spasm and/or swelling. Common causes range from asthma to anaphylaxis to smoke inhalation. If the alveoli fill with fluid, as occurs with congestive heart failure, pneumonia, high-altitude pulmonary edema, and after near drowning or smoke inhalation, the gas exchange cannot take place. If the integrity of the chest wall or diaphragm is broken during trauma, air or blood can leak into the pleural space and prevent one or both lungs from inflating. These types of injuries are medically referred to as hemothorax, pneumothorax, hemopneumothorax, or tension pneumothorax depending on whether blood, air, or both are responsible for the collapse of the patient's lung and whether one lung is so badly damaged that the leaking air and/or blood puts pressure on the patient's opposing lung and heart; the latter quickly leads to death if not promptly treated. An abrupt pressure change through trauma or an improper ascent with SCUBA may rupture multiple alveoli and cause a similar phenomenon.

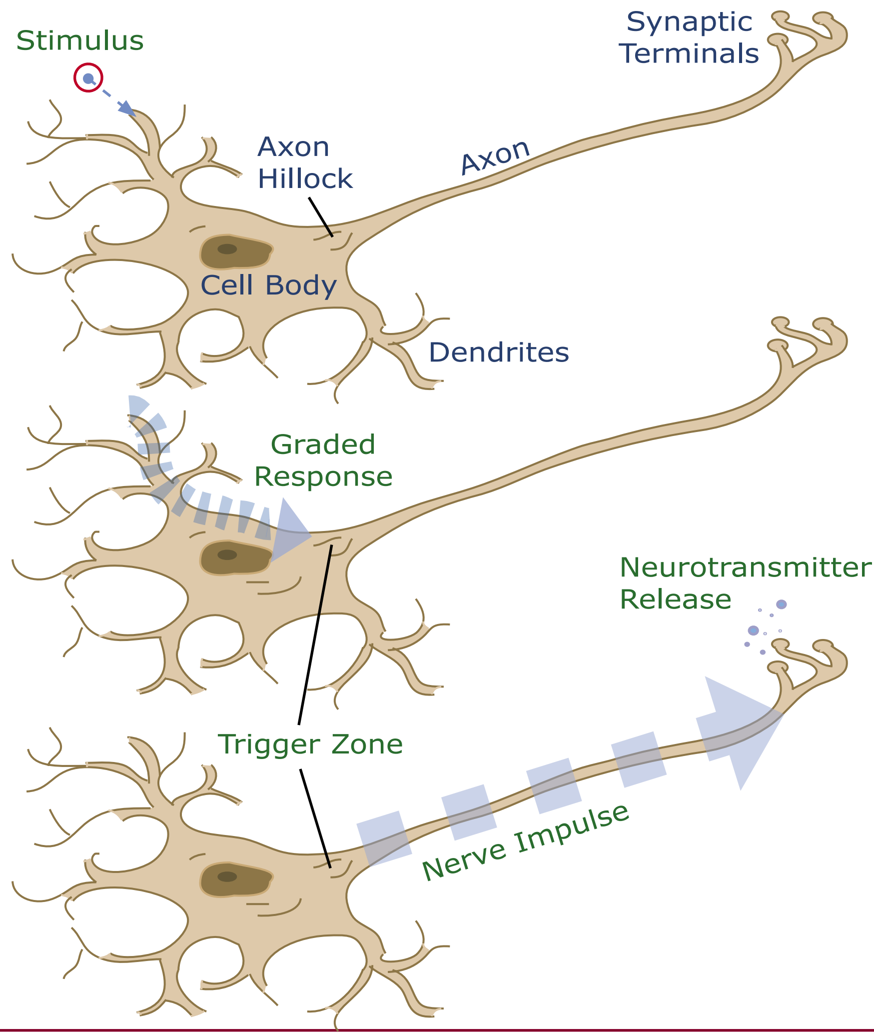
The Nervous System

The nervous system works with the endocrine system to maintain homeostasis by generating and sending the electrochemical signals that provide control and integration for most body functions. .

There are two types of cells within the nervous system: nerve cells, or neurons, and neuroglia. Neurons are responsible for generating and carrying the electrochemical signals that control the body; neuroglia are specialized cells that support neurons. Structurally, the nervous system is divided into the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS is further subdivided into the brain and spinal cord. The cells of the CNS are delicate and well protected by tough stuff sacks, circulating cerebrospinal fluid (CSF), and bone; damage to these cells is permanent. The nerves of the peripheral nervous system are far stronger and require less protection; they tend to follow the medial aspect of the long bones as they travel through the extremities. Peripheral nerves are capable of regeneration.

Transmission of a Nerve Impulse

A chemical or electrical stimulus initiates a graded response along a neuron's cell membrane. If the graded response is strong enough to reach the axon hillock and exceed the hillock's threshold, it triggers a nerve impulse that travels the length of the axon. When the impulse reaches the synaptic knobs, neurotransmitters are released.



On a functional level, the nervous system is divided into two divisions: the voluntary (somatic) nervous system and the involuntary (autonomic) nervous system. The voluntary division of the nervous system contains both sensory and motor nerves. Sensory nerves carry input to the spinal cord and brain, while motor nerves carry messages from them. Through its nerves, the somatic nervous system controls conscious functions, primarily striated muscle contractions. The autonomic division of the nervous system maintains or restores homeostasis by regulating smooth muscle contractions and the glandular secretion of hormones. Most autonomic functions are beyond conscious control.

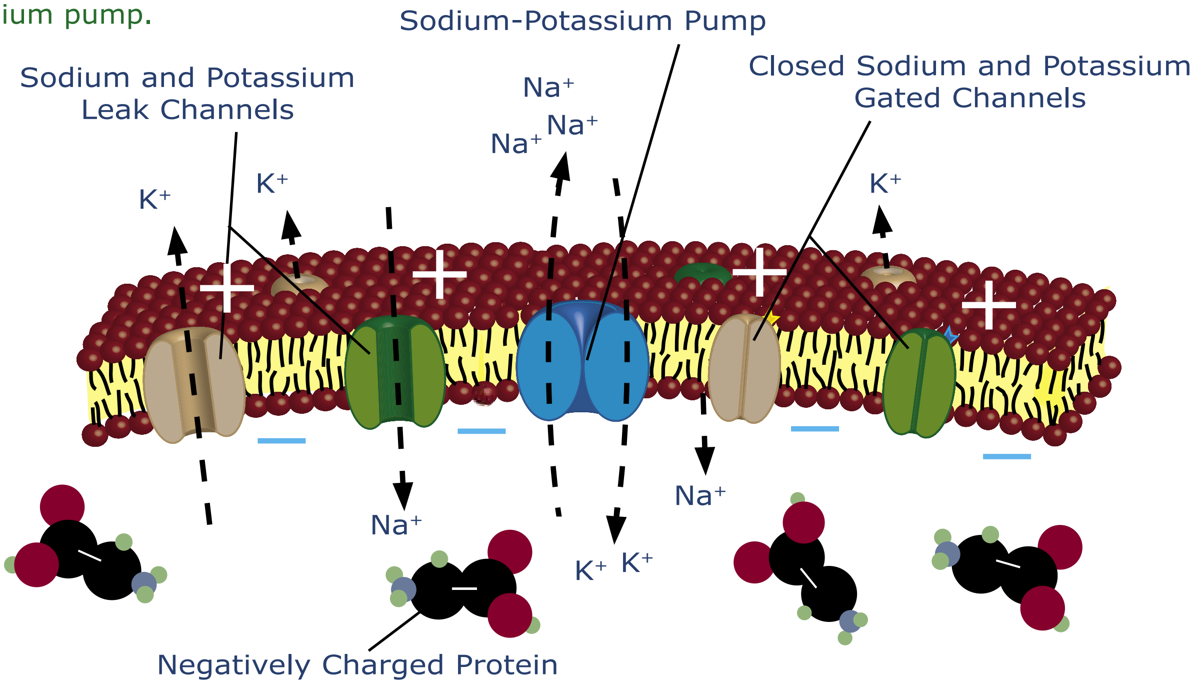
The autonomic division of the nervous system is subdivided into the sympathetic and the parasympathetic systems. The sympathetic system stimulates effectors (cells or organs) while the parasympathetic system inhibits them. Both systems continually transmit impulses to the same effector and act in an antagonistic manner, with the stronger impulse assuming control. Under normal conditions, the sympathetic system is responsible for waking us up and the parasympathetic system is responsible for sleep and digestion.

Neurons and Nerve Impulses

Neurons have three distinct parts—a cell body, a dendrite, and an axon—each with a specific purpose. The cell body houses the nucleus and, as is true for all cells, is responsible for maintaining the neuron's homeostasis. Dendrites receive a stimulus from the extracellular environment, from a neural receptor, or from another neuron and send a local or graded impulse to the cell body and axon. If the graded signal is strong enough to overcome the stimulus threshold at the start of an axon (axon hillock), it initiates an electrical impulse that continues along the axon to its terminus where it communicates with another neural cell, a muscle cell, or other effector via specialized chemicals called neurotransmitters. Graded signals occur in all cells in response to environmental stimuli and trigger changes in cell function. They are a local phenomenon and the signal travels only a short distance before dissipating; graded signals do NOT affect the entire cell membrane. Motor neurons control cells by releasing neurotransmitters near the cell that stimulate a graded response. In highly excitable neurons or muscle cells, a strong graded signal can initiate an electrical impulse that is capable of

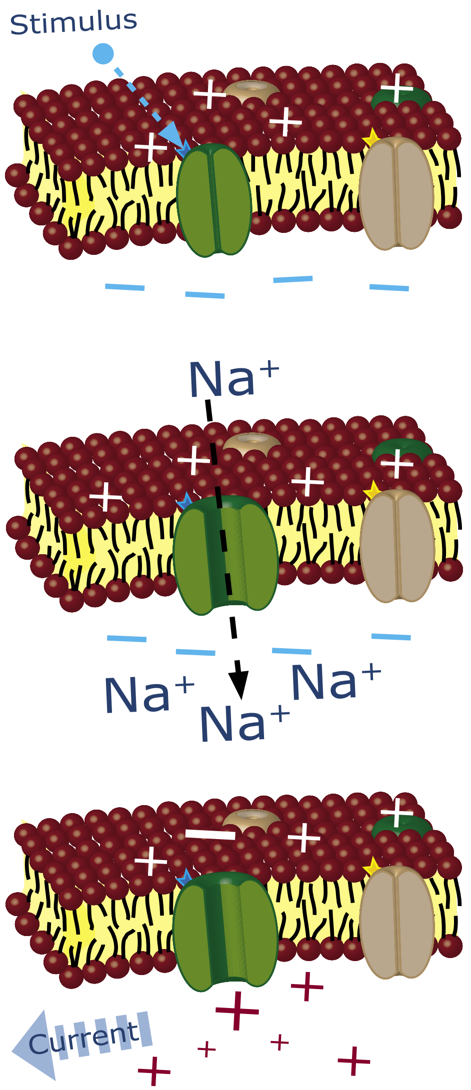
Resting Cell Membrane

At rest, cell membranes have an internal negative charge that is maintained by the sodium-potassium pump.



traveling long distances and affect the entire cell membrane. The motor and sensory neurons of the extremities are several feet long in an adult. These nerve impulses originate from one of three points: a sensory receptor, the spinal cord via a reflex arc, or the brain.

Nervous system signals are electrochemical in nature and directly related to the concentration of electrolytes in the extracellular and intracellular fluids. The intracellular fluid contains more potassium (K^+) and protein (A^-) ions, while the extracellular fluid has more sodium (Na^+) and chloride (Cl^-) ions. There are two types of protein channels in a neuron's cell membrane: leak channels that are always open and gated channels that open only in response to a stimulus. Ions move down the concentration gradient and continually diffuse through specific leak channels in the cell membrane. Because there are more potassium leak channels than sodium leak channels, potassium diffuses out of the cell faster than sodium leaks into the cell. The lipid structure of the cell's membrane acts as a layer of insulation permitting opposing electrical charges to exist simultaneously on either side of the membrane. The net movement of the sodium and potassium ions through the cell membrane, in combination with the negatively charged protein ions that are too big to pass through the membrane channels, leaves the inside of the membrane with a slight negative charge. The sodium-potassium pump acts to maintain the concentration gradient across the cell membrane by exchanging two potassium ions for three sodium ions. Without the sodium-potassium pump, the ion concentration would eventually equalize and neural communication as we know it would not exist.



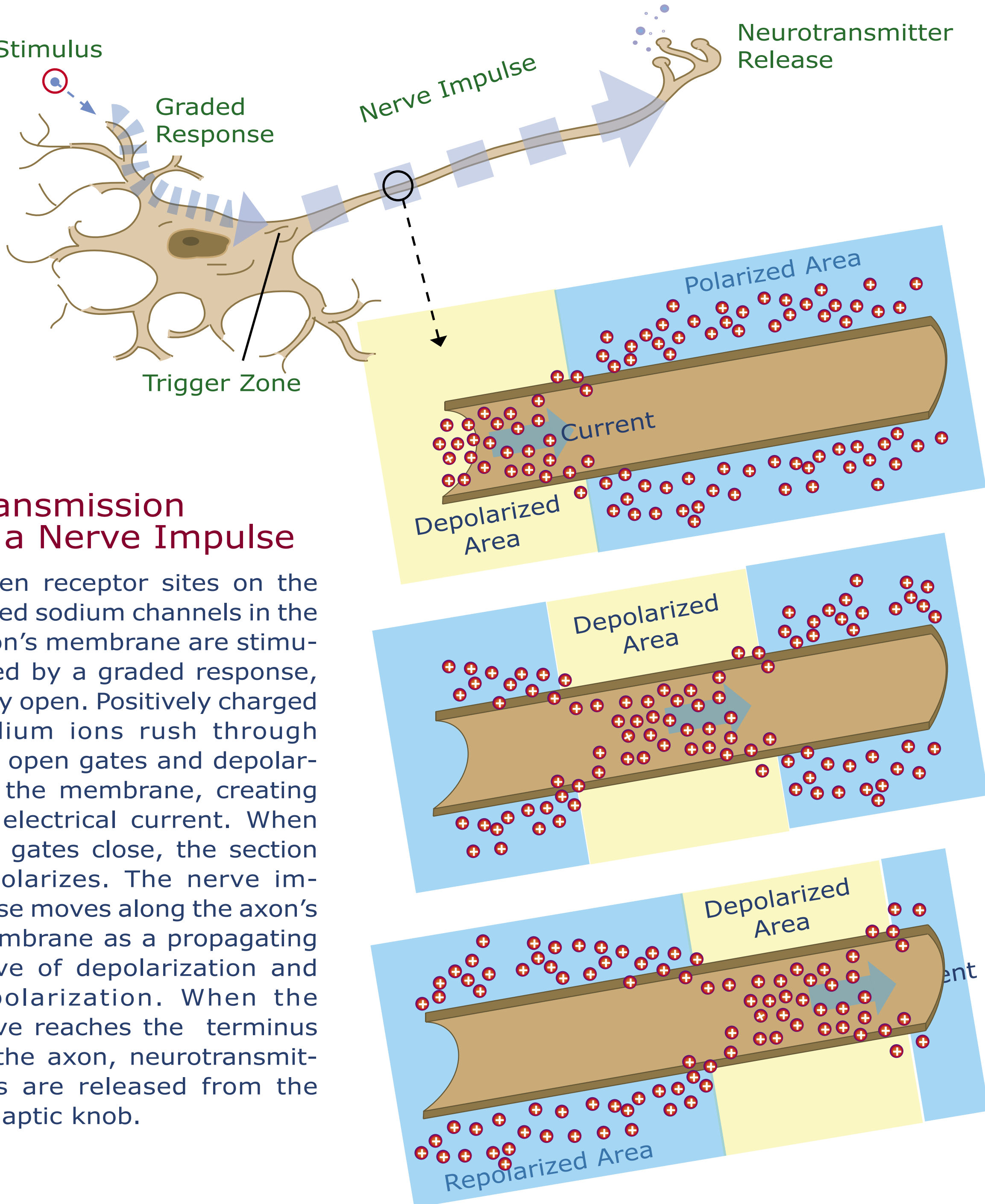
Ion Movement & Current

When chemicals or electricity stimulate the receptor site on a gated sodium channel, the channel opens and positively charged sodium ions flow into the cell, depolarizing the cell membrane at that point. When the cell membrane depolarizes, positive ions flow outward from the point of depolarization, creating a electrical current along the inside of the cell membrane towards the synaptic knob at the terminus of the axon.

In addition to moving down the concentration gradient, ions also move along electrical gradients from positive to negative and vice versa. Electrical and chemical stimuli change the permeability of the cell membrane by opening gated ion channels. If sodium gates are opened, sodium ions flow through the channel and the negatively charged interior cell membrane becomes positive at that point. Nearby negative ions move inward towards the positively charged region and the positive ions move outward; the ion movement along the interior of the cell membrane creates an electrical current that eventually dissipates (graded signal) or, if strong enough, stimulates a nerve impulse in the axon. Typically, nerve impulses are generated at the axon hillock and flow like a wave to its other end. It is clinically important to note that a change in the ion (electrolyte) concentration on either side of a cell membrane or a change in the permeability of the cell membrane is capable of generating a signal.

Neuroglia

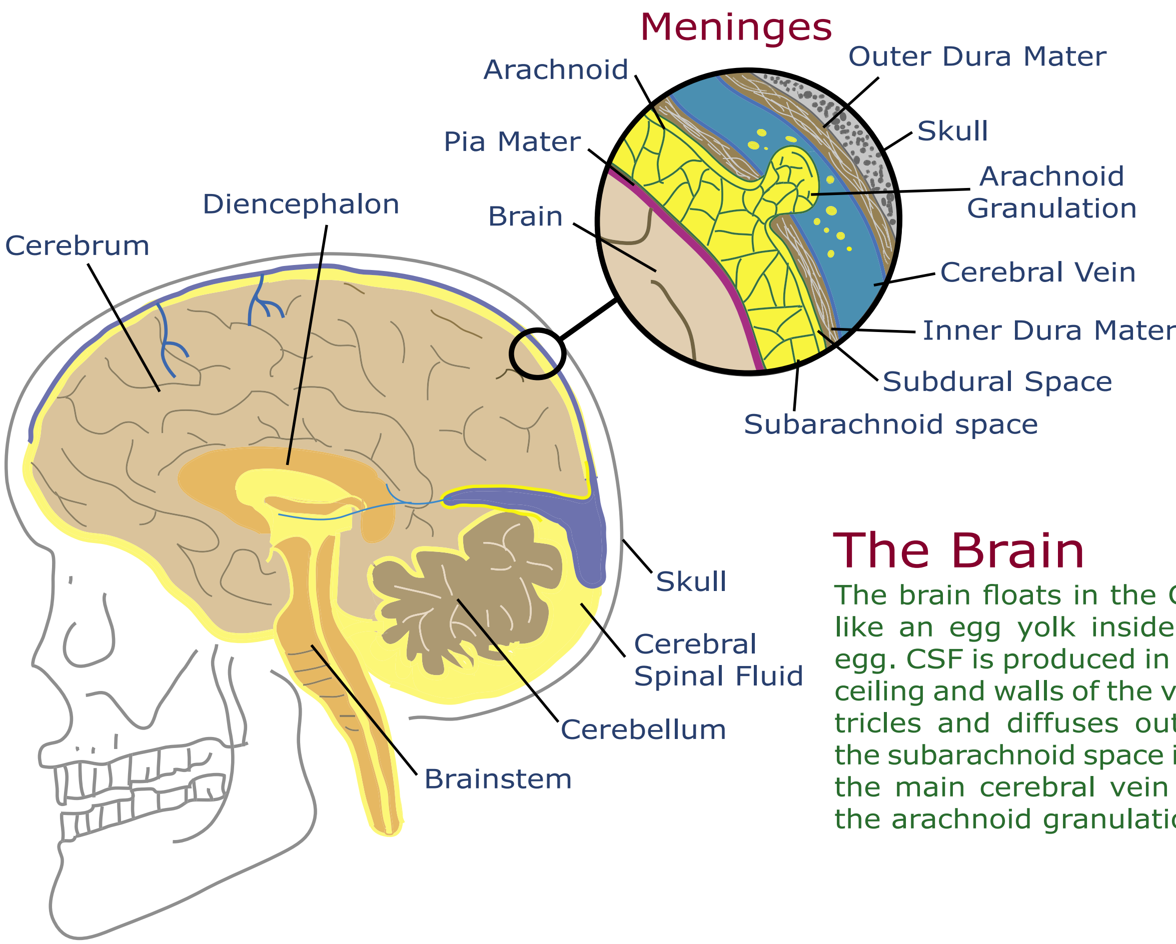
There are four types of neuroglia in the central nervous system: astrocytes, microglia, ependymal cells, and oligo-



Transmission of a Nerve Impulse

When receptor sites on the gated sodium channels in the axon's membrane are stimulated by a graded response, they open. Positively charged sodium ions rush through the open gates and depolarize the membrane, creating an electrical current. When the gates close, the section repolarizes. The nerve impulse moves along the axon's membrane as a propagating wave of depolarization and repolarization. When the wave reaches the terminus of the axon, neurotransmitters are released from the synaptic knob.

dendrocytes; and two in the peripheral nervous system: satellite cells and Schwann cells. Astrocytes are star-shaped cells that make up roughly half of the mass of the brain. In addition to providing the basic structure of the brain, their projections surround almost all of the brain's capillary network and help to create an impermeable blood-brain barrier to many circulating compounds and even the cells of the immune system. In general, only fat-soluble compounds and water can cross the blood-brain barrier freely; water-soluble compounds, including ions, require the assistance of specific carrier cells in order to diffuse into the interstitial tissue. The blood-brain barrier is necessary to maintain the stability of the fluid environment surrounding the brain. In this way, the normal changes in the blood's fluid matrix from general metabolism will not negatively impact brain function, as metabolic waste, many proteins,



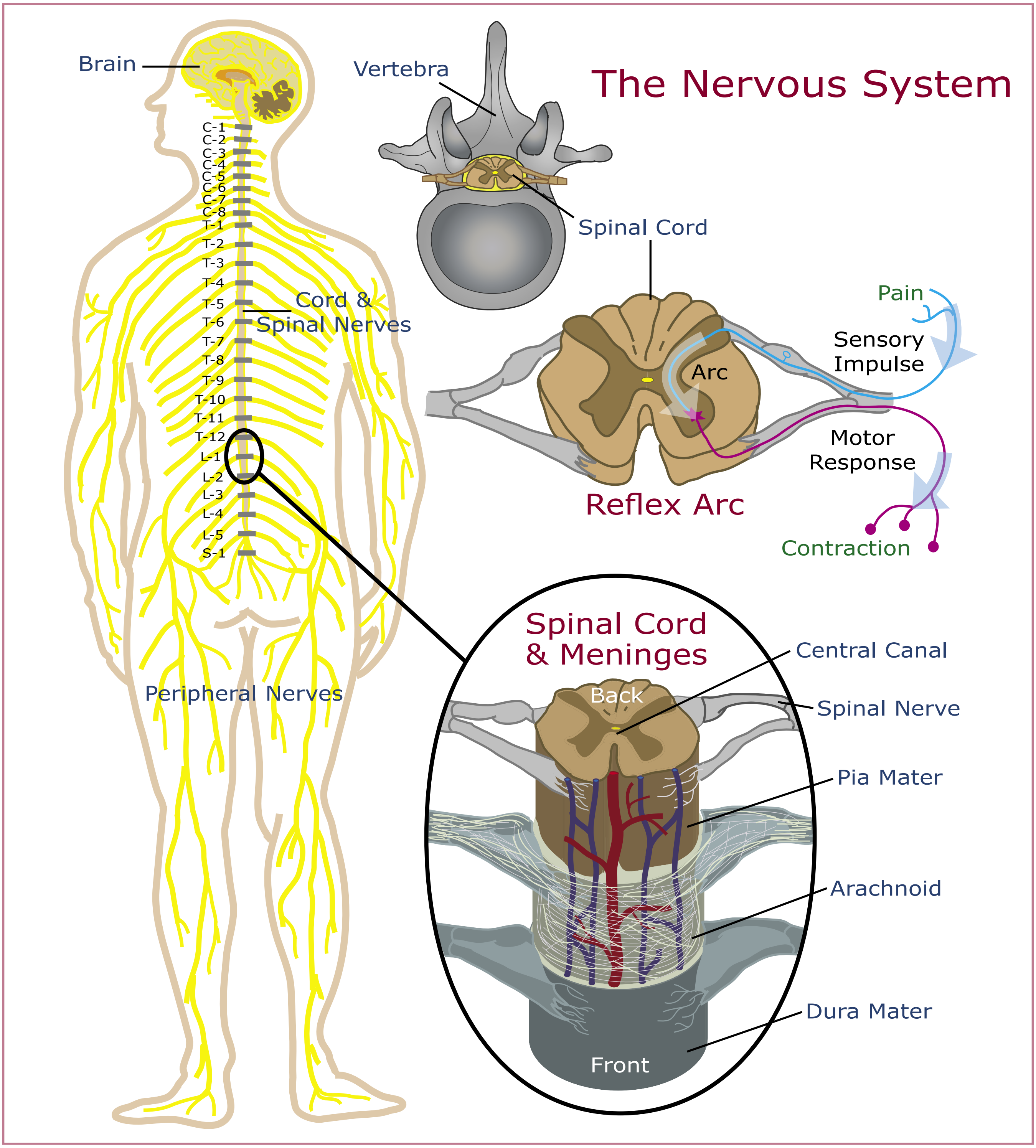
The Brain

The brain floats in the CSF like an egg yolk inside an egg. CSF is produced in the ceiling and walls of the ventricles and diffuses out of the subarachnoid space into the main cerebral vein via the arachnoid granulation.

drugs, and toxins are denied entry. Only the parts of the brainstem that require chemical input from the body's organs via the blood are exempt. Microglia are responsible for maintaining the health of neurons. They are essentially the brain's private defense system and are necessary because the blood-brain barrier denies the brain access to cells of the immune system. Ependymal cells line the tissue spaces and canals filled with cerebrospinal fluid (CSF) and have cilia to assist CSF circulation. While they separate CSF from the brain's interstitial fluid, they remain extremely permeable to ensure rapid diffusion of nutrients from the CSF into the brain tissue. Oligodendrocytes (CNS) and Schwann cells (PNS) wrap fatty extensions of their cell membranes, called myelin sheaths, around axons to insulate and increase the speed of neural transmissions. Schwann cells also assist with regenerating damaged peripheral nerves. Satellite cells surround and strengthen groups of cell bodies or ganglia in the PNS. This strengthens them which makes them stronger and more resistant to physical damage.

The Central Nervous System

The brain is the primary source of the signals necessary to control bodily functions. Its texture closely resembles spongy cottage cheese. While the brain comprises only three percent of the body's total weight, because of its high metabolism, it uses 25% of the body's oxygen and 20% of its sugar. Higher functions, such as sensory awareness, thought and personality, reside in the brain's outer layers known as the cerebrum, while the more basic autonomic functions, such as cardiac, vasomotor, and respiratory centers, lie within the central region of the brain, in the diencephalon and the brainstem. The diencephalon is hollow and filled with CSF; its sides form the thalamus and its bottom the hypothalamus. The thalamus is responsible for processing sensory information, while the hypothalamus connects to the pituitary gland and contains centers for emotions, autonomic function, and hormone production. The brainstem consists of the pons, midbrain, and medulla oblongata. The brainstem contains numerous reflex centers, such as hearing, smell, pupil respons-



es, coughing, sneezing, swallowing, and vomiting. The cerebellum lies adjacent to but outside the cerebrum and controls muscular coordination. Groups of specialized nerves carry signals from the brainstem throughout the brain, permitting it to function as a gestalt. The spinal cord is an extension of the brainstem. In both appearance and texture, the spinal cord resembles strands of "al dente" spaghetti. Both the brain and cord contain white and gray matter. Gray matter is primarily composed of cell bodies, while the white matter is made up of axons.

While its primary function is communication, the cord also contains reflex centers which respond directly to pain. When pain receptors in the skin, joint capsules, bone membranes and in the tissue surrounding blood vessels are stimulated, a signal is sent to the brain via sensory nerves and the spinal cord. On the way, sharp or abrupt pain is routed *across* the spinal cord through a reflex arc causing an immediate muscle contraction away from the source of the pain *before* the pain message actually reaches the brain and consciousness.

Both the brain and spinal cord are surrounded by three stuff sacks, called meninges, and bone. The skull protects the brain much like the shell of an egg protects its yolk and the spine protects the cord. The leather-like outermost meningeal layer, the dura mater, is fused to the lining of the skull and is very tough. Between the two layers of the dura, lies a thin space containing plasma and blood vessels. The innermost layer of the dura extends into the cerebrum and anchors the brain to the skull, further supporting its fragile tissue. A second narrow space below the dura, the subdural space, is filled with lymphatic fluid that serves to lubricate the dura and the second meningeal layer, the arachnoid. Beneath the arachnoid membrane is the subarachnoid space. The subarachnoid space is a hollow elastic layer made of collagen fibers and filled with CSF. The third meningeal layer, the pia, is attached directly to the brain and is highly vascular; it is also extremely delicate.

Both the brain and spinal cord are hollow. The brain contains four interconnected chambers or ventricles: two lateral chambers, one in each of the cerebral hemispheres, a central chamber in the diencephalon, and a fourth in the pons. The cord has a hollow canal running down its center. Each ventricle, the central canal of the cord, and the subarachnoid space contain cerebrospinal fluid (CSF). While the primary purpose of CSF is support and protection—the brain essentially floats in CSF like an egg yolk inside an egg—it also transports nutrients, chemical messengers and waste products. A specialized capillary network, called the choroid plexus, in each ventricle actively filters plasma and selected nutrients from the blood to produce CSF. Once produced, CSF freely circulates until it diffuses through small projections of the arachnoid membrane, the arachnoid granulations, into the superior sagittal sinus and the cerebral veins where it joins general circulation.

The Peripheral Nervous System

The nerves of the PNS resemble strong elastic cords and are primarily responsible for both sensory and motor communication. Sensory nerves carry messages, including pain, pressure, heat, cold, taste, sight, smell, and sound, back to the brain for processing. Conversely, motor nerves carry the brain's commands to specific muscle groups for action. Extreme stimulation of a sensory nerve causes the signal to arc across the spinal cord and send a preemptive message to local muscles to contract *before* the signal reaches the brain. In this manner, many injuries are avoided. In general, peripheral nerves follow the same routes through the body as do the major arteries and veins forming a neurovascular bundle. In the extremities, the neurovascular bundle follows the medial aspect of each limb, through the joints, to its terminus in the hands or feet. In this way, skeletal bones offer some protection from minor trauma.

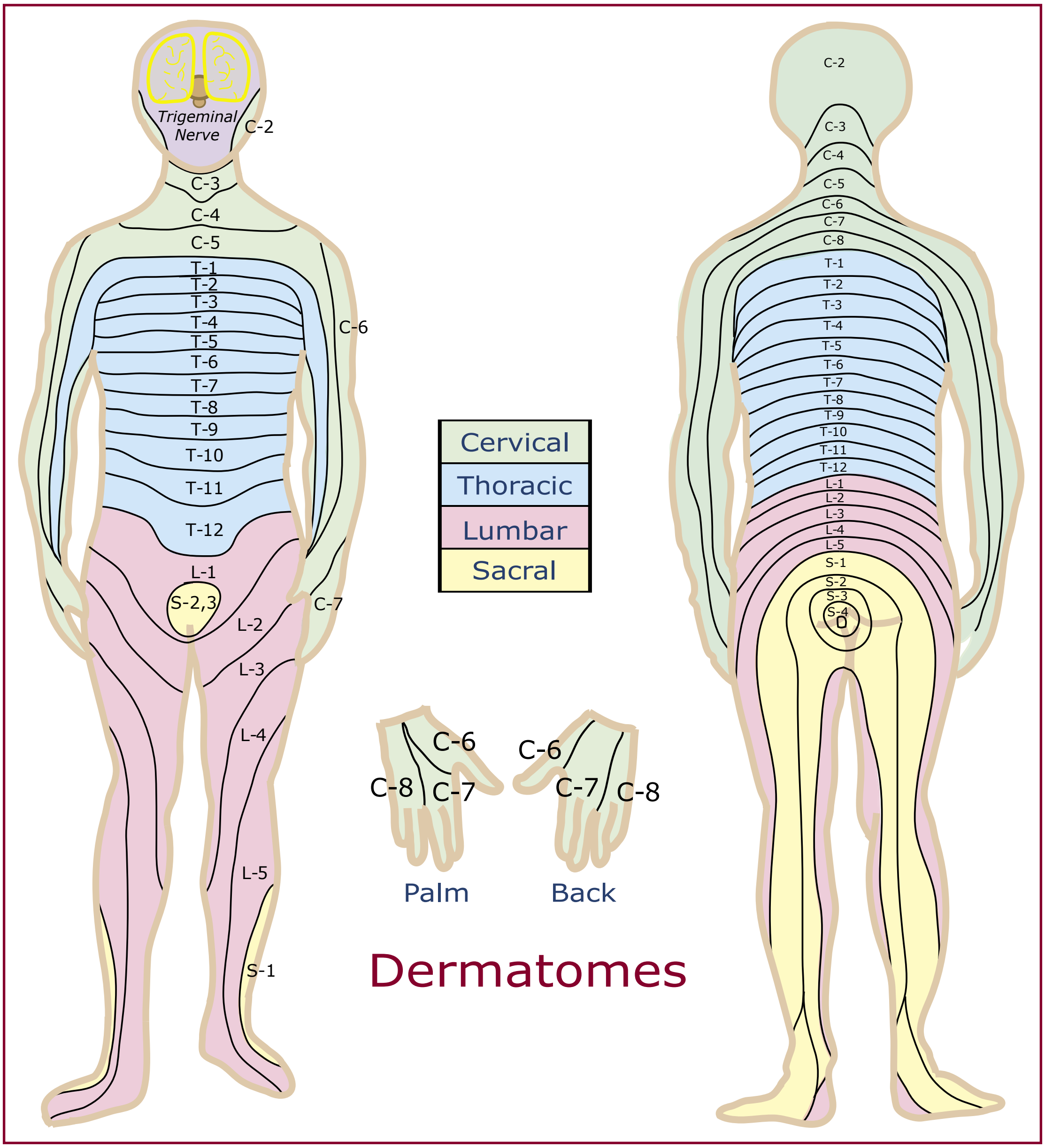
Spinal nerves branch from the cord at each vertebra and form the interface of the CNS with the PNS. Spinal nerves are mixed nerves capable of transmitting both sensory and motor messages. It is important to understand that each spinal nerve root enervates a specific region of the body, such as the skin, muscles, organs, etc. The sensory nerves serving the skin have been mapped; each zone, or dermatome, overlaps slightly. Only C-1 lacks sensory fibers to the skin; instead, the face is served by the three branches of the trigeminal nerve, one of the twelve cranial nerves that connect directly to the brain. Knowledge of a few of the spinal nerves, their pathways, and their functions can assist in the field assessment of trauma patients with a suspected spine injury. Clinically useful motor functions and their nerve roots are: wrist and finger extension and finger abduction/adduction C-7 and C-8, big toe/foot dorsiflexion L-5, and foot plantar flexion S-1 and S-2. Clinically useful sensory functions and their nerve roots are: top of the foot L-4 and L-5, and hands (front and back) C-6, C-7 and C-8. Refer to your handbook for the spine assessment (ruling-out) guidelines.

CNS Problems

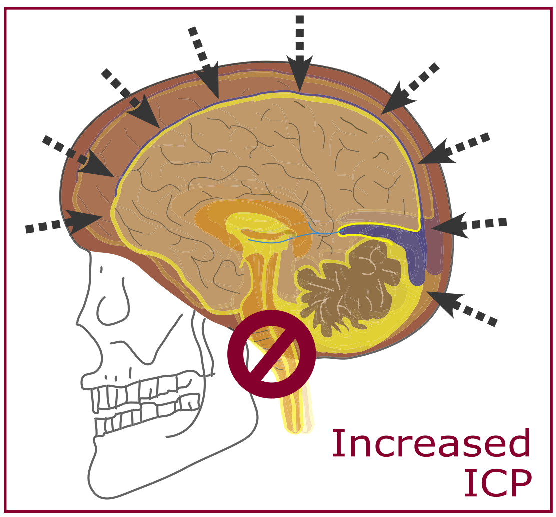
The cells of the central nervous system are extremely delicate and require a constant supply of nutrients, via blood and CSF, and a stable internal environment to function normally. Changes in oxygen concentration, available sugar, temperature, electrical impulses, body chemistry, and pressure may adversely affect the brain and alter the patient's level of consciousness. Significant changes often result in death.

Increased Intracranial Pressure (ICP)

An immediate life-threatening problem involv-



ing the brain is increased intracranial pressure. When brain cells become injured or die, the attendant cellular debris initiates the inflammatory process. If the damage is severe, localized swelling occurs within 24 hours of the insult. The swelling may occur quickly if caused by an arterial rupture, or more slowly, if due to a venous leak or inflammation. In the closed compartment of the skull, swelling means increased pressure. If the pressure builds to a point where it reduces perfusion to adjacent tissue, a negative spiral develops as the newly affected tissue dies. This results in additional swelling, a greater loss of perfusion, increased edema, and increasingly more pressure. If the cycle is not interrupted, the patient may die. Common causes of increased ICP are high altitude, suffocation, head trauma, and stroke.



Two mechanisms damage nerve fibers: pressure and cutting. Pressure on any nerve may interrupt its signals and cause numbness, pain and decreased function. Pressure applied for long periods of time may cause permanent nerve damage. The pressure may be *internally* caused by tissue damage and subsequent swelling from an injury or *externally* caused by poorly adjusted shoulder straps of a backpack or a splint that is too tight. The cutting of a nerve will effectively stop any communication beyond that point. Damage to the spinal cord is permanent, while peripheral nerves often regenerate or heal.

Autonomic Stress Response (ASR)

The autonomic nervous system responds to stress by stimulating either its sympathetic or its parasympathetic division. If the sympathetic nervous system is engaged, the body prepares for "fight or flight": pupils dilate to increase vision; pulse, respiration and blood pressure rates rise to meet an intense physical demand; awareness, often seen as anxiety, increases; sweating increases, while vasoconstriction leaves the skin pale, cool and moist; and endorphins are released to block pain. ***A patient experiencing a sympathetic ASR cannot give accurate information about their injuries. In most cases, the patient is unaware of any physical problems and may not exhibit abnormal signs or symptoms upon examination. Their vital sign pattern may mimic or mask volume shock.***

If the parasympathetic nervous system is stimulated, the patient becomes nauseated, dizzy, and may faint. Blood pools centrally around their digestive tract and their pulse, respiratory and blood pressure rates fall. Their skin is pale and cool. Upon awakening, the patient is often confused. ***A parasympathetic ASR may mimic the signs and symptoms of a concussion and make accurate assessment of a traumatic head injury difficult.***

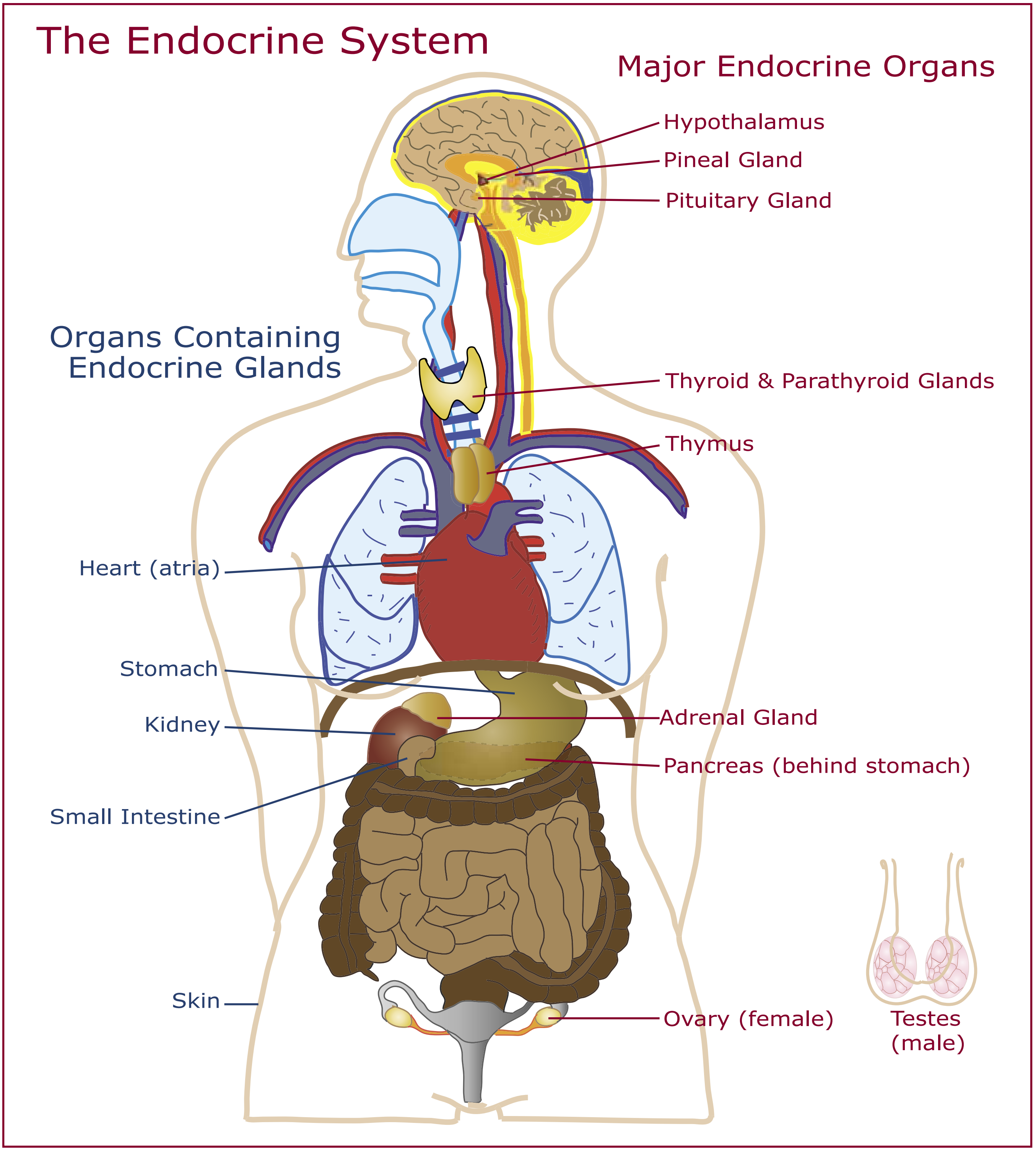
ASR, regardless of the type of response, is not life threatening. Given the removal of the stressful incident, time, and reassurance, its signs and symptoms will disappear. The danger lies not in the ASR, but in the possibility that a serious problem will go unrecognized and untreated because of a lack of physical signs and symptoms in the patient. ***Assume that all patients involved in a stressful incident, especially major trauma, have ASR. Treat***

Major Endocrine Organs & Effect

Hypothalamus	links nerves and hormones; sends regulatory hormones to pituitary gland
Pituitary Gland	controls other endocrine glands
Pineal Gland	controls body rhythms (wake/sleep cycles)
Thyroid Gland	controls rate of metabolism; can store its hormones
Parathyroid Glands	helps to regulate blood calcium levels
Thymus Gland	controls development of the immune system T-cells
Adrenal Gland	regulates metabolism of glucose, sodium and potassium; controls fluid balance
Pancreas	produces insulin and glucagon to respectively lower and raise blood glucose levels
Ovaries	produces female sex hormones
Testes	produces male sex hormones

Organs Containing Endocrine Glands & Effect

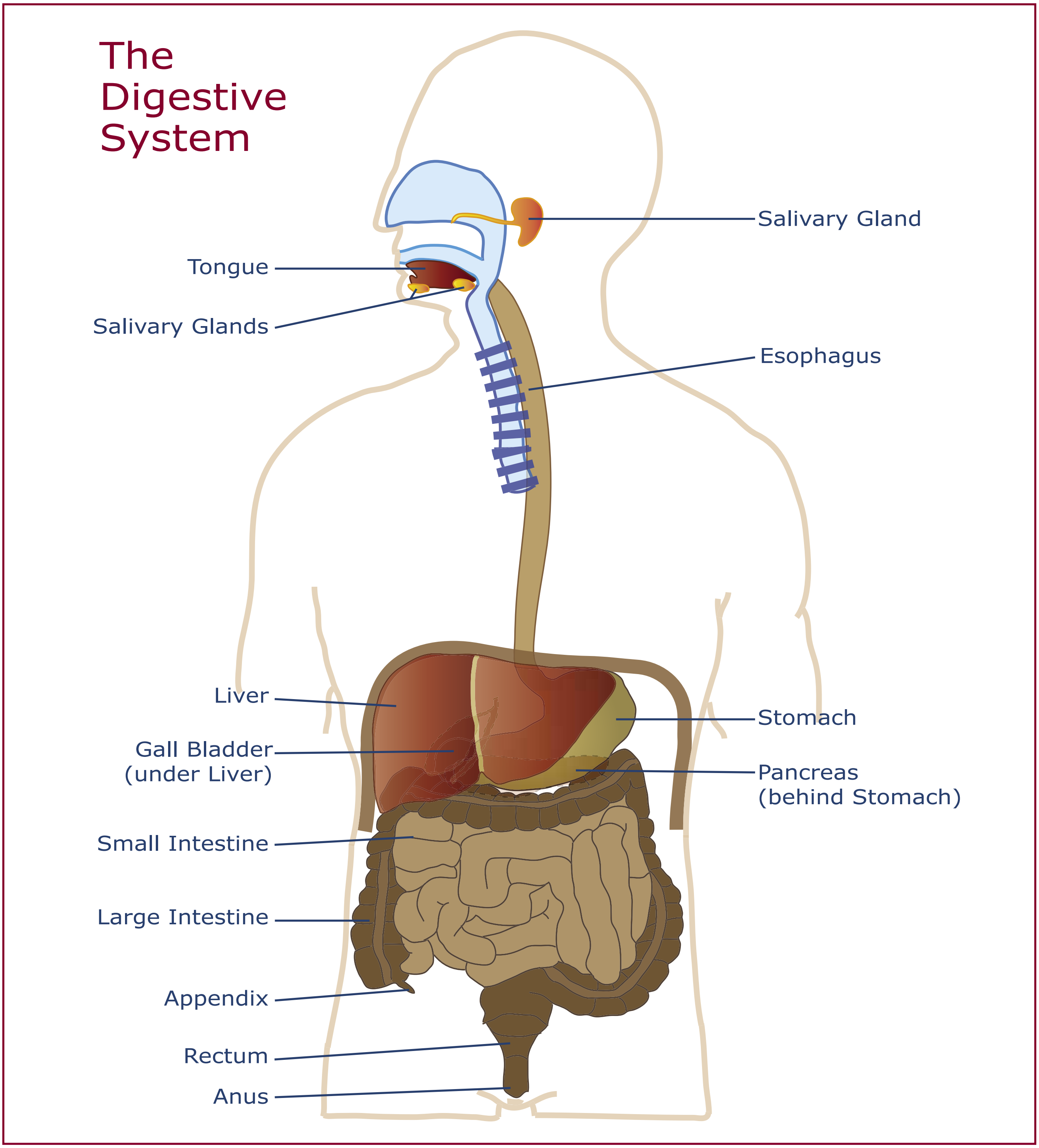
Heart	helps regulate fluid balance by controlling blood volume and pressure
Stomach	controls the release of digestive enzymes
Small Intestine	controls the release of digestive enzymes
Kidney	stimulates the production of red blood cells
Skin	produces vitamin D to stimulate the absorption of dietary calcium from the small intestine



all patients under these situations as if they have the worst possible injuries indicated by the mechanism of injury or illness (MOI).

The Endocrine System

The endocrine system works with the autonomic nervous system to maintain homeostasis. Once stimulated by nerve impulses, its ductless glands release hormones directly into the circulating blood. In contrast to the short, quick nerve impulses generated by the nervous system, body responses to hormones are both slower and longer lasting. Hormones regulate metabolism, fluid and electrolyte balance, blood pressure, blood sugar levels, digestion, growth and repair of tissue, and stress responses. Damage to any of the glands of the endocrine system can usually be attributed a medical mechanism and generally has serious consequences.



The Digestive System

The digestive system is a series of interconnected hollow organs, connecting tubes, and solid organs. Many of the hollow organs are muscular tubes themselves and collectively form a "main" digestive tube. This main tube begins with the mouth and continues down to include the pharynx, esophagus, stomach, and small intestine. From the end of the small intestine, it continues past the appendix into the large intestine and rectum before ending at the anus. This central tube is connected to the liver, gall bladder, and pancreas through the portal vein, bile duct, and pancreatic duct respectively.

The digestive system mechanically and chemically breaks down food, absorbs nutrients and water, and eliminates unusable material. Mechanical breakdown is accomplished initially by chewing and then through the coordinated muscular contractions of the stomach and small intestine. The chemical breakdown of food requires the presence of specific enzymes that are released as food travels through the digestive system. Enzymes chemically break down food into amino acids, simple sugars and fats. These simple substances are then prepared for absorption. The process begins when saliva is released in the mouth and the enzymes contained in the saliva digest starch. In the stomach, gastric juices containing hydrochloric acid are released to initiate protein digestion. Food leaves the stomach as a thick liquid and enters the first part of the small intestine (duodenum), where the gallbladder releases bile and the pancreas releases pancreatic juice. Bile emulsifies fats, while the pancreatic juices continue to break down proteins, fats, and starches. In addition to secreting digestive enzymes, the pancreas secretes insulin and glucagon. Insulin and glucagon are hormones that act to balance blood sugar levels. Insulin lowers blood sugar levels by increasing glucose (sugar) transport into cells, while glucagon acts to increase blood sugar by stimulating the liver to release glucose. The primary purpose of the small intestine is absorption. Nutrients pass directly through the intestinal mucosa into the bloodstream and are immediately transported to the liver for filtering before entering general circulation. In addition to acting as a filter, the liver functions as a storage chamber for glucose and vitamins. Food passes from the small intestine through a valve into a pouch-like structure, called the cecum then past the appendix and into the large intestine. The appendix is a finger-like structure that protrudes from the cecum. It serves as a reservoir for healthy gut bacteria to repopulate the gut after severe diarrheal infections. The large intestine removes water and solidifies fecal matter. Once formed, fecal matter is eliminated through the anus.

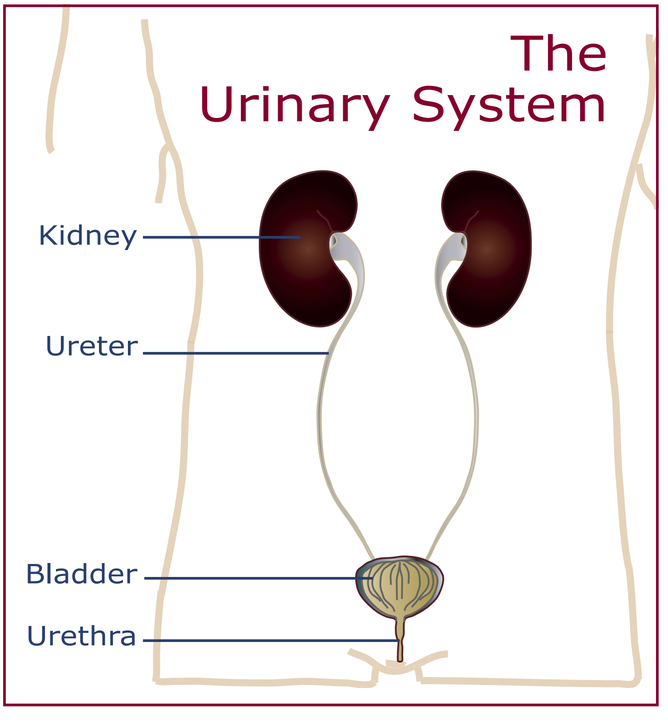
While the digestive organs are susceptible to disease, most problems with the digestive system are associated with the structure and function of its tubes. These tubes can become blocked, kinked, cut, ruptured, irritated by toxins, or infected.

The Urinary System

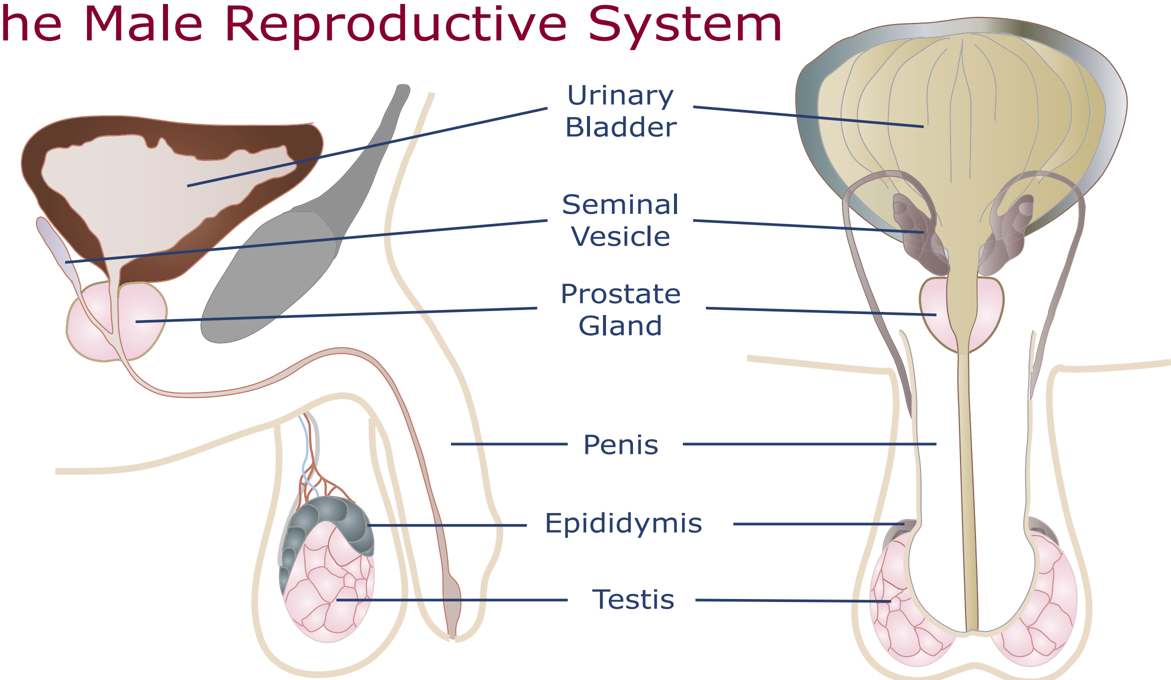
The urinary system is a collection of tubes and solid filter organs. It removes waste products from the blood and eliminates them from the body. A mucous membrane lines the urinary tubes in both men and women. The kidneys are the organs primarily responsible for waste removal. They lie in the rear of the abdominal cavity separated from the other abdominal organs by a strong membrane, called the parietal peritoneum, and are somewhat protected by the floating ribs. In addition to blood filtration, the kidneys balance pH, fluids, and electrolytes in the blood. As the kidneys remove waste from the blood, urine is formed and carried via tubes (ureters) to the bladder where it is collected prior to elimination. Urine is eliminated from the bladder through another tube, the urethra. In women, the urethra is quite short and emerges as a small opening in the anterior vagina. In men, it travels a significantly longer route through the penis.

Normal urine is clear or pale yellow in color. Cloudy urine usually indicates bleeding or infection. High doses of B vitamins will produce a dark yellow or orange-colored urine. The pH of urine is usually acidic, but it may become basic with a predominantly vegetable diet. A high-protein diet increases its acidity. Normal urine does not contain sugar.

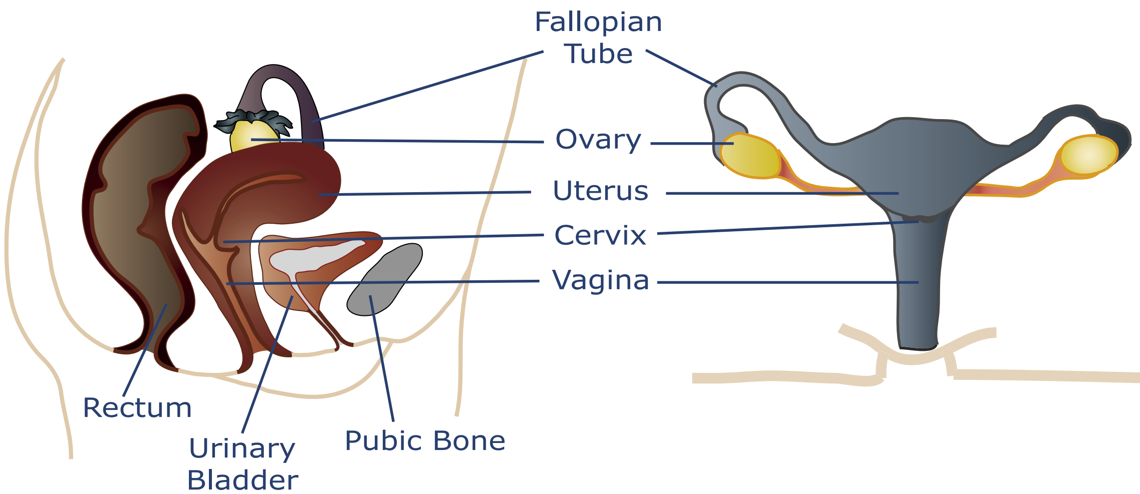
While the kidneys can be injured through trauma or by infection, the most common problems with the urinary system are associated with the blockage of its tubes from kidney stones in both sexes, bacterial infections in women, and sexually-transmitted diseases in men.



The Male Reproductive System



The Female Reproductive System



The Reproductive System

The reproductive system is a series of interconnecting tubes and sex glands. The function of the system in both men and women is reproduction of the species and the secretion of hormones necessary to develop and maintain secondary sex characteristics.

In men, the sex glands or testes are carried outside of the body in the scrotum with tubes connecting to the urethra. The prostate gland aids in semen production, lies below the urinary bladder, and surrounds the urethra, while the epididymis, the coiled tubes where sperm mature, lie above and behind each testis.

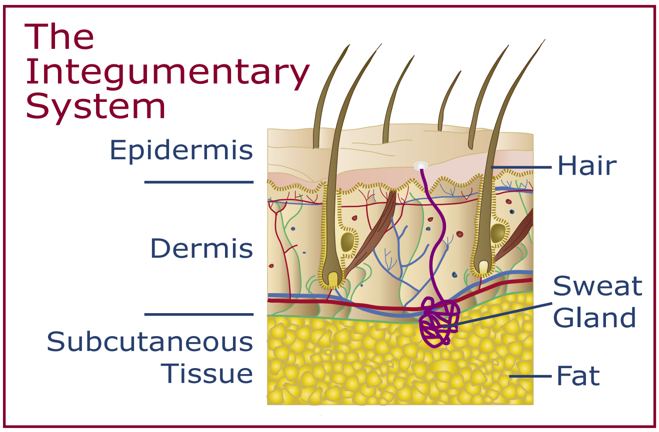
In women, the sex glands are internal (ovaries) with tubes leading to the pear-shaped uterus. The uterus is where the fertilized egg attaches and the fetus develops. The cervix is a muscular opening that separates the uterus from the vagina; its function is to preserve its sterility. A relatively short, muscular tube (vagina) leads from the cervix to the outside. Under normal conditions the mucous lining of the vagina contains a balanced mix of yeast and bacteria.

While both sexes may suffer from sexually transmitted diseases, yeast and bacterial infections are primarily female problems. Women may also suffer from problems arising during pregnancy and delivery. Men can suffer from a twisting of the blood vessels and spermatic cords leading to the testes (testicular torsion), an infection or enlargement of the prostate gland, or an infection of the epididymis.

The Integumentary System

The skin is the ultimate body stuff sack. It varies greatly in thickness, offering both physical protection from minor traumatic injury and denying access to potentially dangerous microorganisms. The outer layer of skin, the epidermis, is extremely tough and contains melanin, while the more sensitive underlying layer, the dermis, contains both blood vessels and nerve endings. Melanin offers protection from prolonged exposure to sunlight. Blood vessels within the dermis aid in thermoregulation as they contract to conserve heat or dilate to release it. Medically, skin color is not related to pigmentation, but to its perfusion status; hence, normal skin color is considered pink regardless of race. Sensory nerves in the dermis transmit environmental messages to the brain. Glands, also within the dermis, excrete water, electrolytes, and oils. Connective tissue (superficial fascia) lies directly underneath the dermis and ties it to underlying structures. A subcutaneous fat layer separates the layers of the skin from underlying muscle.

A number of mechanisms may cause damage to the skin. Any break in the integrity of the stuff sack may expose underlying structures to injury. Trauma may cut or abrade the skin, causing bleeding, tenderness, and pain. Extreme cold or heat may freeze or burn it. Infection may destroy cells locally and then move systemically.



The Musculoskeletal System

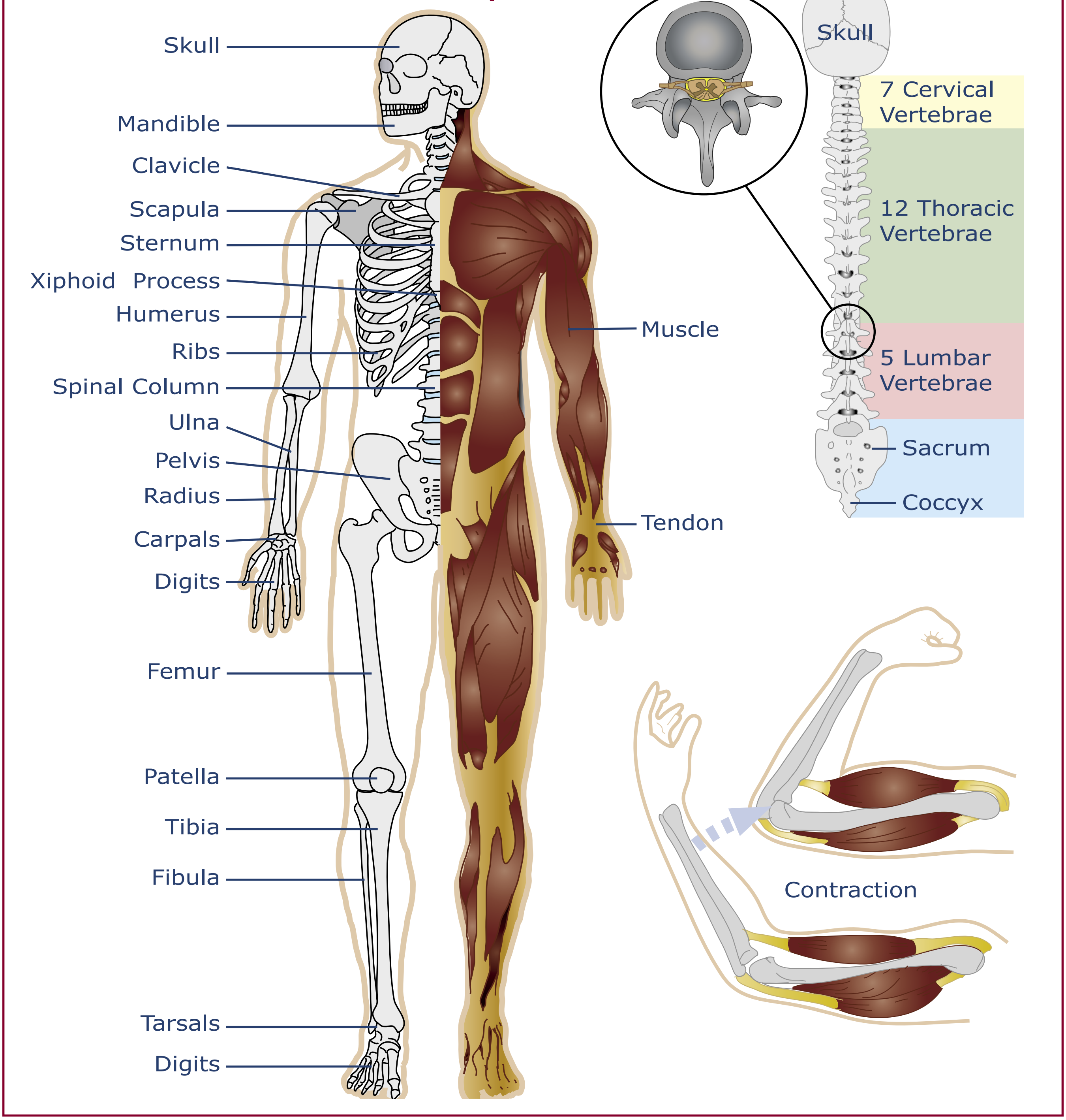
The musculoskeletal system is made up of bones, joints, cartilage, ligaments, tendons, and muscle. It provides the basis for support and movement. All components of the system require both perfusion and communication to develop, function, and heal. Arteries, veins, and nerves combine in the extremities to form neurovascular bundles that travel medially beside the long bones of the body to carry nerve impulses and blood to the hands and feet.

Bones form the rigid structure of the system and are highly vascular. They provide support and protection, are reservoirs for calcium and other minerals, and blood cells are formed in the bone marrow. Bones are surrounded by a highly vascular and innervated stuff sack, the periosteum, that contains special bone-forming cells known as osteoblasts. These bone cells, together with others called osteoclasts, regulate the density and strength of each bone. Continued stress on bones by walking, running, exercising, etc. causes an increase in both density and strength. Conversely, a decrease in stress-producing exercise causes a decrease in bone strength and density.

Joints hold bones together and permit movement. There are three basic types of joints in the human body: fibrous, cartilaginous, and synovial. Fibrous joints are formed when fibrous tissue securely binds the surfaces of the bones so tightly that no movement is possible (e.g.: skull sutures, teeth, radius/ulna, tibia/fibula). Cartilaginous joints have a limited amount of movement and are created when cartilage binds the bones together (e.g.: sternum to ribs, symphysis pubis). Synovial joints are very mobile and extremely complex; they make up the majority of the joints in the body (e.g.: elbow, knee, ankle, spine, etc.). In synovial joints the articulating bone ends are covered with cartilage and the entire joint is encased with a sleeve-like extension of the periosteum (bone stuff sack) that forms the joint capsule. Each capsule is lined with a slippery membrane that both contains and secretes a lubricating fluid. Ligaments are strong bands of fibrous tissue that complete the joint structure by firmly tying the bone ends together. Ligaments, like door hinges, help define the movement of synovial joints.

Muscle tissue comprises about half of the total weight of the body, is highly vascular, provides additional glucose storage, and produces most of the heat generated by the body. Muscles and tendons work together to create movement. Tendons are fibrous bands of tissue that connect muscle to bone. While tendons

The Musculoskeletal System



do not cause movement, they must be intact for movement to occur. When stimulated, muscle fibers contract and pull on the tendon. The tendon transfers the energy of the muscles to the bone, creating movement. Since muscles can only contract and relax, they must work in pairs through opposition to produce movement in two or more directions. ***While both bone and muscle are highly vascular, tendons, ligaments, and cartilage have decreasingly less perfusion.***

Problems with the musculoskeletal system are usually those associated with traumatic injury and classified as stable or unstable. Significant musculoskeletal damage may indicate life-threatening internal injury.

Body Defenses

The body has three levels to its defense system: the skin and mucous membranes, nonspecific chemical and cellular responses, and the immune system. Each level is closely linked to the others and often responds in concert. Understanding the basic physiology of each level of the body's defenses provides a platform for successful prevention and intervention.

Nonspecific Body Defenses

As long as the skin and mucous membranes remain intact, they provide a mechanical barrier to pathogens and toxins. Skin and mucous membrane secretions are antimicrobial and help to protect against infection.

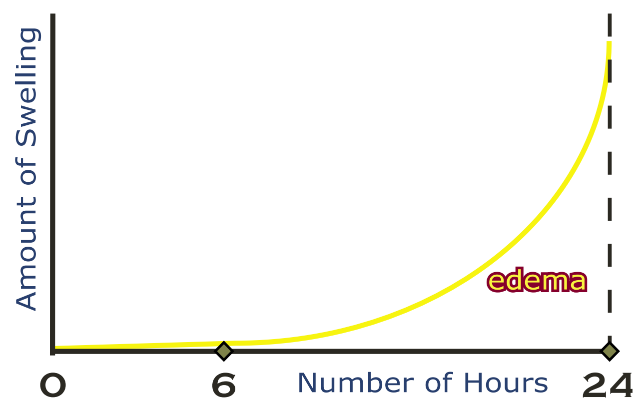
The second line of defense is also nonspecific and relies on chemical and cellular responses. Phagocytes, a type of white blood cell, engulf and destroy pathogens that penetrate the skin and/or mucous membranes. Natural killer cells directly attack and destroy infected and cancerous cells before the immune system is fully mobilized. The inflammatory response isolates the damage, assists in the destruction of invading pathogens, and begins the repair process. Antimicrobial proteins, complement and interferon, are present at all times in the blood and plasma. Complement binds to the cell membrane of invading microorganisms and causes them to explode or lyse. Interferon enters virus-infected cells and interferes with the virus's ability to replicate. Phagocytes actively engaged in fighting invading microorganisms secrete chemicals, called pyrogens, that stimulate the brain to raise the body's temperature. Low and moderate fevers (≤ 102º F) increase general metabolism, raise the effectiveness of all the body's defenses, and speed repair processes; they also tend to suppress reproduction of most pathogens. High fevers are dangerous because too much heat breaks down (denatures) proteins and inactivates the enzymes required for normal body processes.

The Inflammatory Response

When cells are damaged or destroyed by any MOI, a chemical "alarm" is sounded, which activates the immune system and a complex healing process known as the inflammatory response. Numerous chemicals such as histamine, kinins, prostaglandins, complement, and lymphokines, are released locally by the injured cells, mast cells, nerve endings, platelets, and white blood cells (WBC). Together, the chemicals act to increase the permeability of the local capillary network and to encourage healing. Clotting proteins build a fine net designed to wall off the damaged area and keep microorganisms out of healthy tissue. At the same time, specialized white blood cells, called phagocytes, move across the capillary walls and into the damaged tissue. Once there, the phagocytes begin cleaning up the cellular debris and actively devouring any bacteria or toxins present. The area remains "inflamed" until most of the damage has been repaired.

Vasodilation, a component of the inflammatory response, increases the local capillary pressure and forces plasma to move across the vessel walls into the extracellular space. Plasma continues to accumulate in the extracellular space until the pressure is equalized. The extra fluid (edema) helps to dilute any harmful substances and brings in the extra oxygen, nutrients, and clotting proteins necessary for repair. The clotting proteins form a gel-like fibrin mesh that act as an internal protective barrier and prevent the spread of pathogens to other areas. The mesh also acts as a framework for permanent repair.

Swelling due to Inflammation



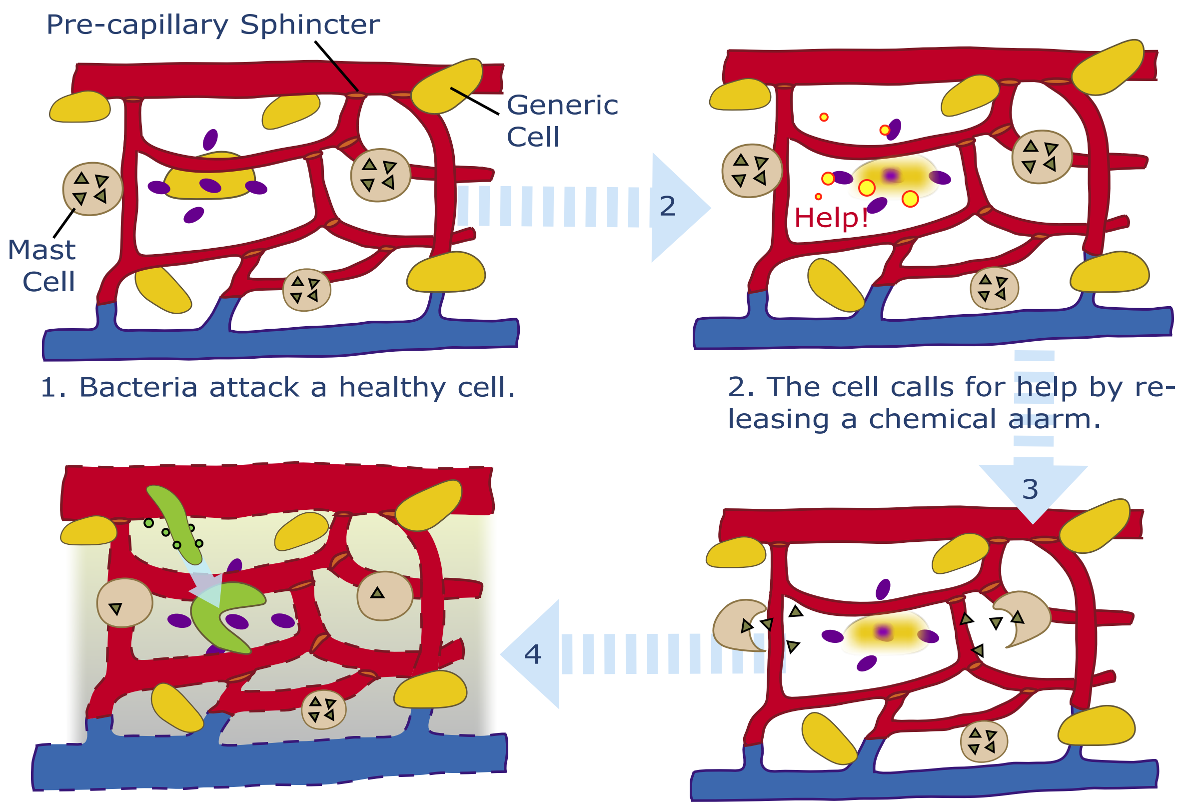
Local pain, redness, heat, and swelling are signs and symptoms of a healthy inflammatory response. The influx of fluid (edema) causes pain as local nerve endings are stimulated. Pain also results from the presence of toxins, a sudden decrease in nutrients and the sensitizing effects of prostaglandins and kinins. Non-steroidal anti-inflammatory drugs (NSAIDs) relieve pain by inhibiting prostaglandin synthesis. In addition to causing pain, prostaglandins decrease collagen production and slow surface healing. While this is helpful for deep wounds that are likely to become infected because it aids in drainage, it is not necessary for superficial wounds. The vasodilation causes redness and increased heat as more blood enters the damaged tissue. Another sign of increased permeability and vasodilation is localized swelling; the edema (and therefore the swelling) is confined to the stuff sack that surrounds the leaky tissue (e.g.: muscle facia, organ membranes, skin, etc.) Generally the greater the tissue damage, the greater the swelling. In the majority of trauma cases, clinically significant swelling due to the inflammatory response reaches its peak within 24 hours. Swelling primarily due to bleeding is much more rapid and usually occurs within six hours of a traumatic event.

Specific Body Defenses: Immunity

Unlike the first two defensive layers, the immune system is specific and has a memory. The cells of the immune system distinguish "self" from "non-self" (antigens) by recognizing specific "self molecules", called MCH proteins, on the surface of the body's cells. There are two types of immune responses: cellular (or cell-mediated) and humoral. Both responses occur at about the same time and both increase the inflammatory response. ***The cellular immune response is designed to attack invaders inside infected cells by chemically destroying the cell. The humoral immune response neutralizes invaders outside the cell and marks them for destruction by phagocytes.***

Both processes begin when a new antigen is engulfed and digested by one of several phagocytes, such as dendritic cells, macrophages, activated B-cells, etc. Once digestion is complete, the cell presents part of the antigen on its surface and travels through the lymphatic system until it encounters a helper T-cell, usually in a lymph node or the spleen. The helper T-cell (T_H) binds with the presenting part of the antigen, clones, and then releases chemicals that stimulate the production of antigen-specific B- and T-cells. The activated B-cells are responsible for the humoral

The Inflammatory Response



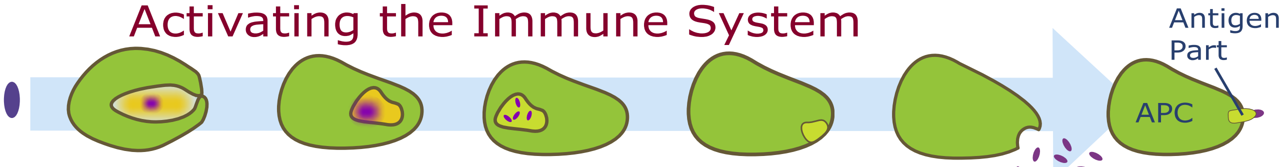
1. Bacteria attack a healthy cell.

2. The cell calls for help by releasing a chemical alarm.

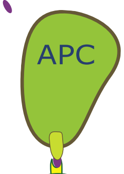
3. Local mast cells respond by degranulating and releasing inflammatory chemicals.

4. Local blood vessels vasodilate and leak causing swelling. Specialized white blood cells (phagocytes) move into the tissue spaces to attack, engulf and destroy the bacteria.

Activating the Immune System



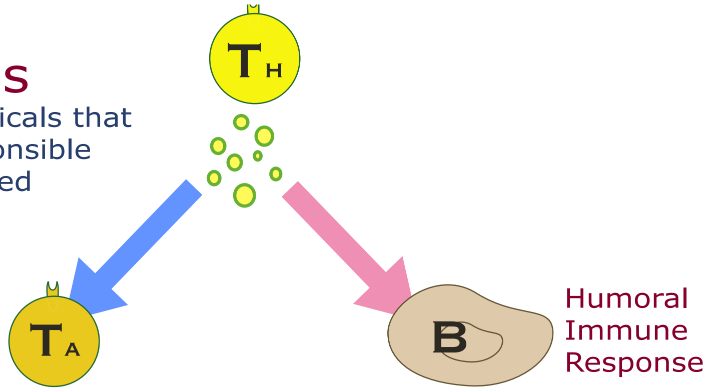
A phagocyte becomes an Antigen Presenting Cell (APC).



Then the APC finds and binds with a Helper T-cell, creates a template of the antigen, and clones additional T-cells.

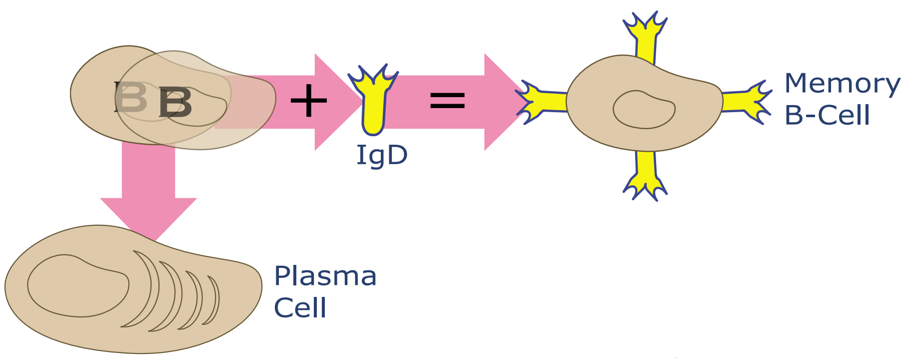
Immune Responses

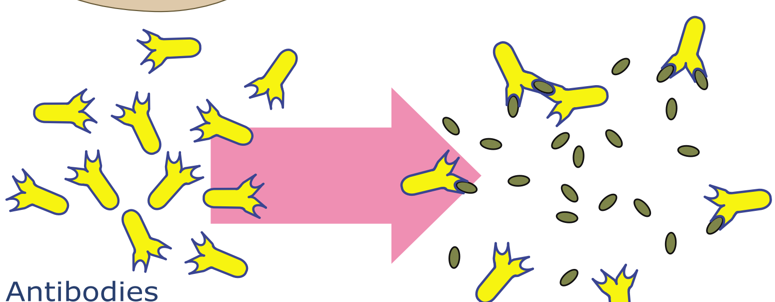
The cloned T-cells release chemicals that activate the B- and T-cells responsible for the humoral and cell-mediated immune responses respectively.



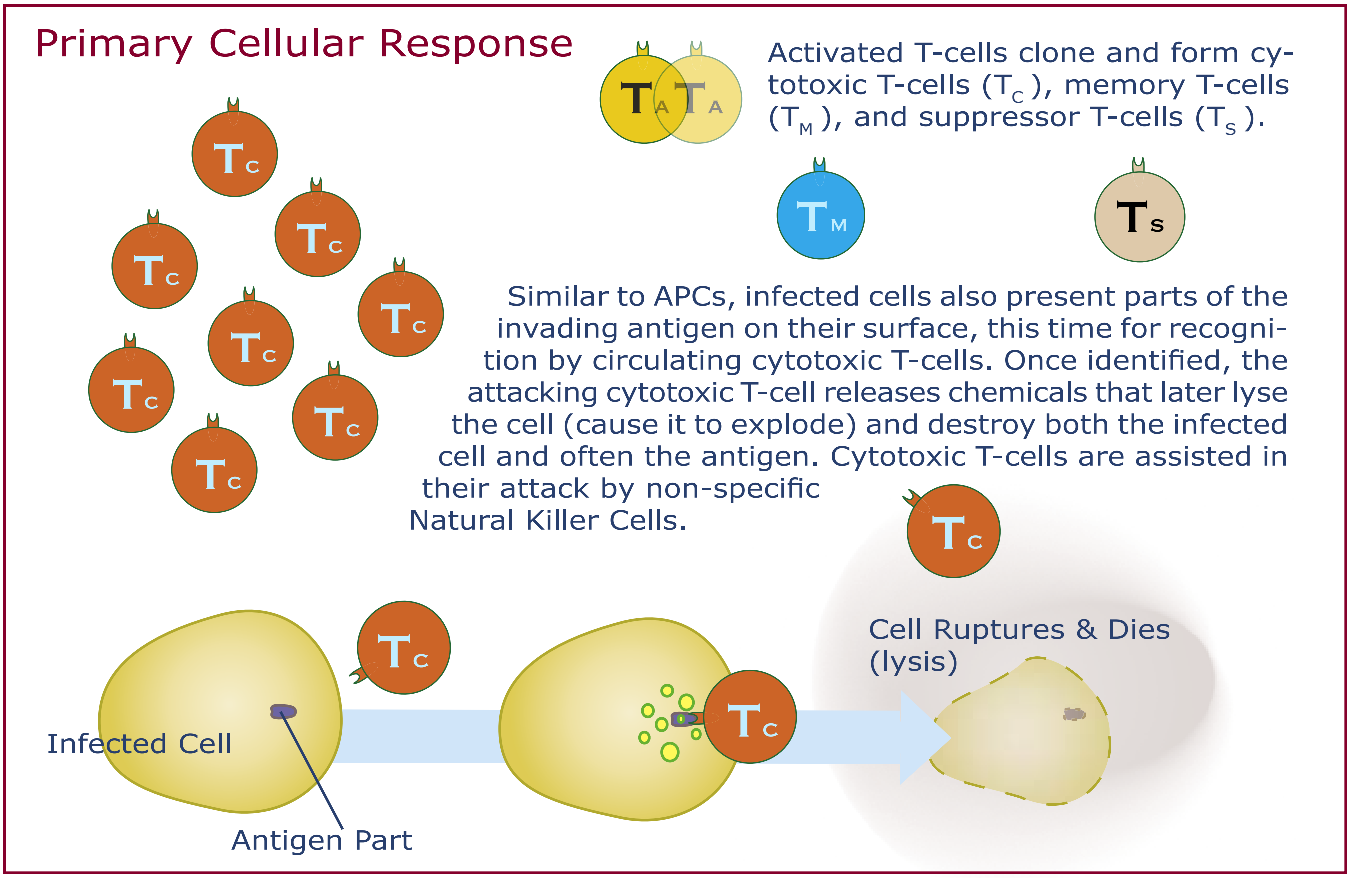
Primary Humoral Response

Activated B-cells clone and become either plasma cells or memory B-cells. Plasma cells are responsible for creating antibodies (IgD, IgM, IgG, IgA and/or IgE). IgD binds with a cloned B-cell to produce a memory B-cell while the other antibody classes are produced depending on the location of the antigen and need.



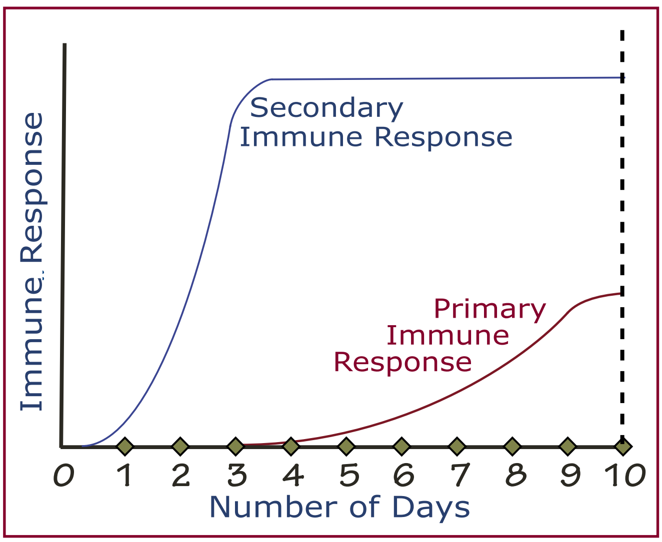


Antibodies bind, neutralize, and target antigens in the extracellular fluid for later destruction. The antigen-antibody interaction also enhances inflammation, activates complement, and increases phagocytosis.



immune response while the activated T-cells are responsible for the cellular immune response.

Once activated, B-cells clone to form both memory B-cells and plasma cells. Memory B-cells have long lives (years) and are able to mount a rapid humoral response within hours if they encounter the same antigen at a later date. Plasma cells produce protein molecules called antibodies or immune globulin (Ig) at an astounding rate of about 2000 per second. Most antibodies freely circulate in the extracellular fluid spaces and bind to the antigens they were created to defend against. Once bound, the antigen is neutralized and targeted for later destruction by circulating phagocytes. There are five classes of antibodies (IgD, IgM, IgG, IgA, and IgE). Each class has a slightly different role in the body's humoral defense processes: IgD usually attaches to the surface of B-cells and gives rise to the memory B-cells responsible for immunological humoral memory. IgM circulates in the blood and is the first antibody to be produced by plasma cells during a primary immune response. IgG is the most abundant antibody in plasma and offers protection against viruses, bacteria, and toxins. IgG also crosses the placenta and transfers passive immunity from the mother to the fetus. IgA is primarily found in body secretions and prevents microorganisms from attaching to the skin and the mucous lining of the lungs and gut. IgE helps to neutralize gastrointestinal parasites. A single plasma cell can concurrently produce multiple classes of antibodies, each specific to the same antigen.



Specialized T-cells are activated at the same time as the B-cells and are responsible for cell-mediated immunity. Cytotoxic T-cells or killer T-cells (T_C) recognize, attack, and destroy infected cells and foreign tissue without damaging healthy cells.

Memory cytotoxic T-cells (T_M) have a long life, potentially years, and are able to mount an attack within hours of a secondary exposure. Suppressor T-cells (T_S) inhibit B- and T-cell activity once the invading antigens have been destroyed.

Problems with the immune system may occur in three separate areas: immunodeficiencies, such as genetic defects or AIDS, autoimmune diseases, such as multiple sclerosis, type I diabetes, and rheumatoid arthritis, and local or systemic allergies. Of these, allergic reactions are the most commonly encountered in a wilderness setting. Acute allergic reactions are caused by "abnormal" IgE antibodies attached to stationary mast cells or circulating basophils and are usually triggered by bites or stings. Acute reactions may be either local or systemic (anaphylaxis) depending on the placement of the IgE. Subacute reactions, usually to food, are caused by "abnormal" IgG or IgM antibodies. Delayed allergic reactions, usually caused by contact with poison ivy, poison sumac, poison oak, or mango skin, are not caused by abnormal antibodies, but by an "abnormal" cell-mediated immune response that produces a skin dermatitis characterized by blisters and weeping. Allergic reactions and their pathophysiology are discussed in your handbook.